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INDUSTRIAL WATER POLLUTION IN A SURFACE WATER SYSTEM IN COLOMBO, SRI LANKA

by

Sithy Kadija Mohamed Ali

**A Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy**

**The Department of Geography
The University of Durham
The United Kingdom**

August, 1991

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بِسْمِ اللّٰهِ الرَّحْمٰنِ الرَّحِيْمِ

In the name of Allah, the most Gracious,
the most Merciful.

"وَمَآ أُوْتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا"

'Of the knowledge it is only
a little that was
communicated to you
(Mankind)'

صَدَقَ اللّٰهُ الْعَظِيْمُ

Verily, Almighty Allah has
said the truth.
(The Holy Quran, 17:85)

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Declaration

The work contained in this thesis has not been submitted elsewhere for any other degree or qualification and that unless referenced, it is the author's own work.

Dedication

This thesis is dedicated to my beloved husband for his encouragement, determination and patience; beloved son Hilal for all that he missed during the long years of my absence: a mother's affection, care and responsibilities, and whose little voice I constantly heard across the oceans; late beloved father who never saw any of my achievements; beloved **mother**, with deep respect, admiration and pride for her hard struggle through life for making me into what I am today; sisters Najiya, Ameena and Shurufa; late grand-parents Pooma and Poovappa; grand-aunt Chachi; uncle Najimdeen marma; alma-mater Sacred Heart Convent, Galle and to Professor I.G. Simmons - my supervisor, a great contemporary geographer and an environmentalist.

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Abstract

Surface waters are increasingly polluted by the industries in Colombo, Sri Lanka. Among these the food and drink industries are prominent in urban Colombo. To understand the extent of pollution of the inland surface waters a project was undertaken in the San Sebastian canal, which runs through the heart of Colombo, and the connecting waterways. It entailed the chemical and physical monitoring of the surface waters and the waste water discharges of the industries. The results indicated that the San Sebastian canal was a highly polluted canal with a very low dissolved oxygen level. The oxygen sag was very marked at the industrial discharges. Most of the industries, by nature of the highly organic waste waters in addition to being untreated failed to meet the specified standards of discharges into inland surface waters. The rainfall-pollutant and the rainfall-lag analysis indicated the poor dilution of these strong waste waters, and the low assimilative capacity of the highly polluted canal system. Hence, the San Sebastian canal polluted the receiving river Kelani, into which it discharges in the east, and the Beira lake in the west, where the polluted waters are pumped from the canal to maintain the level of the lake.

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Chapter I

Water pollution

1.1 Water characteristics

The earth has an extensive hydrosphere. Water is the solvent, transport medium, participant and catalyst in nearly all the chemical reactions occurring in the environment. It is an extraordinary complex substance. Hydrogen bonding between the water molecules has an effect on almost every physical property of liquid water. A molecule of water is made up of two atoms of hydrogen and one atom of oxygen. Therefore,

$$\text{Water} = H_2 + O$$

The structure of liquid water is not known. Various theories account for many of its properties. Models for the structure of water in the liquid state are based on either the Continuum Theory or the Mixing Theory. In the Continuum Theory the water is homogeneous, while in the Mixture model, liquid water is represented as a mixture of distinguishable states (Muller *et al* 1984).

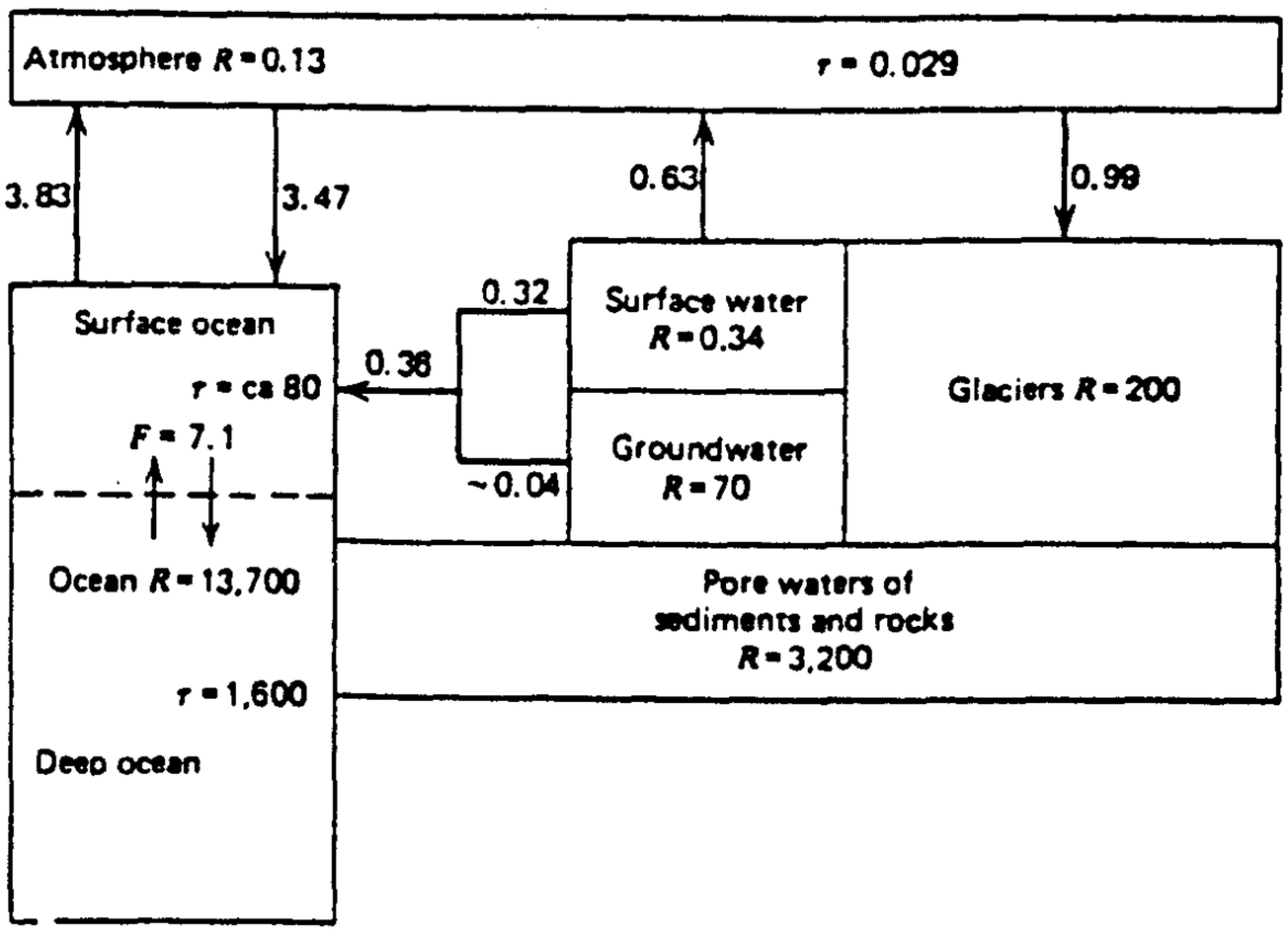
In hydrological estimates of the magnitude of the earths' waters, oceans hold 76% of all water; 21% is contained in pores of sediments and sedimentary rocks. A little more than 1% (or 73% of fresh water) is locked up in ice. The other fresh water reservoir of significant size is ground water. Lakes, rivers and the atmosphrere hold a very small fraction of the earths water. The volume of fresh water is only $\frac{1}{30^{th} \text{ of } 1.25 * 10^9 \text{ Km}^3}$ of water in the salty oceans (Ramanathan, 1984). The magnitude of the main reservoirs and fluxes in the hydrological cycle is shown in figure 1.1.

The chemical characteristics of natural waters can be viewed in the light of the environmental history of the water and chemical reactions of the rock-water-atmospheric system. Sea water is probably the product of the reaction of primary igneous rocks (bases) with excess volatiles (acids) from the earths interior concentrating at the surface by distillation. Similarly the composition of fresh water may be interpreted as a consequence of interaction of water with atmospheric gases(mostly carbon dioxide) and mineral rocks. The interaction of the cycle of rocks with that of water can be seen in figure 1.2. The chemical composition of the principal elements in marine and fresh water can be seen in figure 1.3.

The natural water systems contain many minerals and often a gaseous phase. They include a portion of the biosphere and organisms, and their abiotic environments are inter-related and interact with each other. The distribution of chemical species in water is strongly influenced by an interaction of mixing cycles and biological cycles. (Muller, *et al* 1984).

Pure fresh water is colourless, tasteless and odourless. The boiling point of water is 100 °C and freezing point 0 °C, at sea-level atmospheric pressure. It can be solid ice, liquid water or gaseous water vapour, depending on the temperature and pressure. Pure water will not yield an excessive quantity of albuminoid ammonia, carbon or nitrogen and this water is not injurious to health. Thus water will be **pure** and **wholesome** if it is free from visible suspended matter, colour, odour and taste. It should also be free from all objectionable bacteria indicative of the presence of disease organisms and should not contain dissolved matter of mineral or organic origin which in quantity and quality would render it dangerous to health (Savage - 1954, as quoted by Dissanayake, D.A. 1985). The entire life system on earth depends on fresh water, without which there would be no life.

Atmospheric water is the only continuous source of fresh water supply and ground water is the sustaining source of stream flow. But for much of the land surface, the



R, Reservoirs in units of 10^{14} metric tons; *F*, fluxes in units of 10^{14} t/yr; τ, residence time, yr. R/F = volume/input–output.

Figure 1.1 — The principal reservoirs in the hydrological cycle

Source: Muller C.M. *et al* (1984)

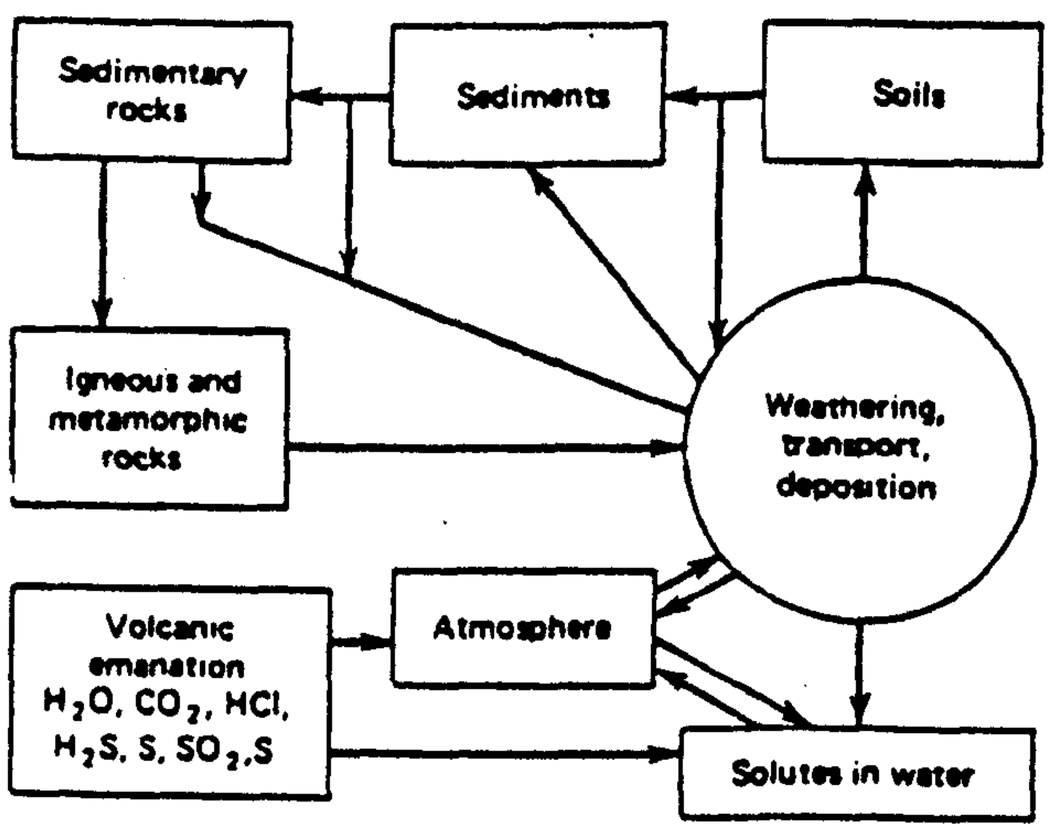
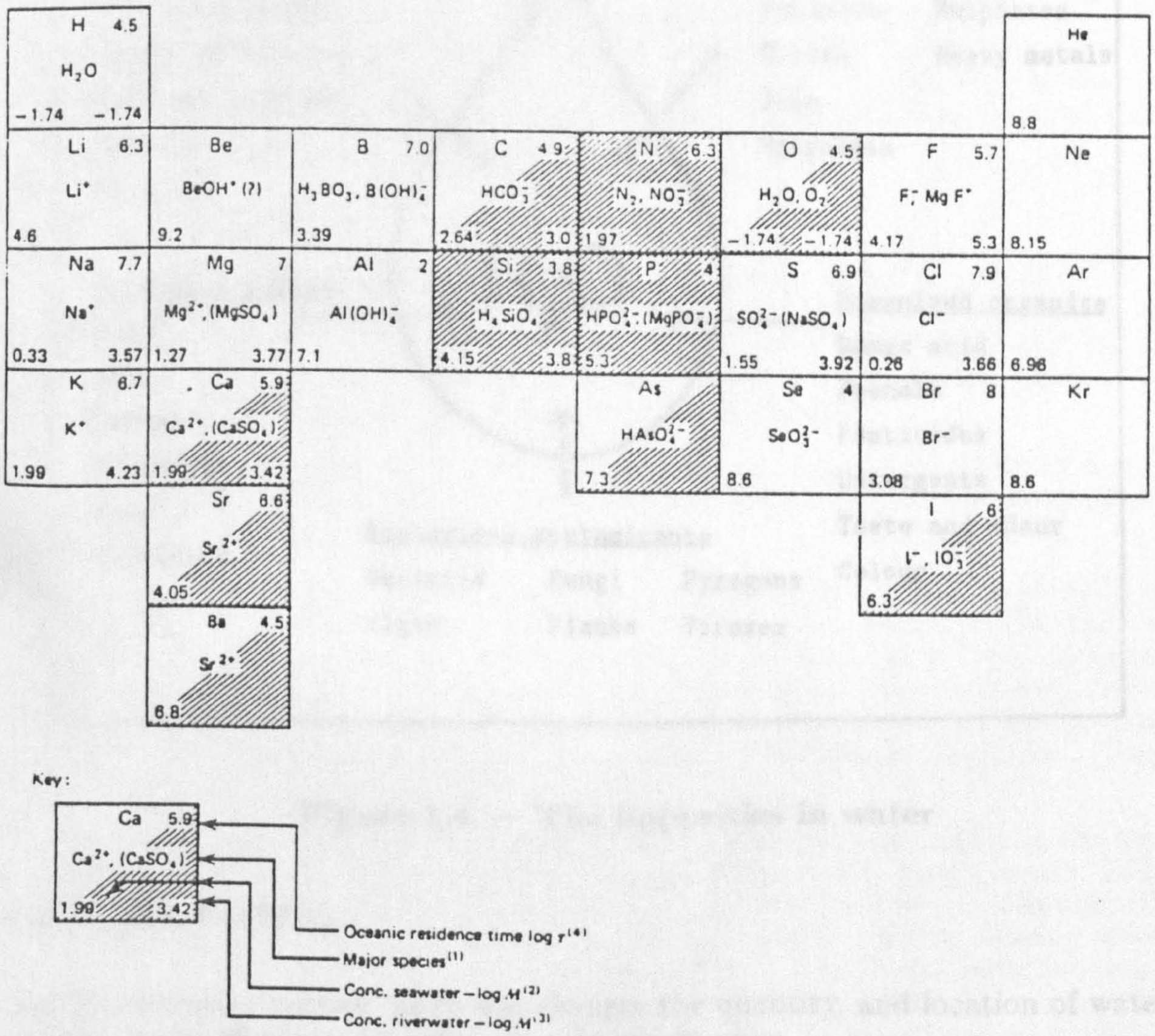


Figure 1.2 — The interaction of the cycle of rocks with that of water

Source: Muller C.M. *et al* (1984)

critical problems of water use are related to its limited volume or to its fluctuations in



Elements whose distribution is significantly affected by biota are shaded; P, N, and Si (fully shaded) are often depleted in surface waters. Species in parentheses are the main ion pairs in seawater. Concentrations (M = mol/L)

Figure 1.3 — Elements in natural waters, their form of occurence and concentration

Source: Muller C.M. *et al* (1984)

its seasonal flow. Natural water supports a complex ecological system and provides sustenance to plants and animals and constitutes the habitat for aquatic organisms.

All natural waters have a certain amount of impurities. The impurities found in natural waters are dissolved gases, dissolved minerals, dissolved organics, biological contaminants and suspended matter as shown below in figure 1.4.

Water is a migratory resource that can be used and reused in successive processes

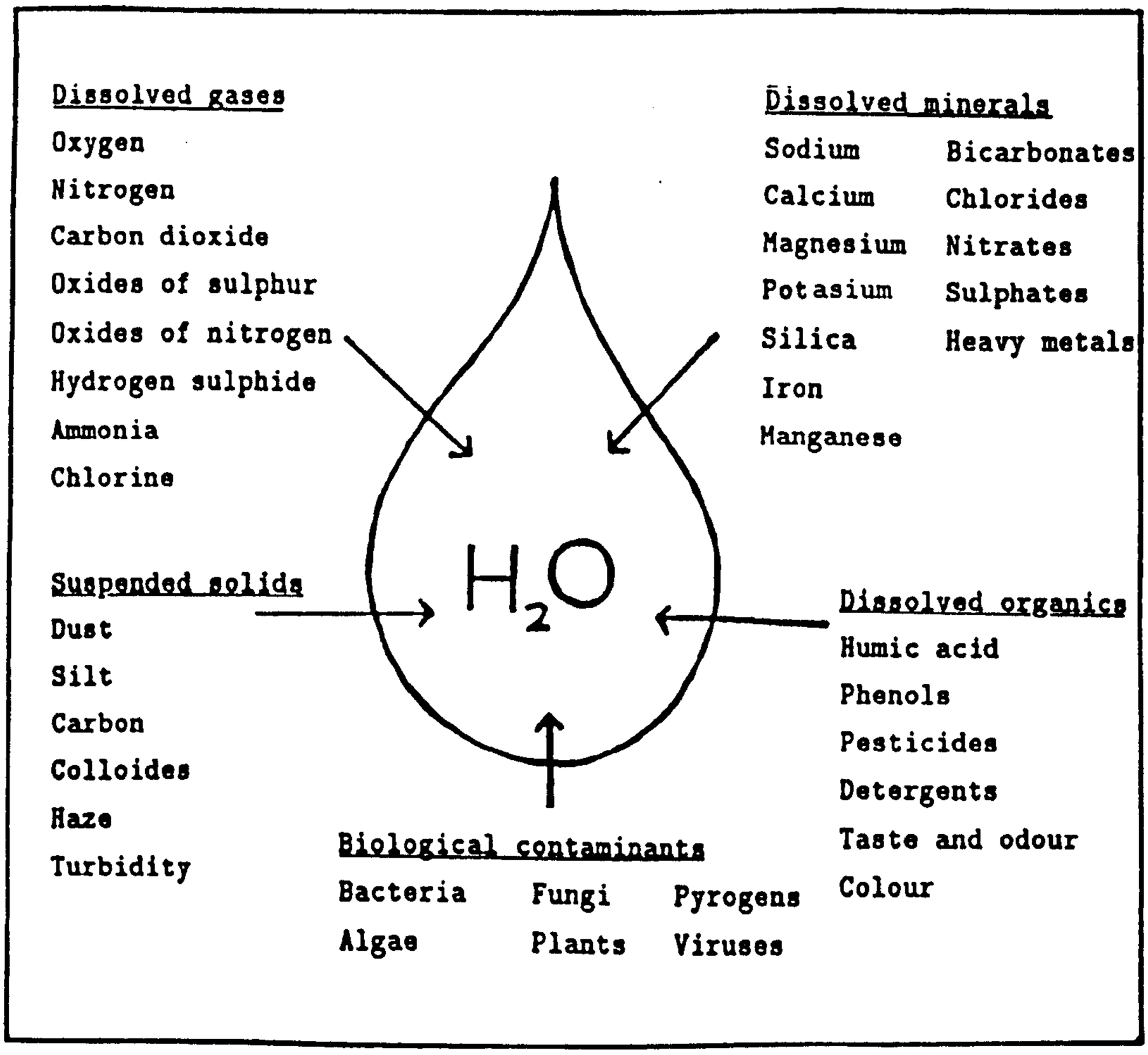


Figure 1.4 — The impurities in water

Source: Hill, R. (1984)

and by successive parties. Each use changes the quantity, and location of water and in these ways influences its value for subsequent uses.

It is also a multipurpose resource and is of utmost importance. It is drunk by humans; animals; and an environment for aquatic species; used for food; fuel or construction; heating or chemical purposes or washing and medicine. It provides transport routes, is a solvent in chemical reactions, provides purification and also the heat-transfer medium both for heating and cooling purposes. Therefore, streams serve people in many ways such as drinking, bathing, fishing, irrigation, agriculture, industry, navigation, recreation, aesthetic and power. In addition to all these uses, it serves as the garbage bin for mankind's waste disposal and carries away polluted substances (Nemerow, 1978).

Water uses therefore can be generally classified as domestic or public water supply, industrial, commercial, agricultural, institutional (schools, restaurants) shipping and livestock (Ramanathan, 1984).

Agriculture makes a great demand for water, but industrial uses have greatly increased in the past few decades. In 1974, million $120m^3$ were with withdrawn for industries in Japan from the natural water reserves, but today more than $\frac{2}{3}$ of the

value withdrawn is recycled water (Holdgate, 1982). The largest consumers of water in the U.S. are the thermal power plants. iron and steel industry, petroleum refinery and food processing industry. They consume more than 60% of the total industrial water need (Ramanathan, 1984).

Because of the cruicial importance of fresh water its quality must be maintained and preserved. Today management of water quality has become a major contemporary task.If it is not maintained in its pure form it affects the entire life system on the earth. Unclean polluted water is the source of many diseases such as bowel diseases such as cholera, dysentry to neurological disorders like Minamata disease and cancers due to bio-accumilation.

Today the earths fresh water resources, particularly rivers do not exist in a relatively clean state as it used to about 200 years ago. With increasing population, industrial, commercial and agricultural growth, not only have the uses of water dramaticlly increased but the resultant discharge of waste waters have changed the virtually **pure** rivers into **polluted** rivers.

1.1.1 Pollution and its history

The word **pollution** is derived from the Latin word **pollutus**, which is the past participle of the verb **pollure** which means to soil or to defile. The Oxford English dictionary defines **pollute** as, to make physically impure; foul or filthy; to dirty; stain; taint; or befoul and **pollution** as the act of polluting or the condition of being polluted; uncleanliness or impurity caused by contamination.

Therefore it is apparent that pollution as far as rivers are concerned have two meanings i.e. the act of polluting or fouling a stream and the actual impurity or contamination introduced into the water-course.

Pollution is not a recent phenomena, although its degree and magnitude varies through time and human history. The earliest cities seem to have shared the source of problems which are worrying their modern counterparts now. For example the Babylon ruins tells us that in ancient times it must have been extremely crowded, garbage accumilated in the houses and human waste disposed in the nearest streets. The water supplies from the wells rivers and canals were likely to be polluted (Hughes, 1975).

The Persians get an important place in the consideration of ecology in the ancient times. Persian religion revered elements of the natural world. Earth, water, and fire, were sacred, and it was absolutely essential to keep them from ritual pollution. There were many rules on cleanliness. Water was kept in pristine quality, flowing or in the lake. Sewage of any sort was not allowed to enter. The worst pollution was the contact with dead bodies in water. But they too had their faults, i.e combined with good attitudes towards nature, there must be accurate knowledge of the workings of nature. This they lacked.

Egyptian environmental history gives us a different picture. Their attitude towards nature was different.They revered nature, and exhibited a practical knowledge of workings of their part of the natural environment and managed the environment with care. Thus, this approach helped its continuity as a civilisation.

In the seventeenth century, the ruling monarch of England prohibited the throwing of garbage into the river Thames to preserve its purity and beauty. There were also incidents of water pollution in Holland by tanneries in the seventeenth century.

The changes that took place in the ancient civilations were massive, but it involved centuries for their accomplishment, but in a modern industrial and materialistic society more significant changes are taking place within a very short period of time. Therefore we may look to the ancients to see the beginnings of many of our modern difficulties, to an environment which is decaying due to human misuse. The ancients did not use the term **pollution** but today it is clear, seeing through contemporary environmental problems, that was what it exactly amounted to.

Therefore, the problem of human communities with their natural environment did not begin suddenly i.e. with the ecological awakening of the nineteen sixties or the industrial revolution of the eighteenth century. Mankind had been challenged to find a way of living with the environment from the earliest times. If our ecological crisis has ancient roots, it might be possible to learn from some of the successes and failures of ancient civilizations as we look forward to the future. Today, technology has advanced to such an extent that it had almost forgotten, an ecological balance in nature is absolutely essential for the survival of humanity itself. Until the 1970's, when it dawned that the natural environment had been taken for granted as something to be freely conquered and dominated without calculation of the resultant cost to humans and the earth. Environmental slaughter had irreversible damages on the ecological systems of the earth. The Greek philosopher Protagoras's idea that **man is the measure of all things** has persisted in western thought until recently i.e. everything in nature must justify its existence by its purposeful relationship to mankind.

The fear of irreversible damage to the natural environment and the modern ecological crisis culminated in the United Nations Conference on the Human Environment in 1972 in Stockholm; which is a landmark in environmental history, where both the East and the West met and pledged to understand their environment and to take actions on a national scale to safeguard their natural environment, whether land, air or water, and thereby safeguard mankind itself from self-inflicted ruination. Thus with the fear of irreversible damage to the environment, the UNEP was set up to deal with issues on the environment.

1.1.2 Pollution: The concept

A **pollutant** is a substance which brings about a change once released into the environment:whether land, air or water, and it is the undesirable and harmful effect on the target that makes the substance a pollutant. Holdgate (1979) explains that **a substance is a serious pollutant if it has significant biological effects at low concentration; diffuses readily in air, water or if it accumulates in living tissues; if it is persistent, their breakdown or combination products whose toxicity persistence and capacity to accumulate equals or is greater than the original material and therefore affects organisms, man and the stability of the global ecological system.** Any biologically active substance can act as a pollutant and there are few substances that have no effect on the biochemistry of the living organisms at some concentration.

The fate of a pollutant as explained by Muller (1984) in an aquatic system may be expressed as follows:

$$\text{Accumulation} = \text{input} - \begin{bmatrix}\text{Interphase} \\ + \\ \text{Intraphase} \\ \text{mass} \\ \text{transfer}\end{bmatrix} - \begin{bmatrix}\text{Chemical} \\ + \\ \text{Biological} \\ \text{reaction}\end{bmatrix} - \text{Output}$$

By evaluating the strength of anthropogenic and natural emission sources, identifying the relevant pathways and characterizing the various processes of dilution, dispersion, transport, partitioning, adsorption, volatalization, chemical and biological transformation and biodegradion that govern the behaviour of chemicals in the environment; the distribution, fate and residual activities of pollutants and their effects on ecological systems and on human health can be predicted. Further the present and future fluxes too can be predicted.

There are many fresh water pollutants. More than 1500 common substances are listed in the Index of Solubility, Toxicity and Biodegradability (INSTAB) by the British Water Research Center. The U.S. Environmental Protection Agency lists 65 chemicals and classes of chemicals which are subdivided into 129 specific substances which are now referred to as **priority pollutants.** The table 1.1 categorises fresh

Table 1.1 — Common fresh water pollutants

Medium	Physical	Substance and source			
	State		Domestic	Industrial	Agricultural
		Primary	Secondary		
Fresh Water	Dissolved	Organic body wastes	Nitrates Phosphates Carbonates	Organic-substances Detergents Oils Pesticides Metal salts	Concentrated organic live-stock wastes
		Detergents	Phosphates		Phosphates Nitrates Pesticides
		Pharmaceuticals Cosmetics Pesticides Metal salts			
	Suspended	Organic and Inorganic Particles		Organic and Inorganic Particles	Organic and Inorganic wastes.

Source: Holdgate, M.W. (1979)

water pollutants.

The **Pathways Concept** is fundamental in understanding pollution. A pollutant enters the environment (water, air, land) from some source: such as an industry, a farm or a residence. The scale of input depends on the number and the kind of sources in an area, such as an industry and residences in an urban area, or a farm in a rural area. In an environment, the pollutants follow diverging pathways, where they are dispersed and diluted. The rate of dispersion and the distance which it travels depends on the properties and the medium to which it is discharged. The main sectors of the environment are fresh and marine water, air and land and these differ in dispersion and dilution characteristics. According to laws of physics the concentration of a substance at the emission point determines the concentration at distances away. The pathways model is linear i.e. the amount reaching a target is a function of the amount emitted. It can be reduced by dilution, and removed or increased by biological or environmental factors. The distance and the rate of movement along pathways is critical. For example in water bodies that are stagnant, a heavy pollution load will have extreme effects than in a well mixed turbulent water course. Growth of industrial and urban communities have modified these pathways. The figure below shows a pathway of a pollutant.

In the concept of pollution, there is one undisputable law that has to be taken into consideration i.e no process in this world achieves 100% conversion efficiency. Therefore output in terms of mass or energy is always less than inputs, and therefore any conversion process has wastes, the amount of which depends on the conversion efficiency. The wastes after being released from production process and consumption, must end up somewhere. They end up eventually in the physical environmental

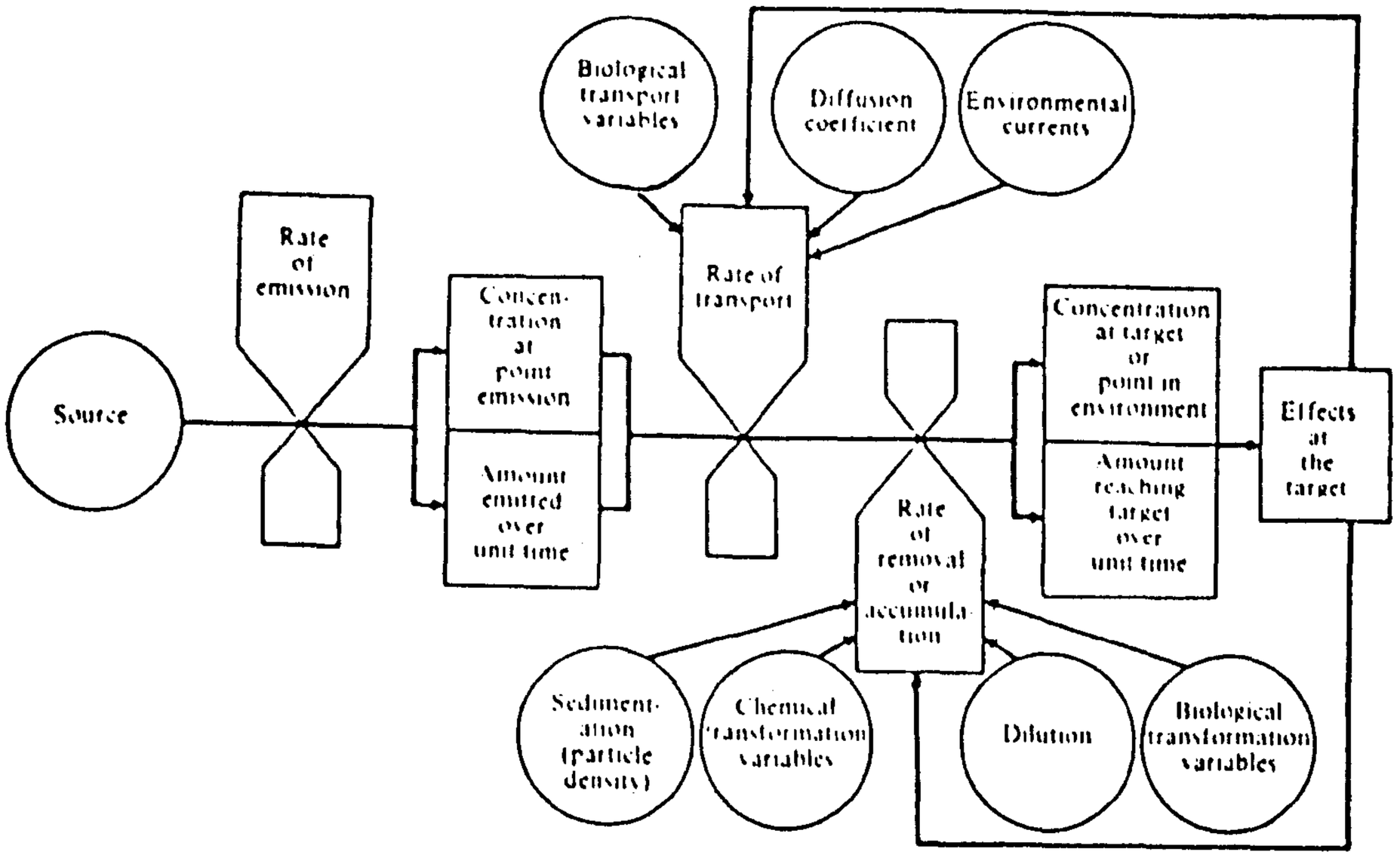


Figure 1.5 — A pollutant pathway

Source: Holdgate, M.W. (1979)

system i.e water, air and soil. This results in environmental pollution. This concept is explained below.

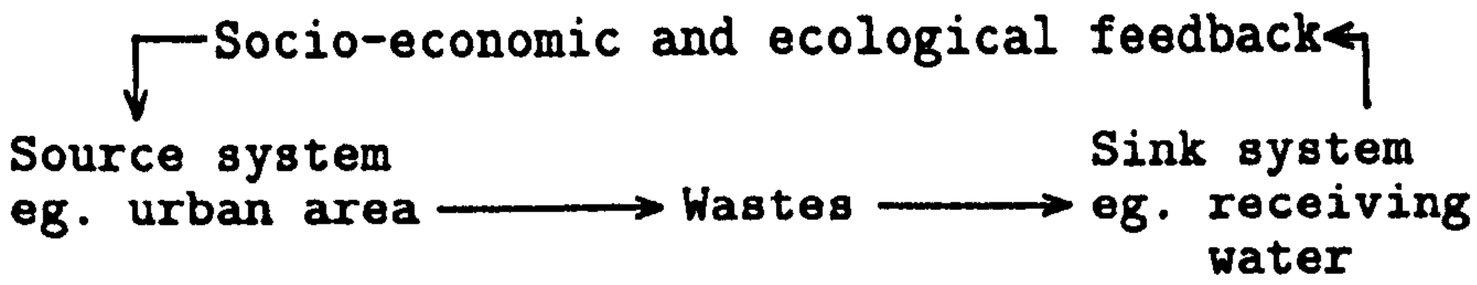
```
                    Conversion System
Input ──────────→ Efficiency <100% ──────────→ Output
                          ↓
                       Wastes
                          ↓
                  Environmental System
                    (water,soil,air)
```

Concept of pollution

Source: Ratasuk, S, 1981

This concept indicates that water, air and soil are natural resources which are utilized for various beneficial purposes for human living and at the same time are also used for waste disposal. Therefore, according to Ratasuk (1981) **environmental pollution is an indication of an unbalanced use of the environmental resources.**

In an attempt to balance the beneficial use of the environment with its unavoidable use as a waste dump Ratasuk (1981) also explains environmental pollution in terms of **systems** as seen below.



Environmental pollution in terms of systems
(modified from Ratasuk-1981)

The sink system in the natural receiving water bodies may be the network of a main river, an estuary, a system of tributary streams, canal or a lake. For some coastal areas the sink system includes the marine system too.The source system covers the entire water basin, and this contains waste generation sources such as urban, agricultural, industrial and residential areas. Therefore urban water pollution is only a component of an entire coherent system. In the case of urban water quality, domestic sewage and industrial effluents are two important components of the polluting discharges.

Pollution: definition

Pollution refers to the introduction into the environment (air, water or land) of contaminants, the quantities, characteristics and duration of which are likely to be injurious to human, animal or plant life (WHO, 1982). It further defines water pollution as **the alteration in the composition or condition of water directly or indirectly as a result of the activities of man, so that it is less suitable for any or all the purposes for which it is suitable in its natural state.** This stresses the importance of water as a resource for all purposes in its natural state. This explicitly accepts that water is life and safe water means a better life. Water is not just simply **another natural resource**, but the survival of human beings itself is dependent on it. The human body is made up of about 70% water and the humans cannot survive without it for more than a day or two.

In its broadest sense pollution may be defined as **any kind of damaging effect on the environment, whether caused by natural or by human agents, whether deliberate or unintentional, whether periodic or continuous, and whether or not percieved by those adversely affected** (Rowley, 1974). Rowley's definition is explained in terms of property rights. Since much of the environment is regarded by society as a common property resource, the problem of pollution is best approached within the context of Property Rights Theory. Where property rights are not clearly defined (or, clearly defined but not enforced) conflict is inevitable between those who stand to benefit from polluting the environment and those who stand to suffer from consequential damage. The polluters would pollute to the extent where their private benefits are maximsed, while the latter group would prohibit all damage to the environment. Where property rights are deficient, normal market processes are highly unlikely to produce an optimal compromise to this conflicting situation. Such arguably is the present situation in U.K. and many other countries concerning indusrtial discharges to rivers. Industrial discharges into the rivers fall within the category of deliberate and human induced pollution and by far the most continuous in nature. The implications of such pollution are only too readily perceived by those adversely affected. Since such discharges differ widely in composition there are wide implications for the river environment.

Holdgate (1979) defines pollution as **the perturbation by man of a series of physical and chemical factors and cycles which has consequence on living and non-living systems.** Pollution is only one of the ways in which man alters the natural world. It operates through changing the levels of chemical and physical factors on whose balance the composition and productivity of living systems depends. In some respects pollution is like the other types of human disturbances such as fire and overgrazing, since all impose stress on the ecosystem and change their balance.

Pollution is also defined by Holdgate as **an introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological system, damage to structure or amenity or interference with legitimate uses of the environment.** This definition was based on GESAMP-1972 (Experts on Scientific aspects of Marine Pollution); Article II of the Paris Convention on prevention of Marine Pollution from land sources; UN Conference on Human Environment, Stockholm-1972 and the UNEP. The important aspects of this definition is that,

1. Pollution is caused by substances or energy
2. It has one or more sources, and are created by man and therefore pollution is **an increment added by man to the biogeochemical cycles**
3. Pollution acts in the environment due to these discharges and follows a pathway leading to the exposure of structures and organisms
4. The significance of pollution is related to its effects on a range of targets, which includes man, resources, and the ecological system on which he depends
5. Pollution is judged by its impacts on the social value of the environmental components, if there is damage to structure or amenity or interferences with legitimate uses of the environment. The substances causing these effects are pollutants
6. The quantification of the scale of hazard or damage.

In the simplest language **pollution is something in the wrong place, at the wrong time, and in the wrong quantity** (Holdgate, 1979). Therefore, in addition to pollution being caused by a substance or energy, the location, concentration and its effects in space and time are crucial. The quantity of pollutant, the scale and its effects must be evaluated, and that a judgement about what is acceptable is inevitable. Therefore pollution has to be seen in the light of a socio-economic context.

Environmental pollution is also defined by Ludwig R.G. (1980) **as the presence, the discharge or liberation into water, air or soil, of all or whatever form of material or energy with intensity, in quantity, in concentration or with the characteristics which produce conditions in the waters, air or soil which are,**

1. **improper, toxic or offensive to health**
2. **inconvenient to public well-being**
3. **damaging to fauna and flora**
4. **prejudicial to the safety use and pleasure of public property or, to normal community activity.**

All human activity whether production or consumption results in the generation of residue. Some of these are readily used or recycled back into the production process. The residue which is not reused or recycled back become wastes. The wastes may be discharged into the environment in their original form or after treatment. The environment possesses a certain capacity for harmless assimilation of some of the wastes discharged into it. **Those wastes which cannot be asssimilated into the environment can be defined as pollution** (Gilad, 1979). This definition holds true for river pollution, where rivers have the capacity to assimilate certain amount of physical, chemical and biological pollutants. The assimilation capacity is the ability of the river to accomodate a particular activity, or rate of activity such a volume of discharge per unit time, quantity of chemicals dumped per unit time, without unacceptable impact (Pravdic, 1987).

Water quality and quantity are independent and interacting elements of a water system. The interrelation of flow conditions and chemistry are relevant in the case of a stream receiving waste liquid elements: both the stream flow characteristics and the chemical nature of the stream water govern the effectiveness of stream processes in dilution and assimilation of waste liquid. Given time the river can purify itself

naturally, but this capacity depends on the volume and strength of the pollutants. Today rivers are misused, and this is due to the increase in population, increased industrial and agricultural activities. The natural waterways are used as disposal grounds for domestic, municipal, agricultural and industrial wastes. If few people live along a river it is able to sustain the natural purification. The waste degrading capacity of the river becomes strained if population and economic activity increase because the resulting wastes are increasingly discharged into the rivers. In such a situation either the sewage or the river has to be purified (Ehrlich, 1977). Scientists have observed that in river Ganges in India pollutants are neutralized in a self-filtering process common to most large river systems of the world. The river Ganges does cleanse itself, but not until 24 km downstream from the major sources of pollution. (Gopalakrishnan, 1985).

Margola (1984), defines a polluted stream as **that which has been supersaturated with a specific pollutant**.

Coulson and Forbes (1952) as reported by Klein (1966), gives a definition of water pollution which has special application in common law, i.e **the addition of something to water which changes its natural qualities so that the riparian proprietor does not get the natural water of the stream transmitted to him.** Three typical examples are given to illustrate this definition, which has formed the basis of successful legal action in Britian, viz:

1. the addition of hard water to soft water,
2. the raising of water temperature,
3. the addition of something which on meeting some other substance already in water, each in themselves harmless causes pollution.

According to Klein (1966a), **pollution may be solid or liquid. If liquid, it may contain dissolved or suspended matter as well as dissolved gas of a polluting character**. The commonest form of pollution caused is liquid-which includes solids in suspension and is generally caused by discharge of sewage and industrial wastes into the rivers. He also defines water pollution as **anything causing or inducing objectionable conditions in any water-course and affecting adversely any use or uses to which the water thereof may be put.** Taking this definition further , as pollution affects the flora and fauna and as it can alter the number of individuals as well as the number of species he says that **it can be defined in relation to its effects on plant and animal life in the river.** Hawkes (1962) as reported by Klein 1966, emphasises this definition by stressing that **although river pollution may be said to be caused by physical or chemical agencies, it is essentially a biological phenomenon.**

Pollution is also defined by UNEP as reported by Holdgate (1982) as **the mismanagement of natural resources, industrial and agricultural development-some local, some regional and some international, such as pollution of water soil and air and this is adverse on human health.** This definition takes into account the natural resources of the world as a finite, exhaustible resource which is essential for development.

Pollution affects human directly too, and it is considered as one of the worst health hazards of modern times. Cancers which were unheard of a few decades back are directly linked to pollution. Singh *et al* (1983), define it as **environmental pollution is a health hazard and is detrimental to human progress. It is observed as a direct threat to human health which is the most obvious aspect of environmental deterioration. Pollutants reach us through the air we breathe, water we drink, food we eat and the sound we hear.** Leukemia in children under five in the neighbourhood of Sellafield neuclear plant in Britian today is a possible example. These technologicaql hazards though invisible are pollutants. In the case of radioactivity and toxic chemicals the feeling remains as if the hazard is yet to come (Baum, as quoted by Zeigler, 1983).

Pollution is also a by-product of development. To maintain the modern civ-

ilization, phenomenal advances in technology have taken place. Mistakes of the past have produced biological, chemical, physical and radiological contamination of land, water, air, food and destruction of natural resources. Rapid urbanisation and population increase also have contributed towards this. Galbraith in 1958 though without using the term pollution said **the more goods people procure, the more packages they discard and the more trash that must be carried away. Greater the wealth, the thicker will be the dirt**. Therefore **pollution** is a necessary evil of development which does not take ecological consideration into account.

1.2 Water pollution: Classification

Water pollution is classified in many ways according to its nature, properties, sectors of the environment, sources, targets and effects.

Classification by nature

The U.S. Senate Committee of 1960, classifies water pollution according to the following categories:

1. Sewage and other oxygen demanding wastes:these are carbonaceous material that can be oxidised by micro-organisms to carbon dioxide and water. Sewage and other oxygen demanding wastes are classified as water pollutants because their degradation leads to oxygen depletion. This affects aquatic life, gives unpleasant odours, impairs domestic and livestock water supplies and leads to scum and solids which impairs recreational uses.

2. Infectious agents: waste water from municipality, sanatoria tanning and slaughter houses may be sources of bacteria or other micro-organisms capable of producing disease in humans and animals. Disease carrying micro-organisms are always present in sewage. Many diseases striking humans are always present in sewage and many disease striking the humans are transmitted by water. London cholera of 1854 was due to contaminated water from a street pipe. Between 1850-1900 a series of major epidemics were observed in the U.K, Germany and U.S.A. The affected areas obtained water from sewage contaminated rivers or wells. High content of organic matter in the water can protect the viruses from disinfectants like chlorine. Hepatitis in the US was suspected to be **toilet to mouth pipeline transmission system of water** (Ehrlich *et al* 1977).

3. Plant nutrients: nitrogen and phosphorous stimulates aquatic plant growth. These are mainly from sewage and agricultural runoff.

4. Exotic organic chemicals: surfactants in detergents, pesticides and other industrial products. Analysis of polluted water shows a wide variety of compounds. Some of these are toxic to fish such as phenol. Many are biologically non-degradable. There are many new chemicals introduced each year without much knowledge of their effects on the natural ecosystem. Wright (1985) lists over 60,000 chemicals in the U.K, most of which are synthetic organic chemicals and these synthetic compounds disrupt the natural cycles of the environment which causes biological damage.

5. Inorganic minerals and chemical compounds: these originate from municipal, industrial waste water and urban runoff. These are injurious to fish and interfere with the suitability of water for drinking or industrial use such as mercury. Mercury is used in many industrial processes and is eventually disposed into the waste water. Metallic mercury was believed to sink and remain chemically inert, but it is now known that anaerobic bacteria in bottom mud can convert mercury into methyl mercury which can concentrate in living beings and lead to mercuric poisoning causing Minamata disease. In exposed coal mines, acid mine drainage is common. Minerals containing sulphur when in contact with water and air form sulphuric acid and this is carried into streams.

6. Sediments: soil and mineral particles washed by storms and flood waters, forest, agricultural and bulldozed urban areas.

7. Radioactive substances: harmful radiation may result in water environments from wastes of uranium, thorium mining and refining; and nuclear power plants. Radioactive substances are also used for industrial, medical and scientific purposes.

8. Heat: water is used for cooling purposes by power plants. This water is discharged at raised temperatures. River Mahoning in Ohio, USA has temperatures as high as 40°C, that fish life is completely eliminated. As temperature increases there are many effects on water. Density and viscocity decreases and therefore suspended solids settle at a faster rate. The evaporation and chemical reaction rate too increases. This leads to faster assimilation of wastes, which result in oxygen depletion. Saturation of dissolved oxygen decreases with increasing temperatures and fish kills are common. Pollution by heat is also termed thermal pollution.

Classification by effects

Based on the above classification Ehrlich *et al* (1977) classify water pollution by its effects such as,

1. Direct impact on health in the form bacterial or viral disease, cancer producing genetic or birth defects.

2. Effects on the ecosystem-an indirect impact on humans.

Other than the direct impact on health by sewage contaminated water that causes water borne diseases such as cholera, typhoid, hepatitis, dysentry, the direct impact by nitrate pollution is also stressed. The heavy use of inorganic nitrogenous fertilizers in agriculture results in the flow of heavy load of nitrates into water courses. In addition to these, effluents from certain industries such as chemicals and explosives are also discharged. Nitrates alone are not dangerous but certain bacteria in the digestive tract can convert nitrates into toxic nitrites. Infants who are less than 6 months old who receive artificial feed of milk diluted with water containing 10-20 ppm of nitrates may develop methaemoglobinanemia, which is not observed in breast fed babies. Cases are reported in UK, Ireland, Belgium, US and Japan. In medical literature this disease is cited often as fatal.

In the Central Valley, California pollution of lakes, streams and wells take place by nitrates. Here it has become a severe health hazard. Winconsin and Missouri have similar problems. In UK the agricultural counties of Suffolk and East Anglia face the same situation.

Identifying three types of adverse effects on the receiving waters Calley *et al* (1977) classify water pollution as follows:

1. Nutritional pollution-which can be either organic or inorganic.

2. Chemical pollution-which includes direct toxicity, acidity, alkalinity and salinity alteration, and

3. Physical pollution-such as changes in temperature turbidity or surface properties of water.

Within these catergories the effect that any particular discharge may have can be often predicted. The exception to this rule is toxicity because the question is **toxicity to what?** Further the toxic nature of various materials can be enhanced by the presence of other pollutants such as the behaviour of heavy metal ions at different pH values.

Classification by degradability

Water pollutants may be classified as degradable or non degradable according to their behaviour once discharged into the river (Rowley, 1974; Holdgate, 1979). The most widespread and the the best known degradable pollutant is domestic sewage. But, in aggregate, industries produce a greater quantity of organic wastes-almost entirely from the food, paper and pulp, and chemical industries (Herfindel *et al* 1965) as quoted by Klein (1966a). They illustrate that a single pulp industry will produce wastes equivalent to the sewage of a large city. Once an effluent containing a large

quantity of organic wastes enters the river the process known as **aerobic degradation** and **anaerobic degradation** are set in motion depending on the oxygen content of the river. Non-persistant is the synonym used for degradable pollutant.

Non-degradable or persistant pollutants are not attacked by the river biota and therefore undergo an insignificant change once they enter the river environment. They are inorganic colloidal matter and ordinary salts of heavy metals. Persistant pollutants are exemplified by the synthetic organic chemicals produced by the chemical industries. They enter the river mainly from industrial effluents and also from waste residues from household and agricultural uses. Detergents, pesticides, phenols and long-life radio-nuclides are the most common among these pollutants. Some of these persistent pollutants are highly toxic. The river James and Chesapeake Bay, USA had to be closed for fishing when Kepone, a deadly pesticide was discharged into these water system owing to the persistant and toxic nature of this pesticide. (Zeigler *et al* 1983). They also produce public health hazard. Chronic effects of prolonged exposure even to very low concentration is observed in workers exposed to Kepone at a pesticide plant manufacturing this in Hopewell, Virginia had disorders in their reproductive and central nervous system. The river biota cannot attack effectively the complex molecular chain of these substances and consequently the persistant pollutants travel long distances in virtually an unchanged form. Many persistent pollutants have the property of bio-accumulation and can pass from low to higher levels and onto the food chains. There is evidence to the fact that environmental damage is an increasing function of the rate of discharge into the rivers of such substances. There is also a build up problem in many cases when non-degradable persistent pollutants concentrate in particular patches of the river and estuary and are not eventually discharged into the sea.

Classification by source

Water pollution can be classified by its source. It can originate from many sources, such as domestic, industrial, agricultural and shipping waste waters.

Domestic waste waters originate from residential and commercial establishments. According to Hodges (1973) in USA, 55% of municipal waste water is from domestic and 45% from indusrtrial sources. According to Ehrhich *et al* (1977), one third of the waste water is from households and two thirds from industrial and commercial establishments in USA. In UK over 4000 million gallons per day of sewage, industrial and mine waters excluding cooling waters are discharged into the rivers. Domestic sewage varies considerably in composition and strength from day to day and season to season, town to town, country to country due to the marked differences in the habits of the poplutation, nature of diet, composition of wastes and water consumption. Sewerage flow increases as the standard of living rises. In USA domestic sewage typically has a biochemical oxygen demand (BOD) of around 200 mg/L. In the U.S, the Population Equivalent (PE) of BOD is 77/grs BOD/person/day, for domestic wastes but when industrial wastes are taken into account it is 230g BOD/person/day (Calley *et al* (1977). In UK it is 60g BOD/person/day and in Thailand < 20g BOD/peson/day (Ratasuk, 1981).

Water pollution originates from industrial sources. Industries are heavy uses of water and a major proportion of this water leaves as effluent. There are over 300,000 water using factories in the USA. These discharge waste water with a total BOD 3-4 times larger than domestic waste water and are several thousand times stronger in concentration, than the domestic sewage.

Agricultural water pollution originates from farms and livestock wastes. These includes fertilizers and sediments and enter the rivers as runoff from agricultural land or by leaching. The main pollutants are nitrogen and phosphorous. Pollution by this source is an ecological hazard as it contributes to the eutrophication of water bodies.

Shipping too contributes to river pollution. Both human sewage and other wastes such as oil originate from shipping and pollutes the navigable rivers. In the USA there are over 8,000,000 watercraft on the navigable rivers, and their combined waste water discharge is equivalent to a city with a population of 5,000,000 million (Hodges, 1973).

Oil is an oxygen demanding demanding waste and the major oil spills are from ships.

Water pollution from sources can be approached from another angle i.e. point source and non-point source pollution.

Point source pollution can be easily defined. In this case waste water discharges are from industries, domestic and municipal sewage outfalls. Non-point source pollution which is more difficult to identify can be defined as **any source of water pollution not coming directly or continually from a pipe** (Nemerow, 1978). This is generally characterised as areas with wide sources of multiple and diffuse discharges, and these sources are tied to rainfall runoff and therefore take a variant nature. This lacks a distinct or continuous effluent.

Non-point source discharges can be catergorised into rural and urban pollution. Potential sources of pollution from the rural environment include wild life wastes, leached plant residues, fertilizers, herbicides & pesticides, nutrient & organic matter eroded with soil, acid mine drainage, farm animal wastes and excess drainage from rural septic systems. Since surface water runoff is the major transporting mechanism, the topography and vegetation exert a major influence on both the quality and quantity of this runoff. Sub-catergories of rural lands with the potential that contribute to non-point pollution include forest and range land, fields used for crop production, animal lands such as pastures and barnyards and land used for mining purposes.

Urban contaminants include street litter, ice control chemicals, rubber, decaying vegetation, domestic pet wastes, fall-out of combustion products from industrial stack emissions, lawn chemicals, pesticides and herbicides, heavy metals, asbestos fibres from auto brake linings, oil, grease, gasoline, paint, dust, dirt and any other substance-natural, domestic, industrial or commercial product- that finds its way into a gutter or a storm water sewer. The major portion of these contaminants consist of dirt and dust particles, but it may include anything. The pollutant accumulation per unit length of gutter is a function of the time between street cleanings. Therefore the major factor controlling the quality of urban discharge is runoff. Due to the impervious nature of the greater part of urban lands which increase the volume of runoff for a given rainfall event, urban lands have a higher yield of pollutants than rural areas.

All water pollutants do not originate from waste water alone. Some are due to the settling in of air pollutants such as sulphur dioxide, which causes acidity in lakes and other water bodies. Similarly, solid wastes (land pollution) are washed away into the rivers by surface runoff. Solid wastes are accumulated on land-such as tailings from mines and sludges from industrial processes or waste dumps from domestic sources. Even polluted underground waters may enter rivers by infiltration and via underground channels and pollute the surface streams.

1.3 Types of pollution

Klein (1966b) explains river pollution in terms of chemical, physical, biological and physiological pollution. In other words river pollution is classified according to the types of discharges that enter a river based on its chemical, physical, biological and physiological properties. He bases his explanations on the two main discharges into the river namely, sewage and trade wastes. The table 1.2 gives this broad classification.

1.3.1 Chemical pollution

Chemical pollution is classified into organic and inorganic pollution.

Organic pollution: the most common form is due to the presence of protiens, fats, carbohydates and other organic substances found in sewage and trade wastes. The nature, composition, properties and occurrence of the important types of organic compounds are as follows:

Proteins: These are nitrogeneous organic substances of high molecular weight

Table 1.2 — Types of pollution in sewage and trade wastes

Chemical	Physical	Physiological	Biological
Organic (carbon compounds)	Colour	Taste	Bacteria (pathogens)
Inorganic (mineral compounds)	Turbidity Temperature SS Foams Radioactivity	Odour	Virus Animals Plants

Source: Klein, L. (1966)

found in the vegetable and animal kingdom consisting of large amount of amino acids. At least 25 different amino acids are found in most animal proteins such as gelatin in animal bones, keratin in wool, fibroin in silk, casein in milk and glutenin in wheat. Different proteins vary in composition, but they all contain carbon, hydrogen, oxygen and nitrogen. Most contain sulphur, and some contain phosphorous as well. A typial protein has approximately 52% carbon, 7% hydrogen, 22% oxygen 16% nitrogen, 0.4-2% sulphur, and 0-2% phosphorous. Under the influence of bacteria and other micro-organisms protein readily undergoes putrefaction giving amino acids, organic bases as well as hydrogen sulphide (H_2S), organic sulphur and phosphorous compounds. Many of the decomposition products have objectionable odours.

Among the trade wastes containing proteins are the food processing wastes. They are grossly polluting in character and much is due to the protein content.

2. Fats: these include animal and vegetable oil. They are insoluble in water, but dissolve in inorganic solvents such as petrol and chloroform. Subject to micro-organic action fats break down to glycerol and fatty acids. Further decomposition gives unpleasant and rancid odours. Fats occur in sewage and trade wastes such as wool scouring, edible oil and fat refining, soap and laundry wastes.

3. Carbohydrates: these are compounds of carbon, hydrogen and oxygen which are widely distributed in the animal and vegetable kingdom. They include simple sugars such as glucose and in cane sugar; starch and dextrin used in paper making and printing and are therefore found in such wastes.

4. Oil: this comes from barges, tankers and boats on the rivers and also from industrial wastes such as edible oil refineries, metallurgical, engineering or trade premises using lubricating oil especially petroleum. Oil is objectionable in streams not only from aesthetic standpoint (visible pollution) but it also spreads to form a thin film f on the water surface which prevents diffusion of oxygen into the water interfering with the reaeration of river water. It also coats the gills of fish and therefore makes dissolved oxygen utilization difficult or impossible. Downing *et al* quoted by Klein (1966b) show that an oil film has a marked effect on the absorption by water of oxygen from the air when film thickness is over 10 cm. Much of this oil is not broken down biologically, but is accumulated as an oily sludge on the stream bed, thus impairing the quality of water. Oil films also show up as bright colour bands on the water surface.

5. Miscellaneous organic compounds: such as hydrocarbons, alchohol and ketone which are prepared industrially, may be present in waste water from chemical and other factories. These compounds are toxic.

6. Dyes: these are intensely coloured syntheic compounds capable of fixing them-

selves permanently to various materials. Now synthetic dyes have replaced other naturally occuring vegetable dyes, mostly in the textile printing.

7. Synthetic detergents: even a small amount cause foams on rivers and sewage plants. They reduce reaeration rate and affect efficiency of sewage purification. It affects the taste in water supply and are toxic to aquatic flora and fauna. Duck kills were reported in USA due to synthetic detergents. The detergents dissolve the oily coating on duck feathers, they becomes water logged and drown.

8. Toxic organic chemicals: many trade wastes contain poisonous organic compounds such as phenols and cyanides. These kill bacteria and renders rivers sterile and make it unable to undergo self purification. Even very low concentration can cause fish mortality. One of the earliest indications of pollution of rivers by such toxic chemicals is the presence of dead or dying fish.

Inorganic or mineral pollution

1. Acids and alkalis: many industrialists discharge inorganic acids or alkalis which harm the stream extensively by breaking down its natural buffer system and altering its normal pH value. Alkaline wastes at times have pH of 12.0 or more, while certain acids wastes 1.0 or even zero. Mine waters are highly acidic and so are battery industry wastes. Tannery, cotton mercerising wastes are highly alkaline. Acids are objectionable in a stream because it causes corrosion to metal structures if the pH falls to <5.0. It may also liberate evil smelling hydrogen sulphide from sludge deposits and river mud. Acids and alkalis can destroy bacteria and other microorganisms and therefore inhibit or even prevent self-purification of a stream. It is also lethal to fish and other acquatic life. Fish thrive in pH between 5.0-8.5, but certain species are affected by acid or alkaline conditions. If sudden changes from acid to alkaline or vice-versa occur the result is dramatic.

2. Toxic inorganic compounds: commonest inorganic compounds are free chlorine, soluble sulphides, hydrogen sulphides and salts of heavy metals such as copper, zinc, lead and mercury. Any appreciable amount of these will hinder or prevent self-purification of rivers and will kill both aquatic plants and animals. 0.14 mg/L of copper sulphate concencentration kills trout. Certain species of blue green algae are killed by 0.1 mg/L. Zinc which is toxic to fish is fatal at 0.15mg/L. Many inorganic gases are very toxic to fish such as hydrogen sulphide at 0.5-1.0 mg/L. Chlorine, ozone, and phosphine are some other toxic inorganic gases to fish.

Salts of heavy metals causes death to fish by coagulating the mucous around the gills and therefore the fish are asphyxiated. The lower forms of organisms upon which the fish depends for food are more susceptible to a particular poison than the fish themselves such as the water fleas *Daphnia magna* are adversely affected by sodium chromate at 0.1 mg/L, while the lethal dose for fish is 20 mg/L.

3. Soluble salts: soluble or dissolved salts are commonly found in streams and discharged to streams are sulphates, chlorides, bicarbonates, phosphates of sodium, potassium, calcium, magnesium, iron and manganese. Small concentrations are harmless to fresh water fish, but discharges from salt water works and water softening plants using ion exchange method will contain large amounts of sodium chloride which will convert fresh water streams into brakish or salt water and pollute the stream which will be unsuitable for vegetation or fish. Excessive amounts of soluble salts in streams is objectionable because it causes corrosion of pipelines, metal structures and or concrete. Particularly sulphates which can be reduced to sulphides, which by oxidation at air level gives corrosive sulphuric acid or directly act on concrete.

4. Inert insoluble inorganic substances: clay, chalk and gypsum are present in trade wastes such as in paper making. They are undesirable in streams since they increase the turbidity of the river.

1.3.2 Physical pollution

Physical pollution of rivers is caused by colour, turbidity, temperature, suspended matter and foam.

1. Colour: many trade wastes have pronounced colour which they give to the water. Most are due to organic dye, but some are due to mineral origin, such as iron compounds and chromium. Colour itself is not harmful. A solution of magenta as 1 in 50,000 parts of water (0.2 mg/L) gives a distinct red colour. Many streams in UK supporting fish life have brown colour. Interaction between two trade wastes in a stream or a trade waste and a substance naturally present in the river can produce an intense colour. If a stream is devoid of dissolved oxygen the water may turn black due to formation of ferrous sulphide. Tannery wastes using vegetable tan causes green or inky blue colour or a precipitate, if discharged to iron containing streams due to the interaction of tannins with iron.

2. Turbidity: a striking physical characteristic of sewage and most industrial waste water is their degree of cloudiness or turbidity caused by either colloidal matter or fine suspended matter, which settles only with difficulty. Matter in the colloidal state differs from coarse suspension mainly due to its particle size.

As a rule, more pronounced the turbidity the stronger is the sewage or trade waste and worse is its effects upon the river. The degree of turbidity of streams is therfore often taken to be an approximate measure of intensity of pollution. Measurement of turbidity in rivers can be used to evaluate the effects of pollution by waste water and even follow the course of self purification of streams. So streams may be turbid due to presence of small amounts of inert harmless materials such as clay and yet be a good fishing stream. Turbidity also causes indirect pollution by cutting of sunlight and thereby affecting photosynthesis and therefore plant life in streams. Absence of turbidity does not imply that a stream is unpolluted, for the cleanest water might be heavily polluted with acids or toxic materials, which do not cause turbidity. Turbidity in water used for domestic purpose is objectionable if it is due to presence of iron as it causes brownish stains in baths and washbasins.

3. Temperature: heated industrial effluent discharges causes the temperature of the receiving water several degrees higher than normal.Water courses unpolluted by heated effluent are usually a little lower than the mean monthly air temperature. When temperature rises in the stream polluted by organic matter, the dissolved oxygen decreases due to lower stability of oxygen at higher temperatures. It has been shown that the BOD_5 of sewage is twice as great at 25 °C as at 5 °C. Fish life is also affected by increased temperatures. Mortality among sensitive fish to temperature is common. Rainbow trout died when temperature increased to 18-19 °C (Klein, 1966b). Rapid changes in temperature result in fish death. Increased temperature is harmful to hatching of eggs of fish. Increase in temperature also increses the lethal effect of compounds toxic to fish such as a 10 °C increase in temperature doubles the toxicity of potassium cyanide to fish. According to Ruttner as quoted by Klein (1966b) oxygen consumption of aquatic fauna nearly doubles itself for each 10 °C rise in temperature. Even a temperature increase of 1 °C is harmful to fish. Heated effluent is discharged from power stations, cooling towers and industries.

4. Suspended matter: insoluble matter in suspension is a common form of pollution and is present in sewage and industrial waste waters. All rivers have suspended matter such as natural silt and sand. Suspended matter can be organic, inorganic, partly organic and partly inorganic. Sewage and dairy waste is largely organic while clay and chalk is inorganic.

Suspended solids are objectionable because they intereferes with self-purification process of the river by decreasing photosynthesis and smothering benthic organisms. It could also damage fisheries and is further unsightly and unaesthetic. Light penetration and therefore photosynthesis is reduced by suspended matter in rivers. According to Hoake, 1959 quoted by Klein (1966b) light penetration can be reduced by 50% in muddy water and 75% in turbid water. SS containing much organic matter in warm weather undergo putrefaction in rivers and thereby solids buoyed up by gas

may rise to the surface leading to the formation of floating masses of evil smelling sludge. SS will also be deposited in the bed if it is slow moving. It will cause silting up of streams. Deposition of insoluble matter on the stream bed may lead to the destruction of plant and animal life and therefore the natural food supplies of fish is affected. If SS is gritty it will cause physical injury to the fish during high stream flow. Patrick, 1953 quoted by Klein (1966b) states that fish eggs become buried by SS and the pressure caused by the weight of solids will cause the less resistant eggs to break. Gangmark, 1956 quoted by Klein (1966b) found that eggs placed in a channel free from silt had a survival rate four times higher than in a silted stream.

5. Foam: foam consists of a suspension or a dispersion of gas bubbles in a liquid medium. Many substances cause foam in water such as soaps and detergents, fish glue and saponins. Organic discharges from paper mills which uses straw for pulp results in scum and froth. But foams of rivers today are of more recent origin i.e. it increased with the use of synthetic detergents and cleansing agents. These detergents have come to stay and are widely used for domestic and industrial purposes. They are widely used in breweries, dairies, soft drinks, laundries, textile industries and also domestically. The widespread use of synthetic detergents leads to their presence in sewage and industrial effluents. The production of foam is a physical phenomenon which causes the lowering of surface tension of and sewage by the detergents. The tendency to foam is greatest in clean waters and diminishes as the amount of pollution increases. Certain detergents are easily oxidised biochemically, while others are relatively resistant and more persistent foamers. Detergents group containing alkyl sulphates are readily oxidised biochemically, whereas alkyl aryl sulphonate and alkyl phenoxy polyglycols are slowly oxidised under similar conditions. These adversely affect the fish and vegetation over long distances. Concentrations of less than 1 ppm may also inhibit oxygenation of the water (Simmons, 1981).

5. Radioactivity: most natural waters have slight radioactivity. An atom is said to be radioactive when it is unstable and tends to attain stability by spontaneous disintergration with the emission of one or more types of radiation. Background radioactivity in natural waters is in the range of 1-1000 $\mu\mu$c/L (Klein, 1966b). In some radioactive water containing radium the level of activity may reach 100,000 $\mu\mu$c/L. It was found that after nuclear tests the level rises such as in UK, in the Stevenage brook the level rose from 24.8 $\mu\mu$c/L on the 20.9.1957 to 1110.0 $\mu\mu$c/L on 25.9.1957. But in natural rain water the level is only a trace.

Wastes from atomic energy establishments, hospitals (research) and industry using radioactive materials have increased. Isotope I^{131} is used for treating disease of thyroid glands. Au^{198} and TA^{182} used for cancer treatment are to be present in laboratory effluents. When radioactive materials are discharged into the river , the radioactivity will depend on the degree of river dilution. Radioactivity will diminish from the source of pollution due to sedimentation, decay of short lived isotopes and uptake by the bottom deposits such as algae, plankton, water weeds and fish. The scales and bones of fish and water weeds can take up Sr^{90} the most dangerous of the B emitters. In river Columbia, USA, the plankton has radioactivity 2000 times more than that of river water.

1.3.3 Physiological pollution.

1. Taste: when water consumption rises, and if this demand cannot be met, it becomes necessary to use the more polluted reaches of the rivers for potable water. in such a situation taste may become important. Industrial wastes contain many chemical compounds which gives unpleasant taste to water, example salts, iron, magnesium, free chlorine, hydrogen sulphide, phenols and unsaturated hydrocarbons. Many of these are easily removed by conventional water treatment processes. Besozzi as quoted by Klein (1966b) has reported that it is practically impossible to produce a drinkable water free from taste and odour at Whiting on Lake Michigan as the town supplies are taken from the lake and is considerably polluted from oil refinery wastes. Water taste have been reported mildewy and mouldy. Extremely small quantities of certain substance can impart a taste to water, such as the inky taste of ferrous

iron can be detected at a dilution of 1:10,000,000 which is 0.1 ppm. Taste due to free chlorine may be evident at 0.1 ppm. According to Southgate quoted by Klein (1966b) phenol produces a taste at 7 ppm.

River water polluted by trade wastes often contain taste producing substances, such as phenols, chlorophenols which may damage the value of fisheries by imparting unpleasant taste to fish. Synthetic rubber waste waters contain taste producing hydrocarbons called styrene ; explosive manufacturing factories contain nitro derivatives of benzene and toluene which gives bitter almond flavour to fish. Oil refinery wastes give objectionable taste. due to naphthenic acids. Many of these can be removed by keeping the fish in fresh water for some time. Peculiar taste is imparted to water by the decomposition of organic matter, algae, fungi and filamentous bacteria.

Odour: is one of the most common characteristics of a polluted river. It may be due to strong smelling chemical compounds (ammonia, phenols, sulphides, cyanide, chlorine) which can be identified and estimated or it may be due to organic materials (essential oils) with algae and other vegetable organisms , which when decomposing is putrescent. Many kind of odours identified as grassy, earthy, musty, mouldy,are caused by traces of chemical substances which is difficult to be identified by chemical analysis. Certain microorganisms have been shown to be responsible for odours in water supplies. *Protozoa,* and alga *Volvox* impart a fishy smell to water. The alga *Rivularia* gives a mouldy odour.

Most unpleasant smells of polluted waters are due to the presence of inorganic and organic compounds of nitrogen, sulphur and phosphorous. These arise from the putrefaction of proteins and other organic matter in sewage and trade wastes. Some worst smells are caused by sulphur compounds such as hydrogen sulphide.

The commonest cause of smells are due to the presence of sulphides. The extent of this odour nuisance appears to depend on pH of the river and the concentration of dissolved sulphides present in the water. Lower the pH greater is the free hydrogen sulphide liberated. Many industrial wastes contain organic substances having odours such as the wastes having phenols, alcohols and sulphur compounds. Food processing wastes which contain high concentrtion of nitrogeneous organic matter develop extremely unpleasant smells when stale due to anaerobic decomposition.

Objectionable odour however unpleasant are not known to be injurious to public health unless they arise from certain toxic chemical gases and vapours. The value of nitrates in polluted streams for preventing bad smells is now understood. If the stream is pure nitrate is of little value. But if a stream is heavily polluted and devoid of dissolved oxygen, then the combined oxygen supplied by nitrates can be of great importance. Nitrates thus act as a kind of last line defence in preventing anaerobic conditions and foul odours in a polluted river. This is further strengthened by research. In USA deliberate addition of nitrates to polluted water is done to prevent or eliminate odour. Pea canning wastes are often treatxed by sodium nitrate in lagoons in USA especially in the hot weather. Also in River Androscogin bad smell from the paper mill wastes is controlled by adding sodium nitrate.

1.3.4 Biological pollution.

Pathogenic bacteria, algae, viruses, pathogenic protozoa, parasite worms, certain fungi and plants or animals multiply excessively under suitable conditions which is undesirable, harmful or injurious.

Biological pollution is often a secondary result of pollution by trade wastes and sewage. When excessive growth of certain green sea weeds in Belfast Lough was investigated by the Royal Commission on Sewage Disposal 1913, it was observed that these plants underwent decomposition with the evolution of H_2S and odour. The discharges of the Belfast Sewage was found to favour the growth of these weeds.

Excessive growth of algae often appear suddenly in reservoirs causing odours and considerable nuisance when the plants die and undergo decomposition. Certain blue green algae are toxic to human beings and animals and can cause epidemics of gastro-

enteritis.

Many of the common infections such as influenza, smallpox, poliomyetis and yellow fever are viral diseases caused by contaminated water. In the tropics in addition to these dysentry and diarrhoea are common. Viruses are the smallest living organisms and are capable of growth only within the cells of the susceptible host. Virus differ from bacteria not only in that they are much smaller in size and inability to grow in artificial media, but also show greater resistance towards disinfectants. One of the dreaded and and important virus is poliomyelitis.

It is unusual for trade wastes to contain pathogenic organisms but wastes from tanneries may have these. Wastes from slaughter houses and dairies handling tuberculosis infected animals may contain tubercle-bacilli. Today in UK salmonella is affecting the poultry farms and waste water from such sources can affect the human health. In July 1989 an entire piggery was destroyed (> 4000 pigs) and the farm sealed in UK due to a deadly infectious disease. These are some of the potential sources of biological pollution.

In the tropics and subtropics amoebic dysentry is caused by *Entamoeba histolytica.* Jaundice and hepatitis are also caused by contaminated water. The ova and larvae of many worms are parasitic to humans and may be passed out into the faeces which results in the contamination of the water.

1.3.5 The oxygen demand of a river

The overall water quality of a river can be explained in terms of the single most important and critical component of a river, that is the oxygen content of a river. Water saturated with dissolved oxygen at 20 °C will have a dissolved oxygen content of 9.2 mg/L or 77 pounds per million gallons; 14.6 mg/L at 0 °C and 7.6mg/L at 30 °C. Warmer water holds less oxygen under saturated conditions.

Whenever organic matter through sewage or industrial discharge enters a natural water course: whether a river, lake or a pond there is a response by the aquatic micro-organisms to utilize organic matter as food supply. This sudden availability of supply prompts an increased rate of metabolic activity. This in turn prompts the microbial population to increase until the available food supply is utilized. The most obvious change in water quality is reflected in the dissolved oxygen content because of the following generalized reaction:

$$\text{Organic matter} + \text{Micro-organisms} + O_2 \rightarrow CO_2 + H_2O + \text{More Organisms}$$

Under normal river conditions the organic matter is broken down aerobically in the presence of dissolved oxygen (DO), by the aerobic bacteria, which utilise the free oxygen in the water. This process of aerobic degradation continues till the dissolved oxygen in the water is completely utilized. The oxygen depletion in a river may be offset by re-oxygenation which takes place through the air-water interface by atmospheric oxygen which is the chief supply source of oxygen to the surface water.

The oxygen balance of a river can be explained in terms of the BOD. The BOD indicates the amount of oxygen required to oxidise the organic matter in a stream by the aerobic micro-organism. It is assumed that the rate of oxidation is proportional to the amount of organic matter remaining. This can be expressed as,

$$BOD_t = L(1 - 10^{-k_1 t})$$

where,

$BOD_t = BOD$ after time t,

$L =$ ultimate BOD,

$k_1 =$ reaction rate constant which is dependent on the nature of organic matter present.

As indicated earlier natural unpolluted water is usually saturated with oxygen, but as soon as the BOD is exerted from effluent discharges the dissolved oxygen falls and an oxygen deficit is created in the water. This oxygen deficit is met by oxygen from the atmosphere to bring the dissolved oxygen to saturation level. The rate of solution of oxygen is proportional to the oxygen deficit, which is expressed as,

$$D_t = D_a 10^{-k_2 t}$$

where,

D_t = oxygen deficit after time t,

D_a = initial oxygen deficit ,

k_2 = rearation constant.

The reaeration constant depends on the nature of flow, channel configuration and also temperaature. A mountain stream will have a rearation constant a thousand times more than a stagnant stream.

As the amount of oxygen consumed by the BOD uptake increases, the oxygen deficit also increases. In such a situation, initially a slow rate of reaeration takes place. If pollution by organic matter is not excessive a critical point is reached where the rate of deoxygenation equals, reoxygenation and therefore the dissolved oxygen will reach saturation point eventually. This results in the classical Oxygen Sag Curve, which is derived by considering the difference in the rate of oxygen uptake and reaeration.

As seen in the figure 1.6 below with moderate pollution (moderate organic load), the dissolved oxygen remains high enough to support fish life. In the case of excessive or severe pollution resulting from a heavy organic waste loading into the river, all the dissolved oxygen is removed from the water and and the river becomes barren and is virtually dead.

It is at this point that the river becomes grossly polluted. This situation can be mathematically expressed as,

$$D_t = \frac{k_1 La}{K_2 - K}(10^{-K_1 t} - 10^{-K_2 t}) + Da 10^{-K_2 t}$$

where,

La = ultimate BOD.

Other symbols are the same.

The Oxygen Sag Curve developed by Streeter-Phelps (1925) as quoted by Nemerow (1978) assumes that only factors affecting the oxygen balance are the oxygen uptake by the BOD and reaeration from the atmosphere, no alteration in the flow and no added pollution in the river under consideration. Though this was developed in 1925, even today it is the most widely used model, in environmental engineering with little modification to evaluate the water quality of a river.

When the oxygen gets depleted due to aerobic degradation, the higher life forms dependent on the oxygen dies and therefore an imbalance in the biological population occurs (Salmon and trout disappear when the DO is <5.0 mg/L for example). At this point the anaerobic degradation processes begins to operate through the anaerobic bacteria, which uses organically or inorganically bound oxygen, common sources of which are nitrates and sulphates. The end product of anaerobic process are the production of hydrogen sulphide and methane. This results in septic conditions and bad odour, which indicates that a river has reached a grossly polluted state. This situation occurs when there is a heavy organic loading into the river. Dissolved oxygen

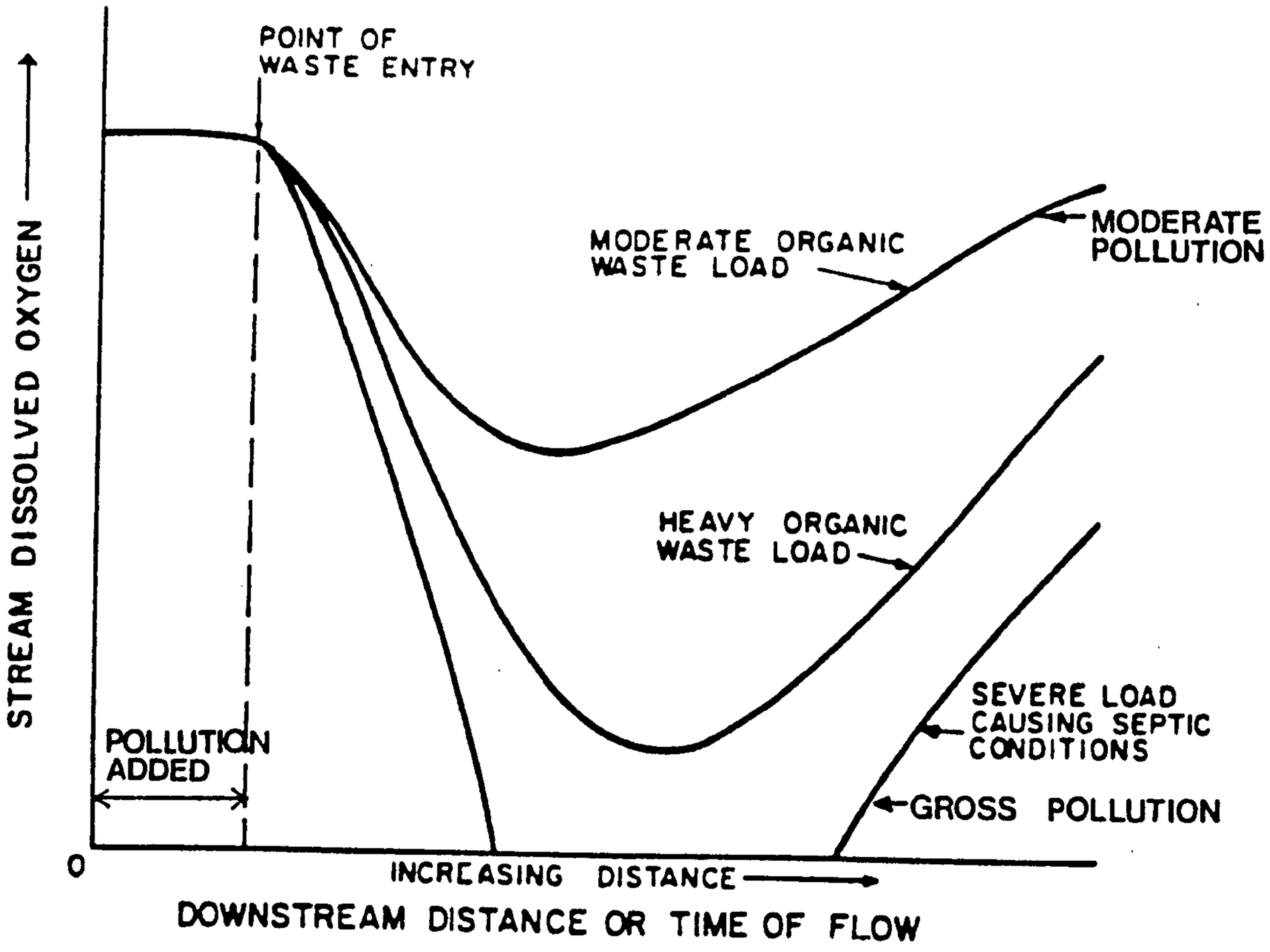


Figure 1.6 — The oxygen sag: Stream DO reductions from moderate to severe pollution

Source: Overcash M.R. *et al* (1983); Tebbutt T.H.Y. (1973)

is very essential and critical for fish and other aquatic life and and for a healthy state of a natural and unpolluted river.

Reaeration and self-purification of a river can occur with time as shown in figure 1.7, but if there is continued ingestion of heavy organic discharges by industries, irreparable damage to the river can result.

1.3.6 Eutrophication

An important aspect of water pollution is eutrophication due to overloading of nutrients into the water system, such as rivers and streams. This is also at times referred to as nutrient pollution.

Natural lakes undergo slow changes from low nutrient content to rich nutrient content waters. They are enriched with organic matter that enter from decomposing plant and animal matter which becomes a source of nutrient for algae and lower aquatic plants. This addition of nutrient to water is termed eutrophication. Eutrophication is enrichment by all forms of nutrients in water, but it is generally meant the build up of nitrogen and phosphorous which control the growth of algae and other aquatic plants. Phosphorous and nitrogen are essential nutrients to phytoplankton and it is not toxic to aquatic organisms. It is also very essential to for a healthy community of fish species. But excess inputs of nutrients causes undesirable effects in the aquatic environment. One such result is hypertrophication, which means excess nutrient supply. This causes red tides, i.e. a formation of anoxic/suboxic water body of methane and hydrogen sulphide gases and the extinction of valuable aquatic organisms can occur (Satomi *et al* 1987).

Natural eutrophication is a gradual process, and under normal conditions takes

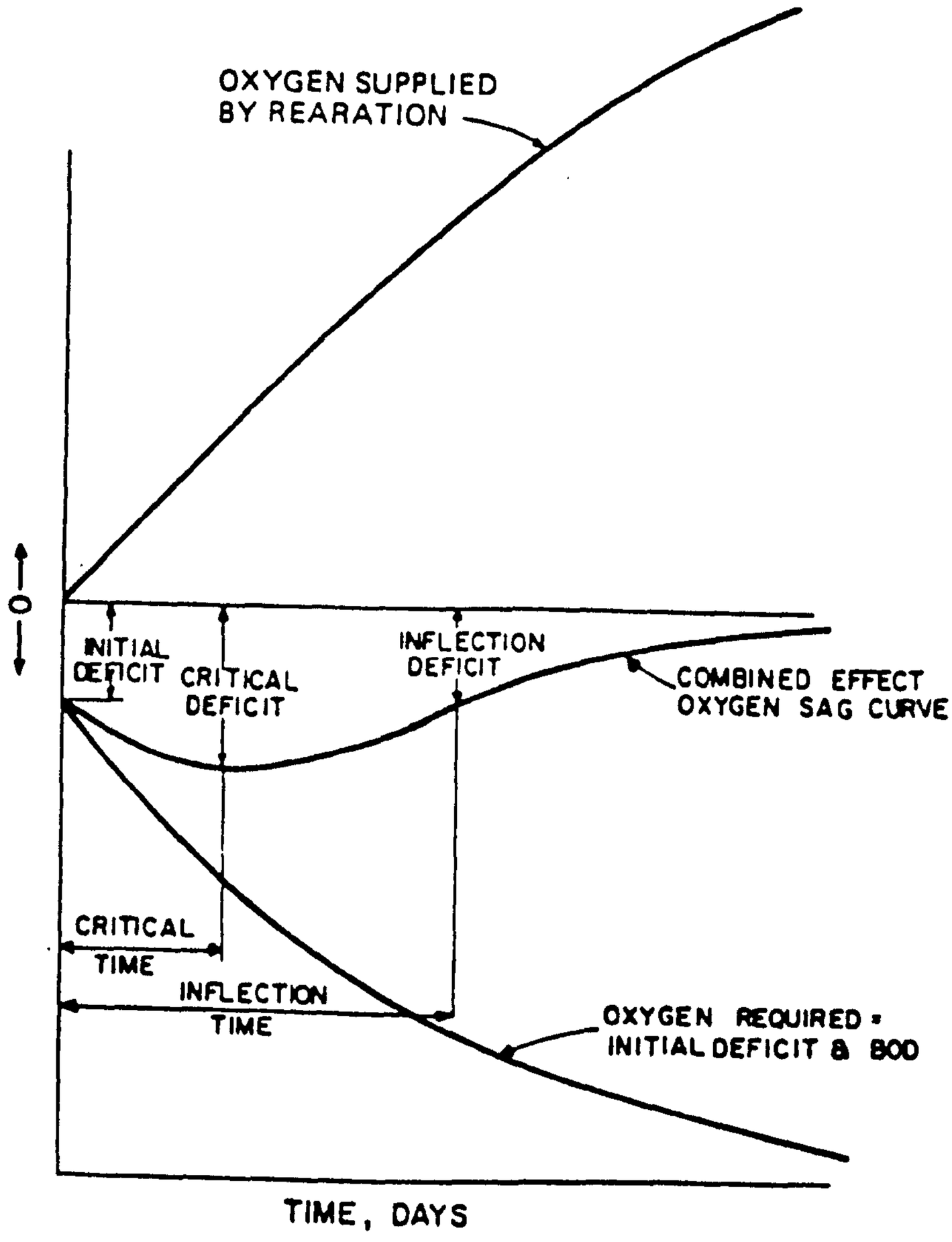


Figure 1.7 — The Oxygen Sag Curve and its components reaeration and deoxygenation parts

Source: Overcash M.R. *et al* (1983)

over hundreds of years to change the character of the the lake. But now the process is accelerated by human activities such as farming where fertilizers are used and therefore nitrogen and phosphorous find their their way into the water bodies. In the urban areas detergents become important, most of which comes comes via domestic and industrial wastes and are becoming increasingly important today. These detergents contain polyphosphates which enrich the waters (Best *et al* 1977). In the US, the Great lakes, and many lakes in Italy and Switzerland are altered radically due to eutrophication. Excessive weed growth and algal blooms interfered with recreational uses of these lakes. Fish were killed by oxygen depletion.

Fewer pike (*Esox lucius*) are found in the inland waters with dense vegetation beds. This is closely related to the water quality with oxygen deficiency in such beds being common. Human induced eutrophication leads to drastic decline in pike as observed in some of the lakes in Turkey (Petr, 1987). This is also true for cray fish and common carp.

Even after treatment nitrate content remains high at times. In Lake Erie chloride content increased by 500% in the last 50 years and ammonia increased by 600% in the last 40 years. In most lakes which have algal blooms the phosphorous level is > 0.1 mg/L, but the critical level is <0.005 mg/L The critical level of nitrogen for algal growth is 0.3 mg/L (Tebbutt, 1973). Nitrogen is also obtained from the atmosphere, but it is mainly the phosphorous which controls growth.

As a catchment area becomes urbanised the effect of agricultural uses of nutrients decrease and the domestic and effluent discharges of industry becomes important and accelerates eutrophication. Lund (1968) and Narshall (1966) as quoted by Best and Ross (1977), reviewing eutrophication have found that there is little distinction between eutrophication and pollution, since pollution also includes the addition of substances to waters, which includes a wide range of contaminating materials such as solid wastes, organic and inorganic nutrients, heated wastes and toxic substances. Therefore, in addition to agricultural waste water, industry, domestic and municipal sewage contribute to eutrophication.

1.4 Overall view of pollution

When the various aspects of water pollution are considered, river pollution can be expressed as,

$$R = f(i, d, a, g, b, e, x, y)$$

where,

i = industrial waste water discharges to the river,

d = domestic sewage entering the river,

a = agricultural discharges entering the river,

g = entry of pollutants through ground water into the river,

e = pollutants settling in the river from the air,

x = assimilation capacity of the river,

y = rate of atmospheric oxygenation or reaeration,

R = river pollution.

Using the above expression, the magnitude of river pollution can be mathematically written as,

$$R = (x + y) - (i + d + a + e + g + b)$$

```
if,   (x+y) > (i+d+a+e+g+b), a river is clean and unpolluted,
if,   (x+y) < (i+d+a+e+g+b), a river is  polluted,
if,   (x+y) = (i+d+a+e+g+b), a very delicate balance exists
                             in a river.
```

(all symbols remains the same)

1.4.1 Regional disparities

Water pollution is a global phenomena, but closer examination of the nations indicate that the principal injections of pollutants into the environment takes place in the mid latitudes of the Northern Hemisphere. Ten highly industrialized countries with the highest GNP fall within this zone such as the USA, USSR, Japan, FRG, France, Canada, Italy, GDR and China. In other words pollution is a problem predominantly of the industrially developed countries, but tropical developing countries are no exceptions. Other than water and land, air too is increasingly being polluted and is excessively higher than in any other regions in the world. In industrial countries too, the industrial urban areas have a higher pollution index than the remoter areas. Pollution of this nature is identified in the developing countries in pockets of regions where rapid industrialization or intensive agricultural development have taken place.

Though the nature of the water pollution problem is essentially the same in mid latitudes of the northern hemisphere and the tropical regions, the sources of pollution differ markedly. Further, the control mechanism of water pollution is much more developed and stringent in the former region.

Emission of sulphur dioxide and nitrogen oxides are becoming an increasing problem as environmental pollutants. Though initially they are air pollutants they end up as water pollutant and finally affect the water bodies by settling in the lakes and rivers. Therefore acidification of lakes by this source is a more recent form of water pollution in the mid latitudes. Lakes and rivers such as in West Germany, USA, Canada are subject to acidification. Between 1970-80, 145.5 million tons/per/year of sulphur oxides and nitrogen oxides were emitted in the northern hemisphere, while in the southern hemisphere it was only 5.5 million tons per year (Holdgate, 1982). Regionally, the total emission in the mid latitudes of the northern hemisphere is greater than in any other region.

In China the planned industrialization after the cultural revolution has prevented massive urbanisation and industrialization. As the industries are dispersed and rural development emphasised in its development plans, massive concentration of pollution in one location was avoided. The industries are mainly medium and small scale rather than the large scale industries of the western nations. Therefore China does not face the pollution problems common to the western developed nations.

1.4.2 Current trends in water pollution

Fresh water, as observed earlier is increasingly becoming limited as a vital resource. As population grew and industrial development rose, a similar trend ran parallel in the water use too. Therefore in the last two decades, there was a strain on the water resources in many countries of the world. In the developing countries water borne infectious disease such as typhoid, cholera, diarrhoea and hepatitis were becoming common. The water pollution problem associated with the developed countries were different and more serious. Though, in these countries the water borne infectious diseases were virtually eliminated the possibilities of cancers due to toxic elements in water was becoming important. Water resources tapped from ground water reserves in advanced countries were found to be polluted with toxic elements. In the river Colorado system the ground water resources contain carcinogenic elements like radium.

The increased use of pesticides, insecticides, weedicides and herbicides in agriculture depicts regional disparities. Where agricultural activities were highest the problem of persistent pollutants persisted in the water courses. Further this was clearly evident in the risk levels involved due to pesticide poisoning. An average low of 3 ppm was recorded in the Alaskan inuits, while in India it was 25 ppm, which was the average highest. In USA, the figure stood at 12 ppm.

A more recent trend is the **transfer of pollution** from the developed to the developing countries. As the developed countries are already saturated with environmental pollution, the hazardous production processes are transported to the less developed nations, with weak environmental laws. An example is the US asbestos

industry. The most hazardous steps in production processes are concentrated in the developing countries like Mexico, Brazil, which have weak environmental laws (Shue-1981 quoted by Zeigler, 1983). The illeffects have manifested. Infants born in the neighbourhood of these industries have partially formed skulls, a disease called **monkey face**, where the patients have distorted faces and a skin disease called **alligator disease**. Union Carbide in Bhopal, India is another recent example.

Summary

As a summary it could be said that river water is used for industrial, agricultural, recreational, navigational and public consumption purposes. Aesthetically, it is a major component of rural and urban landscape. In addition to all these uses it has an ever increasing additional function as a transport medium for the polluting waste water discharges. Therefore, the once **clean, pure, beautiful** and **sparkling** river water has become fouled and polluted and its uses impaired by humans. Apart from the direct threat to public health, water pollution affects the aquatic system and all the other beneficial uses of water. Thus the concept of the river as the **bottomless garbage can** no longer holds today.

Hence, the water quality criteria established by the US Environmental Protection Agency (EPA) in 1976 that "all waters must be free from substances attributable to waste water or other discharges that settle to form objectionable deposits; float as debris, scum, oil or other matters to form nuisances; produce objectionable colour, odour, taste or turbidity; injure, are toxic or produce adverse physiological response in humans, animals or plants; and produce undesirable or nuisance aquatic life" is a good starting point to understand the problems facing the rivers today.

Until the nineteenth century the impact upon the river environment was negligible. It is the transition from the agricultural and rural society to industrial and urban society that began to make a noticeable impact on the environment.

The industrial revolution had twofold effects on the river environment, i.e. (i) it concentrated the population in the centers of industrial development which resulted in the discharge of large quantities of domestic waste water into short stretches of streams whereas previously the polluting matter had been more widely distributed, (ii) it led to the discharge of increased volumes of waste waters from industrial processes. In the post World War II period industrial activity has greatly altered the composition of waste water and more resistant, persistent toxic pollutants are discharged into the rivers. Today industries are the greatest offenders and major polluters of rivers, since the strength, volume and concentration of the discharges are many times greater than domestic sewage. This is clearly illustrated by the palm oil mill effluent in Malaysia. The total industry wide BOD load is 1640 tons/day (5 cubic metres of palm oil mill effluent is generated for every ton of palm oil produced), which is equivalent to the domestic waste from a population of 33 million, hence more than double the size of the entire Malaysian population (UNEP, 1985). Thus, industrial polluting discharges of this nature and magnitude have seriously affected the river environment not only in Malaysia, but in many other countries as well.

Chapter II

Industrial Water Pollution

2.1 Nature of waste waters

All industrial wastes affect the life of a river. When the effect is sufficient to render the stream unacceptable for its **best usage** it is said to be polluted (Nemerow, 1978). Therefore to call a stream polluted means that the stream contains an excessive amount of a specific pollutant or a group of pollutants.

Industrial effluents are airborne such as carbon monoxide, particulates sulphuric oxides, nitrogen oxides, hydrocarbons, gaseous wastes, which are pure gases or vapours; combination of gases and liquids and combinations of gases, liquids and solids; or liquid wastes.

The liquid wastes discharged from industrial processes are so varied that it defies classification. They may contain dissolved gases or solid particles. Pure liquid waste is either aqueous or non aqueous. Aqeous wastes contain high concentration of water with small amounts of dissolved inorganic or organic materials. Nemerov (1984) classifies industrial water pollutants in the following manner. These pollutants when discharged independently or in combination, affect the water quality of the receiving stream. This can also be seen in table 2.1.

1. Inorganic Salts
2. Acids and/or alkalis
3. Organic matter
4. Suspended solids
5. Floating solids and liquids
6. Heated water
7. Colour
8. Toxic chemicals
9. Micro organisms
10. Radio Active materials
11. Foam producing matter

Inorganic salts: These are present in most industrial wastes and causes water to be hard and the stream undesirable for industrial, municipal and agricultural usage. Salt laden waters deposit scale on municipal water distribution pipelines. Hard waters interfere with the dyeing process in the textile industry, brewing in the beer industry and the quality of the product in the canning industry. Magnesium sulphate has a cathartic effect on people. Iron causes spots and stains on goods in textile mills and papers produced in the paper mills. Another disadvantage is that under suitable environmental conditions inorganic salts especially nitrogen and phosphorous induce growth of algae in surface waters. Though algae are secondary forms of pollution, they can be of extreme importance. Their advantage is that of adding dissolved oxygen to the streams, and their disadvantage, the organic loading they contribute after dying.

Acids and alkalis: These are discharged by chemical and industrial plants make a stream unsuitable not only for recreational purposes such as swimming and boating but also for propagation of fish and other aquatic life. High concentration of sulphuric

Contaminant	Source	Effects
inorganic salts	oil refineries, desalination plants, munitions manufacture, pickle curing	interference with industrial usage, municipal water, and agriculture
acids, alkalies	chemical manufacturing	corrosion of pipelines and equipment; destruction of aquatic life
organic matter	tanneries, canneries, textile mills, etc	food for bacteria; oxygen depletion
suspended matter	paper mills, canneries, etc	suffocation of fish eggs; stream deterioration
floating solids and liquids	slaughterhouses, refinery oil	objectionable appearance, odor; interference of oxygen transfer
heated water	cooling waters from most industries and power plants	acceleration of bacterial action, reduction of oxygen saturation
color	textile, metal-finishing, and chemical plants	objectionable appearance
toxic chemicals	munitions manufacture, metal plating, steel mills, etc	alteration of stream biota and animal and human predators
microorganism	tanneries, municipal–industrial sewage plants	unsafe for drinking
radioactive particles	nuclear power plants, chemical laboratories	concentration in fish; unsafe for drinking
foam producers	glue manufacture, slaughterhouses, detergent manufacture	objectionable appearance

Table 2.1 — Figure 2.1 Industrial contaminants of water

Source: Nemerow, N.L. (1984)

acid (pH < 7.0) causes eye irritation to swimmers, deteriorates ship hulls and fishing nets. The toxicity to sulphuric acid for aquatic life is a function of the resulting pH. It is generally agreed that the pH of a stream must not be < 4.5 and not more than 9.5. Yet stream pH between 2-11.0 may occur near industrial sources of pollution. Sodium hydroxide is an alkali and is highly soluble in water and affects the alkalinity and pH. It appears in wastes from many industries including soap manufacture, textile dyeing, rubber and leather industry. Streams having as little as 25ppm of sodium hydroxide are deadly to fish. Water treatment plants are also extremely affected by these pollutants. The pH values due to acidity or alkalinity also affect many other processes such as flavour in soft drinks, taste of canned fruits and cleaning of industrial metals.

Organic matter: It exhausts the oxygen resource of the river and creates unpleasant tastes, odours and general septic conditions. Fish and other aquatic life are stifled by lack of oxygen and the oxygen level combined with other stream conditions determines the life or death of fish. The critical range for fish survival is 3-4 mg/L of oxygen. Some species do not survive in water containing 3 mg/L of dissolved oxygen while some species may not be affected. For example, sensitive trout need at least 5mg/l of dissolved oxygen, while carp and scavenger fish can survive in dissolved oxygen of 1 mg/L. This oxygen shortage caused by organic matter is often considered to be the most objectionable single factor in river pollution. Tanneries, Canneries and textile mills discharge a heavy load of organic matter into the receiving waters.

Suspended solids: They settle to the bottom or wash up on the banks and decompose, causing odours and oxygen depletion in the river. Fish death occurs because of

the sudden lowering of oxygen and the solids that settle, cover the spawning grounds and inhibit propagation. Visible sludge creates unsightly conditions and destroys rivers recreational use. Paper mills and canneries discharge much of the suspended solids.

Floating solids and liquids: These include oils and greases and other materials which float on the surface. They not only make the river unsightly but also obstruct passage of light through water retarding photosynthesis and therefore growth of vital plant food. Oil in streams is objectionable because it interferes with natural reaeration, is toxic to certain species of fish and aquatic life, creates fire hazard on water surface if present in sufficient amounts, destroys vegetation along shore lines with consequent erosion, renders boiler feeds and cooling water unusable, causes trouble in water treatment processes, creates an unsightly film on the water surface and lowers recreational potential such as boating. The main discharges are from slaughter houses and oil refineries.

Heated waters: Discharged as cooling waters from most industrial or power plants have various adverse effects. It increases the water temperature of the stream so that the industry downstream cannot use it. Also warm water is lighter than the cold water and therefore develops stratification and this causes fish life to retreat to the bottom of the stream. Dissolved oxygen is less in warm water, and therefore aquatic life suffers and less oxygen is available for natural biological degradation of any organic pollution discharged into these warm surface waters. Also bacterial action increases in higher temperatures, resulting in accelerated depletion of stream's oxygen resources.

Colour: Is an indicator of industrial water pollution and is contributed by textile, paper mills, tanneries and slaughterhouses. Compounds present in waste waters absorb certain wavelengths of light and reflect the remainder in fact generally conceded to account for colour development of streams. Colour also interferes with transmission of sunlight into the stream and therefore lessens photosynthetic action. It may also interfere with oxygen absorption from the atmosphere. Visible pollution causes more problems for the industry concerned than invisible pollution. Red and deep brown from slaughter houses, browns of paper mills and wastes of various intense colours from textile mill wastes and yellows from plating-mill wastes focuses public indignation directly on those industries. Property values decrease along a visibly polluted river and fewer people swim, boat or fish in streams highly coloured by industrial wastes. Further municipal or industrial water plants have difficulty in removing colour from raw water.

Toxic chemicals: Both organic and inorganic chemicals even in low concentrations may be poisonous to fresh water fish and other smaller aquatic microorganisms. Toxic insecticides such as toxaphene, dieldrin, and dichlorobenzene have killed fish in farm ponds and streams. New, highly complex organic compounds produced by chemical industry for textiles is extremely toxic to fish life. Acrylonitrile, a raw material used in certain new synthetic fibres is an example. Almost all salts even in low concentration are toxic to aquatic life,for example chlorides at 4000 ppm, hexavalent chromium compounds at 5ppm and copper between 0.1, 0.5 ppm are toxic to bacteria and other microorganisms. All three salts are often found in water courses. Accidental or intermittent discharges of certain materials may go unnoticed yet may disrupt stream life.

Microorganisms: A few industries such as tanneries and slaughter houses sometimes discharge wastes containing bacteria. Vegetable and fruit canneries may also add bacterial contamination to streams. These bacteria are of two significant types.

1. Bacteria which assist in the degradation of the organic matter as the waste moves downstream. This process may aid in **seeding** a stream (i.e deliberate innoculation with biological life for the purpose of degrading organic matter) and in accelerating the occurrence of oxygen sag in the river.

2. Bacteria which are pathogenic, not only to other bacteria, but also to humans such as anthrax bacillus, originating in tanneries where hides from anthrax-infected animals have been processed. Municipal and industrial sewage plants also contribute

to microorganisms.

Radioactive materials: The manufacture of fissionable materials and increasing use of atomic energy have resulted in radioactive wastes. The effects of radiation can be immediate or delayed and it has cumulative damaging effects on living cells. Highly active radio isotopes such as Sr^{90} and Cs^{137} release energy for a very long time, i.e. several generations of the human race. Radiative contaminants in the environment are not readily detectable by the conventional methods. Further the biological and hydrological characteristics of a stream may have a profound influence on the uptake of radioactivity. The maximum safe concentration of mixed fission products for lifetime consumption according to U.S. Atomic Energy Commission is 1 $\times 10^7$ micro curies per millilitre. (Nemerow, 1978). Therefore radioactive wastes are very undesirable in surface streams.

Foam producing matter: Discharged by textile mills, soap and detergent industry, pulp and paper and chemical plants, give an undesirable appearance to the receiving stream. It is an indicator of contamination and is often more objectionable in a stream than the lack of oxygen.

2.1.1 Industrial water-uses, volume and effluents

All industrial processes are dependent on water for cooling, condensing, cleansing, drinking and sanitary purposes, incorporation into products, conveyance of wastes, including heat and many other uses, which makes the industries heavy users of water. Waste waters from industries can be considered as process water rather than water used as heat transfer or a transport medium. Process water contains a heavy polluting load composed of an increasingly complex mixture of chemicals (Calley, 1977) whose behaviour towards biological system can be varied.

The primary objective of an industry is to produce the best possible product of its type at the lowest possible cost and the operation schedule of the industry is geared to achieve this end and as a result it is extremely variable. On particular days the plant may operate at normal or above capacity to fill an urgent order, while it may be closed on certain days. It may or may not operate on weekends and seasonality of operation is an important factor in industrial production especially in food industries. Owing to the variable nature of plant operations, the waste water discharges too are highly variable. Depending on the process and the product produced the waste waters could be discharged at different times of the day. Similarly there may be no waste water discharges on certain days. Further no two industrial effluents are alike nor the effluents from different processes within an industry (Margola, 1984).

The volume of water used and the strength of the industrial effluents are highly variable and depends on the type of industry. In the U.S. 21.1 $\times 10^{12}$ gallons of water was withdrawn for industries alone in 1978 and 19 $\times 10^{12}$ gallons were discharged as industrial waste water (Meyer, 1984). The magnitude of industrial water intake and discharge in U.S. can be seen in table 2.2.

In the U.S. industrial waste water BOD loads are 3-4 times larger than the BOD load from sewered population (Hodges, 1973). For example in the Delaware Estuary, U.S. alone there are 18 major industrial waste water sources. The total carbonaceous oxygen demanding waste waters discharged into this estuary was 65% municipal 35% from direct industrial discharges.

In U.K. a total volume of 11.2 million cubic metres of sewage containing an average 17% industrial effluents is treated and released into all 4 major categories of rivers. There are 2959 industrial discharges made directly to the rivers and canals which releases 68.7 million cubic metres of effluent every day (Department of Environment, 1978) The tendency lately has been to discharge industrial effluents to sewers rather than to water courses directly. Therefore the water quality has increased as more industries wastes are treated.

In Rio de Janeiro the volume of industrial waste water load into Guanabara Bay in 1975 was 92,498 kg of BOD/day which is 19.9% of the total discharge. Municipal

Table 2.2 — Water intake and discharge by U.S. manufacturing industries in m^3/day - 1978

Manufacturing industries	Water intake	% Total water intake: all groups	Water discharged
Food and relat -ed products	2801	5.7	2456
Total industries	49175	100.0	44217

Source: Meyer, G. (1984)

load discharge was 311,131kg BOD/day or 66.9% (Biswas, 1979).

2.1.2 Strength of industrial wastes versus municipal sewage

The strength and volume of sewage is well established and this occurs within the range of 100-1000ppm for contaminants measured in volume of 50-150 gallon per person/day. But the strength of the industrial discharges is highly variable ranging from few hundred to several thousands, depending on the type of industry.

The variability in the strength of industrial discharge depends on the nature of the effluent itself. Not all the dissolved or colloidal organic matter in the industrial waste waters oxidizes at the same rate and degree. Sugars are more readily oxidized than starches proteins or fats. The rate of decomposition for industrial organic matter may therefore be faster or slower than that for sewage organic matter. The figure 2.1 illustrates the deoxygenation rates for sewages and industrial wastes.

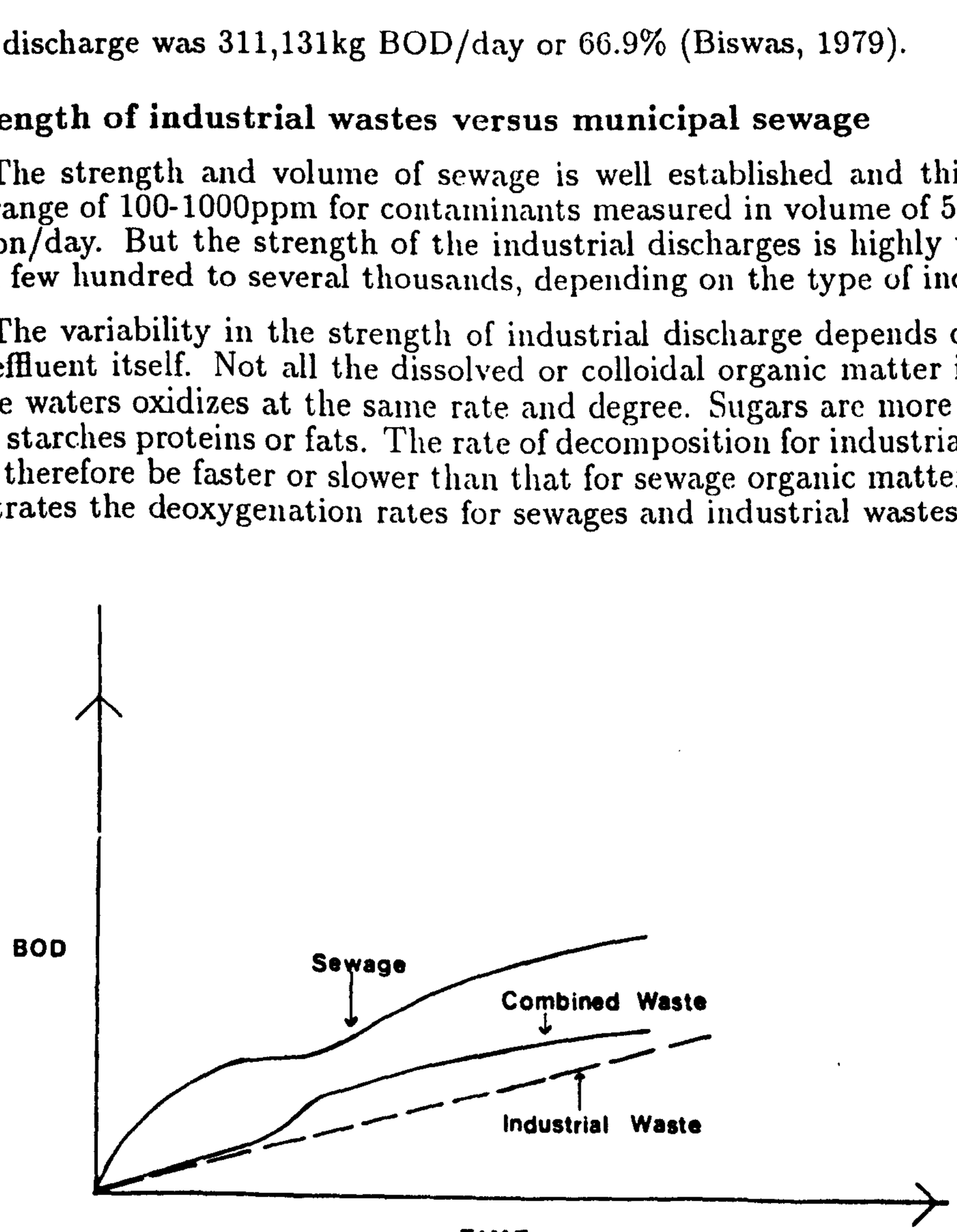


Figure 2.1 — Deoxygenation rates of sewage, and in combined and industrial wastes

Source: Nemerow, N.L. (1978)

In this hypothetical situation where the industrial waste, with its constant rate of

degradation tends to smooth out the rate of decomposition of sewage and therefore the results show less upsurge due to nitrogenation. Also the rate of decomposition of the industrial waste tends to slow down the initial rapid rate of domestic sewage.

Industrial wastes deoxygenates at rates which vary from a negative value to about 5 times the rates at which normal domestic sewage deoxygenates. Some industrial wastes have no organic matter such as metallic trade wastes and thus no oxygenation rates or oxygen demands. While the food industry wastes which have heavy oxygen demands have high deoxygenation rates. The deoxygenation rates of domestic sewage is quite constant and seldom varies from 0.07-0.20 (Nemerow, 1978).

Industrial waste waters have a big influence on the strength of a sewage and its amenability to treatment. Sewage from industrial towns contains varying proportion of trade wastes from industrial premises. The nature and strength of sewage is influenced by the type and proportion of the industrial effluents. On the average industrial effluents in sewage is about 1/5, but in some areas higher.

Industrial water borne wastes present a potential hazard to the natural water systems. These wastes contain either organic matter which causes deoxygenation by promoting microbial activity or material which is directly toxic to various life forms in the system. (Calley, 1977). Some industries release waste water containing residual oil in emulsified form which is very damaging when released to surface waters.

Rivers assimilate a certain quantity of wastes before reaching a polluted state but too much confidence cannot be placed on the self-purification capacity of a stream. A larger swifter and remote stream that is not much used is able to assimilate a considerable amount of waste, rather than a stream which is stagnant and used heavily. When industrial wastes containing organic biodegradable matter are discharged into a water body the dissolved oxygen content of the water decreases considerably within a very short time. If the volume of waste is strong and large, in relation to the reaeration capacity of the receiving water the oxygen demand will be greater than the dissolved oxygen present in water and that supplied by reaeration and therefore the result is that the receiving water will be reduced to a polluted condition and may eventually become septic with the formation of hydrogen sulphide and methane. It is normally recognised that the critical range for aquatic life to survive is 3-4ppm of dissolved oxygen and if this limit is not infringed the receiving water will not show any sign of pollution. Often this shortage of oxygen caused by organic matter in itself is considered to be the most objectionable factor in stream pollution and therefore in water pollution management is usually aimed first at maintaining this minimum oxygen level in all water bodies (Nemerow, 1984).

2.2 Water pollution by food processing industries

Food processing industries are those, whose main concern is the production of edible foods for human or animal consumption. The food processing sector mainly concerns ten industrial branches listed below (UNIDO, 1985).

1. Meat and meat processing industries
2. Dairy industry
3. Fruit and vegetable industry
4. Fishing industry
5. Vegetable fats and oils industry
6. Cereal industry
7. Sugar industry
8. Chocolate and confectionery
9. Animal feed industry

10. Beverage industry

Food processing plants include canneries; dairies; breweries and distilleries; meat packing and rendering including poultry plants and animal feed lot; sugar refineries; pharmaceutical plants; yeast plants and miscellaneous plants producing pickles, coffee, fish, rice, soft drinks, bakeries, water production and confectioneries.

2.2.1 The nature and developments in the food industry

At the international level production and the food processing is is dominated by large transnational enterprises and mainly transnational corporations. These enterprises account for approximately half of the production of this sector in the developed and developing market economies.

In the developing countries, wherever this industry exists at all it is geared mainly towards satisfying domestic demand and in most cases operates with out moded technology and small or medium sized plants. Most of the production in developing companies are related to staple foods with little manufacturing value added as a result the developing countries account for about only 16% of the world manufacturing value added, in this sector (UNIDO, 1985).

The last 100 years saw the development of food manufacturing from the scale of craftsman/cottage industry to its present situation. Today every consumer has readily available to him a complete range of fresh wholesome food, ingredients or fully prepared food. His needs are satisfied by products of high guaranteed quality at competitive prices.

The period between the two world wars saw the development and introduction of many new food products such as breakfast cereals, canned foods and prepared dry mixes. Therefore the range of convenience foods was being extended very rapidly. Among the convenience food ice-cream deserves special mention. Since the 1950's frozen foods have become a new branch of this industry. The refrigeration machine was an important invention for the food industry and this development went parallel with with the frozen foods.

The foundation of canning technology by Appert in 1809 for food preservation and Louis Pasteurs' investigation of bacteria at the turn of the 19th century, has contributed much to the sound scientific understanding of processes involved in the food industry and since then large scale mechanization and automation have occurred in a wide range of food products.

The invention of margarine in 1866 by Mouries in France and its gradual development of using vegetable oils by hydrogenation was another revolution and today margarine is a unique example of manufactured food and is a major food product in its own right and is widely used in various other industries as raw material too (Lawrence, 1976).

Today a fair percentage of household income is spent on food, for example an average British household spends 22% of the total household expenditure on food. The index of production for food in U.K. reached 111.0 by 1982 (1975=100). In U.K. bacon curing, meat and fish products are the largest sector of the food industry and amounted to 28.6% of the sales in 1982. Between 1978-1982 the soft drinks market grew by 8% (North of England Development Council, 1983). This indicates that the Food Industry is a fast developing industry and a major contribution of this industry as a whole is getting the higher proportion of the primary products on to the dining table.

2.2.2 Water use and effluents

The production processes in the food industry consist of the following major stages in production.

1. Cleaning the raw materials

2. Removal of inedible portions
3. Preparation of food stuff
4. Packing

Food industry as a whole uses vast amount of water for its production processes. It is a heavy user of water and needs good quality water for production. The volume of water used varies from industry to industry. Only a small proportion is used for consumptive use and the remainder gets discharged as waste water. Consumptive use of water is greater in proportion in the brewing, distillery and soft-drinks industry ranging from 4 to 25% (Holdsworth, 1970). In the fruit and vegetable processing industry too the water consumption is high. In England and Wales 3-4,000 million m^3 of water per year is used in the food industry. Large quantities of water in this industry is discharged as effluent to surface water. Liquid waste disposal problems in the food industry arise through the use of large quantities of water in the cleaning operation and processing of foods.

The wastes that arises in the food industries are:

1. Spoilt raw materials or spoilt manufactured products
2. Rinsing or washing waters
3. Condensing or cooling waters
4. Transporting waters
5. Process waters
6. Floor and equipment cleaning liquid
7. Product drainage
8. Overflow from tanks or vats
9. Usable portions of the products

There is wide variation in the effluent loading from hour to hour and day to day. Individual factories manufacturing the same type of product may use different production methods which may result in different effluent loadings. Further different processes within an industry can have different pollution loads. A single process may cause the entire pollution load from the entire industry such as blanching in boiling water is often used in vegetable canning industry to destroy the oxydizing enzymes and to facilitate the removal of oxygen. This process produces waste waters on a massive scale, amounting to 25-100% of the pollution caused by the entire process. (UNEP, 1985).

The volumes of waste water may be almost negligible in some industries, but reach one million gallons per day or more in others. The rate of flow of the discharge and the strength of the effluents too vary very widely in this industry.

2.2.3 The composition of food effluents

The effluent characteristics from selected food industries can be seen in table 2.3.

The composition of food industry effluent is extremely varied in and depends upon both the nature of the product and the production techniques. Not only do the volume and strength of the effluent vary from industry to industry, but within the same industry variation occur depending upon good house keeping. The BOD may be as low as 100 ppm or as high as 100,000 ppm. The diurnal and weekly ranges of concentration too are variable. For example spoilt beer has a a BOD upto 100,000 mg/L. A 24 hour study of brewing effluent gave a BOD range of 100.0-4820.0 mg/L (Isaac , 1974). A recent survey in Australia of Australian food processing effluents showed that their strength ranged from 1210-20,000 mg/L BOD per day for dairies. Fruit Canneries BOD ranged from 210.0-6000.0 mg/L (Lane, 1982). According to Cotton (1976) milk wastes have a high BOD of 10,0000 -20,000.0 mg/L. With the

Table 2.3 — Characteristics of food effluents

Industry	Waste characteristics	Source
Edible oil	High in fats, oil, grease, BOD, COD, SS and Dissollved solids	1
Non alcoh -olic beverage	High in BOD, COD, SS, pH and temperature	1
Dairy	Very high in BOD, COD, SS, and temperature. pH high but variable. High total N and P	2
Confectio -nery	High in oil, grease, BOD, COD, SS	3
Meat processing	High in oil, grease, BOD, COD, SS and total N	4

Source: 1 - Middlebrooks, E.J. (1979); 2 - Mohanrao, G.J. *et al* (1972); 3 - Sidwick, J.M. (1974); 4 - Dart, M.C. (1974) and Nemerow, N.L. (1978)

exception of very few food wastes, the BOD exceed the strength of normal domestic wastes which are usually below 200.0-400.0 mg/L (Stavenger, 1970).

The food industry waste water may be highly alkaline with pH of 11.0 or highly acidic with pH of < 3.5. Lye peeling of potatoes is an example of highly alkaline waste. When industrial processes use caustic soda or detergents, the liquid effluents become highly alkaline. Some wastes are acidic such as whey wastes. The pH of fresh cannery wastes is not far from neutrality, but generally these wastes on storage and standing turn acidic, septic and putretible giving bad odours. (Wadley, 1974).

The nutrient content of the food industry waste too varies widely. Nitrogen and phosphous may be totally absent or present in excess. Food wastes such as brewing and canning is deficient in phosphorous and nitrogen (Isaac, 1974). The seasonal nature of some food processing industries can present a particular problem if the effluent is discharged untreated into its river, such as when large quantities of phosphorous are released after canning of mushrooms and kidney beans. Under such a situation the heavy oxygen demand of biodegradable matter can produce an oxygen deficit in the receiving water sufficient to kill all the fish in receiving water (UNEP, 1985).

Sidwick (1974), expresses a different view. Since many of the food industry effluent are deficient in nutrients it will not be a problem if these effluents are discharged to public sewers as domestic sewage has excess nutrients. According to him the waste stream will be neutralized.

Food industry wastes also contain oils and grease which are found in confectioneries, edible oil and refinery wastes. Oils are biodegradable provided that the bacteria undertaking the degradation can reach the substate. But very high concentration of oil and grease is not acceptable though its not toxic, as it forms a surface film on the surface waters and impedes photosynthesis.

Steam and heat are used in large quantities in the food processing plants therefore temperature may be ambient or near boiling such as blancher water from canning

operations. Therefore the effluent discharge from these industries tend to be warm or even hot.

Suspended materials too vary. It is completely absent in some wastes, while high concentrations as 12,000 ppm in others. Wastes from confectionery, preservatives and pickles, fruit and vegetable processing industries contain high suspended solids.

Food effluents may or may not contain inoganic solids. Where caustic soda or brine is used the inoganic salt content in the wastes will be high. Some others constituients of food industry effluent use artificial colourants and flavourings which are at times inhibitory in biodegradability such as menthol used for cough sweets, in confectioneries (Sidwick, 1974).

In contrast to large number of industrial effluents those from food and drink industry do not normally contain toxic materials. The most likely contaminants are detergents used for washing, cooking and fermenting vessels or for general cleaning and bactericides used in sterilization procedures ranging from chlorine to germicides. (Madeley *et al* 1974). and therefore free from metals, pesticides and toxic substances. But health risks and risks to ecosystem in general from the efflents from food processing remain a potential problem sometimes even after biological treatment. Toxins are often produced after processing such as the uncontrolled disposal of suspended solids in the vegetable oil industry can kill fish through aflatoxicosis, while both sugar beet and potato starch yields toxic alkaloids. The effluent may also harbour pathogenic microbes such as those causing infectious hepatitis or myxoboliases in fish (UNEP, 1985).

When compared with domestic sewage the effluents from food and drink industry, are invariably organic and biodegradable, but very much stronger in the polluting strength and volumes of waste water discharged.

The polluting strength of an effluent is best defined in terms of the organic substances which affect the dissolved oxygen content of the receiving waters and this is best explained in terms of the food processing industry.

Food wastes contain organic matter in dissolved or colloidal state in varying degrees and concentration. It is heavily polluting and contains high concentration of biodegraduable organic matter. Effluents are mostly sugars, starches but not toxic or harmful themselves, but can rapidly exert a substantial oxygen demand on the receiving water which is very critical and a heavy loading on the receiving stream renders it completely devoid of dissolved oxygen rapidly. The composition of the food wastes are such that they are generally suitable as a growth medium for micro-organisms (James, 1974). Since these wastes provide an ideal environment for fermentation, a consequent characteristic of these wastes is that they become acidic and septic and is therefore highly putrefactive.

The rapid growth of factory processed foods, such as frozen and dehydrated food, canned and bottled food, and long life milk of modern food technology have led to corresponding growth in food waste production. Much of the processes of this industry was once cleaned and prepared in the domestic kitchen, but is now transferred to factory operations and therefore the resulting efflents are much more concentrated and exert a heavy polluting load on the nearby receiving stream. Further complications arise as a result of the seasonal nature of many of these industries. Though many factories operate throughout the year most have only peak seasons annually, raw materials being based mainly on agricultural products, with peak production often in the summer months, when the receiving waters provide least dilution. The net result is that the food industry wastes being highly polluting in character due to its high organic content depletes the dissolved oxygen, the single most important component of the rivers, depletion of which can destroy the entire aquatic life system dependent on oxygen and, affect human beings themselves.

2.3 Effluent characteristics from selected food processing industries

2.3.1 The soft drinks industry

The soft drink industry falls into three broad categories (MacDonald, 1974):

1. Carbonated soft drinks
2. Fruit squashes and cordials
3. Fruit juices.

2.3.2 Carbonated soft drinks

The standard identity refers to soda water as "the class of beverages made by absorbing carbon dioxide in potable water. They contain no alchohol or only < 0.5% by weight the finished beverage, as is contributed by the flavouring ingredient used" (Jones, 1984). This consists of a range of flavoured ready to drink beverage with or without the addition of fruit juice or whole fruit concentrates. 86-92% of the beverage is water and it must have < 50 ppm alkalinity expressed as $CaCO_3$ and <500 ppm total dissolved solids and < 0.1 ppm iron or Mn and are non alcoholic.

The product is manufactured by proportioning a flavoured syrup with treated water in an atmosphere of carbon dioxide, chilling and then filling into bottles or cans in a pressurised filling system operating at speeds upto 850 containers/minute.

Citric acid occurs naturally in many fruits and is used in orange, lemon, lime, grapefruit, strawberry, raspberry, cherry, lemon and lime flavours. Phosphoric acid is the cheapest acidulant. This is primarily used in cola drinks. Malic acid is widely used in fruit flavoured carbonated beverages.

Fruit squashes and cordials

This range of concentrated fruit flavoured products requires extensive processing techniques than the carbonated drinks, but as squashes are more uncarbonated, simple vaccum filters are used. Process techniques includes homogenisation for fruit pulp dispersion and product appearance, pasteurisation to de-activate pectic enzyme and sterility for good shelf life, and filteration for clean cordials such as lime juice. The quality of water need not be as high as for carbonated drinks.

Bottle washing is an important feature of squash bottling operations, a simple procedure of mainly detergent rinsing.

Fruit juices

These consist of blend of pure fruit juices musts and nectars, sweetened with sugar if necessary. Water quality is not a significant factor, but most come in small 4 fluid ounce bottles. Extensive washing techniques are necessary to remove labels and dried product residue from previous fillings. The final stage of washing process is hot water rinsing

The technical procedures that pertain to the production of fruit juices can be divided into the process of washing, crushing, refining and bottling. In some cases before bottling there is concentration and subsequent dilution. In the extraction of juice from the fruit 3 different methods are used: pressing, extraction and liquidization.

Effluents from soft drink industry

In the Soft Drink Industry, polluting effluents are produced from washing of bottles, production of syrup, treatment of water, and floor washing. Wastes are usually highly alkaline and have high BOD and SS (Nemerow 1978). The main sources of suspended matter are from paper pulp from process plant washout and product spillage, backwash water and sludge discharge of water treatment plant, straw and product residue from the pre-rinse section of the bottle washing plant.

The bulk of the BOD comes from the pre-rinse section of the bottle washers, ingredient and product spillage and product residues from plant washing and foriegn matter such as straws, cigarette butts, paper and other refuse left in the bottle plus the left over drinks in the bottle. These are the major cause of high BOD concentration. Now it is much less as labels are used in the bottles (Nemerow 1978).

Wastes from cleaning of floors, syrup mixing and storage tanks, syrup filters and spillage are intermittent and therefore not considered major source of BOD and SS. Wastes from the water treatment differ widely according to the quality required and the quality of the incoming water.

The bottle washing effluent is alkaline, but acid residues can result from product spillage and plant rinsing process. The bottle washing system contributes highly to the effluent. It contains a series of alkaline detergent baths and therefore the wastes are highly alkaline.

Initially it is a warm water pre-rinse to remove straws and product residue from the bottle. This is a relatively high polluting load. Subsequent washing consists of submerging the bottle in 2% detergent solutions at 70 °C and finally cooling the bottle in stages and also rinsing with warm and cold water. The final rinse employs high grade water and is only lightly contaminated with paper and detergent carry over.

The alkaline solution for bottle washing is composed of caustic soda (sodium hydroxide), sodium carbonate, trisodium phosphate or sodium meta silicate. Caustic soda is the principal ingredient as it has the best germicidal properties (Jones, 1984).

High grade water is also used for general plant cleaning and specific processes and bottle sterilization procedures. The effluent from these are only lightly polluting but includes biocides and chemicals such as hypochorites and alkaline detergent solutions which can create problems in the treatment plants and the receiving waters.

The main sources of pollutants are therefore limited to certain special plant operations and these can be separated from the other plant processes.

Soft drink bottling plants are often located near population centres and the effluents are discharged to to the nearest water body or to the municipal sewer system.

Juice industry effluents

Waste waters arise from fruit juice production after being used as rinsing water; as condensate and cooling water as well as filling and cleaning of bottles. In addition, at all stages of processing waste water results from the rinsing and washing of surfaces, rooms, machines and production wastage of the processed juices and fruits. A considerable part of the pollution created comes from the production wastage of the processed juices and fruits. Bulking sludge is often due to the wastes from the juice industry. Though these wastes are highly organic and biodegradable these wastes cause difficulties when discharged to treatment plants and rivers as the BOD and SS are very high. In the waste waters from the juice industry high organic acids are found and therefore low pH values are caused. The nitrogen and phosphorus content in the waste waters are low (Rosenwinkel, 1982).

In the fruit juice industry, the wastes contain juice and sugars. The combination of constituents in the effluent gives an ideal environment for fermentation and a consequent characteristic of these wastes is that they become acidic and septic and cause problems of smells incompatible with a food factory. The highly organic nature of the effluent exerts, a high oxygen demand.

2.3.3 Edible oils and margarine industry

Margarine industry

Margarine today accounts for an economically important share of the fat consumed in the world. It has firmly established itself as a food item in its own right and competes with butter and is also an important raw material to several other food

industries.

Margarine is an emulsion of water in oil. It is prepared from a blend of refined oils and fats, pasteurised skimmed milk, vitamins, colouring material, emulsifiers and flavouring agent. The blended oil, milk and other ingredients are pumped through a rotator when they are cooled, and emulsified before passing to a packing machine as margarine. The cleaning of milk preparation vessels, mixing tanks, rotators and the washing down of floors contribute to water pollution.

The effluent from a margarine factory amounts to approximately for every 1 in 3 ton of margarine (and after removal of free fat and oil) 600-2000 mg/L might be total fatty matter with BOD in the range 1200-2000 mg/L (Dart, 1974a).

In addition to these major effluents, there are other smaller sources and intermittent sources of effluent such as contaminated surface water, washings from tanks and road vehicles, canteens and domestic water.

The waste water problem associated with this industry in addition to the BOD is fat and oil, which is not only oxygen demanding, but also forms a surface film on the receiving water. The wastes are biodegradable provided bacteria attacking the degredation can reach this substrate. This is often not the case of fat and oil exist in particulate form, when blockage or blinding of biological or other treatment units or pipes can result. If wastes contain synthetic detergents, it may emulsify any grease or oil present.

Edible oil industry

Unrefined edible oils contain impurities which occur naturally or have been produced by changes taking place since harvest of oil bearing material. These must be purified and the oil should be pure, free from taste, smell and colour good housekeeping properties. The impurities can be classified as soluble or insoluble in fat.

The barometric water which contains the organic materials stripped from the oil constitues one main sources of water pollution from the refinery. The largest volume of waste water comes from the deodorising process and this amounts to approximately 50 m per ton of oil refined. This barometric water before the removal of full oil and fat in a fat trap would contain 200-300 mg/L of total fatty matter and BOD of 300-500 mg/L or more (Dart, 1974a).

The aqueous phase of acid water is also strongly pollution. The soap stock from the neutralization process is acidified to pH of 2.5-3.0 with sulphuric acid.

Acid water contains materials such as fatty acids, neutral oil, protein, mucilages and glycerol. It is objectionable not only because of its organic content but also it contains high concentration of sulphuric acid, which even after neutralization can attack concrete. The volume of acid water is approximately 0.5 m^3 per ton of oil and, after removal of free oil and fat it contains 500-1000 mg/L. The sulphate concentration can be expected to be 10,000-20,000 mg/L and pH low as 2.0.

2.4 Dairy industry

Milk and allied products such as butter, cheese, cream, condensed milk, milk powder and ice cream belong to this industry.

The waste waters from the dairies may be broadly classified into three categories (Mohanrao, 1972). These are industrial wastes, domestic wastes and uncontaminated cooling waters. The waste waters are highly variable. Even within a dairy the rate of discharge, the strength of the effluent and volume varies hourly.

The waste waters from a dairy consist of unusable residues, pipeline spillages, overflows, leakages, rinses and washing of milk containers, production equipment and floors. It contains materials relating to the type of processing carried as well as detergents and other chemicals used for cleaning. Domestic water also arise from the canteens and toilets (Borne, 1974).

The dairy wastes are rich in organic matter. Whole milk exerts a very high BOD. The SS, oil and grease too are high in the dairy wastes. There is wide variation in the BOD such as 110,000 mg/L in the full cream milk, 70,000.0 mg/L in the separated milk and 40-45,000.0 mg/L in whey (Muers, 1968). According to Borne (1974) a milk bottling plant may have a lower BOD of 300.0-500.0 mg/L. In the case of a creamery where ice cream is made the waste water may also contain sugar, colour and flavorings.

The dairies also can have high effluent temperatures. Nearly all the dairy processes involve heating and cooling the milk at some stage and is done through the medium of heat exchanges. The cooling water used for pasteurisation, although not contaminated leaves as spent water with high temperatures.

The bottle washing effluent of a dairy is characteristically alkaline. This causes problems in the receiving water and the treatment plants because the bacterial activity tend to be reduced at pH above 9.0.

The most important water pollution problem associated with dairies is the depletion of DO. As the dairy wastes contain all the nutrients essential for bacterial life, the rate of decomposition is high. The high concentration of organic matter added to the high temperature of the effluent is ideally suited for the bacteria. This makes the waste putrefy rapidly resulting in foul odours. In India an average dairy processing 10,000 litres of milk a day adds a BOD load equivalent to an additional population 1,100 on the city sewage plants (Mohanrao, 1972). The waste waters may occassionally carry tuberculosis bacteria.

2.4.1 Confectionery

The chemical principles involved in confectionery manufacture especially of high boiled sweets and toffees are, mainly in manipulating the sucrose level to achieve special textural effects by controlling the state of crystallisation of sugar and sugar moisture ratio. Other ingredients are chosen for their influence on the chemical and physical properties of sucrose.

For each type of sweet the temperature reached in the cooking or boiling process is very important since it defines the amount of water left in the syrup and consequently the texture that the final product can develop. The principal process involved in this industry are cooking, cooling, kneading, shaping, drying, moulding and wrapping.

Bulk of the water pollution emanates from spillage, washing and cleaning of storage vats, dissolving vessels, cookers, shaping, cutting and wrapping machines. Floor washing and cooling water too contributes to the pollution loads. Therefore the main pollutants are the product and its ingredients such as sugar, cocoa, fats and fillings, flavouring and colourants. Menthol is used in cough sweets.

BOD, SS, grease and oil can be high in the effluents. In a particular confectionery in U.K the BOD varied from 900-7000 mg/L and the SS between 200-500 mg/L and the oil concentration about 150 mg/L. An accidental discharge of the product recorded a BOD of 36,000 mg/L in the effluent (Sidwick, 1974).

Confectionery wastes are biodegradable but grease and oil and the inhibitory characteristics of some flavourings and colourants cause problems, in a receiving stream in a particular small scale boiled sweets manufacturing industry in U.K the COD:BOD ratio was 30:1, which is an anomaly. This was due to menthol in the cough sweets, which was a basic product of the factory. Menthol is non-toxic to acclimatized bacteria undertaking the biodegradation, but is inhibitory to unacclimatized bacteria at all concentrations and therefore the oxygen demand in the BOD test was suppressed.

The combination of constituents in the confectionery effluents gives an ideal environment for fermentation and a consequent characteristic of these wastes is that they become rapidly acidic and septic .

2.4.2 Meat processing industry

The meat industry falls into two broad categories namely the slaughter houses and meat processing plants.

In the case of the meat processing, plant operations include cooking, curing and pickling of meat manufacture of smoked meats, sausages, and canning of meat products. Raw materials are purchased from slaughter houses or packing houses in the form of carcasses, various meat cuts and trimmings. Certain plants do have both slaughtering and processing.

The principal sources of waste occur in the processing of sausages and smoked meats. Little or no waste water originates in many of the processing operations. The principal sources during production are water used in cooling or chilling the product. The clean up water following production, contains fat meat particles and blood. The clean up by water from high pressure hoses is a continuous and general practice in the meat industry, and this quantity of water approximates that used in processing operations and therefore there is a direct correlation between water use in the meat industry operations and the resulting waste discharges (Nemerow, 1978).

In addition to these, domestic sewage from canteen and toilets, condensates from the rendering plants and other by product processing also contribute to the polluting load of the waste waters.

The waste water from the meat industry is similar to other food and drink industry. It is highly organic, biodegradable and strongly polluting in character and can have adverse effects if discharged to a river without treatment. The wastes are also very similar to domestic sewage in regard to their composition and effects on the receiving water, but the total organic contents of the effluents are considerably higher than domestic sewage.

In the absence of adequate dilution the principal deleterious effects of meat plant wastes are oxygen depletion, sludge deposits, discolouration and general nuisance condition. Waste liquour containing high concentration of nitrogeneous compounds may result, depending on the process used. In addition the wastes from the meat industry, do have the potential danger from pathogenic organisms.

The extent of processing, quality of housekeeping procedure, the degree to which by-products are utilized the chemical characteristics of waste water differ greatly from plant to plant and there is a considerable variation in the volume, strength and composition of waste water generated and discharged. The rate of discharge and the strength of waste water from the meat processing plants are extremely variable.

In the U.S. it is said that the waste waters from the meat packing industry has the greatest pollution potential of many food industry. This is due to the water distribution of meat processing plants and the total organic load of the waste water (Dart, 1974b).

Effects

Water pollution is a serious problem associated with the food processing industry. The high organic content of its effluents depletes the oxygen content of the receiving water. This situation could be clearly illustrated by a survey done in the Mersey estuary (Porter, 1973). This comparative study shows that the effluents from an edible oil refinery and margarine industry within the Unilever complex at Bebington together with other food processing industries such as biscuits and chocolate manufacture, brewery and a sugar refinery were the major contributors of pollution of this estuary. The dissolved oxygen level had reached a very low level in 1969/70 when compared to 1938 as seen in figure 2.2 that anaerobic conditions prevailed. The pollution load into this estuary was estimated at 203755.0 lbs/BOD/day from 41 industrial discharges.

Deterioration of water quality can be seen in the Humber estuary too. In this estuary Grimsby and Hull have been important food industrial areas for centuries. Since the 18th century processing of grain, oilseeds and sugar, curing and smoking

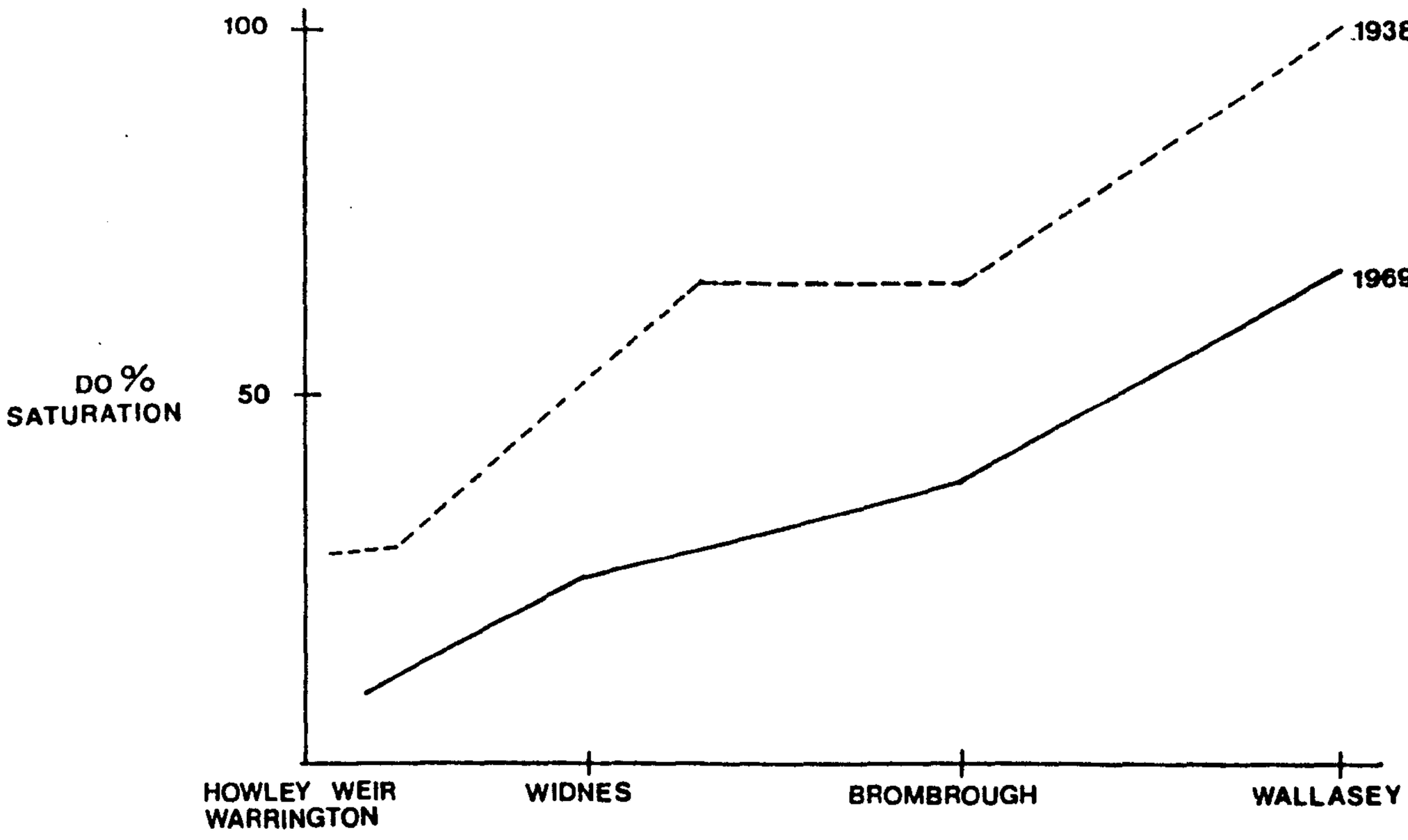


Figure 2.2 — Distribution of DO in the Mersey estuary

Source: Porter, E. (1973)

herring took place in Hull. Birds Eye Foods limited has a freezing and packing plant for fish and vegetables. The effluents from all these industries entered Humber without treatment, and as a result the water quality of Humber deteriorated. This became evident with the decline of salmon as a commercial catch, decrease in sole and shrimps and cod and sprats becoming rarer since 1960. Studies on dissolved oxygen, ammoniacal nitrogen and pH in rivers Ouse and Trent indicated severe pollution of these rivers. Dissolved oxygen level fell considerably by 1969/70 and was reduced to 1/3 of the 1929 level. The pollution load by industries to this estuary was 560,000 lbs/BOD/day, which was three times greater than from the domestic sources. Thames and Tyne too had similar effects till recently.

In France, water quality detereoration purely by food processing industry can be illustrated by a recent example. An abbatoir in France increased chicken slaughtering from 150 in 1956 to 300,000 per day by 1981. 4000 cubic metres of polluted water was discharged daily into the River Guic. Guic, a river famous for its trout became seriously polluted for at least 20 km of its length over a period of 10 years. The level of ammonium in the river increased to 30 mg/L due to this industrial discharge, which was brought down later to less than 0.5 mg/L with the installation of treatment for this discharge (UNEP, 1985).

Briefly it can be summarised that the effluents from the food processing industries are invariably organic and are highly polluting in character and also extremely variable in nature, but biodegradable and amenable to biological treatment.

Chapter III

The water pollution situation in the tropical countries

Surface fresh water forms the principal source of domestic water supply in the tropical developing countries. Various water resource studies to date stress that the availability of sufficient water of appropriate quality could become a critical factor constraining future growth. Apart from being the source of domestic water supply the other uses are for industries, irrigation, fisheries and recreational purposes. Of all the natural environmental elements water is the one most subject to stress, with damage by pollution increasingly predominating in recent times in the tropical countries.

Water pollution in the tropical countries arises from population growth, urbanisation, industrialization, modernisation of agriculture, natural sources as well as poor socioeconomic living conditions of squatters along the water courses especially in the urban areas. In addition to these, the lack of institutional capacities, lack of strict pollution control regulations and policing; and inadequate sewerage facilities have worsened the situation that render the tropical surface waters highly polluted.

Industrialisation can be considered as a major cause of water pollution. The tropical economies which became lop-sided after the colonial era opted for industrialization as a reconstructive measure, and a vehicle for rapid economic development. Therefore, after the Second World War, the developing countries adopted a long term national, social and economic development plan with emphasis on industrialization. Rapid industrial growth was registered as a means to strengthen the industrial base and economic development, but unplanned industrial growth resulted in many industries being located in the peripheral areas of large urban population centres, with consequent pollution problems. Lack of sewerage facilities left the industries with no alternative but to discharge liquid effluents to the nearby surface water. Therefore, the urban water courses in the developing countries are heavily polluted with industrial effluents, in addition to domestic sewage from very high population concentrations.

Due to the high priority given to industrial development as a tool for generating employment and foreign exchange, international investors and multinational companies have been attracted to these countries due to low labour cost, tax incentives and in some instances lack of environmental regulations (Miller, 1982). As a result export of pollution to developing countries by means of hazardous compounds and industrial operations not permissible in developed countries have crept in. The Bhopal catastrophe in India in 1985, exemplifies this situation.

Industries in developing countries tend to be as diverse as they are in the developed countries, but often differs in scale. Smaller production units tend to be developed to serve more limited local markets except when there is a major world market for a particular export product. The bulk of conventional industrial manufacturing is always concentrated around major population centres especially primate cities. But this does not mean that rural areas escape industrial pollution. Industries producing polluting waste waters in urban areas are normally manufacturers of consumer products and the typical examples are food and drinks, soaps and detergents, textiles, leather and petroleum products. In addition metal working and plating shops are also sited that discharge dangerous waste waters containing heavy metals.

A closer look at the nature of water pollution problems in some of the developing countries shows the variation and gravity of the situation in this region, and it is better understood when individual countries are investigated deeply rather than the region as a single entity.

3.1 Malaysia

Water pollution in Malaysia is of a unique nature, in that the industries which are the mainstay of the national economy i.e. palm oil and rubber are also numbered among the worst polluters of the Malaysian aquatic environment. Their significance can be appreciated when it is considered that between them, they account for nearly 90% of the total industrial pollution load into the receiving water.

The problem posed by water pollution reached a level for concern in 1976, when the river Klang in Selangor, the Juru basin in Prai and the river Malacca were estimated grossly polluted. 50% of the rivers had reached critical level at one stretch or another (Singham and Maheswaran, 1985). By September 1980 the Malaysian Deptartment of Environment announced that 24 of its rivers were grossly polluted, 13 remained unchanged and 2 had deteriorated out of a total of 44 main rivers (Friends of the Earth, 1981). The main industry cited as a cause of pollution was the palm oil effluents.

3.1.1 Industrial water pollution

Water pollution is attributable mainly to agro-based industries such as processing of palm oil, rubber, pineapple, tapioca, sugar, sago, distilleries and piggery wastes. Other major industries are chloro-alkali-plants, textiles electroplating and chemicals.

Based on the pollution load and its impacts on the environment the major sources of water pollution can be classified into three broad groups,

1. palm oil effluent,
2. natural rubber processing effluents and
3. effluents from manufacturing industries, as seen below in table 3.1.

Table 3.1 — Sources of water pollution in Malaysia

Water pollution sources	Total effluent (tons/day)	%	BOD load (tons/day)	%
Domestic sewage	210,500	27	715	32
Crude palm oil mills	58,000	8	1200	53
Natural rubber factories	90,000	12	208	9
Manufacturing industries	412,000	53	124	6
Sub-total	560,000	73	1532	68
Grand-total	770,500	100	2247	100

Source: Singham, G. and Maheswaran, A. (1985)

The BOD generated from these sources is 1532 tons/day or 68%, broadly double the load from domestic sources. Natural rubber, palm oil and other crops for domestic consumption and/or export are significant contributors to the Gross Domestic Product. By the same token they are no less significant in terms of potential pollution load.

The palm oil industry contributes 53% of the total pollution load and ranks as the single largest polluter. Between 1970 and 1982 palm oil production increased from 431,000 to 3.51 million tons. Now there are over 210 palm oil mills and the BOD generated is about 1200 tons/day (Singham and Maheswaran, 1985).

Five cubic metres of palm oil mill effluent are generated for every ton of palm oil produced, and the total industry-wide BOD load is equivalent to the domestic waste water from a population of 33 million, hence more than double the size of the entire Malaysian population. Therefore, in Malaysia the palm oil industry is the single largest polluter. The strength of the effluents and the polluting capacity of the palm oil mills can be seen in the table 3.2.

Table 3.2 — Palm oil waste water characteristics

Parameter	Range	Mean
BOD_3 (mg/L)	10,250-47,500	25,000
COD (mg/L)	15,500-106,360	53,000
SS (mg/L)	410-60,360	19,020
Oil and grease (mg/L)	130-86,430	8,370
Total N (mg/L)	180-1820	770
pH	3.8-4.5	-

Source: Singham, G. and Maheswaran, A. (1985)

Rubber production in 1983 amounted to 1,530,000 tons and 375 factories generate 90,000 cubic metres/day of waste water with a BOD load of approximately 208 tons and a PE of 4 million people. Effluents from this industry can be seen in table 3.3.

Table 3.3 — Rubber (latex) waste water characteristics

Parameter	Range	Mean
BOD_3 (mg/L)	200-7,205	2,704
COD (mg/L)	596-10,212	4,626
SS (mg/L)	253-386	1,177
Total N (mg/L)	50-1015	369
pH	5.0-7.5	6.2

Source: Singham, G. and Maheswaran, A.(1985)

Industrial waste water profile by type of industries is seen in table 3.4. Nearly 97% of waste water discharged and 96% of the BOD load are from three industrial categories: food manufacture; industrial chemicals; other chemical products and textiles.

In addition to oxygen demanding effluents, waste waters are generated of inorganic compounds including heavy metals. Significant levels of toxic heavy metals such as mercury, lead, chromium and cadmium were recorded in several basins. Effluents from tin mining too enter the rivers in Malaysia.

3.1.2 Pollution by domestic sewage

Domestic sewage is another significant source of water pollution in Malaysia. Only 4 towns are partially sewered with centralized sewerage facilities i.e Kuala Lumpur, Gengetu, Shah Alam and Kola Kinabam. Inadequate sewerage facilites and sewage

Table 3.4 — Industrial waste water profile by manufacturing industries

Industry type	Waste water volume		BOD		SS	
	$10^3 m^3$/year	%	tons/year	%	tons/year	%
Food	49,960	40.4	12,120	32.5	15,050	34.8
Chemical	43,460	35.2	10,430	28.0	16,900	39.0
Textile	26,230	21.2	13,270	35.6	8,300	19.2
Beverage	2,390	1.9	1,170	3.1	1,380	3.3
Paper	920	0.7	140	0.4	390	0.9
Basic metal	740	0.6	120	0.3	1,230	2.8
Total	123,600	100.0	37,250	100.0	43,250	100.0

Source: Singham, G. and Maheswaran, A.(1985)

treatment contribute to water borne diseases such as cholera, dysentry and diarrhoea. In 1984 only 6.28% of the total population was served by such facilities (Sundaram, 1984). Large colonies of urban squatters living along the urban waterways have significantly contributed to water pollution too in Malaysia (MacAndrews, 1979). Pollution due to sewage can only be overcome by provision of a centralized sewerage system.

The effects of industrial effluents on the rivers can be seen from the water quality deterioration along 30 rivers in the States of Kedah, Penang Perak Selangor, Johore, Pahang and Kelantan. Rubber effluents are the chief cause of fish and prawn kills in the River Sungai Tok; textiles, chemicals, oil and other factories in Tikam Batu Industrial Estate, killing fish and paddies fed by River Sungi Korok; Fish and prawn kills by palm oil effluents into River Sungai Krian and River Sungai Pahang; and a drop in fish catch by effluents into River Sungai Skudai by rubber, pineapple and other factories.

3.2 Thailand

3.2.1 Industrial water pollution: oxygen-demanding wastes

Thailand underwent intensive agricultural and industrial development after the World War II. Industrial development in and around the cities also caused migration of people from rural to urban areas. The sharp increase of population in the cities coupled with an inadequate industrial waste treatment system has resulted in water pollution problems in the Thai rivers. Chao Phraya is one of the most polluted rivers especially in its estuary area due to urban and industrial expansion (Menasveta, 1987a). In Bangkok alone there are over 15,000 factories (Ratasuk, 1981).

River Mae Klong is one of the heavily polluted rivers due to discharge of organic oxygen demanding effluents. Sugar factories and distilleries are among the highest polluters of rivers. The first evidence of pollution in Mae Klong was reported in 1969, during sugar cane milling which occurs during the dry season. The flow rate during the dry season was 30 m^3/sec while in the rainy season it was 1000 m^3/sec. Mae Klong, which was estimated to assimilate up to 35,000 kg/day of BOD could not accept an intake of over 60,000 kg/day BOD. Pollution in the river also occurred in 1972 and 1973 (Menasveta, 1987a). Today there are over 18 sugar factories along Mae Klong with a total capacity of 10,000 tonnes of sugar cane using 2 million cubic metres of water daily which produces a BOD equivalent of 136,512 kg/day. Other factories such as paper mills, noodles and distilleries together release 25,000 m^3 of waste water producing a BOD of 9000 kg/day (Menavesta, 1987a). A molasses alcohol distillery in Thailand generates an average BOD of 30,000 mg/L, though the effluent standard is 60 mg/L (Ratasuk, 1981).

Pollution of these rivers has caused mass mortality of fish and molluscs especially mussels and cockles in the estuarine areas. The damage caused to cockle farms at the river mouth of Mae Klong alone is 1.2 million U.S. dollars. The problem is mitigated by the establishment of the central waste treatment system for the highly polluting sugar mills.

3.2.2 Toxic persistent chemicals

A survey done by Menasveta in 1981 (Menasveta, 1987b) indicates high levels of heavy metals such as lead, copper, zinc, cadmium and mercury at the mouth of Mae Klong, Ta-chin and Bang-Pakong rivers. The levels of lead, zinc, copper, cadmium and mercury in mussels from these rivers are 83.3-330 μ/g, 47.6-91.7 μ/g, 3.75-16.9 μ/g, 2.77-8.21 μ/g and 0.01-0.29 μ/g respectively. Lead was also reported to heavily contaminate phytoplankton and zoo plankton in the inner Gulf of Thailand.

The sources and pathways of lead content in these rivers were due to direct disposal of industrial wastes, lead contaminated runoff and atmospheric fall-outs. Approximately one ton of lead per day is released into the atmosphere through car exhausts and a large proportion of this amount enters the river mouths through surface runoff. Lead from gasoline exhausts from boats is also released into the rivers. Concentrations of DDT, PCB and some other organo-chlorine pesticides in these four rivers are 0.032-0.420 μ/g of DDT and 0.002,0.043 μ/g PCB in mussels (Menasveta, 1987b). These indicate that aquatic pollution in Thailand has limited the aquacultural development, especially mariculture.

3.2.3 Pollution by domestic sewage

In Thailand there is hardly any integrated central waste water collection and treatment system. Normally human excreta receives only rudimentary treatment in cesspools or septic tanks while sullage is directly discharged into the storm drains, with septic tank effluents. Sewers are normally laid along the streets and drain into natural receiving waters at many points.

In the Chao Phraya river estuary sanitary wastes of the Bangkok metropolis, combined with industrial effluents are the major cause of water pollution. It is estimated that the sanitary waste waters from the Bangkok metropolis contribute approximately 70% of the BOD to the river estuary. The rest is contributed by industrial effluents (National Environment Board - 1985) as reported by Menasveta (1987a). The Bangkok metropolis has hardly any sewerage collection system and the effluents from the toilets or larger cesspits seep or are directly discharged (illegally) into the nearest river, canal or ditch. The drainage system is usually clogged with deposits and is unable to discharge the polluted load. As a consequence septic organic material is passed from household drains to rivers through canals. During dry weather conditions the low flow in the canals and aerobic oxidation of organic matter in the waste waters reduces the dissolved oxygen (DO) content of many canals to zero, especially during low tide conditions. The daily BOD in a section of Chao Phraya river is estimated to be 249,180 kg (Menasveta, 1987a). This figure is an accumulation of three BOD sources viz. the amount already in the water before entering Bangkok city limits, direct disposal from Bangkok Metropolis and discharges from various canals of Bangkok. The septic conditions are not apparent due to factors preventing them such as aeration from turbulence of flow, boat propellors and phytoplanktonic photosynthesis.

In the case of Bangkok a separate sewerage system estimated at $ U.S. 544 million for serving 370 km^2 and 3,240,000 people and a central treatment plant estimated at $U.S. 810 million was abandoned due to high costs.

3.2.4 Water pollution from agriculture

Accelerated agricultural development has contributed to pollution of rivers in Thailand. In the Ta-chin river oxygen depletion is due to wastes from agricultural activites such as piggeries and intensive catfish farming. The critically low level dissolved oxygen of 0.2-1.0 mg/L is usually detected between the twentieth and sixtieth

kilometer (National Environment Board-Thailand, 1985) as reported by Menasveta (1987b).

Therefore the major pollutants of Thai rivers are degradable organic wastes and persistent toxic pollutants. The common effects are increased oxygen demand enrichment of nutrients, inputs of pathogens and increased turbidity leading to changes in river water quality, coastal ecosystem and hazard to public health.

3.3 India

3.3.1 Pollution by oxygen demanding industrial wastes

Sugar and distilleries rank among the major industries in India. Many studies in India indicate that agro-based industries rank among the heavy polluters of the receiving streams. Extreme levels of pollution and foul smells are recorded especially in the vicinity of sugar factories and distilleries.

In Uttar Pradesh 25 sugar factories discharge effluents into the receiving waters. The total liquid wastes from the millhouse filter, cloth washing, floor washing and boiler house operations are estimated at 27,987,400 gallons per day, containing 249,767 pounds/day of BOD, 295,613 pounds per day of total solids and 195,184 pounds/day of suspended solids. Grease and oil account for about 14-54 mg/L (Verma, 1978).

The effluent discharged to the Kalinadi river from cooling water from a sugar factory is estimated at 17,300 cubic metres per ton having 9,600-10,000 mg/L of BOD. The brownish black coloured effluent lowered the light penetration, thus limiting the phytoplanktonic density. The high organic load of the effluent tainted the acid levels of the water and lowered the water quality for a stretch of about 10 km. The H_2SO_4 and H_2S levels of the waters were toxic to fish and fish food, while the low pH value and high temperature enhanced the growth of sulphur reducing bacteria which contributed to high concentrations of H_2S. At times of low water the cellulose filtrates together with organic and inorganic chemicals formed a bad substrate. These effluents had harmful results to fish life and also enriched a section of the Kalinadi.

Singh and Bhargava (1984) describe the derogatory effects of sugar and distillery effluents on the river Kalinadi, observing a clear line of demarcation between the light greenish clean water of the river and the deep brownish polluted water.

Over 215 sugar mills and 100 distilleries discharge untreated waste waters into the river Cauvery, Tamil Nadu, which causes oxygen depletion and foul smells (Rahaman, 1984).

Chemical and biological assessment of water pollution made at 5 sites in the Rangpo stream of Sikkim Himalayas indicated that *Chlorella vulgaris*, a pollutant tolerant algal species, dominated near Rangpo, where the Sikkim distilleries discharged their effluents, and the river at this location was found to be heavily polluted (Venu, 1984).

In addition to these industries, untreated wastes from jute mills, tanneries and paper and pulp industries enter the Indian rivers. These effluents enter the river Hoogly from the 45 mile long Culcutta-Hoogly industrial strip. Being one of the most populated urban industrial areas, this stretch of the river is found to be one of the most polluted in India.

The organic wastes having high BOD and COD from these agro based industries in India causes oxygen depletion and enrichment in many of its rivers.

3.3.2 Pollution by toxic substances

Large scale industrialization in the past three decades has led to the production of a variety of chemical substances and the inevitable and indiscriminate discharge of toxic and hazardous wastes to water bodies in India. This has resulted in harmful

effects on the aquatic plants and animals.

The first episode of hazardous waste release was noticed when the River Ganges was set aflame near Monghyr, Bihar in 1968 due to a discharge of oil from a refinery. This caused the suspension of the water supply to Monghyr for a short period (Sunderesan, 1983).

Pollution profile from several sites on the river Damodar in the industrial belt of Raniganj-Durgapur in West Bengal reflects heavy metal contamination of the river from industrial effluent outfalls. This river is polluted along the industrial belt up to 40 km downstream. Silica, calcium, magnesium, COD and various toxic elements are found to be in high concentrations (Anil *et al* 1985). The BOD load to this river is over 43,000 kg/day from 1,591,000 m^3 of waste water (Karan, 1976).

The river Periyar in South India is a sink for liquid effluents from a cluster of chemical industries over a 5 mile area. High concentration of toxic substances are reported especially lead and 210Pb, near the outfall areas. Pb concentration increased during monsoons due to sediment transport from the upstream industrial zone (Borkar, 1984). Tidal oscillations play a major role in transporting the pollutants upstream and the backwater zones of the river serve as the depository.

The Ganges, one of the most polluted rivers in India receives over 120 million litres of sewage and chemical effluents from the world renown silk industry. **Kharnewala soap**, a kind of detergent heavily used in the silk textile industry for washing raw materials is constantly discharged into the surface rivers. This has caused heavy fish mortality. Acute toxicity tests done on catfishes *H. fossilis* and *M. vittatus* for this detergent showed irritation indicated by erratic and jerky body movements and violent actions of the pelvic fins (Ahmad, 1983).

Toxicity studies on air breathing fresh water teleosts from the industrial complex in Durghapur reveal high degrees of fish inhibition. The factory composite effluents were found to be highly toxic. The exposure to these toxicants even for a short time affected the fish internal organs with their respective enzymes (Mukerjee, 1977). The magnitude of damage to the kidney of fresh water fish *Ophicephalus punctatus* and *Clarias batrachus* exposed to phenol, sulphide, ammonia and copper from the Durghapur industrial region was alarming. Even sub-lethal doses of these toxicants caused drastic changes in the physiological system. Fish kills in estuaries, due to toxic substances such as arsenic and heavy metal acids are frequent occurrences.

The effects of industrial effluents on plant communities in River Khan indicated deleterious effects on the macrophytic biomass near the toxic industrial waste water discharges. The number of species are found to decrease by 50% in such areas (Rao, 1981).

Sewage and industrial waste waters have decreased the overall productivity of the shallow turbulent rivers in India and the tropics in general. Rao (1979) concludes that toxic industrial wastes and sewage discharges have a depressing effect on the overall production rates in tropical rivers.

3.3.3 Pollution by agricultural activities

Accelerated economic development particularly in the agricultural sector has increasingly contributed to pollution of surface fresh waters. This is mainly due to indiscriminate use of fertilizers, pesticides, fungicides, insecticides and weedkillers. In addition to toxic pollution by industrial discharges agricultural activities too have increased the level of toxicity in surface waters. The non degradable organic chemicals are on the increase in Indian agriculture, due to intensive farming methods. In Kerala State alone over 1000 tons of toxins are released to surface water every season due to the use of pesticides and fertilizers. D.D.T. is commonly used. Fertilizers have contributed to eutrophication of water bodies in Kerala. They have also affected the aquatic fauna and flora (Pollution Control Board - Kerala State, 1985). But the economic benefits that India gets from the use of pesticides and fertilizers is more than the cost of pollution control (Holdgate *et al* 1982) although an Environmental Task

Force has been created, to abate pollution from pesticides (Sharma, 1983).

3.3.4 Pollution by domestic sewage

Haphazard urban growth in India has led to the location of factories and human settlements along many waterways and this in turn has led to the pollution of water courses arising from untreated domestic sewage and effluents being discharged into these.

A canal discharges 4 million litres of untreated oily wastes from a government owned diesel locomotive works and 8 million litres of sewage from houses of its employees into the river Ganges at a point immediately above a water intake source. None of the large cities on the banks of the Ganges has a sewage treatment plant and of the 2033km of river water, 480km are polluted to varying degrees (Subash, *et al* 1985).

As Ganges water is used for domestic, recreational and religious purposes, many waterborne infectious diseases are a common occurrence in the Ganges area. Incidence of diarrhoea, hepatitis, jaundice, polio and ch1lera rank high among the water borne diseases. In 1927, cholera had India in its grips. The largest viral epidemic attributed to a polluted water supply occurred in Delhi, during 1955-56, when over 20,000 clinical cases of infectious hepatitis were reported (Evison and James, 1977).

Varanasi is a major polluted centre in the Ganges. In addition to water borne diseases, the infant mortality rate is 44% higher than the national average; and many deaths have occurred due to diarrhoea. According to Gopalakrishnan (1985) in India, what flows from the city home taps is nothing but chlorinated gutter water which is obtained from the river Ganges for domestic water supplies.

Calcutta is one of the most polluted cities in India. Between the Calcutta and Hoogly Industrial Strip untreated sewage enters the river Hoogly from a population of over 8 million. In addition to this 0.512 kg/per capita/day of city refuse is dumped uncontrolled in many sites of the lowlying areas, which leaches into the river causing serious water pollution problems (Karan, 1980).

Three hundred and fifty untreated waste water outfalls discharge significant amounts of domestic, industrial and miscellaneous wastes into the Kalyani and Birlapur estuarine zones. The most densely populated area of the estuary has 113 outfalls including 22 major contributors of waste flow. High levels of faecal coliform, *E. coli* and Faecal *streptococci* are recorded in this area. This estuary has been reported unfit for bathing according to Indain standards (Basu, *et al* 1981).

In South India the major source of BOD in the Kerala State is sewage effluent. Since only a small proportion of the population is provided with sewerage systems or conversancy laterines, most of the night soil and community wastes enter surface and subterranean waters. Of the cities only Trivandrum and Cochin have partial sewerage. Periyar river is one of the most polluted rivers in the Kerala State. Over 100 tons per day of BOD entered the rivers in Kerala in 1984/85, which is a significant reduction from 400 tons per day BOD in 1974/75 (Pollution Control Board - Kerala State, 1985).

Overall, 70% of the available surface water in India is still polluted (Khator, 1984) and it is estimated that in the next 25 years rivers will be diverted for consumptive use and the return flows are estimated to increase by 2000%, which means pollution loads into the rivers are expected to increase in the near future.

3.4 Singapore

In 1977 the Singapore river was heavily polluted and the major causes were identified as riverine activities, street hawkers, vegetable wholesalers and unsewered premises.

The riverine activities were transport of goods, light repair and building activities, food and grain sorting and other related trades carried out near warehouses located

on the river banks. Oil sullage water, solid wastes from lighters formed the most serious problems from riverine activities. The river was murky, smelly black water crowded with lighters and littered with rubbish.

There were 1483 unsewered premises in Jalong Bukit, Merah and other towns and squatters and shanties along the river banks, at Jiak Kim Street and Boat Quay. In addition to unsewered premises waste waters were discharged from refuse chutes, bin centres, food processing preparation and washing along the footways and backlanes caused water pollution (Ministry of Culture, 1984). There were 1903 street hawkers in Chinatown.

The Ministry of Environment initiated a clean-up programme in 1977. Over 1730 hawkers were moved to proper food centres with proper treatment facilities. Vegetable wholesalers were also rehoused. By 1983 all lighterage activities were transferred to a new place and the river is off limits to any motor-boat or launch except with the Port Authority's permission.

By 1984, 80-90% of Singapore river pollution was overcome due to clean up programme. There is significant improvement in the appearance and quality. Fish, crabs and prawns have returned, and recreational activities such as swimming, canoeing and dragon boat racing too have returned.

3.5 Mexico

3.5.1 Industrial discharges and domestic sewage

In Mexico, as in many developing countries the chaotic development of industries and explosive population has led to serious water pollution problems.

With regard to water pollution in Mexico two situations can be identified firstly, industries situated in the urban areas equipped with sewerage system dispose their effluents through these systems as treated discharges. The domestic sewage is mixed with these discharges and is finally sent into water bodies or is recycled for irrigation purposes. The second group being industries in suburban or rural areas without sewerage system, discharge their effluents directly into the nearby waterways untreated. This practice has led in the past and continues to lead to very serious water pollution problems, as only a fraction of water used is treated either for recycling or eventual disposal to water ways.

The rivers such as Lerma, Coatzacoalcos, Rio Blanca and Papaloapan are heavily polluted. The river Lerma is polluted from its source by industries in the Lerma-Toluca corridor. After a long process of self purification it is repolluted as it flows through the industrial zones of Salamanca, Irapuato and La Piedad and finally discharges its accumulated effluents into Lake Chapala.

The river Coatzacoalcos receives many industrial waste inflows through Minatitlan , Coatzacoalcos area from petroleum and petrochemical installations. The river Blanco is polluted by effluents from textile and brewing industries in Orizaba and sugar industries have contributed to pollution of the river Paploapan. Other heavily polluted rivers in Mexico are identified as Guayalejo, Balsas, Fuete and Nazas due to effluents from industries. Industrial wastes deposited in municipal dumps without adequate control of its potential impact also enter these rivers as surface runoff (Portillo, 1982).

3.6 Brazil

3.6.1 Industrial Water Pollution

Brazil experienced a profound socio-economic transformation since World War II; from a predominantly agricultural economy to an integrated industrial society. Industrialization coincided with rapid population growth and contributed to accelerated urban migration. Industrial development became concentrated around major urban

centres especially Sao Paulo. It accounts for 60% of Brazil's manufacturing value added inspite of Government attempt to decentralize industries. There are 51,516 industries in Sao Paulo and food processing industries account for 23% of the total and rank the highest. It is the most industrialized area with a population of 12.5 million (Chang, 1982).

Cane sugar and alcohol are important industries in the Brazilian economy. The BOD loads released are as high as 13,000-26,000 ppm from cane sugar industry and 4,000-14,000 ppm from distillation residue in the spentwash process. The pH varies widely between 3.8-7.2 (Monteiro, 1975) quoted by Sivalingam (1978). This indicated the strength of the effluents in terms of oxygen demand exerted on the receiving stream.

A recent University of Sao Paulo survey reveals Cubatao a city close to Sao Paulo as a "Valley of Death". This industrial city with 22 factories discharges over 1000 tons of pollutants per day. Pollutants include mercury and lead.

In greater Sau-Paulo effluents discharged by the rivers far exceeds the natural self purification capacity of the rivers. Compounded by the area's special climatic and topographic conditions, water pollution has reached harmful level, both in respect to public health and aquatic flora and fauna.

3.6.2 Domestic Sewage

Water pollution was identified as a basic health problem in Brazil, particularly in the Greater Sao Paulo region. In addition to industrial discharges, domestic sewage was responsible for pollution of the water ways. An inadequate sewerage system; the discharge of raw sewage and the absence of regulations controlling water pollution contributes to pollution. Sewage collection in Sao Paulo accounted for less than 38% of the population, of the total sewage produced only 4% is treated and 96% is discharged untreated into the rivers and canals. The rivers in Sao Paulo are composed of 25% sewage and 75% water (Chang, 1982).

The contamination of underground and surface water poses serious health problems. High rates of infant mortality and meningitis in Sao Paulo is closely related to contamination of underground and surface water. This is directly linked to contaminated water supplies and lack of sewerage facilities and the affected low income group who are the targets, live along the polluted water courses.

The shanty towns around Cubatao are among the world's unhealthiest communities. The infant mortality rate is 35%, while the long time residents have alligator skins. Of the shanty population 20% suffer from asthma or chronic bronchitis. Anencephaly, a disease causing partial or complete absence of the brain a condition rare in other parts of the world is diagnosed in Cubatao. Brazil's administration estimates over 30 million dollars is needed to decontaminate this city.

It is projected that by the year 2000, 88% of greater Sao Paulo's population will be served by the sewerage system and 95 m^3/sec of domestic and industrial effluents will be biologically treated. (Chang, 1982).

3.7 The Pacific Islands

The South Pacific region is relatively free from major pollution problems but increasing development and fragility of the regional ecosystem enhances potential dangers of pollution. Water resources are the part of Pacific Island's most susceptible to pollution. The rivers, wells and ground water are contaminated by human, chemical and animal wastes.

In Savo, the Kolika stream is contaminated by coliform organisms. Though the level of contamination is not very high it is still a matter for concern. The Vaitupu wells have high levels of coliform ranging between 1000-5000/100 mL. Nitrate levels are also significant.

Water pollution from natural causes is experienced in Savo. Water from this Pacific Island cannot be used for drinking because of the high levels of sulphur compounds. The volcanoes still being semi-active, vent steam and gases into three major streams. The pH of the water is low and therefore acidic (Lee, 1982).

Increasing development is accelerating waste production in the urban areas particularly from bigger processing plants and fish canneries. These are concentrated around the urban centres. Human drift to urban areas and squatter settlements have contributed to domestic sewage which enter the water ways untreated. Lack of maintenance of septic tanks too have aggravated this problem.

Intensive crop production in the agricultural areas has resulted in heavy use of biocides (pesticides, herbicides, insecticides, fungicides and weedicides), which enter the waterways. In Guam, Paraquat, Lindane and 2, 4-D have been detected in ground water. In Hawaii insecticide Heptachlor used in pineapple industry too has been detected (Morrison, *et al* 1983).

3.8 Nigeria

No facility exists for controlling industrial sources of water pollution in Nigeria. Waste water is directly discharged into the rivers, or other receiving waters or to open drains which in effect serve as sewers. Industries have chosen the cheapest disposal methods in Nigeria.

Being an exporter of primary products such as cocoa and cotton before 1960 there were not many industries other than soap making and distilleries. But with consecutive National Development plans emphasis was placed on industrialization. In 1970 there were 600 industries, which contributed to water pollution (Fatoye, 1982). Industrialization and pollution go hand in hand. The waste output from industrial sites are complex and varied. The industrial layouts are located near the major urban centres and each site has a wide range of industries such as textiles, food processing and chemicals discharging untreated effluents into the receiving waters. Until the Third National Development Plan incorporated environmental consideration into planning, no control measures were applied to discharge of untreated industrial effluents into surface streams.

3.9 Ghana

In Ghana the water pollution problem is not widespread and occurs in localized mining, urban and industrialized areas, but these pockets of localized pollution are found to have adverse effects on the river systems.

3.9.1 Natural pollution

There is evidence of nutrient enrichment of surface waters in Ghana. This is mainly due to the organic matter derived from decaying vegetation. The organic matter is of autochthonous origin, mainly of aquatic macrophytes and algal bloom, and allochthonous origin chiefly from over-hanging boughs, twigs and leaves which fall into surface waters and decay ultimately. Ammoniacal nitrogen concentration is $<$ 1.0 mg/L, probably due to autochthonous and allochthonous organic matter. Runoff from surrounding fields which leaches soil nutrients also contributes to the general nutrient enrichment of the rivers. Therefore this could be termed as natural pollution (Amuzu, 1975).

3.9.2 Industrial pollution

Changes in the water quality in some rivers in Ghana revealed that large volumes of untreated industrial effluents discharged directly into the rivers from factories sited near the rivers were the main cause.

The rivers affected by pollution include the Ofin, Birim, Volta, Densu and Ankobra river systems. In most cases the water used in the factory was abstracted from

the same river where the effluents are discharged, which in turn reduces the volume of water which could have diluted the effluents.

The Akasombo textile mills situated on the lower Volta basin discharge 118,600 litres/per/month of effluents containing different types of dye (Mensah, 1976). The effluents contain salts and a higher temperature. The increase in temperature decreased the DO and accelerated putrefaction. Inspite of large volume of water in the Volta, the river water was deeply coloured and had a higher water temperature. The pH (11.4), BOD and ammonia were found to be high. There were no organisms in the samples from this point of discharge and therefore the fauna has been affected when compared with that found upstream and downstream of the point of discharge, indicating gross pollution.

The river Aberewaatea at Kumasi receives effluents from a leather and tanning factory, which had alkaline effluents which were deeply coloured, in addition to a high protein content. Korle Lagoon in Accra is the receiving end for beer, soft drinks and other industries and domestic sewage. The effluents were high in suspended solids, oil and organic matter. Rubber factory effluents are discharged to the river Jimi. The river water quality of Densu is affected by GIHOC cannery wastes and fruit and vegetable and paper pulp wastes which are discharged at Nsawam. Water quality of the River Densu is very poor at this town, inspite of the river Densu being an important source of water supply for West Accra, Nsawam and Koforidna.

3.9.3 Pollution from mining activities

Water pollution occurs from mining activities in localized areas in Ghana. The Birim basin receives effluents from diamond mines especially to the Supong and Asukese tributaries. These effluents are yellowish and contain high suspended solids and oil. The river Ofin receives effluent discharges from gold mines. Gold mine effluents contains toxic chemicals such as cyanide, arsenic, copper and zinc which are harmful to fish. The River Ankobra too receives pollutants from gold mines. The Esuokofie stream at Prestea had 4 ppm cyanide, 0.97 miles (Mensah, 1976) from a mine. This indicated that the lower part of this stream was highly polluted with cyanide (W.H.O. permissible level being 0.05ppm). This could affect the people who use this water for domestic purposes, in addition to being harmful to the aquatic environment, and self purification process.

3.9.4 Pollution from other sources

Studies in the river Densu indicate higher BOD levels in urban areas, which reveal the distribution pattern of organic pollution. Domestic sewage enters this river at Nsawam bridge without any form of treatment which affected the river water quality. Non availability of sewage disposal system and concentration of a large population in certain stretches of the river was the main cause of pollution from domestic sewage.

As far as agricultural pollution is concerned, the Ghanian agricultural system does not involve large scale application of fertilizers, which otherwise would be washed down to rivers by surface runoff.

3.10 The climate, stream flow and pollution

The tropics are climatologically hot and humid with regional climatic phenomena causing distinctive rainfall regimes. Distinctly marked dry seasons alternating with heavy rainfall seasons exert a marked influence on the stream flow and assimilative capacity of the tropical streams, which in turn has a bearing on the dilution or concentration of pollutants in the tropical rivers.

Surface waters: characteristics and assimilative capacity

Tropical surface waters have certain general characteristics which make them different from most surface water in the temperate zone with respect to their capacity for handling waste discharges. Owing to the nature of tropical rainfall streams usually have very high ratios of maximum to minimum discharge and low flows occur for

Table 3.5 — Discharges and low flow periods of some tropical rivers

River	Discharge (m^3/S)		Min/Max Discharge ratio	* Low flow (months)
	Maximum	Minimum		
Mekong	67,000	1250	54	-
Red	35,000	700	50	-
Brahmaputra	72,460	2680	27	6
Ganges	61,200	1170	52	7
Indus	31,200	490	64	-
Chao Parya	6,500	65	100	5
Irrawady	63,990	1306	49	-
Meghua	13,100	370	35	5

Source: Pescod, M.B. (1977). *Arbitrarily chosen as the continuous period during which discharge does not exceed 4 times minimum discharge

extended periods as seen in the table 3.5.

As dilution is of major importance in waste assimilation long periods of low stream flow militate against a stream being able to accept heavy waste loads continously without damage. Low stream flow particularly, in flat delta areas (where many major cities are located) produces little turbulence, which in turn reduces the oxygen diffusion at the surface. In these low lying plains in the tropics wind speeds are also usually low and water surface turbulence from this source is often slight. Surface diffusion normally provides the greatest source of oxygen for biological breakdown of organic materials discharged to surface waters.

In addition to these hydraulic and physical conditions there are other quality characteristics which seriously affect the ability of a tropical stream to assimilate waste, particularly those of an organic nature (such as municipal sewage) which are biologically degradable. Most important of the quality parameters which affect organic waste assimilative capacity are stream temperature, turbidity and dissolved oxygen concentration. High temperatures near 30 °C centigrade in the tropics, not only reduce the amount of oxygen which can dissolve in water, thereby minimizing the oxygen supply available to micro-organisms, but also increase the rate at which oxygen is utilized by micro-organisms. A high rate of oxygen use might result in low or zero dissolved oxygen concentration in a particular stream stretch, according to the traditional dissolved oxygen sag curve, which would impair the streams subsequent capacity to receive further polluting discharges.

The high suspended load prevalent in most tropical surface waters, a measure of which is turbidity, indirectly affects the oxygen supply available to micro-organisms by preventing the transmission of sunlight through a significant depth of water. Photosynthetic plants, mainly planktonic algae, which can supply significant quantities of oxygen under optimum conditions are thus deprived of their activating energy and do not act as an significant oxygen source (Pescod, 1977).

Nature of the problem

Therefore as the oxygen concentration in most tropical urban streams are low resulting in highly polluted waters, the dilution effect cannot be relied upon to improve the water quality as the reaerartion capacity of the water is impaired.

Pollution problems, until recently considered a lesser problem in the developing countries are now recognised as serious ones. A careful look at the pollution problems in the developing countries reveal that industries are the major polluters of the surface waters. The very process of rapid and unplanned industrial development brought to the fore problems of second order i.e deterioration of water quality, damage and disruption of the aquatic environment, which gains significance from year to year. It will not be possible to sustain long term growth, development and improvement to the standard of living if the water courses carry organic pollutants and toxic compounds which endanger human and animal life.

It is also realized that all the developing countries do not face the same environmental problems and do not have a similar social and political mechanism to approach them, but most developing countries have similarities such as social and political structures, lack of institutional capacity and absence of public involvement. Though the environmental problems vary, the overall perception of the environmental problem is the same. During the Stockholm Conference on Human Environment, 1972 all the developing countries stayed together and expressed similar fears and attitudes towards the environmental issues, and since then in many developing countries the necessary regulation for pollution control and the infrastructure have been built to abate pollution. In this sphere Malaysia and Singapore lead the tropical developing countries.

Chapter IV

SRI LANKA

4.1 Location

Sri Lanka is an island in the Indian ocean and lies just south east of the southern tip of India. Its geographical position lies between 5° 55'N and 9° 50'N latitude and 79° 42'E and 81° 53'E longitude as seen in figure 4.1. Its greatest dimensions are 433 km N-S and 225km E-W. Sri Lanka is separated from the Indian mainland by the Palk Straight to the north and Gulf of Mannar to the West. It is a detached portion of the mainland of India and stands upon a small continental shelf which ends abruptly in the south and east from 8-40 km miles from the coast. At this point there is a sudden drop from 60 m to about 180 m or more to the general level of the Indian Ocean. Sri Lanka has a total surface area of 65,610 km^2. It is strategically situated in the east-west sea lane.

4.1.1 Geology and geochemistry

Sri Lanka is primarily a part of the shield which comprises pennisular India. Geologically and physically it is a southern continuation of India, and it was recently separated from the mainland by the shallow sea covering the Palk-straight and the Gulf of Mannar.

On the basis of height and slope characteristics, the island can be divided into 3 main morphological regions.

I - Coastal lowlands with elevations from sea level to 270 m with a few inselbergs. Slopes generally are flat lying in the narrow marshy belt along the coastal fringe while further inland low 'turtle backs' appear.

II - Uplands with elevations from 270m to 1,060m which consist of ridge and valley topography and highly dissected plateaux with narrow arenas and domes occupying nearly 30% of the island. The average degree of the slope varies from 10-35° along the upland ridges depending on the lithology and structure. Well developed steep scarps are common. The arena floors are flat and undulating with gentle slopes ranging from 0-10°.

III - Highlands with a series of well defined high plateaus rimmed with mountain peaks and ridges with elevations from 1,060-2,420m characterize the central part of Sri Lanka. High level topographic discontinuities are common and these form the boundary of a series of high plains, plateaus and structural terraces. Laterites and laterization are common in these places.

Geologically 92% of the country is made up of rocks of the Pre-Cambrian age. The Pre-Cambrian rocks are divided in a three-fold manner into the Highland Series occupying the central part of the island extending towards the northeast, the Vijayan series on either side named Eastern and Western Vijayan and the South West group. The rocks that are found in the Highland series and South West group are charnokites, hornblendes and biotite gneises and the Vijayan Series consists of granites and granitic gneises.

The wet zone is characterized by red-yellow podzolic soils and latosolic soils whereas the dry zone has reddish brown earths and non-calcic brown soils. The intermediate zone consists of some features seen in both dry and the wet zones.

4.1.2 Climate

Sri-Lanka which has a typical humid tropical climate, lies in the monsoon region of south-east Asia. The island is characterized by clearly demarcated wet and dry zones with average mean temperature of 27 °C and 32 °C respectively, and a transition intermediate zone characterizing both the dry and the wet zones. Depending on the altitude, the mean temperature of the highlands vary between 15 °C and 26 °C. The monthly mean maximum temperature is about 29 °C and the mean minimum temperature is around 24 °C. Diurual variation may range around 5 °C. The average annual temperature for the thirty year period 1931-1960 was 27 °C. The mean annual temperature for 1986 was 28 °C. The mean humidity throughout the year is around 75% in the day time and about 90% at night.

In the absence of marked thermal variations, rainfall is the primary factor governing climate. Rainfall over the land varies between 635-6350 mm from one part of the country to another. During the 1931-1960 thirty year annual average, Colombo received 2387 mm of rainfall. The dry zone receives an annual rainfall between 1270-3175 mm, the greater portion of which is obtained from the northeast monsoon from November to February. The wet zone receives an annual rainfall between 3175-6350 mm , the greater portion of which is got from the southwest monsoon from mid May - September. The Intermediate zone receives an annual rainfall ranging from 1905-3175 mm. Sri Lanka also receives rainfall from the activities of the Inter-Tropical Convergence Zone (ITCZ), as it comes under its influence due to its latitudinal position. All three zones receive rainfall from this convectional activity (Inter-monsoon or thunderstorm rains) during the months of March-April (Inter-monsoon-I) which has a mean monthly rainfall of 125-200 mm, and October (Intermonsoon-II) having 300-325mm, the latter being high in intensity. In addition to these rainfall regimes, Sri Lanka lying at the southern edge of the cyclonic belt, receives intense cyclonic rainfall during October-November especially in the north and east, although cyclonic depressions affect the whole island. The central highlands act as a barrier so that the SW Sri-Lanka remains essentially dry and receives hardly any rainfall during the north east monsoon months and vice-versa. February is the driest month in the wet zone receiving very low rainfall or none at all.

Of the 29 billion gallons of rainwater falling on the island annually nearly one third of the water or 10 billion gallons drain out to the sea as surface runoff via the rivers and streams which flow in a radial pattern originating, from the central highland (ESCAP, 1985). The total quantity of water that infiltrates or stored as ground water is not known as statistical data of porosity and permeability of bed rocks is non existent. From general information it can be deduced that the Pre-cambrian gneissic and other metamorphic hard rocks with thin to moderate soil cover that occur in the wet zone have moderate to low permeabities. Among the Quarternary deposits, the alluvial sands, aeolian sands and gravel deposits have moderate to high permeability. Laterites have moderate to low and peat bogs and swamps low permeability. Though the quantity of ground water is limited in the south west region south of Colombo, the water quality in a natural sense (without human influence) is comparatively better. The Pleistocene deposits of the western region are mainly gravel and red earth. The surface water resource potential is about 45 million acre/ft per annum. The ground water potential is 5.8 million acre/ft (Fernando, 1976) from natural recharge.

4.2 Colombo

Colombo is situated on the west coast of Sri Lanka as seen in figure 4.1.

It was the administrative capital of Sri Lanka till recently. In the past it was recognized as the as the capital city for commerce, trade and the principal distributing centre by all the foriegn powers i.e the Arabs, Chinese, Dutch, Portugese and the British. This was mainly due to its strategic position and harbour which was known as the **Gate of Asia**. Colombo and its metropolitan region plays a decisive role in the nation. It is the port and airport through which Sri Lanka is linked to the world. Although not the administrative capital now it is still the financial, commercial and the industrial capital, and continues to be the largest centre for foreign and domestic

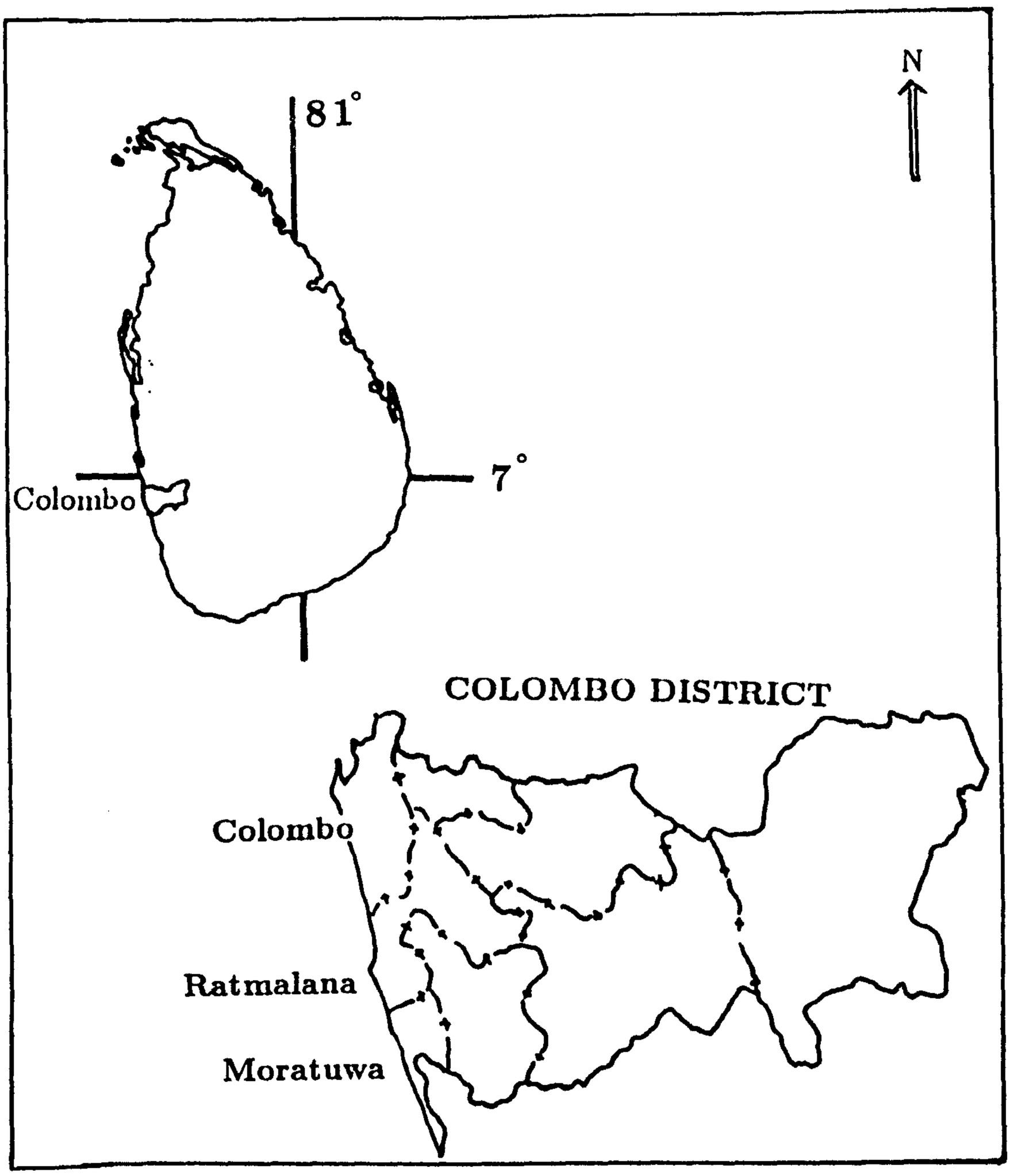


Figure 4.1 — Location: Sri Lanka and Colombo

Source: Survey Department (1983)

trade. It is the primate city, and as a cosmopolis, Colombo has no rival. It is divided into 47 administrative wards.

It is topographically flat having little land above 15 m M.S.L. and hardly rises to 30 m M.S.L. A considerable portion of the area falls below 1.8 m M.S.L. and certain areas even below 0.6 m M.S.L. Some are only 0.0 M.S.L. The highest land points are at Ellie House, Maligakande and Wolfendhal where the ground level reaches 24 m and 21 m respectively. The rise is towards the northeast, with a mean height of 3 m (Liyanage, 1980).

4.2.1 Surficial geology

The coastal plain is covered with Quatenary sands and marshy land. The coastal plain from Mutwal to Mount Lavinia, extends inland to the marshalnds that border Colombo, Kolonnawa and Kotte, and is generally characterized by thick sand deposits which extend to depths of 18m or more. The deposits are typically inter-bedded with layers of clay and mud topped with thin soils of river alluvium, sand, peat and sand stones. In water logged areas, the top layer is typically decomposed vegetable matter. Underlying the sand bed are decomposed rock, laterite, sand stone and crystalline bed rock. Exposed bed rock of granite, gneisses, schists and some low laterite ridges provide occasional relief to the plains. Rock and laterite outcrops occur at the Rock House and Summer Hill at Mutwal, the Light House at Fort and the hillock at Mt. Lavinia.

Soils

Lateritic soils on the higher ground and sands on the lower ground is the major feature in soil formation. Basement complex rocks generally occur between 13-17m below MSL (WHO, 1972a). The major soil types found in Colombo are regosols on recent beach and dune sands; red yellow podzolic soils with soft or hard laterites; red yellow podzolic soils-steeply dissected; bog and half bog soils; alluvial soil of variable drainage and texture; and latosols and regosols on recent beach sand.

Climate

Climatically it has a hot and humid tropical climate with temperature ranging between 21-32 °C. The mean annual temperature in 1986 was 28.2 °C. Although some rainfall can be expected every month of the year, over 50% of the annual rainfall occur during the SW monsoon. April and October bring well distributed heavy convectional thunderstorm rainfall. The mean annual rainfall between January 1986 and February 1987 was 1555.5 mm. February is the driest month, and usually extends into March.

Columbo is a city, a large part of which has grown on land reclaimed from the marshes for the past five centuries. The Colombo municipal area comprises of 3,733 hectares. Of the total land extent, 98 hectares is covered by water bodies, half of which are canals and the rest water courses. The total length of the canal network is 64 km.

Dutch maps reveal that only Fort, Pettah and Hulsdorf, Mutwal and the ridge running south parallel to the sea were highlands (Government of Ceylon, 1957). Prior to the construction (year) of the flood protection bund on the left bank of river Kelani, Wellampitiya to Madampitiy, and Kolonnawa to Angoda, all the low lying areas were subject to floods. Now only the areas north of the bund at Madampitiya and Sedawatte get flooded. During periods of heavy rainfall the water which drains into the swamps south of the flood protection bund cannot flow into the river Kelani as the flood water level is higher in the river than in the swamps. The only outlets for the storm water at such times is the canal system of Colombo with their outfalls at Wellawatte and Dehiwela in the south; Mutwal tunnel outlet to the north; and the San Sebastian canal discharging through the Beira lake and Galle Face spill into the sea in the west.

Population

According to the 1981 census, the Colombo district population stood at 1,699,241 when the Sri Lankan population was 14,846,750. The density of population in Colombo was 2605/km^2 with a land area of 698.7 km^2 against the Sri Lankan density of 230 per km^2 (Department of Census and Statistics, 1986a).

The population of Colombo Municipal Council was 595,000 with an annual increase rate of 0.4% against the Sri Lankan population increase rate of 1.8%. This is significantly lower than in the other developing countries. The first population census of Colombo in 1824 recorded a population of 31,188 while in 1981 it had increased to 595,000, over the period of 57 years. In Colombo, the population is concentrated mainly within the city limits and the city is already saturated. Over 50% of the pop-

ulation in the Colombo municipal area live in slums and shanties. Only 60% of the urban population is served by pipe borne water and only 22% by pipe borne sewerage (Ministry of Local Government, Housing and Construction, 1971). The rest live in sub-standard conditions without basic amenities. As statistics indicate, Colombo's population has increased over the years and it could be predicted that if this trend continues, in future the demand for land, water, housing, sewerage, infrastructure facilities recreation and other social amenities will increase. These will have a direct bearing on the canal system particularly on pollution of the surface waters in Colombo.

Water supply

The source of water supply for Colombo city is from the two reservoirs located at Labugama and Kalatuwewa 40 km from Colombo. Water is delivered to three main service reservoirs at Colombo and Dehiwela by trunk mains of 508-838 mm. in diameter. Water is distributed by a system of pipes. As only 60% of the population have access to pipe borne water, 40% depend on wells, street taps or common stand pipes and surface water for drinking, bathing and other domestic purposes. (Fernando P.L.S.A.M.S, 1982).

4.3 The drainage system of Colombo

The city of Colombo and its suburbs are located on the left bank of the Kelani river delta. The surface drainage system of Colombo and its immediate neighbourhood is mainly effected through the canal system between Kelani ganga in the north and Weras and Panadura ganga in the south as seen in figure 4.2. The storm water in Colombo city and suburbs is discharged by means of this network of canals and rivers. The drainage is divided into two systems. One system flows northwards and the other flows westwards.

The north flowing system discharges into the river Kelani via the San Sebastian canal and through the Main drain and Mutwal tunnel into the sea. Discharge into the Kelani ganga is only possible at low water levels in the river. At high water level when the north lock is closed all the storm water is diverted and discharged via the southern flowing canals through the south lock in the Dematagoda canal into the west flowing system. The west flowing drainage system discharges into the sea at the mouth of Wellawatte and Dehiwela canals. Some water finds its way through the Panadura ganga.

The Wellawatta canal discharge outlet into the sea is protected from the formation of sand bars by groynes constructed into the sea. The groynes at the Wellawatte canal outlet helps to keep this outlet open for most part of the year and is the most effective surface drainage water outlet for the whole of the eastern part of Colombo. At times of flood in the catchment this is the most effective outlet and caters for about 90% of the volume of flood water discharge (WHO, 1972b).

The Dehiwela canal outlet into the sea is obstructed by sand bars for most part of the year and these are swept away only during severe floods. Therefore, this outlet is also not very effective.

When the north lock is closed the surface water from Colombo area takes a long path through the other canals such as Bolgoda canal which flows into the Weras ganga. From here the water flows into the Bolgoda lake and hence to the Panadura river. The Panadura river outlet is only effective during the times of severe floods.

Although there is an independant canal system and related waterways totalling to about 64 km (Arambewela, 1980) the Colombo area is not satisfactorily drained due to malfunctioning of the canal system. This is due to the lack of proper maintenance, siltation, garbage dumping and the growth of aquatic plants such as *Eichornia crassipes* and *Salvina*. During the dry weather these canals are stagnant due to poor gravity drainage resulting from the flat topography of the area.

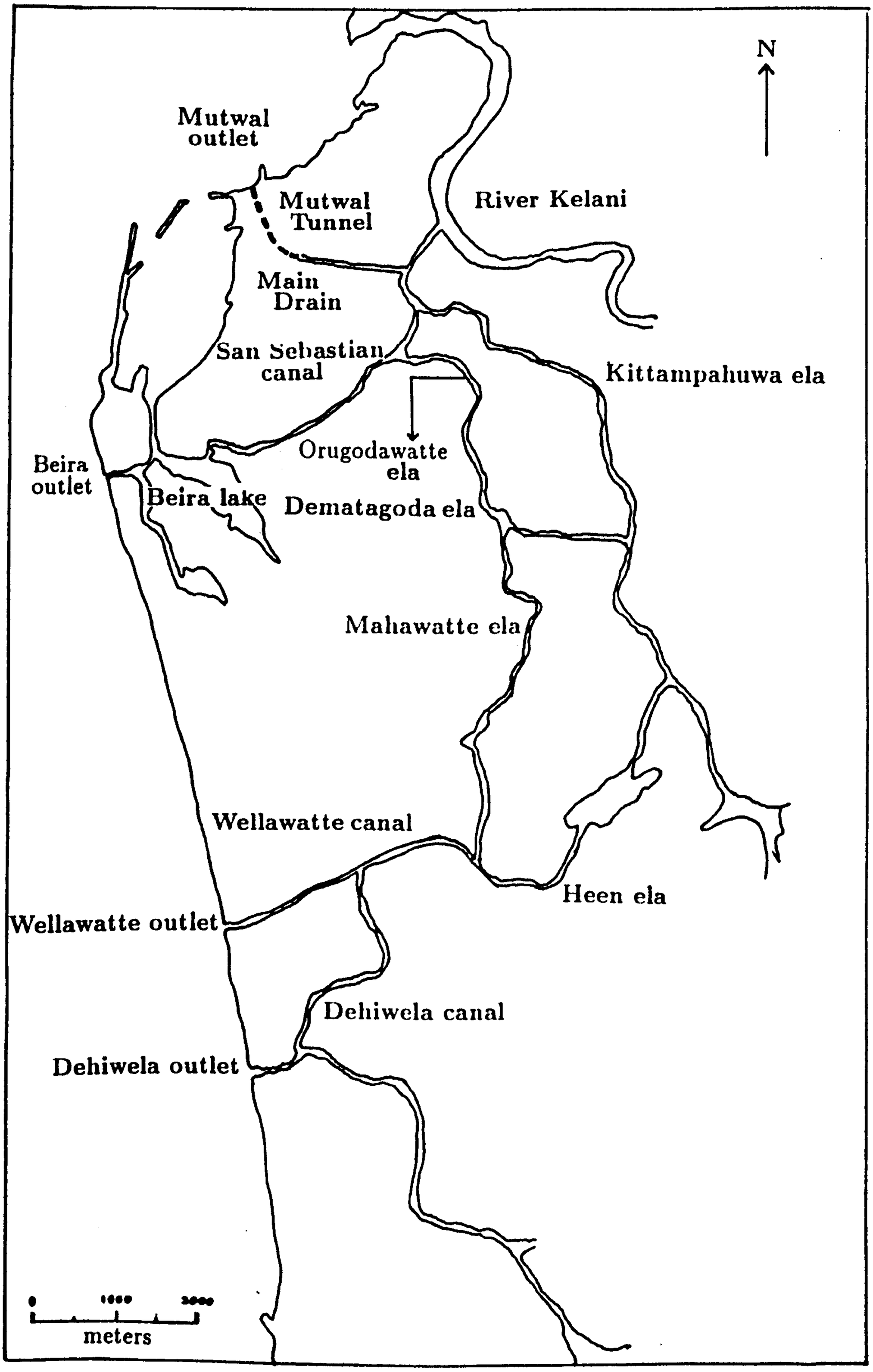


Figure 4.2 — The drainage system of Colombo

Source: Ministry of Housing, Physical Planning and Environment, 1986

4.3.1 San Sebastian canal

The San Sebastian canal, a stagnant, silted waterway forms an inter-connecting system between the Beira lake on the west and river Kelani on the east. The flow is regulated by two locks on either side of the canal. For convenience of maintenance San Sebastian canal is named as San Sebastian canal north and San Sebastian canal south. It has a total length of 3931.5 m (Department of Irrigation, 1966).

San Sebastian canal south

The figure 4.3 and 4.4 shows the characteristics of the San Sebastian canal south.

It starts from the Beira Lake and flows up to the confluence with the Orugodawatte canal. It has a length of 2,020.5 m.

The San Sebastian canal south catchment has an area of 453 hectares (ha) (Ministry of Housing, Physical Planning and Environment, 1986). The section of the canal from San Sebastian locks to the Skinners Road, passes through a heavily built up area and buildings have come up to the edge of the canal. The canal from Maligawatte to Skinners road bridge, passes through a low lying area, but the canal banks are stable due to concrete rivetments already constructed. Close to Skinners road bridge heaps of scrap iron from old automobiles are dumped.

San Sebastian canal north

The figure 4.5 and 4.6 shows the characteristics of the San Sebastian canal north.

This canal starts at the Orugodawatte/ San Sebastian canal confluence and flows into the River Kelani through the North lock at Grand Pass. It has a total length of 1911 m. The drainage area of San Sebastian north catchment is 285.5 ha.

During the period when the Kelani ganga flow is low the North lock gates are kept open and the San Sebastian canal drains into the river. It is usual that at such times the amount of dry weather drainage water in the San Sebastian canal is small and there is no problem of draining the lowlying areas, but when it rains in the Colombo catchment, drainage through the North lock is inadequate. The situation becomes even worse as there is generally a rise in the Kelani ganga consequent to the wide spread rainfall in the river catchment itself. The catchment of Kelani ganga and that of Colombo are both in the western wet zone of Sri Lanka and is exposed to the same monsoonal rainfall. When the level of Kelani ganga rises above the water level in the canal the north lock gates are closed to prevent the backflow of Kelani water into the protected area. At such times this canal ceases to function as a drainage outlet, which is really the most important stage. Therefore, San Sebastian canal as a drainage outlet is only useful as a dry weather outlet and not as a flood outlet. The Sedawatte (plank) bridge crosses the San Sebastian canal near the northern end while Stace road bridge is at the southern end. These two bridges do not obstruct the flow in the canal to any appreciable extent and there is sufficient clearance under the bridge for a dredger to pass through. The canal bed is silted and there is hardly any flow in major part of the canal. The canal banks are fairly stable.

San Sebastian canal: lock gates

Lock gates were constructed to enable boats to travel from one level of water to another, (though there are no boats plying in the San Sebastian canal for the past 20 years) to prevent the ingress of salt water during high tide, and to prevent flood waters.

San Sebastian lockgate

This structure connects the Beira lake with the San Sebastian South canal and and consists of 4 gates, A B C and D. Gate D is usually kept open or closed only when the water level in the Kelani ganga is very high. If the north lock gate does not function or is overtopped this gate protects the Beira and the surroundings from the Kelani floods. Normally the water level of Beira lake is maintained at +1.8 m, which is higher than the San Sebastian canal water level. This was necessary to facilitate

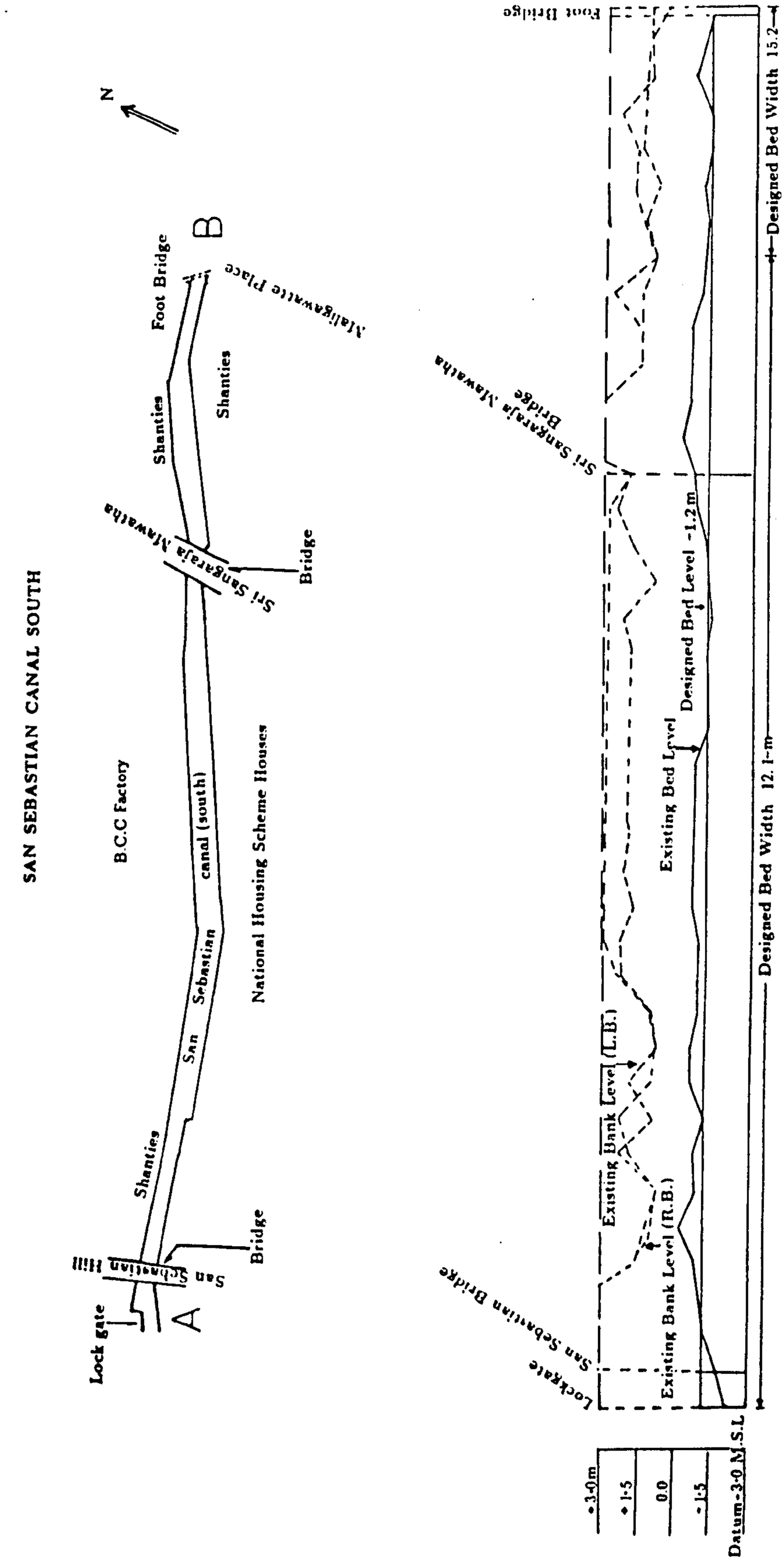


Figure 4.3 — The San Sebastian canal south (A-B)

Source: Colombo District (Low Lying Areas) Reclamation and Development Board 1981

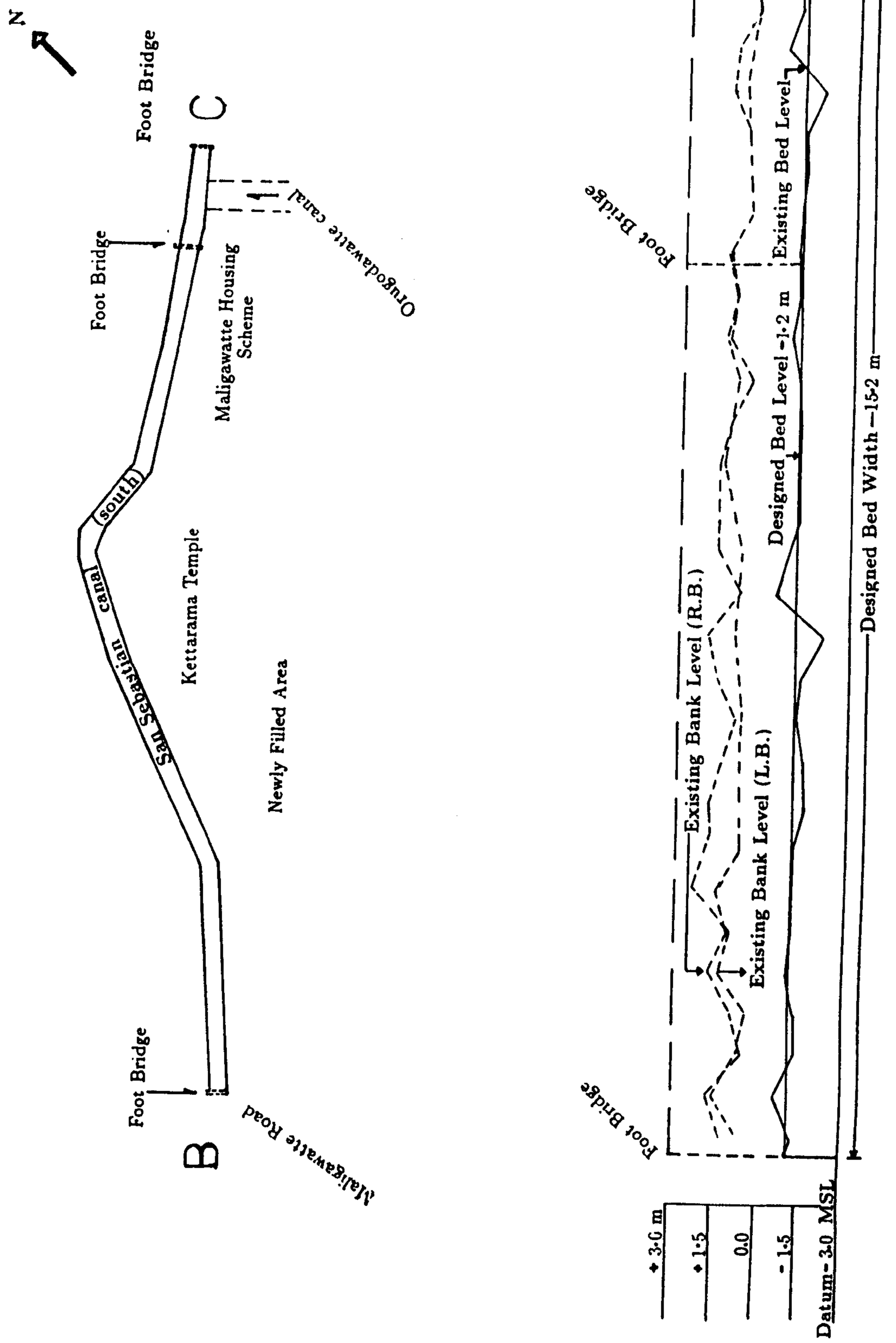


Figure 4.4 — The San Sebastian canal south (B-C)

Source: Colombo District (Low Lying Areas) Reclamation and Development Board 1981

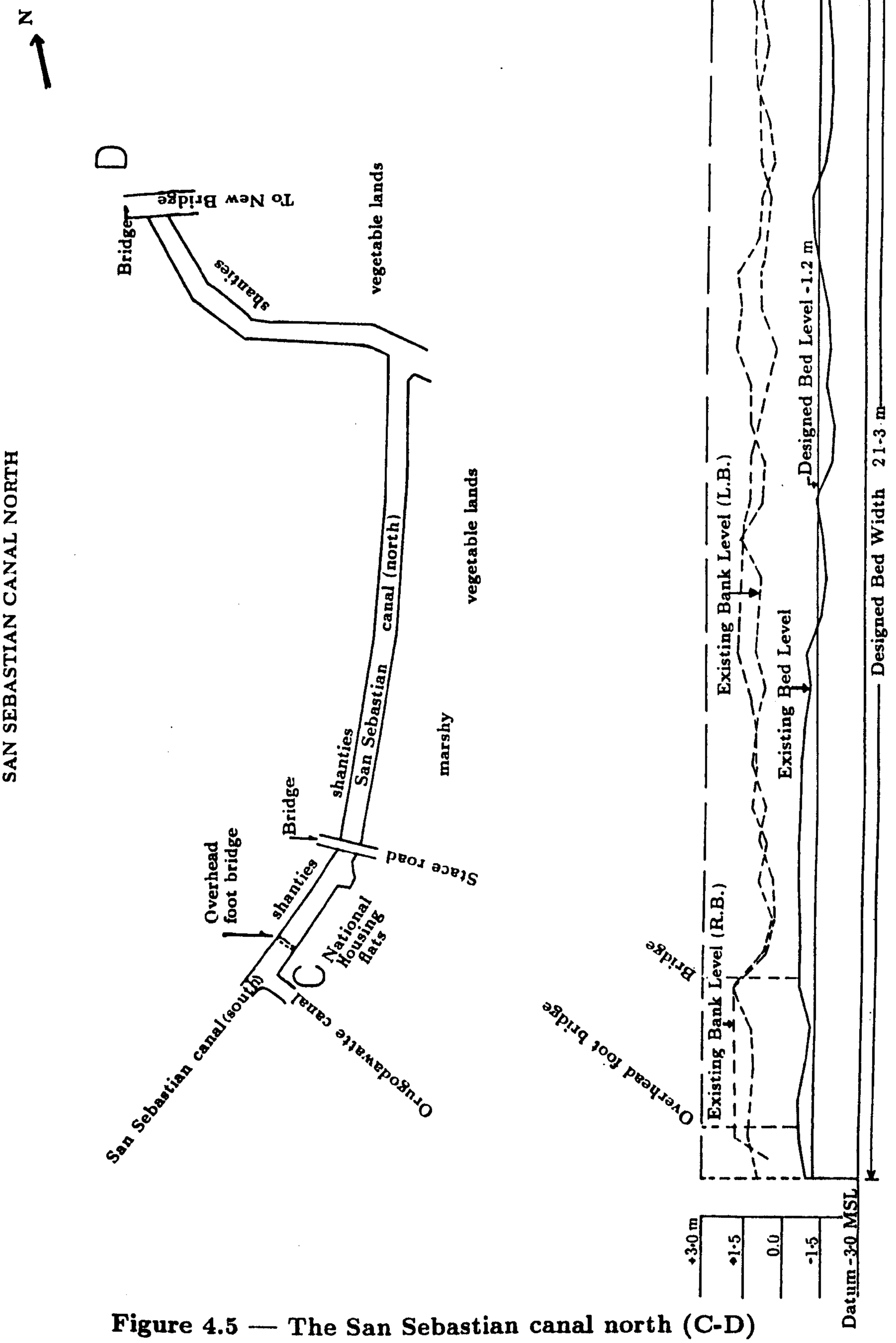


Figure 4.5 — The San Sebastian canal north (C-D)

Source: Colombo District(Low Lying Areas) Reclamation and Development Board 1981

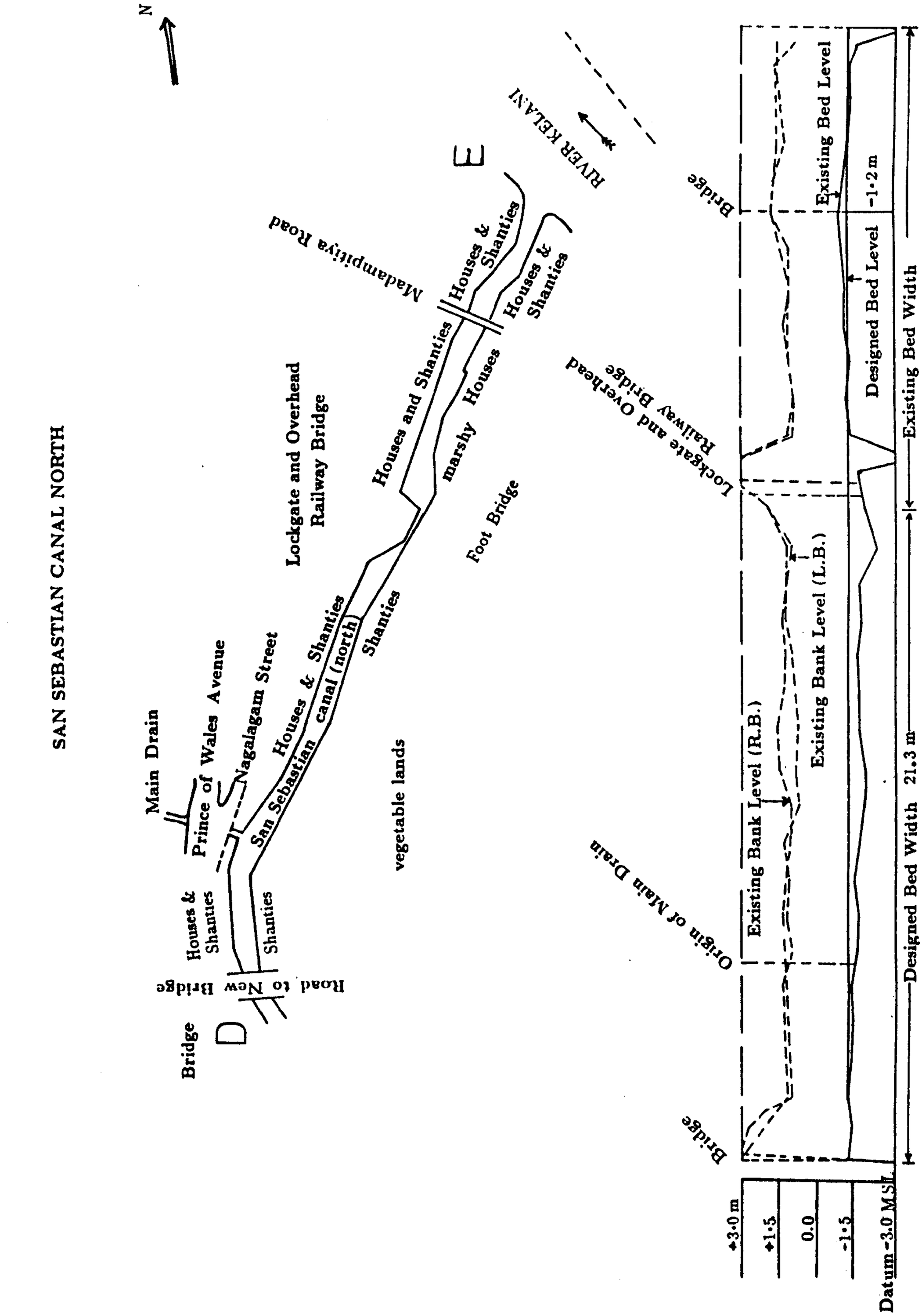


Figure 4.6 — The San Sebastian canal north (D-E)

Source: Colombo District(Low Lying Areas) Reclamation and Development Board 1981

navigation in old days in the lake and also to prevent fluctuation of the water table in the built up areas around the lake. The water loss in the Beira is due to evaporation and lockage at McCallum locks, which connects the Beira to the harbour. This is replenished by pumping water from the San Sebastian canal by the San Sebastian pumps.

Therefore it is imperative that San Sebastian canal water be unpolluted as it is a feeder canal to the fresh water lake. But as the canal water is grossly polluted, the authorities even considered to pump sea water from the Colombo harbour but Beira being a fresh water lake this idea was abandoned. San Sebastian lock is not operated now, and only the pumps work.

North lockgate

This structure connects the San Sebastian north canal with the Kelani ganga at Nagalagam street, Grandpass. The water level in the Kelani ganga is generally higher than the canal water level due to the tidal influence, and floods during rainy weather. The structure consists of 4 lock gates A B C and D. The flood gate is normally kept open, and closed only during an exceptionally high flood level in the Kelani ganga. Therefore this regulates the flow between the San Sebastian canal and the river Kelani. The width of the lock is 4.8 m.

San Sebastian canal basin

The Canal basin was constructed for the purpose of dealing with water borne traffic between the harbour, Ceylon Government Railway and the San Sebastian canal. The dimensions of the basin are 411 m by 45 m.

San Sebastian pumping station

In order to maintain the lake at a fixed level of +1.8 m M.S.L, and to provide the water lost in evaporation and lockage, it is necessary to supply water from the Kelani river which flows along the San Sebastian canal. A pumping station at San Sebastian Hill was constructed at a point nearest to the locks. The level of the pumping station is +4.05 m MSL. The specified duty of the pump is to pump 1,200 cubic feet of water per minute and deliver at a height of six feet at a velocity not exceeding 3ft/ second.

The San Sebastian canal flows entirely in the Colombo north region mostly passing through the wards in District II, (ward 20/24, 18, 16, 12, 14, 13 of Colombo central and wards 6 and 3 of the District I of Colombo north) and flows into the river Kelani at the north eastern Colombo city limits.

The other canals in the drainage system of Colombo which drain into the San Sebastian canal, are the Orugodawatte canal, Dematogoda ela Kittampahuwa ela and the Mutwal Main drain. The latter is the only left bank tributary which contributes to the flow of the Sebastian canal. The Maligawatte and Kettarama drains also enter the San Sebastian canal from the right bank.

Orugodawatte canal

This canal starts at the railway bridge at Dematagoda and joins the San Sebastian canal near the Stace road. The area directly draining into the canal is about 85 ha. The Baseline road bridge crosses the canal, but does not restrict the water flow. The land on either side of the canal is low lying, with many shanty settlements. Canal banks are eroded and the bed silted; and aquatic plants grow in the canal. This canal is only a section of a long network of canals in the south.

4.3.2 Dematagoda canal

Dematagoda canal north

The Dematogoda ela north joins the Orugodawatte canal at the railway bridge and has a length of 1110 m starting from the Kolonnawa bridge. The total area draining into the canal is about 121 ha. Banks are comparatively stable.

Dematagoda canal south

The Dematagoda canal south flows into the Dematagoda canal north. It starts from the Mahawatte canal in the south and flows north joining the Dematagoda canal south at the Kolonnawa bridge. The length of the canal is 1080 m. The area draining into the canal is about 80.9 ha. The south lock on the canal is out of order. The canal beds are silted and banks are eroded. Most of the areas on either side of the canal are low lying. The canal from the Kolonnawa bridge to the south lock passes through a heavily built up area. The oil installation is on the bank of the canal. From the south lock up to confluence with the Mahawatte canal it passes through low lying marshy land.

The Dematagoda ela south and north, and the Orugodawatte canal form a continuous waterway (though named sectionally for maintenance purpose). The entire length of the canal is 3360 m (from Mahawatte ela confluence to the San Sebastian confluence). This canal system joins the San Sebastian canal on its right bank. The Dematagoda ela and the San Sebastian canal defines approximately 50% of the eastern city limits of Colombo.

4.3.3 Mutwal Main Drain

The Mutwal Main Drain joins the San Sebastian North canal on its left bank at the Prince of Wales street through a culvert. It is 1,700 m long and drains an area of about 283.4 ha.

The length of the canal from the Prince of Wales street to Bloemendal passes through a very bad section of a marshy land and therefore canal maintenance has become a problem (grass grows into the canal and covers the surface, and water hyancinth grows very rapidly). From Bloemendal road up to its confluence with the Mutwal tunnel, it passes through highly populated areas. The section from Aluthmawatha road up to the tunnel is crowded with shanties. The the canal maintenance is difficult due to the garbage that is dumped into the canal, which poses a problem in the maintenance of the tunnel outlet for drainage (as it become choked). The culverts at the Bloemendal road, railway line and Aluthmawatha road are small and constitutes a restriction. The Main Drain flows across Bloemendal to join the San Sebastian canal.

4.3.4 Mutwal tunnel

The Mutwal tunnel starts from 182.88 m below the Aluthmawatha road culvert, at the Mutwal Main Drain and discharges into the sea between the fisheries harbour South Jetty and Colombo harbour North Jetty. This is a concrete lined tunnel 576 m long, 1.83 m in diameter and passses through the Rock House Battery Hill with a sill at -5.0 MSL. The volume of water that flow through the canal is small. This tunnel is the only direct outlet to the sea in the North other than the Kelani ganga. The outlet into the sea is exposed to the full force of the sea and is often blocked by a sand bank. A recent inspection of the tunnel showed that the soffit of the outlet was below the sand bank and the inlet soffit was below the approaching drain bed level, therefore it is useless as a drainage outlet. Before the construction of the fisheries harbour the tunnel terminated at a point which at present, is inside the fisheries harbour, and the tunnel functioned better as an outlet. Therefore though the tunnel is expected to take the local flood water of Colombo north it is choked with detritus, garbage and domestic waste in addition to being blocked by sand bar at the mouth. Therefore polluted water stagnates which is a critical factor during the dry weather. However, at times of floods in the Kelani Ganga, when the North lock on San Sebastian is closed the tunnel outlet helps the water in the Mutwal marsh to escape into the sea. At such times there is a flushing out of the canal, into the sea, which helps to cleanse the pollutants in the Main drain and the tunnel. It is said that the tunnel was designed with a hump at the confluence with the Main Drain, in order to protect the sea water that enter up landwards (personal communication - Hettiarachi, D. 1988).

4.3.5 Kittampahuwa Ela

Kittampahuwa ela starts at the Kolonnawa/Heen ela confluence near Gothatuwa and flows north through Wellampitiya and Orugodawatte and enters San Sebastian canal about a 0.4 km north of the Stace road. This waterway is approximately 5600 m long. A branch of this ela, flows to Kelani ganga through a culvert at the Railway bridge and along the Railway bridge. The width of the canal is about 15 m (visual observation). The surface water from the Orugodawatte developed area flows into this ela north of the culvert. There is a lockgate on the ela near its confluence with Kelani river.

4.3.6 Maligawatte drain

Visual observation showed that the Maligawatte drain is about 2.4 - 3.0 m wide. The Maligawatte drain flows through Maligawatte West and New Bazaar and enters the San Sebastian canal.

4.3.7 Kettarama Drain

Kettarama drain is about 1.8 m wide (visual observation). It flows across Grandpass South into the San Sebastian canal near the Kettarama bridge. Other than these canals, the drainage system of Colombo is effected through the south and west flowing canals and water ways such as Kolonnawa canal North and South; Kotte canal, Kirillapone and Wellawatte canals, Dehiwela canal North and South; and the Bolgoda canal. At the southern end the Bolgoda canal terminates by joining the Weras ganga, which flows into the Bolgoda lake and finally into the sea at Panadura through Panadura ganga. Of the drainage outlets into the sea, Wellawatte outlet functions efficiently for about 9 months while the Dehiwela and Panadura outlets are blocked with sand bars for most part of the year.

4.3.8 Surface drainage system and canal pollution

Linking the effectiveness of the surface drainage system of Colombo and canal pollution it can be said that during dry weather, when canals are stagnant and the outlets malfunctioning, pollutants concentrate and tend to remain in the canal for major part of the year. During the rainy weather when the North lock is closed the pollutants become virtually land locked especially in San Sebastian canal as the San Sebastian lock gates are permanently locked. The Beira spill, an efficient outlet is not resorted to due to constraints already mentioned. This situation is true other than during a heavy flood, when sand bars at the outlets get cleared and San Sebastian flood gates are opened. If the flushing of pollutants or dilution occur during wet weather, it is due to the higher water level in the canals and direct dilution by rain water rather than due to the efficiency of the functioning of the canal system as a drainage outlet.

4.4 The sewerage system of Colombo

In the city of Colombo there are separate systems for the collection and transport of waste waters, and the disposal of storm waters. Waste water is discharged by an underground sewer system, while the storm water is discharged by a system of rivers and canals. The existing sewerage system has a significant contribution to pollution of the surface water particularly in Colombo. There are 82 emergency overflows in the sewer system and as a result significant quantities of waste water enter the open water courses.

The Colombo Municipal area is partially served with sewers. The sewers were constructed between 1906 and 1913, and the system was designed to serve an area of about 2,300ha and a population of 373,000 by 1951 with a projected dry weather flow (DWF) of about 42,500 m^3/d. The system was subdivided into a large northern section draining to the Kelani ganga and a smaller southern section draining to the ocean near Wellawatte.

The Northern treatment work was constructed between 1906 and 1908 and provided primary treatment for sewage. Percolating filter beds included in the system suffered blockage by solids overflowing the settling tanks and were removed from use by 1913. The silt pit and screen became blocked frequently and the sedimentation tanks gradually proved inadequate to handle the flows. In 1956 the Northern treatment work was modified and the system functioned for approximately five years. By 1961-62 the tanks became ineffective due to lack of maintenance and therefore the sewage was diverted from the treatment works and pumped directly into the Kelani ganga from the Madampitiya pumping station.

The Southern treatment works were constructed between 1911 and 1913. The discharge into the sea is through an outfall extending 82 meters offshore. The silt pit and screens were frequently clogged and ineffective by 1918 and the sedimentation tank too was abandoned due to odour complaints by local population.

The present sewerage system in Colombo Municipal Council area now consists of 244km of sewers, 11 area pumping stations and two abandoned treatment works. The system was designed to handle only sewage and was not intended to be combined with the surface water drainage except in a few densely populated areas where the overflows were provided for flood waters. The system is overloaded and poorly maintained. The treatment facilities have been abandoned. The pumps are old and their actual capacities are lower than the rated capacities. The most severely overloaded lengths of sewer are those just downstream of the pumping stations. The section down stream of Thimbirigasyaya pumping station is particularly in bad condition and so is downstream of Maligawatte.

4.4.1 The northern and the southern systems

The northern trunk sewer receives flow from the major part of the city, and serve approximately 2,270 hectares, and the flow is 67,500-90,000 cubic meters per day (Ministry of Housing, Physical Planning and Environment, 1986). The flow drains to the Madampitiya pumping station where it by-passes the treatment works and is pumped through the outfall into the Kelani ganga without treatment. Hence the northern area flow is discharged as raw sewage into the river. Two trunk sewers drain to the Madampitiya pumping station. One trunk sewer drains an area of 178 ha north and west of the pumping station, with a catchment of 57 hectares. The other trunk sewer drains the remainder of the northern area of 2,092 ha. The northern system covers the entire San Sebastian area.

The Southern outfall receives sewage flow from 750 ha in the Southern portion of the city. The area drains to the Wellawalte pumping station where it is pumped into the sea through an outfall pipe.

The sewerage system within the Colombo municipal council has not been rehabilitated or extended to any significant extent since the original construction. However over the years there has been a steady increase in the number of household and commercial connections to the sewer system. Approximately 50,000 households have made connections to the existing sewerage system in 60 years (National Water Supply and Drainage Board, (NWSDB) 1981). The existing treatment plants at Madampitiya and Wellawatte are no longer in use. And as noted earlier raw sewage is discharged directly into the Kelani ganga. Neither this nor the effluent discharged into the sea at Wellawatte via a short ocean outfall are chemically treated.

4.4.2 Variation is the waste flow rates

Typically as with most sewer systems the period from 23.00-05.00 hours is the low flow period when the rate is approximately 20% of the average flow rate. Maximum waste flow occurs between 07.00-10.00 and 17.00-20.00 hours when the domestic water use is the highest.

The table 4.1 shows the waste water flows in the San Sebastian canal area. The projected peak flow for the year 2000 is highest at Madampitiya with 151,600 m^3/d.

Table 4.1 — Projected peak waste water flows for the year 2000 in areas close to the San Sebastian canal

Facility	Volume (m^3/d)
Pump stations:	
Madampitiya	151,600
Colombo harbour	37,200
Maligawatte	46,600
Slave Island	16,400
Outfalls:	
Nothern	247,000
Southern	210,800

Source: National Water Supply and Drainage Board (1981)

The second highest 46,600 is at the Maligawatte pump stations. Both are in the San Sebastian canal area. The northern outfall has 247,000 m^3/d projected for the year 2000, against a lower flow in the southern outfall of 210,800 m^3/d. This indicates that the waste water flow is higher from the northern area (NWSDB, 1981). This also means that the contribution to pollution of the canal is higher in the northern area.

The sewers

The Master Plan for sewerage (WHO, 1972a) reported that the existing sewers within the Colombo Municipal Council area were overloaded, and the raw sewage overflowed continuously into the surface drains. By 1981 most of the sewer pipelines were found to contain grit and sand and therefore the hydraulic capacities of these sewers were limited (NWSDB, 1981). This siltation problem was partially due to a large number of illegal storm water drainage connections to sewers over the entire area. The extent of the problem can be gauged by the fact that in a portion of Colombo Municipal District number 4, over 400 such connections are known to exist. Therefore, through illegal sewers and directly from the Madampitiya sewage outfall, the San Sebastian canal waste waters are emptied into the river Kelani without any treatment.

Though most of the sewers are in good condition, there are few cases where structural failures have occured. According to the Master Plan the, crowns of the portions of the trunk sewer between Union Place and Darley road junction, and from Panchikawatte road to Maradana road junction are believed to be damaged as a result of hydrogen sulphide corrosion. Both these areas adjoin the San Sebastian canal and this could possibly be due to illegal acidic industrial discharges.

4.4.3 Sewage treatment and disposal

To overcome the above problems the Sewerage Master Plan considered two methods of sewage disposal i.e secondary treatment of sewage with effluent disposal into an inland watercourse, and the disposal of untreated sewage through an ocean outfall. The new outfalls can be seen in figure 4.7.

In 1981 NWSDB which recognised the importance of the sewage outfalls recommended the constructed length of 219m of the Southern outfall to be extended to its full original design length of 1,189m in the first stage program, as it was found less expensive to construct the complete outfall. It also recommended this since significant public health protection of ocean bathers will not be attained with less than the full length of the outfall.

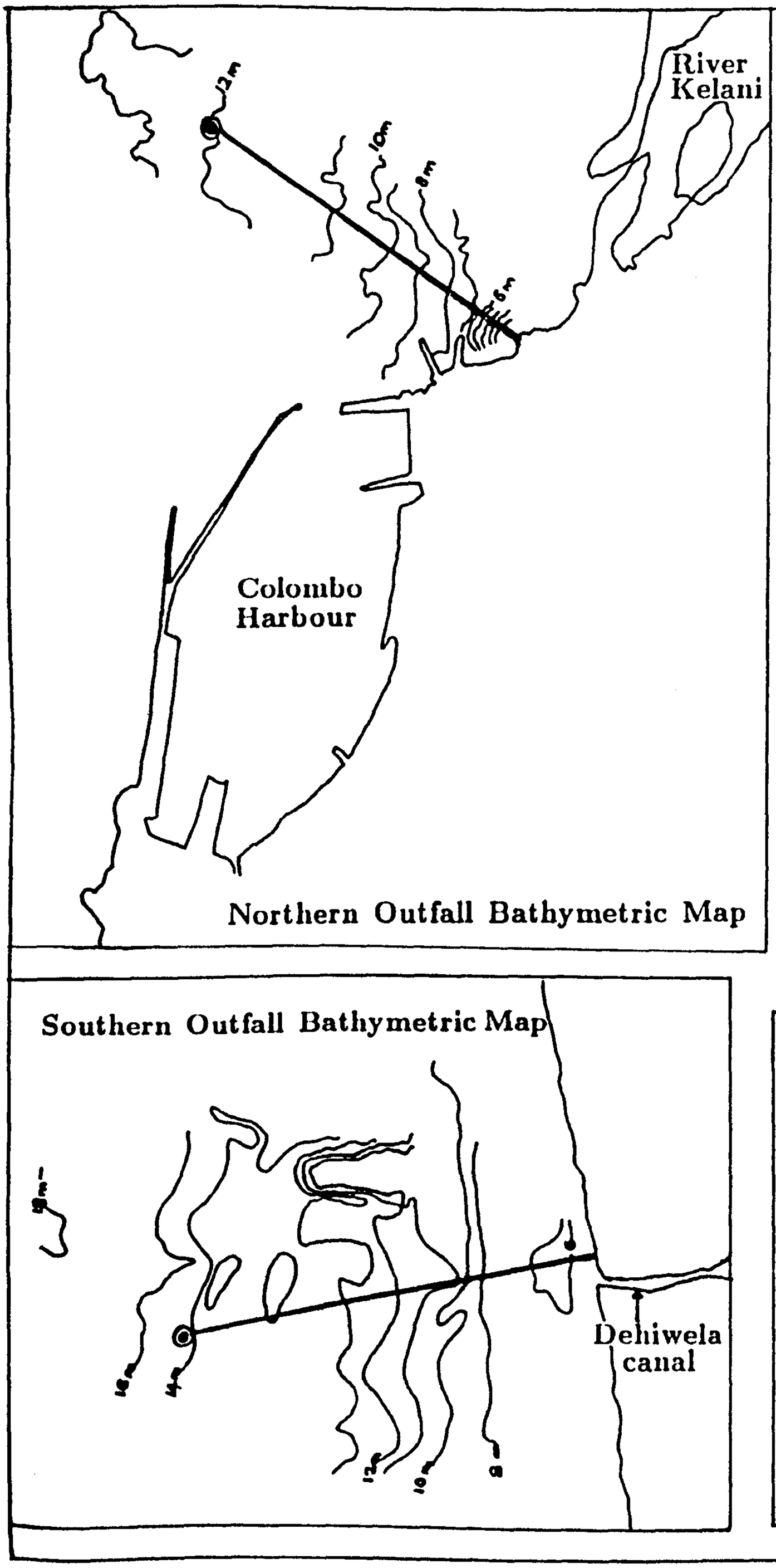


Figure 4.7 — The new sewage outfalls

Source: National Water Supply and Drainage Board 1982

As the proposal to extend the Madampitiya river outfall would have only little effect on the current gross pollution of river Kelani, this river outfall was proposed to be replaced by the Northern Outfall to its designed total length of 2,052m. This was to be discharged into the north at the fisheries harbour. Preliminary treatment of raw sewage was recommended when the outfalls start showing signs of clogging up. This project is under construction. Continued discharge into the Kelani ganga was considered only as a temporary measure until the Northern outfall was constructed.

Sewage treatment and inland disposal were considered to be uneconomical. Ocean disposal of sewage without treatment was recommended because of the relatively simple operation and maintenance, small amount of land area required for headworks, lack of environmental nuisance and as the least cost solution for disposal.

4.5 Shanties and slums in Colombo

Almost 50% of these people either live in decaying and under-serviced slums or squat illegally in semi-permanent shanties. The crowding of so many of Colombo's population into such areas is derived from the lack of affordable alternative accomodation. In this respect Colombo conforms to the experience of many other urban areas of the developing world. The majority of the poorest class of people already in the region are those who migrated to the region since 1946. They have no fixed abode and found the canal banks as the ideal locations to put up their shanties as hardly any action to evict them from these locations was made. The residents of Colombo's slums and shanties generally compose those with the lowest income.

Slums are of 3 types. They are,

Old tenements: were initially erected to accommodate the influx of a new labour force into the city during a period when a thriving plantation industry required labour for processing, packing, storage, handling and shipping.

Slum houses (old residential houses): are located in the former residential areas mainly in the older parts of Columbo north and central (e.g. Pettah, Hulftsdorp, Wolfendhal) which were later turned into stores or apartments for low income workers. They were subdivided into small units, inadequately maintained and largely deprived of basic sanitary facilities.

Shanties: are a collection of small, single unit improvised structures constructed of non durable materials on previously vacant land throughout the city. Shanties illegally occupy crown or private land, usually with no regular water, electricity or sanitary facilities. Majority of these are built on land to subjected to frequent flooding.

Many slum and shanties do not have clean water and an adequate and safe system of sewage disposal. This makes them use the nearby water courses and banks for toilet facilities. Washing is mainly done in the nearby taps (stand pipes) along the canal and as a result all the unclean water freely finds its way to the canal. Household refuse and garbage is also thrown into the canals.

A preliminary census of shanties and slums in 1986 within the city of Colombo, revealed that there were 30,926 tenements and 10,035 shanties by 31.12.86 (National Housing Development Authority, 1986) These broken up electorally is given in table 4.2.

Safely assuming an occupancy rate of 6 per shanty it can be estimated, the population in shanties to be 60,210 and 185,556 in tenements. This totals 245,766, making the percentage of shanty population in the city of Colombo slightly below 50%. It has to be added that additional illegal single shanty units are being constructed in the canal reservations in the Lockgate area, by certain Lockgate rehoused scheme, house owners in 1989. These units are built with wood and rented for Sri Lankan Rupees 50. Therefore new shanties are mushrooming and hence makes the estimated figure much higher. These shanties are encroachments directly into the canal banks. As far as San Sebastian canal is concerned, pollution by the shanties tend to continue as seen with the construction of new units, inspite of the rehousing scheme. This

Table 4.2 — Number of shanties and slums in selected wards in the city of Colombo

Wards	No. of shanties	No. of tenements	Total units
Colombo North	1615	6212	7827
Colombo Central	2721	16316	19037
Borella	2780	3359	6139
Colombo East	2314	3459	5773
Colombo West	605	1580	2185
Total for wards	10,035	30,926	40,961

Source: National Housing Development Authority (1986)

will increase the domestic waste water entry into the canal. The estimated shanty units along the San Sebastian canal by the National Housing development Authority is over 1000 units.

4.6 Food industry in the economy of Colombo and the nation

The economic policy introduced in 1977, by the Government was aimed at far reaching results. The dynamism infused into the economy was to be reflected in the manufacturing sector by way of enhanced investment, production and employment. The new economic policies placed a greater reliance on the manufacturing sector for a self sustained economy. Major elements such as import liberalization, unification of exchange rates, investment relief and incentives were designed to meet the objectives of an expansion of export oriented industries and an increased efficiency of the existing import substituting industries.

Sri Lanka's economy grew by 4% in 1986 (National Development Bank, 1987) The main sources of this growth were in the industrial production, mining, quarrying and services. Agricultural production suffered a set back. Industrial production increased by 12% in 1986 compared to 5% in 1985. This growth was marked in the private sector which grew by 15%. The public sector grew by 8% and contributed to about 13% of the GNP (Ministry of Industries, 1988). The major groups of industries which recorded growth were Food, Beverage and Tobacco; and the Textiles and Wearing apparel industries. The structure of the industrial production heavily depended on the three product groups. These are food and beverage; petroleum and plastic products; and chemicals. In terms of the number of persons engaged, employment renumeration and gross addition to fixed assets the Food, Beverage and Tobacco; Textile and Wearing Apparel; and the leather industry ranked first or second, followed by Chemicals and Petroleum products. These three industries together accounted for a little over 75% of the total value of gross output in Sri Lanka's manufacturing sector.

Manufacturing industries continued to dominate the industrial sector with 91.8% of the value of total gross output. 88.7% of the total work force was engaged in this industrial sector thus, ranked the first among the major industrial divisions (Department of Census and Statistics, 1987a). Within the manufacturing sector Food, Beverage and Tobacco is an important sub-sector. This sector accounted for 30.1% of the total persons engaged, which is only second to the textile industries, and 35.6% of the value of output which takes a close second to manufacture of chemicals, petrol, plastics and the rubber sub sector. In 1985 within the Food, Beverage and the Tobacco sub-sector, the value of output from the processing of meats; dairy products; fish products; fruit; grains; bakery products and sugar amounted to Sri Lankan Rupees (SLR) 2,428,805,154; and from spices, black tea, and animal feed it was SLR 7,517,601,991. The value of output from Beverages accounted for SLR 601,746,868. In the Colombo district the value of output from the respective subsectors) were SLR 1,154,652,323; SLR 380,726,595; and SLR 3,894,211,135 (Department of Census and

Statistics, 1987b). These values indicated that they were the highest recorded in any districts. This indicates the importance of the food and beverage industry in Colombo and the nation.

In terms of financial assistance given to industries, priority is given to three areas i.e. Food processing and Beverage; Rubber based industries; and Light engineering. Of the 42 applications received for assistance from the Ministry of Industries in the latter part of 1987, 50% were related to Food Processing. Of the loans granted to small and medium scale industries upto 1986, food industries got the highest number of loans (i.e. 419, amounting to million SLR 182,921) (National Development Bank, 1987). District wise Colombo, got the highest number of loans which amounted to million SLR 235,001.1 was for the food processing industry. The National Development Bank approved million SLR 186 as loans and equity investments for food processing in 1986, the value was the highest approved to any group of industries.

Between 1977-1986, 34 new Food and Beverage industries were approved by the Ministry of Industreis and Scientific Affairs in the Colombo district (Ministry of Industries, 1988). Today there are 125 registered Food processing industries and 10 beverage industries in the Colombo district and over 70 of these are within the Colombo city limits (Ministry of Industries, 1986). There are probably more industries which are unregistered and have not reported for the Government census. Therefore the importance of the food processing industry stands undisputed.

There is a heavy and unbalanced concentration of industries in Colombo. This applies not only to food industries. But the concentration of this group is comparatively high as it meets the immediate and basic daily needs of an urban population. The government's industrial policy had an impact on the concentration of industries in and around Colombo, to the neglect of the other parts of the island. Therefore industries mushroomed in Colombo without any plan or environmental consideration, since the government's industrial policy paid least emphasis on location and spatial considerations. This trend in conglomeration of industries in Colombo can be seen from post independence time. Although there is a decline in the number of industries located in Colombo due to government restrictions and policies recently, the predominant position held by the Colombo district in respect of the number of industrial units both state and private has been only slightly altered. Nearly 70% of the industries are located in the Colombo district today. This has resulted in the pollution of water ways. Due to heavy concentration of industries within Colombo, as far back as 1974, a municipal councillor highlighted that the water need of industries had reached more than 5 million gallons, in addition to other associated problems like housing congestion, influx of population, emerging shanty colonies and the pollution of waterways. Therefore in 1974, the Colombo Municipal Council passed a motion not to allow new industries to be sited within the city limits, and gradually to shift the existing industries out of the city (Perera, 1976). Although Colombo was saturated with unplanned industries by 1974, it was not till recently that the government totally banned the siting of industries in Colombo, other than in the approved industrial zones which are located outside the city limits.

The short sighted industrial locational policy, urgency for economic growth, mushrooming of shanties along the canals and the other waterways, and the total disregard to environmental considerations, have caused the gross pollution of the waterways in Colombo today.

4.7 The water pollution situation in Colombo and Sri Lanka

In Sri Lanka as in other developing countries there is a severe dearth of material and monitored analytical data that pertain to water pollution. The examination of the available data indicates that water pollution has reached uprecedented levels especially in the water courses in Colombo and the other main cities such as Kandy where few studies are available. Water pollution as a major environmental issue was given significance after the Stockholm Conference of 1972, and with the enactment of the National Environmental Act of 1980. The control measures which were weak hitherto came into force. Although water pollution as a major issue is still in its

infancy, the awareness of the ill effects of polluting the aquatic environment is there in the minds of the polluters and legislative authorities.

A recent water pollution survey (Ministry of Housing, Physical Planning and Environment, 1986) estimates a total waste load of 720,000 population equivalent (PE) released into the surface waters in the Colombo area. Of this 53%, that amounted to 390,000 PE is disposed as sewered effluents into the river/sea outfalls and the remaining 47% i.e. 330,000 PE is discharged into the canals. A break down of this shows that 260,000 PE is of domestic origin and 70,000 PE is of industrial origin.

Therefore the two most important contributors to water pollution are domestic (which includes permanent residential units and shanties) and industrial sources. The existing sewerage system; flow characteristics on the canal (for major part of the year the canals are stagnant); inefficiency of the drainage outlets; the habits of the people and the indifferences to environmental consequences; unplanned economic growth and mushrooming of industries in the cities particularly in Colombo; lack of treatment facilities; and weak environmental laws contribute to water pollution in Colombo and in Sri Lanka in general.

Domestic waste water

Domestic waste water is composed of human body wastes such as faeces and urine and sullage which results from personal washing, laundry and cleansing operations. It may also have infiltration water, that depend on the weather conditions and the sewer network. There could be even radioactive wastes. Fresh sewage is grey, turbid and offensive and as soon as it looses its dissolved oxygen becomes septic and gives an offensive odour. Three main types of organic matter present in the domestic waste water are carbohydrates, nitrogeneous compounds and lipids. The Sri-Lankan domestic waste waters, unlike the developed countries domestic waste waters are likely to have less complex organic matter and a relatively high component of fibrous and cellulose matter. The local domestic waste water degrades more rapidly when compared to that of the developed countries (Sandanam, 1984).

Analysis of domestic waste waters of the Bambalapitiya and Wellawatte pumping stations of the Colombo Municipality gave a BOD_5 of 256.3 mg/L for Wellawatte and 235.3 mg/L for Bambalapitiya (Sandanam, 1984). The average value which was 245.8 mg/L was within the normal range of 200-600 mg/L for domestic waste water, although it was the lower side. A pilot study by Anderson (1979) gave a COD of 336 mg/L for domestic sewage in Colombo. At the Madampitiya treatment works which does not function now, the COD range was 247.0-514.0mg/L. *Coliform* per mL sewage was 9,500 - 349,800 and N total nitrogen had a concentration of 16-32 mg/L (CEA, 1985).

The suspended solid load for Wellawatte was 139.9 mg/L and Bambalapitiya 107.7 mg/l. The mean concentration of 122.3 mg/L for suspended solids was also within the range of 50-250 mg/L. The estimated per capita BOD of 37 gr/hr/day for Bamhalapitiya pumping station, though low is an acceptable value for developing countries. Considering the Colombo City's population, of whom 60% have connections to the municipal sewerage system, (ignoring the sewage overflows) it can be assumed that about 40% of the population i.e. 260,000 people discharge waste water directly or indirectly into the Colombo canals. (Ministry of Housing, Physical Planning and Environment, 1986). The strength of the wastes and the fact that these enter without any form of treatment shows that the canals are continuously being polluted in Colombo.

4.8 Pollution of surface waters other than in the San Sebastian canal

Colombo has a network of canals which are found to be polluted. The canals which run through the city collect massive quantities of effluent from the industrial and domestic sources. Tributary canals also contribute considerably towards pollution.

Wellawatte and Dehiwela canal

These canals traverse the south of Colombo through densely populated areas. Industries such as electroplating, battery manufacture, few food industries and garages which discharge effluents into the canal are found along the canal. These discharge untreated waste waters. Slum dwellers along the canal throw domestic refuse, garbage and discharge domestic waste water. The canals are also used as open sewers and sinks for daily toilet facilities. Foul and illegal industrial drains empty into the canal. At times of cleaning, the municipal sewage too overflows into the canals. Thus these canals are highly polluted. The critical pollution problem arises during the dry season especially in February and March. During this time the flow rate of the canal is considerably decreased and lateral percolation increases due to lowering of the water table. The canal itself emanates hydrogen sulphide in most places and is detectable by its black colour and odour. Hardly any fish can be seen in the canal and aquatic blooms thrive in most places. Despite its poor water quality the Wellawatte and Deliwela canal water is used by slum dwellers for bathing and washing purposes (Dissanyake C.B.*et. al.*1983). In open regions the polluted water percolates into the water table and moves laterally through permeable alluvium and gravel to nearby drinking water wells (the water table is 2-5m below surface) and, thus contributes to ground water pollution.

The dissolved oxygen content of the canals varied from 1-13 mg/L alkalilinity 14-130 mg/L and the pH remained acidic at an average of 5.45. At places where the canal was close to the sea the salinity conditions were marked. (Dissanayake, C.B. *et al* 1983).

The NO_3 content of the canal was extremely low. The canal receives massive quantities of human excreta and other biological waste matter that drains into the canal from the surroundings. In general the eutrophic character has been imparted to the canal and the oxygen content was rapidly utilized by the oxyphiles, the human excreta acting as a reducing medium. This fact was confirmed by the excess of nitrogen species NO_2 and NH^+4 over NO_3. The total phosphorous content ranged from 0.16 - 6.5 mg/L.

The elemental contents of the canal and well water were high showing obvious contamination. The canal had an average of 6,426 μ/L Pb; 770 μ/L Cd; 435 μ/L Cu; and 1,522 μ/L of Zn. WHO standards for drinking water are 100 μ/L Pb; 10 μ/L Cd; 50 μ/L Cu; and 3,000 μ/L Zn (Dissanayake, C.B. *et al* 1983). The high metal concentration in the canal was mainly due to a large number of small effluent drains which unload into the main canal carrying discharges from garages and other workshops using metals. High Pb and Cd were mainly due to battery manufacture, automobile repairing and Pb containing fuel discharges. The Cd loading is very high possibly due to electroplating industrial discharges.

This canal has a massive load of putrifying organic matter. The nitrate loading was chiefly from biological sources; human and animal waste matter accounting for large percentage of the total nitrogen load. The very low nitrate content in the canal water is probably due to the anoxic condition coupled with with presence of nitrogen in complex organic species. Further action of microbes such as denitrifying bacteria could release much of nitrogen.

In the Wellawatte canal, an industrial pollution pilot survey was carried out by Anderson in 1979. Of the eight monitoring stations in the canal five stations had 0.0 DO levels while the rest ranged between 0.6 to 1.7 mg/L; and the COD ranged from 29-288 mg/L.

Of the factories that discharge into the Wellawatte canal, the National Milk Board effluent had a COD range of 715.0-3,300 mg/L. Lanka canneries had a COD of 2240 mg/L, and a BOD of 1,050 mg/L. This shows the nature, strength and the severity of industrial discharges into the canal, and these enter without any form of treatment.

A study on water quality in the canal system of Colombo (Padmaperuma n.d) revealed that the DO levels at all sampling points during the period of study were far below the ideal conditions. 75% of the samples did not meet the Interim Indian Standard for DO standard of 6.5 mg/L and 15% of the sampling points were totally

anaerobic. DO at certain sampling stations improved during the rainy season i.e. in places where DO level was already high, it showed little improvement in stations when DO saturated water was made available. Comparatively the DO of Kittampahuwa ela and Kolonnawa ela were higher than the Wellawatte and San Sebastian canal.

The study revealed that in respect of the canals that the COD values in certain areas were more than the expected value for COD:BOD. This is possibly due to the organic content of the industrial effluents and domestic wastes. This was confirmed by the results of an effluent sampling of an industry.

The total SS was high in the San Sebastian, Wellawatte and Dehiwela canals. Turbidity also showed similar variations. Phosphorous and nitrate levels were fairly high in the canals and eutrophication had taken place in a few sampling points.

4.8.1 Industrial water pollution

Moratuwa and Ratmalana areas

In a preliminary survey conducted in Moratuwa and Ratmalana areas it was revealed that enviromental problems due to industrial water pollution were very accute. Aquatic bodies fringing the areas were highly polluted, and were causing severe health hazards to resident population. The area is highly residential and densely industrialized too. This area has a greater density of industries than the Export Processing Zone of Katutnayake. Many types of industries mainly non-agro based such as paint, galvanising, asbestos, dyeing and finishing, pharmaceutical, battery manufacturing both wet and dry processes are found in these areas. The industries have come into existence in the last three decades. Major part of the industrial discharges were released via surface drainage to Lunawa lagoon and Bolgoda lake (CEA, 1983). These industries have come up in areas designated as 'provisional residential areas' where the chairman of the local authority has the power to approve non residential activities provided it does not cause nuisance. But most of these industries are found highly polluting and a nuisance to the population. Industries are established side by side with residential buildings. Due to haphazard development of industries in this area the immediate danger of industral pollution is now experienced and has become a threat to environmental quality and human life.

Many industries use wet processes involving large volumes of water such as textile printing and chemical processing. Effluent volumes are large and vary from factory to factory depending on the processes used. A common factor is that virtually, in all these industries is that no waste treatment is carried out and nearly all the effleunts are discharged directly into public drains. The distribution of industries are haphazard. The unlined channels that carry the untreated effluents finally fall into two major water bodies i.e. Bolgoda lake and Lanawa lagoon (CEA-1983).

Bolgoda lake system

Most of the industrial effluents drain into the Weras ganger i.e. the north Bolgoda lake. This is a virtually stagnant anaerobic water body and the nature and extent of pollution during rainy and dry period is different, and is largely covered by aquatic plants. Bolgoda lake gets waste water from the Lady Catherine industrial estate and other industries. Poor drainage, bad roads, uncontrolled disposal of wastes and highly polluted water discharges are common features. Lady Catherine industrial estate is a mixed industrial residential area in Ratmalana. Drainage of industrial effluents and storm water is via open drains. Solid waste is collected from factories by private contractors and wastes are dumped along the Bolgoda lake since there is no control. Many factories produce bad odours such as solvent fumes. There are about 30 factories in this area. Glass, garments, processed textiles, paints, chemical, polish, pharmaceuticals galvanized iron sheets, sewing machines and concrete pipes are some of the industries. Accurate data on water consumption is not available. An estimated 180 m^3/d of waste water is discharged into roadside drains, but the volume is underestimated and should be higher.

Waste water is highly polluted with inorganic chemicals, organic solvents dyes

and paint and the colour of the waste waters in the drains vary. Strong smells of paints and chemicals are experienced.

Baxons a textile plant where weaving, dyeing and textile printing is done, had a high COD of 515.0 mg/L, TS of 3,790.0 mg/L and pH of 11.5. 1,200 gal/d of water is used for production. A chemical industry producing starch based adhesives and polythene printing had a COD of 2,140.0 mg/L and PH of 1.0; a pigment plant had COD of 2,866.0 mg/L; pH 3.5 and total solids of 3,820.0 mg/L (Jayatissa, 1981). Bolgoda lake drain had a COD of 1,570.0 mg/L and SS of 50.0 mg/L (Ministry of Housing Physical Planning and Environment, 1987).

Many industries do not have treatment facilities. Very few industries have preliminary treatment such as Chemical Industries (Colombo) Limited. (Some new industries such as Hybro Industries have negotiated to have treatment facilities) and therefore industrial effluents enter the waterways without any form of treatment and it is apparent that a considerable amount of hazardous toxic chemicals are disposed to the suroundings without treatment; and therefore the waste waters are highly polluting.

Lunawa lake

Lunawa lake is heavily polluted by industries and domestic waste water discharges. About 750 m^3/d of industrial waste water is discharged into Lunawa lake mainly from the Central Transport Board Depot, Central Railway Workshop and the textile industries. Overgrowth of aquatic plants in the lake may be due to a higher nitrogen content. The waste water from a housing estate of 3,000 inhabitants is discharged directly into the lake at Angulana. Private toilets also discharge directly into the lake. The lakes outfall into the sea is blocked by a sand bar which makes the heavily polluted water concentrated and confined to the lake for most of the year, thus resulting in stagnant polluted waters.

The landlocked nature of the lagoon helps to act as a pollutant trap. This is evident from following observations reported by the CEA in 1983.

(1) Signs of eutrophication indicated by the presence of organic sediments.

(2) Lagoon had become heavily deprived of DO. Eruption of air bubbles and smell of toxic gases were good indications of these.

(3) Colourful patches of water in parts of the lagoon due to textile dyes.

(4) Lack of mangrove vegetation surrounding the lagoon.

(5) Few species of fish observed, possibly only those that can tolerate low dissolved oxygen levels (traditionally a fishing area).

(6) According to the inhabitants of the area, the adjacent land used for paddy cultivation is now abandoned.

(7) Less fishing activities, due to low stocking density of fish.

(8) The stagnating water has become a mosquito breeding ground. Filaria carried and causing species is abundant. Filaria, malaria and dengue fever are endemic in this area. The extent of pollution in the Lunawa lagoon is much higher than at the Bolgoda lake.

In the past it has been a recreational area for swimming and boating. Where there is no water supply the water from the lake is used for domestic purposes too.

Ground water pollution

The effects of industrial wastes on ground water contamination has been studied around the cities of Sri Lanka. In Sri-Lanka majority of the people obtain water for drinking and other domestic purposes from wells, even around the industrial centers. A study on Cu based industries indicated, that the average Cu^{+2} ion content in Colombo was greater than in the other cities especially in the industrial sites, as

large volumes of waste water are added to ground water from the factories. Therefore fore a higher level of Cu^{+2} ion in both, well and stream water around Colombo. This could be due to contamination by industrial waste water discharges without any treatment. According to geological and soil surveys there are no Cu bearing rocks around Colombo. Therefore industrial effluents could be the only reason (Dissanayake, C.B. - 1980).

Ground water contamination is a definite possibility in both Bolgoda and Lunawa areas. Ground water samples from two shallow wells near Bolgoda and Lunawa indicated pollution. *Coliform* level was high. At Bolgoda it was 93 per 100 mL/MPN. Heavy metals and toxic organic pollution is also a possibility though it is not monitored.

There are no official disposal site for industrial and domestic solid wastes. Dumping is uncontrolled in the drains or in lowlands. A great risk to ground water is caused by soakaway pits. Pollutants such as nitrogen, non-biodegradable organics and metals are not sufficiently absorbed by the soil and continue to pollute the ground water. In the dry season there is concentration in the drains and the lake, and in the wet season spill overs and the pollutants get collected in small ponds, and gardens and lowlying areas. There have been cases where productive paddy fields have been made redundant, due to intrusion of these polluted waters.

4.8.2 Pollution of the Beira lake

It is an artificial fresh water lake, constructed by enclosing a swampy low area by two systems of locks. The McCallum locks give access to the Harbour canal and thereby to the Colombo harbour, and the San Sebastian lock connects it to the San Sebastian canal. The lake water level is kept fixed at +1.8 MSL by pumping water from the pumping station at Sebastian locks and by a spillway on the south west lake at which the excess water, overflows into the sea, south of the former parliament.

The Beira consists of a system of lakes i.e the East, West, Southwest and the Galle face lakes which are connected to one another by channels. Beira is linked to the Colombo harbour which is one of the busiest in sea traffic in the east, and in the British era it was known as the 'Clapham junction of the East' (Brohier-1965). The Colombo port is the biggest in Sri Lanka and handles 96% of the nations port cargo.

It is centrally situated in the heart of the city its importance as a fresh water body is undisputed. This lake is one of the richest fish producing water bodies in Asia and produces over 1,000 kg/ha. It's uses include commercial fisheries, transport of goods to and from the Colombo harbour, recreational, aesthetic, industrial (for cooling water extraction and discharge of effluencts) and domestic . It also provides a habitat for a large number of acquatic organisms forming a rich and complex ecosystem.

The surrounding area of the lake includes various land uses such as for administration, commercial, residential, industrial and open spaces. From the early 19th century it has been used by local dhobies for washing, bathing and possibly for drinking (Brohier, 1984).

This aquatic body over the years has become polluted. Industries such as boat yards, workshops, garages, printing presses, beverage and textile factories, repair shops for steel and wooden barges, warehouses for storing food and tea are situated along the lake banks. These discharge untreated effluents into the lake.

The boatyards discharge oil and grease. The Vauxhall area in the southwest lake is sometimes covered by a thin layer of oil. Ship repairing within the harbour and jetties pollutes the Beira as oil grease and other effluents are discharged. Polluted water with oil is clearly visible near the McCallum locks.

The level of pollution in the lake is indicated by a study done by Wigneswaran in 1983. He observes that the Oligochaetes (an important component of the benthic biomass and considered to be a biological indicator of organic pollution) have increased in 1983 since Mendis' study of 1963. Oligachaetes have the ability to with-

stand polluting conditions resulting in rapid increase in their numbers. Oligachaetes also indicate changes that occur in the overlying water due to organic pollution.

Nutrient analyis of sediments showed accumulation of nutrients in the sediments. Nitrogen content was high and varied in the lake sampling stations from 17.28 to 51.36%. Phosphorus content ranged between 4.8 and 6.8% (Wigneswaran, 1983). The DO content in the East lake above San Sebastian Hill was high, but below San Sebastian Hill showed lower concentration possibly due to de-oxygenation from organic wastes entering from commercial and engineering firms; and from the tenements.

Low DO levels in the South west lake ranged between 0.0-4.93 mg/L. Highest COD levels were observed at the most polluted stations near the sewage flow drains and industrial discharges. The average DO level for all the monitoring stations except one was below the CEA standard for fish and other aquatic organisms. Biological diversity of life too had decreased (Motha, 1985).

The local press highlighted the deterioration of water quality in the Colombo lake due to blue green algae arising from high fertility due to high nitrogen and phosphorus content. Hydrogen sulphide odour was reported which was the by product of anaerobic activity. Costa (1978) records the Colombo lake as an eutrophic body. The dense algae bloom was mainly due to the blue green algae *Microcystis* and *Chlorococcales*. *Eichornia crassispes* and *Ludwigiar adscendans* were found floating in the lake.

Ammonia values were highest at discharge points of large effluents entering the lake. 11.47mg/l of ammonia was recorded by (Motha, 1985). High ammonia levels indicated that enrichment of the lake was taking place. Fish kills were reported in the Beira (Daily Observer, 1984.) High phosphate levels indicated the flow of large amount of organic matter entering from effluents. A recent pollution study indicates that the productivity of Beira lake (west) was affected by varying nutrient levels and the prevailing weather conditions particularly rain fall. *Microcystis aeruginosa Kutzing* was found to be the causative agent of the water bloom. A BOD of 36.3 to 56.1 mg/L, and a turbidity of 12.0-70.0 NTU indicated that Beira is a polluted water body (Lankaputhra, 1986).

Industrial effluent and foul sewage discharges find their way into the Beira. The wastes enter the lake in the raw form without any treatment. Effluents from Volanka, Keells Food products and Ceylon Cold Stores are discharged into the Beira. A COD of 2,780.0 mg/L was reported by Anderson in 1979 from the Cold stores. High pH and alkalinity in addition to high COD were also reported.

Shanties

Another polluting source of the lake is the shanty population which have sprung up in the lake banks.

A study in the east Beira lake shows that of the 10% residences, 59% were tenements slums, 27% squatter settlements and only 14% were mid income residences in the immediate vicinity of the lake banks (Sumathipala, 1984). Further, many shanty colonies in the west of the east Beira lake are without basic sanitary facilities such as toilets, garbage disposal sites, bathing and drinking water. Only 60% had common toilets while the others used the lake for sewage disposal, garbage dumping and toilet facilities directly (the wastes included faecal matter too). There were 192 shanty families on the lake banks. About 98 shanty units were concentrated in a half an acre of land. Large channels of sewage enter from the tenements.

Inadequate sewerage system

There is no efficient sewage system with proper treatment facilities. Some emergency outflow points of the Colombo municipality also discharge sewage into the lake intermittently. There are many surface drains carrying foul polluted water into the lake. This includes faecal matter from the squatter population along the lake. Other than this the lake is a greenish water body due to presence of algae. The lake banks are silted, the sources of which are the open drains. Beira is stagnant and water hyacinths thrive especially at points where foul sewage drains empty and at industrial

discharges. It has become a mosquito breeding ground. Water borne diseases are becoming common, thus posing a health hazard to the residents.

A pollution study of Beira by Lankaputhra (1986) gave MPN counts of *Escherichia coliform* between 12.1-44.5/100 mL which indicated that the water in the lake was subject to faecal contamination due to sewage outfalls and domestic wastes entering the lake. The shanties aggravated the situation, thus making the lake grossly polluted. Inspite of this situation, the lake is still being used for bathing, washing animals and vehicles.

4.8.3 The pollution of river Kelani

The river Kelani undoubtedly is the most polluted river in Sri Lanka. It rises in the central highlands. It flows through the south west of Sri-Lanka across the wet zone. The river Kelani is 150 km long and flows to the Indian ocean at Kelaniya in the vicinity of Colombo i.e. about 4 km north of Colombo.

The average annual rainfall in the 2304.2 km^2 water shed of the river varies from 187-500 cm/y and results in an annual average discharge of 6,850 cu ft/sec in the river (Dissanayake, C.B. *et al* 1985). In the case of a major flood the river discharges between 43-56,000 cu ft/sec, and the Kelani overflows its left bank. The flood water leaves the river near Victoria bridge through the San Sebastian canal and into the southern canal systems, the Main drain or the Beira lake.

Under normal conditions the San Sebastian canal flows into the river Kelani and discharges its polluted waters accumulated from domestic and industrial sources. The point of entry of San Sebastian into river Kelani is marked by a clear demarcation between blackish, mucky polluted waters of the San Sebastian canal and relatively cleaner waters of the river Kelani. It is the only canal that empties water after traversing the heart of Colombo.

The river Kelani has been a focal point for environmentalists since the river water is used to supplement the drinking water supply of Colombo for a population of 1.8 million. Economically and industrially it is the most important river in Sri Lanka since it flows through Colombo. Several major industries are situated on its banks, inclusive of the Export Processing zone such as Biyagama and large volumes of river water is used for production purposes and large volumes are discharged as effluents into the river. The water intake point for Colombo (and Colombo south drinking water supply) is at Ambatale, 12.5 km from the river mouth. The river water and wells along the river are used by residents along the river as domestic water supplies for drinking, washing and bathing purposes.

Industrial growth has taken place rapidly in the recent years in the vicinity of the river. Its proximity to the Colombo harbour, Colombo airport; the capital city, and the availability of abundant water for industrial processes has attracted large capital intensive high technology industries in the environment of river Kelani such as steel, tyre, petrol, fertilizers, plywood, tanneries, textiles, ceramics, refineries, breweries and distilleries. These industries discharge their effluents into the Kelani without any treatment.

These industries contribute largely to the waste load of the river. Most of the heavy metals originate from these sources. With further industrial expansion around Kelani and Biyagama heavy metal discharges are likely to increase in the future. The heavy metal concentration of river sediments of river Kelani is high when compared with the river sediments from other tropical rivers (Dissanayake, C.B. *et al* 1985).

The study by Dissanayake, C.B. *et al* (1985), indicates that in the river Kelani elements such as Ti, V, Cr, Mn, Fe, Co, Ni, Cu and Zn originate from industrial waste waters, and these elements constitute the most important class of elements in view of their capacity to act as pollutants of the aquatic environment. Heavy metal concentration were high at the estuary, Sedawatte, Ambatale and Pugoda. Zn was high at Sedawatte and Ti was the highest at at the estuary. Pb, Cd, Cu and Zn in the river and well water were high. The extensive emanation of automobile exhaust

fumes and the wide use of galvanized material for domestic purposes contribute to Pb and Zn in the water. This study illustrates the high level of urban and and industrial pollution.

The organic pollution load from the industries that discharges into the river Kelani is also high. This can be seen in the table 4.3.

Table 4.3 — Organic effluent characteristics for selected industries along the river Kelani

Industry	Process	COD	Total N	TSS	pH
Leather	Vegetable tanning	5900.0	54.0	13,200	5.5
	Chrome tanning:				
	Soaking	5200.0	377.0	28,000	8.1
	Liming	380.0	414.0	10,200	11.3
	Pickling	-	119.0	12,000	2.7
	Neutralising	1680.0	315.0	18,000	4.4
Brewery	Beer production	1132.0	16.0	540	5.5
Sewage works	-	400.0	25.0	-	6.5

Source: CEA, 1985

The tannery of the leather corporation is situated 300m from the Kelani bank. It uses both vegetable and chrome tanning. The organic load in terms of the COD is very high. So are the solids. The brewery also has a high organic load, both in terms of the COD and the solids. The total N is also very high in the tannery. The pH ranged from acidic to alkaline.

The Madampitiya municipal sewage works enter the river Kelaniya untreated at Thotalanga. The system is malfunctioning now. It is situated 4km from the river mouth and 0.5km from the bank. The volume of waste water discharged is 20 million gal/d. The Madampitiya sewage works also has a high COD and a high nitrogen content. The coliform per mL was 18,500. The samples were taken the channel to the river for disposal. These indicate the high polluting strength of the sewage entering river Kelani.

A study done by Dissanayake, D.A. (1985) on water quality along the river Kelani (up to the Colombo water intake point) indicated strong industrial effluents that enter the river.

Relating the weather conditions to the to the pollutants it was found that the high SS correlated with heavy rainfall in October with 95.3 mg/L at 270.5 mm of rain. Conductivity levels were comparatively higher prior to rains probably due to possible accumulation of substances. Conductivity was also higher in stations close to the sea and ranged from 2,350.0-11,000.0 μmhos/cm. The BOD remained high and the DO dropped during the drier months of January to March and increased with rains from September to October.

The study also indicated that the ammonia levels were high at two sites and exceeded the CEA standard of 0.06 mg/L. This may be due to high organic loading. At site 2, high ammonia (NH_4) of 0.01-2.26.0 mg/L was attributed to the effluents from the Petroleum and Fertilizer Corporation. In 1982 fish mortality was recorded from the river Kelani, and was attributed to a possible leakage or excessive discharge of

urea wastes from the State Fertilizer Corporation. Two sites recorded high PO_4. The State Fertilizer Corporation effluents using sodium hexametaphosphate for treating water had 3.1 mg/L of PO_4. At a site which is used commonly for bathing the high phosphate content of 4.4 mg/L was indicated, possibly due to the soap and detergents used. The DO ranged between 5.65 and 8.2 mg/L. The DO increased with rains from September-October. Of all the sites the estuary recorded the lowest DO due to organic loading from trade, domestic and wastes that enter through the channels. There was a corresponding high BOD. The COD was high at site 4 due to trade wastes. Chloride values remained low during rain and high during the dry periods, and ranged between 1,000.0-36,400.0. It also remained high at the stations close to the sea where sea water mixing took place.

The river also gets pollutants from drains emptying into it. The soaking of coconut husks for softening of fibre, and the decaying of vegetable matter produces hydrogen sulphide. The odour is very pronounced in the vicinity of the soak pits.

4.8.4 Water pollution in the Export Processing Zones

Two major export processing zones are under the jurisdiction of the Greater Colombo Economic Commission (GCEC) which came into being in 1978. They are Katunayake and the Biyagama Export Processing Zones. Production in these zones are export oriented, with foreign collaboration. Since the inception of the GCEC it has been aware of the environmental problems in a purely industrial zone and early action has been taken to minimize and control environmental pollution. Therefore the following methodology is being adopted.

All development projects to be located within the GCEC area are appraised with regard to the environmental impact and necessary advice and instructions are given to the developers in order to abate any pollution hazard. Approval for setting up industries are given only after environmental considerations, and factories which do not conform are not given permission to operate within the zones. Effluent treatment is mandatory, either inplant or by the use of the common treatment facilities in the zones concerned, before discharging into the waterways.

The second methodology is the monitoring of factory effluents periodically to check whether the developers maintain the quality of effluents within the standards stipulated by the GCEC and the monitoring of the inland waterways in and around the export processing zones.

Successful management of the environmental programme within this region was made feasible with the enactment of the National Environmental Act in 1980 and the formation of the Central Environmental Authority which has the legislative power to control environmental pollution in the entire country. The National Environmental Act (Number 47) of 1980 has been incorporated in the GCEC Act by an amendment in July 1983 giving more powers to GCEC in the field of environmental pollution control in its area of authority (Bandaralilleke, 1984).

There are also GCEC enterprises outside the export processing zones which were approved by the GCEC. There were 14 such industries by 1987 and 2 to 3 were under construction (personal communication, K.G.D. Bandaratilleke, 1987).

There are in all about 410 factories within the GCEC which were approved by the GCEC. There are about 520 factories which were in operation before the GCEC came into being on (personal communication, Bandaratilleke, 1987). With regard to already existing factories, there were difficulties in implementing pollution control as these were the industries which existed before the enactment of the Act. Therefore the GCEC does not have powers over them. Two such factories have been taken to court after recommendations to abate pollution by the GCEC were unheeded. These factories were ordered to close i.e. a tyre retreading factory and a tannery at Gonawela.

The BEPZ which is in the southern region of the GCEC, borders the river Kelani. Few major industrial projects such as the oil refinery at Sapugaskanda, fertilizer

manufacturing plant and a gas storage plant are already located in the area. New chemical based industries with larger water usage are expected to come. Waste waters from these factories are expected to contain constituents with high BOD, phenols, oil and grease, alkalis, acids, catalysts, urea, ammonia and heavy metals. Some of the contituents in waste waters are toxic to humans and fish life and create aesthetic problems like colour, taste, and odour problems to the domestic water supply. Kelani ganga into which the waste waters are eventually to be dishcarged is the major source of drinking water supply for the city of Colombo and the suburbs on the right and left banks of the river. Villages use the river directly for domestic purposes. The water extraction point at the river is at Ambatale. The reach of Kelani ganga from Biyagama region to the existing river intake to Colombo water supply and even beyond can be classified as mainly for domestic water consumption (in addition to industrial and agricultureal requirements) and therefore, the waste water treatment system should conform to the standards of effluent discharged into a river system which is used for domestic water consumption. Hence, the industrial uses particularly in an industrial zone based on export oriented processing with both small and large scale industries with diverse production; and the water uses in the river particularly for domestic drinking supply to a metropolitan city and the suburbs within the reach of a few miles are contradictory and conflicting in nature. The installation of a common waste water treatment plant should harmonize the situation. The discharge of treated waste waters into the common conveyance system must conform to standards and each large factory is expected to treat its own waste waters conforming to the desired standards before discharging into the common conveyance system. The outfall point of pipeline discharging the waste waters to the river is 100-150ft towards the centre of the river and the waste waters will be discharged through a series of diffusers to ensure proper mixing and dilution (Raman, 1978). Therefore the water quality of river Kelani near the BEPZ, the quality of effluents and waste water treatment plant is yet to be seen on completion. The water intake into the BEPZ is also from the river.

With the establishment of well demarcated industrial zones, the approval of new industries with treatment facilities for waste waters being mandatory at the Environmental Impact Analysis stage and compulsory conformity to effluent and river water quality standards, positive action has been taken with regard to environmental water pollution control by the government, which in the long run will improve the quality of surface waters. This is a clear deviation from the unplanned mushrooming of industries within Colombo prior to the setting up of the industrial zones.

4.9 Pollution of the San Sebastian canal

4.9.1 Historical importance of canals: pre and post colonial periods

The recorded history of Sri Lanka commences with the landing of Vijaya during the sixth century B.C. Since then and upto the end of the 18th century there had been canal development by the Sinhalese rulers primarily for irrigation purposes in various parts of the island. The abandoned tanks and channels in the dry zone of Sri Lanka stands evidence to this even today.

The construction of a transbasin diversion canal, the famous Jaya-ganga brought the impounded waters of the Kala Oya into the Malwatte Oya basin via Nachchaduwa and Nuwara Wewa during the Anuradhapura period in the 5th century A.D. (Peoples Bank, 1977). King Parakrama Bahu the Great (1153-1186 A.D.) of the Polonnaruwa era was responsible for the construction of no less than 165 diversion schemes, 3,910 canals 163 major tanks and 2,376 minor tanks (Arambewela, 1980). These historical works indicate that canal construction was not a new technology introduced into Sri Lanka by the foriegn invaders.

The arrival of Europeans which started with the Portugese in the sixteenth century resulted in the gradual neglect of the ancient irrigation canals, and the development of a system of canals in the western seaboard based partly on the existing indigenous canals for the transport of goods. Although the Portugese historical records are scarce, the Dutch records indicate that the Portugese started the canal transport

and the Dutch developed the system (Brohier, 1951 as quoted by Arambewela, 1980).

The Dutch engineers used the presence of water and the low topography of the western coastal areas of Sri Lanka for canal construction. Their engineering projects contributed to the prosperity of the districts by the canal cuts to link up the streams, lakes and lagoons. At one time this canal system established a continuous line of waterway between the port and the remoter parts of their territory (Brohier, 1954). It was due to Governor Von Imhoff (1736-1740) that a scheme of inland river communications south of the Kelani ganga was mooted, and the link between Kelani ganga and the Kalu ganga by a continuous waterway was achieved, in addition to the northern waterways, such as Colombo-Puttalam canal.

Canals were used for the transport of export items from their points of origin via navigable waterways where they were loaded into ships and the imported items from the Colombo harbour to the western sector of the island. These canals reduced the circuitous routes in some places. It also provided cheap and easy transport of goods. Even after the advent of the railway the native producers continued to rely on this mode of transport of goods. About 24,000 tons of goods came to Kalutara from Ratnapura along the Kalu ganga and two thirds of these were dispatched from Kalutara to Colombo along the canals (Silva, 1973). Graphite excavated at Dumbara mines near Ingiriya was transported by barges down Kalu Ganga to Colombo in the similar way. (Peoples Bank, 1981). In addition to the transport of goods, passenger transport too developed with the canal cuts. It also aided the agricultural development by draining the neighbouring areas and renderd them suitable for cultivation.

Therefore during the Dutch occupation the canals linked the flourishing trade centres of Colombo to Puttalam in the north and Kalutara in the south. There were other canal schemes in the south such as Mahamodera ela in Galle and the Nupe ela in Matara; and in the eastern areas of Sri Lanka. The grand result of the operation of the canal system was a direct line of water transport and communication between the main agricultural supply centres and the chief distribution depots in the capital city of Colombo (Brohier, 1947).

With the coming of the British and the departure of the Dutch the waterways came to be used more for drainage purposes than for transport, although they did construct a few canals. The canal system fell increasingly into disuse owing to competition by railway and road transport. Unlike in the highly canalized countries like Holland, Belgium and France, no effective attempt was made by the government to protect water transport against the competition of other modern methods of transport. In fact by building the railway so close to the Negombo-Puttalam canal the government virtually killed the canal transport. The Colombo-Puttalam canal has a total distance of 131 km, which started from the Colombo harbour, going through the Beira lake, San Sebastian canal, Kelani ganga to Puttalam (Kurukulasuriya, 1982). This was the busiest and commercially the most important canal link in Sri Lanka.

The overall result was that over a period of nearly one and a half centuries of British rule the waterways finally fell into disuse and became badly silted and neglected. By 1905 there were 260 km (DBU, 1955) of canals maintained by the government and these were mostly in use especially in the western and north western provinces despite rapid extension of railways and roads.

The canals were maintained at a reasonable level of efficiency up to 1950 but with the advent of lorries and cheap fuel transport the inland water transport started to decline in importance; and by 1950 the transport function of the canals completely stopped. Since then the wooden barges (paru) disappeared. With the death of canal transport, canal maintenance was neglected, which resulted in siltation and pollution of the canals. This can be clearly seen in the case of the San Sebastian canal.

It has to be mentioned that during the post colonial period upto the end of 1969 there were hardly any development work except maintenance of the network. The objective of this was flood protection and reclamation for development. The present redevelopment work carried in stages on the Colombo-Puttalam canal is due to the Inter-Ministerial sub-commmittee recommendations of 1974. The development of the

San Sebastian canal belongs to Phase B, which covers river Kelani to the Beira lake. Canal development is still in the stage of the construction of infrastructure.

4.9.2 San Sebastian canal: past glory and subsequent neglect

The San Sebastian canal is one of the most important canals in Colombo and in Sri Lanka. It is a waterway connecting the Beira lake with the Kelani river, the latter is economically the most important river in the island flowing through the metropolis. It originates from the Beira lake on the west, and enters the river Kelani near the Victoria bridge, three miles south of the river mouth. It is connected to the Colombo harbour by the harbour canal, through the McCallum locks on the Beira lake. Constructed by the Dutch, of late years it has been neglected, although it served as the most important canal till recent years. If brought to modern requirements it could be used as a multipurpose canal. Its improvement is mandatory for the efficient functioning of the Beira lake.

As a canal it is a stagnant waterway. It is tidal at the eastern end, with a diurual change in the flow direction. As a flow regulated canal, it has a striking feature of flowing in many directions as the need arise. As seen later this has a bearing on pollution. Though the normal dry weather flow is towards the east to river Kelani, during flood conditions the flow is regulated by the locks on either end of the canal and diverted towards the south, by the south bound canals such as Orugodawatte and Dematagoda ela through the south lock; and north, through the Main drain and Mutwal tunnel; and towards the west, when excess water in the catchment has to be drained or if the Beira water level falls below the datum by pumping water to the lake by the San Sebastian pumps.

From a commercial point of view San Sebastian canal has been the most important Dutch canal in the Island. Linking the Colombo harbour, Beira lake and the river Kelani, an enormous cargo of copra, arecanut, rubber, fibre pepper, cinnamon, bricks and arrack was brought along this canal in padda boats from the Kelani valley and districts beyond. Large quantities of copra has been brought to industries like BCC which is along the canal (personal communication - Fernando N. , 1986). This can be seen in plate 4.1(a). The importance as a commercial waterway can be seen from the large sum of money spent on the maintenance of this canal in the past inspite of its fairly small length, than on any other canal in Sri-Lanka (DBU, 1955). Thus it was a heavily used waterway for import-export trade. Till recently (despite competition with quicker rail and road transport) this canal was used for transport purposes (Brohier, 1978).

The commercial importance of the San Sebastian canal led many large industries (export oriented, or industries dependent on imports) to be situated along its banks such as the British Ceylon Corporation, Levers, Jafferjee Brothers and the Sedawatte Mills to mention a few. These industries other than its navigational benefits, also used the canal water for cooling purposes and discharge of the waste waters into the canal.

The canal is also of importance as affording a means of replenishing the water loss due to lockage and evaporation. Water loss from lockage is important as many barges ply between Beira lake and the harbour through the McCallum locks, and at every such instance considerable water is lost to the sea, from the lake. This loss is replaced by the San Sebastian waters. In the past the locks at the San Sebastian too were operated for the barges and boats to enter the lake.

A feeder canal to the lake, the San Sebastian canal is very important as the only practical source of water supply to the lake. Although the alternative of utilizing sea water from the harbour to replenish the lake was considered many times, after careful consideration it was found undesirable, as it would render the fresh water lake brackish and undesirable.

The San Sebastian canal in the past it has been regularly dredged and desilted. As early as 1950, SLR 243,200 was spent on dredging the San Sebastian canal alone (Department of National Archives, n.d.(a)) and this had helped to maintain the canal

Plate 4.1 — (a) San Sebastian canal: a navigable waterway in the glorious days. Source: Wright, A. (1907); (b) At the same site (near B.C.C factory) today, polluted and unsightly

in a fairly sanitary condition and as a navigable waterway (even though workers working on the canal has done so with reluctance due to pollution as early as 1948). Between January 1986 and March 1987, SLR 682,250 was spent on surface clearing and maintenance of the San Sebastian canal (Sri Lanka Low Lying Reclamation and Development Board - Colombo North, 1987). Though the funds allocated for maintainance have increased over the years, considering inflation the amount spent for clearing is paltry. This indicates the gradual neglect of the San Sebastian canal.

Plate 4.2 — San Sebastian canal: the dredged material piled up in the banks

The dredging of the canal in recent times has been irregular. In the past decade, there was no dredging in 1981. It continued in 1982 and 1983 on a monthly basis costing SLR 760,262 (Sri Lanka Low Lying Reclamation and Development Board, 1987). There was no dredging between 1984-1986. It recommenced in 1986 towards the tail end. This can be seen in plate 4.2. This long lapse in dredging is mainly due to civil disturbances and unrest in the country, and the diversion of funds for security purposes. Civil distrubances since 1983 has hindered the progress of development work due to both rediversification of funds for defence and the disturbances itself.

The canal today does not even serve it's secondary function of importance, that of protection against floods which proves a menace in the low plains of Colombo. As far as the maintenance is concerned, only basic work such as siltation, dredging, surface clearing is done on an irregular basis, for example dredging was done in the canal in mid 1986 after a lapse of three years. (Sri Lanka Low Lying and Reclamation Board, Colombo North - 1987, and personal observation)

Due to the neglect of the canal, today it has fallen into the pitiful situation of being grossly polluted. The discharge of industrial effluents without treatment; solid

waste dumping by the industries situated along the canal; shanty dwellers living along the canal in unauthorized canal reservations and who throw domestic garbage and human wastes; foul water discharges from cesspits and illegal drains into the canal; stagnation of water due to choking, resulting from heavy growth of *Eichornia crassipes, Salvinia* and other water weeds; low capacity flow in the canals during the dry months due to little or no inflow from the catchment; obstruction of flow at outlets due to sand bar formation; and encroachment into the canal banks by shanties and industries, hindering the canal maintenance have directly contributed to the pollution of this canal. A canal once clean, used for bathing and even drinking but now result in skin diseases (related by a worker with over 35 years of service at the locks) if in contact with the canal water (personal communication, North lock operator, Irrigation Department - Colombo North, 1987). It was a recreational waterway with plenty of fresh water fish such as catfish even in the 1950s, but has been pitifully neglected in the recent past (personal communication - Amarasekera, N.D.T. 1988).

The neglect of the proper maintenance of the canal system has caused recurring problems and cost to the government as well as to the residents near the canals. During floods the indundation of neighbouring low lying land and during dry weather the stagnation of water result in health problems. The squatters occupying the crown reservation of the canal banks dispose night soil and garbage while the industries situated along the canals discharge effluents without any control. These cause serious water pollution and health hazards.

4.9.3 Water pollution in the San Sebastian canal: present situation

Water quality in the San Sebastian canal

As mentioned earlier studies on water pollution in the San Sebastian canal is sparse. With the little material available it can be said that the canal is a grossly polluted canal in Colombo.

The San Sebastian canal, with hardly any flow during the dry weather runs through an area of mixed land use, in the heart of the Colombo city. It gets polluted by many sources such as domestically by the residents and shanty dwellers who occupy the canal banks; commercially by business undertakings; industrially by both small, medium, local and multinational industries situated along the canal that discharge untreated effluents; the Colombo Municipal Council sewage overflows and over 78 illegal foul drains; and by natural run off due to washing away of the garbage and the solid wastes dumped along the canal banks.

The pollution of San Sebastian was mentioned as far back as 1921 (Government of Ceylon, 1923). The level of pollution in this canal was highlighted in 1921 as the canal water was used to replenish the Beira lake water loss from evaporation and lockage. The adverse effects on the aquatic environment of the fresh water lake by supplementing the water loss with waters of the polluted San Sebastian canal was highlighted, and warnings were issued by the municipality to maintain the canal clean thereafter. As the barge traffic through the locks increased, the volume of water pumped from the San Sebastian canal was augmented with a resultant deterioration in the water quality of Beira lake. It was also highlighted that though other drains carry raw sewage into the lake, the chief source of pollution eventually was from the San Sebastian canal. Situated in the heart of Colombo, and traversing some of the most highly populated areas, this canal was expected to be polluted always. Basing on a pollution figure of 30 with respect to the amount of dissolved oxygen content present at different temperatures. Rae in 1922, classified the San Sebastian canal to be badly below the standard, when compared with river Kelani which was on the borderline and the lake to be satisfactory (Government of Ceylon, 1923).

A short term water pollution study done by Padmaperuma (n.d.) on eleven WHO recommended basic pollution determinants such as temperature, pH, conductivity DO, TSS, nitrate, total phospate, fecal coliform bacteria, turbidity, COD and BOD indicated gross pollution of the San Sebastian canal. The temperature was higher in the canal near the major industries. The DO of the water was been low due to two

factors i.e. the high temperature of the effluent and the high oxygen demand of the effluent. The pH of the sampling points were found to be in the acidic range except where the alkaline effluents were discharged and in the sea water mixing points. Electrical conductivity was high in the sampling points close to the sea where sea water entry affects the conductivity, and also in the stations that had industrial effluent discharges. The industrial effluents of major industries such as BCC, Levers and Jafferjee Brothers that enter the canal was highlighted in the study.

A survey done along the length of the San Sebastian (Anderson, 1979) on ten sampling sites, gave a COD range of 34.0 to 941.0 mg/L and DO of 0.00 to 0.39 mg/L. Thus the canal appeared to be grossly polluted. This was demonstrated by very low levels of DO. It was aggravated by scum formation during dry weather and foul odour. The DO levels near the industrial discharges recorded 0.0 mg/L of dissolved oxygen. The COD and BOD of the effluents from the industries was high which was the major cause for zero dissolved oxygen in the canal. This study, one of the first pilot surveys, highlighted the poor water quality of the San Sebastian canal in recent times. The report on the pollution of waterways by the Ministry of Housing, Physical Planning and Environment, in 1986 confirms this.

4.9.4 Industrial waste water discharges into the San Sebastian canal

As far as San Sebastian canal is concerned industrial pollutants that enter the canal directly are from some of the biggest industrial concerns in Sri Lanka. The table 4.4 shows the strong effluent characteristics of two discharging industries.

Table 4.4 — Effluent characteristics of industries that discharge untreated waste waters into the San Sebastian canal

Effluent	BOD mg/L	COD mg/L	pH	SS mg/L	Volume discharged L/d	DO mg/L
Soap: BCC[a]	-	100,000	13.4	2,180	11,247	
Oil refinery: BCC[a]	-	2,280	10.5	587	1,082	
Edible fats; toiletries (Levers)	90-162	1,140[b]	-	37-55	-	
Canal water[b]	600	34-941	6.8[c]	160[c]	-	0.0-0.39

Source: a. CEA (1985); b. Anderson (1979); c. Ministry of Housing, Physical Planning and Environment (1986)

The British Ceylon Corporation, at one time the biggest oil refinery in Asia and Lever Brothers an arm of the multinational company, discharge large volumes effluent without treatment directly into the canal. This can be seen in plate 4.3. Jafferjee Brothers, Volanka, Sedawatte mills, fibre and coir mills are some other major industries that discharge untreated effluents into the canal. The automobile spare part garage establishments, along the Panchikawatte area is another major polluter. The BCC which produces cooking oil, toilet and laundry soap, disinfectants and metal drums discharge effluents directly into the canal. Levers have similar waste waters. Soap wastes and white frothy discharge is clearly visible in the canal. These clog the canal during during the dry season, when canal flow is virtually stagnant. The resultant very poor water quality can be seen in the table above. The zero DO levels coincided with high COD values and were found to be near the factory locations indicating gross pollution of the canal. A film of oil was observed in the canal. In addition BCC and Levers have encroached right into the canal.

Plate 4.3 — Untreated discharges to the San Sebastian canal from Lever Brothers

Source: Ministry of Physical Planning, Housing and Construction (1986)

The vegtable plots mainly **keera plots** (green leafy vegetables) in the lowlying areas in the extreme east of the San Sebastian canal have been found to contain toxic elements. The fertilizers, weedicides and insecticides used in keera cultivation in addition to the toxic industrial discharges from the industries around the area contribute to this. This is a thriving cultivation done by the poorest people of the area and it has a ready urban market. It was observed during the field monitoring that the leaves of the coconut trees on either side of the San Sebastian canal between 200-400m upstream from Sedawatte plank bridge had turned completely brown and showed signs of dying. This may be due to the chemicals in the dredged materials or due to the polluted water itself (personal communication - Katugampola, N. 1987)

4.9.5 Pollution from the motor spare garages

Panchikawatte is a highly specialized area in motor spare business. At the Sanjarajah mawatha bridge the motor spare business spans along the canal and the canal's crown reservation. This makes the canal banks inaccessible, due to its encroachment. The existing total floor area under the motor spare parts business in Panchikawatte is 41850.0 m^2 (Dayaratne, 1981) A fair portion of this business is concentrated near the bridge itself. 60% of the total vehicles in the island is concentrated in Colombo and therefore, it can be expected that this business will expand in the future. Scrap metal, car parts, tin, scrap iron and battery cases are thrown into the canal. During the low tide the scrap dumped in the canal is clearly visible as seen in plate 4.4. Scrap metal is also piled on the canal banks. As far back as 1946 licenced padda boat

operators who bring merchandise, copper, bricks and metals have complained about the inability to row their boats through this point due to surfacing scrap metals. Warnings have been issued to private parties by the ward headman and warning sign boards have been erected as far back as 1948. (Department of National Archives, n.d.(b)). Even today the practice of dumping scrap in the canal continues and have increased. This point in the canal is one of the most polluted and unsightly. Floating oil and grease from this occupation is clearly visible in the canal. Dredging has been difficult due to encroachment into the canal by this business, and due to the scrap dumped in the canal.

4.9.6 Contributions from the tributary canals

The tributary canals further pollutes the San Sebastian canal. These canals flow through densely populated urban areas, and hence they accumulate a large pollution load from both domestic and industrial sources, which is discharged into the San Sebastian canal.

The Kelanitissa power station discharges oil into the Kittampahuwa Ela. This is mainly due to oil spillages at many places in the power station where it enters the open drains and finally flows into the ela. Storm water is also discharged by the surface drainage system into the Kittampahuwa ela.

The Petroleum storage at Kolonnawa which produces lubricating oil, agrochemicals, candle, pesticidal chemicals discharges effluents into the Dematagoda ela. The effluents constitutes organochlorines and organophosphates which is harmful to aquatic life due to their toxicity. They also have carcinogenic and mutagenic potential. Though the waste waters from the dangerous zone in the plant is completely surrounded by a bund to prevent it from leaking, it is finally discharged into a nearby marshy land through several interceptors. This could pollute the ground water and during wet weather enter the canal directly. The waste waters from the non dangerous zone goes through several interceptors and finally into the Dematagoda ela, which falls into San Sebastian canal. Oil and grease; and suspended solids, the BOD and the COD were high and failed to meet the CEA standards.

The Synthetic textiles limited discharges waste water after different dye baths, which make the effluent coloured. It is discharged into a drain which falls into the Dematagoda ela. 175.0m^3/d of process water is discharged into the drains which enter the canal.

Agro chemicals, detergents, paints and mosquito coils are produced by the Lankem factory. Pesticides are persistent. Aldrin is readily converted into dieldrin, which is extremely persistent in the environment. This is acutely toxic to fish and and mammals. Aldrin which is used as a raw material makes the effluents highly toxic, (although the method of disposal is adding 5% NaOH, absorbing into saw dust and burning in the backyard). There could be possible leakages into the canal. Monitored results give a high COD of 198.0-380.0 mg/L, total N of 3.92 mg/L, total P of 7.5 mg/L, SS of 50.0-74.0 mg/L and total solids of 390.0-864.0 mg/L (CEA, 1985). Lankem discharges into the Orugodawatte canal which falls into San Sebastian canal. A volume of 70m^3/d of domestic water and 10m^3/d of processing water is discharged from this this factory. Visual observation indicated black tar like formation and scum is visible at the effluent discharge point in the canal during dry weather.

4.9.7 Pollution of San Sebastian by shanties

Other than the industries, domestic waste water from the shanties pollute the canal. The domestic sewage had a COD of 336.0 mg/L even after rain (Anderson, 1979). Concentration of shanties along the canal at Stace road, Panchikawatte, Maligawatte and Nagalagam street is high. At Lockgate and Stace road, the shanties have been demolished and rehoused in new units, but the mushrooming of new shanty units along the canal inspite of government warning and shanty rehousing programme is taking place. New shanty units are put up along the canal on the crown reservations inspite of government warnings and rehousing programmes even now. This can be

Plate 4.4 — (a) Scrap metal dumps of motor spares (b) Government warning against dumping

Plate 4.5 — (a) Construction of new shanty units and (b) Encroachment into the San Sebastian canal

seen in plate 4.5 (a). Garbage and night soil are emptied into the canal.

The problems posed by shanties are multisided. They pollute the canal directly by throwing garbage and have encroached right into the canal. Due to encroachments desilting the full bed width and canal maintenence have proved to be difficult. There is no room even to pile up the dredged earth along the canal in certain places such as at Panchikawatte.

Shanty areas have become insanitary sites. This is augumented by the canal flow characteristics. A stagnant waterway for major part of the year, these sites have become breeding grounds for mosquitos. These areas have become filarial epidemic areas. In 1977 there have been petitions from the residents along the canal to clean it, as these areas have been infested with mosquitos, rats and even reptiles. Even today the municipal wards along the San Sebastian canal have the highest positive microfilaria rate compared to the other wards in Colombo. Wards along the San Sebastian canal have a high shanty population. It is estimated that there are over a 1,000 shanties along the canal (probably more). At Lockgate, opposite the BCC mills all the shanties have been demolished and new units have been built. At Stace road new housing units are being built and rehoused. There were 200-250 shanties remaining to be built at Stace road and 150 units at Navagampura (personal communication - Dayananda, H.M. 1988).

4.9.8 Aquatic plants in the canal

Plate 4.6 — Aquatic plants in the San Sebastian canal

Floating aquatic plants thrive in many parts of the canal. This can be seen in plate 4.6. *Salvinia auriculata* and *Eichornia crassipes* had been common in the past. Pumps had been chocked at the intake point of San Sebatian pumping station and the working of the of the pump had been difficult. Dead weeds and vegetation such as floating banana trees had been common in the canal (Department of National Archives n.d.(a)). Large sums of money has been spent on surface clearing of the canal. In 1974 SLR 5000 was spent for surface clearing of this canal. Salvinia and

Eichornia growth has been mentioned both in Padmaperum'a (n.d) and Anderson's (1979) studies. Today *Eichornia crassipes* is more common in the canal than salvinia, which is manually cleared by boatmen (perssonal communication - Fernando, M.S. 1987). *Eichornia* and *Salvinia* also enter the San Sebastian canal through the tributary canals. A bamboo obstruction has been laid across the Orugodawatte canal to prevent the aquatic plants from entering the San Sebastian canal. At At the Panchikawatte shanty area, San Sebastian Hill, Stace road bridge and Sedawatte plank bridge aquatic plants were found thriving. This, may possibly may due to nutrient input into the canal from the shanties. During the rainy season *Eichornia* and *Salvina* were found to float freely in the canal.

Fauna

Fish is hardly found in the canal, but during rainy season fish enter the canal from the Kelani river or the tributary canals. Near the Sebastian Hill few fish species such as Thilapia were found.

4.9.9 Beira: water loss and pollution by the San Sebastian canal

The San Sebastian canal, although neglected and has gone out of use, is still used to replenish the water loss of Beira from evaporation and lockage. Water is pumped into the lake from the canal at the San Sebastian pump station almost daily (personal communiccation, San Sebastian lock-keeper, 1989). Therefore, it is imperative that the San Sebastian canal water should be clean for this purpose. The San Sebastian canal is far from this ideal situation. It is grossly polluted and aggravates the situation by polluting lake.

The water level of +1.8 M.S.L is maintained in the Beira lake for navigation, which means that the lake water level is higher than that of the canal. This is effected by the San Sebastian lock on the east of Beira lake and the McCallum locks in the north of the east lake. Due to disuse, the San Sebastian locks are hardly opened, except during the floods in the river Kelani, to send the excess water through the San Sebastian canal and Beira to the sea. The McCallum locks are operated daily for passage of boats, lighters and barges between the Beira and the harbour. Between 1986 January and 1987 February 1874 fifty and one hundred tonne barges alone plied through the MacCallum locks (Sri Lanka Ports Authority, 1986 and 1987). This results in the loss of water from the lake to the sea. It is estimated that in 1989 that there was a mean annual loss of 144,000 cubic feet of water from the Beira to the sea due to lockage alone, (personal communication - Ramanayake, M. 1990) the evaporative loss being unaccounted. When the water level drops below the datum in the lake, water is pumped from the San Sebastian canal. Therefore, an equal volume of polluted water from the San Sebastian canal is pumped into the Beira annually to replace this loss. It was informed that the San Sebastian pumps are operated for about 10 minutes daily as the canal is clogged (personal communication - San Sebastian lock-keeper, 1989). If sufficient water is not available in the canal, water is brought along the canal from river Kelani through the north lock for pumping; which means the pollutants in the entire length of the canal is pumped into Beira. Excess water above the datum level in the Beira is emptied into the sea through the spillway.

4.9.10 The tidal effect on the pollution of San Sebastian canal

Tidal effect is felt at the San Sebastian canal as it enters the Kelani river three miles from the river mouth between the Victoria bridge and the Kelani New Bridge. Tidal effects on the river is felt upto Ambatale. Thus the mouth of the canal comes under the tidal influence. Thus, there is a diurnal change in the direction of flow in the canal especially at the terminal sites. It has been observed there is a six hour flow downstream and six hour flow upstream in the canal (personal communication - Katugampola, R. 1987). The smaller lock gates of the North lock, are closed daily if the water level reaches the high tide level, to protect sea water entry in to canal, low lying areas and the shanties. The flood gates are operated to prevent back flow of river Kelani if the water level rises above 1.5 m. This gate prevents floods upto 3.6 m as the bund level is 6.3 m. The tidal effect on the canal has a bearing on the

concentration of pollution in the canal. Tides act as pollution buffer. The pollutants are pushed back and fro, rather than being washed away into the sea. Thus the pollutants become concentrated on the canal. As a stagnant canal for most part of the year this fact has an important bearing on the pollution of the canal.

A recent water quality study done in 1986 by the Ministry of Housing, Physical Planning and Environment, can be used as good summary of the water quality situation in the entire length of the San Sebastian canal. A water quality study on the Colombo canals done by the CEA/Ministry of Housing Physical Planning and Environment in 1986 confirm the general impression that the water quality of the San Sebastian canal is very poor. According to this study the efficient functioning of the canal is affected by the garbage dumped on it's banks; blockage of banks by by the shanty enchroachment into the canal; growth of aquatic plants; and the factories. The most significant pollution spots were be near the factories and the black spots in the water within 100 metres down stream from factory sites indicated total absence of DO. This was confirmed by the monitored results of 0.0 mg/L of DO. This survey done by an ultralight aircraft. The aerial photographs clearly show the colour differences in the canal water along the entire length such as between 500-1,000 m from the east Beira lake the white colour discharges from the BCC factory; between 1,500-2,000 m discharges from Lever Brothers and black spots caused by anaerobic gas development in the canal; between 2,000-2,500 m a discolouration in the canal water near the Stace road bridge from a slum area; greenish discharges of Sedawatte Mills between 3,000-3,250 m; black colour where the Main drain enters the San Sebastian canal between 3,250-3,500 m; and the black colour canal water where San Sebastian discharges into the river Kelani. The analytical results of five samples taken from Colombo canal waters indicate that the San Sebastian as one of the most polluted canals in Colombo.

4.10 Solid waste generation in Colombo

Solid wastes significantly contribute to pollution of the surface waters. In the Colombo Municipal Council (CMC) area this is particularly true as disposal, collection and dumping of solid wastes still has not achieved 100% efficiency, although a great deal of effort has been made recently by the CMC.

There are 586,000 permanent residents in the CMC area who generate about 445.0 metric tons of mixed municipal refuse daily, of which 40% arises from commercial, 5% industrial and 45% residential. The refuse consists mostly of organic matter, averaging 75% readily biodegradable organics. The refuse is dense and wet. The moisture content during the dry season averages around 55-65%. This allows for biodegradation.

The refuse in Colombo municipality varies with the levels of income and housing status of the poople. About 50% of Colombo's residents are estimated to be living in slum and shanty housing conditions. Refuse generation too depends on the income and the overall housing status. The average densities of Colombo municipal refuse ranges from 230.0-270 kg/cubic metre(c.m). The low income residential category has a density of 265 kg/c.m; 230 kg/c.m from the high income residential; 230 kg/c.m from mixed income residential; 300 kg/c.m commercial and 380 kg/c.m in the markets (National Water Supply and Drainage Board, 1982).

There is a substantial difference between the composition of refuse generated by the poor and the rich. Vegetable and putrescible material in the refuse collected from low income residents is higher. This indicates the high organic load from the shanties. As the majority of the shanty dwellers do not dispose their refuse into bins it can be deduced that large percentage of the refuse enters the canals. This increases the organic load into the canal which is evident by the high BOD, COD and the low DO levels near the shanty areas along the canal.

In addition, there are an estimated 250,000 transients who enter Colombo on a daily basis. Two third visit the northern sector of the CMC and one third the south. They generate wastes such as lunch packet refuse.

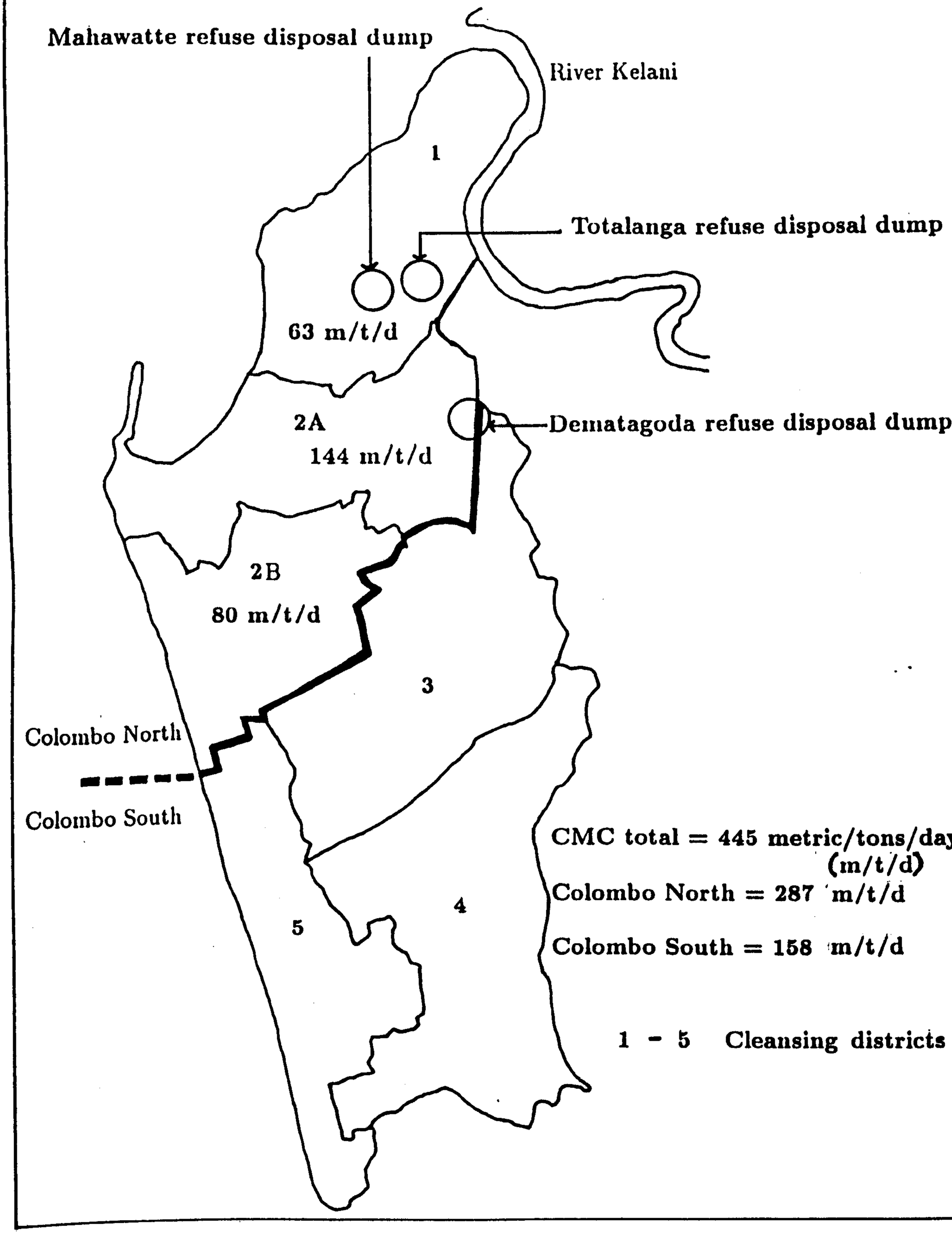


Figure 4.8 — Solid waste generation near the San Sebastian canal area

Source: National Water Supply and Drainage Board (1982)

The figure 4.8 shows the solid waste generation in areas near the San Sebastian canal. Colombo north generates 287 metric tonnes/day (m.t/d) of solid wastes. The highest is in the District 2A, which encompasses the entire length of San Sebastian canal area. The amount generated is 144 m.t/d. This is the highest out of CMC total of 445 m.t/d. The districts adjoining 2A, such as District 1 generates 63.0 m.t/d and 2B, 80 m.t/d. Many other factors contribute to the high waste generation potential of District 2A. This district has the highest total population of 156,900, with the bordering District I having 109,500 and District III (which borders Dematagoda ela) having next highest of 90,000 (Colombo north as a region has a population of 353,300) (Department of Census and Statistics, 1981b). This shows that District 2A has the highest population. This district also has the highest population density of 274.5 people/ha (over 300 typically, but Fort has only 95/ha) (Urban Development Authority (UDA), 1981). The adjoining Districts 2B and I have the next highest densities in CMC area.

The estimated income levels is the lowest in the District 2A i.e. predominantly less than SLR 100/per/cap/month. Despite the highly commercial wards of Pettah and Fort, due to a high percentage of slum population, the income level is the lowest in the CMC area (UDA, 1981). In district 2A, 55% of the permanent population live in the slum and shanties. The neighbouring District I has 45% and 2B, 50%. In 1978, of the approximate number of jobs in the CMC total of 352,000, District 2A had 152,000 (Fort area alone had 130,000) District 1, 37,000 and 2B, 71,000 (UDA, 1981). Therefore, the resultant waste generation per resident is the highest here. As seen earlier District 2A generates the CMC totals highest of 144.0m.t/d.

The above statistics indicate that District 2A which is traversed by the San Sebastian canal, has the highest total population, highest population density, highest percentage of population living in slum conditions with lowest income level within the CMC, and has the highest waste generation rate in the entire CMC area. The implication lies in the fact that all these factors are condusive and contribute to the pollution of the San Sebastian canal. The highest waste generation rate can be directly related to the gross pollution of this canal.

As the production growth rate in Colombo is 5% an increase in the refuse generation also can be expected. The projected municipal refuse generation rates for Colombo is 0.57 kg/cap/day for residences in 2001. (National Water Supply and Drainage Board, 1982). The generated wastes are dumped in many sites by the CMC. There are six regular landfills for dumping municipal wastes. With the exception of the Nawala site all the dumps are within the city limits. The size of the dumps range from one quarter to five acres. Of the current dumps Mahawatte and Thotalanga are close to the San Sebastian canal. Thololanga a two acre site, with 50% already filled and, 15,000 cubic yards yet to be filled is located in the flood plain, while Mahawatte which comprises 4-6 acres, 75% filled, and 58,000 cubic yards yet to be filled is located in a low lying land.

The environmental effects of the waste dumps are the probable contamination of surface water through direct placement of wastes in marshes and run off leaking to streams and marshes; potential contamination of ground water; potential flood water contamination during floods due to direct contact with wastes, vectors for disease such as flies, rodents, mosquitoes and maggots present in the refuse and in the dumps, animals which feed on these dumps have the potential to transmit disease (by contaminated milk and meat products) and by direct contact. As the Colombo waste dumps are located within the city limits with a high population density, the potential dangers always exist.

4.11 Environmental health situation along the San Sebastian canal

The health problems of the population are primarily those of water related disease. Diorrhoeal disease contributing to bulk of the morbidity. Environmental sanitation and water quality play an important role in the occurrence of water borne disease in an endemic form. High population density, poor sanitary facilities, contaminated water supply and uncontrolled solid waste disposal are the major contributory factors. In Sri

Lanka it is reported that 40% of the patients who seek treatment from government medical institutions suffer from bowel and intestinal disease (Ministry of Health, 1986). Amoebic and bacillary dysentry, gastroenteritis, colitis and worm infection are the commonest. Other major water borne diseases are filaria, malaria, typhoid and hepatitis.

Table 4.5 — Treatment of water-borne infectious diseases in the municipal dispensaries along the San Sebastian canal: January 1986 - February 1987

Dispensary	Malaria	Ascariasis	Anklyosotomiasis	Amoebiasis	Filariasis
CMC Polyclinic	200	183	36	-	-
San Sebastian	34	1216	50	-	115
Panchikawatte	-	2147	665	276	224
Grandpass South	-	1451	-	24[a]	52[a]

Source: Municipal Polyclinic - Slave Island, (1987). *a* - only January - February 1987

The table 4.5 shows the treatment of water borne diseases in the municipal dispensaries along the san Sebastian canal. The figures indicate high incidence of ascariasis, malaria and filariasis along the San Sebastian canal. These figures indicate that infective and parasitic disease were prevelent. Further the treatment from the municipal free dispensary indicate that those who visit these dispensaries are fairly representative of the poorer section of the people. Although these figures are not truly representative of the entire population that live along the canals (as some go to private medical clinics and to the general hospital), the fact remains that these municipal dispensaries still serve a good proportion of the population especially the urban poor who live along the canals.

These dispensaries border the San Sebastian canal. There are other dispensaries near the canal, but the records were poor.

Filariasis

Filaria is a common disease along the canals of Colombo. Filaria and malaria are directly due to stagnant and dirty water in the canal during the dry season. The luxuriant growth of *Eichornia crassipes* along the canals is very conducive for breeding of the filarial mosquito. Therefore, culex mosquito breeding is augmented.

There is clear evidence of filarial disease along the San Sebastian canal. The figure 4.9 shows this. The highest positive (percentage) cases of Night Blood Filming for microfilaria (MF) for the entire Colombo city is recorded in the Mahawatte ward (ward 3) in the extreme east of San Sebastian canal. In 1984 the percentage was 3.65 and in 1987 it stood at 2.54. Although there is a gradual decrease over the years (1980, positive percentage being 3.31), this area still continues to maintain the highest rate in the Colombo city. Grandpass north (ward 13) with 1.38 and Grandpass south (ward 14) with 1.26 (Colombo Municipal Council - City Microbiologist Laboratory, 1987) are other areas having high percentage of MF along the canal. Similarly all the other wards along the canal have higher positive percentages than the wards away from the canal.

Others

Where mosquito breeding along the canals is concerned, dengue fever too is found along the San Sebastian canal. This mosquito breeds in clean water especially in clean water pots stored for drinking outside the shanty and slum units (personal communication - Seneviratne, T.L. 1988).

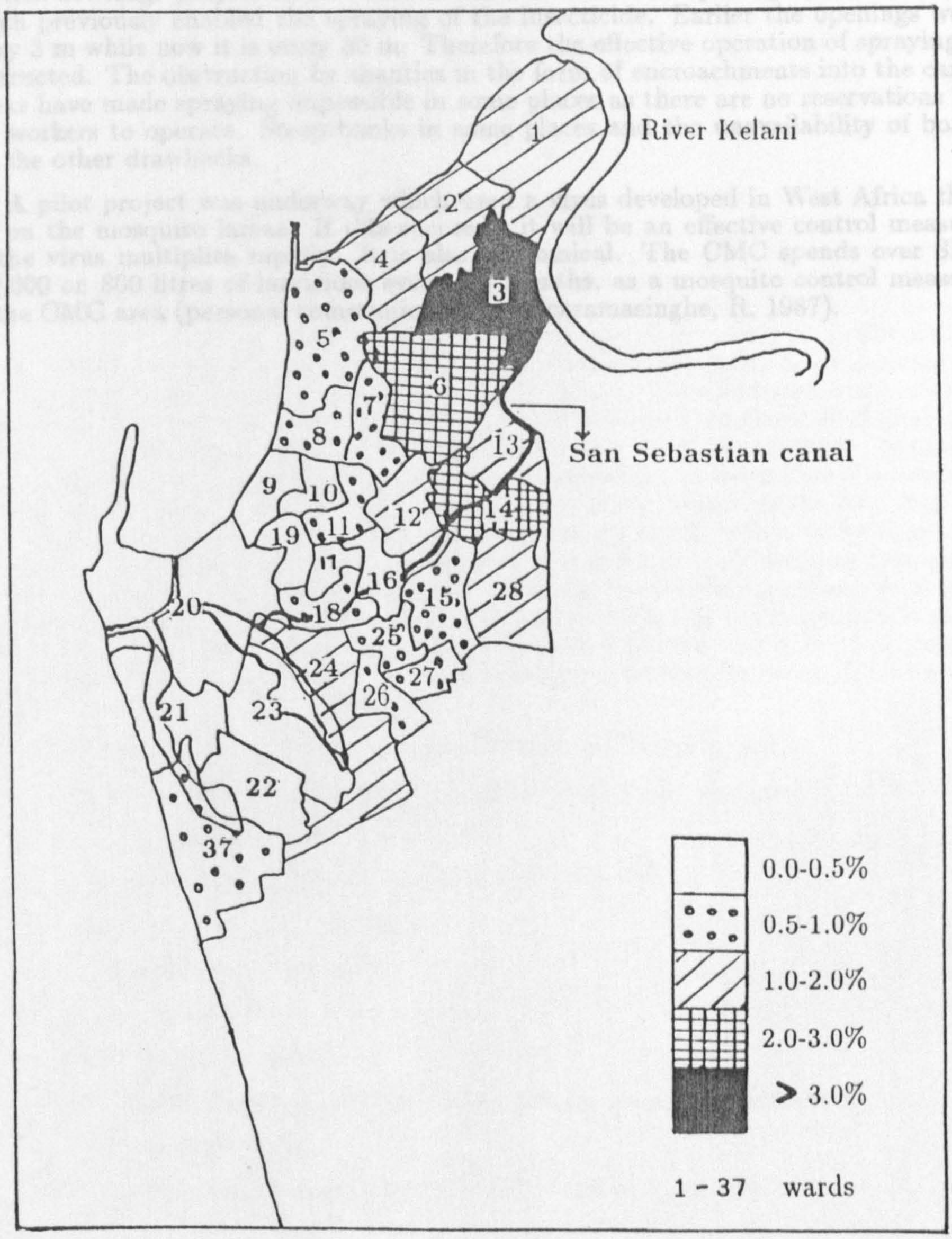


Figure 4.9 — Positive microfilaria rates for the wards along the San Sebastian canal: 1984

Source: Based on data from CMC, City Microbiological Laboratory, 1987

The Colombo Municipal Council controls the mosquito larva by spraying an insecticide called Baytox. The CMC sprays this insecticide on the canals weekly as a larval control measure, which by forming an oil film hinders oxygen from the atmosphere reaching the water and thereby hindering mosquito larval breathing. During dry weather this is an effective measure and the larvae dies within two days.

The illegal underground drains that discharge into the canals, in addition to the

stagnant waste water, bring the mosquito larvae into the canals. It was revealed that the new sewerage project under construction has closed the openings into the drains, which previously enabled the spraying of the insecticide. Earlier the openings were every 3 m while now it is every 30 m. Therefore the effective operation of spraying is obstructed. The obstruction by shanties in the form of encroachments into the canal banks have made spraying impossible in some places as there are no reservations for the workers to operate. Steep banks in some places and the unavailability of boats are the other drawbacks.

A pilot project was underway which used a virus developed in West Africa that fed on the mosquito larvae. If this succeeds, it will be an effective control measure as the virus multiplies rapidly. It is also economical. The CMC spends over SLR 292,000 on 800 litres of larvicides every 3-4 months, as a mosquito control measure in the CMC area (personal communication - Wickramasinghe, R. 1987).

Chapter V

Methodology: parameters, sampling and analytical methods

5.1 Surface water quality and monitoring

Surface water is used for various purposes such as domestic, industrial, agricultural, recreational and aesthetic. Today, natural waters are seldom suitable for the purposes for which they are intended or the diverse uses for which they could be used in their natural capacity. Pollution of surface waters particularly in industrialized urban areas is the order of the day. The overall water quality needs to be assessed before the surface waters can be put to any beneficial use. Therefore a systematic water quality monitoring programme becomes imperative to evaluate the overall quality of a stream or a receiving water body to determine the extent of pollution. Similarly, the monitoring of industrial effluents becomes important to determine the strength of their waste water discharges and to assess their direct impact on the receiving water. Water quality can be measured either against its natural state or by standards defined for various uses i.e by stream or effluent standards. Any decision concerning the stream uses or industrial waste water discharge is entirely dependent on a comprehensive, coherent, integrated and representative stream or industrial waste water sampling programme on which it is based. The many factors that have to be considered when designing a comprehensive sampling programme (Nemerow, 1978) are as follows:

1. The overall and specific objectives of the sampling programme
2. The parameters to be monitored and the data to be obtained
3. Method of sample collection
4. Selection of sampling sites and points of collection
5. Frequency of sample collection
6. Time of the year for collection
7. Volume of samples to be collected
8. Total number of samples
9. Care of sample handling prior to analysis i.e. sample perservation
10. Analytical methods
11. Limitations and related problems in the sampling programme

5.1.1 Objectives

1. To monitor and assess the overall water quality of the San Sebastian canal, tributory canals, and assess their effects on river Kelani and the Beira lake

2. To evaluate the contribution of the tributary canals on the waters of the San Sebastian canal

3. To measure the pollutional strength of waste water discharges from a few representative food and drink industries and estimate their contribution and impact on the receiving canal system (the objective of monitoring the lake site was purely for assessing the contribution to pollution from a food industry rather than lake as an entity)

4. To assess whether the effluents are discharged into the canal system with or without treatment.

5. To see the dissolved oxygen sag characteristics of the San Sebastian canal

6. To estimate the daily, monthly and seasonal impact of rainfall on the water quality of the canal (dilution and concentration)

7. To understand the assimilation capacity of the San Sebastian canal

8. To see whether the canal water quality and industrial effluents comply with the standards of the governmental pollution control regulatory bodies

5.1.2 Rationale for selecting the research area

Pollution as a major environmental issue came into awareness after the Stockholm Conference in 1972. Though the awareness is recent, the problem posed is grave due to gross pollution of canals and waterways in the major cities, particularly in Colombo.

Although studies on water pollution in Sri Lanka are very sparse, a few pilot and short term surveys indicate that the canals in Colombo are grossly polluted. The 1972 report of the special committee on Wellawatte canal pollution (Department of Irrigation, 1972) and a short term survey on water quality in Colombo canals by Padmaperuma (n.d.) highlighted the poor quality of canal water. A pilot survey by Anderson (WHO, 1979) highlighted the gross pollution resulting from industrial discharges into canals causing severe pollution of canal waters in Colombo. The river Kelani pollution study by Central Environmental Athority (CEA) (1985) covers the pollution by industries along the river Kelani, a few industries along the canal and lake. An industrial pollution survey in 1986 and 1987 by CEA and the Dutch Government covered the surface water in and around Colombo and was designed to meet the need for an overall view of surface water pollution in Colombo to indicate, the major polluters and areas which suffer from environmental pollution. This survey although it provides a very good visual image of pollution in the canals and surface waterways in Colombo by means of high resolution aerial photographs, falls short as far as the monitored data is concerned since only one sample site per canal was analysed during the entire survey. It falls short as a comprehensive survey of water pollution. GEMS/WATER programme has a monitoring station in river Kelani but the data returned is widely spaced.

Therefore a long term, coherent, comprehensive and integrated study on water quality in the canals in Colombo has not been attempted until today. In spite of these shortcomings all the studies highlight a state of gross pollution in Colombo canals with particular reference to the San Sebastian canal.

As far as the industries are concerned the water pollution situation is very similar to other developing countries. The need for industrialization as a tool for economic development outweighed ecological consideration and industries of varied nature and scale started to appear in the 1950's and 1960's after independence. These industries started to mushroom in Colombo, in residential areas, except for a few state owned industries outside the city. The industries, found suitable locations along the canals and waterways which are conveniently used for waste water discharge in addition to other industrial uses like cooling water. Therefore the surface water system in Colombo has become a convenient sewer to many industries. Among the industries the food and drink is one of the major groups of industries located in and around urban Colombo to meet the high consumer demand for food and beverages as in other urban areas of the developing countries. According to the Department of Census and Statistics (1987a) it is the second most important group of industries in Sri Lanka, while district wise, it ranks the first in Colombo.

Food industries of varied scales and nature are situated along San Sebastian canal and other waterways in addition to other industries, which pollute the canal indiscriminantly. These are older industries, started before the enactment of the National Environmental Act of 1980, so CEA and therefore the government pollution regulatory body which came into being in 1983, does not have any regulatory powers to control the discharges other than persuasion, and therefore they continue to pollute the waterways regardlessly without any form of treatment, even today. The highly

organic nature of the effluent of these industries exert a heavy oxygen demand on the receiving waters causing very low dissolved oxygen in the canal waters.

Therefore the grave pollution situation in the San Sebastian canal system caused by the food and drink industries and the need to fill the urgent gap in this field of research was the rationale for choosing the area of study for the research. Being a new research field with very little research done, and gaining rapid importance, the data had to be obtained by monitoring because of the dearth of data. A research field with very few studies, baseline monitoring, and the non availability of data on water quality in the canals proved a severe handicap. Monitored data on food industrial effluents was almost non existent. With these two grave situations, threatening the canal system which once gave life and impetus to the city's development now fallen into neglect and misuse resulting in severe pollution, a research project was undertaken to assess the extent of pollution. The availability of a laboratory for carrying out the analysis within close proximity to the monitoring sites and industries enhanced and facilitated the research programme, since most of the laboratory analysis had to be done immediately.

5.2 Parameters

Selection of parameters for monitoring

The parameters selected for monitoring depend on the type of pollution that is being monitored and the objective of such analysis. The main objective in the analysis of water samples is the determination of the water quality or the extent of pollution. As there are many types of substances that may be considered as pollutants the selection of parameters for monitoring must be divised to give good indications of the **undesirable** characteristics of pollutants rather than the exact concentration of each and every substance present in the water (Ludwig, R.G. 1980) as quoted by Ratasuk (1981). The most important factors which contribute to undesirable water quality are low dissolved oxygen concentration at all times, high BOD, pH away from neutrality, excessive amounts of slime, algae, fungi, infectious agents presence of toxic substances, high mineral content, persistent organics, oil and grease; turbidity, colour, radio activity floating solids, scum, suspended solids, foam, and stream water should be free from tastes and odours (Klein, 1972).

The sampling programme of the water quality of a stream should focus on the quality of the receiving water and the analysis done must be directly related to the type of industry being monitored. The waste water discharges from food processing industries are highly organic and biodegradable in nature, oxygen-demanding, putrescible and variable in strength.

The water quality impact of the food processing industries can be evaluated in terms of organic matter, plant nutrients and pathogenic micro organisms in certain industries. Based on the US-EPA reports representing comprehensive and systematic approach to industiral waste water monitoring Ludwig H.F. (1979) compiled the most important parameters applicable to most of the industries.

Therefore after careful consideration of the waste characteristics of this industry analysis was designed to detect the organic pollution from these industries and the overall water quality of the receiving streams. Therefore the physical and chemical analysis for water pollutants were confined to dissolved oxygen, temperature, turbidity, conductivity, pH, BOD, COD, sulphates, total N, total P and SS. Monitoring of these parameters are mandatory on water quality studies, which indicate the level of pollution.

Since the food processing plants do not discharge any toxic and petrochemical wastes, the monitoring of toxic wastes and heavy metals was not attempted. In future studies this has to be done since there are industries discharging these wastes into the canal such as textiles dyes and pesticides.

The basic variables recommended by WHO (1983a) can be seen in table 5.1. The parameters monitored conform to the basic variables recommended for manda-

tory monitoring at sampling locations to give an overall idea of water quality except COD which is an optional variable. Basic variables are the most commonly measured water quality variables, and most of them are monitored in more than 50% of the GEMS/WATER monitoring stations (WHO, 1983a). Optional variables are monitored in 10-50% of the stations. Rivers have been the most studied water bodies and the one for which the maximum number of water quality variables measured in the GEMS global programme of the WHO/UNEP study.

Table 5.1 — GEMS/WATER Quality variables (revised)

Basic variables (mandatory)	Rivers	Lakes
Temperature	X	X
Electrical Conductivity	X	X
DO	X	X
Nitrate	X	X
Nitrite	-	-
Ammonia	X	X
Calcium	X	X
Magnesium	X	X
Sodium	X	X
Pottasium	X	X
Chloride	X	X
Sulphate	X	X
Alkalinity	X	X
BOD	X	-
TSS	X	X
Chlorophyll - a	-	X
Transparency	-	X
Orthophosphates	X	X
Total Phosphorus	X	X

Source: WHO, (1983a)

Parameters may be broadly classified into physical, chemical and biological, although they are interrelated and interdependent in nature.

5.2.1 Physical parameters

Temperature

Temperature is an important parameter in water quality monitoring. Temperature directly affects the solubility of gases especially dissolved oxygen. It also affects the concentration of dissolved oxygen. The rate at which oxygen is consumed during the breakdown of organic matter is dependent on temperature. An increase in temperature decreases the solubility of oxygen.

The rates of most chemical and biological reactions increase with temperature. An approximate rule is that the rate of a reaction will approximately double for each 10 °C rise in temperature (Sawyer and McCarty, 1978). In biological reactions this rule holds true more or less up to a certain optimum temperature as the metabolic activity of the aquatic organisms increase. The net result is that the organisms demand more oxygen at higher temperatures. Above the optimum temperature, the rate decreases probably due to destruction of enzymes at higher temperatures. Saturation oxygen levels at various temperatures are seen below such as at,

20 °C - 9.2 mg/L DO
30 °C - 7.6 mg/L DO
40 °C - 6.6 mg/L DO
50 °C - 5.6 mg/L DO

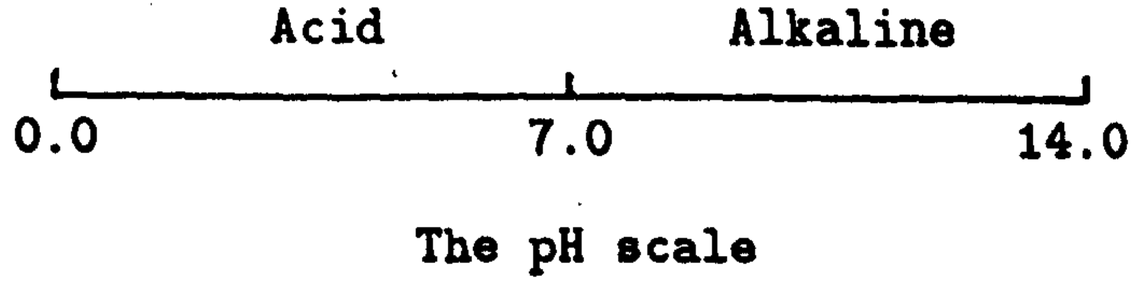
Biological stabilization, like most bio-chemical and chemical reactions take place more rapidly as temperature rises. Heated effluents will therefore increase the rate of oxygen uptake, but the saturation concentration of oxygen falls with increase of temperature. A rise in temperature thus places a double burden on the oxygen concentration of surface waters. Hot effluents can produce dramatic fish kills, both by accentuating the action of poisons and by reducing the dissolved oxygen concentration of the receiving streams. Heated stream water also decreases the value of industrial cooling water. One industry may increase the temperature of the water of a stream so that a neighbouring industry downstream cannot use it. Since the saturation value of dissolved oxygen is temperature dependent, as the heat from thermal wastes dissipates, the saturation value of dissolved oxygen concentration changes from the value at the point when the thermal wastes enter the river to the value of dissolved oxygen concentration of the ambient temperature at the water at some point down stream (Karunaratne, 1984).

An increase in water temperature brought about by discharging heated waste water has various effects. As warm water is lighter than cold water, stratification occurs and this causes the fish life to retreat to the bottom, and thus aquatic life suffers. Any organic pollutants discharged into these warm surface waters will have less oxygen available for natural biological degradation (Margola, 1984). Extremes in temperature causes problems with biological treatment systems. They also affect the rates of chemical reaction and flocculation (Green *et al* 1979).

Temperature is directly measured in situ at the site of the waste stream or water body. It is measured at the sampling site with a thermistor or a mercury thermometer. A mercury thermometer was used for the study and was measured on the site.

pH

pH is a term used to express the intensity of the acid or alkaline condition of a solution. It is an index of hydrogen ion activity and is defined as the negative logarithm of hydrogen ion concentration in moles per litre (Ministry of Environment - Ontario, 1983). It gives the acid-base interaction of the mineral and organic components of the water body. pH is measured on a scale of 0.0-14.0, 0.0 pH being very acidic to pH of 14.0 being very alkaline with a middle value of 7.0 corresponding to neutrality at 25 °C. Acid condition increases as pH value decreases and alkaline conditions increase as the pH value increases. pH of 7.0 has very little significance as a reference point in water chemistry.



The pH scale

The pH of natural waters may range from 6-8.0. A pH value outside this range can cause solubility of certain heavy metals which may be present in waste waters (National Building Research Organisation, 1988). Acids directly and alkali indirectly may corrode structures especially sewers and pipes especially if pH is less than 4.5. It interferes with settling, releases odours and intensify colour of the water body. Extremes in pH both high and low will adversely affect the biological treatment system, chemical reactions, flocculations, ion exchange and other separation mechanisms (Green *et al* 1979).

In the field of water supplies pH becomes important in chemical coagulation, disinfection, water softening and corrosion control. In sewage and industrial waste

water treatment that employ biological processes, the pH is controlled within a range favourable to the particular organisms, involved. For the fundamental relationships that exist between the pH, acidity and alkalinity, pH monitoring in waste water analysis becomes important.

Turbidity

Turbidity is an optical property which causes light to be scattered or be absorbed rather than be transmitted in straight lines, through water. It may be caused by the presence of suspended matter in water such as clay, silt, finely divided organic or inorganic matter, detritus, mineral substances and micro organisms. This reduces clarity and diminishes light penetration.

The size of material causing turbidity may range from colloidal to coarse dispersions depending upon the degree of turbulence (Sawyer and McCarty, 1978). Ground water has low turbidity while a turbid river may contain 10.0-100.0 mg/L or more of suspended matter (Zoetman, 1980). In lakes or other water under relatively quiescent conditions most of the turbidity will be due to colloidal and extremely fine dispersions. In a river under flood conditions coarse dispersions may be the cause.

Turbidity may be caused by a variety of materials. Colloidal rock particles causes turbidity. As rivers pass farming areas, the operations that disturbs the soil causes turbidity. Under flood conditions great amounts of top soil are washed into receiving streams. They are mostly inorganic, but considerable amounts of organic matter are included. As rivers pass through urban areas where domestic and industrial waste water treated or untreated, may be added. Domestic wastes may add great quantities of organic and some inorganic substances that produce turbidity. Organic materials reaching rivers serve as food for bacteria and the resulting bacterial growth and other micro-organisms that feed upon bacteria produce additional turbidity. From the above considerations it can be said that materials causing turbidity may range from purely inorganic substances to those that are largely organic in nature.

Turbidity is an important consideration for public water supplies. It is also important for aesthetic reasons. Turbidity free water is important for drinking purposes as it is associated with possible sewage pollution and hazards. This has a sound basis because in the past water borne epidemics plagued the water industry in Britian (Sawyer and McCarty, 1978). Disinfection of water for public water supplies becomes difficult if the water is turbid. In the cases where turbidity is caused by sewage solids many of the pathogenic organisms may be encased in the particles and protected from the disinfectants. For this reasons the U.S standard for public water supplies is a maximum of 5 units of turbidity. Turbid waters are also undesirable for industrial purposes.

Turbidity is measured either visually or by nephelometric method. The nephelometric method gives greater precision, sensitivity and wider applicability. Therefore, this method is preferred to the visual method (Smart *et al* 1984) and was thus used in the study.

Conductivity

Conductivity of a solution is the measure of its ability to carry an electrical current through water and is dependent on the temperature and the number of ionic substances in solution. Soluble inorganic salts, acids and bases are excellent conductors. Organic ionic compounds such as proteins, free fatty acids, organic acids or detergents are poor conductors. Dissolved ions such as chlorides, suphates and calcium renders water conductive. Freshly distilled water has a conductance of 0.5-2.0 μmhos/cm (Sawyer and McCarty, 1978).

In many waters there is a direct linear relationship between dissolved solids concentrations and conductivity. There is a general correlation between specific conductance and filterable solids. Sucrose is non conductive while salt brines are 1000's of μmhos/cm conductive. In most waste waters when conductivity data is multiplied by a factor ranging from 0.55-0.70, the product is equal to mg/L of filtrable solids. The proper factor depends on the ionic components in the solution.

Conductivity measurements are frequently used in water analysis to obtain a rapid estimate of dissolved solid content. They can be easily measured without interferences from solid content, turbidity or pH. For this reason they are popular as a continual recording system for monitoring industrial waste waters. Conductivity serves as a control parameter and is an excellent indicator of water quality changes as it is sensitive to variations in dissolved solid concentrations.

A variety of conductivity water probes are available for measuring conductivity. A conductivity meter using probes was used to measure the conductivity of the water samples.

5.2.2 Chemical parameters

Dissolved Oxygen (DO)

All living organisms are dependent upon oxygen to maintain the metabolic processes that produce energy for growth and reproduction. Aerobic processes are the subject of greatest interest because of their need for free oxygen. All gases of the atmosphere are soluble in water to some extent and oxygen is classed as poorly soluble.

The solubility of atmospheric oxygen in fresh water ranges from 14.6 mg/L at 0 °C to about 7.0 mg/L at 35 °C under one atom of pressure. It's solubility varies directly with the atmospheric pressure at any given temperature (Sawyer and McCarty, 1978).

The low solubility of oxygen is the major factor that limits the purification capacity of natural waters and necessitates treatment of wastes to remove pollutional water before discharge into receiving streams. In most conditions oxygen concentration, greater than approximately 14.0mg/L is not encountered in fresh water (Vowels *et al* 1980) although it can occur under supersaturated conditions.

Dissolved oxygen in water originates directly from the atmosphere or through photosynthesis in aquatic plants. Ample dissolved oxygen is necessary to maintain satisfactory conditions for fish and other biological life in water. Dissolved oxygen is the gas of primary importance in both waste waters and receiving waters and the polluting strength of an effluent is best defined in terms of the organic substances which affect the dissolved oxygen of the receiving water (Anderson, 1979).

In liquid wastes dissolved oxygen is the factor that determines whether the biological changes are brought about by aerobic or by anaerobic organisms. The former use free oxygen for oxidation of organic and inorganic water and produce innocuous end products, where as the latter bring about such oxidation, through the reduction of certain inorganic salts such as sulphates, the end products being obnoxious. Since both types of organisms are ubiquitous in nature it is very important that conditions favourable to the aerobic organisms be maintained, otherwise, anaerobic conditions result. Thus the dissolved oxygen determinations are used for a wide variety of purposes. In most instances it involves the control of stream pollution as it is desirable to maintain conditions favourable for the growth and reproduction of a normal population of fish and other aquatic organisms. This condition requires the maintenance of dissolved oxygen levels that will support the desired aquatic life in a healthy condition at all times.

Dissolved oxygen measurements are vital for maintaining aerobic conditions in natural waters that receive polluting matter and in aerobic processes intended to purify domestic and industrial waste waters. It is important in water quality control to have a measure of the potential oxygen uptake that accompanies the bacterial consumption of organic material in a waste discharge. This is the basis of the BOD test. BOD test is based on the dissolved oxygen determinations of the samples on days one and five.

The fact that dissolved oxygen serves as the basis for the BOD test, makes it the foundation of the most important water quality determination used to evaluate the pollutional strength of sewage and industrial wastes. The rate of biochemical oxidation can be measured by determining the residual dissolved oxygen in a system

at various time intervals.

In other words DO is the key test in water pollution control activities. It is also important in waste water treatment process control. DO is one of the major indicators of river water quality, with high DO levels in unpolluted waters and very low levels in the presence of sewage and industrial pollutants.

All aerobic treatment processes depend upon the presence of dissolved oxygen and the test for it are indispensable as a means of controlling the rate of aeration to make sure that adequate amounts of air is supplied to maintain aerobic conditions and also to prevent excess use of air.

Oxygen is a significant factor in the corrosion of iron and steel especially in the water distribution system, and in steam boilers. The removal of oxygen from boiler feed waters is a common practice in the power industry. The dissolved oxygen test therefore serves as a means of control.

Dissolved oxygen determinations have to be carried out in the sampling sites insitu since, the longer the time lag between sampling and the measurement, the greater is the chance that the dissolved oxygen concentration diminishes because of chemical or biological activity in the sample.

Chemical Oxygen Demand (COD)

Organic wastes have long been analysed for their oxygen demand by oxidizing them chemically. The COD test measures the oxygen equivalent of the organic matter in a sample that is susceptible to oxidation by a strong oxidant. In other words the COD test estimates the amount of organic matter in waste water that is readily oxidized by a dichromate acid reflux method (Greenberg *et al* 1980). The COD test is widely used as a means of measuring pollutional strength of domestic and industrial trade wastes. This test allows measurement of a waste in terms of the total quantity of oxygen required for oxidation to carbon dioxide and water. It is based on the fact that all organic compounds with a few exceptions can be oxidized by the action of strong oxidizing agents under acid conditions.

It is generally interpreted as organic matter, however there are some inorganic materials such as sulphites and nitrites which are oxidized and some organic materials such as acetic acid which are not oxidized (Sawyer and McCarty, 1978).

During COD determination organic matter is converted to carbon dioxide and water regardless of the biological assimilability of the substances. COD values are almost always higher than BOD, but it may be much greater when significant amounts of biologically resistant organic matter is present such as wood pulping wastes which have a high lignin content.

The major advantage of the COD determination is the short time required for the test. This test can be done in 3 hours against five days for BOD. For this reason it is used as a substitute for BOD. The COD data can be interpreted in terms of BOD value to establish reliable correlation factors. When the characteristics and the organic content of a waste remain reasonably constant, it is generally possible to obtain a fixed relationship between the COD and BOD. The COD test is of considerable value in routine waste water analysis as the dichromate-acid reflux method can be easily done in about three hours, if something goes wrong or if a new process or treatment method is being explored.

The main limitations of the COD test is its inability to differentiate between biologically oxidizable and biologically inert organic matter. Also, it does not provide any evidence of the rate at which the biologically active material would be stabilized under conditions that exist in nature. Another limitation is the number of special COD reflux apparatus available in a laboratory.

The application of the COD data it is extensively used in the analysis of industrial wastes, and water quality studies in general. In conjunction with the BOD test COD is helpful to indicate the toxic conditions and presence of biologically resistant

organic substances. It is also widely used in environmental engineering especially in surveys designed to determine, control and losses to sewer system; and such data are frequently used by the municipalities as the basis for charging for the reception and treatment of industrial wastes.

Biochemical Oxygen Demand (BOD)

The BOD test is one of the first methods for determining the amount of organic matter in waste water and receiving water. It is ingenious and simple for detecting biodegradable organic pollutants. It has become a world wide standard method in water quality studies. In recent decades other methods for estimating oxygen demand have been devised, which are faster than the BOD test such as, Total Organic Carbon (TOC) and the COD. Although the newer methods are accepted BOD still remains the standard for comparison (Green *et al* 1979).

BOD is defined as the amount of oxygen required by bacteria for oxidation while stabilizing decomposable organic matter under aerobic conditions (McCarty and Sawyer, 1978).

The BOD test is widely used to determine the polluting strength of domestic and industrial wastes in terms of oxygen that they will require for oxidation if discharged into natural water courses in which aerobic conditions exist. Five day BOD (BOD_5) is a laboratory measurement of the amount of oxygen consumed in a sample incubated for five days at 20 °C. The BOD test is esentially a bioassay procedure involving the measurement of oxygen consumed by living organisms mainly bacteria while utilizing the organic matter present in a waste under conditions as similar as possible to those that occur in nature. Since this is a bioassay procedure it is extremely important that the environmental conditions be suitable for living organisms to function in an unhindered manner at all times. This condition means that toxic substances must be absent and all other nutrients needed for bacterial growth such as nitrogen, phosphorous and certain trace elements be present. Biological degradation of organic matter under natural conditions is brought about by a diverse group of organisms that carry oxidation to completion i.e. almost entirely to carbon dioxide and water. It is important that a mixed group of organisms, commonly called **seed** be present in the test. Therefore the BOD test may be considered as a wet oxidation procedure in which living organisms serve as the medium of oxidation of the organic matter to carbon dioxide and water.

The oxidative reactions involved in the BOD test is a result of biological activity. The amount of oxygen required by carbonaceous matter is referred to as the first stage BOD and that by nitrogeneous matter in the waste is called the second stage BOD. Although it takes about 20-30 days for the complete oxidation of carbonaceous matter in the waste, more than two thirds of it usually gets oxidized within the first five days, and the 5 day BOD is accordingly used as a valuable parameter. The first stage BOD includes the immediate dissolved oxygen demand exerted by certain other substances too.

Apart from the immediate dissolved oxygen demand, the oxidation of the carbonaceous materials present in the waste commences almost immediately and continues at a general declining rate, until complete oxidation is accomplished. The nitrogenous materials in the waste water on the other hand, do not usually start getting oxidized up to about 8-12 days after commencement of the oxidation process. Thereafter, the nitrogenous oxidation commences and proceeds at a relatively slow rate. The carbonaceous oxidation will be almost complete in about 30 days time where as the nitrogenous oxidation takes a much longer time for completion. The variation of BOD with time is shown in figure 5.1.

The rate at which the reactions proceed is governed to a major extent by population numbers and the temperature. The higher the temperature, the greater is the metabolic activity and faster is the depletion of oxygen. The temperature effects are controlled and held constant by performing the test at 20 °C, which is more or less the median value as far as the natural bodies of water are concerned in the temperate climates. In tropical climates, however the temperatures being higher, make the

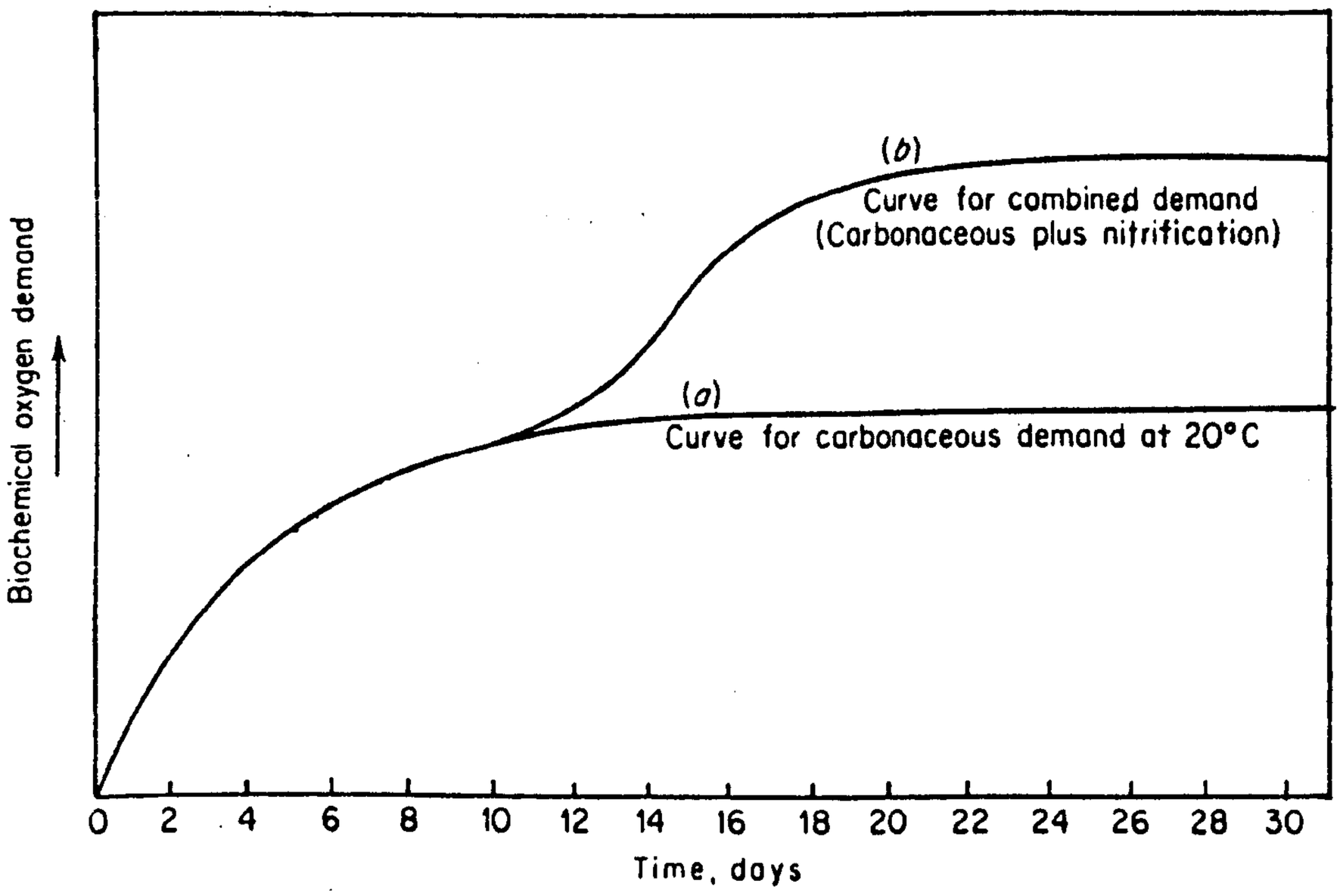


Figure 5.1 — The BOD curve. (a) normal curve for oxidation of organic matter (b) The influence of nitrification

Source: Sawyer and McCarty, (1978)

situation different. Though still BOD_5 is used widely, a BOD_3 test performed at 27 °C (80 °F) gives similar results with sewage and sewage effluents to the BOD_5 test. This modification is very useful in tropical countries. Today Malaysia uses the BOD_3 at ambient temperature.

The predominant organisms responsible for the stabilization of organic matter in natural waters are forms native to the soil. The rate of their metabolic processes at 20 °C and under the conditions of the test is such that time must be reckoned in days. Theoretically, an infinite time is required for complete biological oxidation of organic matter but for practical purposes, the reaction may be considered complete in 20 days. But 20 days is too long to wait for results. By experience it has been found that a large percentage, about two thirds, of the total BOD is exerted in 5 days; consequently the test has been developed on the basis of 5 day incubation period, therefore 5 day BOD represents only a portion of the total BOD. In the case of domestic and most industrial wastes it has been found that 5 day BOD value is 70-80% of the total BOD. This is a large enough percentage of the total so that the 5 day values are used for many considerations.

With certain industrial wastes the proportion of BOD exerted in 5 days can be markedly different. BOD requiring large amounts of oxygen give high BOD values upon analysis. A high BOD load requires more bacterial activity and hence uses more of the oxygen dissolved in the water. This is especially true of food processing industries where the BOD are found to be extremely high.

This test is of prime importance and is widely used to assess the water quality in rivers and strength of industrial waste waters. It is also used in regulatory work and in studies designed to evaluate the purification capacity of receiving bodies of water. BOD data are used to design biological treatment units, to control the quality of effluents discharged into receiving waters, to fix charges made by local authorities for the reception of industrial effluents and therefore the test is one of the most important in stream pollution control activities.

The advantages of the test are that it is relatively easy to perform though tedious with equipment costs being moderate and is a routine test done in almost all the water

quality testing laboratories. It also approaches very close to conditions taking place in the natural aquatic environment. The main disadvantages of the test is that it does not necessarily determine the entire amount of biodegradable organic content, as some organic matter is slowly biodegradable. Potential presence of inhibitors, oxidation of inorganic compounds such as sulphides and ferrous ions, oxidation reactions catalyzed by the presence of ions such as copper and errors in the dilution factor or choice of seeding inoculum are other shortcomings. BOD tests also lack reproducibility and the time required to obtain results is long. COD and TOC are far quicker in spite of their limitations. Another drawback is the scheduling of laboratory personel as the tests cannot be started on certain days, as it needs five days to obtain the results. Holidays also can upset the schedule.

Total Nitrogen (total N)

Nitrogen makes up 0.002% of the total elemental composition of the earths crust including the hydrosphere and the atmosphere. Over 99.99% of the nitrogen in the atmosphere is N_2 which is the principal reservoir of nitrogen in the biosphere. Most living organisms contain 9-15% nitrogen on a dry weight basis (Humitake, 1982).

Nitrogen is important in the life process of all animals and plants. The chemistry of nitrogen is complex because of the several oxidation states that nitrogen can assume and the fact that these changes can be brought about by living organisms. The oxidation state changes wrought by bacteria can be either positive or negative depending upon the aerobic or anaerobic condition (Sawyer and McCarty, 1978). In the biosphere 1000 million tons of nitrogen are estimated to pass into the nitrogen cycle every year (Humitake, 1982). The relationships that can occur in nature are best illustrated by the nitrogen cycle. Atmosphere serves as the reservoir from which nitrogen is constantly removed by action of electrical discharge and nitrogen fixing bacteria and algae. During electrical storms and ultra violet light from the sun, large amounts of nitrogen are oxidised to N_2O_5 and its union with water produces HNO_3, which is carried to the earth in rain.

In waters and waste waters the forms of nitrogen of greatest interest in the order of decreasing oxidation state are nitrate, nitrite, ammonia and organic nitrogen (Greenberg *et al* 1980). All the above forms of nitrogen as well as nitrogen gas are biochemically convertible and are thus components of the nitrogen cycle. This cycle is affected by fauna, flora, physical factors such as lightening and temperature, in addition to the important part played by the micro organism.

The reduced form of nitrogen, ammonia is naturally present in surface water, ground water and in waste water. It is produced largely by the deamination of organic nitrogen containing compounds and by hydrolosis of urea. It may also be produced naturally by the reduction of nitrate under anaerobic conditions. As a commercial fertilizer urea is one of the popular ammoniam compounds. It releases ammonium gradually. Ammonia and ammonium compounds are applied to soils for plant life. Ammonia in receiving water is toxic to both fauna and some flora.

Nitrite is not a stable form of oxidized nitrogen. It is readily oxidized to nitrate by some micro-organisms or mild chemical oxidants and therefore contributes to oxygen demand factors of receiving water and waste water. It is indirectly toxic in that it can be converted to nitrate. (It is also toxic in its own right). It is also intermediate in microbiological decomposition of protein. Excessive nitrite formation in meat, fish or dairy waste waters means the loss of valuable protein from potentially recoverable byproducts. Therefore nitrite is monitored if proteinaceous by products are to be recovered.

Nitrite is an intermediate state of nitrogen both in the oxidation of ammonia to nitrate and in the reduction of nitrate. Such oxidation and reduction may occur in waste water treatment plants, water distribution systems and natural waters. Nitrite can enter a water supply system through its use as a corrosion inhibitor in industrial process water.

Nitrate is the most highly oxidized form of nitrogen. Trace amounts of nitrates

occur in natural surface waters, but higher concentrations are found in ground water. Excessive amounts of nitrates in drinking water causes methemaglobianemia, which attacks bottle fed infants if the concentrations are high. Nitrates in drinking water are also fatal to cattle. A limit of 10mg/L nitrate as N has been imposed on drinking water to prevent this disorder (Greenberg *et al* 1980). Nitrate is found only in small amounts in fresh domestic waste water but in effluents of nitrifying biological treatment plants nitrate may be found in concentrations up to 50.0mg/L. Nitrate is an essential nutrient for many photosynthetic autotrophs and in some cases it is identified as growth limiting nutrient. High levels of nitrates in water bodies accelerate the rate of eutrophication, causing algal blooms thus increasing the photosynthetic activity, and as a result the oxygen content of the water is depleted. Nitrate is usually found in polluted waters that have undergone some degree of self purification. It can be found in water courses intercepting drainage from fertilized agricultural areas. In unpolluted rivers, the nitrate nitrogen concentration is generally low, amounting to less than 0.5 mg/L (Ministry of Environment, 1983). In food processing wastes which contain high concentration of nitrogeneous organic matter, unpleasant odour is emitted when staling owing to anaerobic decomposition. In polluted waters with low dissolved oxygen the combined oxygen supplied by nitrates becomes important, which acts as a last line of defence in preventing anaerobic conditions and foul odours in a polluted water. In U.S.A. nitrates are deliberately added to polluted streams to prevent odour. Sodium nitrate was added to stop the H_2S odour in Androscoggin river (Klein, 1966).

Organic nitrogen includes such natural materials as proteins, peptides nucleic acid, urea and numerous synthetic organic materials. The organic nitrogen concentrations of water and waste water vary from less than 10 mg/L in the former to over 10mg/L in the latter (Greenberg *et al* 1980).

Summation of all forms of nitrogen is Total N.

Inorganic salts (nitrogen and phosphorus) which are present in most industrial wastes and in nature cause the water to be hard and makes the stream undesirable for industrial, municipal and agricultural usage. Nitrogen and phosphorus also induce the growth of microscopic plant life in surface waters. If effluents are discharged into lakes, ponds or sluggish streams, these nutrients tend to stimulate growths of plytoplankton (algal blooms) and also can stimulate weed growth. This makes monitoring important.

Phosphorous (Total P)

Phosphorous makes up 0.105% of the total elemental composition of the earths crust (Humitake, 1982). Phosphorous occurs in natural and waste waters almost solely in the form of various types of phosphates. These forms are commonly classified into orthophosphates, condensed phosphates ($pyro^-$, $meta^-$ and polyphosphates), and organically bound phosphates (Greenberg *et al* 1980). The sum of these is total phosphorous. They occur in both dissolved and particulate form. These may occur in the soluble form in particles of detritus or in the bodies of aquatic organisms. The vast majority of phosphorous in aquatic environment is present as inorganic phosphates. Phosphorous is a primary nutrient for plant and animal life, and like nitrogen passes through cycles of decomposition and photosynthesis. All polyphosphates gradually hydrolyse in aqueous solution and revert to ortho form from which they were derived. The rate of reversion is a function of temperature and increases rapidly as the temperature approaches boiling point. The rate is also increased by lowering the pH. The hydrolosis of complex phosphates is also influenced by bacterial enzymes. The rate of reversion being poor in pure waters but more rapid in waste waters. In addition to phosphates in the natural form, it is also found in untreated or treated sewage, some industrial wastes. Agricultural and urban drainage significantly contain concentrations of phosphorous which are discharged to water courses.

No life is possible without phosphorus and all organisms contain phosphorus in amounts ranging from 0.05% in certain plants to 6% in certain vertebrates (Humitake, 1982). Most phosphorus occurs in cells as organophosphates with ionic phosphates. Micro-organisms and many animals decompose organo-phosphorus compounds in

dead material with the liberation of phosphates. Such phosphate is assimilated by plants and heterotrophic microorganisms for their phosphorus requirements.

All surface water supplies support growths of minute aquatic organisms such as the free swimming and floating organisms are called plankton. This is composed of both zoo plankton and phyto plankton. The latter are predominantly algae and since they are chlorophyll bearing organisms their growth is determined by the amount of fertilizing elements in the water. In aquatic environments, microbial activities play an important part in the solubilization and precipitation of phosphates. Phosphates precipitate in high pH waters and are soluble in low pH waters.

In certain euphotic zones primary production by phytoplantkton is restricted by a storage of available phosphates. In other euphotic zones of coastal regions or inland waters, extensive algal blooms develop and form redtides because of an excess supply of phosphates. Generally in most oligotrophic waters phosphorus is recognized as the limiting nutrient. In eutrophication of a water mass, there is a definite correlation between the degree of enrichment and two important factors, phosphate nutrient loading and mean depth of the water.

Although there is no firm criterion for phosphorus, it is generally considered that to eliminate excessive plant growth in rivers and streams, total phosphorus should not exceed 0.03 mg/L. To avoid nuisance concentrations of algae in lakes, average total phosphorus concentrations for the ice free period should not exceed 0.02 mg/L (Ministry of Environment-Ontario, 1989).

Domestic waste water is relatively rich in phosphorous compounds. Prior to the development of synthetic detergents, the content of inorganic phosphorous usually ranged from 2.0-3.0 mg/L and organic forms varied from 0.5 to 1.0 mg/L. Most of the inorganic phosphorous was contributed by human wastes as a result of the metabolic breakdown of proteins and elimination of the liberated phosphates in the urine. The amount of phosphorous released is a function of protein intake, for the average person in the US, it is about 1.5 g/day. Most of the synthetic detergents designed for household markets contain large amounts of polyphosphates. They contain from 12-13% phosphorous or over 50% polyphosphates (Humitake, 1982). The use of these materials as substitutes for soap has greatly increased the phosphorous content of domestic waste water. Domestic waste water now contains 2-3 times more inorganic phosphorous than before the detergents were introduced.

Today large quantities of detergents, containing the same compounds are used in water for laundering or cleaning since, these are major constituents of many commercial cleaning preparations. Detergents form layers of foam and prevent oxygen uptake of the water, disrupts the nitrification process and inhibits the breakdown of organic substances.

Industrial uses include phosphates added to some water supplies in the course of water treatment. Phosphates are also extensively used in the treatment of boiler waters, and in steam power plants to control scaling in boilers. These find their way into surface waters and pollute the water in addition to phosphates applied to commercial agriculture or residential cultivation of land as fertilizers, with storm water run off. Phosphates are also contributed to sewage in body wastes and food residues. Phosphates also occur in bottom sediments and in biological sludges both as precipitated inorganic forms and incorported into organic compounds.

Phosphorus data are becoming more and more important in environmental research because of its significance as a vital factor in life processes. In the past, the data have been used principally to control phosphate dosages in water systems for corrosion prevention and in boilers for control of scale. Today phosphorus determinations are extremely important in assessing the potential biological productivity of surface waters, and in many areas limits are being established on amounts of phosphorus that may be discharged to receiving bodies of water, particularly lakes and reservoirs. Phosphorus determinations are routine in the operation of waste water treatment plants and in stream pollution studies in many areas. Because of the importance of phosphorus as a nutrient in biological methods of wastewater treatment,

its determination is essential with many industrial wastes and in the operation of waste treatment plants.

Sulphate

Sulphur makes 0.026% of the total elemental composition of the earth's crust, and 0.0885% in sea water (Humitake, 1982). Sulphates may occur naturally in water and may be contained in industrial wastes. They are produced from the final oxidation stage of sulphides, sulphites and thiosulphates.

The sulphate ion is one of the major anions occurring in natural waters. It is of importance in public water supplies because of its cathartic effect upon humans when it is present in excessive amounts. For this reason the recommended upper limit is 250 mg/L in water intended for human consumption (Sawyer and McCarty, 1978). Sulphates are important in both public and industrial water supplies because of the tendency of waters containing appreciable amounts to form hard scales in boilers and heat exchangers. Sulphates are of considerable concern because they are indirectly responsible for two serious problems often associated with the handling and treatment of waste waters. These are odour and sewer corrosion problems resulting from the reduction of sulphates to hydrogen sulphide under an aerobic conditions.

In the absence of dissolved oxygen and nitrates, sulphates serve as a source of oxygen (or more correctly as an electron acceptor) for bio-chemical oxidations produced by anaerobic bacteria. Under anaerobic conditions the sulphate ion is reduced to sulphide ion which establishes an equilibrium with hydrogen ion to form sulphide. At pH values of 8.0 and above most of the reduced sulphur exists in solution as HS^- and S^2- ions, and the amount of free H_2S is so small that its partial pressure is insignificant, and odour problems do not occur. At pH levels below 8, the equilibrium shifts rapidly toward the formation of unionized H_2S (Hydrogen sulphide) and is about 80% complete at pH 7.0. Under such conditions the partial pressure of hydrogen sulphide becomes great enough to cause serious odour problems whenever sulphate reductions yield a significant amount of sulphide ion.

In many areas of the U.S. especially in southern states where the domestic waste water temperatures are high, detention times in the sewers are long, and the sulphate concentrations are appreciable. The crown corrosion of concrete sewers has been an important problem. The aqueous solution of H_2S, called hydrosulphuric acid has little effect on good concrete, but crown corrosion of gravity type sewers, for which H_2S is indirectly responsible does occur.

Many micro-organisms can utilize inorganic sulphate, SO_42^- as the sole source of sulphur to synthesize amino acids and other sulphur containing compounds. The assimilated sulphate is reduced to sulphite (SO_32^-), then to sulphide (HS^-) and finally to organic sulphurs. Sulphate reducing bacteria belonging to the genus *Desulfovibrio* reduces sulphate to hydrogen sulphide (H_2S) as the the product. The biological oxidation of hydrogen sulphide and of elemental sulphur is brought about by autotrophic bacteria which require oxygen. Reduced sulphur can be oxidized either anaerobically by colourless sulphur bacteria *thiobacillus* or *thioploca*, or aerobically by the photosynthetic purple and green sulphur bacteria *chromatium* or *thiopedia*. Bacteria capable of oxidising hydrogen sulphide into sulphuric acid are ubiquitous in nature and are always present in domestic sewage, and it is natural that they bring about strong acid attack on concrete as mentioned earlier.

Sulphide is formed by bacterial reduction of sulphate and organic sulphur compounds under anaerobic conditions. It is therefore commonly found in domestic waste water, industrial waste water, sludges, hypolimnions of stratified lakes and any aquatic system where anaerobic conditions prevail.

The sulphate content of natural waters is an important consideration in determining the suitability for public and industrial water supplies. The amount of sulphate in waste waters is a factor of concern in determining the magnitude of problems that can arise from reduction of sulphates to hydrogen sulphide. In anaerobic digestion of sludges and industrial wastes, the sulphates are reduced to hydrogen sulphide, which

is evolved with methane and carbon dioxide. A knowledge of sulphate content of the sludge or waste fed to digestion limits provides a means of estimating the hydrogen sulphide content of the gas produced and this is important in installation of scrubbing facilities. Many organic compounds contain sulphur as sulphates, sulphonates or sulfides. During aerobic treatment of such wastes complete utilization or dissimilation results in the release of the organically bound sulphur as sulphate ion. Sulphides also contribute to the oxygen demand of water and waste water. In the presence of anaerobic conditions sulphates are converted to sulphides in water and waste water. Sulphur compounds in waste water are a major problem for some food processors. The use of sulphur dioxide in pretreatment of fruits or sodium bisulphide in processing may result in sulphur content of waste water (Green *et al* 1979).

Sulphates and sulphides are also tested if the waste water is to be recycled in the plant, or outfalls upstream from a drinking water supply.

Suspended Solids (SS)

All matter except water contained in liquid material is classed as solid matter. The usual definition of solid refers to matter that remains as residue upon evaporation and drying at 103-105 °C (Sawyer and McCarty, 1978). Solids are classified as dissolved, undissolved, volatile, fixed, settleable, suspended and total solids. Solids enter the water courses from virtually every source, the most important are from sewage treatment plant effluents, municipal storm water drainage, industrial discharges and erosion. Solids significantly affect water uses. Highly turbid water is undesirable for municipal and industrial supply, fish and aquatic life, recreation and aesthetic reasons.

Suspended solids are the amount of solids in suspension, and corresponds to filterable residues and affects the water quality in many ways. Suspended solids lead to the blockage of drains and ditches if discharged without primary treatment, such as tannery wastes which contain hair and flesh, which causes problems. It also causes turbidity of the receiving waters as well as build up of bottom sediments, by settling and can therefore, affect the spawning grounds for fish, destroy fish food and inhibit propagation of fish. The visible pollution creates unsightly conditions preventing water to be used for bathing, washing and recreational and other purposes, and waste water treatment processes remove SS to minimize these problems. It can also wash up on the banks where their organic portion eventually decomposes undergoing putrefaction and causing odour. Suspended solids also enhance flooding of streams since the stream bed volume becomes diminished by the accumulation of sludge at the bottom of the water. It can also transport significant quantities of organic and inorganic trace contaminants. Waters with high residues are generally of inferior palatibility and induce an unfavourable physiological reaction. Highly mineralized waters are also unsuitable for many industrial applications. Water with higher solid content have a laxative and sometimes opposite effect upon people whose bodies are not adjusted to them.

The SS determination is extremely valuable in the analysis of polluted waters and sewage. It is one of the major parameters used to evaluate the strength of the domestic waters and to determine the efficiency of the biological treatment units. In larger treatment plants SS determinations are routinely done as a measure of the effectiveness of treatment units especially in activated sludges. In stream pollution control work all SS are considered to be settleable solids as time is not a limiting factor and deposition is expected to occur through biological and chemical flocculation. Therefore measurement of SS is considered fully as significant as BOD, and its removal as important as BOD removal. Where turbidity measurements are not adequate to provide information on water quality, SS monitoring becomes important.

5.3 Sampling

Selection of sampling sites

The choice of sampling sites is not an exact science (Nemerow, 1978). With vari-

ations in river conditions it is difficult to choose sampling points which are completely representative, but sampling sites have to be selected with care and with special consideration to sources of pollution, dilution or contribution by branch streams, changes in surrounding topography and slope of the river. A sampling point above all has to be representative of the water quality of the catchment under study. Monitoring stations are often chosen downstream of major pollutive or potentially pollutive sources such as industrial discharges, sewage outfalls, shanty colonies, agricultural areas, municipal water intake points and recreational areas, particularly bathing and swimming. Relatively unused sampling points upstream are also chosen to provide a comparison of water quality along the length of a waterway. Sampling stations also should be located as nearly as possible, at points of uniform cross section, non shifting bottom, minimum stream width and average stream velocity for practical purposes. In addition accessibility of sampling points, easy approach to the sampling site, such as bridges and roads, facilitate collection of uniform samples. The permanancy of a sampling site is also important i.e. as far as possible, sampling sites should not dry up during the dry periods. A minimum of four stream stations (sampling points) is recommended i.e. (1) an upstream site where water is uncontaminated, (2) just below source of pollution or dilution, (3) where stream is in the worst condition due to specific source of pollution such as bottom of an oxygen sag and (4) a point midway between bottom of an oxygen sag and oxygen recovery level (Nemerov, 1978), although closer the stations, the better understood the stream water quality becomes.

With these basic considerations monitoring sites were carefully selected along the San Sebastian canal, Beira lake, river Kelani and the tributary canals. The selected sites were at upstream and downstream of food industrial waste water discharge points, sites at shanty colonies, entry points of tributary canals into San Sebastian canal, a relatively unpolluted sampling point, upstream and downstream of San Sebastian canal entry into the river Kelani (from the river), and from a site where the east Beira enters the sea. The samples were collected from the bridges at mid stream, except near industrial discharges where bridges were not found. In such sites samples were collected from the bank by throwing the bucket tied to a rope into the mid stream. The samples from the industries were collected from waste water streams within the industrial production unit, or from sites outside the production unit, but within the industrial premises. All the samples were collected with a plastic bucket in the water bodies and a with a plastic bottle in the smaller industrial effluent drains. Sites were selected to represent Beira lake-San Sebastian canal-river Kelani as an inter-connecting entity. The total number of sampling sites monitered in the surface waters were 27. The sites are as follows,

San Sebastian canal, S01-S10
River Kelani, R01-R02
Beira Lake, U01-U02
Tributary canals
Maligawatte ela, T01
Kettarama ela, T02
Dematagoda ela, T03-T06
Kittampahuwa ela, T07-T10
Main Drain, T11-T13

In addition to sampling sites on the water bodies, food industries along the canal, lake, and the tributary canals which were directly discharging in to the water bodies were also selected for monitoring. Food industries which were not discharging directly into the canals, but of diverse nature such as with and without treatment facilities, multinational food industries within the industrial zone, fast growing exported oriented local food industries, industries geared mainly to the local market which were located in Colombo, within close proximity to the laboratory. Some of these were selected as supplementary industries to assess the strength of the food processing effluents.

Sample collection: type and method

Sample collection is one of the most important aspects of water quality and waste water monitoring. Without proper sampling collection techniques the results of any waste monitoring programme are not valid even when the most accurate analytical procedures are used (Green *et al* 1979). The sample must be representative of the entire monitoring programme. If the sample is carelessly collected, the purpose of sampling is defeated. Unrepresentative sampling may even be dangerous since it can give rise to unjustified confidence in quality of water. It may also cause unnecessary cost and unwanted health effects (Ministry of Environment - Ontario, 1983).

There are several types of sample collection techniques labelled by their method of collection and each has its own use depending on the purpose of collection (Green *et al* 1979). Two of these sampling techniques are for individual samples which measures instantaneous conditions of the waste stream, while the others are composite samples.

Individual samples such as **grab** or **discrete** samples measure instantaneous conditions that occur at a single moment of time. Both these sampling techniques have their advantage in waste water monitoring.

Grab sample

A sample collected at a particular time and place represents the composition of the source at that time and place only, but when the source is known to be fairly constant in composition over a considerable period of time or substantial distances in all directions, then the sample may be said to represent a longer time period or a larger volume or both, than the specific point at which it was collected. In such circumstances some sources may be well represented by single grab samples (Greenberg *et al* 1980). The grab sample serves some useful purposes, where individual samples for particular parameters require special handling, preservatives, or transport back to laboratory for immediate analysis; to avoid interactions which could affect results. Parameters such as pH, residual chlorine, dissolved oxygen, oil and grease microbial analysis, specific organic compounds such as sulphides or sulphites are best collected as grab samples (Green *et al* 1979). A grab sample is manually collected. Generally samples can be scooped out to obtain a larger volume for laboratory analysis. A clean wide mouthed bottle of about 200-300 mL is useful. The bottle should be immersed facing upstream and at approximately 0.4-0.6m (Green *et al* 1979) in depth to avoid obtaining a disproportionate amount of floating material such as grease and oil or settleable solids from the bottom. To achieve a good mixing of grab samples buckets can be used. A bucket of waste water is removed and vigorously stirred or poured back and forth between two buckets to achieve mixing, a sub sample is removed for laboratory analysis. A two litre sample is sufficient for most physical and chemical analysis (Ludwig, R.G. 1980). About 2-3 litres of sample was collected for laboratory analysis.

Composite samples

In most cases the term **composite** sample refers to a mixture of grab samples collected at the same sampling point at different times (Greenberg *et al* 1980). In composte sampling individual samples taken on some defined schedule are pooled into one container. Variations in composite sampling range from simple composite to flow proportioned composites regulated automatically. This can be done manually too. The sequential composite sampling method combines the advantages of both discrete and composite sampling, where a sub sample in an overall sample collection programme is collected at short intervals such as hourly to detect a heavy intermittent load, which otherwise will be missed.

Discrete samples

A discrete sample measures the instantaneous conditions of a waste water stream. The sample is collected and kept in separate containers, but is a part of a series of samples collected on a periodic or proportional to flow basis. This can be either collected manually or by an automatic sampler.

Integrated samples

For certain purposes, the information needed is provided best by analysing mixtures of grab samples collected from different points simultaneously. Such mixtures are called integrated samples (Greenberg *et al* 1980). Need for such sampling arises in a river or stream that varies in composition across its width and depth. Preparation of integrated sample usually require special equipment to collect a sample from a known depth without contamination with overlying water.

Although composite samples were more representative for certain parameters and particularly industrial waste water monitoring this was not resorted to due to certain limitations. The preparation of a composite sample involves collection of waste water at regular intervals during a day (the more samples, the better it is), the storage of these samples at a temperature less than 5 °C to prevent biochemical reaction and eventual mixing of all samples collected on that day. The main restrictions to this were non availability of adequate storage facilities at sites of collection, limited cooperation from industries, limited time, supporting labour and the necessary instruments for sampling.

Hence, grab samples were collected from the surface waters and industries. The sample collection started at about 08.30 hours and terminated by about 14.00 hours each day. Sample collection started at the Beira lake, through the San Sebastian canal and terminated at the Kelani river sites. The tributary canals, and the industries, both the directly discharging and the supplementary industries were monitored on separate days. The lake site U02, was sampled on the same days as the food industry on the lake. The samples were brought to the laboratory immediately for analysis. The sample collection in the supplementary industries took longer time because of the distance from the laboratory and the time taken in transporting the samples to the laboratory. The samples were transported as soon as possible to the laboratory since certain parameters needed immediate analysis.

Time of sampling

The time of the year is of utmost importance in stream sampling as the receiving streams should be sampled under the most critical conditions (Nemerow, 1984) likely to be encountered at the lowest stream flow, highest river temperature and maximum flow of industrial wastes and therefore higher pollution concentration. Since it is not possible to sample under these three extreme conditions simultaneously, the stream is usually sampled under the most critical conditions, existing during hot, dry weather. These critical conditions occur during the driest months. The chemical quality of water in the water body too may change seasonally or in response to weather conditions. (Ministry of Environment-Ontario, 1983).

In Colombo, the study area the weather pattern is more influenced by the rainfall regimes, and was thus monitored throughout the year in 1986, and in January and February 1987. The research area experiences both high seasonal rainfall and short dry spells. Therefore to see the effect on the the concentration and dilution of the pollutants, monitoring was done regularly throughout the year. February, the driest month in Colombo, was monitored twice (1986 and 1987) to observe pollution concentration under the most critical dry weather conditions, when the mean monthly rainfall approaches zero and the temperature is also high. Therefore monitoring was carried out for a period of 14 months, commencing on 9.1.1986 and terminating in 28.2 1987.

Sampling time could not be adjusted as the laboratory was opened only till 16.00 hours. This was a severe limitation particularly on the monitoring of industrial waste water discharges. Monitoring of the variation in the effluent load, over a 24 hour period was not possible. For example if a heavy polluting load is released at the time of sampling, it may be detected in the analysis, but if these loads were discharged in the evening these peak discharges would go undetected. The day of the week has been constantly altered, in the monitoring programme with a view to detect pollutants.

Frequency of sampling

The higher the frequency of sampling, higher is the degree of resolution. It is im-

portant to note that a single sample is of limited value, since the most a single sample can show is water quality at the time of examination. Therefore, repeated sampling is necessary to get an adequate knowledge of the water quality (Ministry of Environment, 1983), and the pollution condition in the canal. Common frequencies range from yearly, monthly, weekly, daily, even hourly or less in the case of some industrial effluents (Ludwig, 1980). The necessary frequencies depend on the desired degree of statistical confidence, objective of sampling programme, and the type of parameters measured in addition to the other limitations within the sampling programme.

Initially it was intended to monitor the San Sebastian canal on a weekly basis, but due to various problems, especially during the first two months of the sampling programme the canal sampling was done on an average of once in ten days (three times per month) on the San Sebastian canal, river Kelani and and site U01 on the Beira lake. Sampling was done on a monthly basis in the tributary canals of Orugodawatte, Dematagoda ela (north and south), Kettarama, Maligawatte and Kittampahuwa ela. The site U02 on the lake had a monitoring frequency of 15. The Main drain was monitored 17 times during the research period. The monitoring was limited to monthly sampling in the industries that discharged directly into the San Sebastian canal and the Beira lake. The factories E and F were monitored 17 times each. The supplementary industrial group was monitored 6 times each during the research period. This was due to the reserved attitude and partial cooperation with the sampling programme shown by certain industries in addition, to the limitations of carrying out an intensive and a tight scheduled sampling programme. Monitoring in certain industries were strictly confined to waste water drains within the premises but outside the main production line. Although this gave the total strength of the effluents from the entire production process in an industry, the strength and characteristics of individual processes within an industry was not measured. The recommended annual sampling frequency can be seen in table 5.2.

Table 5.2 — Recommended annual sampling frequencies: GEMS/WATER programme

Station type	Rivers	Lakes
Baseline station	4-12	4
Impact stations:		
Drinking	12-24	6-12
Irrigation	12	2
Aquatic life	12	6
Multiple impact	12	4
Trend stations	12-24	2-6

Source: WHO, (1983a)

Total number of samples

The total number of samples monitored depends on the objective and the amount of time and effort available. The use of few locations and enough samples to define the results in terms of statistical significance is much more reliable than using many stations with only a few samples from each, therefore concentration on a well defined, frequent and intensive sampling programme is recommended. A minimum number of samples are generally accepted for reliable analysis and predictions. If a dissolved oxygen profile during low flow is to be determined 2-3 samples during low flow are sufficient. Four to six river samples are generally acceptable (Nemerov, 1978). However industrial processing is usually so varied and unpredictable, that many samples

of the receiving water under all conditions becomes necessary to evaluate truly the effect of a waste upon a stream.

Collection and preservation of samples

The result of any test procedure depends on the sample on which it is performed. The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the water being sampled. This implies that the relative proportions or concentrations of all constituents will be the same in the sample as in the material being sampled and that samples will be handled in such a way that no significant changes in composition occur before the tests are made.

In a sampling programme certain general precautions have to be taken, to meet the requirements of the sampling programme and the sample must be handled in a way that it does not deteriorate or become contaminated before it reaches the laboratory. Bearing this in mind the sample collection bottles and glassware were thoroughly rinsed before use. While collecting samples, the sample bottles were rinsed out with the sample itself twice. Every sample collected was carefully identified, labelled and recorded in every bottle with date, time, hour and the exact location. Bottles were cleaned with detergents and then rinsed with tap water. Prior to analysis the glassware were rinsed with distilled water except for phosphate determinations where acid washed glassware was used. Distilled water had to be used very sparingly due to limitations in the water supply. It had to be transported even from other laboratories frequently. The reagents used were of analar grade representing the best quality chemicals.

Sample preservation

Complete and unequivocal preservation of samples in domestic, industrial waste waters or natural waters, is a practical impossibility and complete stability for every constituent can never be achieved. Preservation techniques only retard chemical and biological changes that inevitably continue after sample collection. It also retards hydrolosis of chemical compounds and complexes and reduces the volatility of the constituents. Sample preservation is difficult because almost all preservatives interfere with some tests. Immediate analysis is ideal, but due to practical impossibilities, storage at low temperature (4 °C) is the best way to preserve most samples, until the next day. But chemical preservatives have to be used if the analysis takes a longer time, or due to unforeseen problems encountered. Preservation methods are limited to pH control, chemical addition, refrigeration and freezing. The temperature changes quickly, pH changes significantly, dissolved gases like dissolved oxygen may be lost and in such cases determinations have to be done insitu in the field. In general shorter the time that elapses between sample collection and analysis the more reliable is the analytical results. It is impossible to say how much time may be allowed between sample collection and its analysis, as this depends on the character of the sample, analysis to be made and the storage conditions, but certain guidelines are set for sample preservation; and in accordance with these guidelines, samples were preserved according to standard methods (Greenberg *et al* 1980) as far as possible.

Sample volume

The volume of sample collected should be sufficient to perform all the required analysis in addition to provide for any sample spillage or for repeat examinations. 2-3 litres of samples were collected.

5.4 Industrial waste water monitoring

The effects of industrial waste water discharges are felt more intensely on the receiving waters than any other source of pollution because of the strength and volume of these wastes. This is especially true of the effluents from the food processing industries, which provides organic matter that serves as food for micro-organisms living in the receiving waters. The high organic content in the wastes exert a strong oxygen demand causing depletion of oxygen in the receiving water.

An industrial waste water monitoring programme was carried out on a wide range of food industries as possible, based on the the waste water characteristics and and their probable impact on the receiving water. The major criteria considered in selecting the industries was the food industries that discharge directly into the San Sebastian canal and the other surface waters which connect the canal. Few food industries outside the area were selected to supplement these industries. The industries also had to be selected within fair distance to the laboratory since certain parameters needed immediate analysis such as dissolved oxygen, pH and water temperature. Therefore proximity to the laboratory was another deciding criterion, the selected industries fell within and outside the Colombo city limits. A problem encountered in selecting a wider range of industries was that, although these existed in the official records of the Department of Census and Statistics and the Industrial Development Board, on preliminary visit to these industries were found to have shifted premises or closed down. Cooperation from the industries too had to be considered, although on subsequent monitoring visits there was reluctance and disheartened cooperation by the industries. Monitoring at one of the selected industry had to be abandoned due to civil disturbances, this was the jam factory of the A group which was monitored only once, after which it was bombed and discontinued production.

The industrial monitoring programme was made feasible purely because of being attached to the departmental laboratory of the Division of the Occupational Hygiene, which had the authority to visit the factories. Inspite of these advantages there were limitations on the total access to the industries concerened (even at U01 and S10 which are surface water sites that were controlled areas by the Ports Authority and the check point of the Petroleum Corporation respectively). In certain large scale industries permission was not given to enter the production areas and therefore waste water samples had to be collected from the factory drains which were outside the production areas but within the factory premises. The samples were representative in the fact that the waste waters originated from the processes within the factory but the ongoing process was never known. The disadvantage in the inaccessibility to the production area was that the samples from the various processes within the plant could not be collected and therefore a composite sample was not possible. Therefore grab samples were collected which gave the total strength of the samples at the time of monitoring, although a composite sample would have been more useful to assess the variability of the effluent.

Waste waters from ten industries were monitored for the eleven parameters. Of this factory D was a non food industry and B, although not a purely food industry, it was a coconut oil based industry. The food industries directly discharging into the canal and the lake were monitored monthly while the other four supplementary food industries were monitored once in two months. Most of these industries had sub departments producing various food products. Where there were more than one department samples were taken from some of the departments too.

As far as possible sampling was done on alternative days of the week. This gave the varialibility in the effluent strength to a certain extent. Photographs were not allowed in certain factories. As the research was carried out during the height of the the civil disturbances even the sampling material were subject to rigorous security checks. At many instances it was eyed with suspicion. Monitoring of industries became mandatory since there were hardly any comprehensive monitored data on food effluents. Even the available data did not cover most of the parameters. Although initially weekly monitoring of the industries were planned, due to inaccessibility, the frequency of industrial monitoring had to be changed. Thus in the main group of industries only monthly sampling was possible.

In the entire programme the COD, BOD, pH, sulphates, DO, water temperature, turbidity, conductivity, SS, total N and total P were monitored on the San Sebastian canal, tributary canals, Beira lake, the Kelani river and the industries. The data was virtually non-existent for these parameters and therefore self monitoring had to be done.

A statistical analysis was done on the laboratory analysed results.

5.5 Analytical Methods

The analytical methods adopted for testing of water pollutants are standard methods used for examination of water and waste waters, and were carried out in accordance with the latest edition of standard methods (Greenberg *et al* 1980). These methods were used because they satisfy the following criteria:

(a) These methods are sufficiently tested to establish their validity and are widely used in most laboratories of the world both in the temperate and the tropical countries.

(b) They give good measurement of the required parameter, precision and accuracy even in the presence of interferences normally encountered in polluted waters.

(c) The methods use simple equipment readily available in an average water pollution monitoring laboratory.

(d) The methods are fairly rapid and can be performed routinely for the examination of a large number of samples.

(e) The methods are constantly revised and the methodology constantly improved.

Other standard specified methods were used when the necessary equipment was not available to carry out methods recommended by the American Public Health Association (APHA). Such tests were sulphates, using volumetric method according to approved methods for physical and chemical examination of water (Hoather, *et al* 1960) and nitrogen determination based on the Kjeltec Auto Manual.

All the analyses (surface waters and industrial samples) were carried out in the water laboratory, Division of Occupational Hygiene, of the Department of Labour (Jawatte, Colombo) Sri Lanka, except the nitrogen determination which was carried out in three laboratories i.e. sample preparation at the Occupational Hygiene laboratory, digestion of sample at the Nuffic Laboratory Department of Geography, University of Colombo; and the distillation and titration in the laboratory of the Department of Chemistry, University of Colombo. This was due to malfunctioning of the apparatus necessary for nitrogen determination (Kjeldhal) at the Division of Occupational Hygiene. Phosphate determination was partially carried out at the chemistry laboratory of the Colombo University, when the SP 500 spectrophotometer of the Occupational Hygiene Laboratory was malfunctioning for some time and was under repair. The phosphate samples were prepared, digested and the colour developed at the Occupational Hygiene, while the DMS-90 UV spectrophotometer of the Chemistry Department, Colombo University was used for determining the sample absorbance.

5.5.1 Dissolved Oxygen (DO)

The analysis of dissolved oxygen in national and waste waters is a key test in water quality analysis, pollution control and waste treatment control and process. Two methods for dissolved oxygen analysis are recommended: Winkler or iodometric method and electro metric method using the membrane electrodes (Greenberg *et al* 1980). The iodometric method is a titrimetric procedure based on the oxidising property of dissolved oxygen while the membrane electrode procedure is based on the rate of diffusion of molecular oxygen across a membrane. The choice of the test procedure is dependent on the interferences present, accuracy desired and in some cases convenience or expedience. The Winkler titration has been the prefered method for dissolved oxygen determination for many years for its reliability, although tedious. The basis of this analysis is the quantitative oxidation of alkaline manganous hydroxide by the oxygen in the sample. Upon acidification in the presence of excess iodine, an amount of iodine equivalent to the dissolved oxygen is released. The iodine can then be titrated with standard sodium thiosulphate of the methods for dissolved oxygen analysis. The Winkler or Iodometric test remains the most precise and reliable titrimetric procedure for dissolved oxygen analysis. Among the several modifications of the Iodimetric method, the widely used procedure is the azide modification which

minimizes the effect of interferences present in the sample

Winkler azide modification method

Reagents

(a) Manganous sulphate solution:
480 gr $MnSO_4.4H_2O$, 400 gr $MnSO_4.2H_2O$ (alternatively 364 gr $MnSO_4.H_2O$) was dissolved in distilled water and diluted to 1 litre.

(b) Alkali-iodide-azide reagent:
500 gr $NaOH$ and 135 gr NaI (or 150 gr KI) was dissolved in distilled water and diluted to 1 litre. 10 gr sodium azide NaN_3 dissolved in 40 mL distilled water was added.

(c) Concentrated sulphuric acid (H_2SO_4)

(d) Starch:
Aqueous solution was prepared by adding 5 gr of soluble starch in cold water suspension to 800 mL boiling water, diluted to 1 litre and settled overnight and preserved with 1.25 gr of salicylic acid.

(e) Sodium thiosulphate stock solution 0.10N:
24.82 gr $Na_2S_2O_3.5H_2O$ was dissolved in boiled and cooled distilled water and diluted to 1 litre. This was preserved by adding 5 mL chloroform.

(f) Standard soldium thiosulphate titrant 0.0250N:
250 mL sodium thiosulphate stock solution was diluted to 1000 mL and preserved with 5 mL chloroform.

Procedure

2 mL of manganous sulphate solution was added to 100 mL sample, followed by 2 mL alkali iodide azide reagent, stoppered carefully to exclude air bubbles and mixed by inverting the bottles several times. When the precipitate settled 2.0 mL concentrated sulphuric acid was added and mixed by inversion until dissolution of the solution was complete. 100 mL of sample was titrated with thiosulphate solution to colourless end point adding starch indicator when pale straw (yellow) colour was reached.

DO was fixed immediately in the field by adding 2 mL manganous sulphate solution and 2mL alkali iodide azide reagent. The rest of the procedure was carried out in the laboratory immediately on the same day. Samples were collected in narrow mouth glass stoppered BOD bottles. The bottles were allowed to overflow leaving no air bubbles trapped. They were stoppered and sealed with plastic caps. Samples were done in triplicate.

5.5.2 Biochemical Oxygen Demand (BOD)

The BOD is an emphirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewaters, effluents and polluted waters. The test measures the oxygen required for biochemical degradation of organic material and the oxygen used to oxidize inorganic materials. The method consists of placing a sample in a full, air tight bottle and incubating it under specified conditions for a specific time. Dissolved oxygen is measured initially and after incubation. The BOD is computed from difference between initial and final dissolved oxygen.

Reagents

(a) Phosphate buffer solution:
8.5 gr KH_2PO_4, 21.75 gr K_2HPO_4, 33.4 gr $Na_2HPO_4.7H_2O$ and 1.7 gr NH_4Cl were dissolved in distilled water and diluted to 1 litre.

(b) Magnesium sulphate solution:
22.5 gr $MgSO_4.7H_2O$ was dissolved in distilled water and diluted to 1 litre.

(c) Calcium chloride solution:
27.5 gr $CaCl_2$ was dissolved in distilled water and diluted to 1 litre.

(d) Ferric chloride solution:
0.25 gr $FeCl_3.6H_20$ was dissolved in distilled water and diluted to 1 litre.

Dilution water

Experience has showed that synthetic dilution water prepared from distilled or demineralized water is best for BOD testing. Before use the distilled water was aerated for about two hours to saturate it with oxygen.

Procedure

1mL phosphate buffer solution, 1mL magnesium sulphate reagent, 1mL calcium chloride solution, 1mL ferric chloride solution and 1mL seed and a volume of sample depending on the dilution were pipetted into a 1 litre volumeric flask and made up to 1 litre with aerated distilled water. The seed of microbial population was obtained from a domestic waste water drain near the laboratory, and was settled before use. The necessary dilutions were calculated for determination of BOD, depending on the strength of the wastewater. The stronger the waste water the higher is the dilution necessary. The COD values were used as a guide in selecting dilutions, as COD can be correlated approximately with the BOD (Greenberg *et al* 1980). Three different dilutions for one set of sample was done in triplicate. 3 blanks were prepared with nutrients and seed, but without sample, in 1 litre of aerated water.

The prepared solutions were transferred into BOD bottles, allowing it to overflow the mouth, to prevent trapping of air bubbles, stoppered and sealed with plastic water seal caps.

DO was determined from each dilution and a blank immediately on day one, and the rest of the BOD bottles were incubated in a Gallenkamp BOD incubator controlled at 20 °C. The residual DO was determined on the fifth day after incubation.

Calculation:

$$mg/L\ BOD = (D_1 - D_2) - (B_1 - B_2) \times dilution$$

D_1 =dissolved oxygen of the sample on day one.
D_2 =dissolved oxygen of the sample on day five.
B_1 =dissolved oxygen of the blank on day one.
B_2 =dissolved oxygen of the blank on day five.

The BOD analysis was done immediately after samples were brought to the laboratory from the sites. When this was unavoidable samples were stored below 4 °C.

5.5.3 Chemical Oxygen Demand (COD)

The COD is a measure of oxygen equivalent to the organic matter content of a sample susceptible to oxidation by a strong chemical oxidant. The dichromate reflux method is preferred over the other methods because of its superior oxidizability and applicability to a wide variety of samples. When there was a delay in analysis the sample was preserved by acidification to pH 2 with sulphuric acid (H_2SO_4).

Dichromate Reflux Method

Reagents

(a) Standard potassium dichromate solution 0.250N: 12.259 gr $K_2Cr_2O_7$ previously dried for two hours at 103 °C was dissolved in distilled water and diluted to 1000 mL.
(b) Silver sulphate:
Ag_2SO_4 powder.
(c) Sulphuric acid reagent:
22 gr Ag_2SO_4/4 Kg bottle of concentrated H_2SO_4 was added and allowed to dissolve.
(d) Concentrated sulphuric acid (H_2SO_4).
(e)Ferroin indicator solution.
(f) Standard ferrous ammonium sulphate titrant 0.25N:
98 gr ferrous ammonium sulphate was dissolved in distilled water. 20 mL concentrated H_2SO_4 was added, cooled and diluted to 1 litre. This solution was standardised daily against a standard potassium dichromate solution, by diluting 10 mL standard potassium dichromate solution to 100 mL, to which 30 mL concentrated H_2SO_4 was

added and cooled. This was titrated with ferrous ammonium titrant using 2-3 drops of ferroin indicator. The normality of ferrous ammonium sulphate solution is:

$$\frac{Volume\ 0.25N\ K_2Cr_2O_7\ solution\ titrated,\ mL \times 0.25}{Volume\ of\ Ferrous\ Ammonium\ Sulphate\ used\ in\ titration,\ mL}$$

(g) Mecuric Sulphate-$HgSO_4$ powder was used.

Procedure

0.4g mercuric sulphate ($HgSO_4$) was placed in a reflux flask. 20mL sample or aliquot diluted to 20mL with distilled water was added and mixed, to which 10 mL standard potassium dichromate was added and a few glass beads. 30 mL concentrated H_2SO_4 containing silver sulphate was carefully added to the solution cooled and refluxed for two hours. This solution was cooled, condenser washed down with distilled water and diluted to 100 mL and cooled to room temperature. The excess dichromate was titrated with standard ferrous ammonium sulphate using 2-3 drops of ferroin indicator. The end point of the titration was taken as first sharp colour change from blue green to reddish brown. A blank containing 20mL distilled water and the reagents was refluxed and titrated in the same way. Samples were run in duplicate.

Calculation:

$$mg/L\ DV = \frac{(a-b)C \times 8000}{mL\ sample}$$

where,
a = titration for blank
b = titration for sample
c = normality of ferrous ammonium sulphate

5.5.4 Total N

In wastes and waste waters, the detection of nitrogen is important. Although nitrogen in its reduced forms can be detected separately and are more useful for individual purposes, due to unavailability of necessary instruments, nitrogen in its total form was analysed. Digestion was carried out in a micro Kjeldal while distillation and titration was done in a Kjeldal 1030 auto analyser.

Procedure

150 mL of sample was placed in a digestion tube to which 4 grams of copper sulphate catalyst and half a tablet of Kjeltab selenium catalyst were added. 5mL of concentrated sulphuric acid was added to the solution and mixed carefully by swirling the tube. The sample was digested at 420 °C in a fume cupboard, until the liquid left was green and free of black particles (to about 10 mL). When cooled, 75 mL of distilled water was added. 50 mL of this sample was fed into the auto analyser for distillation and titration. Samples were duplicated and a blank was run in the same way.

$$\%N = \frac{(a-b) \times M \times 1.401}{Volume\ of\ sample}$$

where,
a=Volume of HCl used in the sample titration.
b=Volume of HCl used in the titration of the blank.
M=Molarity of HCl which is 0.1.

$$(1\%N = 10000\ ppm\ or\ mg/L)$$

Therefore,

$$mg/L\ N = \%N \times 10000$$

5.5.5 Total P (PO_4)

Total phosphate was determined by digesting the sample using sulphuric acid-nitric acid digestion procedure, to release the phosphate from combination with organic matter. (The total phosphate content of the sample includes ortho, condensed, soluble, insoluble organic and inorganic forms of phosphate). The nitric acid-sulphuric acid digestion is recommended for most samples (Greenberg *et al* 1980). After digestion of the sample, total P was determined by using vanadomolybdic acid colorimetric method. Glassware previously washed with hot dilute HCl was used.

Sulphuric Acid-Nitric acid digestion

Reagents:

(a) Sulphuric acid, concentrated H_2SO_4.
(b) Nitric acid HNO_3 conc.
(c) Phenolphthalein indicator solution.
(d) Sodium hydroxide, $NaOH$, 1N

1 mL concentrated H_2SO_4 and 5 mL concentrated HNO, was added to 50 mL sample in a micro Kjeldahl flask and a few glass beads added. The solution was digested to a volume of 1mL The digestion was continued till the solution became colourless. After cooling, approximately 20mL of distilled water, 1 drop of phenolphthalein and 1N NaOH were added to bring the solution to a faint pink colour. It was neutralized with a drop of dilute HCl to remove the pink colour. The neutralized solution was transferred to a 100mL volumetric flasks. Turbid samples were filtered, and filter washings were added to the flasks. The sample volume was made up to 100mL with distilled water. A blank using distilled water instead of the sample was run using the same procedure.

After digestion total P present was determined using vanadomolybdic acid colorimetric procedure.

Reagents

(a) Phenolphthalein indicator solution
(b) Concentrated Hydrochloric acid, HCl
(c) Activated carbon
(d) Vanadomolybdate reagent

25 grams of ammonium molybdate was dissolved in 400mL distilled water. 1.25 gr of ammonium metavanadate was dissolved by boiling in 300mL distilled water. This was cooled and 330mL HCl was added. Ammonium molybdate solution was poured into this and diluted to 1 litre.

(e) Standard phosphate solution. 219.5mg anhydrous potassium dihydrogen phosphate dried at 100 for 1 hour was dissolved in distilled water and diluted to 1 litre.

Procedure

pH of the sample was corrected when it was outside the recommended range of 4-10. Excess colour when present was removed with activated carbon.

Colour development

35mL sample was placed in a 50mL volumetric flask, 10mL vanadate molybdate reagent was added and diluted to 50mL with distilled water. A blank was prepared using the same procedure in which 35mL of distilled water was used instead of the sample. The solution was left for about 10 minutes for colour development. A yellow colour developed, its intensity giving the phosphate concentration. After 10 minutes absorbance of the sample was measured against the blank at a wavelength of 470 nm. in a SP 500 spectrophotometer or DMS-90 UV spectrophotometer, when the former was malfunctioning.

Calibration curve

A calibration curve was prepared by using suitable volumes of standard phosphate solution to cover the range of PO_4 present using the same procedure. A blank was run in the same way. Sample absorbance was read against the calibration curve and PO_4 was recorded in mg/L.

When the spectrophotometer, SP 500 was malfunctioning the absorbance was determined at the Colombo University (Chemistry Department), although the samples were prepared, digested and the colour developed at the Occupational Hygiene Laboratory.

5.5.6 Suspended Solids (SS)

100mL of well mixed sample was filtered through GF/C glass fibre filter paper, which was previously dried and weighed. The filter paper was dried at 103-105 °C in an oven for 1 hour, cooled in a dessicator and re-weighed.

Calculation:

$$SS\ mg/L = \frac{(A - B) \times 1000}{ml\ sample}$$

where
A = weight of the filter paper plus the residue
b = weight of the filter paper.

5.5.7 pH

pH can be either measured colorimetrically or electrometrically. Though less expensive, the colorimetric method of measurement suffers from interferences. The glass electrode method has become the standard technique because of this.

An EIL portable pH meter model 3030 was used for the glass electrode method. The electrode system was calibrated with buffer solutions with pH approximating that of the sample. Fresh buffer solutions were prepared regularly, within 2 or 3 weeks and was stored in pyrex glassware. The reference electrodes tips were kept immersed in distilled water. Before use the electrodes were rinsed with distilled water. The instrument was standardized with electrodes immersed in the buffer solution. The pH of the sample was then measured by immersing the electrode in the sample. The samples were agitated for homegeneity and to keep solids in suspension. Electrodes were rinsed and kept immersed in water until the next measurement.

5.5.8 Conductivity

Conductivity was measured with a Hach's conductivity meter and reported in μmhos/cm.

5.5.9 Water temperature

Temperature was measured with a mercury filled celsius thermometer with a scaling for every 0.1 °C. Temperature was measured on the site and reported in °C.

5.5.10 Turbidity

Turbidity can be measured by different methods. The Nephelometric method is preferred to the visual methods due to its great precision, sensitivity and applicability over a wide range of turbidities.

Turbidity was measured with a Turbidity meter. The meter was Hach's Turbidity Model 2100A. For turbidity of over 100 NTU it was standardized with Formazin standard reference solution. All samples were shaken vigorously before measurement. The results were reported in NTU units.

5.5.11 Sulphate (SO_4^-)

A more tedious volumetric method to determine sulphates was used instead of the gravimetric method. This is due to the malfunctioning of the muffle furnace necessary for ignition at a high temperature if gravimetric method was used. The titrimetric method used was an approved and reliable method for sulphate analysis (Hoather, *et al* 1960).

Reagents

Titrating solution:

4 gr of EDTA was dissolved in 1 litre of distilled water. This was standardized by titrating against the $BaCl_2$ standard solution using the buffer solution.

Buffer solution:

pH = 10

67.5 gr of pure NH_4Cl was mixed with 570mL of NH_4OH(d:0.88) and diluted to one litre with distilled water.

Indicator solution:

A small quantity of Erichrome Black T was dissolved in 2mL distilled water by shaking, warmed and finally cooled. Though this solution was stable for days, fresh solutions were prepared daily.

$BaCl_2$ Standard solution

2.443 gr of $BaCl_2$ was dissolved in distilled water and diluted to one litre. 1 mL of this solution is equivalent to 1mg of $CaCO_3$ or 0.96 mg of SO_4^-. (Normality of $BaCl_2$ is 0.01N).

$$1mL\ 0.01M\ EDTA \equiv 0.961mg\ SO_4^-$$

$$1mL\ 0.01N\ BaCl_2 \equiv 0.96mg\ SO_4^-$$

Procedure

100mL of sample was neutralized with 1N HNO_3 adding a slight excess and was boiled to expel CO_2. 10mL (slightly more if required) of $BaCl_2$ standard solution was added to the boiling sample and cooled. The cooled sample was diluted to 150 mL, and the precipitate was allowed to settle. 50 mL of clear supernatant was withdrawn. 0.5-1.0 mL of buffer solution and several drops of indicator solution was then added. This solution was titrated with EDTA to blue colour. The end point did not change by adding further drops of EDTA.

Colour change was from red (almost purple) to dark blue. A blank was run along with the samples.

Calculation:

$$SO_4^- \ mg/L = \frac{0.961 \times Normality\ of\ EDTA \times ml\ BaCl_2 \times 1000}{0.01 \times Sample\ Volume}$$

5.5.12 Biological analysis

Biological analysis was done for one set of canal samples by the Medical Research Institute, Colombo (MRI) for faecal coliform. Though the Occupational Hygiene had the facilities for microbiological research, the laboratory section was non functional at the time of research.

Supplementary data

Supplementary hydrological and meteorological data were obtained from official records of government departments such as water levels, and rainfall. Waterloss, flow rate, velocity and discharge volume of the canals were not available. Certain socio-economic statistics too was obtained from official records.

Others

The terms **strong** and **strength** in relation to waste water were used frequently in the text. In environmental engineering this term is very commonly used to indicate the high concentration of the pollutants.

Chapter VI

Data analysis

6.1 The sampling procedure in the inland surface waters

A chemical and physical analysis was done in the system of surface waters. A few selected industrial waste water discharges from the food and drink industries were also analysed. The water samples were analysed for dissolved oxygen (DO), water temperature, pH, conductivity, turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), sulphates, total nitrogen (total N), total phosphorus (total P) and suspended solids (SS), for a period of 14 months between the period January 1986 and February 1987 both inclusive.

Figure 6.1 shows the sampling points in the surface waters (and industries) and appendix A explains the sites in the San Sebastian canal. Ten sampling sites (S01-S10) were selected along the San Sebastian canal, and the samples were monitored at a frequency of 3 per month (except in January and February 1986, when only 2 samples were monitored per month), which occurred on the average once in 10 days. This totalled to 40 samples per parameter for DO, water temperature, pH, conductivity, turbidity, COD, BOD and SS. Also monitored were 39 sulphate samples, 14 total N and 27 total P samples were monitored. Total N was monitored once a month except in October 1986 and January 1987 when two samples per month was done. Total N was not monitored in January and February 1986. The total P was monitored twice a month except in January 1986, when it was monitored only once. Other than the sulphates, total N and total P, all the other pollutants were monitored regularly which amounted to 40 samples per parameter per site along the San Sebastian canal, the river Kelani and the site U01 on the Beira Lake. The frequency of monitoring can be seen in table 6.1.

The river Kelani was monitored at 2 sites upstream and downstream of the entry point of the San Sebastian canal into the river. The monitoring frequency was similar to the San Sebastian canal. The Beira Lake was monitored at two points. The sampling of the site U01 on the Lake was similar to the San Sebastian canal. In the site U02 on the lake, 15 samples per parameter for DO, water temperature, pH conductivity, turbidity COD, BOD, sulphates, total P and SS were monitored. Total N was not monitored in January and February 1986. All the parameters were monitored once a month except in October 1986 when water samples were monitored twice a month.

The aggregate sampling per parameter in the surface waters can be seen in table 6.2. A total of 400 samples each for DO, water temperature, pH conductivity, turbidity, COD and BOD; 390 samples for sulphates, 140 samples for total N, and 270 samples for total P were monitored in the San Sebastian canal. This aggregated to 4000 samples for the 10 sites along the San Sebastian canal for the entire monitoring period. This total when categorized into the parameters monitored, accounted to a total of 400 DO samples, 400 water temperature samples, 400 pH samples, 400 conductivity samples, 400 turbidity samples, 400 COD samples, 400 BOD samples, 390 sulphate samples, 140 total N samples 270 total P samples and 400 SS samples monitored on the San Sebastian canal.

Table 6.1 shows the number of cases sampled in the river sites and the lake sites. Appendix B explains the sites of monitoring. On the river Kelani a total of 80 samples each for DO, water temperature pH, conductivity, turbidity, COD, BOD SS and 78 sulphate, 28 total N and 54 total P were monitored for the two sites. This aggregated to 800 samples on the river. This is seen in Table 6.2. Similarly on the Beira lake 55 samples each for DO, water temperature, pH, conductivity, turbidity, COD, BOD, SS and 54 sulphates, 27 total N and 42 total P samples were analysed. This aggregated to 563 samples for both the sites on the lake during the period of research. This can be seen in table 6.2.

The monitoring programme commenced on 9.1.1986 on the San Sebastian canal, river Kelani and the site U01 on the Beira lake and ended on 24.2.1987. The sampling

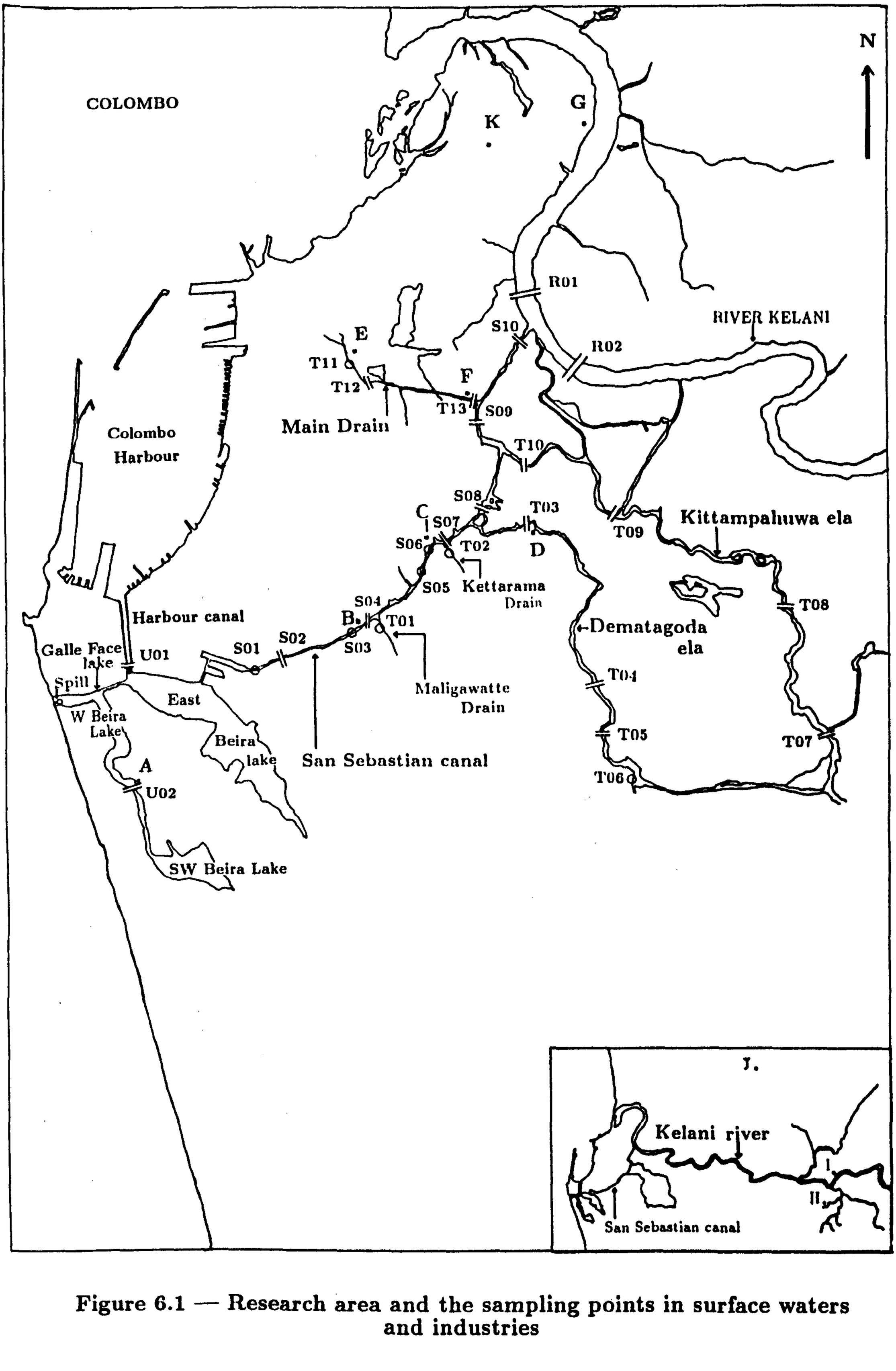


Figure 6.1 — Research area and the sampling points in surface waters and industries

Source: Field monitoring

Table 6.1 — Number of sampled cases in the surface waters

Site	DO.	W T.	pH	CT.	TB.	COD.	BOD.	SULF. S M	T N. S M	T P. S M	SS.
S01	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S02	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S03	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S04	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S05	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S06	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S07	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S08	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S09	40	40	40	40	40	40	40	39 1	14 26	27 13	40
S10	40	40	40	40	40	40	40	39 1	14 26	27 13	40
R01	40	40	40	40	40	40	40	39 1	14 26	27 13	40
R02	40	40	40	40	40	40	40	39 1	14 26	27 13	40
T01	14	14	14	14	14	14	14	14	12 2	14 -	14
T02	14	14	14	14	14	14	14	14	12 2	14 -	14
T03	14	14	14	14	14	14	14	14	12 2	14 -	14
T04	14	14	14	14	14	14	14	14	12 2	14 -	14
T05	14	14	14	14	14	14	14	14	12 2	14 -	14
T06	14	14	14	14	14	14	14	14	12 2	14 -	14
T07	14	14	14	14	14	14	14	14	12 2	14 -	14
T08	14	14	14	14	14	14	14	14	12 2	14 -	14
T09	14	14	14	14	14	14	14	14	12 2	14 -	14
T10	14	14	14	14	14	14	14	14	12 2	14 -	14
T11	14	14	14	14	14	14	14	14	12 2	14 -	14
T12	14	14	14	14	14	14	14	14	12 2	14 -	14
T13	14	14	14	14	14	14	14	14	12 2	14 -	14
U01	40	40	40	40	40	40	40	39 1	14 26	27 13	40
U02	15	15	15	15	15	15	15	15	13 2	15 -	15

Columns: DO= Dissolved Oxygen, WT= Water Temperature, CT= Conductivity, TB= Turbidity, COD=Chemical Oxygen Demand, BOD=Bio-chemical Oxygen Demand, Sulf=Sulphate, TN=Total Nitrogen, TP=Total Phosphates, SS= Suspended Solids, S=Sampled cases and M=Missing cases

Source: Field monitoring.

started at site U01, continued along the San Sebastian canal and terminated at site R02 on the river Kelani. The sample collection was carried out between 08.30 hours and 14.00 hours.

The tributary canals comprise of five distinct waterways namely the Maligawatte Drain, the Kettarama Drain, the Dematagoda canal, the Kittampahuwa ela flowing into the San Sebastian Canal from the right bank and the Mutwal Main Drain flowing into the canal on its left bank as seen in figure 6.1. Appendix B explains the sampling sites. The site T01 on the Maligawatte drain was monitored once a month for all the parameters except the total N, which was not monitored in January and February 1986. Thus a total of 14 samples per parameter was monitored except total N which had 12 samples. Thus a total of 152 samples were monitored on the Maligawatte drain.

Table 6.2 — Total number of samples in the surface waters (Jan. 1986-Feb. 1987)

Pollutant	DO.	W T.	pH	CT.	TB.	COD.	BOD.	SULF.	T N.	T P.	SS.	Grand Total
Surface water												
San Sebastian canal	400	400	400	400	400	400	400	390	140	270	400	4000
River Kelani	80	80	80	80	80	80	80	78	28	54	80	800
Maligawatte ela	14	14	14	14	14	14	14	14	12	14	14	152
Kettarama ela	14	14	14	14	14	14	14	14	12	14	14	152
Dematagoda ela	56	56	56	56	56	56	56	56	48	56	56	608
Kittampahuwa ela	56	56	56	56	56	56	56	56	48	56	56	608
Main Drain	42	42	42	42	42	42	42	42	36	42	42	456
Beira lake	55	55	55	55	55	55	55	54	27	42	55	563
Grand total	717	717	717	717	717	717	717	704	351	548	717	7339

Source: Field monitoring.

The Kettarama drain too had the same frequency of monitoring which totalled to 152 samples at T02. Table 6.2 shows these.

Four sites (T03, T04, T05 and T06) were monitored on the Dematagoda ela (i.e Orugodawatte, Dematagoda North and South), on a monthly basis, while the total N was monitored only from March 1986. Thus 56 samples each for DO, water temperatyure, pH, conductivity, turbidity, COD, BOD, sulphate total P, SS and 48 samples for total N was analysed. This aggregated to 608 samples as seen in table 2.

The Kittampahuwa ela was monitored at four sites and followed the same monitoring pattern as the Dematagoda ela. Thus the total samples amounted to 608 at the sites T07, T08, T09, and T10 as seen in table 6.2. The Mutwal Main drain was sampled at three sites (T11, T12 and T13) on a monthly basis. This amounted to 42 samples each for DO, water temperature, pH, conductivity, turbidity COD, BOD, sulphate, total P and SS. Total N which was monitored only from March 1986 amounted to 36 samples. Thus the total samples aggregated to 456. Thus in the entire tributary canal system a total of 1976 samples were monitored.

Classified according to the variables a total of 182 samples were monitored per variable except total N, which amounted to 156 samples. The sampling of the tributary canals commenced on 28.1.1986 and ended on 12.2.1987. This was monitored between 08.35 and 14.50 hours. Sampling started at T01 on the Maligawatte drain, continued through the Kettarama drain, the Dematagoda ela, Kittampahuwa ela and terminated at the site T13 on the Main Drain.

Table 6.3 shows the grand total of surface and industrial sampling. When the entire monitoring on the surface waterways is considered, 717 samples per parameter

Table 6.3 — Grand total of surface and industrial sampling

	DO.	W T.	pH	CT.	TB.	COD.	BOD.	SULF.	T N.	T P.	SS.	Grand Total
Surface water												
Monitored	717	717	717	717	717	717	717	704	351	548	717	7339
Missing	-	-	-	-	-	-	-	13	366	169	-	548
Industries												
Monitored	180	178	180	180	180	180	180	168	149	178	180	1933
Missing	-	-	-	-	-	-	-	12	28	2	-	44
Grand Total												
Monitored	897	895	897	897	897	897	897	872	500	726	897	9272
Missing	-	2	-	-	-	-	-	25	394	171	-	592

Source: Field monitoring.

for DO, pH, water temperature conductivity, turbidity, COD, BOD, SS and 704 sulphate samples, 351 total N and 548 total P samples were monitored. This aggregated to 7339 samples in the San Sebastian canal, River Kelani, the Beira Lake, the Maligawatte drain, the Kettarama drain, Dematagoda ela, Kittampahuwa ela and the Main Drain. In addition to these one set of samples along the San Sebastian canal was analysed for feacal coliforms by the Medical Research Institute, Colombo.

6.2 The industrial sampling procedure

Table 6.4 shows the sampling frequency in all the industries. Appendix C shows the points of monitoring in the industries.

The industrial group A is a pure food and drink industry producing different food products in different departments but within the same premises. A2 had a monitoring frequency of 1 per month except in October 1986 when 2 samples were monitored, for DO, water temperature, pH, conductivity, turbidity, COD, BOD, total P and SS. Each parameter totalled to 15 samples; 14 sulphate and 11 total N samples were monitored during the period of monitoring. Thus a total of 160 samples were monitored at A2. Total N was not monitored during January and February 1986.

The site A3 was monitored monthly for all the parameters except total N which was not analysed in January and February 1986. Thus 15 samples each for DO, water temperature, pH, conductivity, turbidity COD, BOD, total P, SS and 12 total N samples were monitored which totalled to 162 samples. In October 2 samples per parameter was done.

A4 had a monitoring frequency of 3 during the entire period of research for all the parameters except total N which was not monitored. Two sulphate samples were monitored. This aggregated to 29 samples.

The industrial site A5 was monitored once a month for all the parameters except in October 1986 where 2 samples were monitored during the month. Total N was not monitored from January to March 1986. Thus 15 DO, 15 water temperature, 15 pH, 15 conductivity, 15 turbidity, 15 COD, 15 BOD, 15 sulphate, 15 total P, 15 SS, and 12 total N samples were monitored totalling to 162 samples.

A1 was monitored only once for all parameters because, this department ceased to function when it was bombed during the research period. Thus a total of 11 samples were monitored at A1. A raw water sample (A6) too was monitored from this factory. It was monitored for DO, pH, conductivity, turbidity, COD, BOD and SS, which aggregated to 7 samples.

Table 6.4 — Industrial sampling: Number of cases

Site	DO.	W T.	pH	CT.	TB.	COD.	BOD.	SULF.		T N.		T P.		SS.
								S	M	S	M	S	M	
A1	1	1	1	1	1	1	1	1	-	1	-	1	-	1
A2	15	15	15	15	15	15	15	14	1	11	4	15	-	15
A3	15	15	15	15	15	15	15	15	-	12	3	15	-	15
A4	3	3	3	3	3	3	3	2	-	-	-	3	-	3
A5	15	15	15	15	15	15	15	15	-	12	3	15	-	15
A6	1	-	1	1	1	1	1	-	-	-	-	-	-	1
B1	14	14	14	14	14	14	14	14	-	12	2	14	-	14
B2	14	14	14	14	14	14	14	14	-	12	2	14	-	14
C1	13	13	13	13	13	13	13	13	-	11	2	13	-	13
C2	13	13	13	13	13	13	13	13	-	11	2	13	-	13
D	2	2	2	2	2	2	2	2	-	2	-	2	-	2
E	17	17	17	17	17	17	17	17	-	15	2	17	-	17
F	17	17	17	17	17	17	17	17	-	15	2	17	-	17
G1	6	6	6	6	6	6	6	4	2	6	-	6	-	6
G2	6	6	6	6	6	6	6	4	2	6	-	6	-	6
H1	6	6	6	6	6	6	6	4	2	6	-	6	-	6
H2	3	3	3	3	3	3	3	3	-	-	3	3	-	3
I1	6	6	6	6	6	6	6	5	1	6	-	6	-	6
I2	6	6	6	6	6	6	6	5	1	6	-	6	-	6
J	6	6	6	6	6	6	6	6	-	5	1	6	-	6
K	1	-	1	1	1	1	1	1	-	-	-	-	-	1

A1-K are factory sites

Source: Field monitoring

Table 6.5 shows the total sampling in the industries. Thus within the A group of industries 50 DO, 49 water temperature 50 PH, 50 conductivity, 50 turbidity, 50 COD, 50 BOD, 47 sulphates, 36 total N 49 total P and 50 SS samples were monitored. The total amounted to 531 samples. The group A was monitored between 20.1.86 and 23.02.87 samples were taken in the morning between 09.00 and 10.00 hours.

At Factory B, basically an oil refinery with oil based products, the effluents from the soap department was monitored since the raw materials used were organic (coconut and palm oil and tallow). This was directly discharged into the San Sebastian canal. Effluents from the refinery was not monitored because the industry was undergoing a critical period during the research period due to financial difficulties and had temporarily ceased production.

Factory B was monitored at two effluent outlets. B1 was the soap factory effluent and B2, the cooling water. They were monitored once a month except in June 1986

Table 6.5 — Industries: Total sampling

Indus.	DO.	W T.	pH	CT.	TB.	COD.	BOD.	SULF.	T N.	T P.	SS.	Grand Total
A	50	49	50	50	50	50	50	47	36	49	50	531
B	28	28	28	28	28	28	28	28	24	28	28	304
C	26	26	26	26	26	26	26	26	22	26	26	282
D	2	2	2	2	2	2	2	2	2	2	2	22
E	17	17	17	17	17	17	17	17	15	17	17	185
F	17	17	17	17	17	17	17	17	15	17	17	185
G	12	12	12	12	12	12	12	8	12	12	12	128
H	9	9	9	9	9	9	9	7	6	9	9	94
I	12	12	12	12	12	12	12	10	12	12	12	130
J	6	6	6	6	6	6	6	6	5	6	6	65
K	1	-	1	1	1	1	1	-	-	-	1	7
GRAND TOTAL	180	178	180	180	180	180	180	168	149	178	180	1933

Source: Field monitoring

when no monitoring was done. Samples were monitored fortnightly in October 1986. Thus 14 samples per site per parameter was monitored except total N which was not monitored during January and February 1986. This can be seen in table 6.4. Thus for the entire industry 28 samples per DO, water temperature, pH conductivity, turbidity COD, BOD, sulphates, total P, SS and 24 total N samples were monitored. This aggregated to a total of 304 samples. This can be seen in table 6.5. Effluent monitoring was done from 20.01.86 to 23.02.87 between 10.20 and 12.05 hours. The points of sampling can be seen in appendix C.

The waste water from C an edible fat (and toiletries) industry was monitored at 2 points i.e. the margarine factory outlet and the fat trap. Monthly monitoring of the effluents were done except for total N in January and February 1986. In October 1986 fortnightly monitoring was done. Table 6.4 gives the frequency of sampling. Thus, 13 samples per effluent point of monitoring per parameter was done, which amounted to 26 samples each for DO, water temperature, pH conductivity, turbidity, COD, BOD sulphate, total P, SS and 22 for total N. This totalled to 282 samples. This can be seen in table 6.5. In the entire factory sampling was done from 20.1.86 to 23.2.86 and the sampling time ranged from 10.55 to 12.45 hours. The points of sampling can be seen in appendix C.

Factory D a chemical industry (fertilizers, paints, insecticides) although not a food industry was monitored twice, to see the strength of the effluents because it was directly discharging into Dematagoda Canal and is almost at the confluence of Dematagoda and the San Sebastian canals. All the parameters were monitored, thus the total number of samples amounted to 22. Table 6.5 gives the frequency of monitoring. It was monitored on 20.8.86 and 6.1.87. The points of sampling can be seen in appendix C.

Factory E and F, both confectioneries was monitored monthly, except in July, October and November 1986 when 2 per month was monitored. Total N was not done in January and February 1986. Thus each factory was sampled 17 times per parameter for DO, water temperature, pH, conductivity, turbidity, COD, BOD sulphate, total P, SS and 15 samples for total N as seen in table 6.4. Thus factory E and F had a total monitoring of 185 samples each as seen in table 6.5. These were monitored from 20.1.86 to 23.02.87 and the sampling time in the factory E ranged from 13.00 to 13.40 hours, and in the factory F from 13.34 to 14.26 hours. The points of sampling can be seen in appendix C.

Factories G,H,I,J and K are food industries outside the canal system.

Factory G a meat processing factory was monitored at two sampling points at a frequency of 4 per year (once in 3 months) in 1986 and monthly in 1987, for all the parameters except the sulphates on two days. Thus G1, meat cutting and processing section was monitored for 6 samples per parameter i.e. DO, pH, water temperature, conductivity, tubidity, COD, BOD, total N, total P, SS and 4 samples for sulphates as seen in table 6.4. This totalled to 64 samples. G2, meat packing section too had a similar monitoring pattern totalling to 64, therefore the total for the entire industry was 128 samples as seen in table 6.5. Monitoring commenced on 12.3.86 and ended on 19.2.87. Sampling time in G1 ranged from 13.10 to 14.15 and G2 from 13.20 to 14.25 hours. The points of sampling can be seen in appendix C.

Factory H a soft-drinks plant, was monitored at 2 points. H1 (bottle washer effluent) had the same pattern of monitoring except the two sulphate samples which was not monitored. Thus 6 samples each for DO, pH, water temperature conductivity, turbidity, COD, BOD, total N, total P, SS and 4 sulphate samples were monitored. This added to a total of 64 as seen in table 6.4. H2, the carbon dioxide plant was monitored only three times. All the parameters were monitored except total N. Thus 3 samples per parameter except total N being monitored amounted to 30 samples. The entire industry was monitored for 94 samples as seen in table 6.5. Monitoring started on 9.6.86 and ended on 19.2.87. The time of monitoring varied from 09.27 to 09.50 hours. The points of sampling can be seen in appendix C.

Industry I (carbonated soft drinks) had two monitoring points. The bottle washer effluent (I1), was monitored 6 times as seen in table 6.4 i.e once in 3 months in 1986 and once a month in 1987. All the parameters had this monitoring frequency except the sulphates which was only monitored once. Thus I1 was monitored 6 times for DO, pH, water temperature, conductivity, turbidity, COD, BOD, total N, total P and SS except sulphates which was monitored 5 times as seen in table 6.4. Thus the total samples amounted to 65. The I2, the aeration tank sampling point had the same pattern of monitoring resulting in 65 samples. The total for the industry was 130 samples as seen table 6.5. Sampling commenced on 12.3.86 and ended on 19.2.87. Monitoring time varied from 10.20 to 11.10 at I1 and 10.30 to 11.25 at I2. The points of sampling can be seen in appendix C.

Factory J (fruit and milk based drinks) was monitored 6 times and had the same frequency as factory H and I. 6 samples per DO, pH, water temperature, conductivity, turbidity, COD, BOD, sulphates, total P, SS and 5 total N samples were monitored as seen in table 6.4. As seen in table 6.5 samples aggregated to 65. Monitoring was done on the same days as factories H and I, the time of sampling varied from 11.50 to 13.10 hours. The points of sampling can be seen in appendix C.

One set of samples from the industry K (yeast based), was analysed as it was a food industry. Samples were monitored for DO, pH, conductivity, turbidity, COD, BOD and SS. This aggregated to 7 samples and was analysed on 13.6.86. Thus taking industrial effluent monitoring as a whole, 180 DO, 178 water temperature 180 pH, 180 conductivity, 180 turbidity, 180 COD 180 BOD, 168 sulphate, 149 total N, 178 total P and 180 SS samples were monitored. This totalled to 1933 samples as seen in table 6.4.

Table 6.3 shows the total number samples in the entire monitoring programme. The entire sampling programme had a total number of 9272 samples (7339 + 1933) monitored. This was made up of 897 DO, 895 water temperature, 897 pH, 897 conductivity, 897 turbidity, 897 COD, 897 BOD, 872 sulphate, 500 total N, 726 total P and 897 samples.

The total number of sampling points monitored in the waterways and industries aggregated to 48 sites. A break up of this figure gives 27 sampling sites in the surface waterways and 21 sampling points in the industries. This includes all the monitoring related to the industrial and surface water monitoring.

Sampling was carried out in a largely regular temporal pattern. The San Sebastian canal (S Series) the river Kelani (R Series) and the site U01 on the Beira lake was monitored on the same days throughout. The tributary series bearing identification code T were monitored on the same days. The monitoring of factory D coincided with this series on 2 days of monitoring. The major industrial group discharging directly into the surface waterways were monitored on the same days except factory E and F

which had two extra days of sampling. Monitoring started at factory A, followed in sequence by B,C,E and F respectively. Site U02 on the Beira lake too was monitored on the same days as factory A. Monitoring of the subsidiary industries G,H,I and J here was done on the same days.

All the samples were brought to the laboratory for analysis within 1-5 hours of sample collection. Sample from factory K was analysed in the laboratory from a sample brought for a different purpose and therefore the factory itself was not visited.

The results of the chemical and physical surface and industrial water monitoring are appended. Appendix D gives the results of the analysis in the San Sebastian canal, site U01 of the Beira lake and the sites in the river Kelani. Appendix E gives the results for the tributary canals and Appendix F, the results of the factories monitored.

6.3 Statistical measures

The variability within the environmental data is extremely high. This is especially true of the pollutant discharge data in the food and drink industry. The pollutants may range from a very low to an unacceptably high concentration depending on the process of production, the day, time and the season of monitoring. Depending upon the nature of its production the strength of the pollutants among the same group of industry may vary widely. The natural environmental phenomena (especially rainfall, temperature and biological activity) are also highly variable. Due to this the variability in the pollution data may be high on a daily, monthly or a seasonal basis. The variability both within and between the sites was high. When the variability is high in the data, the distribution becomes non-normal. This asymmetry can be seen in the range and the standard deviation in most of the variables. So appropriate techniques have to be made use of in the data analysis.

One possible approach devised to handle non-Gaussian or non-normal data are the non-parametric or distribution-free statistics. Non-parametric methods are applicable to estimation or hypothesis testing problems when the population distribution need only be specified in broad terms and need not belong to specific families such as normal, uniform, and exponential (Sprent, 1989). The non-parametric techniques are most useful when parametric procedures are not appropriate such as when data is nominal, ordinal or when interval data are from markedly non normal distributions. If an assumption of normality were not justified, analysis based on ranks is the most efficient. The non-parametric methods was stimulated by requirements for data which were ranked or for data distorted by extremities and outliers. The necessity arose since the parametric analytical methods based on normal distribution for continuous data, binomial and Poisson distribution for discrete data (although still and always important) does not embrace in all the situations. (Sprent, 1989). As non-parametric measures were more suitable for the wide ranging pollution data it was used in the analyses done.

The statistics normally used in water quality analysis are the minimum, the maximum, the arithmetic mean, the median range, percentiles and the standard deviation (WHO, 1983a). Other than these, the geometric mean and the percentage sample excluded have been used in water quality analysis by the Ministry of Environment, Ontario (1989). Ratios are usually used between certain pollutants in the industrial analysis to decide on the treatability criteria. Correlations have been used in understanding the pollutant relationship in the water quality of the receiving streams for understanding the source of contamination and for remedial action in the industries. The time variability is an important criteria normally used in environmental data analysis (Gilardi, 1982).

In the research undertaken, both the arithmetic mean and the median were used as measures of central tendency. The median was the preferred and the mostly used measure, but where necessity arose the arithmetic mean has been used. The median is the most widely used measure in environmental data analysis as it represents the central location best in an asymmetric distribution. It lies between the mean and the mode both in a positive and a negativly skewed situation. Hence in highly variable data such as in the monitored pollution data, the median was found to be the most appropriate measure, since the distribution was highly skewed for most of the pollutants. The median also remains unaffected by the extreme values in the data. Further the median does not affect the Spearman's ρ used in the analysis since the coefficient

is calculated on the difference in the ranks and not on any measure of central location of the data.

Although the median was used as a measure of central tendency the directly analogous measure to the median i.e the quartile deviation was not resorted to, since it is a measure arbitrarily defined as half the distance between the first and the third quartiles. Therefore, it does not take the advantage of all the information. Thus the standard deviation which has this property was used as the measure of dispersion. For most data the standard deviation will be appropriate (Blalock, 1972). The percentiles which are directly analogous to the median were used. The 90th percentile usually used in environmental data was used in the research.

Among the several non parametric techniques available for computing the correlations the Spearman's ρ was found more appropriate for the analysis since this measure of correlation based on ranks may be applied either to data which consists *ab initio* of ranks or to ranks derived from continuous data or counts. This is just Pearsons's product moment coefficient calculated for the ranks (Sprent, 1989). Spearman's ρ shares the same property with that of the Pearson's r in that the coefficient lies between +1 and -1. When there is complete agreement between the ranks it is denoted by +1 and vice versa. If the ranks show no obvious relationship values of ρ, near zero may be expected. The correlation coefficient by itself can be a misleading summary of data concerning a relationship. It is therefore advisable to use the averages, standard deviation and the data points in addition to the correlation coefficient (Freedman *et al* 1978). The Spearman's ρ was also found useful in tests for trend. The significance levels were computed with the correlation coefficient ρ.

Based on these measures a statistical analyses was done on the chemically and the physically monitored pollution data. The data remained essentially the monitored data. The statistical package SPSS-*X* was used for this purpose. The statistical analyses done on the receiving water bodies was to understand the nature of pollutants and their relationships with the rainfall. The water quality standards were also tested. The statistical analyses done on the industrial pollutants were mainly to understand the nature of the pollutants, the treatability criteria, the standards performance, and the impact of the industrial pollutants on the receiving water bodies. The analyses on the receiving water bodies encompassed external environmental factors such as rainfall to understand the relationship with the pollutants. This was in addition to some of the analyses common to both the industrial and the receiving waters.

As far as possible equal emphasis was given to both the industrial and the receiving water quality statistical analyses. But, more stress was laid on the receiving water bodies, particularly in the rainfall based pollutant analysis. This was done with the main purpose of understanding the dilution capacity of rainfall on the pollutants, and the assimilative capacity of the receiving waters. This was achieved by using a time series analysis. The aim behind the analysis was to examine the capability of the rainfall as a natural dilutant for the industrial discharges which enter the canal. Where there is no natural dilution, treatment or pollution abatement measures become imperative. Further the factory effluent data could be easily tested against the relevant industrial waste water discharge standards into the inland surface waters. If the standards were not met mandatory discharge standards could be imposed on the industries. The receiving surface water encompassed the factory discharges and the receiving site conditions which included rainfall. Therefore, it served as a complementary analysis to the industrial discharge data analysis. Thus, the time series analysis to a certain degree was an all encompassing analysis in understanding the overall pollution relationship between the factory discharges and the receiving sites.

Time series analysis

Time series analysis is increasingly used in the scientific analysis of data in the physical, biological sciences and in econometrics. Time series arise when data are collected over time either continuously or at discrete time intervals, usually on several related intervals, (Aoki, 1983) in which one has a set of observations on some variables for the same unit of analysis over a series of time points such as days, months and years. Some variables exist at every point such as temperature at a given place, while others exist only in virtue of aggregation over a period of time such as rainfall and industrial production.

A general series can be considered as a mixture of four components i.e. a trend or

a long term movement; fluctuations about the trend of a greater or less regularity; a seasonal component (trends and seasonality are essentially entangled); and a residual, irregular or a random effect (Kendall, 1976). An important aspect of the seasonal effect, although it may vary from their average time of occurrence during the year, is that it has a degrees of regularity which the other elements of the time series do not possess as a rule.

A characteristic feature of the time series is that the observations occur in a temporal order, thus the time at which the observation was made is critically important. The implication is that we shall be interested in the relationship of values from one term to the next in the serial correlation along the series or several series as a multivariable complex, since there is a relationship between the observation of a variable or variables over time. Here we are concerned with relationships and interrelationships among the variables. This brings us into a situation where the cross correlations have to be considered when one or more lead or lag behind the other variables (Kendall, 1976).

Thus some relationships often require the inclusion of lagged exogeneous variables. It may be argued that it is plausible to explicitly incorporate time lags into a relationship because the dependent variable cannot be expected to respond immediately to a specific increase or decrease in the independent variables. The lag formulation acknowledges that it takes time for one variable to affect another. One possible formulation is to assume that it takes a specific period of time for example xt to affect yt. But it is not usual to specify the exact amount of time it takes xt to affect yt (Ostrom, 1978). In many biological models it has been found necessary to allow the rates of change of the variables to depend on the past history rather than only on the current value of the variables (MacDonald, 1978). Similar dependence arises in environmental system of climatic, pollutant and biotic influences and thus, this relationship between the observation of a variable or variables over time is referred to as a lagged correlation (Bennett, 1979).

Although a very useful mechanism to understand relationships, prediction and forecasting, in time series analysis there are rarely rules of general and universal application. A great deal depends on the purpose of the study (Kendall, 1976).

6.4 Pollutant fluctuations: inland surface waters

6.4.1 Fluctuations in the San Sebastian canal

DO: data variability

The data variability can be seen in table 6.6.

The DO data shows considerable variability in the DO levels along the canal, the absolute maximum values range from 14.8 - 0.6 mg/L, and the minimum levels from 4.5 - 0.0 mg/L. The median values range from 9.65 - 0.01. It is immediately apparent that apart from sites S01 and S02 the other sites have very low DO levels. The standard deviation is also high at S01 and S02.

Fluctuations and relationships

The DO in the Sebastian canal showed that the dissolved oxygen was the highest at the origin of the canal at the sites S01 and S02 as seen in figure 6.2 virtually with no trace of pollution or dissolved oxygen depletion. These sites are free from industrial discharges and tributary canal contributions. They are also free from direct domestic waste water discharges. The fall in the DO was sharp at S03 and continued till S07.

The site S03 is at the discharge point of the factory B while S04 is immediately downstream of this factory. The Maligawatte drain enters the San Sebastian canal very close to this site. The site SO5 is between the factories B and C and also a domestic site. This is reflected in the higher DO. The site S06 is the direct discharge point of factory C and S07 is immediately downstream from C, at which point the Kettarama drain enters the San Sebastian canal. The shanty colonies along the canal particularly near the site S03 (Lockgate area), the Panchikawatte bridge (S04) and the Stace road bridge (S08) too augment the DO depletion in the canal. A commercial laundry at the site S07 (near the Kettarama bridge) discharges a large volume of soapy water into the canal daily. This is highly organic in nature. There is slight improvement in the DO at SO5 which reaches a maximum of 1.9 mg/L, and after

Table 6.6 — The variability of DO (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th%
1							
S01	9.40	2.76	9.7	4.5	14.2	9.50	13.20
S02	9.69	2.94	10.8	4.0	14.8	9.65	14.18
S03	0.17	0.25	0.9	0.0	0.9	0.03	0.60
S04	0.20	0.31	1.2	0.0	1.2	0.01	0.60
S05	0.39	0.40	1.9	0.0	1.9	0.30	0.99
S06	0.24	0.45	2.5	0.0	2.5	0.05	0.68
S07	0.11	0.16	0.6	0.0	0.6	0.01	0.39
S08	1.89	0.75	3.0	0.3	3.3	2.10	2.69
S09	1.31	0.85	4.0	0.0	4.0	1.30	2.48
S10	0.60	1.09	6.6	0.0	6.6	0.35	1.18
2							
R01	6.15	0.76	4.2	5.1	9.3	6.05	7.00
R02	7.02	1.13	6.1	5.5	11.6	6.80	7.60
3							
U01	2.24	2.08	6.4	0.0	6.4	1.6	6.00
U02	1.30	0.27	0.9	0.9	1.8	1.3	1.68

Sections: **1** = SanSebastian canal **2** = River Kelani **3** = Beira lake

Source: Field monitoring.

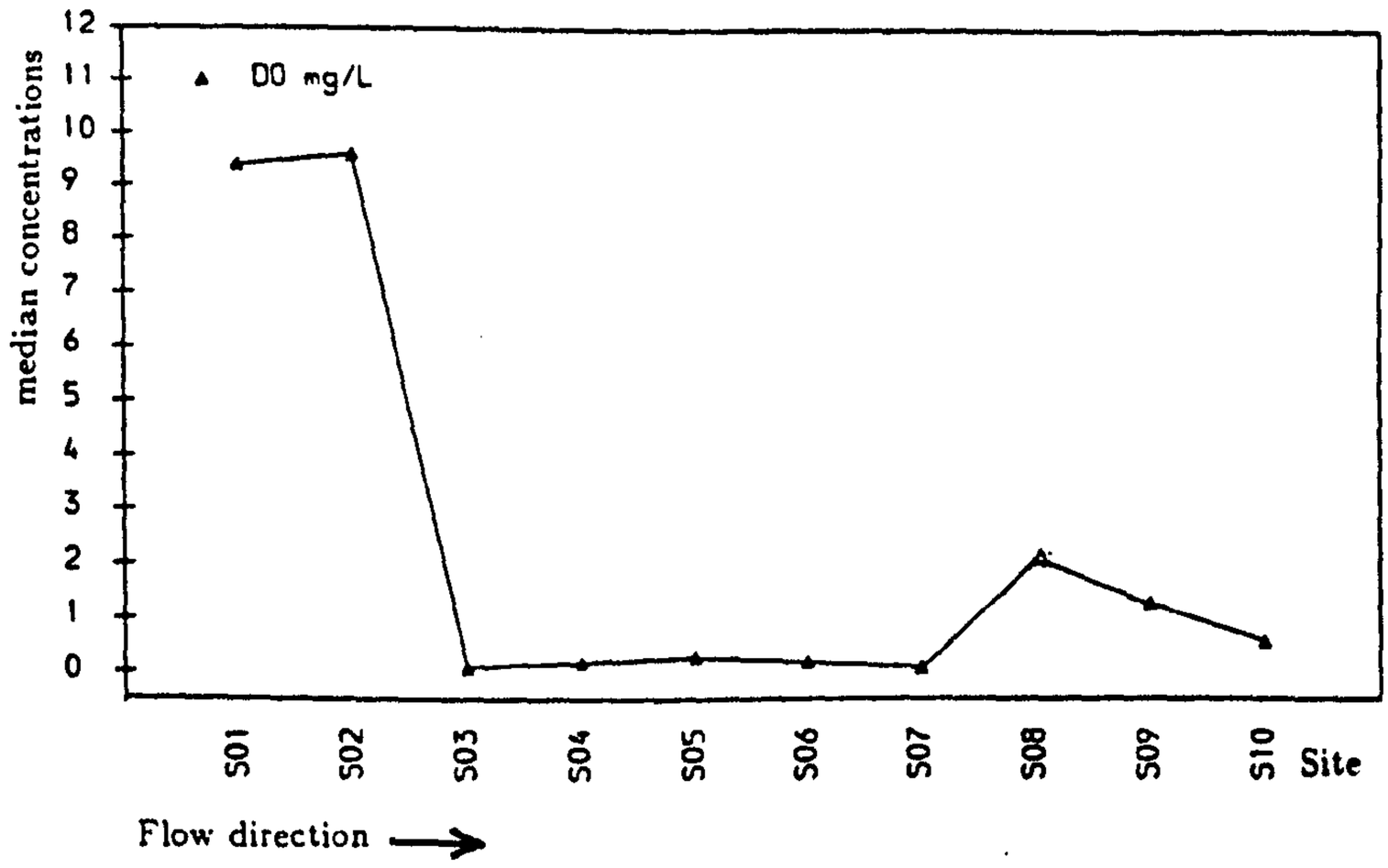


Figure 6.2 — DO fluctuations along the San Sebastian canal

Source: Based on field monitoring

S07, but fell again at S10. Although the DO had improved slightly from the sites S08 downstreams the comparatively low concentrations indicate the tributary canals, such as the Dematagoda canal which enters at S08, and the Main Drain and the Kittampahuwa canals contribute high organic loads into the San Sebastian canal, thus depleting the DO. Although a DO value of of 6.6 mg/L had been reached at the site S10, the 90th percentile fell at 1.18 indicating that 90% of the observations fell below this level. Therefore, although slight reaeration had taken place away from the factory sites, the bufferd effect at the site influenced by the tides indicated the concentration of the pollutants were confined to the canal. This may have resulted in the very low DO in the canal in the downstream sites. Thus the high organic load from the upstream industrial discharge sites and the buffered effect of the tidal site (in addition to lockage) has rendered the San Sebastian canal devoid of the dissolved oxygen. Therefore this canal enters the receiving river Kelani as a grossly polluted canal. Appendix G shows the percentages of the DO at 0.0 mg/L and less than 1.0 mg/L from the sites S03 downwards in the San Sebastian canal. From this too, it can be seen that the level of DO had sagged from the industrial site S03.

COD: data variability

The data variability along the San Sebastian canal can be seen in table 6.7.

Table 6.7 — The variability of COD (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	20.98	19.66	66.0	4.0	70.0	12.00	61.3
S02	19.47	17.56	76.0	4.0	80.0	12.00	47.6
S03	448.38	278.30	1284.0	38.0	1322.0	368.55	905.2
S04	428.20	212.97	776.0	152.0	928.0	391.77	853.1
S05	282.87	135.90	499.0	101.0	600.0	259.50	480.8
S06	389.59	161.80	632.0	64.0	696.0	402.00	611.1
S07	341.60	165.90	677.7	53.3	731.0	358.90	583.7
S08	116.79	74.90	309.0	21.0	330.0	99.50	218.9
S09	115.76	67.40	287.4	10.6	298.0	102.00	231.7
S10	139.00	79.00	290.4	10.6	301.0	128.00	265.3
2							
R01	38.20	22.60	80.0	4.0	84.0	36.00	78.9
R02	23.06	20.27	100.0	4.0	104.0	17.00	50.3
3							
U01	650.80	206.20	756.0	272.0	1028.0	618.00	943.7
U02	878.00	515.64	1779.0	168.0	1967.0	773.00	1936.0

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

Analysis of COD data for the San Sebastian canal indicates a close relationship between the sites S01 and S02 with minimum value at 4.0 mg/L at both the sites and the maximum 70.0 and 80.0 mg/L respectively. Though the median remained the same at 12.0 mg/L for both the sites, the 90th percentile fell below 47.6 mg/L for site S02, while it was 61.36 for S01. This indicates S02 is less polluting than S01 based on the COD.

The site S03 recorded the highest COD for the San Sebastian canal with a maximum value of 1322.0 mg/L. Both the 90th percentile and the median were high. The variability the COD was very high with a range of 1284.0 mg/L and a standard deviation of 278.3. The COD at the site S04 had the next highest. The COD increased at the site S06 with maximum reached at 696.0 mg/L, median of 402.0 and

the 90th percentile at 611.1. The range was high with a value of 632.0 and so was the standard deviation of 161.8. Although S07 had a maximum COD value of 731.0 mg/L the median was lower than at S06, with 358.9 mg/L. The 90th percentile fell at 583.7. The minimum COD at S07 was 53.3 while at S06 it was 64.0. This indicated that S06 is more polluted than S07. The COD improved at S08 and S09 falling to a minimum value of 21.0 and 10.6 and a maximum of 330.0 and 298.0 respectively. This is reflected in the 90th percentile too. COD at S10 increased in comparison to S08 and S09. This was clear in the median and the 90th percentile.

Fluctuations and relationships

The fluctuations in the COD can be seen in figure 6.3.

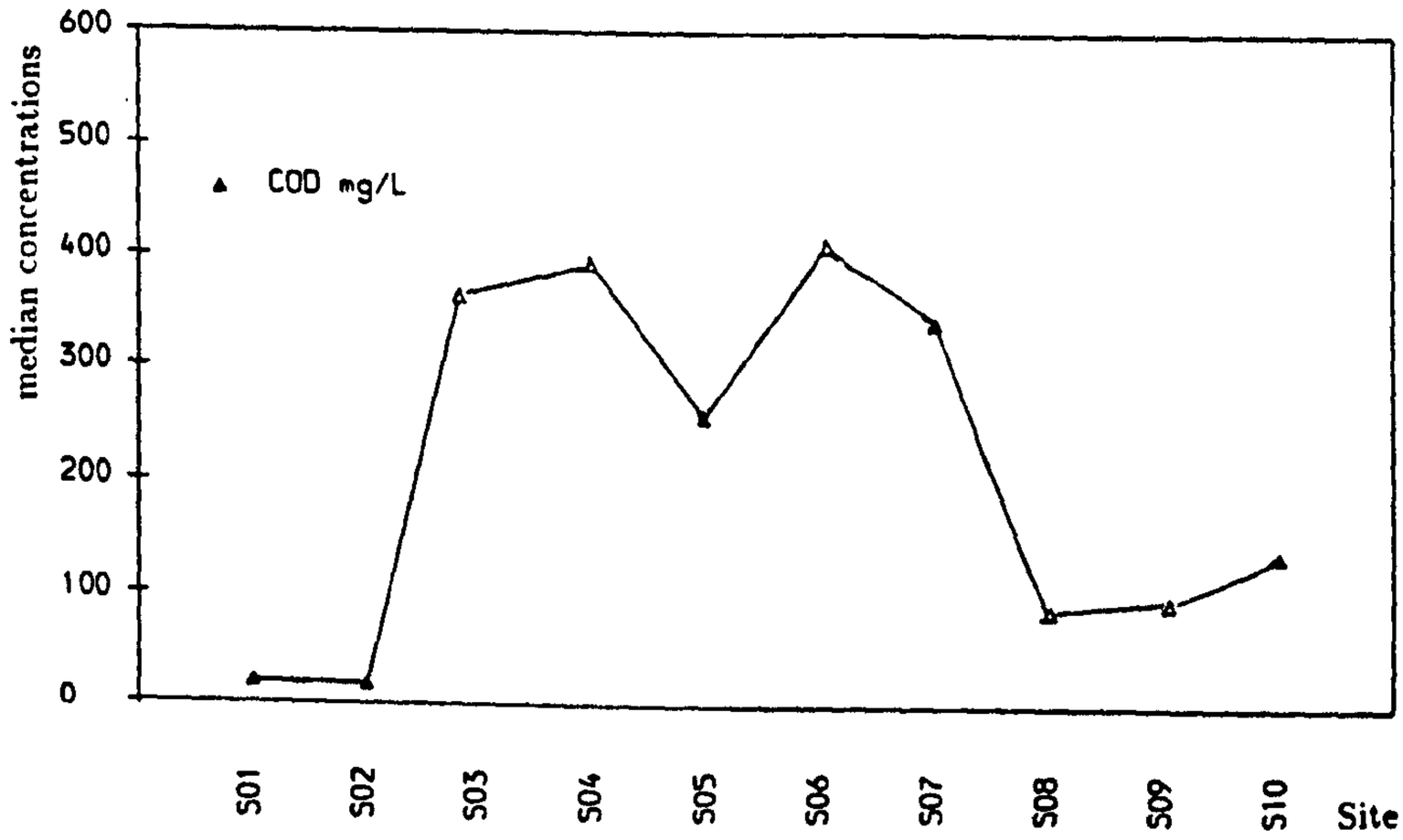


Figure 6.3 — COD fluctuations along the San Sebastian canal

Source: Based on field monitoring

The COD for the entire San Sebastian canal indicates that the sites S03, S04, S06 and S07 are the most polluted, with high COD values. These sites exhibit sharp contrast to sites S01 and S02, which are relatively unpolluted sites. This is seen in the low COD. Again at the site S10 the COD increases possibly due to the tidal buffering and concentration of pollutants for longer periods of time. As the San Sebastian flows into the river Kelani, the downstream site R01 receives a high organic load and thus get polluted. Further the Beira lake at the other receiving end is also polluted by the water pumped from the canal. This is specially true during the dry periods as the Kelani water is led along the canal for this purpose. This situation was magnified in 1986 and 1987 (January and February) with lower rainfall than usual.

The high COD between the sites S03-S07 is mainly contributed by the untreated waste water discharges of two large scale industries at S03 and S06. The industries are B and C respectively. The tributary canal sites T01 and T02 may also contribute as they enter the San Sebastian canal near these sites. The fall at the site S05 is due to it being a domestic site. The contribution by the tributary canals, the Dematagoda ela, the Main Drain and the Kittampahuwa ela between S08 and S10 is also evident. At this stretch the concentrations was higher than at the origin of the canal.

BOD: data variability

The data variability for BOD can be seen in table 6.8.

Table 6.8 — The variability of BOD (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	13.78	13.45	48.0	1.0	49.0	9.0	36.9
S02	11.73	12.35	57.0	2.0	59.0	8.0	27.0
S03	289.70	197.30	849.0	21.0	870.0	226.0	594.6
S04	267.00	148.61	566.0	65.0	631.0	239.0	480.4
S05	195.07	116.60	423.0	47.0	470.0	172.0	395.5
S06	278.42	148.60	542.0	39.0	581.0	293.0	492.5
S07	234.70	145.40	517.0	39.0	556.0	215.5	479.8
S08	73.22	53.60	254.0	15.0	269.0	62.0	167.8
S09	71.10	49.90	255.0	6.0	261.0	64.0	154.8
S10	83.90	53.20	205.0	3.0	208.0	79.5	185.0
2							
R01	23.76	16.50	65.0	2.0	67.0	19.5	49.9
R02	13.50	12.72	65.0	2.0	67.0	9.5	33.4
3							
U01	65.00	202.92	751.0	65.0	816.0	508.0	770.8
U02	522.06	309.55	1165.0	100.0	1265.0	466.0	1025.0

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

The BOD followed a very similar pattern to the COD. The sites S01 and S02 have the lowest BOD values with the minimum reached at 1.0 and 2.0 mg/L at S01 and S02 respectively. The maximum at S01 was 59.0, and at S02 it was 49.0 mg/L. The median was lower at S02 with 8.0 mg/L. The 90th percentile at S02 was lower with a value of 27.0. The standard deviation for both the sites were close.

The site S03 had very high BOD values with the maximum reached at 870.0 mg/L. This was the highest for the entire canal. Although the 90th percentile fell at 594.6 the median was 226.5. The site S04 too had high COD values although it was lower than at S03. The median was higher than S03 with 239.0 mg/L, but the 90th percentile was lower than at S03. The BOD fell at site SO5 with the median at 172.0. The BOD increased at S06 with the maximum at 581.0 and the median of 293.0 was the highest in the entire length of the canal. It was evident in the 90th percentile of 479.8 mg/L. The site S07 also had high values. At S10, the BOD was higher than at the former two sites. This was indicated by the median of 79.5 which was higher than at S08 and S09. The variability in the BOD was high within the sites, such as the highest range recorded for BOD in the canal was 849.0 at S03. The variability across the sites was also high with the minimum BOD of 3.0 at S01 and the maximum of 870.0 at S03.

Fluctuations and relationships

The fluctuations in the BOD can be seen in figure 6.4.

In the San Sebastian canal the BOD essentially followed the COD with low values at S01 and S02 leaping at S03 to S07, while falling slightly at S05. There was a drop in the BOD from S08 to S10, although the values increased slightly at S10. These clearly indicate the high BOD and the COD contribution by the industries in the sites between S03 and S07. The concentrations from S08 remained higher than the sites at the origin of the canal which indicated the contribution from the tributary canals. Thus a high BOD load is discharged into the receiving river, the Kelani. As seen later the downstream site R01 is more polluted on the river. The lake on the other end is also polluted due to pumping of water.

SS: data variability

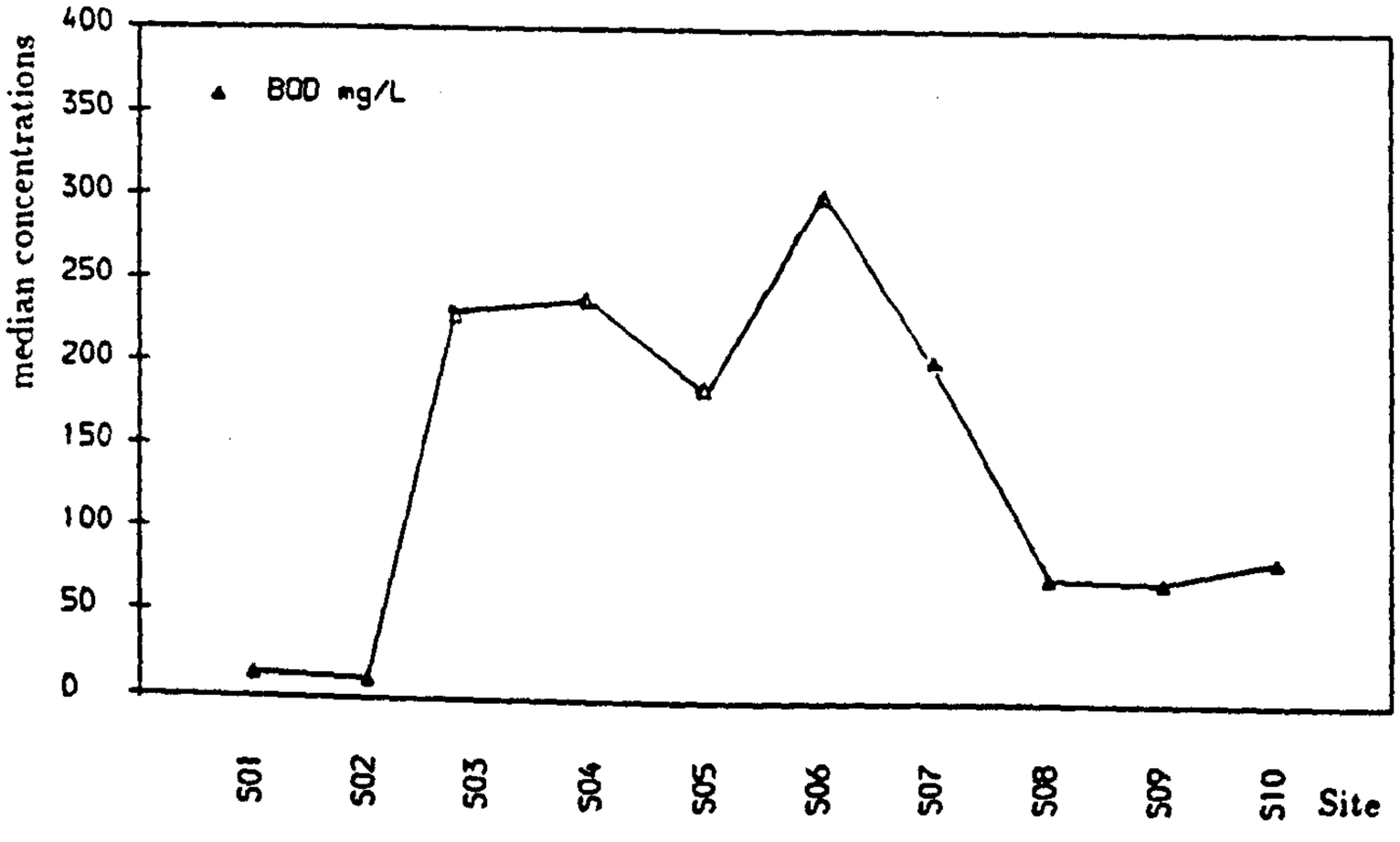


Figure 6.4 — BOD fluctuations along the San Sebastian canal

Source: Based on field monitoring

Table 6.9 — The variability of SS (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	28.90	29.00	149.38	6.85	156.2	22.20	51.64
S02	22.67	23.89	155.09	7.25	162.3	18.30	31.57
S03	110.55	87.40	454.60	29.00	483.6	80.70	211.40
S04	110.21	101.90	391.53	18.27	409.8	73.20	331.23
S05	86.78	80.23	356.60	9.56	366.2	62.15	204.70
S06	112.30	84.18	441.70	30.55	472.3	89.00	237.42
S07	122.90	95.42	460.00	28.25	488.3	93.36	261.00
S08	45.60	80.40	482.90	9.74	492.7	20.75	100.20
S09	55.21	53.60	256.40	10.14	266.6	29.30	123.20
S10	40.30	43.30	278.20	3.12	281.3	33.30	68.76
2							
R01	25.55	23.59	100.70	5.80	106.5	16.20	61.40
R02	28.80	23.20	121.60	3.60	125.2	22.42	61.62
3							
U01	122.87	77.47	340.80	26.36	367.2	98.30	219.02
U02	209.49	199.79	581.14	10.20	591.3	100.10	558.73

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

The data variability can be seen in table 6.9.

The SS load at the San Sebastian canal remained low at S01 and S02.

As the canal progressed the SS load increased at S03 with the maximum at 483.6 and median of 80.7. This was evident in the 90th percentile of 211.4 and a high range of 454.6 mg/L. The SS load decreases at S04. The median was 73.2 but the percentile was higher than S03 with 331.23 mg/L. Although the range was lower the standard deviation remained high. The SS fell at S05 but increased at S06 and S07. The minimum at S06 was the highest recorded minimum SS value for the San Sebastian canal. The median of 89.0 was higher than at the site S03. The highest median value of 93.36 fell at S07. SS concentration was different to the other variables at S08, It had the highest recorded maximum value of 492.7 mg/L. The median was low and ranked next to S02 and S01. The range was the highest at this site with 482.9 mg/L. There was a slight increase of the SS at S10 with median at 33.3. The lowest recorded SS was at this site with 3.12 mg/L. The variability in the SS load at the San Sebastian canal across the sites was high. It ranged from 3.12 at S10 to 492.7 at S08.

Fluctuations and relationships

The fluctuations in SS can be seen in figure 6.5.

As with the COD and the BOD the SS was higher from S03-S07, which indicates high discharges from the industrial sources B and C. The downstream sites of B and C i.e. S04 and S07 also had high concentrations. The main contributions are from the upstream industries. The site S04 also had direct discharges from the motor spare workshops and shanties, while S07 had laundry waste water discharges. In addition to this the piled up dredged material (dredging took place at the time of monitoring) may also have entered the canal. The concentrations fluctuated at S05, the domestic site. The concentrations in comparison to S01 and S02 were higher from S08, which may be due to the contributions from the discharging tributary canals. Next to the industrial discharge sites of S03 and S07, the SS median value was the highest at S10 possibly due to turbulence resulting from the diurnal (push forward and backward) action of the tides at this site, to some extent.

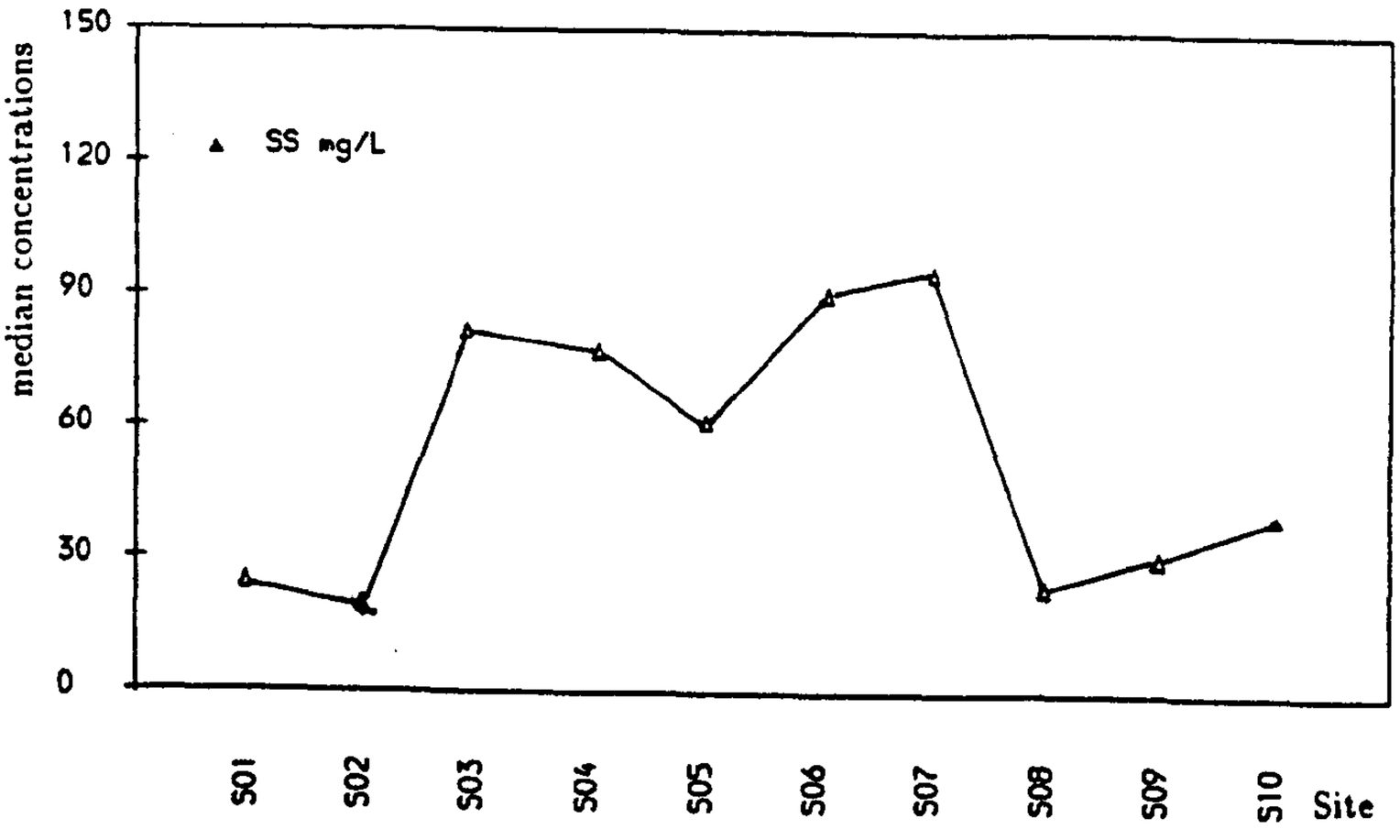


Figure 6.5 — SS fluctuations along the San Sebastian canal

Source: Based on field monitoring

Turbidity: data variability

The data variability in turbidity can be seen in table 6.10.

The turbidity values indicated low values at the sites S01 and S02. The median was higher at S02 with a value of 6.4 mg/L. The range and standard deviation are also closely spaced between these two sites. The site S01 appears to be the less turbid of these two sites. The turbidity increased at S03 with the minimum at 8.5, maximum at 65.2 and the median at 21.55. This is almost treble the value of sites S01 and S02. The 90th percentile and the standard deviation were high, which indicated the high and variable data. S04 turbidity decreased with the median at 21.15. This trend is continued at S05 but increased at S06 and S07. The maximum turbidity for the San Sebastian canal was recorded at S07. The range was highest at S07 with 64.7 and standard deviation 12.93. Turbidity fell sharply to a median of 7.27 at S08. S09 saw an increase in turbidity which was continued into S10, The lowest turbidity was recorded at S10 with 2.05 NTU but the maximum was similar to the sites S04 and S05. The turbidity across the sites was 69.6 with a minimum of 2.05 at S10 and a maximum of 71.6 at S07.

Fluctuations and relationships

The fluctuations in turbidity can be seen in figure 6.6.

The turbidity was lower at canal origin sites. The site S01 appears to be the less turbid than S02. The reason for S02 being more turbid than S01 may be due to the turbulence caused by the pumping of water to the Beira lake from this site almost daily. the turbidity sharply increased from S03. The fluctuations are similar to the discussions on SS earlier. After a drop at S08, it showed an increase till the end of the canal. Although there is a drop at this domestic site, the contribution from the tributary canal, the Dematagoda ela is clear as the concentrations remain higher than the canal origin sites. The turbidity (and SS earlier) increased from S09. This site is between the Main Drain and the Kittampahuwa ela, so there is a contributary load of SS from the tributary canals. In addition to this the effect of the tides at the eastern end of the canal may also be a contributory cause.

Conductivity: Data variability

Table 6.10 — The variability of turbidity (NTU) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	7.27	3.38	19.2	3.8	22.0	6.27	10.95
S02	7.12	3.24	18.5	4.1	22.6	6.40	10.67
S03	24.24	11.41	56.7	8.5	65.2	21.55	41.92
S04	23.07	13.06	56.8	6.0	62.8	21.15	49.20
S05	20.04	11.40	56.3	4.0	60.3	18.40	39.80
S06	24.96	11.82	61.7	8.2	70.0	22.07	40.00
S07	24.73	12.93	64.7	6.9	71.6	23.10	38.50
S08	9.21	5.75	25.8	3.2	29.0	7.27	18.18
S09	14.92	8.80	46.3	6.0	52.3	13.30	26.40
S10	14.00	9.04	57.2	2.0	59.3	12.30	21.27
2							
R01	8.68	5.06	27.6	2.0	29.6	7.50	16.08
R02	8.36	5.00	21.5	2.0	23.5	7.25	14.90
3							
U01	9.63	5.02	26.9	2.7	29.6	8.27	17.77
U02	35.80	21.53	61.5	8.5	70.0	30.00	70.00

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.
Source: Field monitoring.

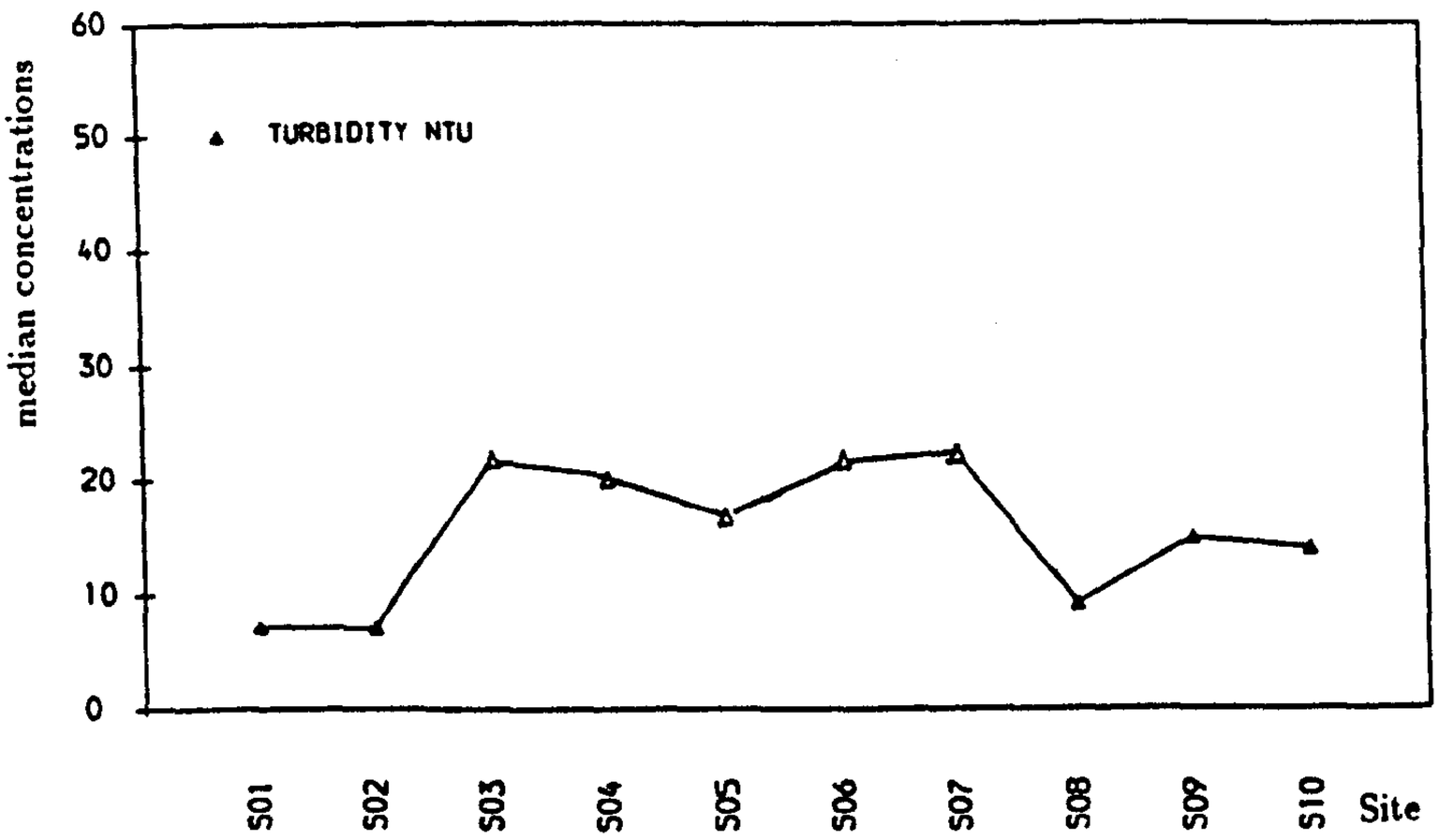


Figure 6.6 — Turbidity fluctuations along the San Sebastian canal

Source: Field monitoring

Table 6.11 — The variability of conductivity μmhos/cm in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	546.12	89.06	325.0	395.0	720.0	542.5	603.7
S02	242.18	57.97	225.0	145.0	400.0	242.0	325.0
S03	702.75	339.00	1600.0	250.0	1850.0	600.0	1147.0
S04	587.00	159.70	610.0	395.0	1005.0	560.0	898.0
S05	559.70	129.68	510.0	410.0	920.0	527.5	733.5
S06	643.25	227.17	1185.0	400.0	1585.0	615.0	828.0
S07	661.10	208.50	1160.0	400.0	1560.0	592.5	947.5
S08	790.70	628.80	1100.0	150.0	2250.0	540.0	2000.0
S09	860.12	635.70	2815.0	170.0	2985.0	535.0	1862.0
S10	640.10	600.00	2760.0	40.0	2800.0	462.5	1548.5
2							
R01	723.20	1116.30	3345.0	30.0	3375.0	75.7	2932.5
R02	529.00	840.70	2565.0	35.0	2600.0	70.0	2298.5
3							
U01	19832.00	1528.80	4650.0	16350.0	21000.0	21000.0	21000.0
U02	528.33	252.17	920.0	200.0	1120.0	500.0	928.0

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.
Source: Field monitoring.

The data variability can be seen in table 6.11.

At the site S01 the conductivity was much higher than at S02. Conductivity fell drastically at S02 with the median at 242.5. The 90th percentile was 325.0 which is almost half at S01. The conductivity increased at the site S03 to a maximum of 1850.0, and a median of 600.0. The 90th percentile fell at 1147.0. The range was also high with 1600.0. So was the standard deviation. The conductivity fell at S04 and continued to fall at S05 with the median at 560.0 and 527.5 respectively. The conductivity increased at S06 with the maximum at 1585.0 and the median of 615.0. This was the highest median for the canal. The range was high with 1185.0, with the standard deviation at 227.17. The conductivity fell slightly at S07 with the median at 592.5, but increased from S08 to S10. The site S09 recorded the highest conductivity with a value of 2985.0. The 90th percentile was at 1862.0. Conductivity was also very high at S10 with a maximum of 2800.0. The range was high with 2760.0 and the 90th percentile fell at 1548.5. Conductivity displayed highly variable values with the minimum for the canal reading 40.0 at S10 and the highest value recorded, 2985.0 at S09. The range for the entire canal was 2945.0.

Fluctuations and relationships

The fluctuations in the conductivity can be seen in figure 6.7.

The high conductivity at S01 may be due to the location of the site at the eastern edge of the Beira lake and with possible entry of sea water during lockage at McCallum locks, which are operated almost daily. Further commercial activities along the East Beira lake may contribute to the dissolved salts at the site S01 which is located almost at the boundary of Beira and the San Sebastian canal. The lake water may mix with the canal water. There are also shanties along the lake. Conductivity fell at S02, but increased at the industrial discharge sites of S03 to S07. This may be due to salts that enter from the industrial processes which makes the water highly conductive. There is also an increase in conductivity values from S08 through S10. At S08 it could be due to contributions from the industries upstream and the tributary canal (the Dematagoda ela) which has many industries such as chemical and textiles which

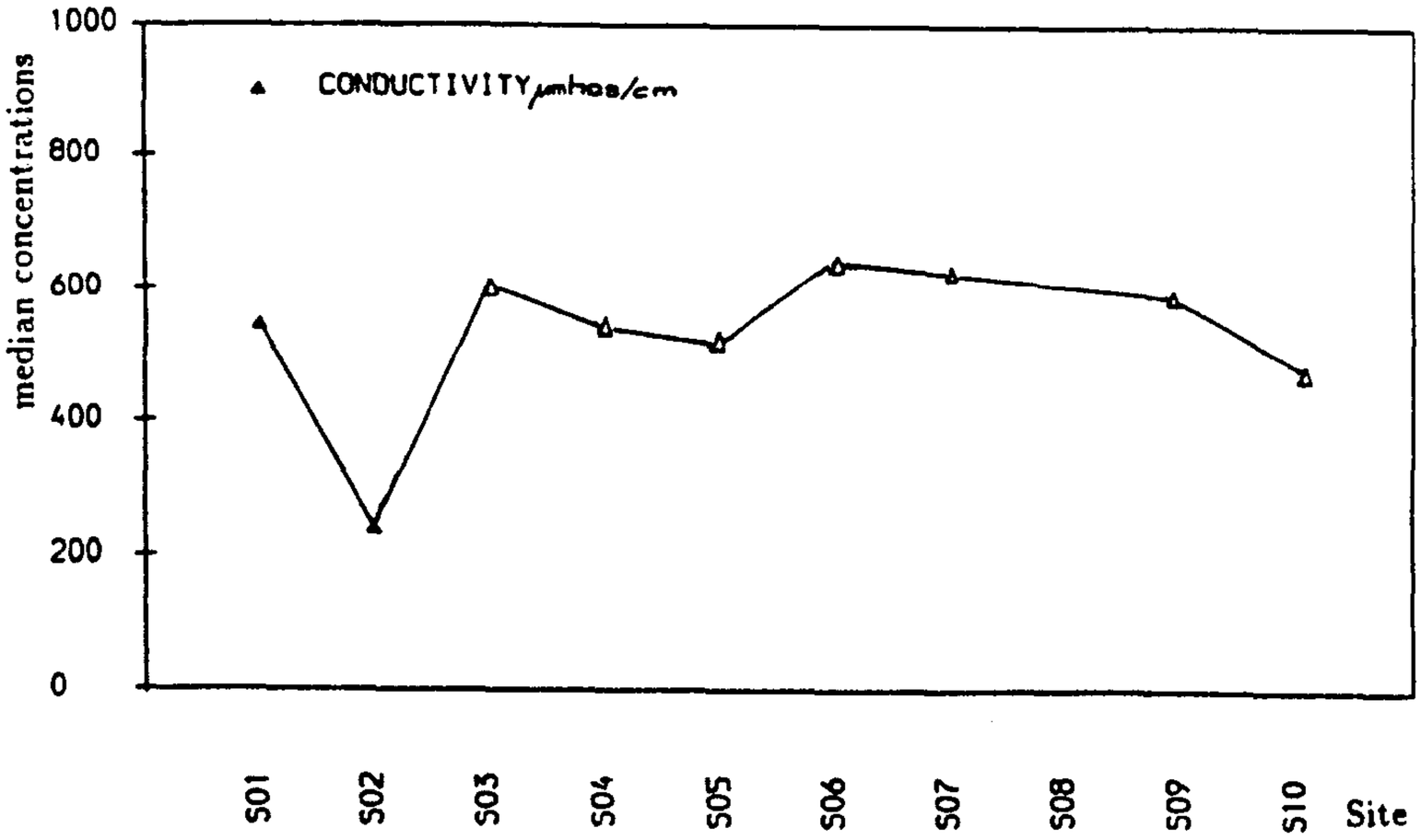


Figure 6.7 — Fluctuations in conductivity along the San Sebastian canal

Source: Based on field monitoring

discharge to the canal. These are only a few metres from the San Sebastian canal. The high conductivity at S09 may be due to contributions from the Kittampahuwa ela and the Main drain in addition the tidal effect which may be felt at this site. Sea water is highly conductive, and therefore for the highest conductivity value to be recorded at this site, there must be the effect both of internal forces mentioned earlier and influence of sea water at this site due to tidal effects. As far as conductivity is concerned this site seems to be the most buffered site from either side and therefore the concentration of salts is very high. The site S10 also had very high conductivity values with the maximum at 2800.0 and the median at 462.5. The 90th percentile fell at 1548.5. This is obvious since S10 is affected by the tides. Although there is high concentration of dissolved salts at the industrial sites as reflected by the conductivity values, the contribution to the receiving river and the lake is not clear. This is because both the receiving ends have sea water influence.

pH: data variability

The data variability for pH can be seen in table 6.12.

The pH in the San Sebastian canal appeared to be slightly alkaline at S01 and S02 with the median at 8.1. The range was very narrow with 1.6 and 1.5 respectively. So was the standard deviation at 0.36 and 0.04 respectively. The pH at S03 increased from a minimum of 8.0 to a maximum of 10.1. The median was 8.6, and the 90th percentile fell at 9.39. There was an improvement at S04 and S05 where the median fell to 8.5. Alkalinity increased at S06. The highest median was recorded at this site. It was evident in the 90th percentile of 9.18. The site S07 remained essentialy the same. 9. to 8.9. The pH continued to fall from S08. The median at S09 was 8.2, and 8.27 at S10. A minimum of 7.6 at S09, and 7.65 at S10 were recorded.

Fluctuations and relationships

The fluctuations in pH can be seen in figure 6.8.

The pH was weakly alkline at S01 and S02. It rose from the site S03, thus the canal was more alkaline up to S07 and gradually approached the levels of the original sites again from S08 to S10. The alkaninity of the water body between S03 and S07 is mainly due to the soap and detergent waste water discharges both at industries B

Table 6.12 — The variability of pH in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	8.17	0.36	1.6	7.6	9.2	8.1	8.6
S02	8.21	0.40	1.5	7.7	9.2	8.1	8.9
S03	8.70	0.49	2.1	8.0	10.1	8.6	9.3
S04	8.59	0.38	1.6	7.9	9.5	8.6	9.1
S05	8.51	0.35	1.9	7.6	9.6	8.5	8.9
S06	8.68	0.42	2.1	8.0	10.1	8.6	9.1
S07	8.62	0.36	1.7	8.0	9.7	8.6	8.9
S08	8.01	0.41	1.7	7.2	8.9	8.0	8.7
S09	8.29	0.36	1.5	7.6	9.1	8.2	8.8
S10	8.32	0.32	1.2	7.6	8.9	8.2	8.8
2							
R01	8.15	0.49	2.8	7.0	9.8	8.0	8.7
R02	8.10	0.63	3.6	6.0	9.6	8.0	8.8
3							
U01	8.23	0.26	1.1	7.8	8.9	8.2	8.5
U02	8.02	0.75	2.8	6.2	9.0	8.0	8.9

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

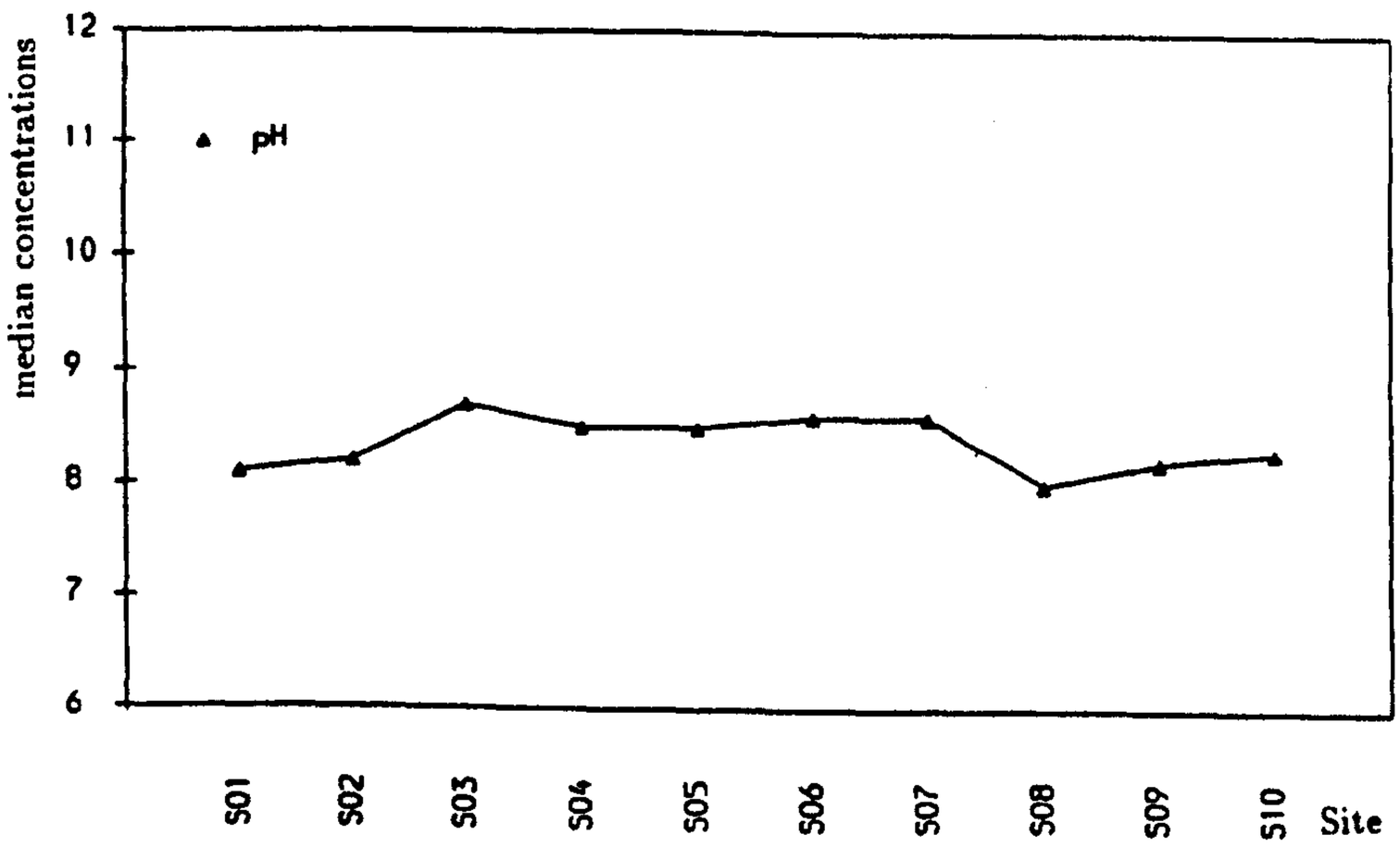


Figure 6.8 — Fluctuations in pH along the San Sebastian canal

Source: Field monitoring

and C on a large scale. Both production waste waters and cleaning water effluents were led of to the canal. The slight increase from S09 may be due to industrial discharges which enter from the tributary canals. The contribution into the receiving river appeared minimal.

Water temperature: data variability

The data variability can be seen in table 6.13.

Table 6.13 — The variability of water temperature °C in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	30.90	1.14	6.6	27.0	33.6	31.00	32.00
S02	31.00	1.27	6.9	27.0	34.8	31.10	32.28
S03	33.90	2.44	12.7	30.0	42.7	33.25	38.39
S04	34.12	2.31	11.0	29.0	40.0	33.62	33.45
S05	32.60	1.22	6.0	30.0	36.0	32.85	34.00
S06	33.12	1.43	7.0	29.5	36.5	33.00	34.78
S07	32.84	1.26	6.8	29.0	35.8	33.00	34.00
S08	31.41	1.08	5.6	28.0	33.6	31.50	32.60
S09	32.00	1.14	6.5	28.5	35.0	32.00	33.20
S10	32.00	1.22	6.0	29.0	35.0	32.00	33.50
2							
R01	30.03	1.53	7.5	25.0	32.5	30.40	31.70
R02	29.69	1.40	6.5	25.5	32.0	30.00	31.50
3							
U01	30.40	1.10	5.5	27.0	32.5	30.40	31.98
U02	31.04	0.93	4.0	29.0	33.0	31.00	32.40

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

The water temperature in the San Sebastian canal was usually near ambient temperature at the sites S01 and S02. At S03, the ambient air temperature was never followed by water temperature. It was always higher than the air temperature. The minimum water temperature was 30 °C, while the maximum 42.7, and the median fell at 33.25. The 90th percentile was 38.39. The range at S03 was the highest recorded in the San Sebastian with a value of 12.7. So was the standard deviation of 2.44. The water temperature at S04 closely followed S03, but the values were lower. The water temperature fell at S05 with the median at 32.85. At S06 it was slightly higher than at S05. S07 too had similar values as S06 except that the 90th percentile was 34.0. The water temperature fell at S08, with the median at 31.5 and 90th percentile, 32.6. The sites S09 and S10 were similar with the median slightly higher than at S08. The range of temperature across the sites was high with a minumum of 28.5 at S09 and a maximum of 42.7 at S03. There was a difference of 14.2 degrees C between the sites.

Fluctuations and relationships

The fluctuations in the water temperature can be seen in figure 6.9.

As seen in figure 6.9 the water temperature is lower at the sites S01 and S02. The water temperature at the sites S03 to S07 was always higher than the ambient air temperature. This is purely due to heated industrial waste water discharges at these sites. Although S05 was between two industrial discharge points, the water temperature at this site too remained relatively higher. This high water temperature may also be the cause of the very low DO in the canal stretch from S03 to S07 in addition to the high BOD and COD at these sites. The higher the water temperature, the lower is the DO in the surface waters. The water temperature appeared more

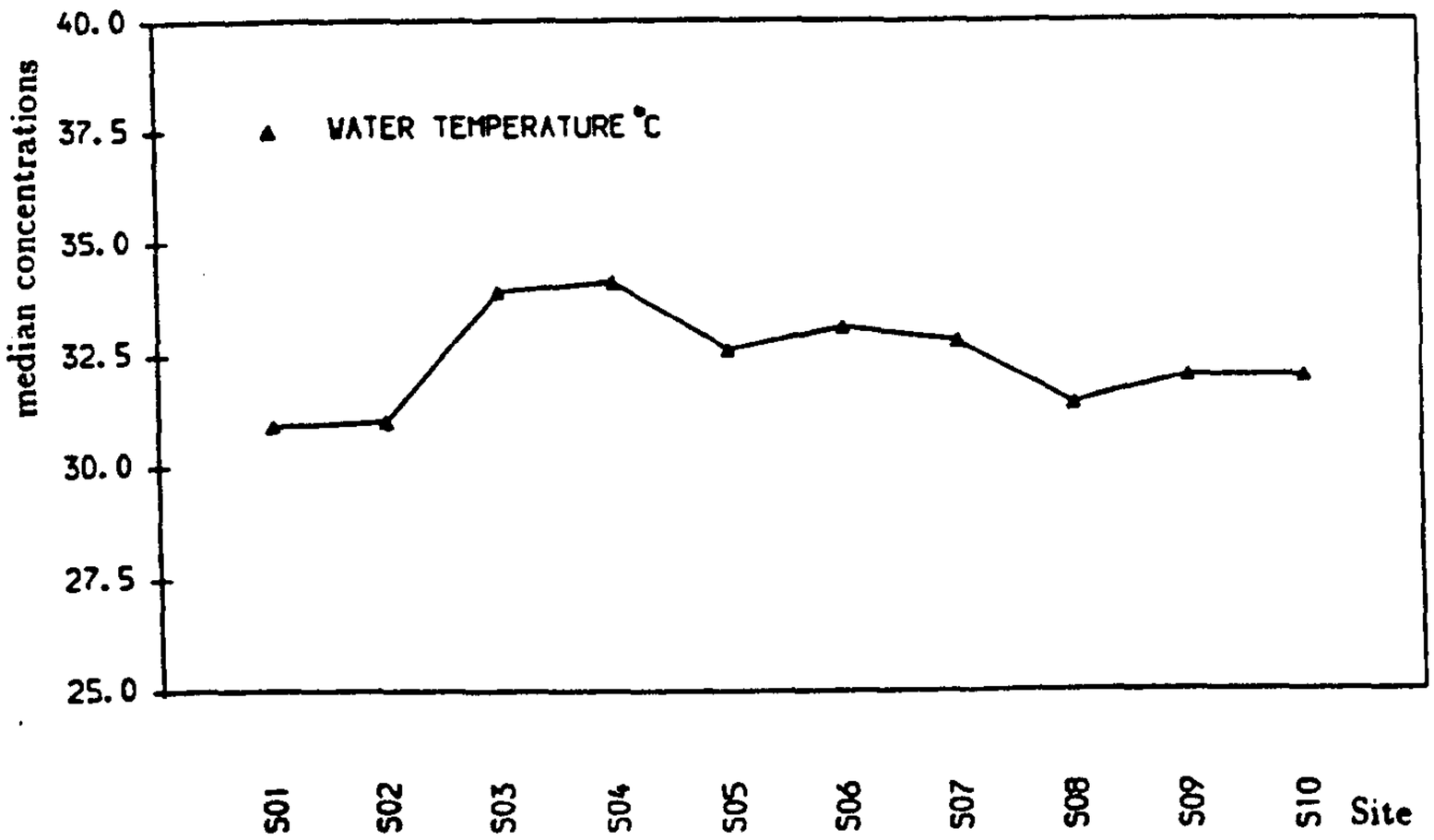


Figure 6.9 — Fluctuations in water temperature along the San Sebastian canal

Source: Based on field monitoring

stabilised at S08, but the slight increase downstream may be due to warmer water from the tributary canals, which enter at this stretch.

Total P: data variability

The data variability in total P can be seen in table 6.14.

The total P at the site S01 was higher than at S02, but the concentrations remained low at both the sites. At S03 the total P increased with the minimum at 1.2 mg/L to a maximum of 8.75. The median rose to 2.3 while the 90th percentile was at 6.58. The range was high with 7.55 and so was the standard deviation at 2.12. The total P slightly decreased at S04 with maximum reaching only to 5.65. The median was at 2.0. It continued to fall at S05 with the median was 1.45. The total P increased at S06 with the highest median recorded at this site, for the entire canal with a value of 3.25 mg/L. The total P slightly fell at S07 with the median at 2.8. At S08 it recorded the minimum value and the maximum for the entire San Sebastian canal. The median of 1.9 was lower in comparison to the other sites. The total P concentration tended to fall slightly at S09 and S10. Although the maximum recorded value was 6.5 and 6.1 at S09 and S10 respectively. The median was 1.85 at S09 and 1.0 at S10 which was lower than at S08. The range across the sites in the San Sebastian canal was 9.25, with the minimum of 0.0 recorded at S02, S06 and S05; and the maximum at S08 with a value of 9.25.

Fluctuations and relationships

The fluctuations in total P can be seen in figure 6.10. .

The total P remained quite low at the S01. and S02, Although the concentrations were comparatively low, the total P is high enough to induce plant growth. Aquatic plants were observed at site S02. The total P concentration was higher in the industrial sites especially S03 and S06. This is due to the high phosphate content in the industrial effluents. Both factory B and C manufacture detergents, and these commercial detergents contain high amounts of phosphates. Detergents are also used freely at at factory C for floor washing. Possibly due to this the highest median was recorded at S06. The total P fell compartively at S08, although it was higher than

Table 6.14 — The variability of total P (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	1.54	1.06	4.80	0.20	5.00	1.11	2.85
S02	1.34	1.66	6.90	0.00	6.90	0.95	4.37
S03	3.40	2.12	7.50	1.20	8.75	2.30	6.58
S04	2.36	1.27	5.35	0.30	5.65	2.00	4.68
S05	1.90	1.20	4.90	0.50	5.40	1.45	4.25
S06	3.36	1.56	6.25	0.00	6.25	3.25	5.85
S07	3.06	1.25	5.40	1.35	6.75	2.80	4.55
S08	2.23	2.12	9.25	0.00	9.25	1.90	5.46
S09	2.46	1.90	6.20	0.30	6.50	1.85	5.87
S10	1.69	1.54	5.90	0.20	6.10	1.10	4.50
2							
R01	1.69	1.28	6.10	0.15	6.25	1.35	4.08
R02	1.80	0.70	3.70	0.65	4.35	1.70	2.81
3							
U01	2.04	1.04	4.70	0.25	4.95	2.15	3.30
U02	3.10	2.70	11.35	0.00	11.35	2.50	7.63

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

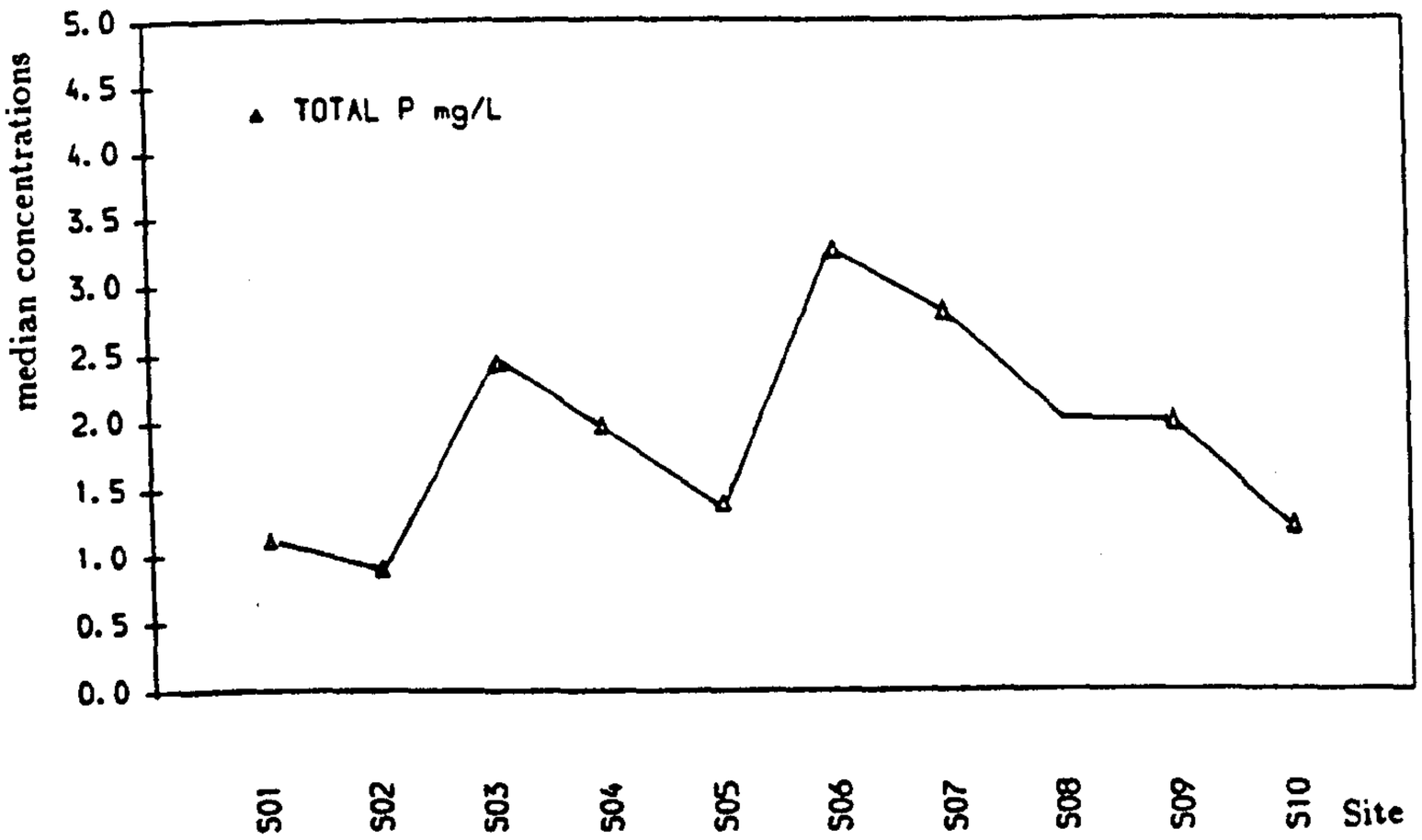


Figure 6.10 — Fluctuations in total P along the San Sebastian canal

Source: Based on field monitoring

at the downstream sites. There was a luxuriant growth of *Eichornia crassipes* at this site. The shanties at the Stace road also contribute to total P in addition to the load brought about by the Dematagoda canal, particularly from the factory D waste waters. This factory produces fertilisers. The total P fell slightly at S09 and S10. At S10 *Eichornia crassipes* was luxuriant. It was also found at S09. The fertiliser runoff from the adjoining vegetable plots also may contribute to total P.

Total N fluctuation: data variability

The data variability can be seen in table 6.15.

Table 6.15 — The variability of total N (mg/L) in the surface waters.

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	2.46	1.18	4.09	0.23	4.32	2.40	4.15
S02	0.86	0.66	1.81	0.10	1.91	0.82	1.82
S03	9.55	1.92	5.74	6.39	12.13	10.30	11.72
S04	8.72	2.05	5.92	5.66	11.58	9.19	11.45
S05	5.60	2.64	8.17	2.63	10.80	4.14	10.08
S06	12.00	3.34	10.48	5.88	16.36	12.56	16.35
S07	10.54	2.38	7.40	6.25	13.65	10.50	13.65
S08	2.65	0.98	3.46	1.16	4.62	2.41	4.27
S09	3.13	1.15	4.15	0.28	4.93	3.58	4.23
S10	2.89	1.19	4.20	0.23	4.43	3.04	4.32
2							
R01	1.67	1.07	3.72	0.14	3.86	1.51	3.56
R02	1.33	0.95	3.17	0.01	3.18	1.23	3.05
3							
U01	5.80	2.22	8.65	0.72	9.37	5.73	8.86
U02	37.24	20.31	61.43	10.60	72.03	39.20	68.51

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

The total N levels in San Sebastian canal varied widely between the sites. At site S01 the median fell at 2.4. The range was high with 4.09 and the standard deviation 1.18. This site has total N much higher than S02 which has a maximum of only 1.19 mg/L with median at 0.82. The total N increased at S03 with a minimum of 6.39 to a maximum of 12.13 while the median was at 10.3 mg/L. The 90th percentile of 11.72 indicated high values at the site. Total N was also high at S04 with the median at 9.19 but was slightly below S03. S05 saw a slight fluctuation with median at 4.14. The range was high at S05 with 8.17 and standard deviation 2.64. The nitrogen level saw an increase at S06 with the maximum of 16.36, which was the highest value recorded for the entire canal. The minimum was at 5.88 while the median was the highest for the canal with 12.56. The 90th percentile was 16.35, and the range was high with a value of 10.48. S07 also had high total N values with the median at 10.5. The total N decreased at S08. At S09 the median was higher with 3.58 mg/L. At S10 there was a slight fluctuation where the median fell to 3.04. The total N ranged from 0.10 at S02 to a maximum of 12.56 at S06.

Fluctuations and relationships

Figure 6.11 shows the total N fluctuations.

The comparison of total N with the other parameters on the same grounds is difficult since it was based only on a total of 14 monthly observations. Therefore, a comparison with other parameters may not prove very accurate.

Of the observations available it can be said, that the overall total N levels were high. The concentration of total N is high with a fluctuation at S02. The cause for

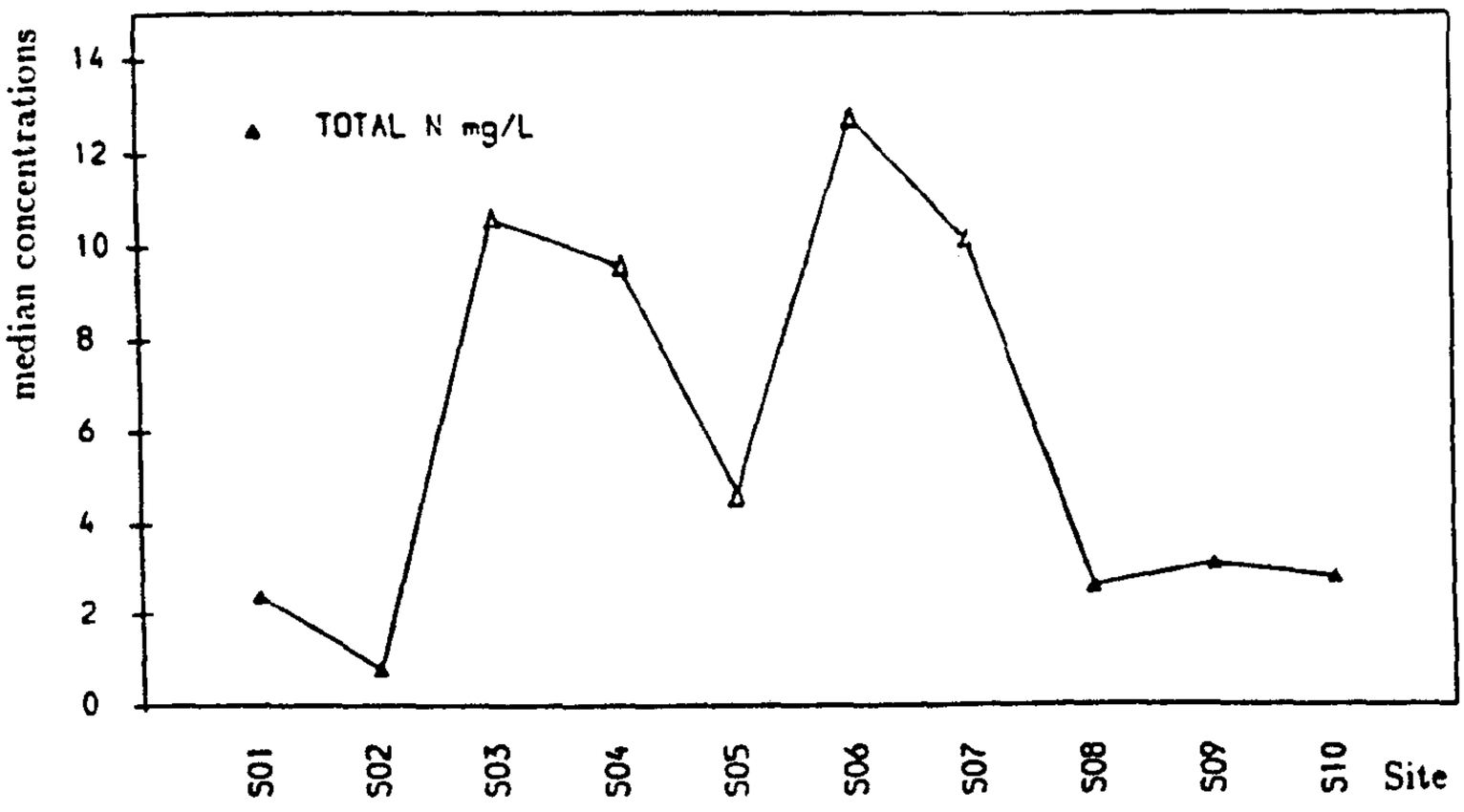


Figure 6.11 — Fluctuations in total N along the San Sebastian canal

Source: Based on field monitoring

higher Total N values at S01 may be the influence of the lake, nitrogeneous matter contributed by the shanty dwellers and the commercial activities. The concentrations increased sharply from S03 which receives industrial discharges and domestic wastes from the shanty population. This is especially true of the site S03 which has the lock-gate upgraded scheme. Although toilets are built in the new upgrading (rehousing) scheme, makeshift toilets are erected on the canal banks from which the waste matter freely passes into the canal. This is also true of sites S04 and S07. The situation is further aggravated by the Maligawatte and the Kittampahuwa drains which run through highly congested, residential areas of Colombo. These discharge additional nitrogeneous matter into the canal The site S04 has a luxuriant growth of aquatic plants including *Eichornia crassipes.* This was clearly visible during the dry periods when the canal was clogged and stagnant. The high concentration at S06 is purely due to the effluent discharges of the factory C. The total P at S07 may also be due to the laundry effluents which enter the canal at this point. Total N fluctuated from site S08. Although total N values at S08, S09 and S10 were much lower, they were high enough to induce aquatic growth due to nutrient enrichment. The toilets at the Stace road shanties (now upgraded) erected on the canal banks, in addition to other domestic chores may have resulted in nitrogeneous and phosphorous matter entering the canal. From S08 to S10 nitrogen was much higher than at S02 because Dematagoda ela, Kittampahuwa ela and the Main Mrain also contribute to the load. It was observed that *Eichornia crassipes* floated freely in the Dematagoda and the Kittampahuwa ela when the canal flow was high, so that bamboo obstructions were erected at the entry point of these canals into San Sebastian. The aquatic plants were removed manually by boatmen. The high total P and total N between S08 and S10 may also be due to fertilizer run off which enter the canal from the keera plots (green leafy vegetable) which are a specialized market- garden area.

Sulphates: data variability

The data variability in sulphates can be seen in table 6.16.

The sulphates at S02 was lower than at the site S01. At S01 the maximum was 682.6 and the median 159.0. The range was high at S01 with 607.3 while the

Table 6.16 — The variability of sulphate (mg/L) in the surface waters

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
S01	180.70	109.02	607.3	75.3	682.6	159.0	306.6
S02	104.97	52.60	199.5	37.6	237.1	89.6	206.1
S03	205.48	129.86	553.7	79.6	633.3	156.2	376.2
S04	205.71	131.16	459.4	63.3	522.7	163.3	450.0
S05	149.80	91.00	346.6	40.0	386.6	100.3	296.2
S06	195.59	110.00	494.9	16.1	511.0	170.6	356.4
S07	166.50	92.40	389.4	43.8	433.2	142.9	270.0
S08	110.50	53.20	164.5	40.3	204.8	93.8	197.8
S09	128.62	56.50	239.4	59.6	299.0	118.0	153.0
S10	104.50	67.30	279.6	26.7	306.3	85.6	183.9
2							
R01	113.30	106.00	363.3	9.2	372.5	63.1	347.0
R02	95.60	103.00	362.7	6.3	369.0	42.8	306.2
3							
U01	1630.60	424.70	2071.8	836.0	2907.8	1562.2	2011.4
U02	177.15	62.46	194.5	96.2	290.7	182.0	277.2

Sections: **1** = San Sebastian canal, **2** = River Kelani and **3** = Beira lake.

Source: Field monitoring.

standard deviation was at 109.02. The suphates were high at S03 with the maximum at 633.3. The median fell at 156.2. The 90th percentile fell at 376.2. The site S03 exhibited similar patterns to S01. Sulphates continued to increase at S04 although the maximum recorded was lower with a value of 522.7, the median was higher with 163.3. At S05 the sulphates fluctuated with the median at 100.3. It increased at S06 with the median reaching the highest for the canal at 170.6. This site also had the lowest value of 16.1 for the entire canal. The range was high. The suphates were high at S07, although lower than at S06, and the median recorded at 236.1. There was fluctuation in sulphate values from S08 to S10 with a higher median value of 118.0 recorded at S09.

Fluctuations and relationships

The fluctuations in sulphate can be seen in figure 6.12.

The sulphates depicted a different picture to the other pollutants. The sites S08 to S10 depicts sulphates level different from S03 to S07, which are influenced by industrial discharges. The values are much higher at the latter group with the maximum value reaching 633.3 at S03, while the highest median fell at S06. Both these sites have direct industrial discharges. The site S01 too had higher values, and the highest value for the entire canal was recorded at this site with a value of 682.6 mg/L. This may be due to the influence of the adjoining lake which recorded the highest sulphates values for the entire water surfaces monitored. There is a possibility of the lake water mixing with the canal. The situation between S01 and S10 although both are close to the sea, are different. S10 is tidal but has only a daily occurrence of sea water entering along with the fresh waters of the river. At S01, the site being much closer to the sea, comes under the influence of sea water, thus brackish water may be mixed with the canal water as the locks are operated several times a day. Further, as the Beira is a lake, retention of sulphates may be high. This can be seen in the high conductivity values too, although the minimum and maximum is not as high as at S10. Thus there may be a mixing of brackish water of the lake with the canal water at this point because both the conductivity and sulphates values at S01 are much higher than at S02.

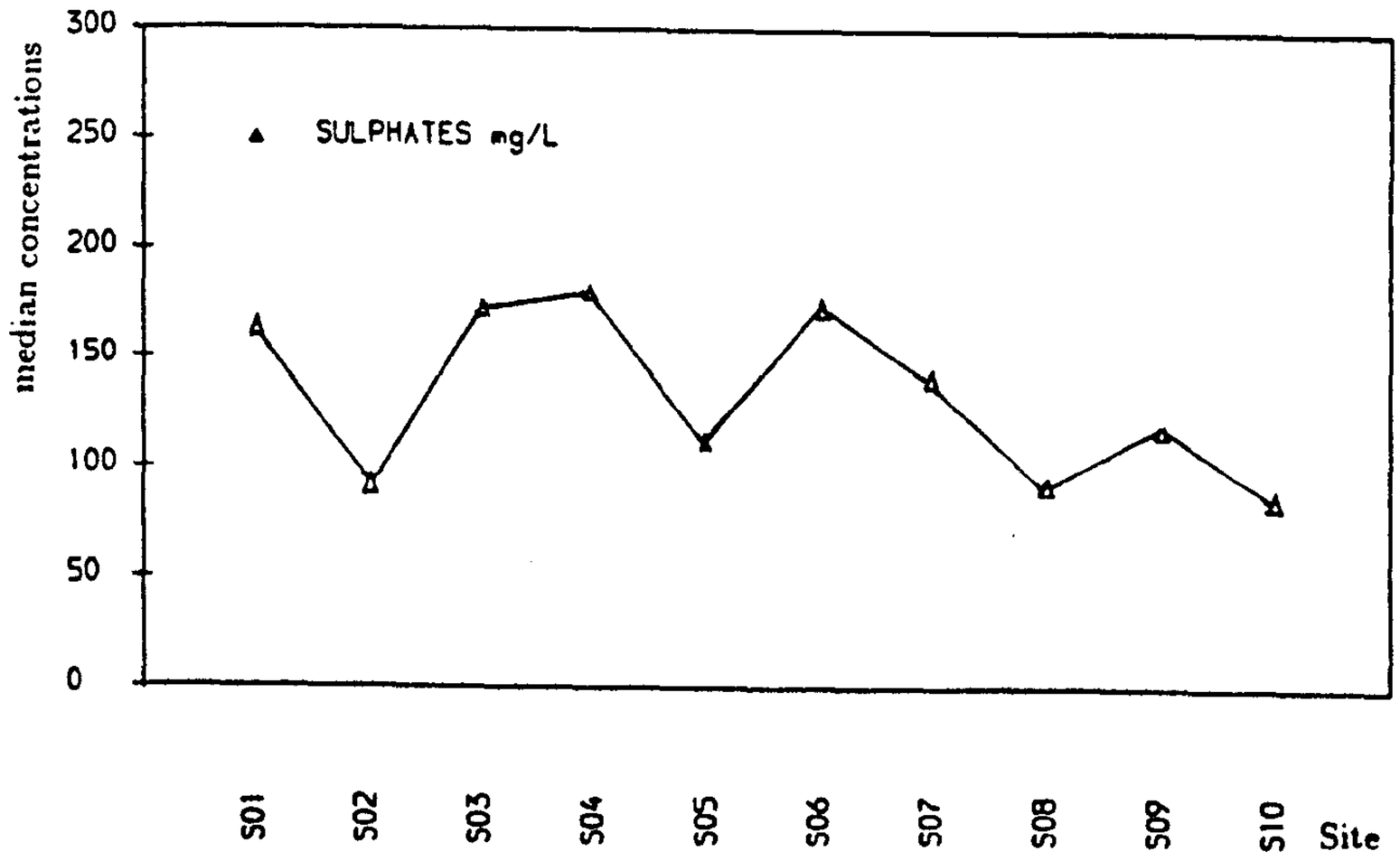


Figure 6.12 — Fluctuations in sulphate along the San Sebastian canal

Source: Based on field monitoring

6.5 Fluctuation of pollutants in other water bodies

6.5.1 Fluctuations in the river Kelani

Data variability

Table 6.6 shows the data variability for DO in the river. The DO levels in the river Kelani (sites R01 and R02) resembled each other closely. The lowest DO was recorded at R01 with 5.1 mg/L and the highest fell at R02 with 11.6 mg/L. The highest DO for R01 was 9.3 mg/L. The median for R01 was 6.05 and 6.8 for R02. The range was higher for the site R02 with a value of 6.1. The standard deviation was lower for R01 with 0.76.

Table 6.7 shows the data variability for COD in the river. The COD in the river sites depicted a fairly regular pattern except that the minimum at both R01 and R02 were 4.0 mg/L. The highest COD was recorded at R02 with 104.0 mg/L. Although the highest value was recorded at R02, the median at R01 was twice as high with 36.0 mg/L than at R02 The 90th percentile for R02 was 50.35, while the figure was higher with 78.9 for R01.

Table 6.8 shows the data variability for BOD in the river. The BOD in the river had a minimum of 2.0 mg/L at both the sites. The maximum at both the sites remained the same with 67.0 mg/L. The median at R01 was 19.5 which was almost double the value at R02, which read 9.5 mg/L. This is also seen in the percentiles. The percentiles for R01 and R02 were 49.9 and 33.4 respectively.

Table 6.9 shows the data variability for SS in the river. The SS at the Kelani river recorded a minimum of 3.6 and 5.8 at R02 and R01 respectively. The maximum was higher at R02 with 125.2. The median was lower at R01 than R02. The 90th percentile for both the sites were around 61 mg/L.

Table 6.10 shows the data variability for turbidity in the river. The turbidity in the river was higher at R02 where the median reached 7.5 at R02 and 7.25 at R01. The maximum turbidity was reported at R02 with 29.6 NTU. The minimum remained the same at both the sites with 2.0 NTU. The range was 27.6 at R02 and 21.5 at R01. The standard deviation remained 5.0 at both the sites. The 90th percentile at

R01 was 14.9 while at R02 it was 16.08.

Table 6.11 shows the data variability for conductivity in the river. The conductivity in the river was higher at R01 than at R02. A maximum of 3377.0 μmhos/cm was recorded at R01 while 2600.0 was the maximum at R02. The minimum recorded for the sites are 30.0 for R01 and 35.0 for R02. The range was high with 3345.0 and 2565.0 respectively. The standard deviation too depicted the same trend with 1163.0 at R01 and 840.7 at R02.

Table 6.12 shows the data variability for pH in the river. The pH of the river remained neutral with a median of 8.0 at R01 and 8.05 at R02. The minimum recorded at R01 was 7.0 and 6.0 at R02. The 90th percentile was 8.7 and 8.89 respectively. The maximum reached at R01 was 9.8 and 9.9 at R02.

Table 6.13 shows the data variability for water temperature in the river. The water temperature minimum recorded at R01 and R02 are 25 and 25.5 °C respectively. The maximum reached are 30.4 and 30 °C respectively. The range had a difference of one degree while the standard deviation was essentially the same. The median value for the sites were 31.0 and 30.8 for R01 and R02. The 90th percentiles were 31.7 and 31.5 respectively.

Table 6.14 shows the data variability for total P in the river. The maximum recorded total P was 6.2 at R01 and 4.35 at R02, and the median fell at 1.35 and 1.7 respectively. The range was higher at R01 with 6.1 and the standard deviation at 1.28. The 90th percentile at R01 was 4.08 and 2.81 at R02. The median was higher at R02 with 1.7.

Table 6.15 shows the data variability for total N in the river. The total N minimum of 0.14 was recorded at R01 while it was 0.01 at R02. The maximum recorded was 3.86 for R01 and 3.18 mg/L for R02. The median too was higher with 1.51 at R01 while it was 1.23 at R02. The 90th percentile fell at 3.56 for R01 and 3.05 for R02.

Table 6.16 shows the data variability for sulphates in the river. The maximum sulphates recorded at R01 was 372.5 and 369.0 at R02. The minimum recorded for R01 was 9.2 and 6.3 for R02. The median for R01 and R02 were 63.1 and 42.8 respectively. The range between the sites was very narrow with 1.0 mg/L . So was the standard deviation.

Fluctuations and relationships

Figure 6.13 (a,b,c) shows the DO, COD and BOD fluctuations in the river.

The Sebastian canal enters the river Kelani midway between R01 and R02. As seen in the figure the DO is lower at R01. This shows that the San Sebastian canal enters the river as a polluted waterway and thus pollutes the downstream site of the receiving river. The low DO at R01 is also indicated by the high COD and the BOD at the site. This indicates that the San Sebastian canal enters the river with a high organic load. The high organic load contributed by the canal thus causes the oxygen depletion in the downstream site of the river.

Figure 6.13 (d,e) shows the SS and turbidity fluctuations in the river. The SS load is higher at R02 than at R01, which gives a different picture to the other pollutants. Thus the contribution from the San Sebastian canal to the reciving river appears less when compared to the upstream site. But it has to be added that although the upstream site R02 may receive higher SS loadings from the upstream sources, the difference between the SS at both the sites is not wide. Turbidity did not differ much between the sites, although R02 remained the more turbid site.

Figure 6.13 (f) shows the conductivity fluctuations in the river. The higher conductivity at R01 is obviously due to sea water which enter the river. The entry of industrial salts from the canal may contribute to higher conductivity values in the receiving river.

Figure 6.13 (g,h) shows the pH and water temperature fluctuations in the river. The pH of the river remained weakly alkaline at both the sites. Thus the contribution from the canal to the river appeared minimal. The water temperature was slightly higher at R01. But, as most of the water temperature readings fell in the river sites were about two degrees below the maximum air temperature the direct impact on the receiving river appeared minimal.

Figure 6.13 (i,j) shows the total P and total N fluctuations in the river. Although the total P median situation remained lower, the fact that R01 has a higher value (in comparison to R02) at the 90th percentile indicates that R01 is the more polluted

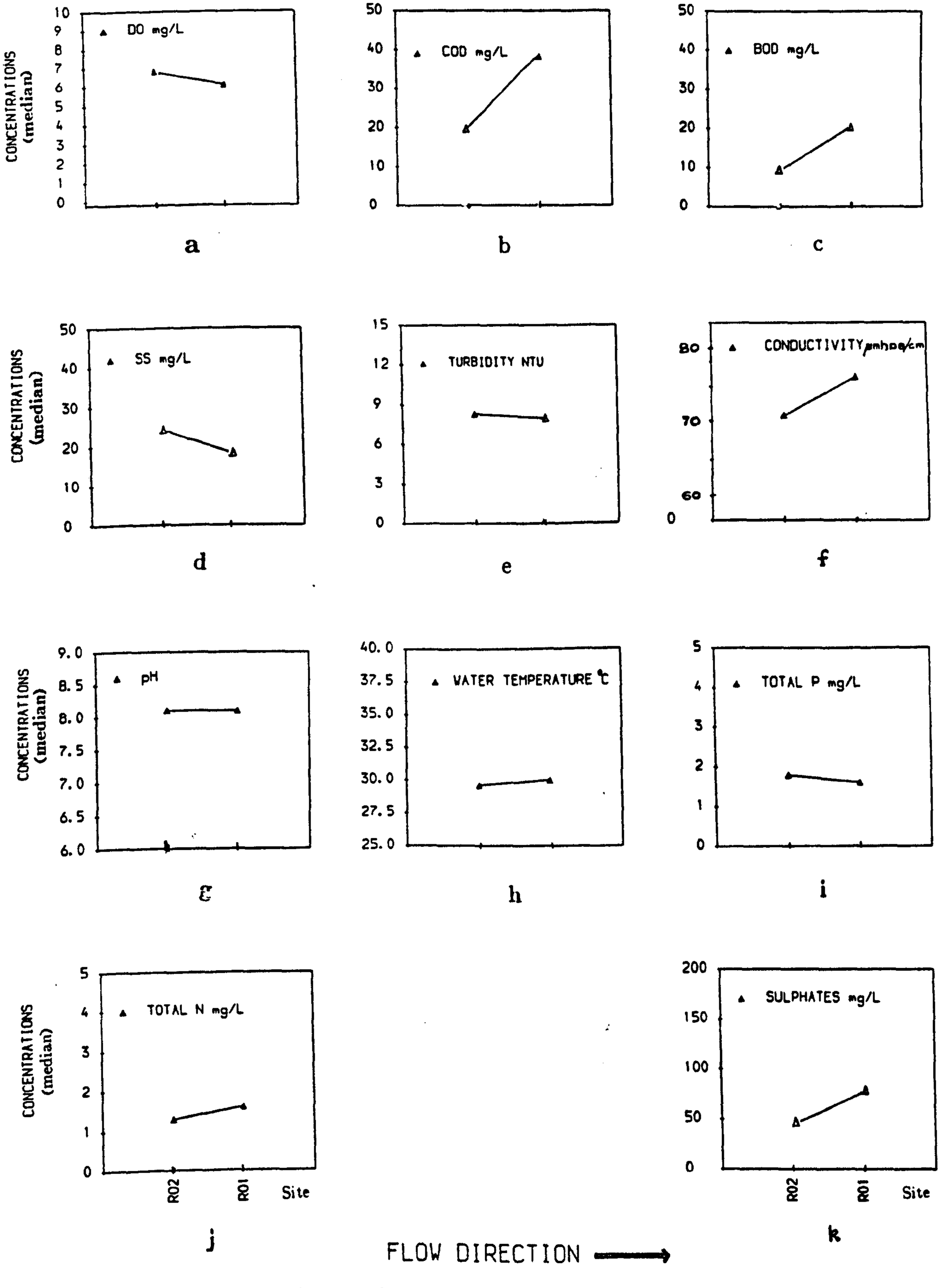


Figure 6.13 — Fluctuations of pollutants in the river Kelani

Source: Field monitoring

of the two river sites. Thus the contribution by the San Sebastian canal becomes evident. The total N in the river was higher at R01 than at R02. Therefore R01 which is downstream of the San Sebastian canal contributes total N into the river.

Figure 6.13 (k) shows the sulphate fluctuations in the river. The sulphates in the river was higher at R01 than at R02. Being the downstream site, there is a possible contribution from the San Sebastian canal. In addition to this, sulphates from the tidal water may also be a contributary cause. This trend was also seen in the conductivity values.

6.5.2 Fluctuations in the Beira lake

Data variability

The data variability for DO in the lake can be seen in table 6.6. Of the sites in the Beira Lake, U01 which is on the East Lake had a DO minimum of 0.0 and maximum value of 6.4, the median at 1.6 and the 90th percentile fell at 6.0. The range is higher at 6.4 with the standard deviation at 2.08. The site U02 which is on the West Beira lake had a DO minimum of 0.9 mg/L and a maximum of 1.8 with the median at 1.3.

The data variability for COD in the lake can be seen in table 6.7. The COD at the lake sites depicted very high values both at U01 and U02. The minimum for U01 was 272.0 and maximum 1028.0 with the median at 618.0 while 90th percentile fell at 943.7. The range was very high with 756.0 and standard deviation 206.2. The minimum at U02 was 168.0 with the maximum reached, 1967.0 and the median at 773.0. The range was very high with a value of 1799.0. The standard deviation was 515.64.

The data variability for BOD in the lake can be seen in table 6.8. The BOD for the lake sites were also very high with the minimum at U01 being 65.0 and the maximum 508.0. The range was high with a value of 751.0. The standard deviation fell at 202.92. The median for the site was 508.0. The 90th percentile was at 770.8. BOD at U02 followed a similar pattern except the median which was lower than at U01, with a value at 466.0. The maximum BOD reached was 1265.0.

The data variability for SS in the lake can be seen in table 6.9. The SS load was higher at U02 than at U01. The median approached the same value at both the sites with 98.30 and 100.1 at U01 and U02 respectively. The minimum at U01 was 26.36 while the maximum was 367.2. The standard deviation was 77.49 and the 90th percentile, 219.02. The values at U02 are much higher with the SS reaching a maximum of 591.3 and a minimum of 10.2. The range was high and the 90th percentile was at 558.8 mg/L.

The data variability for turbidity in the lake can be seen in table 6.10. The turbidity values at U01 are lower. The minimum was at 2.7 and the maximum was at 29.6. The median was 8.67 with the 90th percentile falling at 17.77. The range is low with 26.9 and standard deviation 5.02. At U02 water is much more turbid with the maximum reaching 70.0. The median value was 30.0 with the 90th percentile at 70.0. The range was 61.5 and standard deviation 21.53.

The data variability for conductivity in the lake can be seen in table 6.11. The conductivity values recorded at the site U01 is one of the highest in the entire monitoring programme. A minimum of 16350.0 μmhos/cm and a maximum of 21,000 with the median at 21,000 was recorded (any value above 20,000 was recorded as 21,000 as the conductivity meter read only up to 20,000 μmhos/cm). Therefore the actual value for conductivity may be even higher than 21,000. The 90th percentile was at 21,000. The range was 4650.0 and standard deviation at 1528.0. The conductivity at U02 was much lower than at U01. The minimum was 200.0 and the maximum 1120.0 with the 90th percentile at 928.0.

The data variability for pH in the lake can be seen in table 6.12. The pH was slightly alkaline at both the sites in the lake. The minimum recorded at U01 was 7.8 and maximum fell at 8.95. The median was 8.2. The 90th percentile fell at 8.5. The range was narrow with a value of 1.1 and the standard deviation fell at 0.26. The pH at U02 fell to a minimum of 6.2 while the maximum reached was 9.0. The median was lower at U02 with 8.0.

The data variability for water temperature in the lake can be seen in table 6.13. The water temperature was higher at U02 with the minimum of 29.0 and a maximum of 33.0. The median was 31.0. The 90th percentile fell at 32.4. The range was 4.0

and the standard deviation 0.93. The minimum temperature at U01 was 27.0 and the maximum, 32.5. The median fell at 30.4.

The data variability for total P in the lake can be seen in table 6.14. The total P content too is higher at U02 with the maximum reaching 11.35 mg/L.

The data variability for total N in the lake can be seen in table 6.15. The total N levels were lower at U01 with the minimum at 0.72 mg/L and maximum 9.37. The median fell at 5.73. The 90th percentile was 8.86. At U02 higher total N values were recorded with the minimum at 10.6 and the maximum 72.03. The median reached was 39.2. The 90th percentile was marked by 68.5 mg/L. The range was very high with 61.43 and the standard deviation 20.31.

The data variability for sulphate in the lake can be seen in table 6.16. The sulphate levels at U01 was very high with the minimum at 836.0 and the maximum reached at 2907.8 mg/L. The median fell at 1562.2 mg/L. The range was high with 2071.8 and the standard deviation fell at 424.7. The 90th percentile fell at 2011.8 and standard deviation at 424.7. The 90th percentile fell at 2011.4. The sulphate level at U02 was very low in comparison, with the minimum of 96.2 and the maximum reached only 290.7. The median was at 182.0. The 90th percentile was at 277.6. The range was very low comparatively with a value of 194.5 mg/L.

Fluctuations and relationships

The DO level was low at both the sites. The percentage DO concentrations as seen in appendix G indicates that although the DO was low at both the sites, there were more occasions on which DO was zero at U02. The comparison between the two sites have to be done cautiously since U01 is based on 40 observations and U02 on 15 observations. Also the dates of monitoring differed. U02 was monitored along with the industrial group A, mainly to see the effects of its discharges on the site U02. When the low level of DO in the lake at U01 is considered it may be said that the San Sebastian canal contributes to the oxygen depletion of the site. Both sites appeared to be equally polluted with very low DO levels. The median of the site U02 was 1.3 which is lower than U01. At U01 the low DO levels may be due to oil spills at the site by the motor boats which ply frequently between the lake and the harbour and from the boat-repairing workshops along the lake. These hinder reaeration of surface water by atmospheric oxygen. A film of thick oil was observed on all the days of monitoring. The DO at U02 is much lower with the maximum reaching only 1.8. This site receives industrial waste water discharges directly from a creamery, and some other food divisions of the same industrial group. A big culvert empties raw sewage, and many smaller sewage outlets empty untreated waste water at this point. Obviously this could be the more polluted site on the lake since the creamery wastes enter untreated. The nature of its strength is highly polluting. U01 was the closest site monitored to the San Sebastian canal. The polluted water pumped from the canal may exert an oxygen demand at U01. The site U02 is unaffected by the canal water.

The oil at U01, and the food wastes and the raw sewage at U02 are both high oxygen demanding organic wastes which may have contributed to high COD values. The BOD essentially follows the COD. The site U02 appears to be more polluted than U01 inspite of the lower median. The polluted water of the San Sebastian canal may contribute to the high COD and BOD at U01.

The high SS load is obvious at the site U02, with unscreened, untreated and unsettled industrial waste water discharges from the A group of industries and the raw sewage which enter this site. U02 is more polluted than U01 with a higher SS load. As with SS, the turbidity was higher at U02, which is explainable because of the constant industrial discharges and the sewage which enters this site. The SS and turbidity follow a very similar pattern at these two sites.

The conductivity at U01 was higher because of the influence of sea water at U01, while in U02 (a purely land locked fresh water lake) the conductivity was low, although salts entered from the industries. The contribution from the San Sebastian canal to the site U01 appears minimal.

The pH was near alkaline at both the sites in the lake although there was greater fluctuation at the site U02. This may be due to both the acidic and the alkaline nature of the food waste water which enter at this site. The site appears unaffected by the San Sebastian waters.

Although there was no wide variation in the water temperature, the water temperature at U02 was higher. This is possibly due to heated effluents entering the lake from the creamery and the other divisions of the industrial group A. The temperature at U01 was near ambient temperature or usually a degree or two below the ambient air temperature.

The total P content too was higher at U02 and this may be due to the detergents which enter the lake from the creamery after the washing of the floor, vats and utensils. The lake may receive total P from the other sources common to the other pollutants. The higher total P at U02 explains the luxuriant growth of *Eichornia crassipes* at this site. At the time of monitoring a dredger was used to clear the aquatic plants in the lake. Although there is contribution from the San Sebastian canal to the East lake, it is lower than at U02.

The high total N content at U02 could be due to the culvert discharging untreated sewage at this monitoring site. The discharge of effluents from the meat processing industry A3, may be a major contribution at this site. The other divisions of the industrial group A also may have contributed. The high phosphates and high nitrogen levels at this site has caused eutrophication which is evident in the growth of *Eichornia crassipes* and the other aquatic plants. Although there is contribution from the San Sebastian canal to the East lake, the impact at U01 is lower.

The high sulphate at U01 may be due to the mixing of sea water at the McCallum locks, as sea water contains magnesium sulphate. The sulphates at U02 was lower than at U01. These contributions may be both from the industrial waste water discharges and the culvert.

6.5.3 Fluctuations in the Maligawatte (T01) and Kettarama Drains (T02)

Data variability

The data variability for DO at T01 and T02 can be seen in table 6.17.

Table 6.17 — The variability of DO (mg/L) in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	1.01	0.90	3.45	0.00	3.45	0.65	2.72
2							
T02	0.98	0.85	3.05	0.00	3.05	0.62	2.57
3							
T03	1.75	1.79	6.20	0.00	6.20	1.00	5.05
T04	1.53		3.95	0.00	3.95	1.30	3.80
T05	2.05	1.14	4.00	0.10	4.10	2.20	3.70
T06	0.85	0.63	2.00	0.00	2.00	0.65	1.92
4							
T07	1.18	0.80	2.65	0.05	2.70	1.05	2.32
T08	0.56	0.39	1.09	0.01	1.10	0.55	1.10
T09	0.92	0.37	1.50	0.10	1.60	0.90	1.45
T10	0.84	0.69	2.10	0.00	2.10	0.70	1.90
5							
T11	0.52	0.42	1.50	0.00	1.50	0.42	1.25
T12	0.82	0.53	1.60	0.02	1.62	0.60	1.62
T13	0.42	0.35	1.20	0.00	1.20	0.35	1.00

Sections: 1 = Maligawatte drain, 2 = Kettarama drain, 3 = Dematagoda ela, 4 = Kittampahuwa ela and 5 = Main Drain.

Source: Field monitoring.

The median DO level recorded for the Maligawatte Drain at T01 was 0.65 mg/L and 0.62 at T02. This indicated low values. The variability in the data was low as seen in the standard deviation.

The data variability for COD at T01 and T02 can be seen in table 6.18.

Table 6.18 — The variability of COD (mg/L) in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	159.15	62.88	180.00	87.00	267.00	142.50	264.30
2							
T02	158.15	70.70	205.00	90.00	295.00	133.95	280.50
3							
T03	121.17	67.47	254.40	26.60	281.00	114.60	232.50
T04	91.98	44.74	174.70	21.30	196.00	90.15	178.50
T05	78.56	68.30	209.00	15.00	224.00	50.60	206.50
T06	89.87	56.29	178.00	21.00	199.00	74.00	184.50
4							
T07	72.83	62.80	182.70	13.50	196.20	54.80	189.60
T08	95.06	58.20	172.50	26.50	199.00	75.30	186.00
T09	96.71	59.62	175.20	36.00	211.20	77.50	209.40
T10	113.60	64.43	199.60	39.00	238.60	102.70	220.80
5							
T11	291.40	70.35	282.60	133.00	415.00	300.50	391.00
T12	191.80	48.43	169.00	90.00	259.00	206.00	258.50
T13	417.50	159.78	602.00	209.00	811.00	406.50	710.00

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

The COD at T01 and T02, as seen in table 6.18 remained essentially similar. The median at T01 was 142.5 mg/L whilst at T01 it was 133.95.

The data variability for BOD at T01 and T02 can be seen in table 6.19.

The BOD essentially followed the COD at both T01 and T02. The BOD at T02 was similar to T01 with the median at 91.6.

The data variability for SS at T01 and T02 can be seen in table 6.20.

The SS at T01 had a median of 20.5. The 90th percentile was at 89.7. A range of 88.96 and a standard deviation of 29.67 was recorded at T01. The SS at T02 was higher than T01 with the median reaching 27.15, although the 90th percentile was lower with 84.4.

The data variability for turbidity at T01 and T02 can be seen in table 6.21.

The turbidity at T01 and T02 were basically similar. The median at T01 was 10.27. The range and the standard deviation at both the sites remained essentially the same.

The data variability for conductivty at T01 and T02 can be seen in table 6.22.

The conductivity at T01 and T02 appeared similar. Although the conductivity at T02 was slightly higher than at T01 it did not differ very much. The sites T01 and T02 had the lowest recorded maximum value in the tributary canals.

The data variability for pH at T01 and T02 can be seen in table 6.23.

The pH at T01 and T02 were weakly alkaline with the median of 8.15 at both the sites. The range was narrow with a value of 0.7 and standard deviation 0.17.

The data variability for water temperature at T01 and T02 can be seen in table 6.24.

Table 6.19 — The variability of BOD (mg/L) in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	97.50	44.42	130.00	47.00	177.00	85.00	171.50
2							
T02	103.52	46.80	136.00	50.00	186.00	91.60	182.00
3							
T03	66.28	37.78	133.00	11.00	144.00	75.00	121.00
T04	55.35	28.60	107.00	13.00	120.00	55.00	104.50
T05	50.26	44.70	155.00	8.00	163.00	35.10	133.00
T06	53.90	32.68	113.00	10.00	123.00	43.00	111.00
4							
T07	41.21	36.60	104.00	8.00	112.00	28.50	112.00
T08	58.52	35.79	107.00	15.00	122.00	47.50	116.50
T09	63.12	48.37	167.00	16.00	183.00	38.50	162.00
T10	79.00	47.70	159.00	26.00	185.00	77.50	161.00
5							
T11	194.28	65.04	223.00	79.00	302.00	189.50	292.00
T12	129.28	41.50	140.00	64.00	204.00	114.50	194.50
T13	307.78	131.20	534.00	103.00	637.00	299.50	522.00

Sections: 1 = Maligawatte drain, 2 = Kettarama drain, 3 = Dematagoda ela, 4 = Kittampahuwa ela and 5 = Main Drain.

Source: Field monitoring.

The water temperature at T01 and T02 have been near the ambient air temperature. The The median was at 30.75 at T01. The range was very narrow with 3 °C and standard deviation 0.89. The water temperature at T02 was similar to T01.

The data variability for total P at T01 and T02 can be seen in table 6.25.

The total P levels in the Maligawatte and the Kettarama Drain appeared very similar. The median at T01 and T02 fell at 0.9 and 0.8 respectively.

The data variability for total N at T01 and T02 can be seen in table 6.26.

The total N a median of 6.85 at T01. At the site T02 the total N values were lower, although the median appeared similar.

The data variability for sulphate at T01 and T02 can be seen in table 6.27.

The sulphates appeared to be higher at T02 with the median at 117.4. The range was high in both the sites.

Fluctuations and relationships

These two drains which empty into the San Sebastian canal run through highly urbanised areas, with squatter population living along certain sections of the drains. The Maligawatte drain at T01 enter the San Sebastian canal very close to the site S04. The site S04 is one of the most polluted sites with 45.0% of the observations having 0.0 mg/L DO levels and 52.5% of observations with less than 1.0 mg/L of DO. Thus 97.5% of the total observations at S04 are less than 1.0 mg/L. This indicates that the Maligawatte ela empties polluted water with low DO into the San Sebastian canal. This aggravates the pollution level that already exists in the San Sebastian canal. Thus in addition to the upstream industrial discharges, motor spare work shops and the shanties at S04, T01 also contributes to low DO at the San Sebastian canal. The contribution of the Kettarama drain at the site T02 is similar, which enters the San Sebastian canal at S07. The site S07 has 45.0%, 0.0 mg/L DO observations and 55% falling below 1.0 mg/L DO. The Site T02 with its very low DO levels aggravate the situation at S07 in the San Sebastian canal. T01 and T02 appeared equally polluted with very low DO levels, but when the percentage observations is considered, T01

Table 6.20 — The variability of SS (mg/L) in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	36.02	29.67	88.96	7.26	96.22	20.50	89.70
2							
T02	35.82	26.30	91.40	6.90	98.37	27.15	84.40
3							
T03	69.30	50.93	208.00	8.65	216.60	70.40	158.10
T04	73.42	61.72	257.20	12.10	269.30	58.80	185.20
T05	27.07	22.10	73.80	7.60	81.40	17.36	76.06
T06	90.04	37.20	125.50	13.75	139.20	90.17	139.10
4							
T07	37.21	28.60	69.60	8.01	77.60	26.80	74.10
T08	111.94	60.58	222.20	10.70	233.00	99.70	226.10
T09	45.90	36.40	100.10	10.00	110.20	28.20	108.90
T10	101.19	63.20	260.30	15.80	276.10	90.54	222.80
5							
T11	100.90	45.80	154.10	26.35	180.50	100.75	170.40
T12	59.08	26.20	82.80	10.27	93.10	66.84	90.60
T13	128.80	51.45	152.30	59.30	211.60	124.30	200.50

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

has a higher percentage of DO observations which falls below 1.0 mg/L as seen in appendix G. This indicates it is slightly more polluted than T02.

The COD at T01 and T02 remained essentially similar. The high COD in these canals is from the domestic sources such as the shanties. The backyard industries and the other drains which lead into these canals may also contribute a high organic load into the canals. Thus a fairly high organic load is discharged into the San Sebastian canal by these canals. It has to be added that the load at these canals is comparatively lower than at the San Sebastian

The BOD at T02 was slightly higher than at T01, but these two drains have essentially the same waste water input characterstics as both run through comparatively similar urban areas. Although the BOD are lower than at the San Sebastian canal, they are high enough to contribute to the oxygen depletion. These canals may aid in the depletion of the DO by discharging organic load into the San Sebastian canal at S04 and S07.

The SS and turbidity levels of both the Maligawatte and the Kettarama drains are less than the equivalents at sites S04 and S07, thus they contribute no further lowering of the quality to the water in the San Sebastian canal.

The conductivity values at T01 and T02 were considerably lower than at S04 and S07. Therefore it can be said that the higher conductivity at S04 and S07 are due to salts entering the San Sebastian canal from industrial processes. The contribution from T01 and T02 appear to be minimal.

Among the tributary canals, the pH values at T01 and T02 appear to be the least alkaline. The pH at T01 and T02 were much lower than at S04 and S07. Thus the influence of these two canals on the San Sebastian waters is negligible.

The water temperature at both sites had been a degree or two below the daily maximum air temperature except in February 1987, when the water temperature was slightly higher than air temperature. There are no direct heated industrial waste water discharges at these sites, therefore the water temperature has been about normal

Table 6.21 — The variability of turbidity (NTU) in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	11.53	4.58	15.50	5.00	20.50	10.27	19.50
2							
T02	11.35	4.26	14.50	4.50	19.00	11.00	18.50
3							
T03	17.61	12.30	42.50	4.00	46.50	16.25	43.00
T04	19.83	18.84	72.80	7.20	80.00	13.00	58.00
T05	9.92	5.15	17.50	3.00	20.50	8.50	19.50
T06	24.90	7.44	30.00	6.50	36.50	26.00	34.50
4							
T07	11.32	4.44	15.00	4.00	19.00	12.00	17.75
T08	25.70	9.34	32.50	5.50	38.00	27.00	37.50
T09	13.25	4.94	14.50	6.00	20.50	13.50	20.00
T10	24.70	11.06	45.00	6.00	51.00	21.50	44.25
5							
T11	22.57	6.52	20.90	10.60	31.50	21.70	31.25
T12	15.64	4.97	19.50	5.00	24.50	16.00	23.50
T13	27.71	8.98	28.00	15.00	43.00	24.00	41.50

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

observed in the surface waters. The water temperature medians at T01 and T02 were among the lowest in the tributary canals recorded. Thus the contribution to the San Sebastian canal is minimal.

The total P levels in the Maligawatte and the Kettarama Drain appeared very similar. The total P is mainly contributed by the domestic sources, since there are no industries discharging into these canals at the monitored sites. There were aquatic plants particularly *Eichornia crassipes* at T01. Although the concentrations were comparatively low, they will have contributed to the San Sebastian canal.

Although both T01 and T02 have quite high nitrogen levels, they are less than at either S04 or S07 and thus will act to lower the nitrogen levels of the San Sebastian canal. The aquatic plant growth at T01 is evidence of the higher nitrogen levels.

The sulphate levels at T01 and T02 are much lower than in the sites on the San Sebastian canal(i.e. S04 and S07), and thus the effect appears minimal.

6.5.4 The fluctuations in the Dematogoda ela (T03 - T06)

Data variability

Table 6.17 shows the DO variability in the Dematagoda ela. The median DO levels varied along the length of the ela. The site furthest from the San Sebastian canal (T06) had the lowest median value of 0.65 mg/L, whilst the two intermediate sites saw some improvement. The median fell again at T03, the site nearest the San Sebastian canal.

Both the COD and BOD figures show a similar pattern to the DO levels as seen in tables 6.18 and 6.19. T06 has quite high levels with improvement to site T05, before both increase progressively to T03 which has the highest COD and BOD demands on the ela (median 114.6 and 75.0 mg/L respectively). The COD levels at T03 showed considerable variation.

Table 6.20 shows the SS variability in the Dematagoda ela. The SS at the De-

Table 6.22 — The variability of conductivity μmhos/cm in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	290.20	67.60	240.00	160.00	400.00	305.00	390.00
2							
T02	300.07	78.17	213.00	187.00	400.00	318.00	400.00
3							
T03	1049.80	766.52	2200.00	300.00	2500.00	787.50	2425.00
T04	315.60	170.06	507.00	100.00	607.00	263.00	593.50
T05	475.03	229.50	840.00	160.00	1000.00	452.50	848.50
T06	474.70	231.70	841.00	185.00	1026.00	483.55	850.50
4							
T07	267.17	132.00	465.00	101.00	566.00	215.00	504.50
T08	566.40	265.20	1065.00	245.00	1310.00	580.00	1008.00
T09	404.40	163.89	513.00	190.00	703.00	385.00	695.00
T10	923.70	300.20	1000.00	400.00	1400.00	820.50	1400.00
5							
T11	363.40	113.30	464.00	201.00	665.00	371.50	594.00
T12	461.00	165.60	540.00	210.00	750.00	402.00	738.50
T13	729.20	350.40	1270.00	390.00	1660.00	590.00	1363.00

Sections: 1 = Maligawatte drain, 2 = Kettarama drain, 3 = Dematagoda ela, 4 = Kittampahuwa ela and 5 = Main Drain.

Source: Field monitoring.

matagoda ela gave higher values for T03 and T06 with the median of 70.4 at T03 and at 90.17 at T06. The standard deviation remained high at T03 and T04. This indicated the variable nature of the data. The SS fluctuated at T05 and the median fell to 17.36. This site had the lowest SS in the Dematagoda ela, and in all the tributary canal sites monitored. The range across the sites was (minimum of 7.6 at T05 and maximum of 269.3 at T04) 261.7.

Table 6.21 shows the turbidity variability in the Dematagoda ela. The turbidity at the Dematagoda ela was comparatively higher at T03, T04 and T06. The median values were 16.25 NTU, 13.0 and 26.0 respectively. The range was the highest at T04. The SS fluctuated at T05. The range in turbidity between the sites in this canal was (minimum of 3.0 at T05 and maximum of 80.0 at T04) 77.0 NTU.

Table 6.22 shows the variability in conductivity in the Dematagoda ela. The conductivity in the Dematagoda ela was high at T03 with a median of 787.5 μmhos/cm. The minimum recorded at this site was 300.0 and maximum, 2500.0. The 90th percentile fell at 2425.0. The range was high with a value of 2200.0 and the standard deviation 766.52. The conductivity fell at T04 and increased at T05 and T06, but comparativly much lower than at the site T03. The range in conductivity between the sites in this canal was 2400.0, with the minimum at T04 with a value of 100.0 and the maximum recorded at 2500.0 at T04.

Table 6.23 shows the pH variability in the Dematagoda ela. The pH at the Dematagoda canal was weakly alkaline and the median at all the stations fell between 8.25 and 8.77. The pH at T03 was slightly higher with median at 8.77. At T04 and T05, pH remained essentially the same with the median at both the sites at 8.3. T06 recorded the lowest pH with a median of 8.25. The range in pH between the sites was 1.8 with the minimum at T04 with 7.4 and the maximum at T03 with 9.2.

Table 6.24 shows the water temperature variability in the Dematagoda ela. The water temperature in the Dematagoda ela was higher at T03 with the median at

1							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T01	8.16	0.17	0.70	7.9	8.6	8.15	8.45
2							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T02	8.16	0.13	0.40	8.0	8.4	8.15	8.40
3							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T03	8.73	0.41	1.25	8.0	9.2	8.77	9.22
T04	8.20	0.29	1.25	7.4	8.6	8.32	8.60
T05	8.38	0.17	0.60	8.1	8.7	8.35	8.67
T06	8.22	0.18	0.60	8.0	8.6	8.25	8.50
4							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T07	8.08	0.09	0.30	8.0	8.3	8.05	8.27
T08	8.13	0.12	0.45	7.9	8.3	8.10	8.35
T09	8.27	0.12	0.40	8.0	8.4	8.27	8.45
T10	8.51	0.24	0.95	8.2	9.2	8.52	8.90
5							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T11	8.24	0.14	0.55	8.0	8.5	8.20	8.50
T12	8.20	0.17	0.60	8.0	8.6	8.20	8.50
T13	8.44	0.16	0.50	8.2	8.7	8.40	8.67

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

Table 6.23 — The variability of pH in the tributary canals

Site	Mean	S.D.	Ran.	Min.	Max.	Med.	90th %
1							
T01	30.71	0.89	3.0	29.0	32.0	30.75	31.90
2							
T02	30.59	0.79	2.9	29.1	32.0	30.40	31.75
3							
T03	31.65	1.05	3.0	30.0	33.0	31.55	33.00
T04	30.90	1.02	4.0	29.0	33.0	30.90	32.70
T05	30.82	0.65	2.0	30.0	32.0	31.00	31.75
T06	30.37	0.55	2.0	29.3	31.3	30.30	31.10
4							
T07	30.08	0.44	2.0	29.0	31.0	30.00	30.80
T08	29.92	0.80	3.1	28.0	31.1	30.00	31.00
T09	30.92	0.72	2.5	29.5	32.0	30.95	32.00
T10	31.70	1.72	5.6	28.0	33.6	31.97	33.60
5							
T11	31.16	1.08	3.9	29.6	33.5	31.00	33.02
T12	30.80	0.77	2.5	30.0	32.5	30.70	32.25
T13	36.00	2.06	8.0	32.0	40.0	36.15	39.00

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

Table 6.24 — The variability of water temperature (°C) in the tributary canals

1							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T01	1.16	0.70	2.25	0.55	2.80	0.90	1.16
2							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T02	1.30	0.83	2.20	0.60	2.80	0.85	2.50
3							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T03	4.42	3.96	16.10	0.30	16.40	3.70	12.10
T04	0.56	0.58	2.00	0.10	2.10	0.35	1.85
T05	0.27	0.23	0.95	0.00	0.95	0.25	0.70
T06	1.24	0.53	1.65	0.50	2.15	1.35	2.07
4							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T07	0.92	0.46	1.60	0.35	1.95	0.87	1.77
T08	2.25	0.82	3.60	0.75	4.35	2.05	3.70
T09	0.53	0.86	3.20	0.00	3.20	0.28	2.40
T10	3.90	1.32	4.65	1.60	6.25	3.85	5.75
5							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T11	1.69	1.41	4.35	0.30	4.65	1.25	4.32
T12	1.13	0.42	1.70	0.30	2.00	1.20	1.82
T13	1.93	1.17	4.30	0.00	4.30	2.02	3.95

Sections: **1** = Maligawatte drain, **2** = Kettarama drain. **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

Table 6.25 — The variability of Total P (mg/L) in the tributary canals

1							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T01	6.21	2.57	8.92	1.03	9.95	6.85	9.55
2							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T02	6.20	1.98	7.12	1.21	8.33	6.66	8.22
3							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T03	4.68	1.71	5.68	1.67	7.35	4.82	7.20
T04	0.57	0.45	1.29	0.01	1.30	0.82	1.19
T05	0.62	0.54	1.65	0.00	1.65	0.41	1.54
T06	4.01	1.70	6.51	0.30	6.80	3.94	6.60
4							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T07	1.88	1.29	3.26	0.56	3.82	1.69	3.78
T08	1.58	1.09	3.33	0.50	3.80	1.25	3.54
T09	1.24	0.83	2.60	0.21	2.90	0.92	2.81
T10	5.59	2.85	9.08	1.26	10.34	5.37	10.06
5							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T11	7.33	2.04	7.20	2.86	10.00	7.90	9.93
T12	7.72	2.08	7.72	3.00	10.72	8.05	10.52
T13	9.21	2.74	10.37	2.38	12.75	9.03	12.43

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

Table 6.26 — The variability of Total N (mg/L) in the tributary canals

1							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T01	93.29	37.78	140.2	24.3	164.5	99.6	148.0
2							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T02	100.34	39.80	136.60	24.7	161.3	117.4	146.2
3							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T03	157.40	67.40	219.10	59.3	278.4	142.5	271.8
T04	91.14	39.70	125.50	36.1	161.6	85.9	156.6
T05	64.84	26.07	82.20	14.2	96.4	66.7	94.9
T06	106.20	41.30	143.00	47.8	191.1	93.9	178.1
4							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T07	69.25	27.00	84.80	23.4	108.2	68.3	104.7
T08	104.78	43.70	156.30	40.7	197.0	96.4	193.8
T09	529.85	188.95	652.00	207.3	859.3	506.7	827.6
T10	185.70	75.60	281.50	66.2	347.7	181.8	306.5
5							
	MEAN	S.D	RAN	MIN	MAX	MED	90th %
T11	151.99	64.37	254.30	67.0	312.3	146.5	261.9
T12	116.02	43.23	135.20	43.1	178.3	112.0	172.0
T13	201.12	105.20	368.50	71.1	439.6	179.2	405.3

Sections: **1** = Maligawatte drain, **2** = Kettarama drain, **3** = Dematagoda ela, **4** = Kittampahuwa ela and **5** = Main Drain.

Source: Field monitoring.

Table 6.27 — The variability of sulphate (mg/L) in the tributary canals

31.55 °C. A high median was also recorded at T05 with 31.0. The maximum reached at this site was 32 °C. The water temperature at T06 remained the lowest.

The total P in the Dematagoda ela as seen in table 6.25, was high at T03 with the median at 3.7. The range was high with 16.1 and the standard deviation 3.96. This indicated high and variable values. There was a progressive decrease of total P at T04 and T05 with the median falling at 0.35 and 0.25 respectively. It increased at T06 with the median at 1.35. The range in the total P between the sites was 16.4 mg/L with the minimum of 0.0 mg/L at T05 and a maximum of 16.4 mg/L at T03.

Table 6.26 shows the total N variability in the Dematagoda ela. The total N in the Dematagoda canal was high at T03. The median was 4.82 and the 90th percentile at 7.2 mg/L. The range was high with a value of 5.68 and the standard deviation at 1.71. The total N fluctuated at T04 and T05 with the median at 0.82 and 0.41 respectively. The total N increased at T06. The range in total N between the sites in the Dematagoda ela was 7.35 mg/L, with 0.0 mg/L at T05 and 7.35 recorded at T03.

Table 6.27 shows the sulphate variability in the Dematagoda ela. The sulphates in the Dematagoda ela was high at T03 with the median at 142.5. The 90th percentile fell at 271.8. The range was high with 219.1 and the standard deviation was 67.4. The sulphates decreased at T04 and T05 and the median was 85.95 and 66.7 respectively in the sites. The site T06 saw slightly higher sulphate values. The range between the sites was 264.2, with the maximum recorded at T03 with a value of 278.4 and the minimum of 14.2 at T05.

Fluctuations and relationships

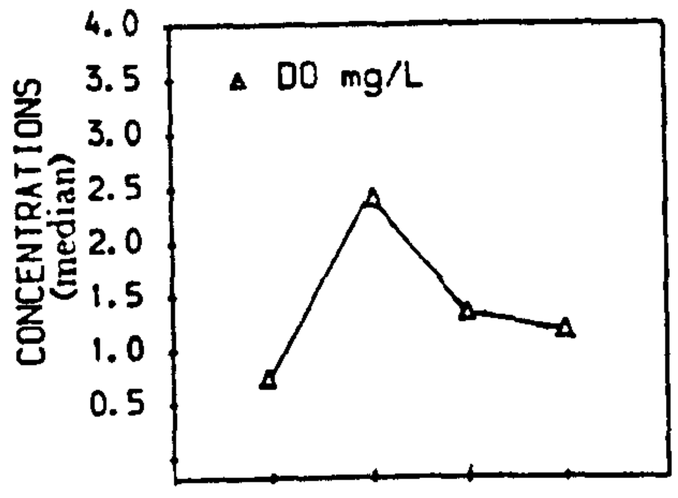
The DO in the Dematagoda ela at site T03 was low as seen in figure 6.14 (A).

The factory D and many others including a textile factory discharge their waste water discharges directly into the canal at this point. In addition to these the shanties, are located near this site. The Navagampura shanty upgrading scheme is located between this site and the San Sebastian canal. The DO improved slightly at T04 although it still remained very low. The Kolonnawa oil installation is situated close to this site, and the waste water discharge enter Dematogoda ela. Oil in addition to being an oxygen demanding waste, hinders atmospheric reaeration, by forming a film on the surface of the water. T05 saw a slight improvement, but at T06 which receives the Heen ela water at this point, saw a fall in the DO. This may be due to the organic load which enter the Dematagoda ela from the Heen ela. The shanties also contribute to the low DO along the Dematagoda canal.

Thus the Dematagoda ela enters the San Sebastian canal between S07 and S08 as a polluted canal with very low DO levels that contribute and aggravate the pollution level in the San Sebastian canal at its entry point. The DO median is was lower with 1.0 mg/L at T03 than at S08 with 2.1, which indicates clearly that as far as DO is concerned TO3 is more polluted, than S08 with lower DO levels. As mentioned earlier many industrial discharges enter the canal at T03. Therefore the Dematagoda ela at T03 empties polluted waters with very low DO levels, between S07 and S08. This contributes to and aggravates,the pollution of the San Sebastian canal.

As seen in the figure 6.14 (B) the COD increased downstream from T06 (high at T06 also). Of the overall COD, it can be said that the sites T03 and T04 which had industrial waste waters discharges into the canal had higher COD values. The sites which had shanties such as at Kolonnawa (T04) and Meetotamulla (T05) also contributed to a higher organic load resulting in higher COD. The Dematogoda ela enters the San Sebastian canal as a polluted canal with a higher COD at T03, than at S08. The median at S08 was 99.5 while it was 114.6 at T03. The 90th percentile at S08 was 218.9 while at T03 it was 232.5 (although the maximum COD was recorded at S08 was 330.0 mg/L). Therefore it is clear that the Dematagoda ela at T03 contributes to a high organic load into the San Sebastian canal between S07 and S08. The effect of this is felt at the downstream site S08.

The BOD essentially followed the COD with the the highest median at T03. The fluctuation along the site can be seen in the figure 6.14 (C). The site T04 had the next highest median. The BOD was comparatively lower at T05. At T06 the BOD increased again. This indicated that the organic load from the Heen ela contributed to the BOD at T06 in addition to its own BOD load, while at T03 and T04, higher BOD can be accounted for by the higher organic load which enter the canal from



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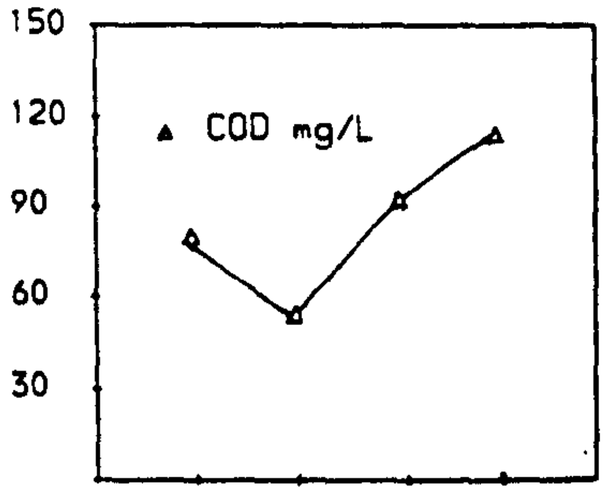

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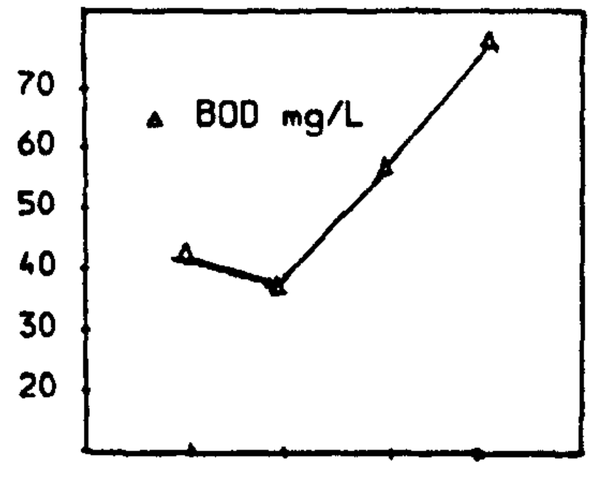

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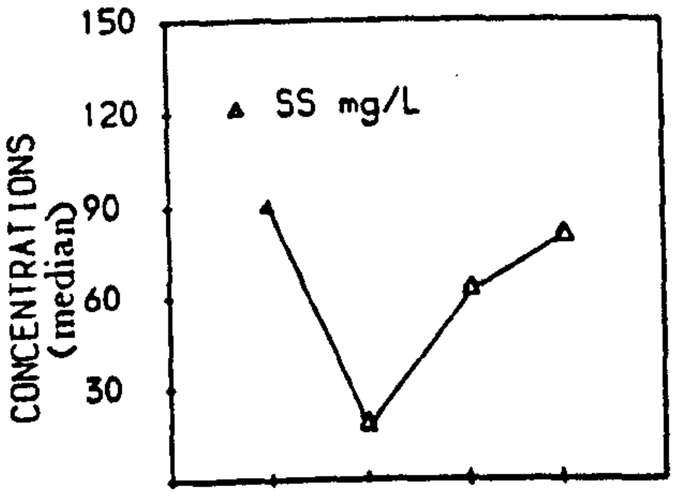

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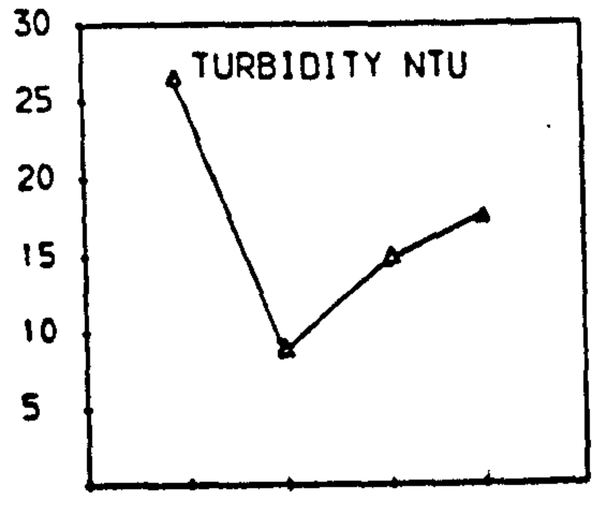

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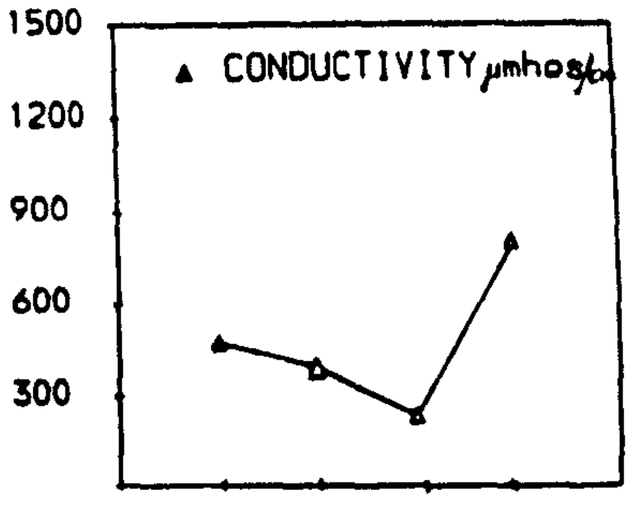

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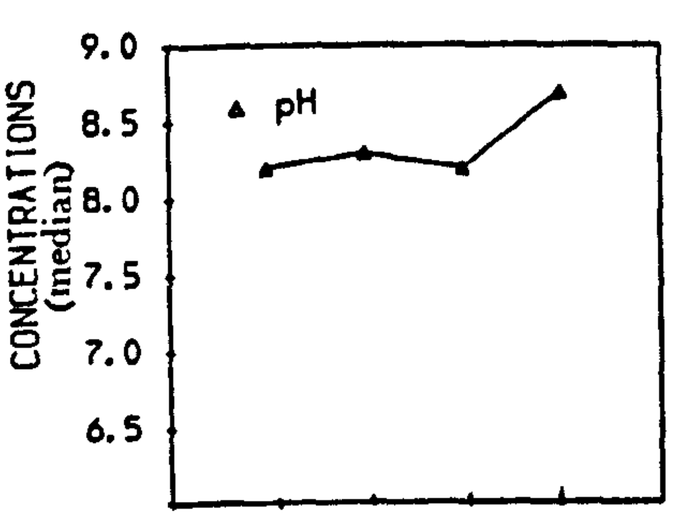

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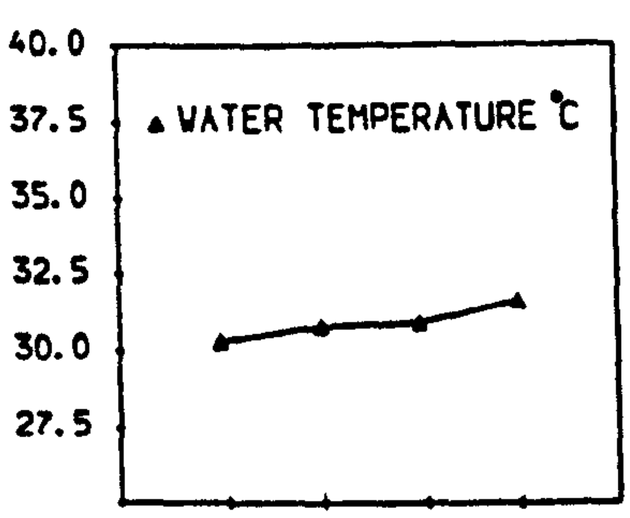

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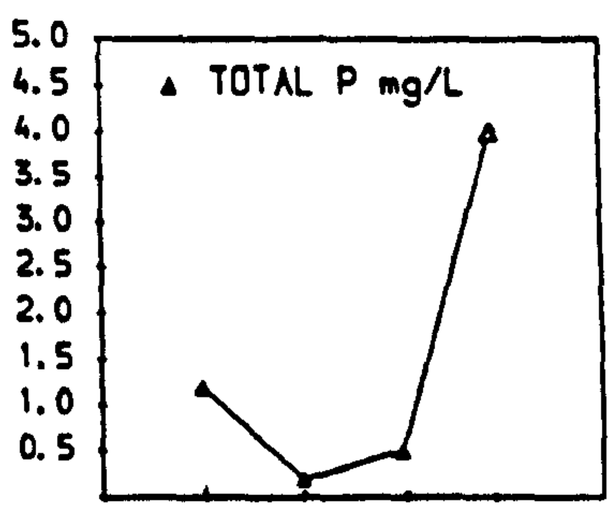

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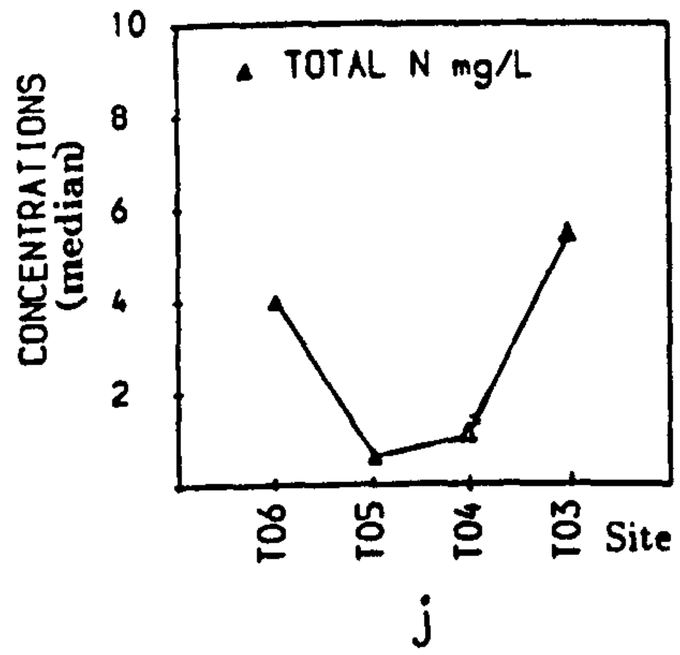

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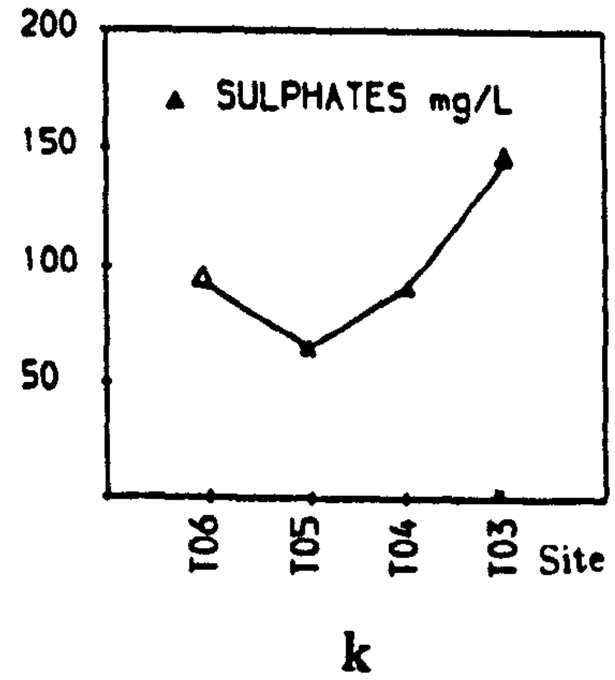


k

FLOW DIRECTION ⟹

Figure 6.14 — Fluctuation of pollutants along the Dematagoda canal

Source: Based on field monitoring

the industrial discharges at these sites. In addition to these the shanties and other domestic sources at the sites contribute to a higher BOD When the contribution of the BOD of the Dematagoda canal to the San Sebastian canal is considered, it can be said that the BOD at S08 and T03 were comparable and depicted a good relationship. The BOD at S08 is higher with a higher maximum of 269.0. But the median was higher at T03 which was 75.0 mg/L against 62.0 at S08. Therefore in addition to the organic load that enter from the upstream sites, T03 also appear to contribute to the BOD load at S08.

The SS in the Dematagoda canal saw a fluctuation at T05, but increased towards the downstream site T03 as seen in the figure 6.14 (D).The higher SS at T06 is obviously from the Heen ela which discharges at this point. The increase in the SS load downstreams of the Dematagoda canal is from the contributory load from the downstream sites. The higher load at T03 is due to industries which discharges at this site. The shanties also contribute. Therefore at S08, a site relatively free from direct industrial discharges (although it is located in the middle of a shanty area), a fairly high SS level is maintained by the Dematagoda ela which has a higher median and percentile value.

As seen in the figure 6.14 (E) the turbidity in the Dematagoda ela was higher at T03, T04 and T06 comparatively. The turbidity essentially is a reflection of the SS. Thus the explanation of SS also holds true for the turbidity. When the turbidity in the Dematagoda ela at T03, and S08 at San Sebastian canal is compared, it can be said that S08 was less turbid with a median turbidity recorded at S08 of 7.27. The median at T03 was 16.25. This indicates, that the Dematagoda ela, had more turbid waters at T03, than at S08. Thus the contribution of the tributary canal was positive.

The conductivity in the Dematagoda ela as seen in the figure 6.14 (F) was high at T03. The high conductivity at T03 is due to the salts that enter from the factory D, and other factories including the effluents from a textile factory. These effluents are discharged directly into the canal without treatment. When the relationship between the conductivity at T03 and S08 is compared, it can be said that the waters at T03 are more conductive with higher amount of salts present in the industrial discharges. The median at T03 was 787.5 μmhos/cm while at S08 it was 540.0. Therefore highly conductive waters are entering from T03 into the San Sebastian canal near S08. This contributes salts to San Sebastian at S08, which makes the waters more conductive. On the other hand it is also possible that the tidal effect felt from the eastern end of the canal the San Sebastian canal may influence the tributary canal as both the canals have similar higher maximum and percentiles values, although the median at T03 was higher. Thus the contribution is not very clear.

The pH in the Dematagoda canal was weakly alkaline in most of the stations. The pH at T03 was slightly higher as seen in the figure 6.14 (G). The reason for a higher pH at T03, may be due to alkaline wastes which may enter from the industries at this point. Compared with S08, the pH of T03 is higher, the median pH being 8.0 at S08, while it was 8.77 at T03. Therefore the water at the Dematagoda ela at T03 is more alkaline than at S08 due to industrial waste water discharges, and thus acts to raise the canal pH.

The figure 6.14 (H) shows that the water temperature had gradually increased downstream with the higher water temperature at T03. Temperature at T06 remained the lowest. The temperature at the sites remained near the ambient air temperature usually a degree or two lower than daily maximum air temperature. Water temperature at the sites remained at or above the daily maximum air temperature in February 1987, which was the driest month. Water temperature at T03 was higher than the maximum air temperature which may be due to the industrial effluents that enter the canal at this point, particularly from textile dyeing and printing processes of the textile factory. The water temperature at S08 where the Dematagoda canal enters the San Sebastian canal, was near the daily maximum air temperature or usually a degree or two lower than the air temperature. The median at S08 was 31.5 °C which was the same as T03, but the minimum at S08 was 28.0, while 30 degrees was the minimum at T03. The maximum reached 33.6 at S08, and 33.0 at T03 while the 90th percentile was 32.6 and 33.0 respectively. Therefore the water temperature at the site T03 was slightly higher than at S08 in the San Sebastian canal. Although the water temperature difference is not very great, warmer water enters the receiving

canal from the tributary canal.

The figure 6.14 (I) shows the fluctuations in phosphate levels in the Dematagoda canal. The total P at the Dematagoda ela was high at T03. The concentration at the site T06 was higher than at T04 and T05. The higher total P at at T03 was obviously due to the industrial effluent discharges by factory D, which produces fertilizers, detergents and pesticides. Fertilizers are high in phosphates. Detergents also have high phosphate content. Slightly higher total P at T06 may be due to phosphate contributions from the Heen ela. The domestic waste waters especially from the shanties along the sites may also contribute to higher total P. Considering the total P at S08, the concentration of total P is higher at S08 than at S09 and S10. But the total concentration at T03 is very much higher than at S08. The maximum reached 16.4 and median at 3.7 mg/L in the former. The 90th percentile was 12.1 at T03 and 5.46 at S08. Therefore the Dematagoda canal with a high total P concentration at T03 enters and contributes to total P at S08. The higher value of total P at S08 than at S09, or S10 is evidence for this. The presence of aquatic plants both at T03 and S08 indicates that these sites have high nutrient loadings.

The total N was high at T06 and T03 as seen in the figure 6.14 (J). The cause for higher total N at T03 is obviously due to industrial wastes of fertilizers from the factory D. Urea is produced at this factory which may contribute to high total N in the canal. In addition to these the shanties at T03 may also contribute to total N in the canal. The contributions to T06 may be from the Heen ela. This site had abundant *Eichornia crassipes* and other aquatic plants caused by nutrient loading at this site. Aquatic plants were luxuriantly growing at T03 too, but were regularly cleared by the Low Lying Reclamation Board, Colombo North. When the concentrations of the total N at T03 and S08, are considered the total N concentration was very much higher at T03 than at S08. At S08 the median was only 2.41 while at T03 it was 4.82 mg/L, the maximum recorded was 4.62 and 7.35, while the 90th percentile was 4.27 and 7.2 respectively. Therefore, it is clear that T03 contributes to the total N at S08 in the San Sebastian canal.

As seen in the figure 6.14 (K) the sulphates are high at T03 and T06. There was fluctuation at T05. The sulphates may be high at T03 due to sulphates that enter from the industries at this site. When the sulphates at site S08 and T03 are compared, the sulphates at the site T03 was higher with median at 142.5 while at S08 it was 93.8. The maximum was 278.4 and 204.8 respectively. The 90th percentile fell at 271.8 and 197.8 respectively. Therefore the sulphate content at the Dematagoda ela in site T03 was higher than at S08, thus the flow of the Dematagoda ela contributes to the sulphate content at S08, in addition to the sulphate at the site from the domestic (shanty) sources and contribution from the upstream sites.

6.5.5 The fluctuations in the Kittampahuwa ela (T07 - T10)

Data variability

The data variability for DO in the Kittampahuwa ela can be seen in table 6.17. At Kittampahuwa ela which joins the San Sebastian canal between S08 and S09 (closer to S09) the DO content in the sites became progressively lower as the ela approached the San Sebastian canal. There is a little streamlet emptying into the river Kelani which branches off near T09 at the Dematagoda railway bridge. The DO was higher at T07 with the median at 1.05. The DO fluctuated at T08. It was slightly higher at T09 with the median at 0.90. The site T10 had the lowest DO. The range and the standard deviation remained high at T07 and T10. Across the sites the range was 2.7 (the minimum of 0.0 was recorded at T10, The percentage DO concentrations indicate the very low level of the DO in the canal, particularly in the downstream site T10.

The data variability for COD in the Kittampahuwa ela can be seen in table 6.18. The COD at the Kittampahuwa ela saw a progressive increase from T07 to T10. The median at T07 was 54.8 mg/L and at T08, the median increased progressively till 102.7 mg/L at T10. The 90th percentile, the median, the minimum and the maximum increased progressively. The range and standard deviation were higher at T07 than at T08 and T09. The maximum and the minimum recorded were the highest at T10. The highest 90th percentile of 220.8 fell at this site. The range in the COD between the sites was 225.1 with the lowest value of 13.3 recorded at T07 and the highest

maximum value of 238.6 recorded at T10.

The data variability for BOD in the Kittampahuwa ela can be seen in table 6.19. The BOD at Kittampahuwa ela too saw a progressive increase from T07 to T10 with a slight fluctuation at T09. The median BOD recorded at T07 was 28.5, which increased to 77.5 at T10 with a fluctuation of 38.5 at T09. The standard deviation and the range were high at T10, which indicated the variable nature of the data. The range across the sites was 177.0 mg/L with the minimum at T07 and maximum at T10.

The data variability for SS in the Kittampahuwa ela can be seen in table 6.20. The SS in the Kittampahuwa ela increased sequentially from T07 to T10 except at T08 with a higher load recorded at this site. The highest median for the ela was recorded at T08 which was 99.7. The 90th percentile was also the highest at this site with a value of at 226.1 mg/L. The Median for T07 and T09 were comparatively lower with 26.8 mg/L and 28.2 mg/L respectively. The median was also high at T10. The highest (maximum) value of 276.1 and the highest (minimum) value of 15.8 mg/L too was recorded T10. The 90th percentile at T10 fell at 222.8 mg/L. The range was the highest at T10 with 260.3 and the standard deviation 63.2 mg/L. The range between the sites along the ela was 268.09, with a minimum of 8.01 at T07 and a maximum of 276.1 at T10.

The turbidity at the Kittampahuwa ela (table 6.21) shows a very similar trend to the SS load at the sites. There is a progressive increase of the turbidity from T07 to T10 with a fluctuation at T08, with the highest median value. The highest 90th percentile fell at T10 with a value of 44.25. The range was the highest at T10 with a value of 45.0 and the standard deviation stood at 11.06. The range in the turbidity between the sites was 47.0 (with the minimum at T07 and the maximum at T10).

The data variability for conductivity in the Kittampahuwa ela can be seen in table 6.22. The conductivity values at the Kittampahuwa ela, sequentially increased from T07 to T10, except at T08, which recorded higher values than T09. The conductivity increased markedly at T08 and the median went upto 580.0. was at 245.0 and maximum, 1310.0. The 90th percentile 1008.0. At T09 the values fell but increased at T10. The highest minimum value of 400.0, the maximum of 1400.0, median of 820.5 and a 90th percentile of 1400.0 was recorded at this site. The conductivity range between the sites was 1299.0, with the minumum at T07 and maximum at T10.

The data variability for pH in the Kittampahuwa ela can be seen in table 6.23. The pH at the Kittampahuwa ela was weakly alkaline, with a slight increase from T07 to T10. The median at T07 was 8.05 and 8.25 at T10. The range and the standard deviation were low at the sites. The range between the sites was 1.3, with the minimum at T08 and the maximum at T10.

As with previous properties the water temperature (table 6.24) in the Kittampahuwa ela also saw a progressive increase from T07 to T10. At T07 the median was 30.27. The median was 31.97 at T10. The maximum recorded at this site was 33.6 and the minimum fell to 28.0. The range was the highest at 5.6 and standard deviation 1.72. The water temperature between the sites had a range of 5.6 with the minimum of 28.0 recorded at T08 and a maximum of 33.6 at T10.

The data variability for total P in the Kittampahuwa ela can be seen in table 6.25. The total P was high at T08 and T10. The median fell at 2.05 in the site T07 and the median at T10 was 3.85. The total P was the highest at T10. The maximum recorded was 6.25 and the median fell at 3.85. The 90th percentile was marked by 5.75. The range and standard deviation were the highest at this site with 4.65 and 1.32 mg/L respectively. The range between the sites at the Kittampahuwa ela was 6.25 mg/L with minimum recorded being 0.0 at T09, and the maximum of 6.25 at T10.

The data variability for total N in the Kittampahuwa ela can be seen in table 6.26. The total N in the Kittampahuwa ela was fairly high at the sites T07 and T08 while it fluctuated at T09. The total N at T10 was the highest recorded for the entire ela with the maximum reached at 10.34, the minimum at 1.26 and median at 5.37. The 90th percentile was at 10.06. The variability between the sites was 1.05, with the minimum at T09 and the maximum at T10.

The data variability for sulphate in the Kittampahuwa ela can be seen in table 6.27. The sulphate levels at Kittampahuwa ela varied with the lowest (median) value

recorded at T07 with a value of 68.3 mg/L. T09 had unusually high sulphates with the median at 506.7 and the maximum reached at 859.3. The minimum recorded at this site was 207.3. The range was the widest with 652.0 and standard deviation 188.95. The range in the sulphates between the sites was 835.9 with minimum at T07 with a value of 23.4 and maximum of 859.3 at T09. T10 had values next to T09.

Fluctuations and relationships

The fluctuations in the DO in the Kittampahuwa ela can be seen in figure 6.15 (A). At the Kittampahuwa ela which joins the San Sebastian canal near S09, the DO in the sites became lower as the ela approached the San Sebastian canal. The DO fluctuated at T08 but was slightly higher at T09. The DO fell at T10 again. But the overall DO remained low. T07 is free from any industrial discharges directly. The low DO at T08 is not very clear. T09 is at the Dematagoda railway bridge which has contribution from the domestic sources especially the shanties. The very low DO at T10 can be explained by the fact that it is at the neck of the ela, which passes through a highly urbanised area. Thus a high organic load gets accumulated at this site. At this point of monitoring at T10 the ela water enter two culverts and the ela is clogged with the growth of aquatic plants and garbage. The flow of the canal is also very low. The effluents from the Toyota factory enter this ela at T10. Therefore due to high organic content of the water at this site the DO level is very low. When the contributions of the canal to S09 is considered the, site T10 had a lower median value of 0.7 mg/L while S09 had 1.3 mg/L as the median. This shows that T10 was more polluted of the two sites, thus enters the San Sebastian canal as a polluted ela with a high organic load and low DO, and contributes to the pollution of the San Sebastian at S09.

The COD at the Kittampahuwa ela saw a progressive increase from T07 to T10, as seen in the figure 6.15 (B).Therefore it can be said that the Kittampahuwa ela collects organic load progressively throughout its flow. The highest COD is recorded as it approaches the most urbanised area where the organic load is highest at T10. This high organic load is reflected in the high COD values at T10. In addition to the domestic sources the industrial discharges also causes a higher COD at T10 than at the other sites.

The COD at S09 was comparable to T10. The median at S09 was 102.0 mg/L and 102.7 at T10. The COD values appeared very similar in both the sites, although it was slightly higher at S09. Thus the Kittampahuwa ela has little effect on the COD levels of the San Sebastian canal.

The BOD concentration at the Kittampahuwa ela is essentially similar. This can be seen in the figure 6.15 (C). here was a fluctuation at T09. The the organic loading was the highest at T10. The highest COD value was also recorded at this site. The reason for a high BOD remains essentially the same at T10.

The BOD at S09, the receiving site on the San Sebastian canal was comparable although it had a slightly lower median value of 64.0 against 77.5 mg/L at T10. Since the values are very closely spaced, it is difficult to decide which site is more polluted of the two, but when the median is considered which is higher at T10 (and the 90th percentile) it appears that T10 is the more polluted site than S09. Therefore, Kittampahuwa ela enters San Sebastian canal near S09 with a high organic load with the potential of further polluting the San Sebastian canal.

The SS in the Kittampahuwa ela increased sequentially from T07 to T10 except with a higher load recorded at T08. This can be seen in the figure 6.15 (D).This indicates that SS was higher at T10 and T08 compared to the other two sites. The high SS at T08 may be due to the particles in suspension which enter the ela from the adjoining paddy fields, with a high percentage of silt, and detritus. The SS was also high at T10. This may be due to accumulation of SS due to the blockage of water that flow through the culverts in addition to the solids that enter from the industrial discharge and garbage thrown by wayside pedestrians. Domestic sources also may contribute. The canal banks at this site are not maintained, and there is continued siltation by eroded banks. This also helps to increase the SS of the canal.

The SS at S09 with the median value at 29.3 mg/L, was much lower than at T10 which had a median of 90.54. Therefore, the comparison of sites T10 at Kittampahuwa ela with S09 in the San Sebastian canal shows that, T10 with a higher SS contributes to the SS loading in the San Sebastian canal.

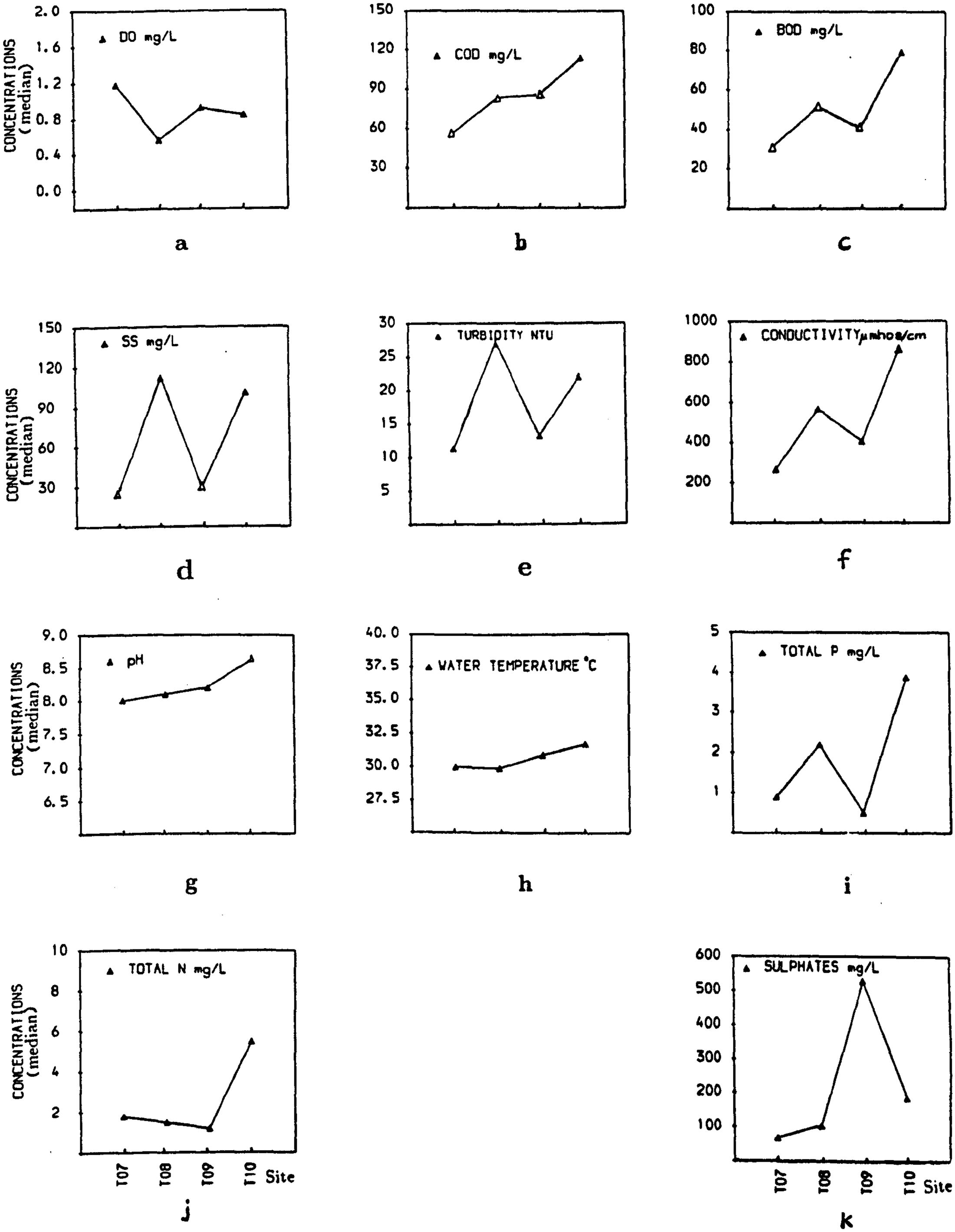


Figure 6.15 — Fluctuations of pollutants along the Kittampahuwa ela

Source: Field monitoring

The turbidity fluctuations can be seen in figure 6.15 (E). The turbidity in the Kittampahuwa ela shows similarity to the SS load at the sites. There is a progressive increase of turbidity of waters from T07 to T10 with a break in the load at T08 with the highest value recorded at this site. Cross relating T10 and S09 shows that the turbidity was higher at T10 than at S09 with a median of 21.5 as compared with 13.3. Therefore the waters were more turbid at T10 than at S09. The turbidity at S08 was much lower than at S09 with the median at 7.27. Thus it becomes clearly evident that more turbid waters enter S09 from T10 than from S08. Thus T10 contributes to higher turbidity at S09. The reason for the turbidity fluctuations is the same as for the SS discussed earlier.

The conductivity at the Kittampahuwa ela, has increased from T07 to T10, except at T08, which records higher values than T09. This fluctuation can be seen in the figure 6.15 (F). The higher conductivity values at T08 may be due to the salts that enter the ela from the fertilizers used in the adjoining paddy fields which makes the water conductive. The values were also higher at T10 due to higher salt content at this site. As this is the most urbanised site in this ela, salts are picked up along its flow and the highest concentration occurs at this site due to the addition of salts entering from the industrial waste waters. Another possibility for higher conductivity at the site may be from the tidal influence felt at this site, being very close to the river mouth. A back flow of tidal waters from the San Sebastian canal may have influenced the site T10. Comparing T10 and S09 makes it clear that the conductivity values were high at S09 with the maximum recorded value of 2985.0, median at 535.0 and the 90th percentile at 1862.0. Although the median at S09 is lower than at T10, the conductivity at S09 can be considered much higher at S09 than at T10. Therefore the contribution of the dissolved salts from T10 i.e. Kittampahuwa ela to San Sebastian canal appears to be minimal. There is a greater possibility of salts entering the Kittampahuwa ela at T10 from S09 due to the tidal influence and backflow of water.

Figure 6.15 (G) shows the fluctuations in the pH at Kittampahuwa ela. The pH in the Kittampahuwa ela was slightly alkaline. The increase from T07 to T10 was marginal although it was slightly more alkaline at T10 than at the other sites. The pH at S09 was slightly lower than at T10 with the median at 8.2 in the former site, while the median was 8.52 at T10. The 90th percentile at both sites approached 8.9. The slightly higher pH at T10 therefore may be due to industrial waste water discharges. This water is discharged into the San Sebastian canal.

The figure 6.15 (H) shows the fluctuations in water temperature in the Kittampahuwa ela. The water temperature had been near the daily maximum air temperature or a degree or two below in the sites except at T10 which recorded higher values than the daily maximum air temperature. February 1987 recorded the highest with 33.6 °C, i.e 2.3 °C higher than the air temperature.

The figure 6.15 (I) shows that the total P was high at the sites T08 and T10. The high total P at T08 may be due to the nutrients that enter from the adjoining paddy fields which use fertilizers that contain phosphates. The total P at this site was considerably higher than at T07 and T09. Higher total P was recorded at T10. The total P may be high at this site due to industrial waste water discharges from the nearby industries containing detergents with total P. In addition total P from the domestic sources from an urban site also may enter the site.

When the sites S09 and T10 are compared it can be seen that the total P at T10 was much higher than at S09. The median at S09 was 1.85 Therefore T10 is a potential contributor to the nutrient loading in the form of total P into the San Sebastian canal at S09. The luxuriant growth of *Eichornia crassipes* and the other aquatic plants at T10 was evidence for this.

The total N at the Kittampahuwa ela was found to be fairly high at T10 but it fluctuated at T07, T08 and T09 as seen in the figure 6.15 (J). At T10 the high total N may be from domestic and the industrial sources. Nitrogeneous matter from the way side boutique thrown into the ela and the garbage may contribute. This site has a foot path above the culvert and below the bridge indicating that this is a heavily used site by the shanty dwellers downstream. It is possible that they throw garbage at this point since, visual observation showed many domestic items at this site on the ela. Due to the nature of blockage at the culvert, nitrogeneous matter may accumulate at this site as flow in the canal is poor. The runoff from the leafy vegetable plots around

the site may also contribute to the nutrient loading.

The total N at S09 was lower than that of T10 with the median at 3.58. Therefore T10 contributes to the total N loading of the San Sebastian canal at S09. The presence of aquatic plants at the sites confirm this.

The sulphate levels at the Kittampahuwa ela varied. As seen in the figure 6.15 (K), the concentration was very high at T09. It is not clear how or from where this high level of sulphate that entered the ela at this point. T10 had higher sulphates than the other sites except T09. Therefore the sulphates increased from the downstream site T07, with an unusually high occurrence at T09. The sulphate contribution to T10 may be from both domestic and the industrial discharges in addition to the contribution from T09. The Sulphates at S09 on the San Sebastian Canal was lower than at T10. Therefore it appears that the Kittampahuwa ela with a higher sulphate concentration enters the San Sebastian canal near S09 contributes to the sulphate load at this site.

6.5.6 The fluctuations in the Main Drain (T11 - T13)

The data variability for DO in the Main Drain can be seen in table 6.17. The Mutwal Main Drain joins the San Sebastian canal between S09 and S10. The DO in the Main Drain was very low with a median of 0.42 at T11 which rose to 0.6 mg/L at T12 and fell again to 0.35 at T13. The lowest value recorded was 0.0 at the sites T11 and T13, with the maximum of 1.62 at T12, thus gave a range of 1.62 mg/L. Both the standard deviation and the range were low in the sites, hence the variability was low in the data.

The data variability for COD in the in the Main Drain can be seen in the table 6.18. The COD in the Main Drain saw high values at T11 and T13 with fluctuation at T12. The median at T11 was 300.5. At T12 the median fell to 206.0. The COD recorded at T13 was the highest for the water course with the median at 406.5. The range in COD across the sites was 721.0 with the minimum of 90.0 recorded at T12 and the maximum 811.0 at T13.

As can be seen in table 6.19 the BOD in the Main Drain had the same trend. The median BOD at T11 was 189.5. and increased to T13 to a median value of 199.5 with the minimum at 103.0 and the maximum at 637.0 The 90th percentile was 522.0. The standard deviation and the range were the highest at T13 which indicated the high variability at the site. The range between the sites in the Main Drain was 573.0 with the minimum at T12 and the maximum at T13.

The data variability for SS in the Main Drain can be seen in the table 6.20. The SS at T11 had a median of 100.75 mg/L. The SS fell at T12 with the median at 66.84. It increased at T13 to a median of 124.3. The minimum read 59.3 and maximum reached 211.6. The 90th percentile at this site was 200.5. The range in the SS between the sites in the Main Drain was 200.9 mg/L with minimum value of 10.27 at T12 and the maximum recorded at T13 with a value of 211.6.

The data variability for turbidity in the in the Main Drain can be seen in the table 6.21. The turbidity in the Main Drain had a very similar trend to the SS. The Two sites with industrial discharges at T11 and T13 had higher turbidities. T11 had a median of 21.7. T13 recorded the highest values in the water course with a minimum of 15.0 NTU, maximum of 43.0 and a median of 24.0. The 90th percentile fell at 41.5. The highest range was recorded at this site with a value of 28.0, while the standard deviation stood at 8.98. The range between the sites was 38.0, with the minimum at T12 (with a value of 5.0 NTU) and the maximum at (43.0 NTU) T12.

The conductivity in the Main Drain (table 6.22) depicted a different picture to the other parameters. There was a progressive increase in the conductivity values from T11 to T13. The median at T11 fell at 371.5. The conductivity increased at T12 and the median fell at 402.0. It was highest at T13 with the minimum recorded at 390.0 and the maximum at 1660.0. The median was the highest for the water course with a value of 590.0. The 90th percentile fell at 1363.0 and the range recorded the highest value for the site with 1270.0. The standard deviation was at 350.4. The range between the sites at the Main Drain was 1459.0 with the minimum at T11 with a value of 201.0 and the maximum at T13 with a value of 1660.

The data variability for pH in the in the Main Drain can be seen in the table 6.23. The pH in the Main Drain recorded values which were alkaline. The pH at the Main

Drain had a median value of 8.2 at T11 and T12. The pH at T13 was slightly higher. The median was 8.4. The range was 0.5 and the standard deviation 0.16. The range between the sites was very narrow and the variabily low.

The data variability for water temperature in the Main Drain can be seen in the table 6.24. The water temperature in the Main Drain was near the maximum daily air temperature at the site T12 with a value of 30.7 °C. The water temperature was slightly higher at T11 with the median at 31.0, reaching its highest at the site T13 was the highest for the water course with the median recorded at 36.15, minimum at 32.0 and the maximum at 40.0. The 90th percentile was 39.0. The range was high with a value of 8.0 and the standard deviation 2.06. The range between the sites was high with 10.4 °C, with the minimum at site T11 (29.6) and the maximum value of 40 °C recorded at T13.

The data variability for total P in the in the Main Drain can be seen in the table 6.25. The total P in the Main Drain recorded higher values at T11 and T13. The site T11 had the highest total P value recorded with 4.65 mg/L. The total P fell slightly at T12 with the median recorded at 1.2 mg/L. There was hardly any difference in the median value between T11 and T12. T13 had the highest median for total P with a value of 2.02. The maximum was 4.3. The 90th percentile was recorded at 3.95. The range between the sites was 4.65 with a minimum of 0.0 at T13 and maximum of 4.65 at T11.

The data variability for total N in the Main Drain can be seen in the table 6.26. The total N in the Main Drain increased from T11 towards T13. The median at T11 was 7.9 mg/L, 8.05 mg/L at T12, and 9.03 at T13. At T13 minimum was 2.38 and the maximum value read 12.75. The 90th percentile was 12.43 with a range of 10.37. The standard deviation read 2.74. The range in the total N between the sites was 10.37 with the minimum value at T11 and the maximum recorded at T13, 12.75.

The data variability for sulphate in the Main Drain can be seen in the table 6.27. The sulphate in the Main Drain, shows higher concentration at T11 and T13 than at T12. The median at T11 was 146.5. The sulphates fluctuated at T12 with the median at 112.0 and increased to a median of 179.2 at T13. The minimum at the latter site was 71.10 and maximum, 179.2. The range was the highest in the site, with the value at 368.5. The standard deviation fell at 105.2. The 90th percentile was 405.3. The range between the sites was 396.5.

Fluctuations and relationships

The fluctuation of DO in the Main Drain can be seen in the figure 6.16 (A).

The Mutwal Main Drain joins the San Sebastian canal between S09 and S10. There was a slight improvement at T12 but the dissolved oxygen in the Main Drain was very low. The reason for very low DO concentrations in the Main Drain is that it flows through a highly industrial, and urban area and thus picks up a high organic load along its course till it enters the San Sebastian canal through a culvert. The two confectioneries situated along the canal discharge waste waters directly into the Main Drain at T11 and T13, the factories being E and F respectively. Thus the lower DO at T11 and T13 is due to the high organic content of the waste water discharges from these food industries. There are also many shanties near the Bloemendhal bridge at T12. The table appendix G indicates the percentages of the DO along the canal. The very low values at the industrial discharge sites T11 and T12 can be assessed. It is also possible that waste water from industries around the area enter the Main Drain indirectly. This Main Drain catchment area being the earliest developed parts of Colombo, has a very high concentration of industries, residences and shanty population.

The contribution of Mutwal Main Drain to the pollution (organic load) of the San Sebastian canal between S09 and S10 is not very clear because the canal comes under the tidal influence at this stretch. But the very low DO level at S10 with median at 0.35 inspite of the maximum DO of 0.6 mg/L recorded at this site, perhaps may be attributed to the high organic load that enter the San Sebastian canal from the Main Drain. This is in addition to the organic load contributed from the sites upstream.

The COD at the Main Drain saw high values at T11 and T13 with a fluctuation at T12. This can be seen in the figure 6.16 (B). Therefore it is clearly evident that due to the high organic loading from the confectioneries into the canal, the COD values were high at the industrial sites, with fluctuations at T12 where there was no

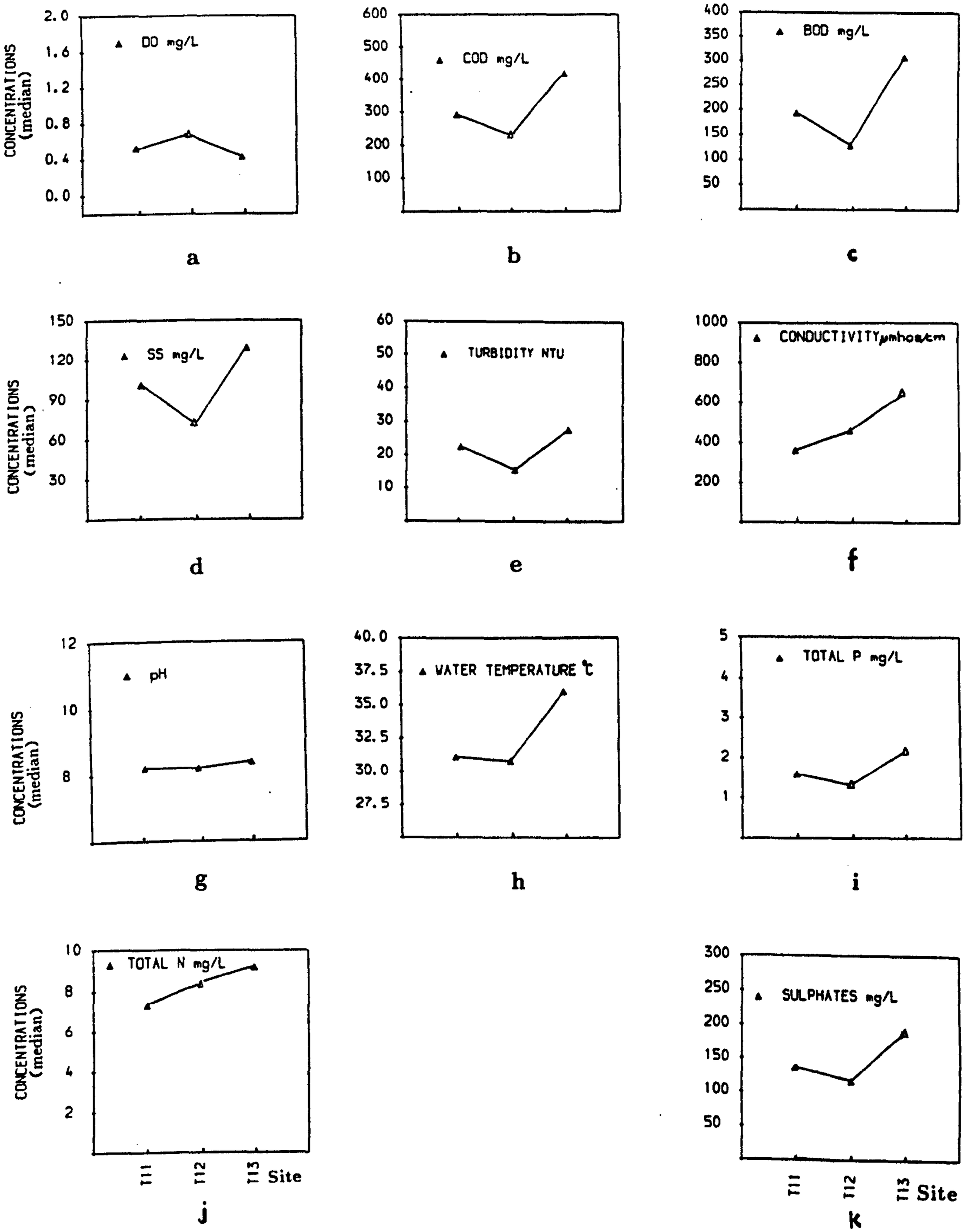


Figure 6.16 — Fluctuation of pollutants in the Main Drain

Source: Field monitoring

direct industrial discharges into the canal. The canal was also sluggish and stagnant. A thick tar like formation at the factory F discharge point in the canal was clearly visible.

The COD at S09 was lower than at T13 with the median at 102.0. The COD at T13 had a median of 406.5. This indicated that site T13 had a higher organic load and was a polluted site which contributes to the pollution of the San Sebastian canal. But due to the possibility of tidal effects fell at these sites, the trend in the concentration of pollutants is not very clear. When the COD in all the tributary canals are considered, the Main Drain had higher COD values. The site T13 had the highest median recorded which indicated the nature and strength of pollution at the site.

The BOD at the Main Drain had the same trend as the COD with obviously lower values. As seen in the figure 6.16 (C) shows the COD is higher at T11 and T13. The reason for the higher BOD at T11 and T13 is same as for the COD. Therefore the higher BOD at T11 and T13 are due to high organic load that enter from the two industries that directly discharge into the canal. The load at T13 is higher than at T11 because the factory F, which is a larger scale industry than factory E, thus the organic load was obviously higher at T13. In addition to this load it, also receives organic load from the upstream discharges of industrial and domestic wastes. Confectioneries use large quantities of sugar and milk, which are highly organic in nature.

The BOD in San Sebastian canal at S09 was much lower than at T13. The median was 64.0 at S09, while it was 299.5 at T13. Thus, the Main Drain enters the San Sebastian canal as a very polluted waterway and contributes to the pollution of the canal. It has to be added that although T12 was comparatively lower than at sites T11 and T13 on its COD and BOD load, it has comparative higher values than any other tributary canal sites. The median BOD at T12 of 114.5 mg/L was even higher than at sites T03 and T10 which were industrial discharge points at the Dematagoda ela and the Kittampahuwa ela respectively. The reason for this is that T12 gets a higher organic load from the food industrial waste water discharges from the upstream site in addition to the domestic wastes from residences and shanties in the area. (It is important to stress that among the industrial groups, food industrial wastes have very high COD and BOD. This is due to its high organic content and the high volume of waste water discharged from the industrial process, such as washing utensils and vats, and the floor washings done on a daily basis).

The SS as seen in the figure 6.16 (D) remained higher at T11 and T13. The high SS concentration at T11 and T13 was due to solids that enter the canal from the industries in the form of confectionery wrappers, cartons and product particles in addition to silt from the canal banks and the load carried with the canal flow. Comparatively high SS at T12 (when compared with other sites on the tributary canals) is due to domestic refuse and garbage thrown into the canal by the residents and the shanty dwellers living close to the site.

The SS at S09 on the San Sebastian canal was lower than at T13 with the median in the former site being 29.3 and 124.3 at the latter. Hence, T13 is the more polluted site than S09 due to its industrial discharges. The Mutwal Main Drain, thus enters the San Sebastian canal with a a high SS load with a potential of polluting the canal.

The turbidity in the Main Drain is very similar to the SS concentrations. As seen in the figure 6.16 (E), the concentration at the non industrial site T12 is lower. The turbidity can be explained in terms of the SS load at the sites. Higher the SS, higher is the turbidity of the water. The SS at T11, and T13 had been comparatively higher than T12, which is reflected in the higher turbidity median at T11 with 21.7 and 24.0 at T13 against 16.0 at T12. Comparing the turbidity at the site T13 with S09 on the San Sebastian canal, it can be said that the turbidity was comparatively lower at S09, than at T13. The median at S09 was lower than at T13. Therefore it can be said that more turbid waters enter the San Sebastain canal from the Main Drain, thus increasing the pollution of the San Sebastian canal.

The conductivity in the Main Drain depicted a different picture to the other pollutants. There was a progressive increase in the conductivity values from T11 to T13. This is seen in the figure 6.16 (F). Therefore factors other than the salts that enter from the industrial waste waters have influenced the conductivity at the sites

T12 and T13. When the conductivity at S09 in the San Sabastian canal is considered this becomes clear.

The conductivity values of S09 was much higher than at T13. The maximum recorded at S09 was 2985.0 μmhos/cm and the 90th percentile was at 1862.0 although the median was slightly lower than at T13 with a value of 535.0. Thus it is possible that more conductive waters from S09, exerted an influence on the conductivity of T13, rather than Main Drain entering the San Sebastian canal with higher dissolved salt concentration. Therefore higher conductivity at T13 may possibly be due to the influence felt at this site. Another possible explanation for conductivity at these sites, in addition to domestic and industrial discharges is that the sea water may be entering through the Mutwal tunnel during high tide(inspite of the slight hump at the meeting point of the Main Drain and the Mutwal tunnel). Therefore tidal influence from either side of these sites on the Main Drain may be a possible explanation for higher conductivity values at these sites. The fact that there is no fluctuation at T12 in the conductivity helps to strengthen this fact. Thus high conductivity cannot be solely attributed to industrial waste waters. With the high conductivity levels of S09 the Main Drain has no adverse effect on this already high conductivity.

The pH in the Main Drain recorded values which were near neutral. The fluctuations in the pH as seen in the figure 6.16 (G) are negligible. The pH of the sites did not seem to be affected very much by the industrial waste water discharges, although the slightly higher value at T13 could be due to the detergents that enter the canal, hence making it slightly alkaline.

The pH at S09, the receiving site in San Sebastian canal had a median of 8.2 which was lower than at T13. Although there is not much difference between these sites to comment upon the pH at T13 appears to be slightly higher. Thus the contribution by the Main Drain to the San Sebastian canal in terms of the pH appears minimal.

The water temperature in the Main Drain was near the maximum daily air temperature at the site T12, with the median at 30.7 °C. The higher water temperature at T13 as seen in the figure 6.16 (H) is higher. The higher values at T11 and T13 can be expected with the heated effluents that enter the Main Drain. Comparatively the water temperature was the highest at T13 due to larger volume of heated water that enter the Drain.

Comparing the water temperature at T13 with S09 on San Sabestian canal it can be said that T13 had a much higher water temperature than at S09. The median at S09 was 32.0 while at T13 it was 36.15. Therefore heated water from T13 enter the San Sebastian canal and thus contribute to warmer water at S09. The contribution from T13 to a slightly higher water temperature at S09 becomes clear, since water temperature at site S08 was lower than at S09.

As seen in the figure 6.16 (I) the total P was higher at T11 and T13. The higher total P at the sites T11 and T13 may be due to the total P that enter the Main Drain in the form of detergents used for cleaning and washing in the industries. The total P may also enter the sites from the domestic sources. This is particularly true of the site T12. Total P at S09 had comparative median value with that of T13. The former had 1.85 mg/L and the latter 2.02 mg/L. The minimum and the maximum values recorded at S09 was higher with 0.3 and 6.5 respectively, while it was 0.0 and 4.3 at T13. The 90th percentile recorded at S09 was 5.87 and at T13 it was 3.95. Thus the total concentration at T13 was lower than at site S09. Therefore the contribution to total P at S09 by the Main Drain appears negligible. Although the contributions are low, the presence of aquatic plants at the sites indicate nutrient loading. This may be due to an accumulation effect.

The total N in the Main Drain increased from T11 towards T13 as seen in figure 6.16 (J). Therefore the total N in the Main Drain has progressively increased downstream. Total N can enter the water course from the industries, although the confectioneries do not discharge very high nitrogenous wastes. The total N contributions into the drain may be mainly from the domestic sources, both from residences and the shanties in the area. The site T12 has many shanties. Illegal drains which enter the Main Drain also may contribute to nitrogeneous matter. Other industries from the neighbourhood may also contribute.

The total N at S09 in the San Sebastian canal was lower than at T13. The medain at S09 was 3.58 and it was 9.03 mg/L at T13. The higher total N values at

T13 indicate that the Main Drain is a contributor to the nutrient loading into the San Sebastian canal. The high nitrogen and phosphate values at T13 has caused the aquatic plants to thrive at this site. *Eichornia crassipes* was observed along the Main Drain.

The sulphate in the Main Drain, shows higher concentration at T11 and T13 than at T12. This can be seen in the figure 6.16 (K). Therefore it can be seen that the sulphates are higher at the industrial sites. The values fluctuated at T12. Comparing the sulphate at T13 with the sulphate at S09 it can be said that is was lower at S09 with the median value of 118.0, while it was 179.2 at T13. Thus the sulphate concentration being obviously higher at T13, it enters the San Sebastian canal as a polluted drain.

Summary

The pollutant concentrations along the San Sebastian canal indicate certain important features. The canal can be broadly divided into three sections. The sites S01 and S02 at the origin of the canal appeared less polluted with higher DO levels and lower pollutant concentrations. Of the two sites, site S01 which was closer to the Beira lake had higher concentrations, although the difference was negligible. These two sites were free from direct industrial and domestic waste water discharges.

The sites S03 to S07 had very high concentrations of the polllutants. The DO of the canal at this stretch was very low and often reached zero level during most of the monitoring period. The very high concentrations of the pollutants between these sites is due to the two large scale industries B and C. Industry C, a food processing industry and B an oil based industry discharge very strong organic waste waters at S06 and S03 respectively. The downstream sites S04 and S07 were affected by the upstream sites. The oxygen depletion by these industries is very high. Therefore the canal at this stretch was at the bottom of the oxygen sag curve. The shanties along the stretch (none at S06) also contribute to the pollution of the canal. But the contribution to the pollution of the canal by the shanties when compared with the industrial discharges appear to be very low. The effect on the downstream sites is high. The domestic site S05, which is in betweeen two major industries experienced fluctuations in the pollutants and slight aeration was evident. But the background level of the pollutants remained very high. This is clearly evident when the concentrations are compared with the site S08 which is downstream, but not influenced by direct industrial discharges, although it has tributary canal contributions.

The stretch from S08 to S10 had lower concentrations of the pollutants than between S03 to S07, but the sites appeared more complex. The relationships were thus less clear. This may be due to the contributions from various sources such as the tributary canals, agriculture, domestic, indirect industrial discharges and the commercial sector. The influence of the tidal river in the eastern end of the canal also contribute to the complexity. Further the proximity and the exposure of the canal to the sea near and through the Main Drain may have added to this. This was clear in the conductivity values.

The tributary canals too contributed to the pollution of the San Sebastian canal. This was clearly evident in most of the pollutants that entered from the Dematagoda ela, the Kittampahuwa ela and the Main Drain. Although there were contributions from the tributary canals such as the Maligawatte and the Kettarama canals the loadings into the receiving sites appeared minimal. This is mainly due to the entry points which have strong organic discharges from the large scale industries. Thus the effect is not felt much. Of the tributary canals the Main Drain appeared to be the most polluted water way. This is due to the presence of two confectioneries that discharge into this canal. The organic loading was very high. Even the Dematagoda and the Kittampahuwa canals had industries near the confluence of the San Sebastian canal. Thus the loading into the canal was high.

Thus the San Sebastian canal, overall presented a grossly polluted canal. Although the water was relatively clean at the origin of the canal (possibly due to the pumping station), it became heavily polluted as it progressed. The contrast between the sites S02 and S03 was very sharp. As the industrial discharges entered at the latter site the DO level fell from a median of 9.65 at S02 to 0.03 at S03. Thus from S03 downwards till S07 the pollutants were very high with slight fluctuations. Although there was a fall in the pollutant concentrations from S08, a high level was still

maintained by the upstream industrial sites and the tributaries that discharge into the San Sebastian canal. Thus the San Sebastian canal discharges highly polluted waters into the receiving river Kelani. This was very clear in the concentrations in the downstream site R01, which was higher than in the upstream site of the confluence with the San Sebastian canal. Although there was a buffered effect at the terminal site on the canal due to low flow (or even stagnation), lockage and the tidal effect (which also may have helped to contain the pollutants within the canal), it discharged highly polluted waters to the Kelani river. At the other end of the canal the pumping of the water into the Beira lake potentially polluted the lake. Thus it polluted the receiving waterways at both ends.

6.6 The correlation of pollutants in the surface waters

An analysis of relationship between the pollutants indicates some important relationships. Clear relationships were observed in certain variables such as the BOD, COD, DO, turbidity, SS and water temperature. There were no clear relationships between some pollutants. Peculiarities were observed in some parameters. These can be seen in the strength of the correlation between the pollutants which was computed by using the Spearman's correlation coefficient ρ.

6.6.1 The correlation between COD, BOD and the DO

San Sebastian canal (S01-S10)

COD/DO: coefficient variation

Table 6.28 shows the correlation coefficient for COD/DO.

The examination of relationships between the pollutants gave a striking relationship between the COD and DO. The correlation between COD and DO was negative in all the sites along the San Sabastian canal except at S08 which gave a positive correlation coefficient of 0.11. The level of significance was insignificant. The occurence appeared isolated.

The coefficient for COD/DO varied widely between the sites along the canal with the lowest coefficient of -0.20 at S09 to the highest correlation of -0.86 at S01. The latter was .001 significant. The coefficients were high at S01 with -0.86 and -0.70 at S02 respectively. Both had significance levels at .001. The coefficients fell from the site S03 downstream.

Correlations

These two highly negative coefficients are in the sites at the origin of the canal which are also free of industrial discharges. Through the relationship between the pollutant COD and the DO levels, the water quality in the canal becomes clear. As the canal approaches the site S03 which gets industrial discharges from the factory B, the negative correlation coefficient values is still maintained but the strength in the relationship becomes less, which is indicated by the coefficient -0.51 at S03. The level of signifiance still remained high at .001 level. It further fell to -0.37 at S06. The level of significance remained at .01.

From the sites S03 to S09 the strength of the coefficient decreased gradually, although the negative correlation was still maintained. It is possible that there is a saturation in the COD in the canal site from S03 to S07 due to industrial, commercial and domestic (shanty) waste waters that enter the canal which results in this relationship. However much the COD decreases the DO does not increase, i.e. the organic content in the canal is so high that the micro-organism are continually using up the available DO for oxidation of the wastes in the canal. In other words the reaeration rate is minimal at these sites. Even if the DO level rises slightly due to atmospheric reaeration (from rainfall), there is continued injection of waste water discharges from the polluting sources at these sites, which causes the microganism to use up the available DO immediately and whenever available for the biodegradation of the organic wastes.

There is an isolated occurrence with a positive correlation coefficient of 0.11 at S08, which is difficult to explain. At S10 the relationship between COD and DO becomes more established. The correlation coefficient of -0.50 (significance at .001), may be due to the tidal influence at this site. This has a two way effect on the DO. The DO increases due to river water with a higher DO level entering the canal, and

Table 6.28 — Spearman's ρ between pollutants: surface waters

Site	COD/BOD.	COD/DO.	BOD/DO.	TB/SS.	DO/W T.
S01	0.98***	-0.86***	-0.84***	0.57***	-0.32*
S02	0.96***	-0.70***	-0.70***	0.69***	-0.30*
S03	0.85***	-0.51***	-0.47***	0.87***	-0.28*
S04	0.87***	-0.42**	-0.42**	0.74***	-0.35**
S05	0.96***	-0.42**	-0.46***	0.86***	0.07
S06	0.95***	-0.37**	-0.37*	0.71***	-0.01
S07	0.83***	-0.25*	-0.27*	0.72***	-0.26*
S08	0.97***	0.11	0.21	0.69***	-0.07
S09	0.93***	-0.20	-0.25*	0.75***	-0.19
S10	0.92***	-0.50***	-0.42***	0.58***	-0.32*
U01	0.95***	-0.51***	-0.42**	0.70***	-0.49***
U02	0.95***	-0.09	-0.06	0.93***	-0.12
R01	0.94***	-0.64***	-0.58***	0.87***	-0.30*
R02	0.95***	-0.46***	-0.45***	0.81***	-0.25*
T01	0.94***	-0.81***	-0.71***	0.85***	-0.05
T02	0.82***	-0.89***	-0.71***	0.84***	-0.23
T03	0.95***	-0.55**	-0.59**	0.87***	-0.51*
T04	0.98***	-0.16	-0.21	0.74***	0.45*
T05	0.99***	-0.77***	-0.78	0.91***	-0.01
T06	0.93***	-0.37	-0.36	0.73***	-0.26
T07	0.98***	-0.54*	-0.57**	0.86***	0.00
T08	0.99***	-0.35	-0.33	0.78***	-0.23
T09	0.93***	-0.84***	-0.74***	0.89***	-0.33
T10	0.94***	-0.78***	-0.80***	0.74***	-0.05
T11	0.70***	-0.56**	-0.46*	0.66***	-0.70***
T12	0.90***	-0.39	-0.28	0.67***	-0.56**
T13	0.93***	-0.39	-0.33	0.63***	-0.25

* = .05 (Level of significance), ** = .01, *** = .001

Source: Field monitoring

also due to the surface turbulence caused by the tidal action, which increases the DO levels in surface waters. Therefore a comparatively higher negative correlation coefficient of -0.50 may be due to a fall in the COD with an increase in the supply of DO at this site.

Therefore the negative correlation is maintained between the COD and the DO in all the sites except at S08 in the San Sebastian canal.

BOD/DO: coefficient variation

Table 6.28 gives the correlation coefficient for BOD/DO. The computations were based on 40 values. The correlation coefficient ranged from -0.84 at S01 to -0.27 at S07. The significance was .001 and .05 respectively. S02 had a coefficient of -0.70, with significance at .001. The same isolated occurrence at S08 is reflected in the BOD/DO, with a coefficient of 0.21. The significance was low.

Correlations

The BOD/DO relationship in the San Sebastian canal also had a very similar relationship like the COD/DO except in the slightly variable strength in the correlation coefficients. This is understandable in the fact that both the COD and the BOD move in the same direction with DO. This relationship is more clear in the organic wastes. The differences occur only in the actual strength of the COD and the BOD, rather than in their relationship with the DO. As in the COD the BOD/DO also has a negative correlation which indicates, higher the BOD, lower the DO and vice versa.

There is also a striking difference between the COD/DO and the BOD/DO correlation coefficients along the sites in the San Sebastian canal i.e. the coefficient does not decrease progressively along the sites from S03 to S07 as in the COD. This may be due to the biological factors operating differently in the sites, in terms of their metabolic activity of the microorganisms. The difference in water quality between the sites is thus clear due to the medium of oxidation.

The correlation coefficient fell drastically at S03 from the coefficient at S02 which had a value of -0.47 (the level of significance was .001). The strength in the coefficient decreased at S04, but it increased slightly at S05 with -0.46, with the significance at .05. The site S05 does not have any direct industrial waste water discharges and therefore the BOD is lower than at S04, which has influence from the accumulated effect of the industrial discharge from factory B (B1 and B2) the automobile spare part shops and the shanties around the area. Therefore the slight reaeration that takes place at S05 (which is between two industrial sites), is reflected in a slightly stronger coefficient, whereby even with a little aeration the BOD value falls in terms of its strength at this site. This may be also due to no direct injections of industrial waste water discharges with high organic content, and therefore with the available DO, the fall in the BOD is seen. At S06, the complexities of industrial discharges is reflected in the coefficient with a comparative but weaker relationship of -0.37. The level of significance was .05. This shows that the biological mechanism is different in the industrial sites than in the non industrial sites.

Although the BOD and the COD are somewhat similar in terms of its definition, the different media acting on the tests is clearly evident in the correlations. In the BOD even a slight variation in the metabolic activity is detected as seen above while in the COD, the differences in the microorganic activity is not reflected. It has the smoothing effect on the correlation due to the media of oxidation used (the strong acid dichromate). The BOD only oxidses the organic components in the wastes, while the COD detects both the organic and the non organic components in the sample. It may be possible due to this, that the slight differernces between the sites from S03 to S07 was less clear in terms of the COD, while, more understandable in terms of the BOD.

As far as the sites S01 and S02 are concerned, the BOD/DO correlation coefficient is high with -0.84 and -0.70 respectively. The significance was .001. These two sites give a simpler relationship which means that when the DO is available, the BOD values fall in a simple, direct relationship. These two sites which are relatively unpolluted (with higher reaeration capacity) gave an uncomplicated relationship which is seen from the coefficients. The site S09 had a coefficient of -0.25 and S10 -0.42. The level significance was .05 and .001 respectively. The factors operating at S10 may be same as for the COD mentioned earlier.

Lake: coefficient variations (U01-U02)

The correlation data for COD/DO and BOD/DO can be seen in table 6.28. The COD/DO correlation coefficient at the lake sites U01 and U02 also had a negative correlation with the coefficient of -0.51 at U01 while at U02 the correlation was very poor at -0.09. The former was .001 level significant, while the latter was insignificant. The BOD/DO correlation coefficient for U01 was -0.42 and -0.06 for U02. The significance was .05 at U01, and not significant at U02.

Correlations

The coefficient for COD/DO and BOD/DO at U02 also may be due to the same factors operating in the industrial receiving sites as in the canal. The creamery (A5) wastes, meat industry waste (A3) and the carbon dioxide plant (A4) waste waters enter the lake at this point. The lake at this point is also a reception site to the culvert that empties raw sewage. Therefore even if there is a variation in the COD and BOD values, there is not much difference in the corresponding DO values. The DO ranges

only between 0.9 mg/L to 1.8 mg/L at U02, although there is wide variation in the COD and the BOD at this site. This situation may be due to the continous high organic waste water discharges from the food industries mentioned and the raw sewage which keeps the DO level in the lake site very low. Even if reaeration takes place, the rate of reaeration is very low in comparison to the highly variable COD and BOD values at the lake site. Therefore the negative correlation associated with COD/DO and BOD/DO is very weak at the site U02. The already low DO may not be responsive to the variation in the waste water discharges with high BOD and COD.

The correlation coefficient at U01, which is free from the industrial waste water entries has a higher coefficient. The pollutant that hinders the reaeration process at this site is usually the oil spills from the boat repair yards and thelaunches that ply between the lake and the harbour canal through the MacCallum Lock. Therefore the relationship between, COD/DO and BOD/DO is less complicated at U01.

River Kelani (R01-R02): coefficient variation and correlations

Table 6.28 shows the correlation coefficient for COD/DO and BOD/DO in the river sites. The correlation between COD and DO gave a correlation of -0.64 at R01 and -0.46 at R02 and a BOD DO correlation coefficient of -0.58 and -0.45 at R01 and R02 respectively in the river Kelani sites. The significance levels were .001 at both sites. In the river essentially the same relationship was maintained. The implications of industrial discharges were not clear as there were no direct discharges into the sites.

Tributary canals (T01-T13): coefficient variation and correlations

The correlation coefficient in the tributary canals for COD/DO and BOD/DO can be seen in table 6.28. The computations were based on 14 values.

The correlation between COD and DO at the tributury canal sites gave a very high negative correlation of -0.81 at T01 in the Maligawatte Drain and -0.89 in the Kettarama Drain. The significance was .001. The BOD/DO coefficient was same with -0.71 in both sites. Both the canals did not have direct industrial discharges. Thus the coefficients indicated a simple relationship.

In the Dematagoda ela the COD/DO coefficient varied from T03 to T06 with a poor correlation of -0.16 at T04 to -0.55 at T03. The latter was .01 level significant. The lowest coefficient of -0.16 was at the Kolonnawa bridge i.e T04 which receives waste water from the oil installation. The DO level in the site is low. The BOD/DO correlation at the Dematagoda ela gave a negative relationship with varying strength. The correlation was poor with -0.21 at T04. The highest was at T05 with -0.78. The latter was .001 significant. The relationship at T03 the industrial waste water receiving site in comparison had a lower coefficient in common with the other sites on the tributary canals. The level of significance was .01.

In the Kittampahuwa ela all the sites had a fairly high correlation between COD and DO except at T08 which had coefficient of -0.35. The BOD/DO correlation had the same pattern with the coefficient varying from -0.33 at T08 to -0.80 at T10, the latter significant at .001.

In the Main Drain the correlation between COD and DO was -0.39 at T12 and T13, and increased to -0.56 at T11. The latter significant at .01. The BOD/DO correlation varied from -0.28 at T12 to -0.46 at T11. There is fairly steady negative relationship at T11 and as the canal flows downstream the strength of the correlation between COD, BOD and DO has fallen. The industrial site of T13 had an insignificant coefficient of -0.39 for COD/DO and -0.33 for BOD/DO. This indicates the same relationships as in the other industrial sites.

6.6.2 The correlation between SS and turbidity

San Sebastian canal: coefficient variation

Table 6.28 indicates the coefficients between SS and turbidity. The relationship between the SS and turbidity gave a positive correlation in all the stations in canal, tributaries lake and the river sites. The correlation coefficient ranged from 0.57 at S01 to 0.87 at S03. The signifance was .001 at both the sites. The correlation coefficient was higher at the industrial sites of S03 which receives discharge from the factory B. The correlation tended to remain high from S03 to S07 with a slight fluctuation at S08, and the correlation strengthened again at S09, and fluctuated at S10.

Correlations

The basic relationship of higher the SS, higher the turbidity is maintained in all the sites at San Sebastian, which is indicated by a positive correlation with varying strength in the sites.

The correlation coefficient is relatively lower at S01 and S02, which are relatively undisturbed sites in relation to sites S03 onwards.

It is possible that a very strong correlation of SS and turbidity at S03 may be due to the industrial discharges from factory B as mentioned earlier. The suspended matter at B1 was very high although it ranged very widely. The maximum SS measured was very high and the corresponding turbidity was 300.0 NTU. Therefore it is not surprising that the correlation between SS and the turbidity at this site should be very high. The canal water appeared turbid throughout the year except a few days after heavy rainfall when the water appeared more clear. The soap effluents that enter the canal at this point had frothy, milky appearance in addition to the solidified soap nigger on the canal banks. It was floating in the canal itself. At S04 there is a slight fall in the strength of the correlation with the coefficient at 0.74. The SS/turbidity correlation increased at S05 with a correlation of 0.86. The level of significance at both the sites was .001. It is possible that at S05, although not an industrial site the dredged material from the canal which was piled up along the canal may have re-entered due to rainfall. It may be a cumulative effect of suspended matter flowing through this site.

The shanty population from S03 to S05 may also contribute to the suspended matter by throwing garbage constantly into the canal, thus disturbing the canal. The temporary makeshift toilets erected along the canal also washes away sand and silt into the canal. Further the stand pipes along the canal are constantly used for washing clothes and utensils by many shanty dwellers along this section of the canal. This may increase the amount of silt that enters the canal, which increases the SS in the canal and results in higher turbidities.

The coefficient is slightly higher at S07 than at S06 with a coefficient of 0.72 against 0.71. The level of significance was .001. This may be due to the cumulative effect of the industrial discharge from the factory C flowing through this site (which is not far away). The Kettarama drain brings suspended matter and the open laundry operating at this site may causes the silt to enter the canal. The laundry operates daily and therefore silt may enter the canal throughout the year irrispective of rainfall.

The correlation coefficient is higher at S09 with the coefficient at 0.75, and the significance at .001. This may be due to higher SS that enter the San Sebastian canal from the Kittampahuwa ela or even the back wash of suspended matter enter from the Main Drain due to the tidal flow. The suspended matter from the river itself could enter this point. The correlation coefficient is comparatively lower but significant at S10. There are no direct industrial discharges at S10. The SS may be due to the solids transported to and fro from the tides.

The significantly high correlation along the canal, may also be due to the dredging of the canal which took place during the period of monitoring. The dredged materials were piled up along the banks for a long period so that during the rainy days part of the material may have re-entered the canal. The Hulstdorf courts complex construction work, may have significantly contributed to the canal near site S03. On many occasions piles of sand and other building material from the construction works were observed in the canal. Rainfall would have washed off fair amount of the sand and silt into the canal from this source.

Thus the SS/turbidity correlation coefficient, which is highly significant in all the sites, is a situation, contributed by external factors which took place during the period of monitoring in addition to the industrial, domestic discharges, and the natural surface run off.

River Kelani: coefficient variation and correlations

The correlation data for SS/turbidity is given in table 6.28. There was a high positive correlation between the SS and turbidity in river Kelani with the coefficient at 0.87 in R01 and 0.81 at R02. The significance level was .001. The correlation was higher at R01.

This may be due to a large volume of suspended matter that enter from the municipal sewage treatment works near the Victoria bridge. The sewage is emptied raw without any treatment. Further saw and fibre mills near this site contribute to a con-

siderable amount of suspended matter. The San Sebastian canal may also contribute to the downstream site R01. The tidal effect of the river may also contribute to a higher correlation between SS and turbidity.

Lake: coefficient variation and correlations

Table 6.28 gives the correlation data for SS/turbidity. The correlation between turbidity and SS was very high in the Lake site U01, which gave a positive correlation coefficient of 0.93. The significance level was .001. The correlation between SS and turbidity at U02 was also positive and high. The coefficeint was 0.70 at this site with the significance at .001.

This may be due to the fact that oil and grease enter this site from the boat repair workshops, and the boats that plying between the lake and the harbour. Further the turbidity may be due to the turbulence caused by the passage of boats and lighters. The frequency of boats and barges plying through the MacCallum locks at this site is very high. As mentioned earlier, between 1.1.1986 and 28.2.1987, 1874 fifty, and one-hundred ton barges and boats plied through the locks (Sri Lanka Ports Authority, 1986 and 1987) and (personal communication - Ramanayake, M. 1988).

The coefficient at U02 was also high. This may be due to the high amout of SS matter entering from the industries such as A3 and A5 and the other industries around. Further a culvert empties raw sewage at this point. Further aquatic plants and microorganisms may contribute to the correlation between SS and turbidity as this is a highly productive lake with a high nutrient content.

Tributary canals: coefficient variation and correlations

The correlation data for SS/turbidity in the tributary canals can be seen in table 6.28. In the tributary canals the correlation between SS and turbidity was positive and high. The correlation coefficient ranged from 0.63 at T13 to 0.91 at T05. The significance was .001. In the Maligawatte drain the coefficient was 0.85 at T01 significance was .001. At T02 in the Kettarama drain the coefficient was 0.84 which also had a significance of .001. In the Dematagoda canal the coefficient ranged from 0.73 at T06 to a 0.91 at T05. The coefficient ranged from 0.74 at T10 to 0.89 at T09 in the Kittampahuwa ela, with a significance level of .001.

The coefficient appeared to be comparatively lower in the sites in the Main Drain although it was still a position correlation. At T11 it was 0.66, at T12, 0.67 and at T13 it was 0.63. The level of significance was .001. Inspite of the two industries directly discharging into the canal at T11 and T13, the correlation has been comparatively lower at these sites than in the other canals. It may be possible that the solids settle due to very low flow and the blockage of the canal at the culvert which connects it to San Sebastian canal.

When the the confluence points of the tributary canals with that of the San Sebastian canal is considered, it can be said that T03 in the Dematagoda canal had a high correlation coefficient of 0.87. The significance remained high at .001. This is obviously due to a drain that brings industrial effluents from many industries bordering the canal.

The site T10, which is at the confluence on the Kittampahuwa ela had a coefficient of 0.74 with a significance of .001. This also could be from the bordering industry and the shanties around in addition to the silt load brought from the ela further down due to reclamation of low lying areas in and around Orugodawatte. This is also evident from the high correlation coefficient of 0.89 at T09. The significance was high. As mentioned earlier at T13 on the Main Drain some other factors may be operating with regard to the relationship between suspended solids and turbidity.

Fundamentally, in all the sites on the water bodies there was a positive correlation between suspended solids and turbidity. This indicates that higher the suspended solids in the sites the more turbid is the water.

6.6.3 The correlation between water temperature and DO

San Sebastian canal: coefficient variation

The correlation data for water temperature/DO can be seen in table 6.28. In San Sebastian canal the correlation coefficient varied from -0.01 at S06 to -0.35 at S04, S01 and S10. The level of significance was .01 in the latter. There was a isolated occurrence at S05 with the correlation coefficient at 0.07. Overall the relationship between DO and water temperature appears very complex.

Correlations

The relationship between water temperature and DO in the water bodies indicated a negative correlation. As the temperature decreases the solubility of oxygen, a negative correlation between water temperature and DO is to be expected. This situation is exacerbated by the fact that as temperatures rise the rate of oxygen uptake by micro-organisms increases. The data for the sample sites however does not provide the strong correlation expected. At all sites the correlation is relatively weak, the highest being -0.35 at S04.

The low correlations are almost certainly the direct result of other factors such as COD and BOD having a greater influence on DO levels than the temperature.

COD/BOD: surface waters

Table 6.28 shows the correlation coefficients for COD/BOD in the surface waters In the San Sebastian canal the correlation coefficient was very high between the BOD and the COD. This was observed in the lake, river and the tributary canal sites. This indicates the organic nature of the waste waters. Since the variation in correlation was not high a detailed explanation was not attempted.

Summary

There was a negative correlation between the COD and the DO in all the sites except at S08 in the San Sebastian canal which indicates that higher the organic wastes in the canal in terms of the COD, the lower will be the DO in the corresponding sites. Three situations were encountered in the canal sites. The sites S01 and S02 with higher correlation coefficients which indicated a direct relationship of a less polluted situation, the sites S03 to S07 with lower correlation coefficients which indicated the more polluted sites of industrial origin and the sites S08 to S10, with variable coefficients which indicated the complexities of the entry of the tributary canals, agricultural runoff, tidal influence and discreet industrial waste waters.

The BOD/DO essentially remained the same except the importance of the microorganic activity of the medium of biodegradation. This was not clear in the COD/DO. Both these indicated the derogatory nature of the organic wastes on the DO of the canal.

The situation in the lake was essentially the same. In the tributary canals other than at T10, all the confluence sites which also had industrial discharges had essentially the same relationship as that of San Sebastian canal. The relationship in the river was difficult to be assessed as there were no direct industrial discharges. But the downstream site of San Sebastian canal had a higher coefficient.

The correlation between the SS and the turbidity was positive in the San Sebastian canal. The coefficients were higher from the site S03 downstream than at S01 and S02. This may be due to both the industrial discharges and the dredged materials that may have entered. The tributary canals too contributed. This was reflected in the higher coefficients at the confluence sites other than at T13 (but the significance was high). Thus the entry of turbid waters into the San Sebastian canal is evident The river had a higher coefficient at the downstream site of the San Sebastian canal. The lake sites had high correlations as well.

The water temperature/DO indicated a negative relationship. In the San Sebastian canal the coefficient was stronger at the industrial discharge sites of S03 and S04. S06 remained low. The higher water temperatures decrease the the solubility of DO and increases the rate of DO uptake by the microorganisms. Even in the relatively unpolluted sites there was a distinct relationship. The lake site U02 did not reflect the other industrial discharge sites. In the tributary canals other than at T13 high coefficients were observed. In the river the downstream site had a higher correlation coefficient.

This indicates that in the surface waters the heated industrial effluent discharges, have a clear detrimental effect on the DO. But as indicated by the sites in the origin of the canal, the high diurnal air temperatures in the tropics may have a background effect on the DO. In an over all view, it can be said that whatever the determining factor is, there is a distinctive negative correlation between water temperature and the DO.

6.7 Food effluents: effects on the receiving water

6.7.1 Confectionery effluents

Two confectioneries were monitored, coded as E and F, both of which discharge into the Main Drain at T11 and T13 respectively. Both factories had a monitoring frequency of 17 during the entire period of monitoring. They were monitored on a monthly basis except in July and November 1986 when two samples per month were monitored. Total N was not monitored in January and February 1986.

The samples were collected from within the industries. At E it was collected from the main outlet drain within the factory premises where the waste water from all the processes of production flow through, into the Main Drain. Therefore, the sample is the final effluent of the industry. The effluent from factory F was collected within the industrial premises, from the drain which leads into the sump. Hence, this sample too was the final. The effluent comprised of both the boiling, syrupping, ingredient mixing, and the floor washing operations. Of the confectioneries, factory F is the larger of the two.

COD, BOD and the DO: Data variability

COD

The data variability at E and F can be seen in table 6.29 and the daily concentrations in figure 6.17 and 6.18.

The factory E had a COD minimum of 607.0, maximum of 5931.0 mg/L and a median value of 1856.0. The 90^{th} percentile fell at 4160.6. These values indicate very high COD values. The range was high with a value of 2076.0 and a standard deviation of 1318.8, which indicates the high variability of the waste waters.

The values of COD at F recorded a minimum of 756.0 mg/L, maximum of 29920.0 and a median of 4167.0. The 90^{th} percentile was 18272.0. Therefore this indicates very high COD values at F. The high variability in the concentration can be seen in the range which had a value of 29164.0 and a standard deviation of 7241.0.

BOD

The data variability at E and F for BOD can be seen in table 6.29 and the daily concentrations in the figures 6.17 and 6.18.

The minimum BOD at E was 217.0 mg/L, the maximum 4186.0 and the median, 1001.0. The 90^{th} percentile fell at 2685.2. These indicate very high BOD values. Similarly the data variability is clear with a high range of 3969.0. and a standard deviation of 965.98.

The BOD at F was very high and ranged widely. The minimum recorded in this factory was 365.0, while the maximum reached 22800.0. The median fell at 2137.0. The 90^{th} percentile was 13572.8. The range recorded 2243.50 and the standard deviation fell at 5618.1.

The highest values for COD and BOD among the factories were recorded at F. The range in the COD between the two factories was 29313.0. The range in the BOD between the two factories was 22583.0. This indicates the wide variation in the monitored values recorded for the factories.

The DO of the factories remained low as seen in table 6.29.

Relationships and effects

Both the factories were equally polluting in nature, although the strength of the wastes differed. Industry F had stronger wastes, as seen from the very high COD, BOD and the very low DO levels. These highly organic wastes as indicated by the COD and the BOD are very representative of the wastes from the food industries. At confectioneries the strength of the waste is higher because they are sugar based. The effect of the very high wastes is reflected in the receiving canal sites.

The DO level of the canal sites at T11 and T13 where the effluents from industry E and F enter was very low. It can be seen that the DO median at T11, where the factory E waste water enter was very low at 0.42 mg/L, and the maximum reached only 1.5. As a high DO level is required to oxidise the high organic content in the waste waters the continued discharge of these wastes deplete the DO in the canal. This results in the very low DO levels. Further the oxygen-demanding wastes from sources other than the factory E, such as domestic waste waters from the neighbourhood may also enter the canal site at T11. But the contribution to DO depletion in comparison

Table 6.29 — Confectionery Effluents

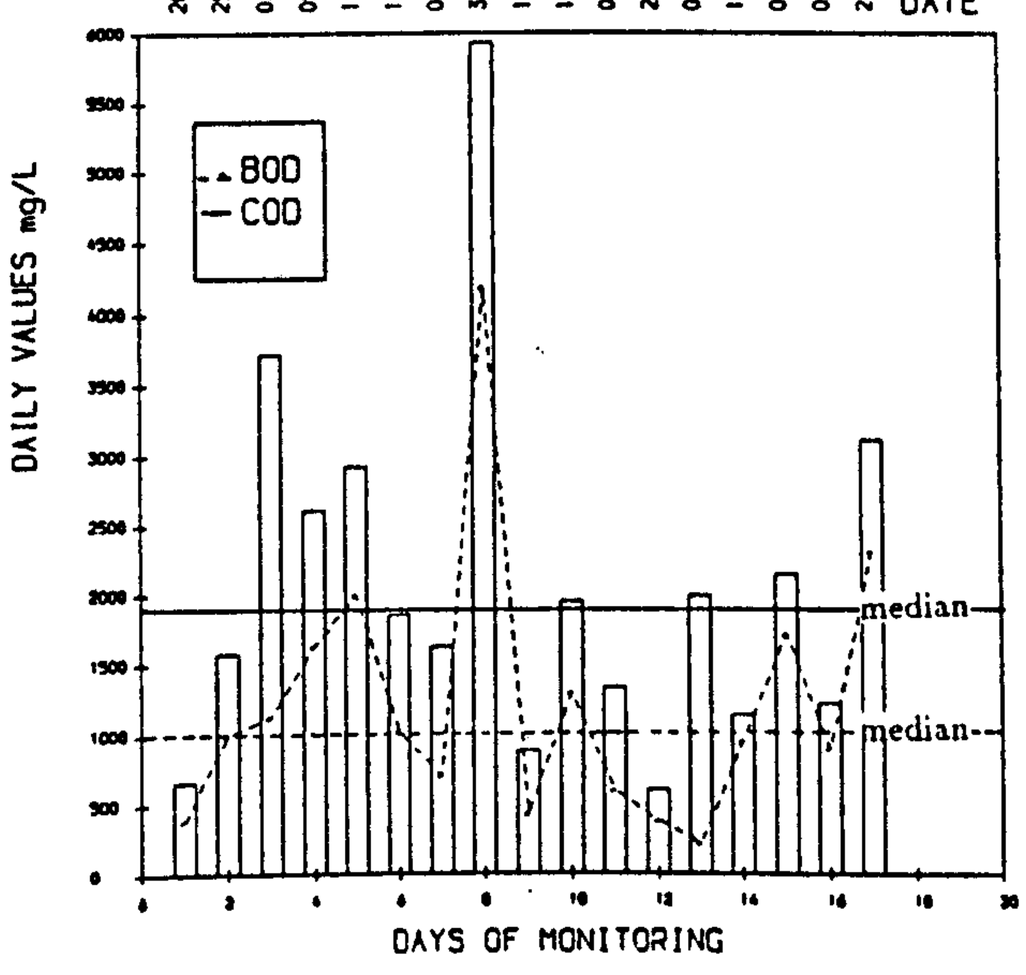
Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75%	90%	Fact.
DO	2.8	0.76	3.2	0.4	3.6	0.59	3.15	3.44	E
DO	0.7	1.00	3.2	0.0	3.2	0.20	1.1	2.72	F
COD	2076.0	1318.80	5324.0	607.0	5931.0	1856.00	2766.0	4160.6	E
COD	5853.5	7241.00	29164.0	756.0	29920.0	4167.00	6938.0	18272.0	F
BOD	1229.0	965.98	3969.0	217.0	4186.0	1001.0	1672.0	2685.2	E
BOD	4095.4	5618.13	22435.0	365.0	22800.0	2137.0	4960.5	13572.8	F
SS	277.1	159.00	543.3	46.3	589.6	271.0	391.9	522.84	E
SS	248.1	214.67	683.7	9.3	693.1	181.27	427.6	642.02	F
TB	38.2	9.57	38.0	20.0	58.0	35.0	47.2	51.2	E
TB	35.0	16.10	55.5	5.0	60.5	36.0	48.2	56.1	F
CT	285.2	69.51	310.0	125.0	435.0	270.0	330.0	379.0	E
CT	564.9	263.92	1095.0	160.0	1255.0	610.0	697.5	875.0	F
pH	7.3	0.99	3.2	6.1	9.3	7.25	8.0	9.14	E
pH	8.1	1.07	4.0	6.2	10.2	7.9	9.0	9.72	F
W T	31.7	2.60	10.5	30.0	40.5	31.0	32.0	36.1	E
W T	38.9	2.80	11.0	34.5	45.5	38.5	40.0	43.9	F
T P	3.3	2.50	8.2	0.9	9.15	3.2	4.5	8.43	E
T P	3.8	1.89	7.7	1.0	8.75	3.7	5.05	5.95	F
T N	5.2	5.50	16.4	0.3	16.84	1.78	8.3	16.09	E
T N	4.3	4.76	18.9	0.4	19.36	3.5	3.97	14.16	F
SULF	155.7	89.42	310.0	27.0	337.00	113.6	226.5	305.2	E
SULF	206.7	283.96	1226.1	41.2	1267.30	115.3	230.1	499.2	F

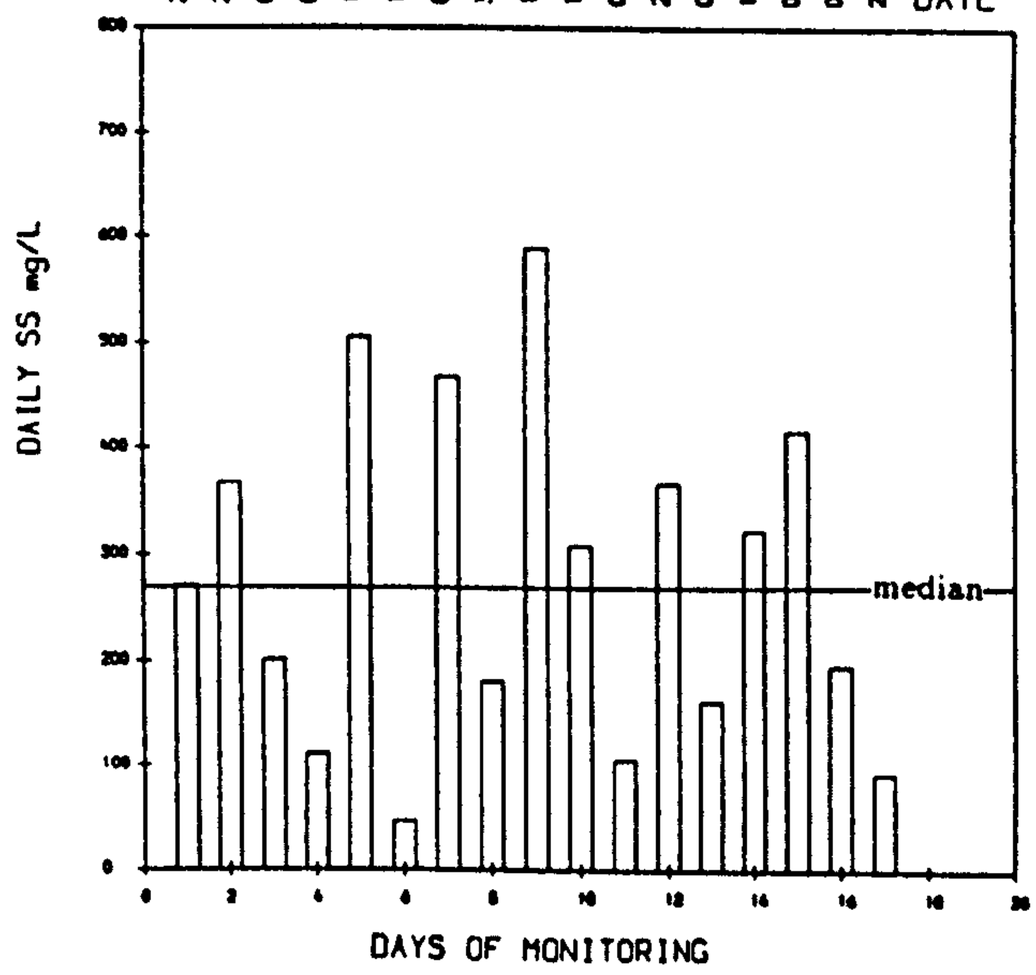
Source: Field monitoring.

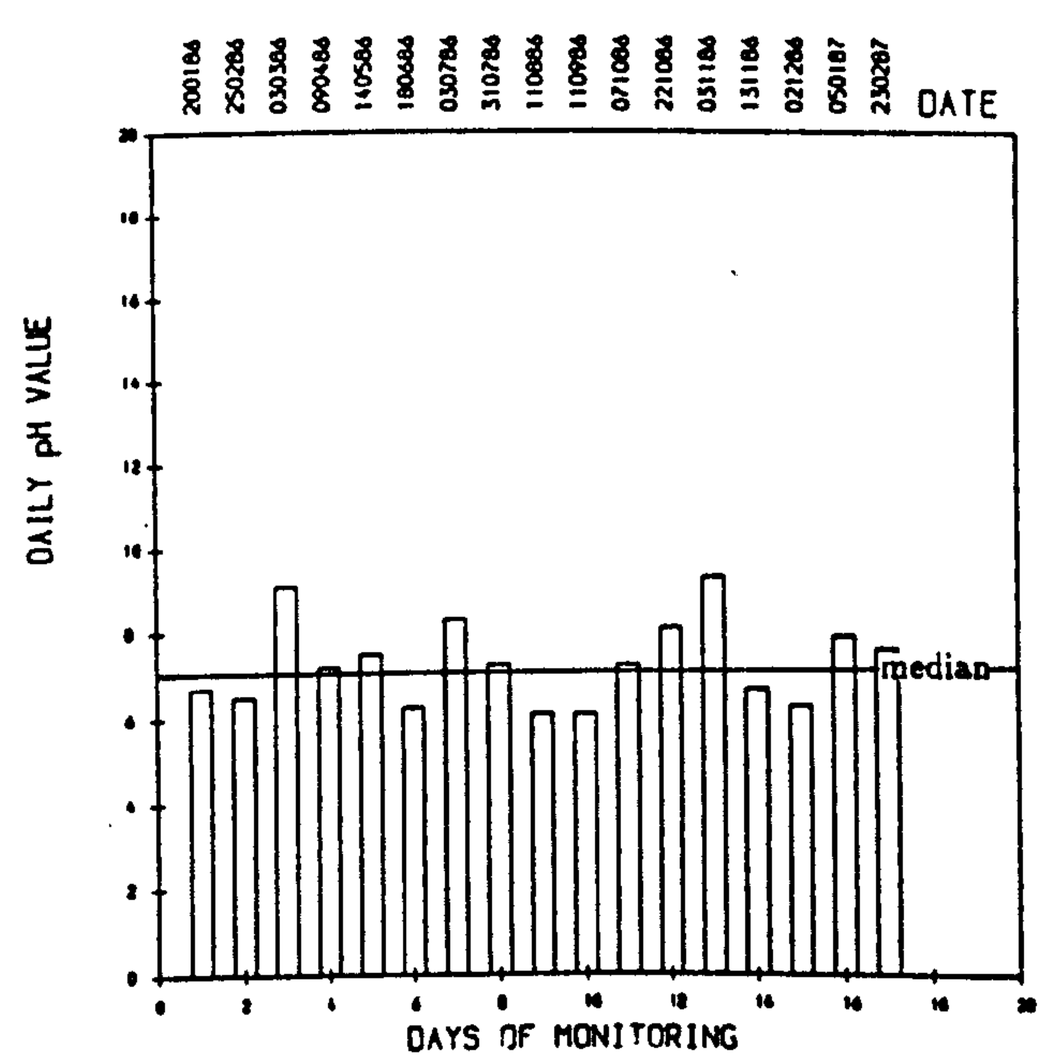
to the confectionery waste waters appears minimal.

The factory F has the highest organic load discharged into the Main Drain. This was clear in the very high organic load in terms of COD and the BOD. Being an industry of a bigger scale than E this load can be expected. Among the monitored tributary canal sites, T13 reported the highest value of 811.0 mg/L for the COD which was second only to the COD in the San Sabastian canal at sites S03 and S04, which had 1332.0 and 928.0 respectively. The BOD of 637.0 was next only to site S03 of San Sebastian canal which had a value of 870.0.

These high COD and the BOD at T13 which are due to the confectionery waste waters from F, are clearly reflected in the very low DO values at the site. The DO at F with the minimum, maximum and median at 0.0, 3.2 and 0.20 reflect the high strength of the waste waters that enter T13. The DO at T13 had a minimum value







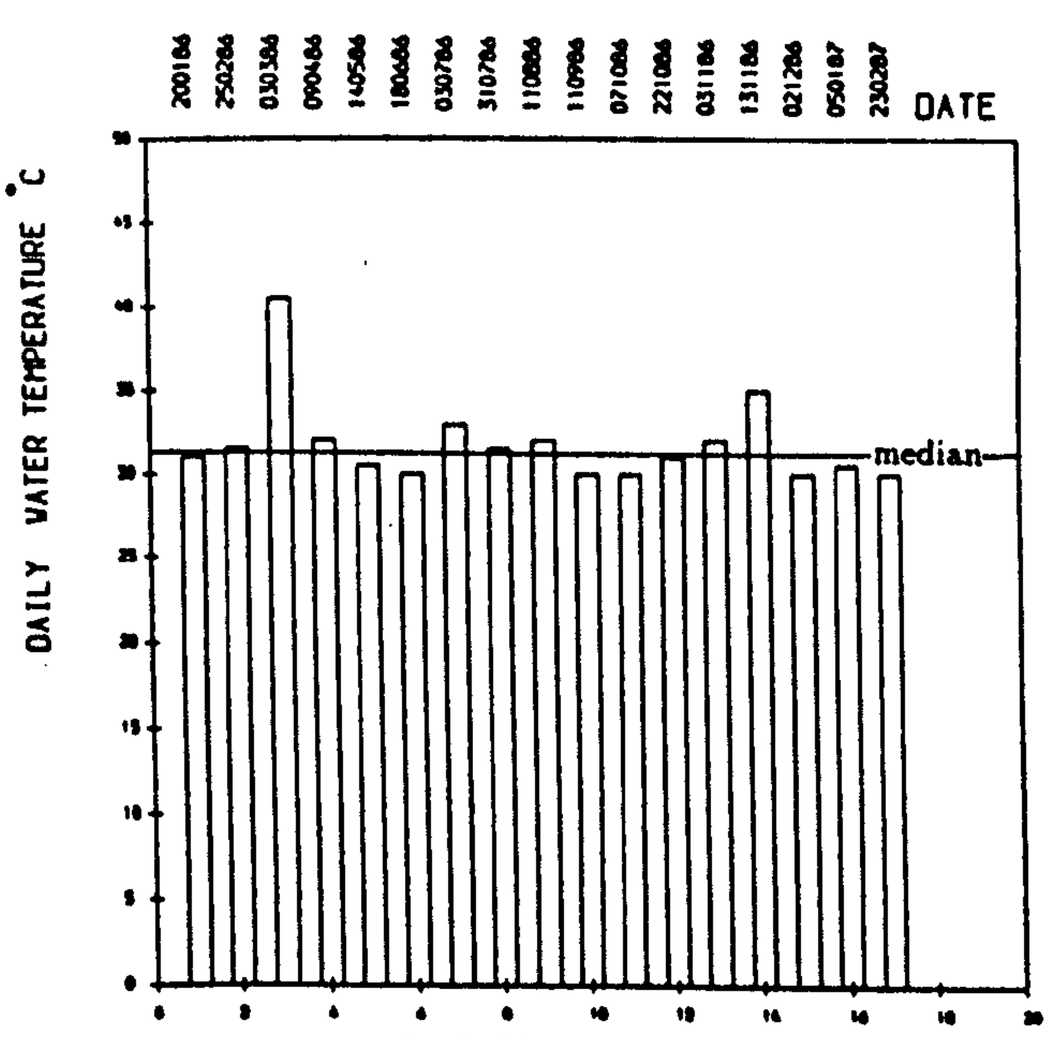
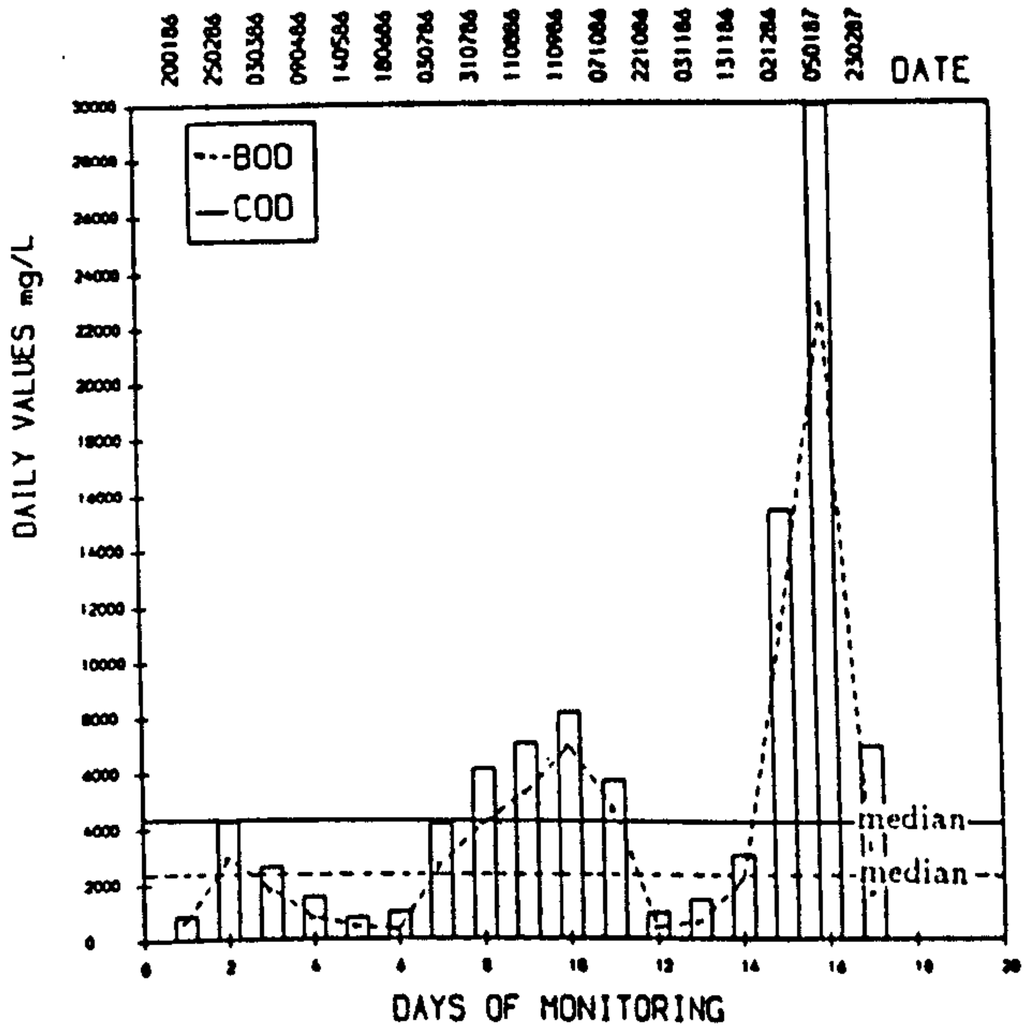
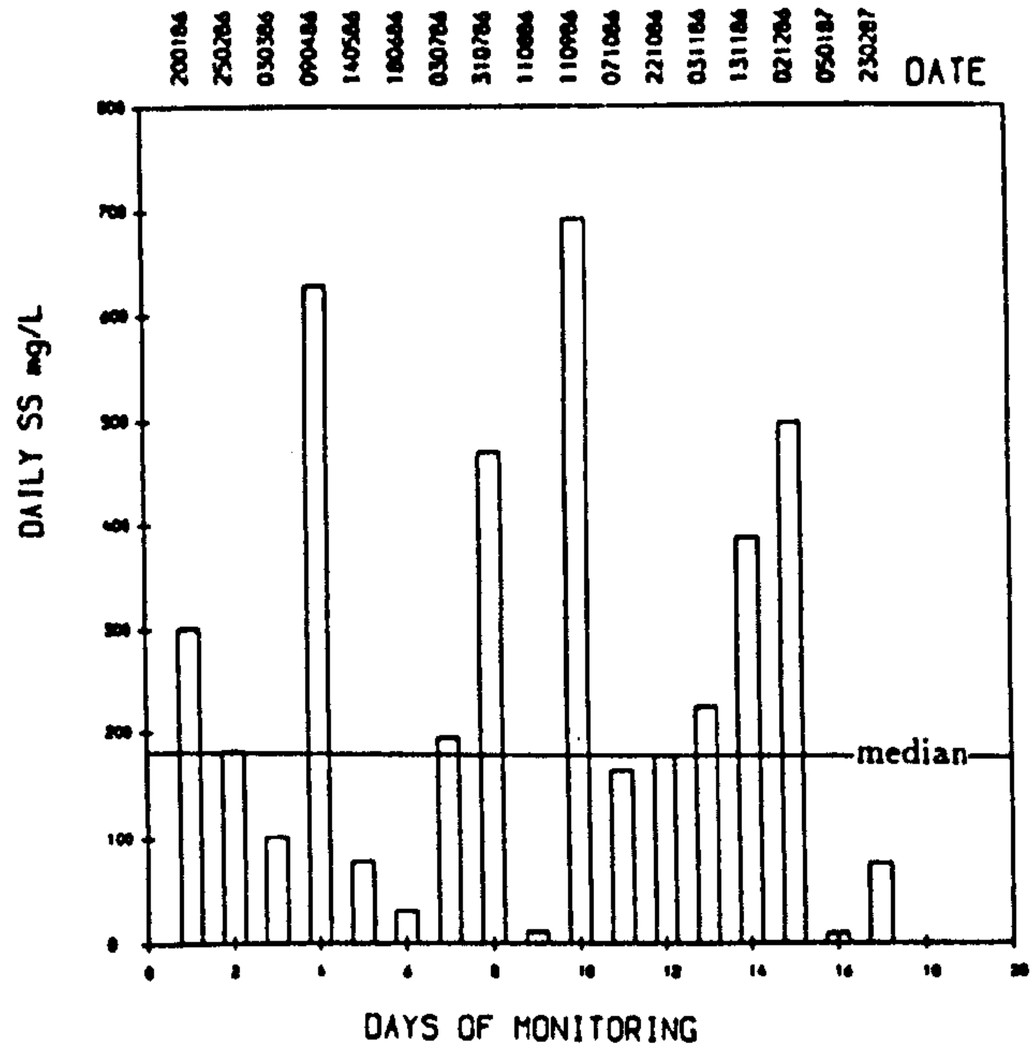
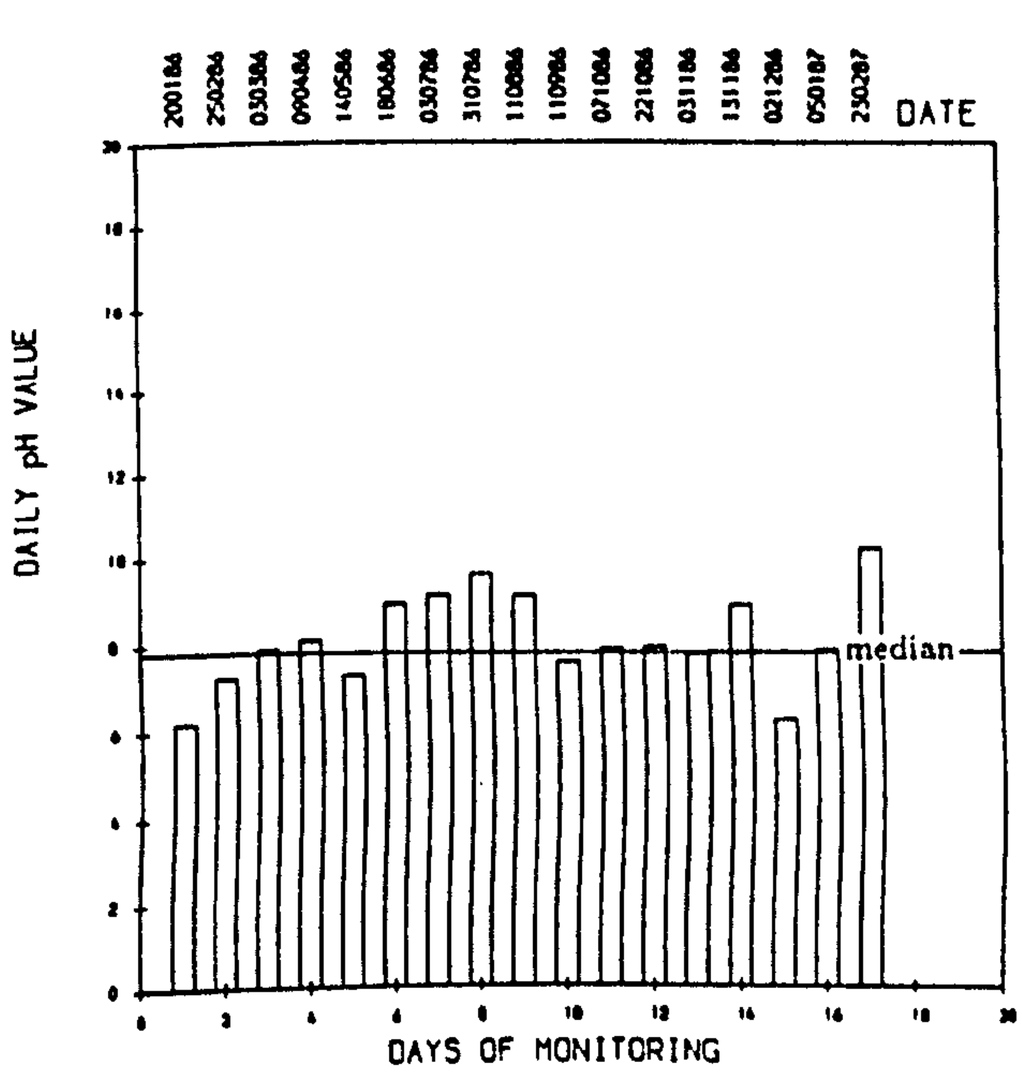


Figure 6.17 — Waste water concentrations in the confectioneries: E

Source: Field monitoring







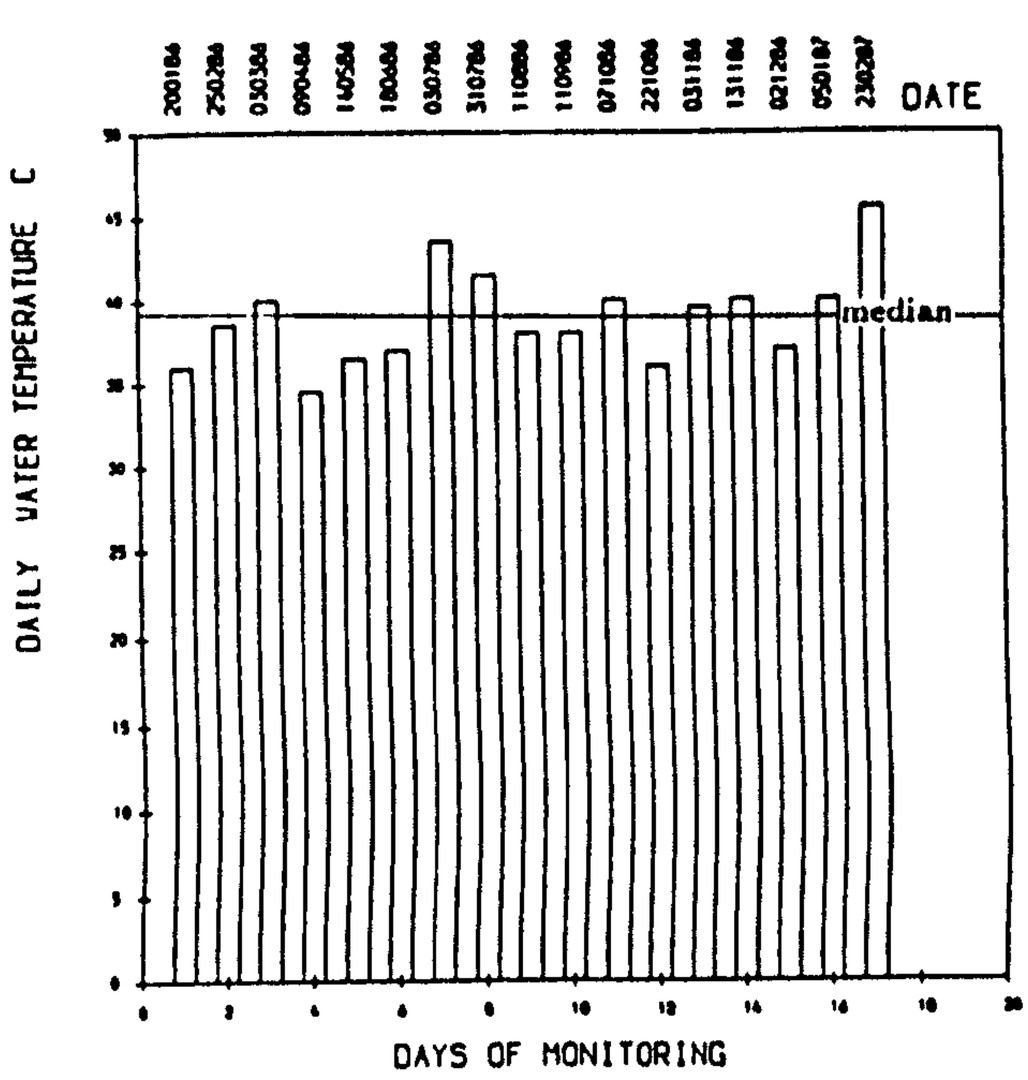


Figure 6.18 — Waste water concentrations in the confectioneries: F

Source: Field monitoring

of 0.0, maximum of 1.2 and a median of 0.35. This indicates that T13 is highly a polluted site in the entire surface water system.

Site T12 which is between T11 and T13 (i.e in between the discharges of E and F) in the Main Drain also had very low DO levels. Although the DO levels are very low in all the three sites, there is slight improvement in T12, because it does not get direct industrial discharges. The DO minimum at T12 was 0.02, while at T11 and T13 it was 0.0 mg/L with the median at 0.42 and 0.35 respectively. The median at T12 is 0.6.

The DO at T12 is kept low by the organic load that enters from T11. Domestic sources may also contribute a little. In addition to the canal being stagnant, there is no time nor the distance for reaeration, because it enters T13 where the factory F discharges its effluents.

Thus the canal water is depleted of its DO along its entire length by the organic waste water discharges of the two confectioneries

SS

Data variability

The data variability at the factory E and F can be seen in table 6.29 and the daily concentrations in figure 6.17 and 6.18. The SS at factory E had a minimum of 46.3 while the maximum reached 589.61. The median fell at 271.0. The SS at factory F had a minimum of 9.36, maximum of 693.1 and median of 181.27. At E the 90^{th} percentile was at 522.84. At F The 90^{th} percentile fell at 642.02. Therefore although the median was low, the percentiles at the factories indicate high concentrations.

The variability in the concentrations are also high. This is reflected in the range and the standard deviation. The factory E had a range of 543.3 and a standard deviation of 159.0. The factory F had a range of 683.74 and a standard deviation at 214.67. The range in SS between E and F is 648.8 mg/L.

Relationships and effects

When the SS of factory E and F was compared with the other industries, the SS was lower than most of the other factories monitored. It is higher than at B2 and C1, but lower than the rest of the factories.

The SS in the factory waste waters is mainly due to the wrappers and cartons or to pieces of the product itself. The SS was lower at F than at the factory E. The higher SS at E may also be due to bad housekeeping in the factory. This was observed on many occasions when, both wrappers and the product remnants were seen on the factory floor. The SS at this factory may be high due to paddy husks which enter the effluent drain, as these were put out to dry on the factory floor very close to the monitoring point. Housekeeping at factory F had a higher standard. The floor was much cleaner with fewer solid wastes in the form of wrappers. The lower SS median of 181.27 may be even due to this reason, or to a cleaner effluent produced by floor washing.

The corresponding SS at the canal locations T11 and T13 (discharge sites of E and F respectively) were also high. This indicates that the SS at E and F contributes to a high SS load of the receiving sites.

Turbidity

Data variability

The data variability in turbidity at the factories E and F can be seen in table 6.29. The turbidity at industry E had a minimum of 20.0 NTU, maximum of 58.0 and a median value of 35.0 The turbidity at F had a minimum value of 5.0 NTU, maximum of 60.5 and median of 36.0. These values indicate that the turbidity is similar in both the waste waters.

The 90^{th} percentiles of 51.2 at F and 56.9 at F indicate similarities. The ranges of 38.0 at E and 55.5 at F with the standard deviations of 9.57 and deviation 16.1 indicate variability, but were lower in comparison to some other pollutants.

Thus the turbidity values at F are very similar to E, but slightly higher. Although the turbidity clearly followed the SS load in E, this is not very clear in factory F.

Relationships and effects

The turbidity at the canal site T13 was higher than at T11, although the SS load was lower from factory F. This site records the highest turbidity values in the entire Main Drain, with the median at 24.0 . The higher turbidity at T13 may be due to the contribution from the factory F. The site T13 is also closer to the tidal river which

may cause turbulence at certain times of the year. As the site is at the confluence with the San Sebastian canal, it in turn discharges turbid waters to the canal.

Conductivity

Data variability

The spread of conductivity data are seen in table 6.29. The conductivity at E recorded a minimum of 125.0 μmhos/cm and a maximum of 435.0. The median was 270.0. The conductivity at F recorded a minimum of 160.0, maximum of 1255.0 and a median of 610.0. Thus the conductivity is higher at F. The 90^{th} percentile at E was 379.0, and 875.0 at F which again indicates higher concentrations at the factory F.

The range at E was 310.0 and the standard deviation, 69.51. The range was higher at F with 1095.0. The standard deviation was 263.92. This indicates higher variability at F. The range in the conductivity between E and F was 1120.0, which indicates the high variability between the factories.

Relationships and effects

The conductivity values of E and F, when compared with the other industries were some of the lowest. This may reflect the low use of salts in the confectionery production process. For example when compared with G1 (meat cutting and processing section) the median value fell at 2150.0. This was much higher than at E and F. The conductivity values at the canal receiving sites T11 and T13, were higher than the factory values at E and F. The minimum of 201.0, maximum of 665.0 and the median of 415.3 at T11 was lower than at T13 which had a minimum of 390.0, maximum of 1660.0, and a median of 590.0. The median at T13 was much higher with 1363.0 at T13 than at F which had 640.0. This was similar at T11. Therefore the conductivity at the canal sites at T11 and T13 was higher than the corresponding factory values. This indicates that these industries are not responsible for the high conductivity of the Main Drain waters at these sites. The values at T13 were much higher and this could possibly be due to the tidal effects.

pH

Data variability

The table 6.29 gives the pH data for the factories E and F, and the concentrations in figures 6.17 and 6.18.

The minimum pH recorded at E was 6.1, the maximum, 9.3 and the median, 7.25. The pH at F had a minimum of 6.2, a maximum of 10.2 and the median at 7.9. The pH of E and F were very similar and ranged from slightly acidic to strongly alkaline values.

The 90^{th} percentile at E fell at 9.14. The range was 3.2 and the standard deviation 0.99. The 90^{th} percentile at F was 9.72, the range, 4.0 and the standard deviation fell at 1.07. Although in absolute terms the variability is low, the range in values from acidity to alkalinity indicates the variable nature of the waste waters.

Relationships and effects

As mentioned earlier, the pH of E and F were very similar and ranged from slightly acidic to alkaline values. The acidicity in the waste may be due to the high organic content. The waste on standing becomes acidic. The alkalinity of the waste water may be due to the detergents used in washing and cleaning the floor and the utensils (vats) which contain high phosphates. The canal sites at T11 and T13 had slightly alkaline values (At T13 the pH values were slightly higher). Thus the effect of the industry waste on pH of the Main Drain is variable, however the general effect of the canal receiving points is a neutralising effect on the industrial waste water.

Water temperature

Data variability

The variability in the data at E and F for water temperature can be seen in table 6.29 and the daily concentrations in figures 6.17 and 6.18. The water temperatures at E had a minimum of 30 °C and a maximum of 40.5. The median fell at 31 °C. The water temperature recorded at F had a minimum of 34.5, a maximum of 45.5 and the median at 38.5. Thus the values at F were higher.

The 90^{th} percentile at E was 36.1, range 10.5 and the standard deviation 2.6. The 90^{th} percentile at F was 43.9. The range was 11.0 and the standard deviation was 2.8. The percentiles indicate higher temperatures at F. The range in the temperature was high in both the factories.

Relationships and effects

At factory E the water temperatures were near normal, except on one occasion on 3.3.86 when the water temperature reached 40.5 °C. In factory F, higher water temperatures were recorded more regularly during the monitoring period. The boiling syrup drain was located closer to the monitoring point thus the temperature was very high. Further, the lower water temperature at E may also be due to the fact that the vats are washed using hot water only in the evenings when production stops. Therefore the boiling effluents did not enter the drain during sampling, other than on rare occasions. (same vat was used for different types of candy toffees produced successively).

The water temperature at the receiving site T11, was close to the daily maximum air temperature with the median at 31.0. It was higher than at T12, which indicates that the warmer industrial waste waters from factory E had increased the canal's water temperature on certain days. The water temperature at T13 was the highest recorded for the Main Drain. It had a minimum of 32 °C, a maximum of 40 °C, and the median at 36.15. This indicates that the factory effluents from F was a contributory factor in increasing the water temperature at the site.

Total P

Data variability

The data variability at E and F for total P can be seen in the table 6.29. The total P level at E gave a minimum of 0.9, maximum of 9.15 and a median of 3.2. The total P levels at F had a minimum of 1.0 mg/L, maximum of 8.75 and a median value of 3.7. This indicates that the total P at the factory F was higher. The percentile was higher at E. But the standard deviation was lower. The range was comparatively similar. Thus the variability of the data was not very great.

Relationships and effects

The total P levels at the confectioneries E and F were comparatively lower than in the other factories. But the levels were slightly higher than the receiving sites especially at F. The phosphates in the industrial waste waters at E and F may be from the detergents that are used for cleaning purposes, rather than from the production process itself.

When the total P values along the Main Drain at sites T11, T12, and T13 are considered, there is not much difference in the phosphate levels among these sites although the industrial discharge sites at T11 and T13 had slightly higher values. This indicates that phosphate input into the canal at these sites is not purely industrial. Domestic sources may have contributed to the total P at all these sites. The very close median values of 1.25, 1.2 and 2.02 mg/L at T11, T12 and T13 explains this situation. The difference in the median between T12 and T13 was only 0.82, while the difference between T11 and T12 was only 0.05 mg/L.

Total N

Data variability

The table 6.29 indicates the data variability of total N at E and F.

The total N level at factory sites E recorded a minimum of 0.36 mg/L. The maximum was 16.84 and the median 1.78. The total N at factory F had a minimum of 0.40, maximum of 19.36 and the median at 3.5. Thus the difference in the values at between the factories is marginal. This was also reflected in the range, the percentiles and the standard deviation.

Relationships and effects

The total N levels at the confectioneries E and F were one of the lowest among the industrial total N levels. As not many nitrogeneous materials are used in the production process (other than the milk and butter) the contribution to total N in the waste waters may be from the domestic uses in the factories such as from the toilets.

The contributions from the factories into the receiving sites appear marginal. The total N at the receiving canal site T11 had a higher median value of 7.9. The minimum value of 2.86 was also higher than the factory site E. This indicates that although the maximum total N value of 16.84 was recorded at E, the overall total N level was higher in the canal site than in the discharging factory.

The total N values at T13 on the canal gave a minimum of 2.38, maximum of 12.75 and a median value of 9.03 mg/L. The canal nitrogen level at T13 was obviously

higher than at the factory F. There was a wide fluctuation in the total N level at factory F with the range recording a value of 18.96 mg/L, (from a minimum of 0.4 to 19.30 mg/L) which indicated that the release of total N into the canal from the industry was variable. This situation was not observed in the canal. The total N level in the canal sites T11, T12, and T13 had very close median values of 7.9, 8.05 and 9.03 respectively. The nitrogen level at T12, which was not an industrial discharge site, had a higher median than the site T11 which had industrial discharges from E. Similarly the median at T13 with a value of 9.03, was only 0.98 mg/L higher than at T12. Therefore the total N level in the canal, although slightly higher at T13, than in the other two sites, also had higher total N levels at T12. Hence it is possible that it received its nitrogen load from the congested residential area and shanties located near the site. Discreet industrial discharges from other industries into this site may be another cause for high total N levels at T12. The higher levels of total N recorded at T13 may be due to the cumulative effect of total N at this site, which is at the receiving end of the canal. The stagnation of the canal, and blockage due to the culvert, may also contribute to the higher total N levels at this point. There were aquatic plants in all the sites in the Main Drain, which indicated high nutrient loading.

Sulphate

Data variability

The data variability of sulphates at E and F is shown in table 6.29. The sulphate levels at factory E had a minimum of 27.0 mg/L, maximum of 337.0 and a median value of 113.6. The sulphate at F was higher with a minimum value of 41.2, maximum of 1267.3 and a median of 115.3. Although the median values are close, the variability is high between the factories. The variability is higher at F as reflected in the range with a value of 1226.1 and a standard deviation 283.96.

The corresponding sulphate at the canal receiving site T11, which gets discharges from factory E were higher (with minimum of 67.0, maximum of 312.3 and median of 146.5) The close medians at E and T11 indicate a good relationship. Thus E may contribute sulphates to the canal. It is also possible that the background sulphates ares high at T11.

But the concentrations at T13 were higher, which is the discharge site of F. The median at T13 was 405.3. Therefore the canal site at T13 had higher values than the factory at F. Although the sulphate at F ranged widely with a value of 1226.1, the median was lower than the canal site. Thus the higher sulphate in the canal originate from sources other than the industrial discharge of F.

6.7.2 Meat processing effluents

Two meat processing industries were monitored. A3, a meat processing industry, had a frequency of 15 monitoring days during the research period. It was monitored monthly except in October 1986, when the monitoring was done twice a month. Monitoring was carried out in the morning. No total N monitoring was done in January, February and November 1986. This meat processing industry directly discharged its waste waters into the Beira lake at the site U02. The sample collected was the final effluent from the drain immediately outside the processing section but within the factory premises.

The factory G was monitored at two points. G1, the meat cutting and processing section, and G2, the meat packing section. Samples were collected from the effluent drains within the respective production areas. The effluents enter the Kelani ganga at Mutwal. This factory was monitored six times during the period of research. The receiving site for G was not monitored.

COD, BOD and DO

The data variability for the COD and the BOD in the meat industries can be seen in the table 6.30 and the daily concentrations at A3, G1 and G2 in figures 6.19, 6.20 and 6.21 respectively.

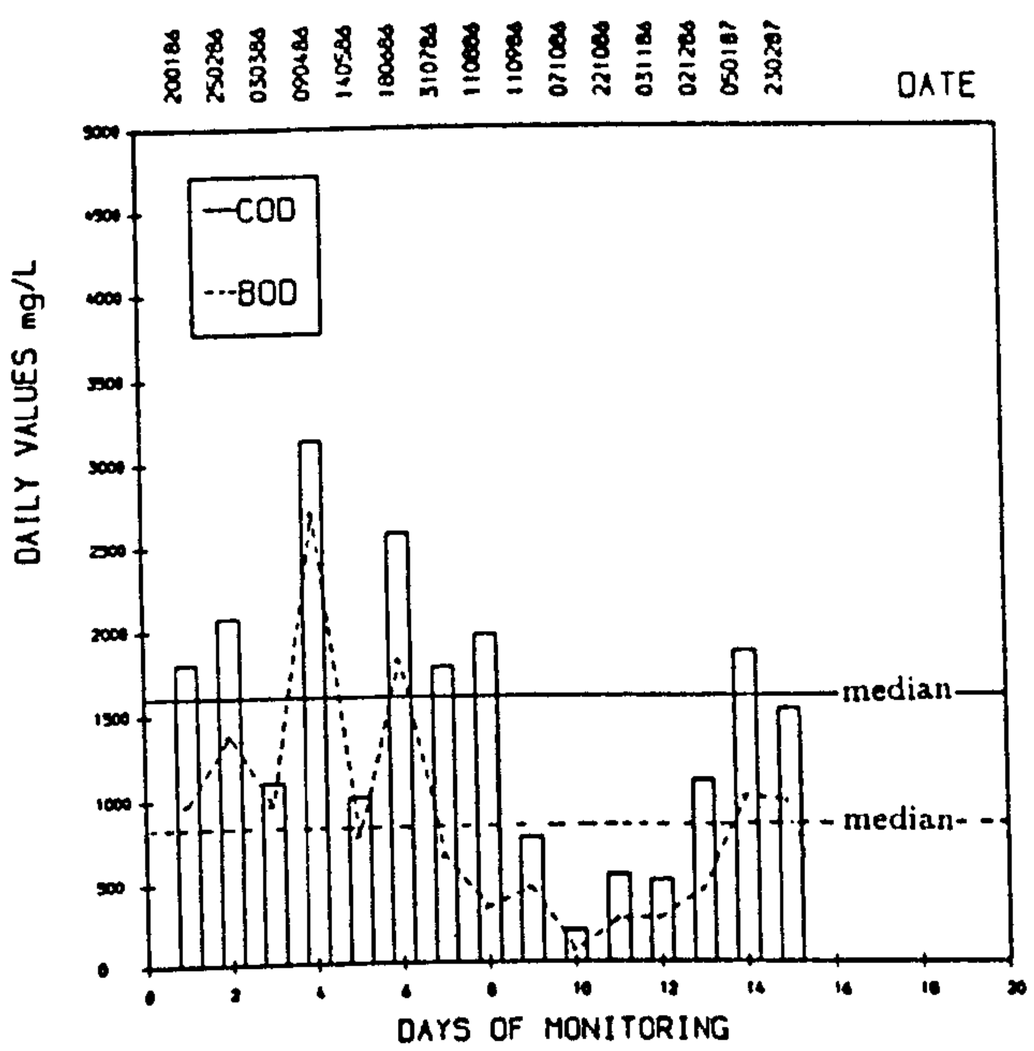
The COD at A3 gave a minimum of 196.0, maximum of 3136.0 and a median value of 1520.0. The 90^{th} percentile was 2803.0. This indicated very high concentrations. The data variability was high and is reflected in a range of 2940.0 and a standard deviation of 820.4.

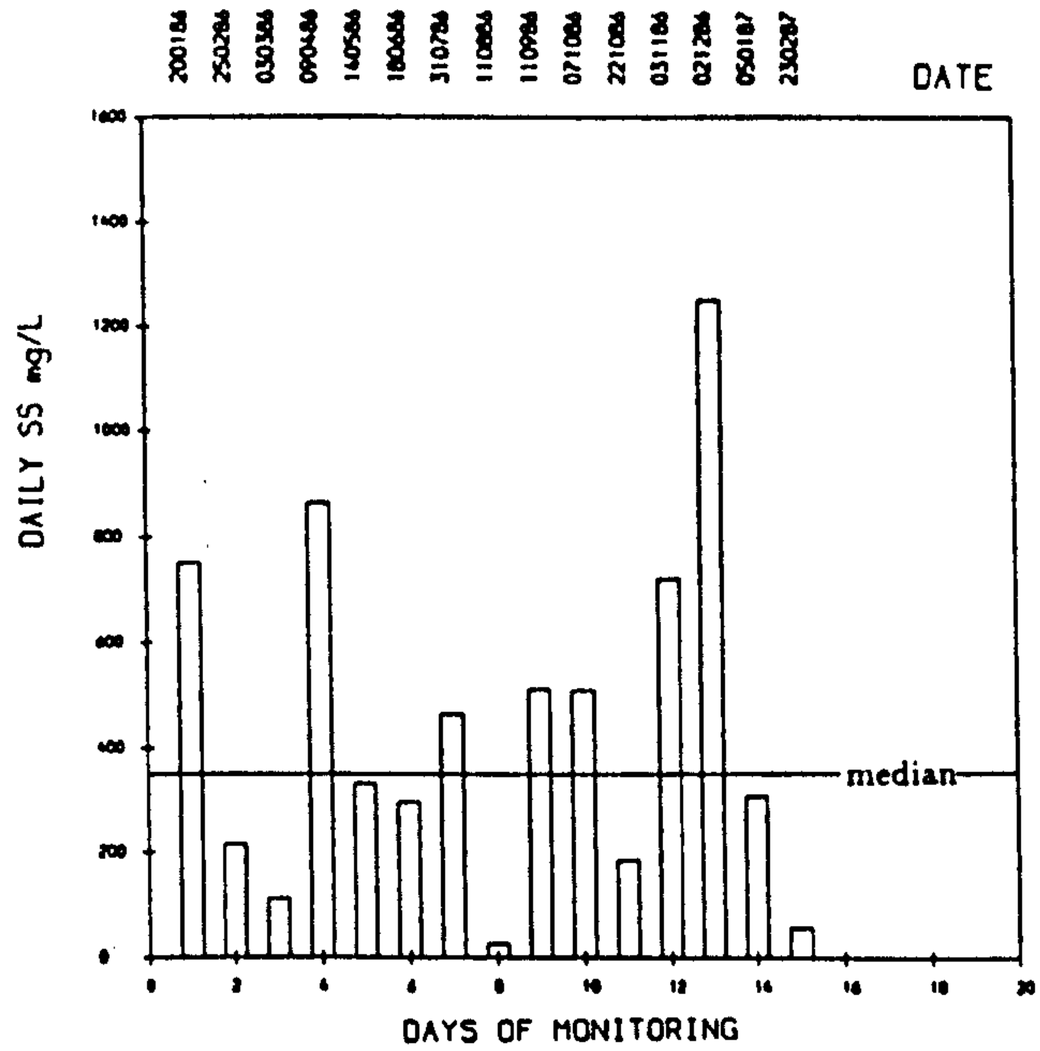
The COD at G1 was higher than at G2, although the latter also had high con-

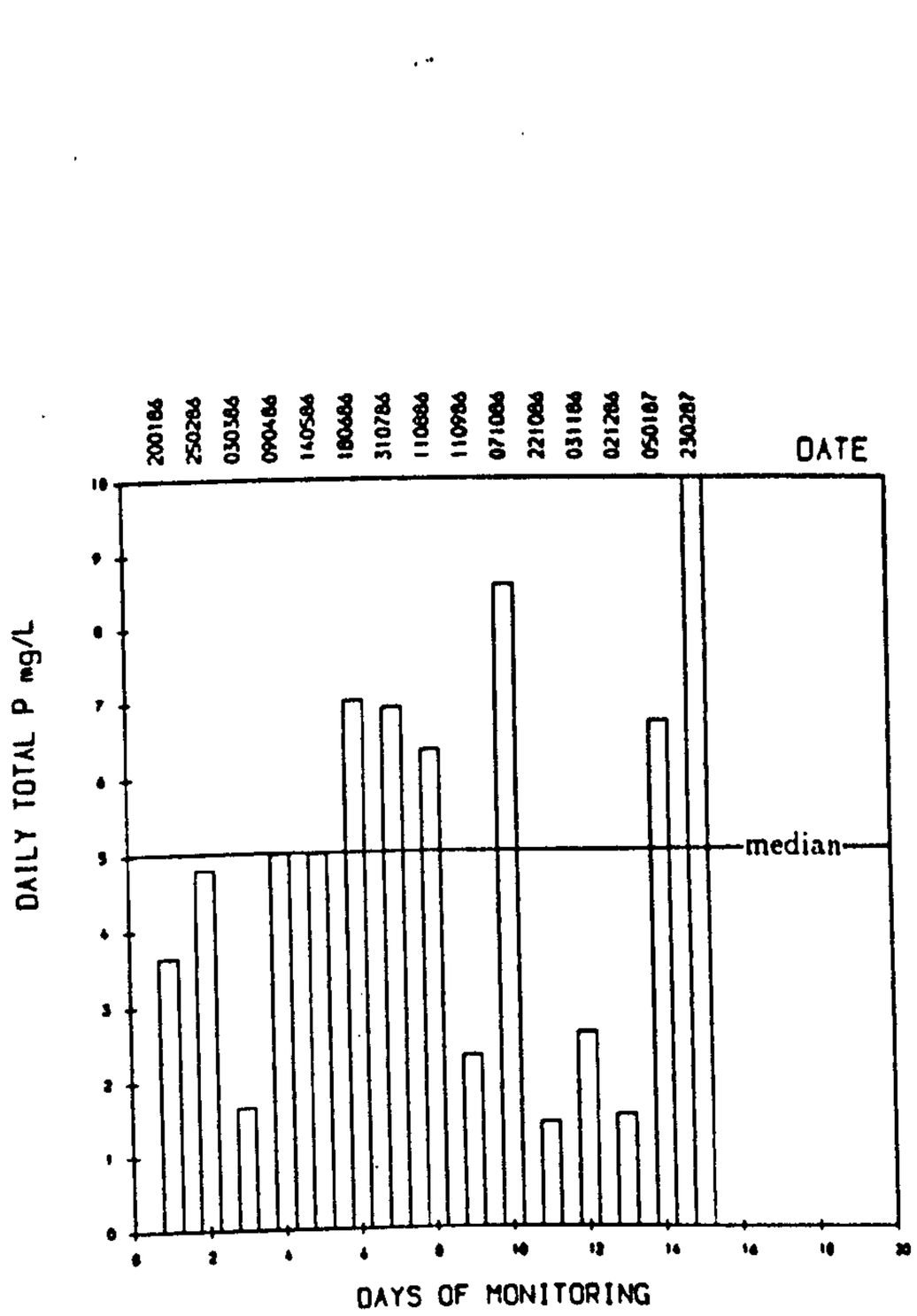
Site	Mean	S.D.	Ran.	Min.	Max.	Med.	75%	90%	Fact.
DO	3.5	2.08	5.60	0.10	5.7	4.6	5.6	5.64	A3
DO	1.31	2.3	5.9	0.1	6.0	0.45	2.02	-	G1
DO	5.0	0.52	1.4	4.6	6.0	4.8	5.3	-	G2
COD	1460.0	820.4	2940.0	169.0	3136.0	1520.0	1963.0	2803.0	A3
COD	2223.3	881.79	2479.0	801.0	3280.0	2296.0	2925.0	-	G1
COD	986.6	423.02	930.0	621.0	1551.0	780.0	1512.7	-	G2
BOD	875.2	687.29	2629.0	76.0	2705.0	775.0	1005.0	2174.6	A3
BOD	1579.0	7424.4	2000.0	710.0	2710.0	1525.0	2177.5	-	G1
BOD	581.16	230.3	580.0	401.0	981.0	471.5	797.2	-	G2
SS	439.0	339.0	1221.7	28.3	1250.0	331.07	720.0	1018.0	A3
SS	584.73	502.07	1290.4	96.3	1386.7	453.9	1049.2	-	G1
SS	405.03	128.49	330.5	277.3	607.8	534.6	534.6	-	G2
TB	39.73	15.21	48.0	10.0	58.0	38.5	53.5	57.1	A3
TB	42.61	19.09	50.5	20.0	70.5	39.8	59.62	-	G1
TB	40.4	7.88	20.4	31.6	52.6	38.0	49.0	-	G2
CT	1362.2	852.97	2775.0	480.0	3255.0	1130.0	1850.0	3102.0	A3
CT	2173.33	862.87	2240.0	910.0	3150.0	2150.0	3037.5	-	G1
CT	1176.6	505.4	1500.0	400.0	1900.0	1275.0	1487.5	-	G2
pH	8.3	0.68	2.55	6.5	9.05	8.35	8.9	9.02	A3
pH	7.75	1.07	2.30	6.7	9.0	7.70	8.81	-	G1
pH	8.41	0.85	2.2	6.9	9.1	8.75	9.02	-	G2
W T	31.7	1.22	3.5	30.0	33.5	32.0	33.0	33.2	A3
W T	23.3	0.4	1.0	23.0	24.0	23.25	23.62	-	G1
W T	27.41	0.58	1.5	27.0	28.5	27.5	27.7	-	G2
T P	4.89	2.68	8.6	1.4	10.0	5.0	6.9	9.13	A3
T P	6.3	2.9	8.4	3.6	12.0	5.62	7.87	-	G1
T P	4.66	2.32	7.05	1.35	8.4	4.67	6.07	-	G2
T N	117.84	86.63	270.4	15.6	286.0	105.4	179.66	271.21	A3
T N	235.0	77.90	203.7	97.6	301.3	271.18	286.37	-	G1
T N	32.9	39.57	101.25	9.35	110.6	13.7	56.67	-	G2
SULF	52.57	36.34	107.0	16.6	123.6	37.3	86.3	106.6	A3
SULF	40.05	16.25	36.0	16.7	52.7	45.4	51.85	-	G1
SULF	23.2	10.17	23.3	12.7	37.0	21.5	33.5	-	G2

Source: Field monitoring

Table 6.30 — Meat processing effluents







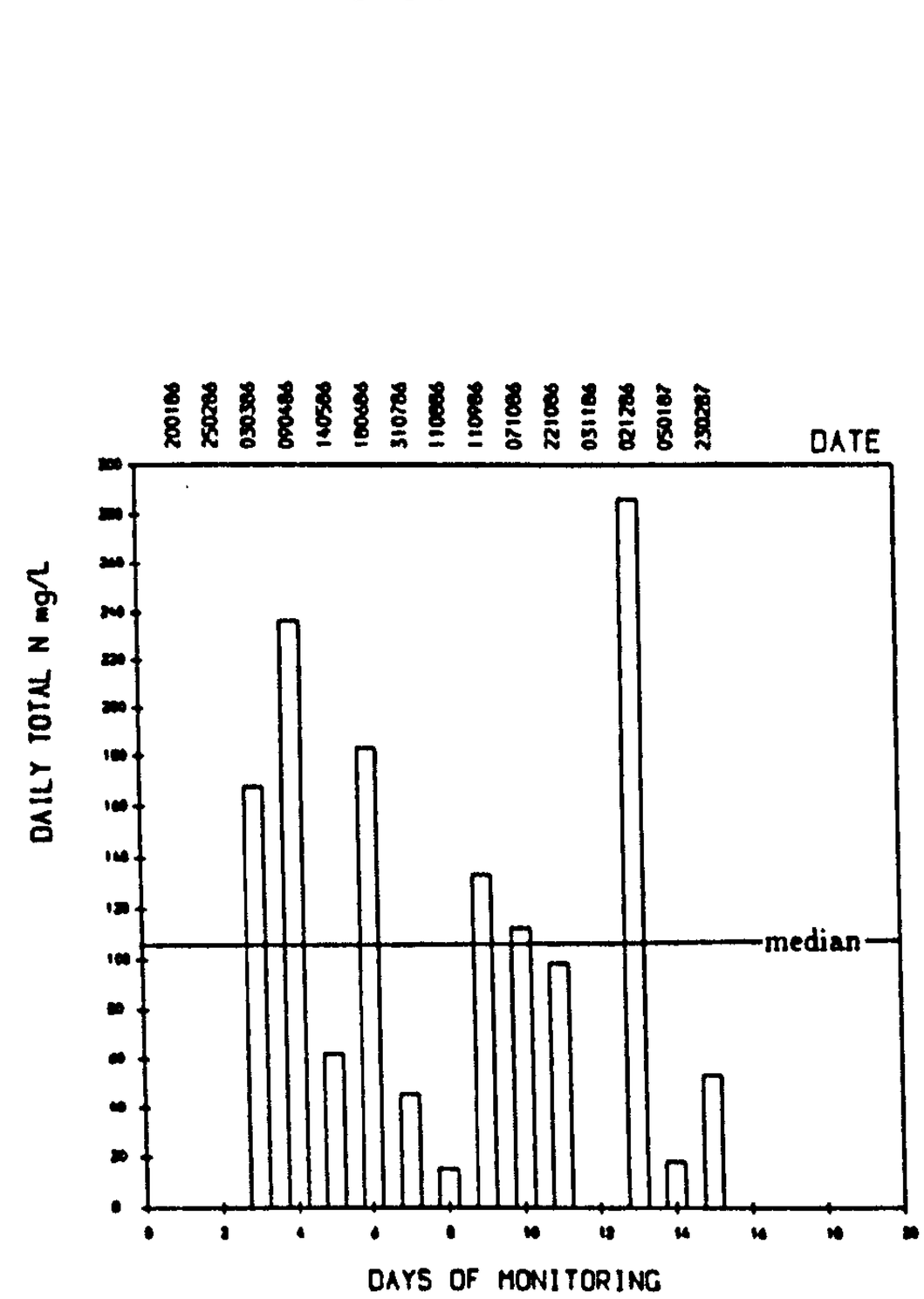


Figure 6.19 — Waste water concentrations in the meat processing factory : A3

Source: Field monitoring

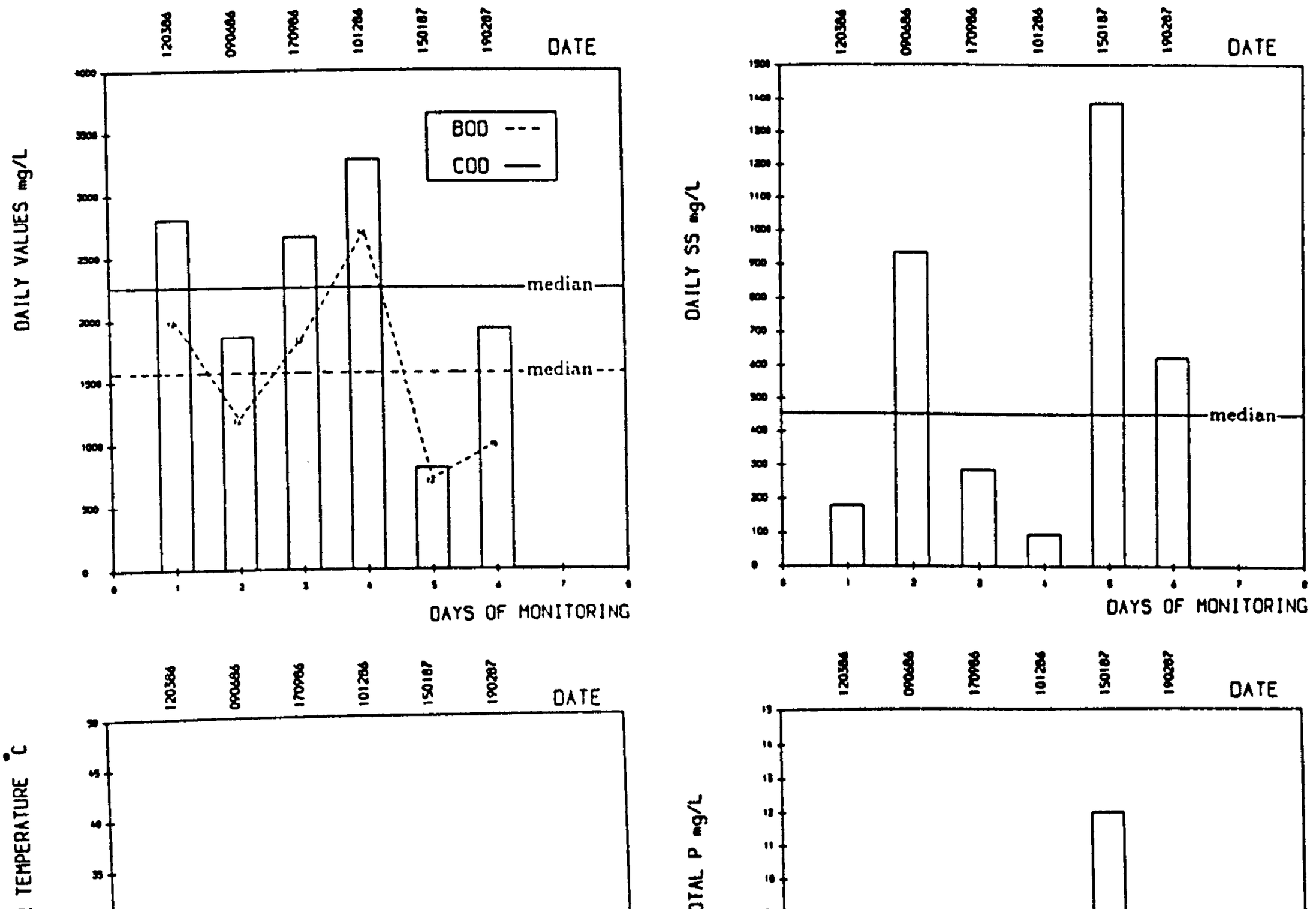
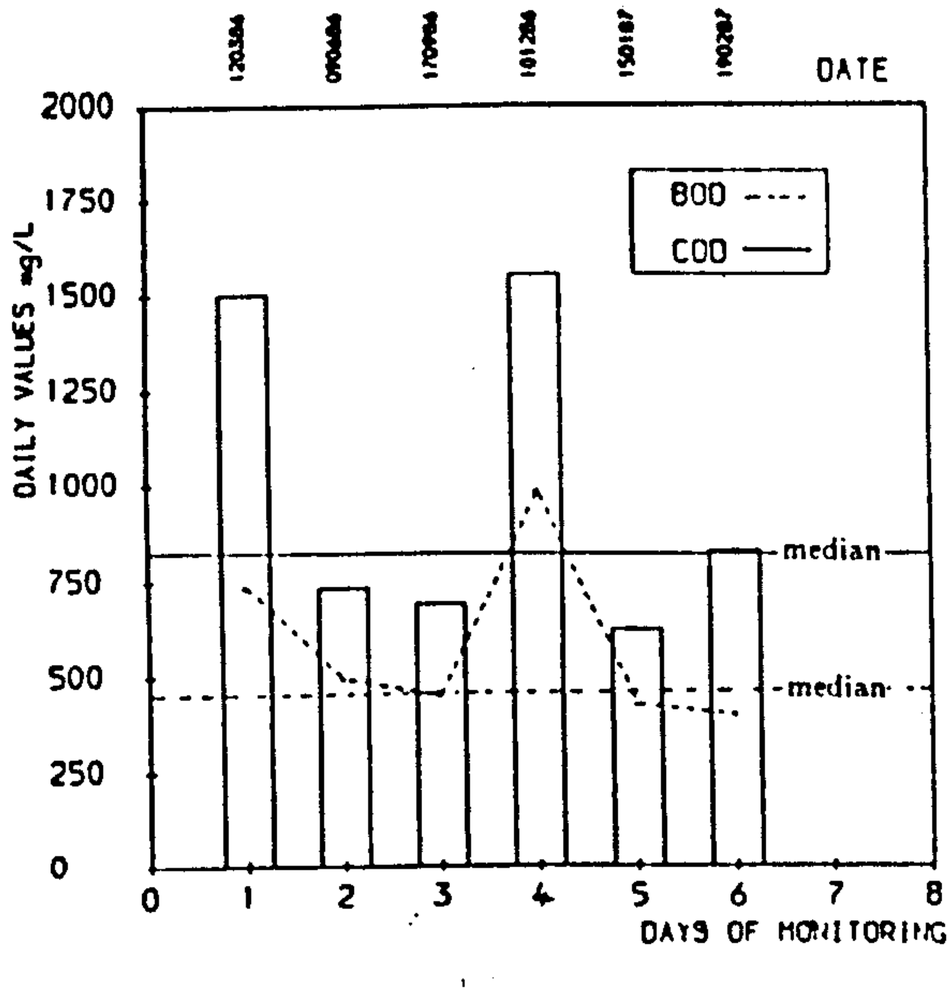
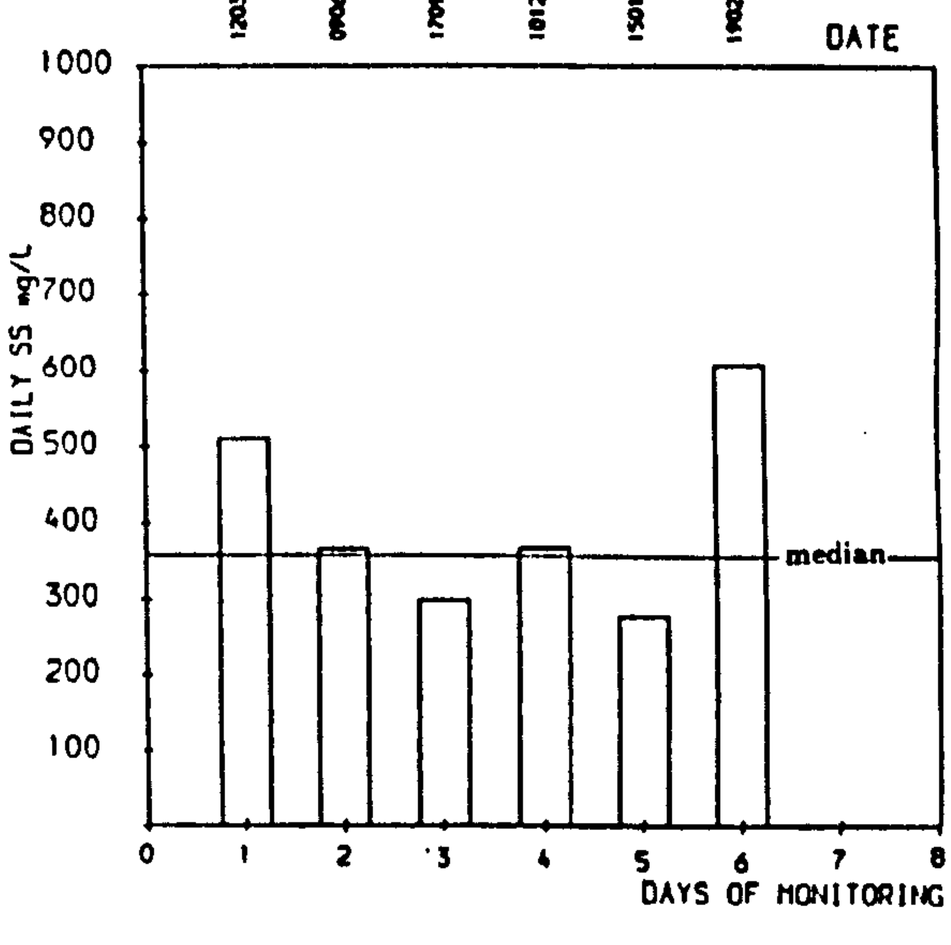
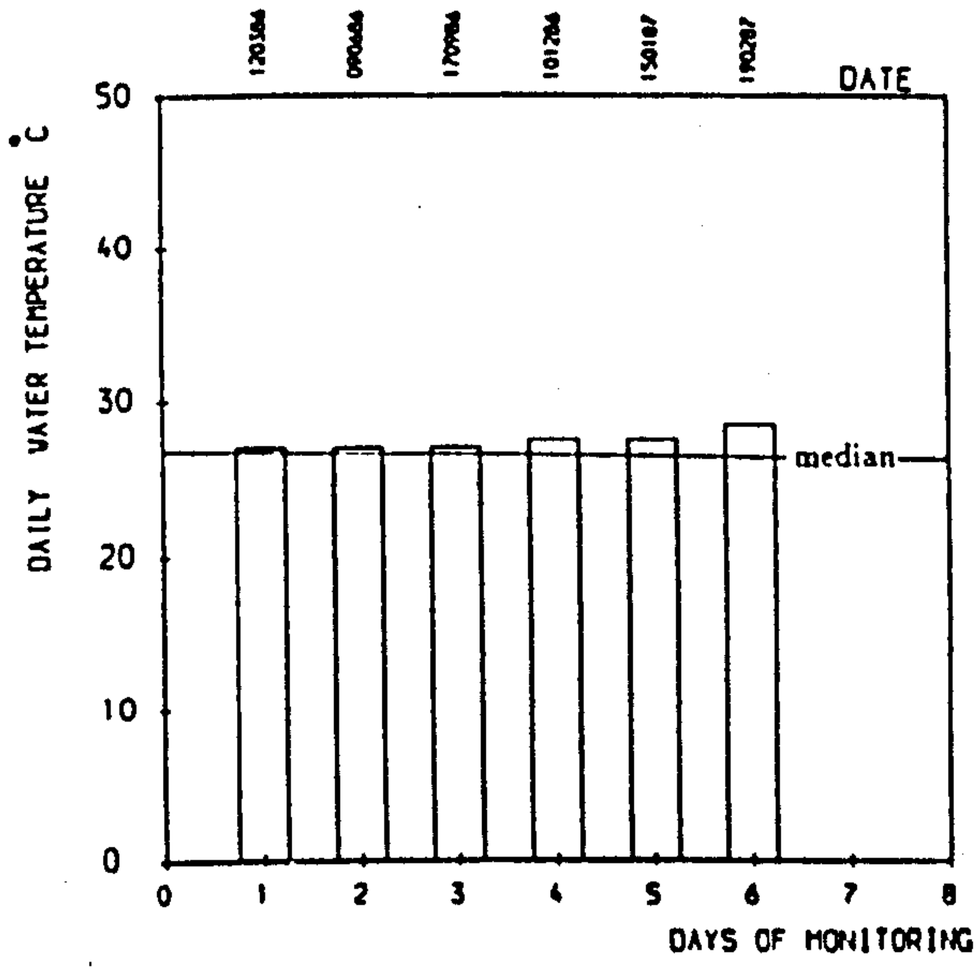


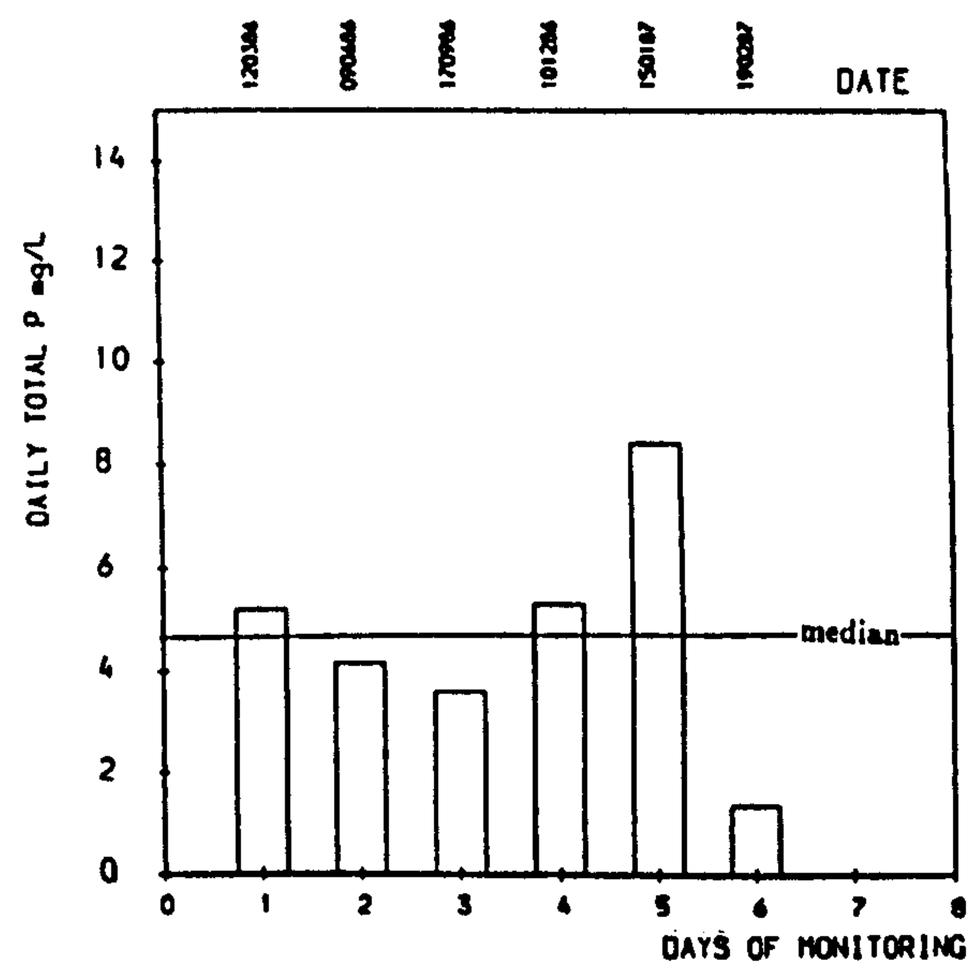
Figure 6.20 — Waste water concentrations in the meat processing factory: G1

Source: Field monitoring









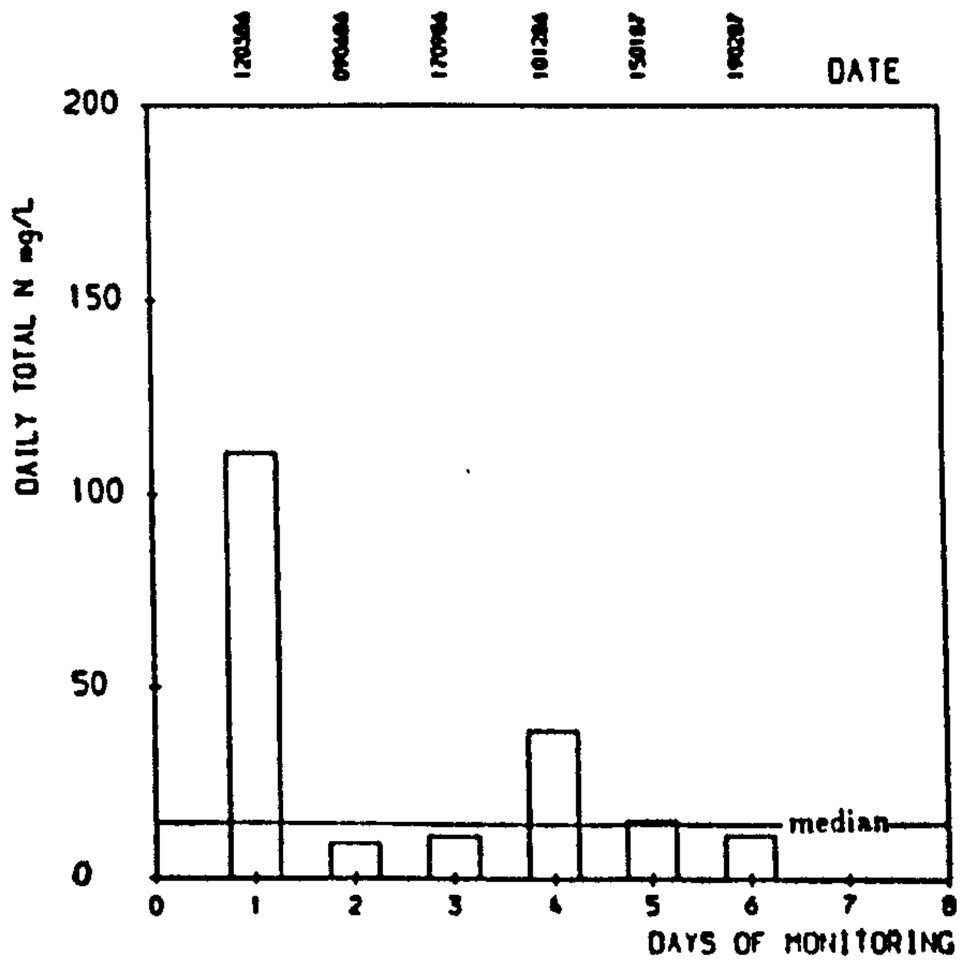


Figure 6.21 — Waste water concentrations in the meat processing factory: G2

Source: Field monitoring

centrations. The COD at G1 had a minimum of 801.0, maximum of 3280.0 and the median at 2296.0. The 75th percentile was at 2925.0. These indicated very high concentrations. The high range of 2479.0 and the standard deviation of 881.79 indicated the variability in the data.

The BOD at A3 was lower than at G1. The BOD at A3 had a minimum of 76.0, maximum of 2705.0 and a median value of 775.0. The 90th percentile was 2174.6. These indicate high concentrations. Similarly the range with a high value of 2629.0 and the standard deviation at 687.29 indicate variability in the data.

The BOD which was higher at G1 had a minimum of 710.0, maximum of 2710.0 and a median of 1525.0. The 75th percentile was 2177.5. High concentrations are indicated by these values. The variable nature of the effluents is evident in the high range and the standard deviation.

The range in BOD in the meat industry was 2634.0, with the minimum value of 76.0 at A3 and the maximum of 2710.0 at G1.

Relationships and effects

The COD and BOD are higher at A3 and G1, than at G2. None of these wastes are treated. It is understandable that higher COD and BOD are recorded at A3 and G1 since these two industries have higher organic wastes in the form of meat cuts (remnants) and blood in the effluent drain, while G2 was a comparatively less polluting source, since it involves only packing. The effluent BOD and COD at G2 mainly arise from the floor, table washing and cleaning operations. The BOD and the COD are reflected in the DO of the industries. The latter in turn reflects the high organic strength of the effluents.

The high organic discharges of A3 is reflected in the very low DO of the receiving site U02. The DO median at U02 in the lake, was 1.3. The maximum of 1.8 and minimum of 0.9 at U02 also indicate the very low DO content in the receiving site. In addition to A3, the creamery (A5) and carbon dioxide (A4) plants also discharge their waste waters at this point. In addition to this a culvert empties untreated sewage at the same site. Therefore the lower DO at U02 is a cumulative effect of the industrial and municipal sources.

The waste water of G1 and G2 may have the same effect on the river Kelani. The receiving site on the river was not monitored since it was outside the research area and was not directly relevant (The factory sites G1 and G2 were monitored to supplement the industrial waste water monitoring in order to assess the strength of the food processing wastes as not many food industries were found along the canal). Although the effect on the receiving river may be less as the river has a larger volume of water for the dilution of the wastes, the continued discharge at the tidal receiving site may have a cumulative effect.

SS

Data variability

The data variability at A3 is given in table 6.30 and the daily concentrations in in figure 6.19.

The SS at the factory A3 gave a minimum value of 28.3 mg/L, maximum of 1250.0 and the median of 331.07. The 90th percentile was 1018.0 (the 75th percentile was 720.0). The strength of the wastes is evident from the median and the percentiles. The standard deviation had a value of 339.0 and a range of 1221.7. This indicates the wide variation in the data as seen in the range and the standard deviation.

The data variation at G1 and G2 also can be seen in table 12.2. and the daily concentrations in figure 6.2 and 6.3.

The SS at G1 had a minimum of 96.3, maximum of 1386.7 and a median value of 453.9. G2 sampling point had a minimum SS of 277.3, maximum of 607.8 and a median of 368.05. Thus of the two sections G1, had stronger waste waters. Both the median and the maximum were higher. This is also evident in the percentiles. The 75th percentile was 1049.2 at G1, but lower at G2.

The standard deviation was 502.07 and the range 1290.4, at G1, whilst at G2 it was 128.49 with a range of 330.5. The variability of the data is thus higher at G1 as seen both in the standard deviation and the range.

Relationships and effects

It is difficult to assess the contribution of G1 and G2 to the receiving river as it

was not monitored at this point. But the load from G1 appears to be higher which may contribute to the receiving river. The SS load was comparatively lower at G2, since not much SS is generated in this section.

At A3 the SS varied from 28.3 to 1250.0, which indicated that the effect of the different processes of production has a bearing on the SS of the final effluent. The monitored drain had effluent from all the processes of production. When the contribution of A3 into the receiving site U02 is considered, the SS median at A3 was 331.07. The SS at U02 was lower than the SS at A3. The maximum recorded at the factory A3 was 1250.0, while it was 591.3 at U02. This indicates that the factory site A3 had higher SS, and therefore contributes a high SS load to site U02.

The meat industry as a group had high SS when compared to the other industries.

Turbidity

Data variability

The distribution of data can be seen in table 6.30 for turbidity.

The turbidity at A3 had a minimum of 10.0, maximum of 58.0 and a median value of 38.5. The 90^{th} percentile was at 57.1 (the 75^{th} percentile was at 53.5). The range was 48.0 and the standard deviation 15.21. Thus the waters were fairly turbid and the data was ranging widely.

The turbidity was the highest at G1, while at G2 and A3, the median values were close with 38.0 and 38.5 respectively. The lowest value of 31.6 was at G2. This indicated a higher background level at G1. The turbidity ranged from 10.0 at A3 to 70.5 at G1.

Relationships and effects

The turbidity values closely followed the SS. When there is an increase in the SS, the turbidity values also increased. But it did not necessarily fluctuate proportionally with SS.

As mentioned earlier, the contribution of G1 and G2 is difficult to be assessed. As the data indicate G1 had a higher load than A3, the impact on the receiving site will probably be detrimental.

With regard to A3, the turbidity median was higher with a value of 38.5 than at U02. Although the turbidity was also high at U02 with the median at 30.0 NTU, A3 contributed an increase to the turbidity.

Conductivity

Data variability

The data variability in the factories A3, G1 and G2 can be seen in table 6.30. The conductivity in the meat processing industry varied widely from a minimum of 400.0 μmhos/cm at G2, to a maximum of 3255.0 at A3. At A3 the minimum conductivity recorded was 480.0, and the median 1130.0. This indicated high conductivity values. This was further evident in the percentiles. The 90^{th} percentile fell at 3102.0 (75^{th} percentile was 1850.0). The range and the standard deviation both indicated high variability. The range at A3 was 2775.0 and the standard deviation had a value of 852.97.

High values were recorded at G1 too. The median was 2150.0, which was the highest among this group and the 75^{th} percentile fell at 3037.5. The range of 2240.0 and the standard deviation of 862.87 indicated the variable nature of this group of industries. At G2 the values were lower, but indicated the same trend as A3 and G1.

Relationships and effects

The conductivity was higher at A3 and G1 because of the nature of the processing that was being carried out there. Salts are used in the processing section for various meat preparation, which makes the water more conductive.

The effect on the lake and the river will be detrimental. The conductivity at A3 was much higher than the receiving lake site. The latter had a median of 700.0 while the former had a median of 1130.0. The effect on the receiving river may be minimal because this stretch of the river comes under the tidal influence, thus the water may naturally have high conductivity.

pH

Data variability

Data variability for A3, G1 and G2 can be seen in table 6.30.

The pH of the factory waste water in the meat industrial group depicted both

acidic and neutral values. The minimum at A3 was 6.5, and the maximum fell at 9.05 with the median at 8.35. The 90th percentile was 9.02 (75th percentile at 8.9). The range was 2.55 and the standard deviation 0.68 at A3. Both G1 and G2 had very similar values. The range between the factories was 2.55. Thus the variability of the pH data is lower than for the other pollutants.

Relationships and effects

Although the median indicated slightly alkaline values at the factories the maximum values indicate alkalinity of the waste waters. The high pH values at A3, G1 and G2 may be due to the cleaning operations of the factories in which detergents are used. Thus the waste waters are alkaline, although the production process itself would have neutral wastes.The pH in this group of factories did not fall below 6.5. This indicated that the wastes waters were not very acidic and thus had not turned putrescible.

The pH at U02 was close to (fairly represented) the pH of factory A3. But the minimum was lower with 6.2 at U02, which indicated that these wastes may result in bad odour in the lake site. The effect on the river however may be minimal as the neutralising capacity of the receiving water may be high.

Water temperature

Data variability

The data variability at A3, G1 and G2 can be seen in table 6.30. and the concentrations in figures 6.20 and 6.21 for G1 and G2 respectively.

The water temperature in the meat industry differed widely. At A3 the temperatures were higher than at G1 and G2. The minimum at A3 was 30°C, the maximum 33.5 and the median 32.0. The 90th percentile was at 33.2 (75th percentile fell at 33.0). The median at G1 and G2 were 23.2 and 27.5, which indicate lower temperatures.

The range at A3 was higher than at G1 and G2. The range at A3 was 3.5 and the standard deviation 1.22. But when compared to the other pollutants the variability is low within the factories, but the variability is high between the factories with 10.5 °C.

Relationships and effects

The water temperatures were lower at G1 amd G2 as mentioned earlier. The temperatures were reflective of the production processes. Where chilling was necessary such as in the cutting section G1, the water temperatures remained low. At A3, where the waste water was collected outside the factory the temperature may have been influenced by other water streams and the air temperature.

The meat industry as a group had some of the lowest water temperature values recorded. The water temperature at site the U02 was near the daily maximum air temperature. The median water temperature was 31.0 while the maximum reached was 33.0. At A3 the median was 32.0 and maximum 33.5. Therefore A3 would have minimal influence on the water temperature of the lake at U02. The discharges of both G1 and G2 do not appear to affect the receiving site on the river.

Total P

Data variability

The data variability in total P at A3, G1 and G2 is shown in table 6.30 and the daily concentrations in figures 6.19, 6.20 and 6.21 respectively.

The Total P level in the meat industry ranged from a minimum of 1.4 mg/L at A3 to a maximum of 12.0 at G1. At factory A3, the minimum value recorded was 1.4, maximum 10.0, and the median, 5.0. As far as the median is concerned all the three factories have very similar values. The percentiles also confirm this. At A3, the 90th percentile was 9.13.

At A3, the range was 8.6 and the standard deviation 2.68. G1 and G2 also had very similar values. The range in phosphates between the industries was 10.6 which is wide.

Relationships and effects

The total P value for this industrial group was one of the highest in the monitored industries. The highest total P values was recorded at G1 with a value of 12.0. The median total P was high in all the three factory sites. Higher total P in this industrial group may be due to the organic nature of the product itself. In addition to this, detergents used for cleaning and washing purposes may contribute to higher

phosphates in the effluent samples. The total P at the receiving site was lower than at A3, although a higher maximum was recorded at U02 with a phosphate value of 11.35. The maximum at A3 was 10.0. Therefore A3 contributed a higher total P load into the receiving site U02. This site had a luxuriant growth of *Eichornia crassipes* and other water plants which indicate a high loading of nutrients. The industrial sites G1 and G2 may also have similar effects on the receiving site. As the river is a larger water body the impact may be smaller.

Total N

Data variability

The variability in the data at A3, G1 and G2 is recorded in table 6.30 and the daily concentrations in figures 6.19, 6.20 and 6.21 respectively.

The total N levels in the meat industries was the highest recorded among the industrial groups monitored. The total N level at G1 was the highest in this industrial group with the minimum recorded value of 97.6, maximum of 301.3 and the median at 271.18. The 75^{th} percentile was 286.37. At A3 the median was lower with 105.4, although the maximum was similar. The total N levels were lower at G2 with a median of 13.7 although the maximum had reached 110.6. Thus the concentrations were high but varied. This was reflected both in the percentiles and the range The range in the total N between the industries was high with a value of 291.95, with the minimum at G2 and the maximum at G1.

Relationships and effects

The high total N content in the waste waters in these factories is due to the nitrogeneous nature of the product. Meats contain a higher percentage of nitrogen than any other food industry monitored. The lower nitrogen content in G2 is due to the nature of factory operation in this section. Since only packing is done, not much nitrogeneous waste matter enters the waste water drains.

The total N at the receiving site U02 was the highest among the sites monitored in the surface waters. The median was 39.2, maximum 72.03 and the minimum was 10.6. The total N at A3 was much higher with the median at 105.4 and a maximum recorded value of 286.0 mg/L. Thus A3 releases a very large amount of nitrogeneous matter into the receiving site U02. This high concentration at U02 caused nutrient enrichment at this site, which was evident from the heavy growth of *Eichornia crassipes* and other aquatic plants. At the time of monitoring dredgers were used to clean the lake site of water plants. The contribution by G1 and G2 was lower but should have similar effect.

Sulphate

Data variability

The data variability in the sulphates at A3, G1 and G2 can be seen in table 6.30.

The sulphate level in the meat industry varied widely, with a maximum value of 123.6 mg/L at A3 and the minimum at G2 with a value of 12.7. The highest range was recorded at A3 with a value of 107.0. The median at this factory was 37.3. The 90^{th} percentile was 106.0 (75^{th} percentile 86.3) at A3, which was the highest. The median was highest at G1 with 45.4 and lowest at G2 with 21.5 . Thus these values indicate that the sulphates are not very high in this group of industries.

Relationships and effects

The sulphates concentrations at U02 were higher than at factory A3. The minimum recorded at A3 was 96.2, maximum, 290.7 and the median, 182.0. Therefore the higher sulphates values at the lake site U02 indicate that there were other sources such as the other factories that contributed to sulphates at U02. The other branches of the A group may also have contributed.

6.7.3 Soft drinks (bottle washer) effluents

Four soft drink industries were monitored. Three of these industries were carbonated soft drinks. A2 discharges its waste water untreated into the central (municipal) sewage system. This effluent reaches the Kelani ganga at Madampitiya near the Victoria bridge. This plant had a monitoring frequency of 15. Total N was not monitored in January, February, August and September 1986; and sulphate was not monitored on 20/01/86. Samples were collected from the manhole which receives the bottle washer effluent of this plant. Monitoring was done on a monthly basis except in Oc-

tober 1986 when two samples were monitored. Samples were collected in the morning between 08.45 and 10.18 hours. In addition to their own carbonated drinks, Pepsi Cola was also bottled in this factory.

The factory H1 was a multi-national company producing carbonated soft drinks such as Coca Cola, Sprite and Fanta. This factory discharges its effluents into a small channel, which enters a nearby paddy. The factory itself is located near a tributary of the Kelani ganga. No treatment of waste waters is done. This factory has a water purification plant for production purposes. Two samples were taken from the factory, H1 from the soft drink bottle washer effluent stream within the factory, and H2 from the carbon dioxide plant effluent outside the factory but within the factory premises. Production alternated with different types of soft drinks, such as Coke, Sprite and Fanta bottled on different days or on the same day.

Six sets of samples were analysed during the research period at H1. Sulphates were not monitored on 12.03.86 and 09.06.86. Three sets of samples were monitored at the sampling point H2. Total N was not monitored at this site. No treatment is carried out on the effluents. H1 was monitored between 9.15 and 10.05 hours in the morning.

The factory bearing identification code I is a carbonated soft drinks factory, situated in the Biyagama Industrial Zone. Being a new factory, biological treatment facilities have been installed but as it was in the initial stages of installation it was not functioning efficiently. Part of the treatment works was still under construction during the research period. The system was working, but it was still in a stage of experimentation. The waste water from this factory entered the river Kelaniya through a pipe 300 metres long (at the time of monitoring). Therefore, it is not accurate to say an efficient treatment of waste water was performed at this stage. Although the treatment plant was only partially effective, it was the only such facility among the factories monitored. It was chosen for monitoring for this purpose, although later it was found that the treatment works was in its initial stages, and thus not functioning efficiently.

This factory was a branch plant of the multinational company mentioned above and thus produced the same carbonated soft drinks. Samples were taken 6 times during the research from two sampling points. I1 was the sampling point at the bottle washer effluent drain just outside the production line, but within the factory premises. This sample was collected from the effluent drain which leads into the aeration tank. Therefore the sample was raw untreated effluent.

The sample I2 was collected from the aeration tank and had a frequency of 6. The system was working, but not functioning efficiently.

A fruit and milk based soft drinks factory (J) was monitored. Although this was grouped under soft drinks, it was not a carbonated soft drinks factory like the previous factories A2, H1 and I1. The factory was abbreviated J and discharged its effluents untreated into land at the time of monitoring. Towards the later part of the research, a sump or a settling tank was under construction for the collection of the waste water. The samples were collected from a drain which had effluents from the bottle washing processes from both the fruit and milk based soft drinks. Bottles were washed manually. Product spillages (i.e. syrups) also enter the effluent drain. Six samples were monitored. Total N was not monitored on 09.06.86.

COD, BOD and DO: Data variability

COD

The data variability of the soft drinks group can be seen in table 6.31 and the concentrations in the figures 6.22, 6.23 and 6.24 for A2, H1 and J respectively.

Among the industries A2 had the highest COD concentrations with a minimum COD of 252.0 mg/L, maximum of 3280.0 and median of 1627.0. The 90^{th} percentile fell at 2710.0. Thus the factory waste water was very strong in nature. The range and the standard deviation was high which indicated high variability in the data. The range had a value of 3028.0 and the standard deviation was 792.49. The COD ranged from a mimimum of 184.0 mg/L at H1 to a maximum of 3280.0 at A2. Therefore the range among the factories was high with a value of 3096.0. The other industries in this group also had similar values as seen in the table above.

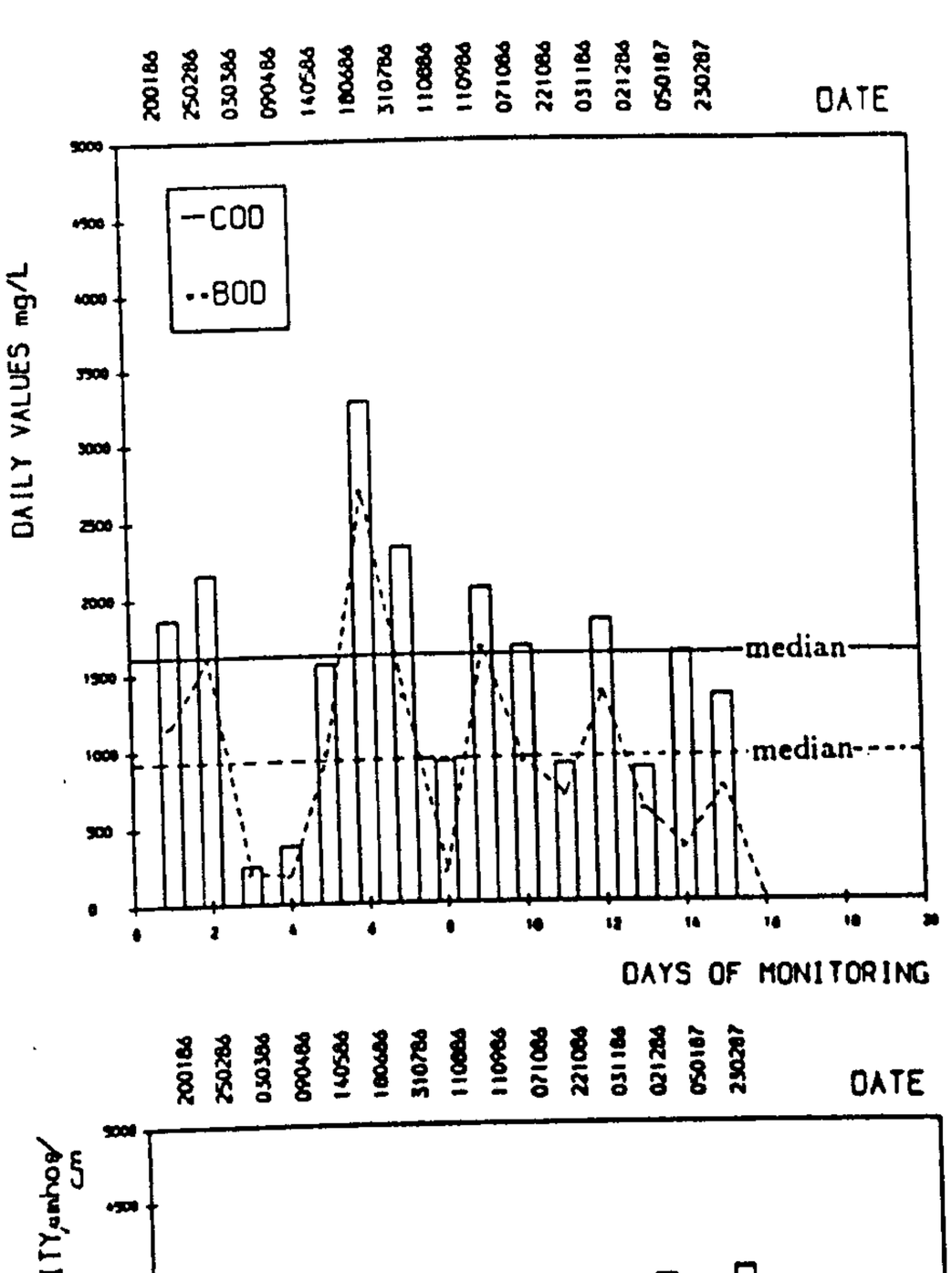
BOD

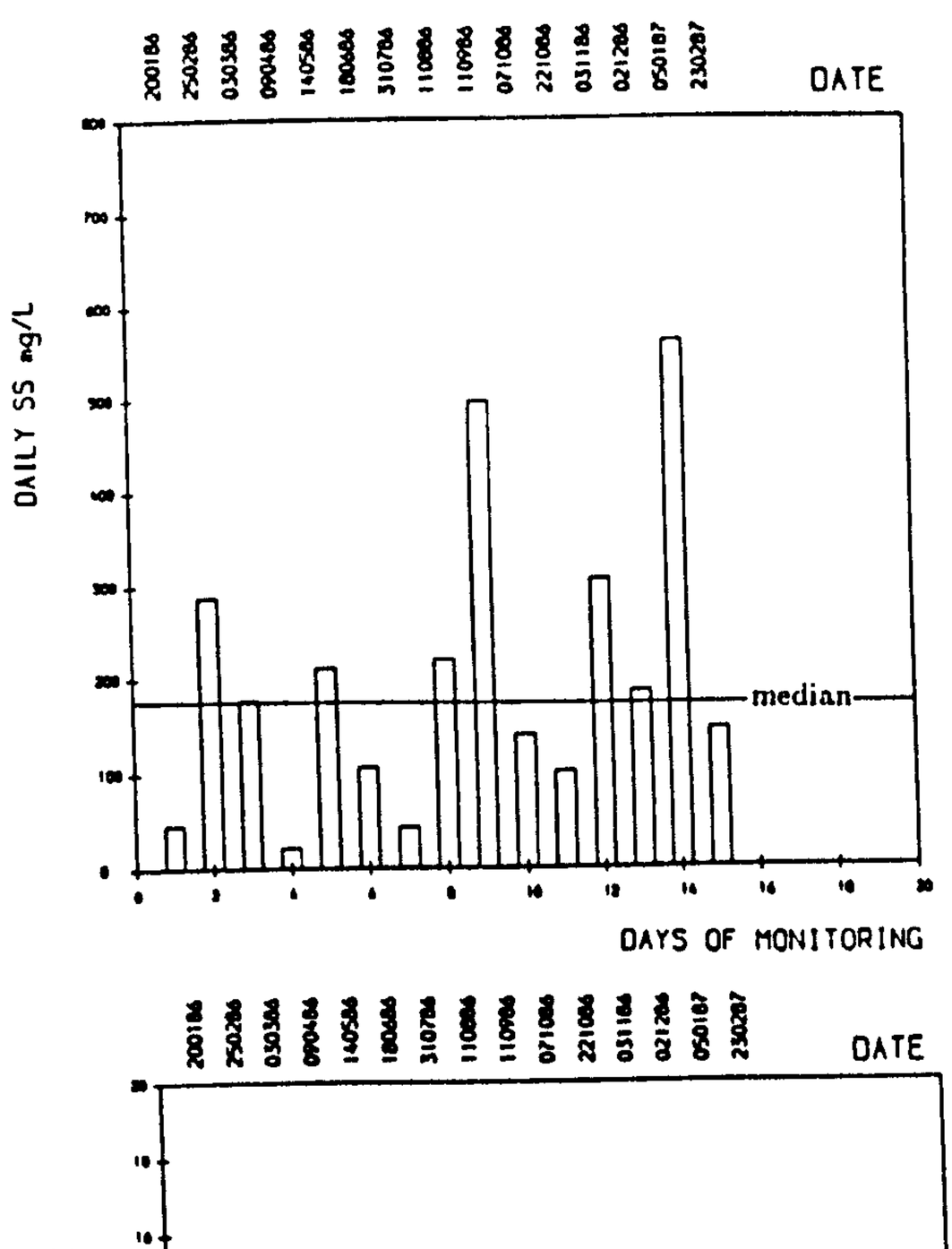
The data variability in the soft drinks group of industries is seen in the table 6.31

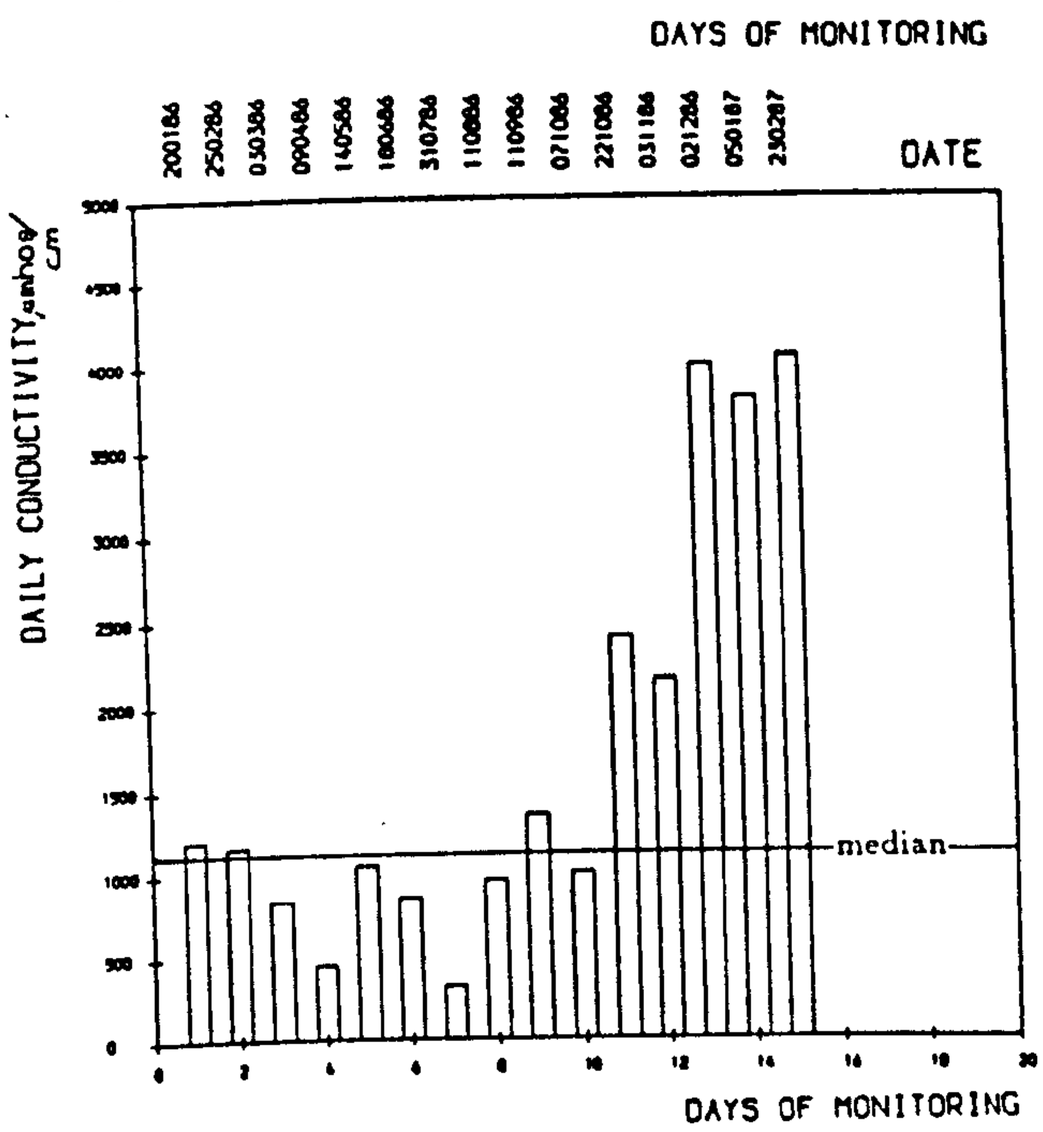
Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75%	90%	Indus
DO	4.4	1.01	3.6	2.3	5.9	4.5	5.1	5.7	A2
DO	1.7	0.97	2.6	0.1	2 7	1.8	2.6	-	H1
DO	2.06	1.83	4.1	0.0	4.1	2.2	3.9	-	I1
DO	1.41	0.53	1.3	0.7	2.0	1.6	1.7	-	J
COD	1536.0	792.49	3028.0	252.0	3280.0	1627.0	2053.0	2710.0	A2
COD	1562.0	1029.62	2927.0	184.0	3111.0	1584.5	2359.0	-	H1
COD	1243.1	865.33	2441.0	190.0	2631.0	982.5	2050.0	-	I1
COD	1860.0	945.81	2280.0	920.0	3200.0	1480.0	2960.0	-	J
BOD	982.7	686.0	2502.0	185.0	2687.0	920.0	1364.0	2074.0	A2
BOD	1008.16	911.71	2403.0	100.0	2503.0	746.5	1864.7	-	H1
BOD	769.33	444.6	1314.0	142.0	1456.0	735.0	1114.7	-	I1
BOD	957.16	409.68	1136.0	636.0	1172.0	805.0	1136.7		J
SS	203.2	156.75	539.6	21.6	561.3	176.8	286.5	522.7	A2
SS	373.86	216.26	623.0	112.2	735.2	378.8	512.0	-	H1
SS	362.71	307.24	851.0	116.3	963.3	258.3	517.0	-	I1
SS	207.89	107.93	263.2	103.6	366.9	173.7	322.1		J
TB	26.04	12.34	45.8	6.7	52.5	26.0	34.0	46.8	A2
TB	31.76	12.10	34.0	12.5	46.5	32.7	42.0	-	H1
TB	31.0	7.62	22.0	22.0	44.0	28.7	38.0	-	I1
TB	38.0	11.72	33.0	27.0	60.0	35.5	45.0	-	J
CT	1706.3	1280.0	3730.0	320.0	4050.0	1160.0	3 20.0	4020.0	A2
CT	3192.5	2154.0	6010.0	490.0	6500.0	2825.0	5097.0	-	H1
CT	2108.3	1528.4	3910.0	190.0	4100.0	1930.0	3762.0	-	I1
CT	1608.3	1309.9	3020.0	480.0	3500.0	1072.0	3125.0	-	J
pH	10.88	1.15	3.6	8.9	12.5	10.7	12.0	12.4	A2
pH	11.15	1.55	4.0	8.9	12.9	11.7	12.3	-	H1
pH	10.43	1.76	4.2	7.8	12.0	11.0	11.9	-	I1
pH	9.48	2.07	4.8	6.8	11.6	9.90	11.5	-	J
W T	37.28	3.69	13.0	30.0	43.0	37.5	40.0	42.1	A2
W T	38.58	3.4	9.5	33.5	43.0	39.0	41.5	-	H1
W T	39.26	3.47	9.0	34.0	43.0	39.0	43.0	-	I1
W T	32.0	4.01	10.0	26.0	36.0	33.7	34.8	-	J
T P	5.7	2.33	7.6	0.9	8.5	5.9	7.9	8.2	A2
T P	5.71	3.16	7.9	1.3	9.2	6.4	8.4	-	H1
T P	6.3	1.16	3.1	5.0	8.1	6.0	7.3	-	I1
T P	7.6	4.24	12.9	2.1	15.1	7.1	9.8	-	J
T N	1.97	1.73	5.9	0.8	6.7	1.3	2.6	6.0	A2
T N	2.49	2.06	5.1	1.0	6.2	1.4	4.2	-	H1
T N	0.98	0.20	0.5	0.7	1.3	0.9	1.1	-	I1
T N	15.12	9.32	24.3	2.1	26.5	16.1	23.5	-	J
SULF	160.57	206.89	785.3	20.7	806.0	92.2	148.7	601.0	A2
SULF	197.9	262.68	552.4	37.6	590.0	82.0	467.6	-	H1
SULF	107.38	58.11	134.0	37.6	171.6	91.6	167.3	-	I1
SULF	207.46	249.70	628.7	87.8	716.5	108.6	273.6	-	J

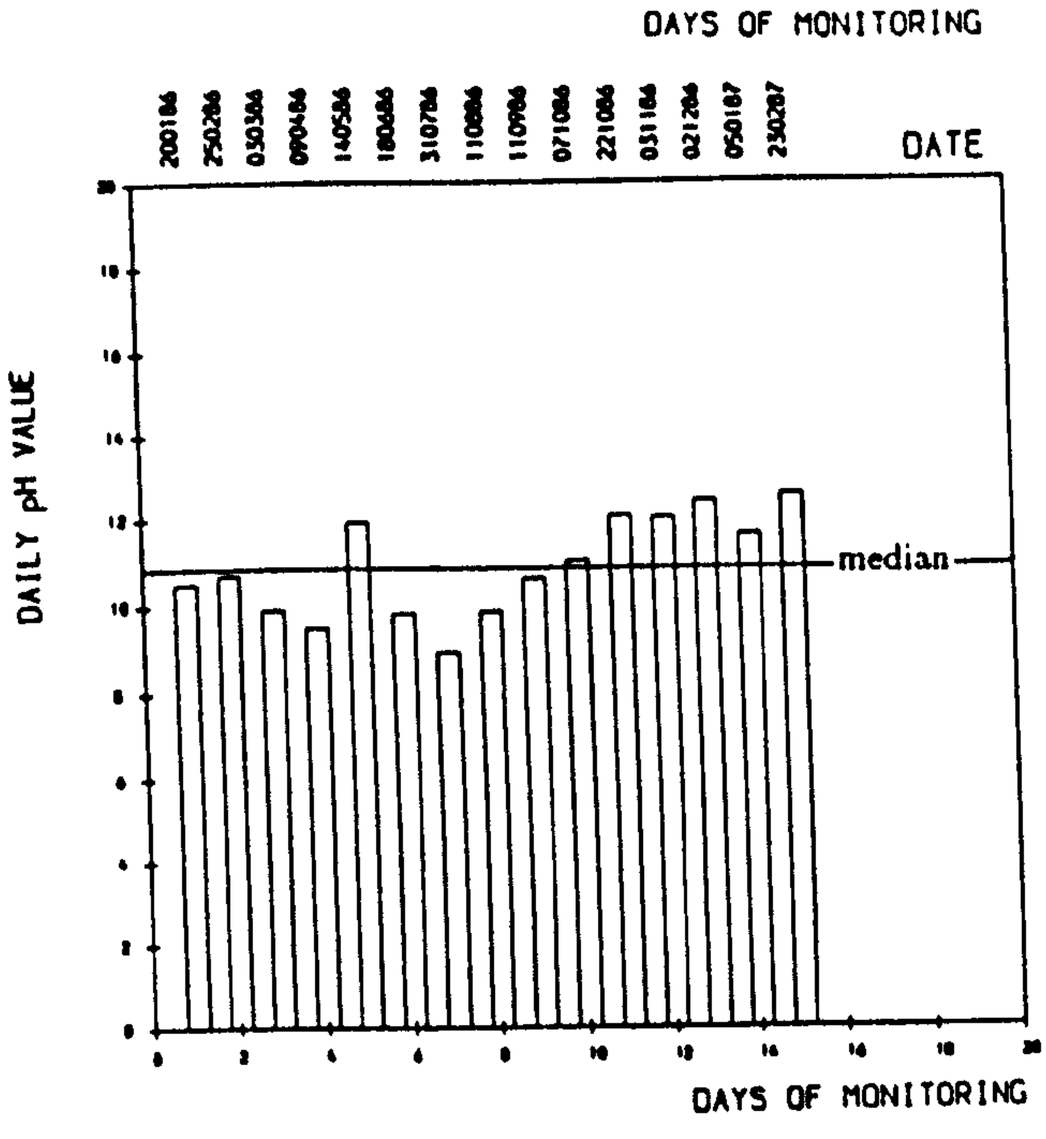
Source: Field monitoring.

Table 6.31 — Soft drinks effluents









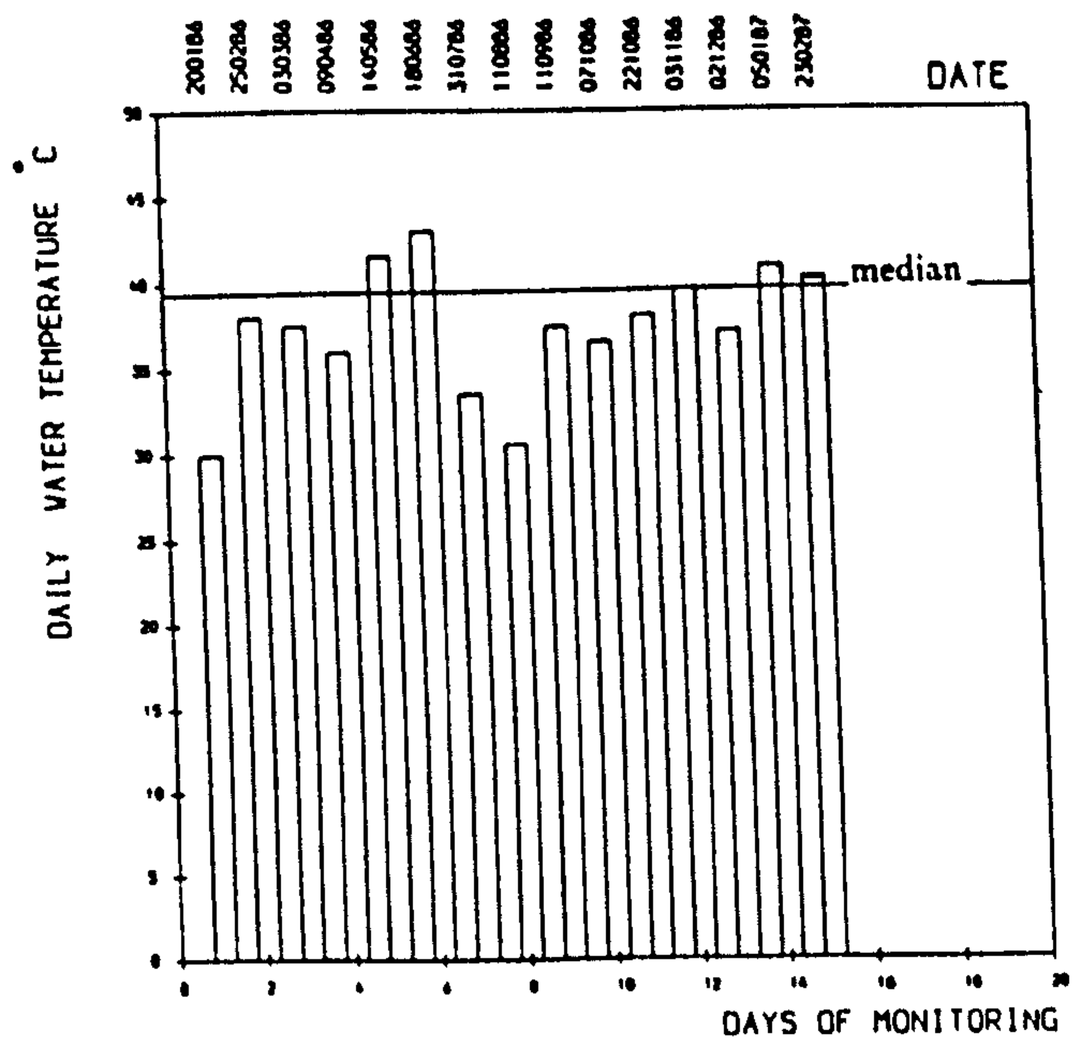
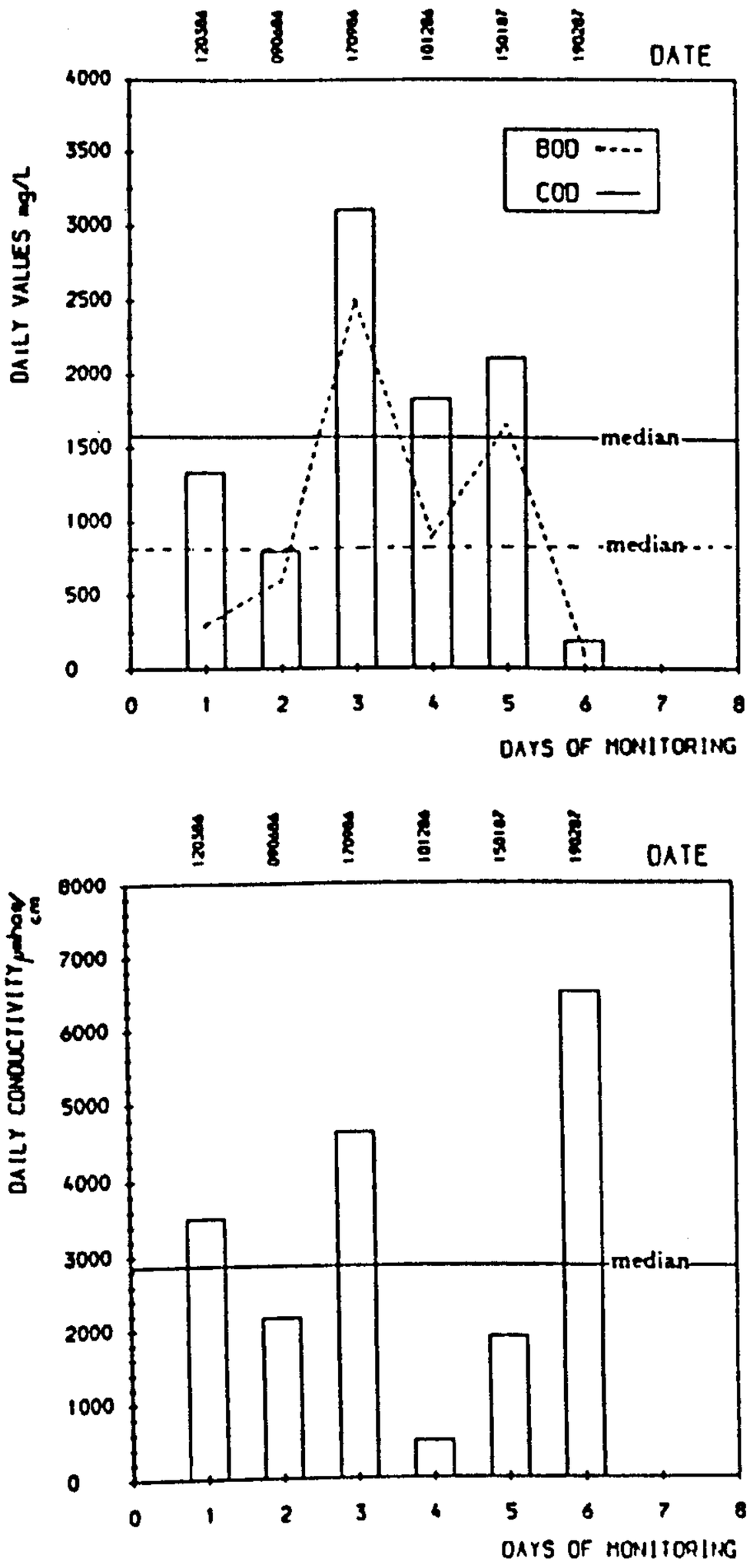
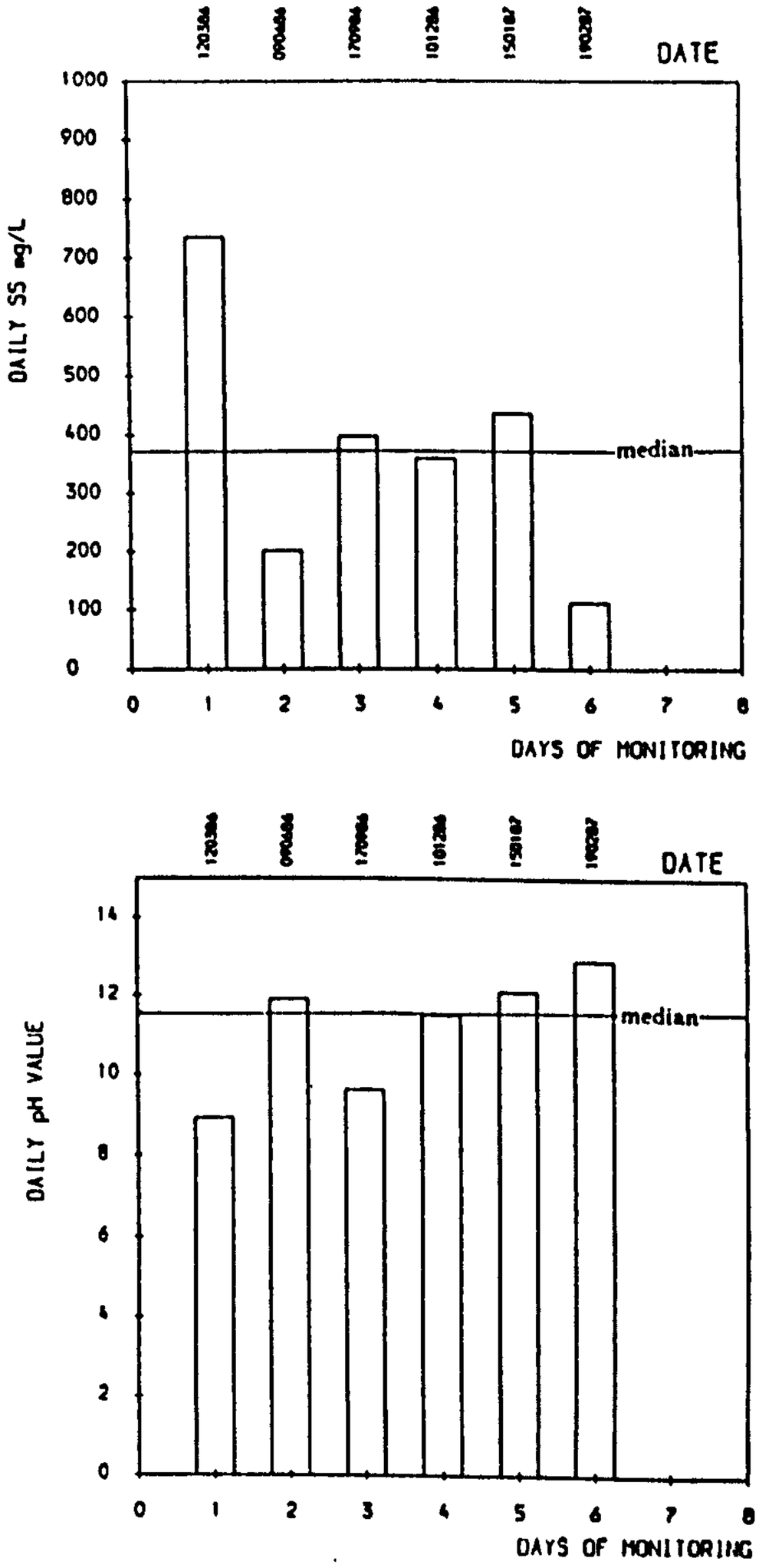


Figure 6.22 — Waste water concentrations in soft drinks factory: A2

Source: Field monitoring





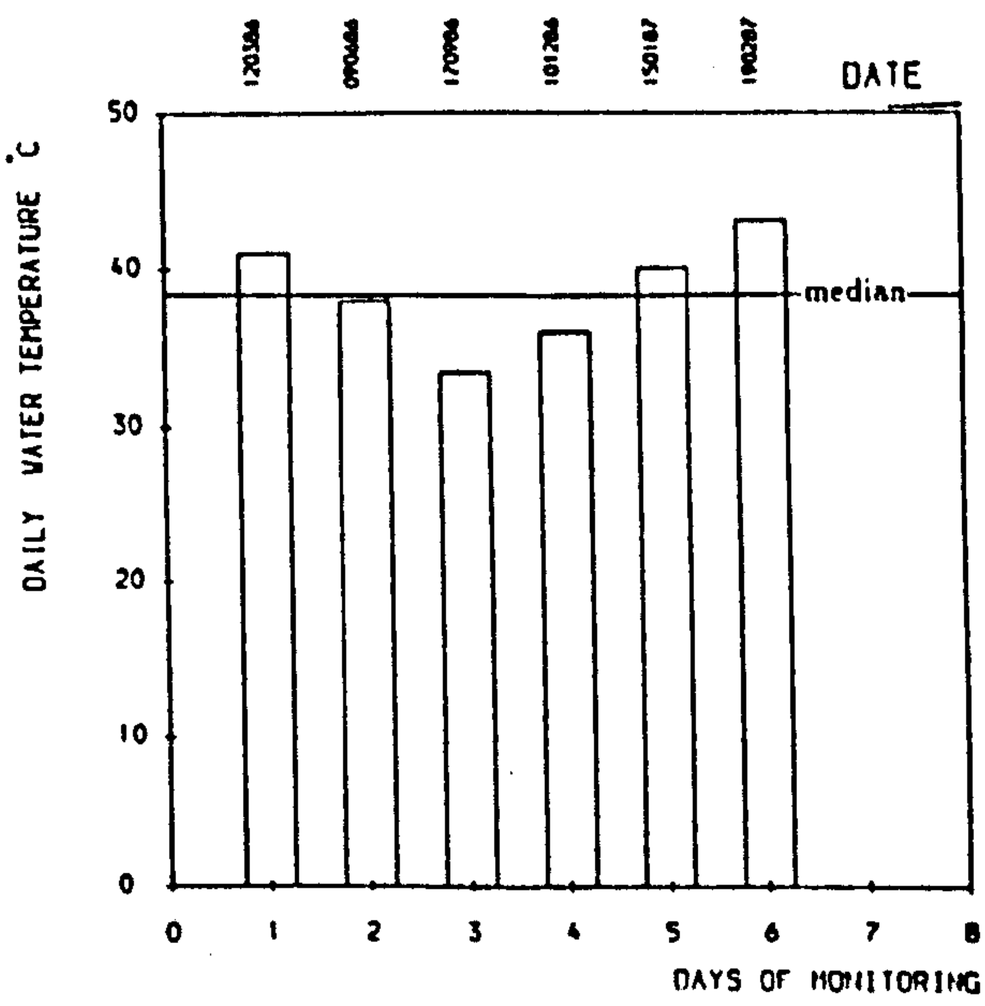
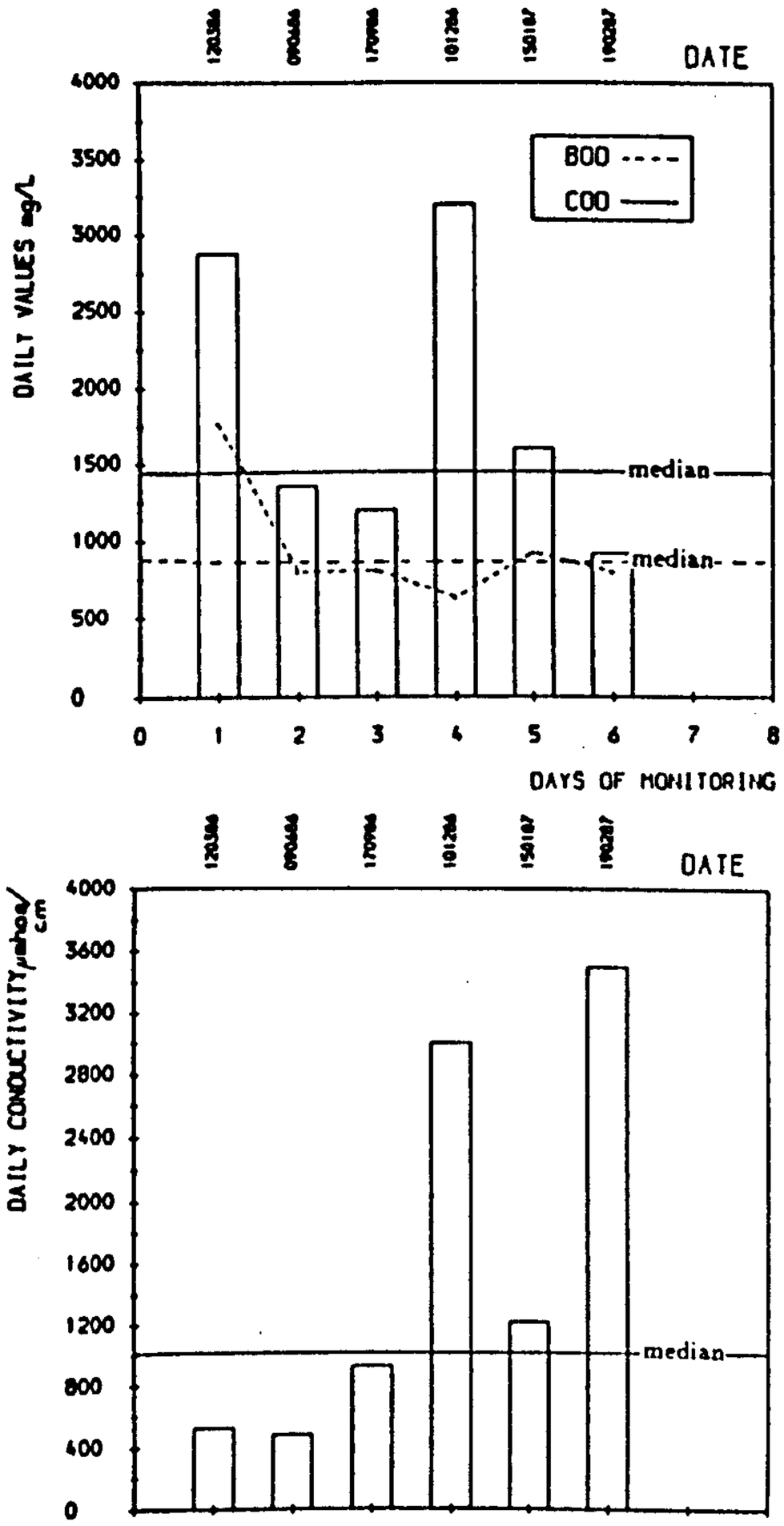
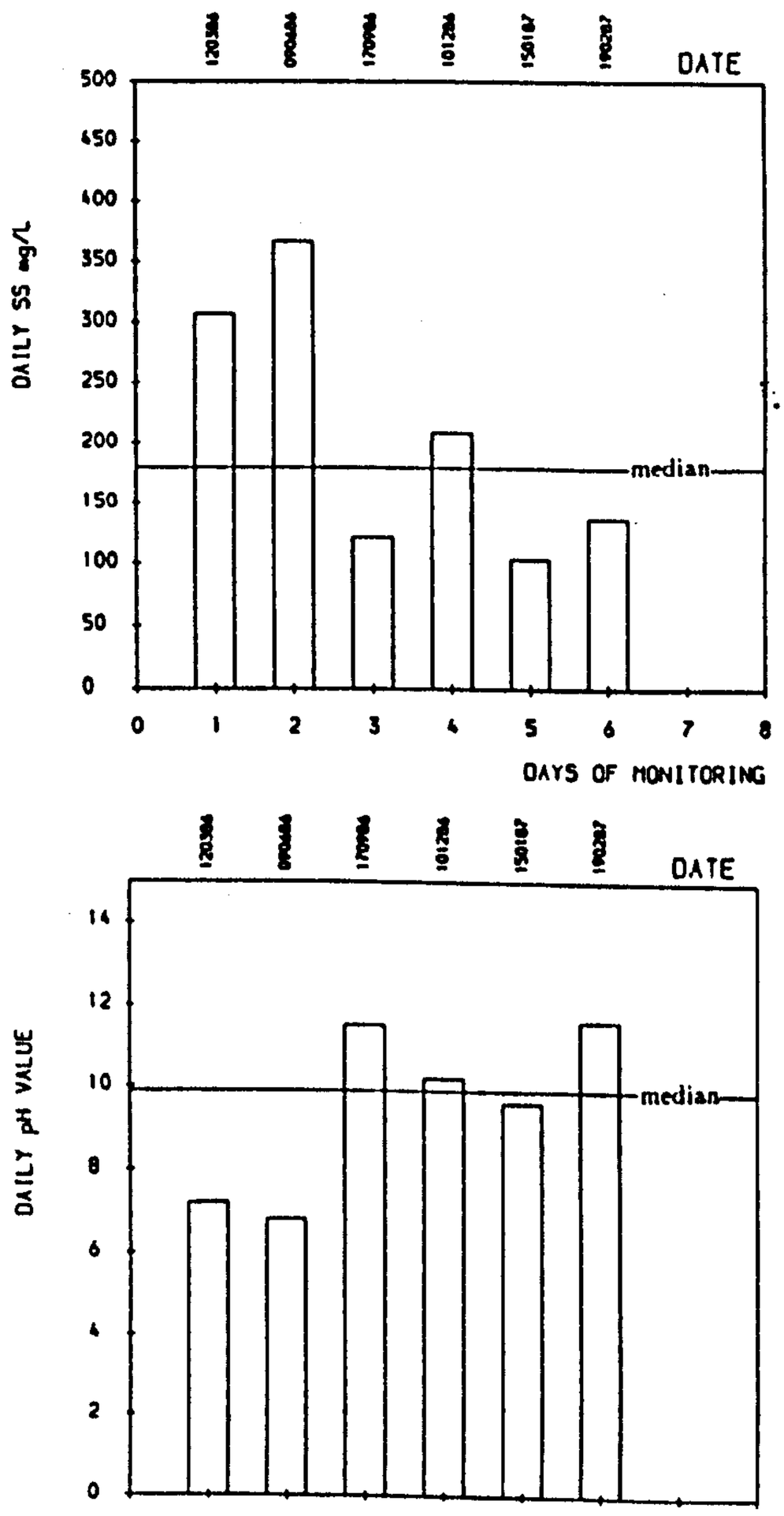


Figure 6.23 — Waste water concentrations in soft drinks factory: H1

Source: Field monitoring





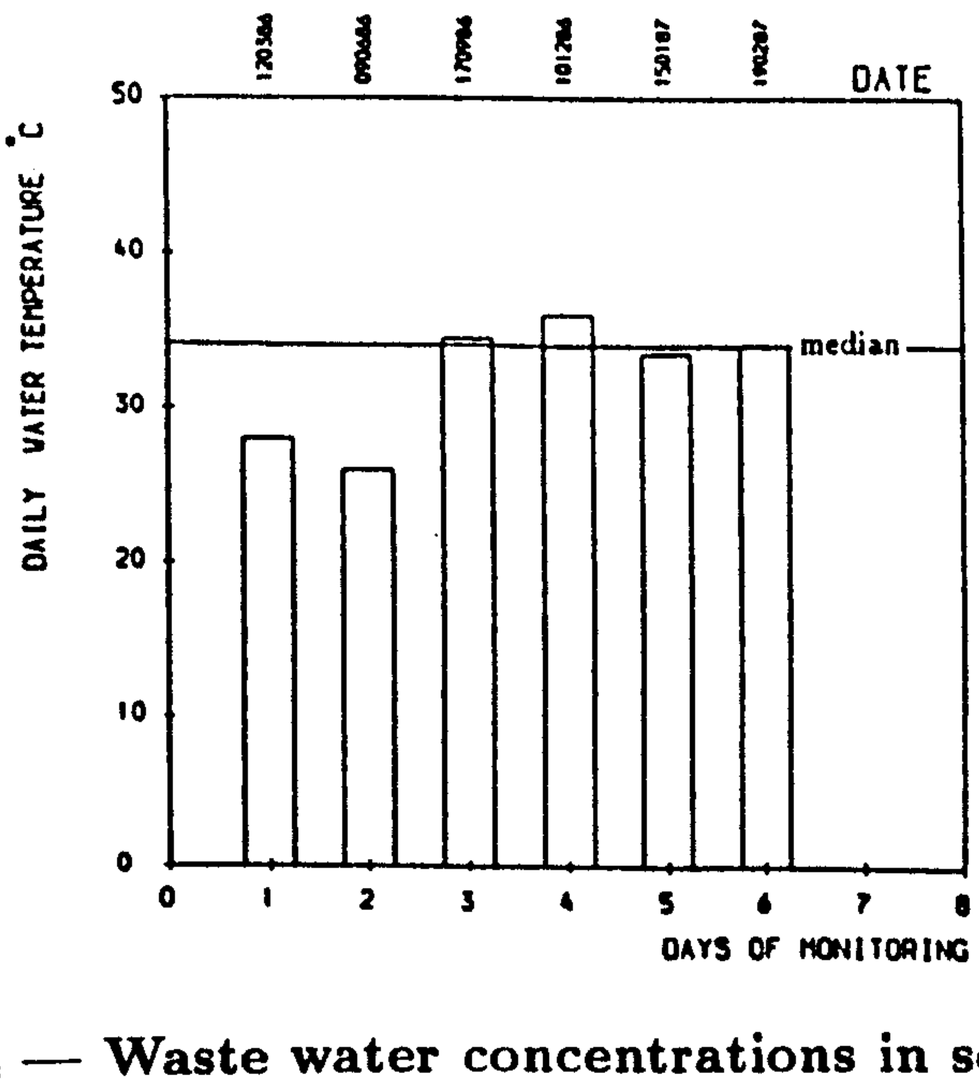


Figure 6.24 — Waste water concentrations in soft drinks factory: J

Source: Field monitoring

and the concentrations in the figures 6.22, 6.23 and 6.24 for A2, H1 and J respectively.

The BOD was also the highest at A2. The minimum at A2 was 185.0, maximum 2687.0 and the median 920.0. The 90th percentile was 2074.0. These indicated the strong nature of the waste waters of this industry. The variability of the data is evident in the high range and the standard deviation The range recorded a value of 2502.0 and the standard deviation 686.0. The BOD of the soft drink industry also varied widely among the industries. A minimum of 100.0 mg/L was recorded at H1 and the maximum of 2687.0 at A2, therefore the range between the industries was 2587.0. The other industries in the group also had similar concentrations and variations.

Relationships and effects

The high COD and the BOD indicates that these industries contribute a very high organic load to the receiving waters. The high COD and BOD are due to the nature of the product itself, i.e. fruit based soft drinks, high sugar content, and other left overs such as cigarette butts and straws. This high organic load demands a high oxygen content for the break down of the organic matter in the waste waters. This high organic load in terms of COD and BOD is reflected in the very low DO value of the respective factories (the BOD and COD may vary according to the number of bottle washing operations. For example the first bottle wash will have a higher COD and BOD than the final wash). The DO was low at H1, I1, and J1 with very low median values of 1.8, 2.2 and 1.6. The minimum values recorded were 0.10, 0.0 and 0.7. This indicates the strength of the waste waters of this industrial group. The high organic load aggravates the anaerobic process in the factories and in the receiving waters. If these wastes are discharged without treatment, it will exert a very high oxygen demand causing depletion of the DO in the receiving waters.

The effects of the industrial site A2 is difficult to assess as it discharged into the municipal sewer. H1 entered a paddy, J enters bare land and I1 entered the river Kelani. The latter was partially treated but the COD levels especially (higher than other 3 sites) indicates that the treatment system is not working very efficiently.

SS

Data variability

The data variability in the SS at A2, H1, I1 and J can be seen in table 6.31 and the concentrations in figures 6.22, 6.23 and 6.24 for A2, H1 and J respectively.

The highest median value was recorded at H1 with 378.8 mg/L. The maximum values remained high, with the highest recorded at I1 with a value of 963.3. H1 and A2 also had high values. The 75th percentile ranged from 286.5 at A2 (the 90th percentile was 522.76) to 517.82 at I1. These indicated that the SS was high in this group of factories.

The SS at the soft drink industrial group ranged widely. It recorded a minimum of 21.65 mg/L at A2 and a maximum of 963.3 at I1. The range was the highest at I1 with a value of 851.0. Thus the variability of the concentrations was very high. This was also reflected in the standard deviation. The highest was recorded at I1 with a value of 307.24.

Relationships and effects

Except for I, none of the other factories discharged directly into a receiving body of water. Thus the assessment of the impact on the receiving water is difficult. A3 waste waters enter the Kelani river through the municipal sewage lines, where it enters untreated as the municipal treatment plant was out of order (the present situation may be different if the sewage system is completed).

The high SS values at H1 and I1 may be due to the left-overs in the bottle washer effluent. The SS in the effluent stream which has labels and suspended particles also contributes to a higher load. This is true for A2 and J.

The SS at I1 was also high. The SS at I2 was higher than at the factory sampling point which indicates that the waste waters were discharged with a high SS load into the receiving river Kelani. This has serious implications because the water is abstracted downstream for potable water supplies for Colombo.

Although the contributions into the receiving water were difficult to evaluate, it can be said that the discharges have a cumulative effect on the receiving sites.

Turbidity

Data variability

The data variation in the soft drinks industry can be seen in table 6.31. The turbidity at the soft drinks industry generally followed the SS load, although there were deviations from this trend. The lowest SS of 21.65 at A2 was reflected by the lowest turbidity value recorded at A2 with a value of 6.7 NTU. But the highest SS at I1 with a value of 963.3 mg/L was not reflected by the highest turbidity value. The maximum turbidity value was recorded at J with a value of 60.0 NTU. The highest minimum value of 27.0 NTU and the highest median value of 35.5 were also recorded at J.

The range was high at all the factories. The range in the turbidity between the factories was 53.3 (minimum of 6.7 was recorded at A2 and the maximum fell at J). This indicated the variability in the data. The standard deviation had close values at A2, H1 and J, which were higher than at I1.

As the turbidity reflect the SS load, the relationships and the effects are essentially the same.

Conductivity

Data variability

The data variability at the soft drinks plants can be seen in table 6.31 and the daily concentrations in figures 6.22, 6.23 and 6.24 for A2, H1 and J respectively.

The conductivity in this industrial group had comparatively higher values than most of the other industries monitored. The highest values were recorded at H1 with the minimum value of 490.0, maximum of 6500.0 and median of 2825.0. The median in all the industries indicated fairly similar values which indicated that the average conditions in all the plants were nearly the same. The median conductivity remained high in all the factories. This is also seen in the percentiles. The 75^{th} percentile was the highest at H1 with 5097.0. The higher percentiles are also reflected in the other plants.

The range was the highest at H1 with 6010.0 and the standard deviation was 2154.0. The standard deviation was high in all the plants. The range between the industries was also high with minimum of 190.0 recorded at I1 and the maximum value recorded at H1 with 6500.0.

Relationships and effects

The high conductivity reflected in the plants is due to the presence of dissolved salts in the effluents. This may be partly due to the production and partly to the cleaning operations. The effect at the receiving site of I1 will be detrimental as it is upstream of the water supply abstraction point. The conductivity levels are also generally higher than either the confectionery or meat processing wastes.

pH

Data variability

The data variability in the soft drinks plants is shown in table 6.31 and the concentrations in figures 6.22, 6.23 and 6.24 for A2, H1 and J respectively.

The pH in this group of industries ranged from slightly acid values to highly alkaline values. The highest pH values was recorded at H1 with a minimum of 8.9 and maximum of 12.9. The median value was 11.7. The percentiles remained high in all the industries. The 75^{th} percentile at H1 was 12.3, which was the highest. This indicates that the pH is high in this group.

The range was the highest at J, with a value of 4.8. The range had fairly similar values in all the plants which suggests that the nature of the waste waters is similar. The standard deviation was the highest at J with a value of 2.07. The other plants too had close values. This indicates that the data variability is high.

Relationships and effects

The pH may be high in these industries due to the alkaline effluents discharged after the bottle washing process. Detergents are used profusely for bottle washing operations other than hot water cleansing. This was observed at A2, H1 and I1. Thus it is natural that high pH values are recorded in the effluents. The pH was not neutralised at I1, and is discharged into the river. Continued discharge may affect the quality of water at the intake point. At H1, where the waste water is discharged into a paddy without treatment, there have been serious complaints regarding the unproductive fields, which once had high yields. This was directly linked by the farmers to the factory discharges. The pH was lower at J. This may be due to less detergents used in the bottle wash process. More chlorinated water was used for

this purpose. The immediate effect was not felt as it was discharged into bare land. Overall the median values were much higher than the wastes of other indistries.

Water temperature

Data variability

The data variability at the soft drink plants are shown in table 6.31 and the daily concentrations at A2, H1, and J in figures 6.22, 6.23 and 6.24 respectively.

The water temperature in the soft drinks group of industries recorded high values at A2, H1 and I1. At J the temperatures were lower. The highest water temperature in the waste water was recorded at I1 with a value of 43 °C. The median remained high in all the factories except at J. The 75^{th} percentile at A2, H1 and I1 recorded above 40 °C which indicated high temperatures of the effluents.

The range was highest at A2 with a value of 13.0. The values in the other industries remained similar. The standard deviation was the highest at J. The other plants also had very similar values. These indicated variability in the data.

Relationships and effects

The water temperatures are high in this industry because high temperatures are used in bottle washing in addition to the detergent baths. Thus the effluent water temperatures are higher than in most of the other industries. The water temperature at J was the lowest with a median value of 33.7, while A2, H1 and I1 had 37.5, 39.0 and 39.0 respectively. The lower water temperatures at J may be due to the fact that bottle washing at J is done with chlorinated cold water (2 ppm). The bottles are only briefly dipped in hot water at the final wash. The release of effluents with high temperatures is detrimental. It reduces the DO and affects the aquatic fauna and flora.

Total P

Data variability

The data variability of total P can be seen in table 6.31. The total P was high in the soft drinks industry. High values in the minimum, maximum and median were recorded at H1 with 1.3 mg/L, 9.25 and 6.47 respectively. This was next to factory J which recorded the highest at 2.15, 15.1 and 7.15 respectively. At A2 and I1 also the total P remained high. The range was the widest at J with a value of 12.9. The range between the industries was 9.85, which indicated high variability between the plants. The standard deviation was the highest at J.

Relationships and effects

The total P levels in the soft drinks industry recorded some of the highest levels in the factories monitored. This may be due to the large amount of detergents used for cleaning purposes. These detergents are high in phosphates. It is difficult to explain the lower total P at A2 which recorded the lowest median value, as this plant also used detergents for bottle wash. Furthermore its size is large. The effects on the receiving water of the discharges is detrimental. High total P discharges lead to aquatic plant growth. This was evident in the lake where the other plants of industry A discharged their effluents.

Total N

Data variability

The data variability in the soft drinks plants can be seen in table 6.31.

The total N levels were comparatively low in this industry. A minimum of 0.73 mg/L at I1 and a maximum of 26.5 at J were recorded. I1 had the lowest total N level among the soft drink industries with the median at 1.14. But median value at this factory (16.1) was the highest recorded.

The range recorded a high value of 24.33 at J. The range between the plants was high with a value of 23.74. The standard deviation was the highest among the factories at J.

Relationships and effects

The reason for higher total N values at J may be due to the milk based drinks, which enter the effluent drain. Further natural fresh fruit concentrates are used in the variety of fruit drinks made in this factory, which ranges from herbal drinks to pure fruit drinks. These may also add to the total N content in the effluent. Although there was a high level of total N at factory J, the levels in the other plants remained low. The discharges of J enter bare land, thus the effects were not clear. With the exception of J the median levels were lower than wastes from either confectionery or

meat processing wastes.

Sulphates

Data variability

The data variability is given in the table 6.31.

The sulphates in the soft drinks group had wide variations. The minimum sulphate was recorded at A2 with a value of 20.7 mg/L and the maximum was also recorded at the same site with a value of 806.0. The highest median was recorded at J which had a value of 108.0. The sulphates were also varied and recorded high levels at J. The minimum was at 87.8, and the maximum recorded was 716.5. Although highly variable values were recorded, the median in all the plants remained fairly low.

The data variability also can be seen in the range. The range was the highest at A2 with a value of 785.3. This was reflected in the standard deviation which had a value 206.89. The range between the plants was 785.3.

Relationships and effects

The sulphate data in the plants varied widely. Only 4 sulphates samples at H1 and 5 samples at I1 were monitored. Thus the frequency of monitoring in some plants was low. Sulphates may enter from the production processes as it is used as a preservative. Though the effects on the receiving sites is not measurable, high sulphates lead to the corrosion of the sewers. The sulphate concentration of these wastes fall between those of the meat processing and confectionery industry.

Carbon dioxide plant effluents

The carbon dioxide plant effluents abbreviated A4, H2 (which belongs to the A and H soft drinks plants) were monitored three times each. A4 discharges into the Beira lake near U02, while H2 entered a paddy. The effluent samples at both A4 and H2 was collected from the waste water stream outside the plants. Although not food industry in themselves they were monitored because they were part of the industrial set up in the manufacture of carbonated drinks. The results are in appendix H.

6.7.4 Biological treatment plant

The biological treatment plant I2 (aeration tank) was monitored six times during the research period. This is a part of the factory I. It was still under construction during monitoring and therefore in a stage of experimentation. The sample was collected from the treatment plant itself, i.e. from the aeration tank. Sulphates were not monitored on 17.09.86. This water was discharged into the river Kelani, upstream of the Ambatale water intake point. DO was high. The effluent quality from this plant is important because it is just above the water intake point.

DO

The data variability in the treatment plant can be seen in table 6.32.

The DO at I2 ranged from a minimum of 0.20 to a maximum of 4.8 mg/L. The median was at 2.95. The 75^{th} percentile fell at 4.42. The range was high with a value of 4.6 and the standard deviation was 1.98. Of the samples 33.33% fell below the 1.0 DO level.

This indicates that the DO of the aeration tank was low and that it did not function efficiently. Since the treatment plant was in its initial stages, its real capacity has yet to be seen. The DO was slightly higher than in the factory effluent I1, which indicates that aeration was taking place slightly although not efficiently.

COD and BOD

The data variability in the plant can be seen in table 6.32 for the COD and the BOD.

The COD of the tank had a minimum of 165.0 mg/L and a maximum of 1639.0 mg/L. The median was 778.5. The range was high with a value of 1474.0 and the standard deviation, 519.0. Thus the both the concentration and the variability is high.

The BOD at I2 had a minimum of 87.0 maximum of 1107.0 and a median of 467.0. The range had a high value of 1020.0 and the standard deviation 345.74.Thus the BOD too indicated both high and variable concentrations.

The COD and the BOD at I2 indicate highly ranging values. These values are very high for an aeration tank. But both COD and BOD at I2 are lower than in the factory effluent I1. The COD medain at I1 was 982.5, and the BOD median was

Table 6.32 — Variability in data: factory I2

Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75th %
DO	2.66	1.98	4.60	0.20	4.80	2.95	4.42
W T	33.58	0.97	2.50	32.00	34.50	33.75	34.50
pH	8.53	0.68	1.60	7.70	9.30	8.50	9.22
CT	2701.66	1373.90	3000.00	1200.00	4200.00	2605.00	4050.00
TB	40.41	7.90	21.00	35.00	56.00	37.25	44.75
COD	795.33	519.03	1474.00	165.00	1639.00	778.50	1159.60
BOD	509.16	345.74	1020.00	87.00	1107.00	467.00	745.00
SULF	124.66	46.51	102.80	83.40	186.20	106.30	173.75
T N	1.44	0.64	1.61	0.74	2.35	1.33	2.05
T P	5.67	1.03	2.65	5.00	7.65	5.20	6.41
SS	543.40	440.46	1117.50	234.60	1352.10	324.30	908.02

Source: Field monitoring.

755.0. The lower DO level at I2 was obviously due to high COD and BOD and also due to the inefficient functioning of the treatment system. Thus at the time of the research the water released from the treatment system was of low oxygen quality. This may have contributed to the pollution of the receiving river.

SS

The data variability for the SS can be seen in table 6.32.

The SS at I2 had a minimum of 234.6 and a maximum of 1352.1 with median at 324.3. This indicates that the SS was high. The range had a high value of 1117.5 and the standard deviation 440.46. Therefore the data depicted variability.

The SS at I2 was higher than at the factory site I1 which had a median of 258.35. This may be both due to the load from the factory and the sand and silt that entered the tank from the load piled up by the tank. Thus the water discharged from the tank may have contributed adversely to the receiving site.

Turbidity

The data variability for the turbidity can be seen in table 6.32. The turbidity at I2 had a minimum of 35.0 NTU, maximum of 56.0 and median of 44.75.

The turbidity at I2 was higher than at I1. The latter had a median value of 38.0. This may be due to the initial inefficient functioning of the system.

Conductivity

The data variability in conductivity can be seen in table 6.32. The conductivity at I2 was high with a minimum of 1200.0 μmhos/cm maximum of 4200.0, median of 2605.0. The range was high and the standard deviation 1373.9. Thus the data indicates high and variable values.

It is not clear from where the dissolved salts enter the tank other than from the factory waste waters. One possibility is that the dissolved ions may enter from the construction material which was piled up. Whatever the source it has a considerably higher conductivity than I1.

pH

The data variability for pH can be seen in table 6.32. The pH ranged from a minimum of 7.7 to a maximum of 9.3, with the median at 8.5. Thus the pH was high. The standard deviation was 0.68, which means the variability in the pH was low.

The pH values indicate slightly alkaline to alkaline values typical of this industry. The pH was lower at I2 than at I1. This shows that some degree of neutralisation of the pH had taken place. The discharges into the river may not have adverse effects.

Water temperature

The data variability for water temperature can be seen in table 6.32. The water temperature at I2 had a minimum of 32 °C, maximum of 34.5 and median of 33.75.

The range was 2.5 and the standard deviation 0.07. Both the range and the

standard deviation indicated lower variability of the data.

The values were lower than I1. This indicated that on standing the effluent temperature has become lower. Thus as far as the water temperature is concerned the discharge may not affect the receiving water.

Total P

The data variability for the total P can be seen in table 6.32.

The total P at I2 had a minimum of 5.0, maximum of 7.65, and a median value of 5.2. Thus the value was high.

This value was lower than at I1 which had a median of 6.0. This indicates that there was reduction in the total P. But the concentration in the discharge still remained high.

Total N

The data variability for the total N can be seen in table 6.32.

The total N level at I2 was slightly higher than at I1 with the minimum total N at 0.74, maximum at 2.35, median at 1.33.

It is possible that nutrients may be added to the tank for the bacteria to decompose the waste waters.

Sulphate

The data variability for the sulphate can be seen in table 6.32. The sulphates in the aeration tank I2 had a minimum value of 83.4, maximum of 186.2 and a median of 106.3. As with conductivity, the sulphate levels are higher at I2 than I1.

6.7.5 Dairy (creamery) effluent

The creamery department of the A group of industries coded A5 had a monitoring frequency of 15. This factory produces ice cream and bottled fresh milk. Access into the factory was not given. Thus the sample was collected from the effluent drain leading from this factory just outside the factory premises, before it entered the lake. Total N was not monitored in January, February and March 1986. This factory discharged the waste water directly into the Beira lake at U02.

COD, BOD and DO: Data variability

COD

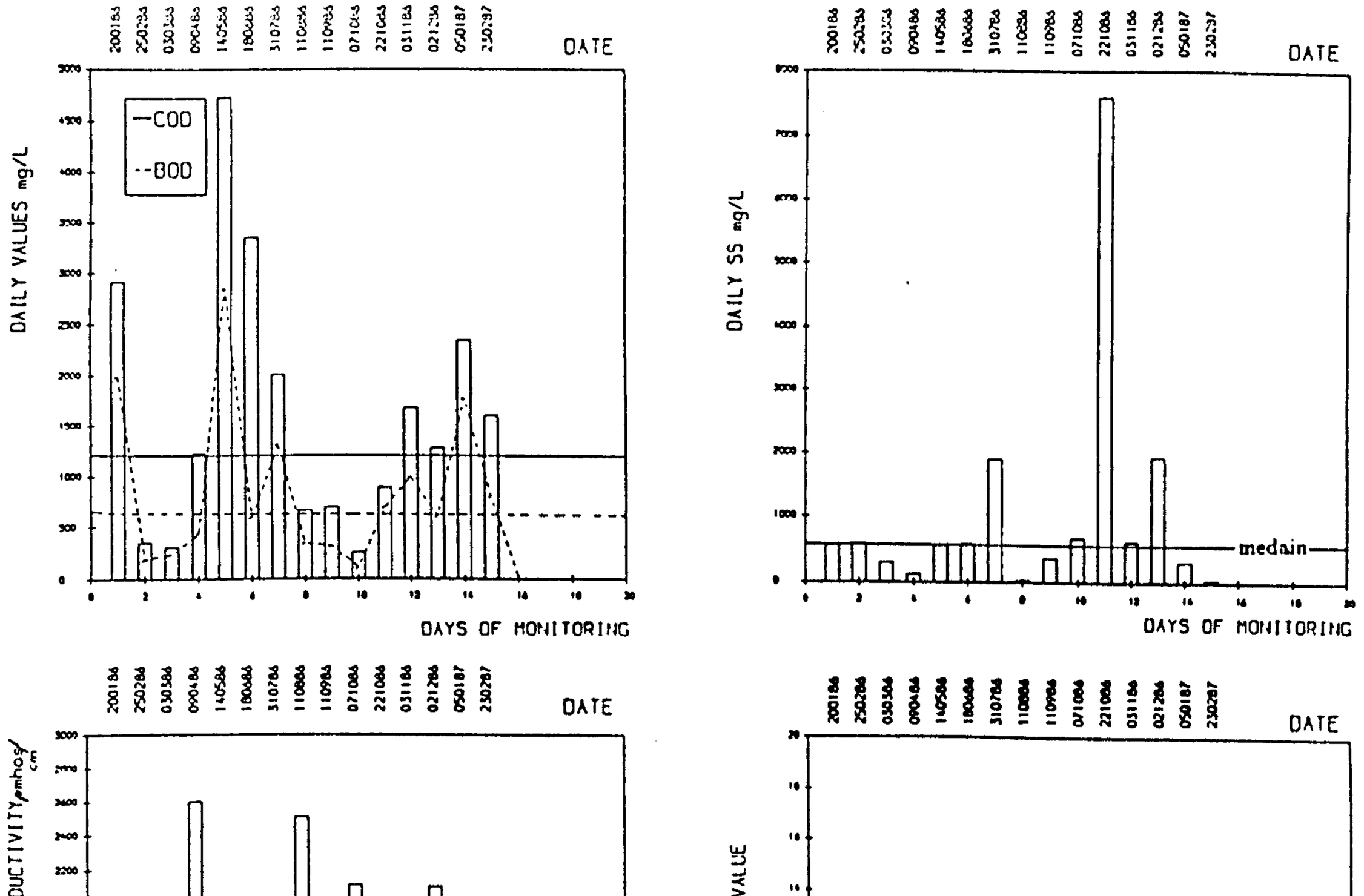
The data variability in the COD can be seen in table 6.33 and the daily the concentrations in figure 6.25.

Table 6.33 — Variability in data: factory site A5

Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75th %	90th %
DO	3.17	0.39	1.20	2.4	3.60	3.35	3.40	3.54
W T	32.36	1.93	6.50	28.0	34.50	32.50	34.00	34.50
pH	8.40	1.78	7.00	5.30	12.30	8.30	9.15	11.52
CT	1082.00	821.72	2425.00	175.00	2600.00	710.00	2100.00	2546.00
TB	95.68	153.08	625.00	10.00	635.00	60.50	72.50	347.00
COD	1622.33	1276.24	4468.00	265.00	4733.00	1280.00	2350.00	3909.00
BOD	885.73	784.44	2749.00	111.00	2860.00	606.00	1320.00	2336.80
SULF	165.31	77.39	210.60	71.00	281.60	130.90	251.30	278.78
T N	77.15	38.58	120.75	10.30	131.05	79.05	111.76	129.00
T P	4.56	4.60	16.80	1.00	17.80	2.50	7.60	12.73
SS	1082.78	1894.67	7577.60	30.30	7607.90	567.60	684.00	4213.70

Source: Field monitoring.

The COD recorded a minimum of 265.0 and a maximum of 4733.0 with the median at 1280.0. The 90^{th} percentile fell at 3909.0. These values indicate the strong nature



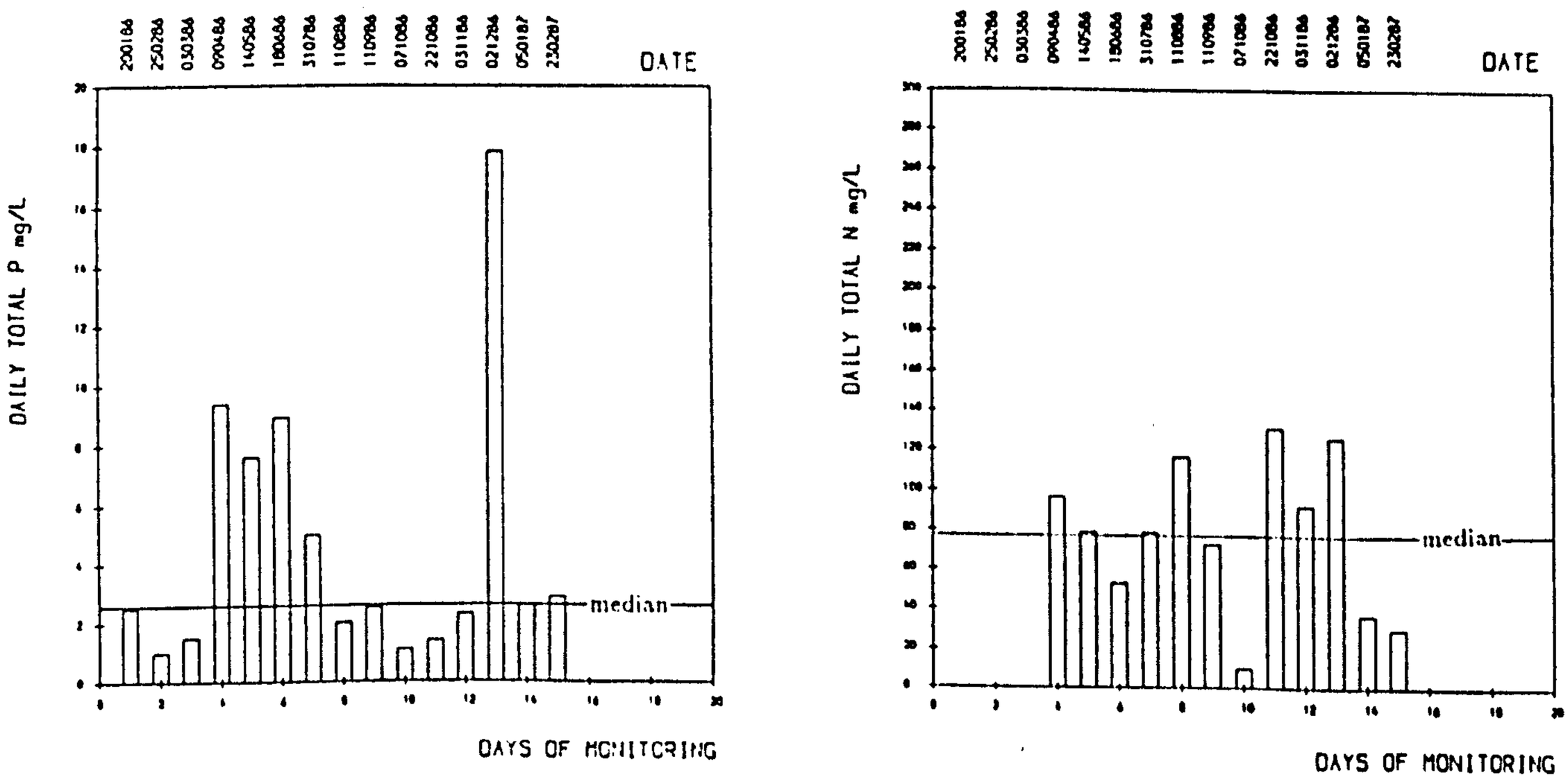


Figure 6.25 — Waste water concentrations in the dairy: A5

Source: Field monitoring

of the effluents. The range was very high with a value of 4468.0 and the standard deviation 1276.24. The high range and the standard deviation indicate the variability of the data.

BOD

The data variability in the BOD can be seen in table 6.33 and the daily concentrations in figure 6.25.

The BOD at A5 gave a minimum value of 111.0, maximum of 2860.0 and median of 606.0 mg/L. The 90^{th} percentile fell at 2336.8 mg/L. These values demonstrate the nature of the high concentration. Further the data variability is evident with a high range of 2749.0 and a standard deviation 784.44.

Relationships and effects

Therefore it becomes very clear that high COD and BOD, which is typical of highly organic waste waters, had corresponding low DO levels. Production in the creamery, being based mainly on milk and sugar, is highly organic and therefore produces an oxygen demanding waste. A very low DO of 2.6 mg/L was recorded on 21.01.86. when the COD was high with a value of 2916.0 and the BOD was 1988.0 mg/L. This indicates both the high organic content and the nature of the effluent (which has a very low DO content), that enters the receiving site U02.

When the effect of the discharges of A5 on the receiving site is considered, the values indicate that both the COD and BOD values were higher at A5 than at U02. The median COD at U02 was 773.0 and the median BOD 466.0. The median COD at A5 was 1280.0 while the median BOD was 606.0, which indicates that the factory values were higher than the lake COD and BOD values. Extremely high COD and BOD values of 4733.0 and 2860.0 respectively have been recorded at A5. The high organic load has a marked effect of the DO level in the receiving lake site U02. The DO had a very low minimum of 0.9, a maximum of 1.8 and a median of 1.3 mg/L. The very low DO levels at U02 indicated the high organic strength of the waste waters that entered this site from A5.

It has to be mentioned that at the site U02, waste waters from three factories i.e. from the meat processing industry (A3) the carbon dioxide plant (A4) and the creamery (A5), enter the lake at this point. Since both A3 and A5 have highly polluting organic wastes from food processing industries, the resulting very low DO levels in the lake site cannot be attributed to one particular industry alone, rather it is an accumulated effect of all three industrial waste waters that enter the lake at this point. However A3 has poorer quality waste water than A5. In addition to this the domestic sewage also finds its way into U02.

SS and turbidity

Data variability

SS

The data variability of SS in the creamery can be seen in table 6.33 and the daily concentrations in figure 6.25.

The SS at A5 had a minimum of 30.3 and a maximum of 7607.9. The median was 567.6. This indicated high concentrations. The 90^{th} percentile at 4213.7 further strengthens this. The range was very high with a value of 7577.6 and the standard deviation had a value of 1894.67. Thus the variability in the data was also very high.

Turbidity

The data variability of turbidity in the creamery can be seen in table 11.5. The turbidity had a minimum of 10.0 NTU and a maximum of 635.0. The median value was 60.5 with the 90^{th} percentile at 347.0. Thus turbidity also shows high values.

The range in turbidity was high with a value of 625.0, and the standard deviation of 153.08 also indicated the variable nature of the effluent.

The SS is related to the turbidity of the water. The highest SS value of 7607.9 mg/L corresponded to the highest turbidity value of 635.0 on 22.10.86 and the minimum SS of 30.3 corresponded to 12.5 NTU, although it was not the lowest turbidity recorded. The lowest turbidity of 10.0 had a SS value of 37.88 on 23.02.87.

Relationships and effects

The SS were some of the highest recorded in the industries monitored. The turbidity was also very high at A5, probably due to the high SS load. The high SS and the resultant turbidity may be due to the products themselves.The SS at the receiving site U02 also remained high, where the median was 100.1. The turbidity at

U02 also remained high and the median fell at 30.0. But both the SS and the turbidity were lower than at A5, which indicated that A5 contributes to a high SS load and therefore turbid waters. This can be expected in a milk based industry. Therefore A5 contributes to pollution by discharging a very high SS into the receiving site U02, and being higher than A3 discharges plays a significant part in lowering the U02 water quality.

Conductivity

Data variability

The data variability of conductivity in the creamery can be seen in table 6.33 and the concentrations in figure 6.25.

The conductivity in A5 was also fairly high. The minimum conductivity value was 175.0 μmhos/cm and the maximum reached 2600.0 with median at 710.0. The 90^{th} percentile fell at 2546.0. This indicated the high dissolved solid concentration in the effluent.

The variability in the data was represented in the range and the standard deviation. The range was high with a value of 2425.0 and the standard deviation fell at 821.72.

Relationships and effects

The conductivity at U02, the receiving site was also relatively high with the median value at 500.0 and the maximum value at 1120.0. This indicated that this site had comparatively high conductivity values although they were lower than at A5. The dissolved solids in the waste waters of A5 may contribute to the conductivity, but the high conductivity values at U02 were both due to the discharges of A5 and the cumulative effects of the other industries that discharged into U02, especially the very high conductivity waste from A3. and A3.

pH

Data variability

The data variability of pH in the creamery can be seen in table 6.33 and the daily concentrations in figure 6.25.

The pH at A5 ranged from a value of 5.3 to a value of 12.3. The median was 8.3. The range was high with a value of 7.0 and the standard deviation 1.78. This indicated the high variability of pH in the effluents.

Relationships and effects

The pH range indicated both acidic and alkaline waste waters, although the median indicated alkalinity. The lower pH value of 5.3 was due to the organic nature of the food waste water which on standing becomes acidic. The alkaline values of the effluent may be due to the detergents used for cleaning the vats and the floor in addition to bottle washing operations, which make the waste waters alkaline.

The pH at U02 was slightly less alkaline with minimum at 6.2 and the maximum at 9.0 while the median fell at 8.0. The median value was probably due to the neutralising effect of the waste water discharges. These values indicated that in terms of pH, the waste waters of A5 did not have a harmful effect on the receiving water at U02.

Water temperature

Data variability

The data variability of water temperature in the creamery can be seen in table 6.33. The water temperature at A5 had a minimum value of 28 °C and a maximum of 34.5. The median fell at 32.5. This indicates that the water temperature was not very high, but a range of 6.5 and a standard deviation 1.93 indicated that the variability in the temperature was fairly high.

Relationships and effects

The temperature difference at A5 was due to the boiling and chilling operations in the factory. However, as the median temperature at U02 was 1.5 °C lower than A5, the A5 waste would act to raise the water temperature of U02 slightly.

Total P

Data variability

The data variability of total P in the creamery can be seen in table 6.33 and the daily concentrations in figure 6.25.

The total P level at A5 recorded a minimum of 1.0 mg/L and a maximum of 17.8.

The median was at 2.5. The 90th percentile fell at 12.73.

The variability was high with a range of 16.8 and a standard deviation of 4.6.

Relationships and effects

The total P indicated a high range, which may be due to the discharge of effluents with detergents carrying phosphates. Being a creamery both the cleaning operations of the vats and the bottles and the floor are performed daily. The total P at U02 had a median of 2.5 and a maximum of 11.35, which was similar to A5, but slightly lower. This indicates that there is some contribution into the receiving site. The principal source of total P however is from the meat processing plant A3. The presence of aquatic plants such as *Eichornia crassipes* indicated the discharge of this nutrient.

Total N

Data variability

The data variability in total N can be seen in table 6.33 and the concentrations in figure 6.25.

The total N level at A5 was one of the highest recorded in all the industries, except for the meat industries. The minimum was 10.3 and the maximum 131.05 mg/L. The median was 79.15. The 90th percentile fell at 129.5. As with the other food industries the data variability is high. This can be seen in the range and the standard deviation.

Relationships and effects

The nitrogeneous matter in the waste water was high at A5. This may be due to the main ingredient milk, which has a high nitrogen content. The total N in the lake site U02 was also high with the maximum at 72.0 mg/L and the median value at 39.2. Although the total N at U02 was not as high as A5, the contribution from A5 to U02 will be considerable. Therefore the nutrient content at U02 was increased due to the waste water discharges from A5, which added to the extremely high total N discharges from A3. The aquatic plants at the receiving site reflected the effects of the high total N content of the factory discharges.

Sulphates

The data variability of sulphates can be seen in table 6.33.

The sulphates at A5 had a minimum value of 71.0 mg/L, maximum of 281.6 and a median of 130.0. The 90th percentile was 278.7. The range was 210.0 and the standard deviation 77.39 indicated variability in the data.

The sulphates at the receiving site U02 was higher than at A5. The minimum of 96.2, maximum of 290.7 and the median value of 182.0 remained higher than A5 and therefore A5 is not a contributory industry as far as sulphates are concerned.

6.7.6 Margarine effluents

The factory C was monitored at two points the margarine outlet (C1) and the fat trap (C2). C1 was sampled from the drain just outside the margarine department. Access to the production area was not given. Therefore the sample collected from the point C1 was the final effluent from factory. The sample was collected from the waste water drain within the factory premises, but outside the production unit.

The site C2 was sampled from the fat trap which is at the far end of the factory which is within the factory premises and near the canal. Effluent from the factory was discharged into the San Sebastian canal at site S06 without any treatment other than the fat trap, where fats and oils are collected for reuse.

The factory site C1 and C2 were monitored on a monthly basis except in July and November 1986. Sampling was done twice in October 1986. The total N was not monitored in January and February 1986. C1 and C2 had a monitoring frequency of 13 during the entire period of monitoring and the sampling programme was carried out in the mornings between 10.55 and 12.38 at C1, and 11.06 and 12.45 at C2. Being a private multinational company, not much encouragement was given to the pollution monitoring programme. Photographs were not allowed in the factory and the responsible staff gave their cooperation within the strict limitations of the factory regulations.

COD, BOD and DO: Data variability

COD

The data variability of COD in the factory can be seen in table 6.34 and 6.35 and

Table 6.34 — Variability in data: factory site C1

Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75th %	90th %
DO	2.57	1.78	5.10	0.10	5.2	2.60	4.5	5.0
W T	34.40	5.85	15.00	30.00	45.0	31.50	41.1	44.4
pH	8.03	1.10	3.90	5.00	8.9	8.30	8.8	8.9
CT	485.80	164.47	550.00	200.00	750.0	520.50	641.2	720.0
TB	16.42	7.16	21.50	8.00	29.5	14.00	23.5	23.5
COD	358.07	158.26	534.00	152.00	686.0	368.00	465.0	611.6
BOD	199.38	145.00	463.00	63.00	526.0	153.00	314.5	474.8
SULF	128.43	99.09	373.20	27.10	400.3	108.60	183.8	317.6
T N	15.00	6.19	20.46	6.84	27.3	15.61	18.3	26.3
T P	3.56	2.04	6.85	0.40	7.2	3.20	5.0	6.8
SS	70.50	37.22	127.69	9.90	137.6	78.56	96.6	125.0

Source: Field monitoring

Table 6.35 — Variability in data: factory site C2

Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75th %	90th %
DO	0.95	1.18	3.10	0.0	3.1	0.2	2.0	2.98
W T	33.60	1.90	5.50	31.0	36.5	34.0	35.0	36.50
pH	8.50	0.67	2.20	6.9	9.1	8.7	8.8	9.10
CT	721.10	254.50	900.00	300.0	1200.0	725.0	905.0	1090.00
TB	38.65	13.13	43.00	7.5	50.5	42.5	47.5	50.30
COD	490.80	248.60	1000.00	216.0	1216.0	398.0	559.0	995.60
BOD	316.46	197.84	790.00	76.0	866.0	269.0	384.5	716.40
SULF	394.80	392.36	1014.10	63.1	1077.2	169.0	881.7	1030.70
T N	14.34	9.62	27.01	5.3	32.3	9.3	21.6	30.57
T P	4.10	2.50	8.25	0.6	8.8	4.2	5.7	8.25
SS	301.53	235.40	924.90	10.2	935.2	283.0	414.5	759.30

Source: Field monitoring.

the concentrations in figures 6.26 and 6.27 for C1 and C2 respectively.

The COD of factory at C1 had a minimum value of 152.0, a maximum of 686.0 and a median value 368.0. The 90^{th} percentile fell at 611.6. Thus the COD indicated very high concentrations. The range at C1 was 534.0 and the standard deviation 158.26. The data variability can be seen in these values.

The COD at the site C2 had a minimum value of 216.0, a maximum value of 1216.0 and a median of 398.0. The 90^{th} percentile fell at 995.0. Thus the concentrations were higher than at C1. The range was 1000.0, and the standard deviation fell at 248.6. Both the range and the standard deviation were higher than at C1, indicating a higher variability of the data.

BOD

The data variability at C1 and C2 can be seen in the table 6.34 and 6.35 and the concentrations in figure 6.26 and 6.27 respectively.

The BOD at both C1 and C2 had high values. The minimum recorded at C1 was 63.0, the maximum 526.0, the median 153.0. The 90^{th} percentile fell at 474.8.

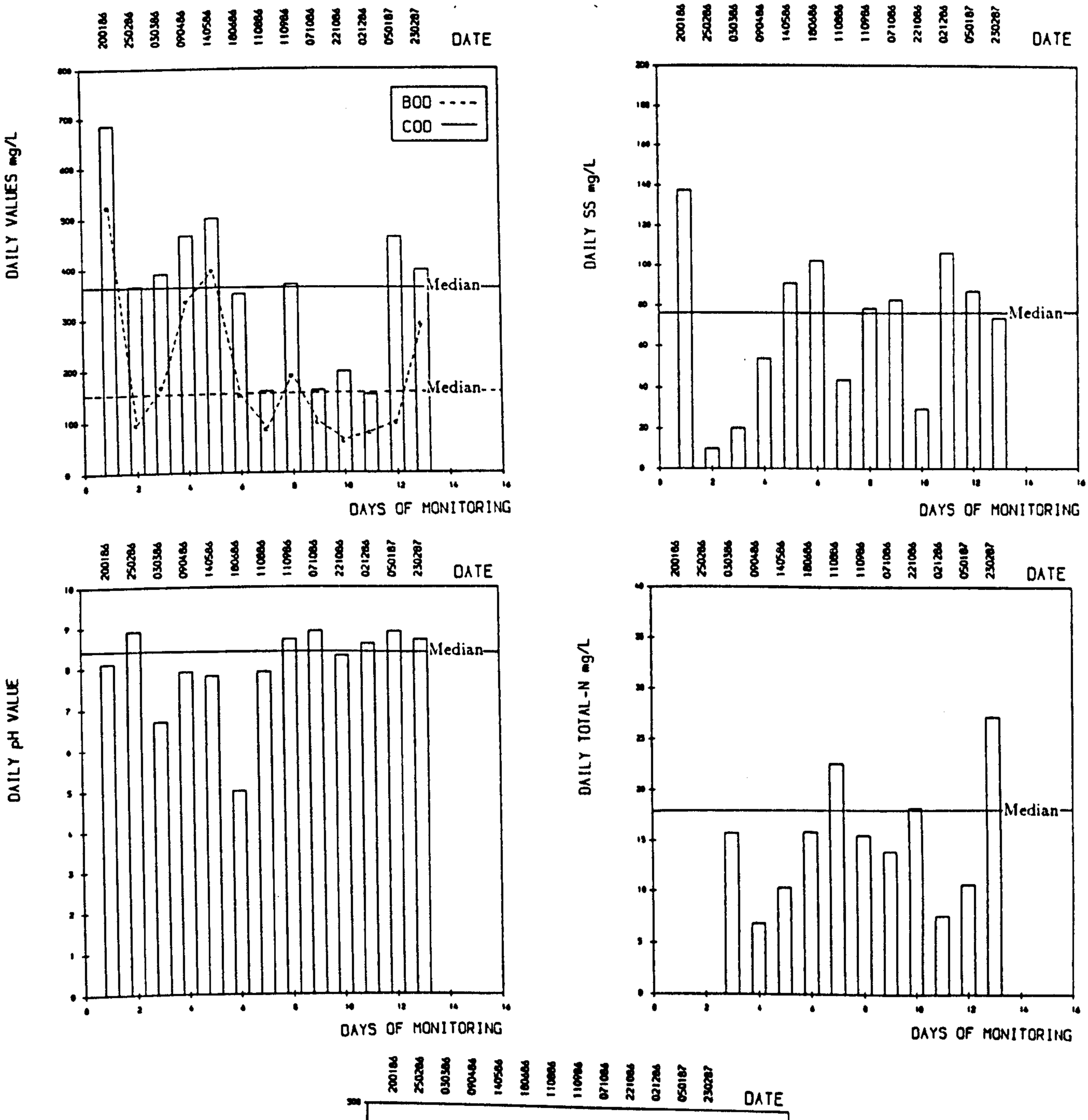


Figure 6.26 — Waste water concentration in a margarine plant: C1

Source: Field monitoring

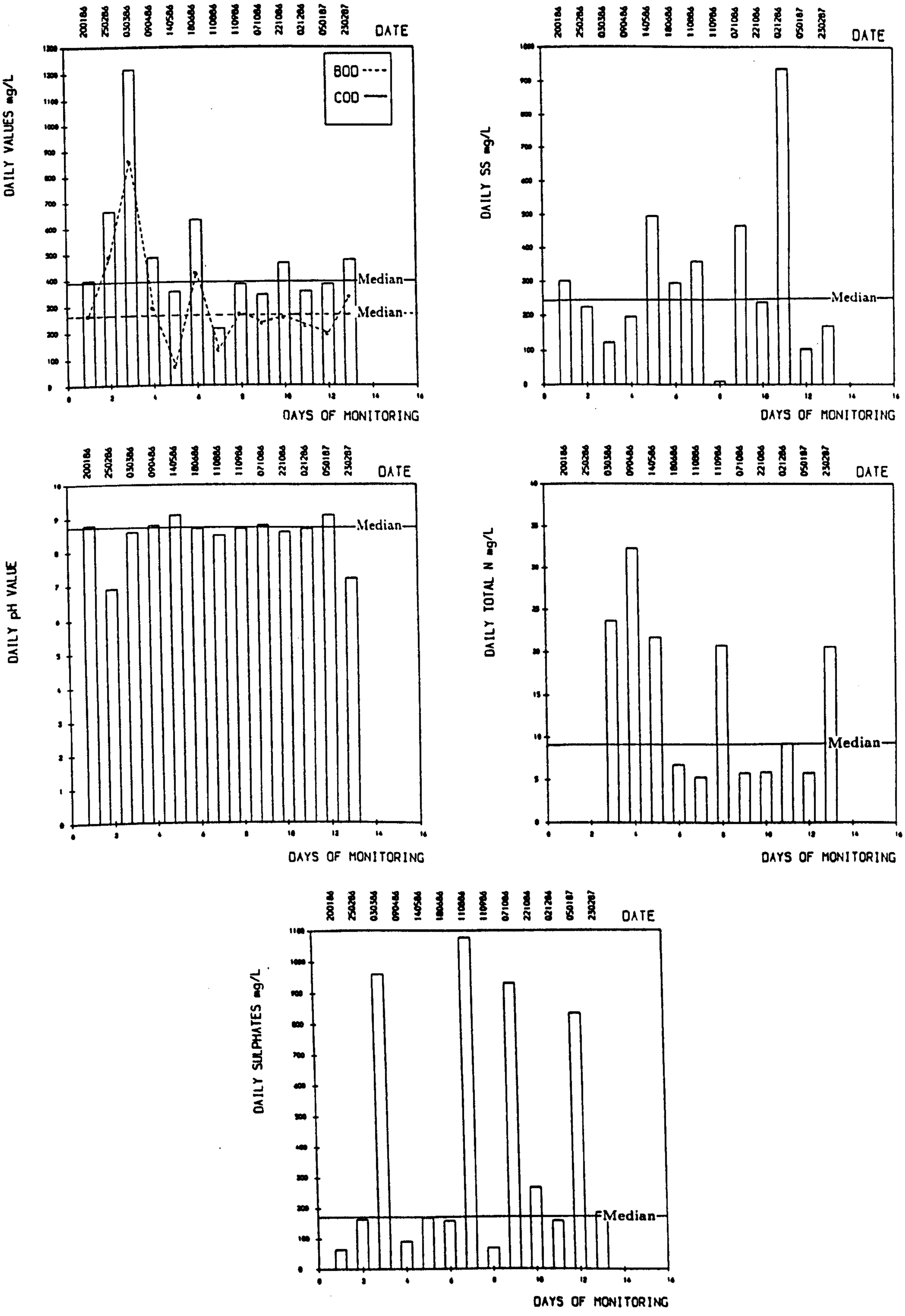


Figure 6.27 — Waste water concentration in a fat trap: C2

Source: Field monitoring

These indicate the strong nature of the waste waters. The range was 463.0 and the standard deviation 145.0. These indicated the variable nature of the wastes.

The BOD at C2 had higher values. The minimum was 76.0, maximum 866.0, and the median 269.0. The 90^{th} percentile fell at 716.5. These values indicate stronger wastes. The range was 790.0 and the standard deviation fell at 197.84. The high range and the standard deviation indicated the variability of the concentrations.

Relationships and effects

The COD and the BOD values showed that the waste waters from C1 and C2 were highly organic, which demands a high oxygen level for biodegradation. Although the COD and the BOD values were high, as a food industrial group this industry had lower organic content in terms of the COD and BOD when compared with the soft drinks, confectionery and the meat processing industries. The COD was higher at C2, due to higher concentration of oils and fats at the fat trap.

When the effects of the high COD and the BOD of C1 and C2 on the receiving canal site S06 is considered, the COD and the BOD at S06 remained very high. A minimum of 64.0 mg/L, maximum of 696.0 and a median of 402.0 mg/L were recorded for the COD. The BOD had a minimum of 39.0 mg/L a maximum of 581.0, and a median of 293.0 at S06. The median COD was higher at S06 with a value of 402.0 mg/L than at the sites C1 and C2 which had 368.0 and 398.0 respectively. The maximum level at S06 was 696.0, while the maximum level at C1 and C2 were 686.0 and 1216.0 respectively. The minimum COD level recorded at C1 and C2 were three to four times the minimum COD value of S06. The maximum BOD at C2 was higher than at S06 and the minimum recorded BOD at C2 was almost double the BOD at S06. The median at S06 was higher with a value of 293.0, while C2 had 269.0. C1 had a minimum value which was higher than the BOD at S06, while the maximum, although slightly lower than the canal site, had a very near BOD value of 562.0 against 581.0 at S06. These BOD and COD values at C1, C2 and S06 indicated that the factories sites were partially responsible for the high organic content in the receiving canal site S06.

The DO had a minimum of 0.0, a maximum of 2.5 mg/L and the median DO was 0.05 mg/L at S06. This site was one of the most polluted canal sites in the entire monitoring programme, where the DO levels remained very low throughout the monitoring period.

The DO content in the waste water was low at both sites, having median values of 2.6 and 2.2 at C1 and C2 respectively. Being a vegetable oil and milk based product the margarine outlet had a very low DO, although the maximum DO value had reached 5.2 mg/L. Margarine, edible fats and oils were produced in this department had high oxygen demanding wastes which deplete the oxygen very rapidly. The site C2, which is the fat trap, had a very low DO content. The minimum recorded was 0.0 mg/L and the maximum 3.1. The median value fell at 0.2, while the 90^{th} percentile fell at 2.98 mg/L. The range was 3.1 and the standard deviation 1.18. Therefore this site had very low DO levels, and the waste waters from C1 and C2 entered the canal at S06 untreated.

In contrast to S03 there were no shanties in the immediate vicinity of S06. Therefore the very low DO cannot be attributed to domestic sources. In addition to the high oxygen demanding waste waters, a film of oil was always visible at this site which prevented atmospheric oxygen from penetrating into the surface water of the canal and therefore hindered the aeration process. Comparing the DO at C1, C2 and the receiving site S06, it can be said that all the three sites had very low DO values; although C1 had a slightly higher median of 2.6 mg/L while C2 and S06 had 0.2 and 0.05. This indicates that the very low DO level in the canal is partially due to the waste waters from C1 and C2 that enter the canal untreated. In addition to the oils and edible fats this industry produced many other products such as toiletries, personal use items, toothpaste, soaps and washing powder. The waste waters from these departments also entered the San Sebastian canal at S06 untreated as did the domestic waste water from the factory toilets. There were three major waste water outlets into the canal from this site. This indicated that the DO content in the factory sites had very low DO levels capable of bringing about septic and anaerobic conditions in the canal. This is due to the high organic content of the wastes. Hence the receiving site S06 can be explained in terms of the organic load (COD and the

BOD) of the waste water from the factory sites.

SS

Data variability

The data variability for the SS can be seen in table 6.34 and 6.35. The daily concentrations can be seen in figures 6.26 and 6.27 for C1 and C2.

As seen in the table the SS is lower at C1 than at C2 with a median of 78.56 mg/L. This can be seen in the 90^{th} percentile of 125.08 mg/L. The range and the standard deviation too were comaparatively lower.

The SS at C2 was higher with a minimum of 10.22, maximum at 935.2, and the median value at 238.0. The 90^{th} percentile had a value of 414.5 and 759.3. The range was 924.9 and the standard deviation 235.4. The higher range and the standard deviation indicated a degree of variability which was high.

Relationships and effects

The lower SS at C1 may be due to the nature of the product. Good housekeeping practices within the industry may be also a contributory cause. C1 recorded one of the lowest SS loads in the industries monitored. The solids at C2 was much higher with the maximum reached, 935.2. The higher SS at C2 may be due to accumilation of SS in the fat trap.

The SS at the receiving site S06 had a minimum of 30.55, maximum of 488.3 and the median value of 89.0. The SS at the canal site therefore was lower than at C2 in terms of the median value. The minimum SS recorded at S06 i.e. 30.55 was higher than both C1 and C2. This indicated the high base level SS at S06. The median SS at S06 was higher than at C1, but lower than at C2. The SS load in the receiving site was the second highest recorded in the canal. This higher load at S06 on the canal is mainly the result of waste from factory C.

Turbidity

Data variability

The data variability in the turbidity can be seen in table 6.34 and 6.35. The turbidity at C1 was lower than at C2. This can be seen in the above table. The turbidity at C2 recorded a minimum of 7.5, maximum of 50.5, a median value of 42.5. The 90^{th} percentile fell at 47.5 respectively. The range was high with 43.0 and the standard deviation, 13.13.

Relationships and effects

The turbidity at C1 was one of the lowest recorded among the industries. C2 had highly turbid waters, with high values recorded next to B1 and A5. Thus the suspended solid load at and C2 is reflected in the turbidity of the waste water. The turbidity at the receiving site S06 was the second highest in the San Sebastian canal with a median of 22.07, and the maximum reached at 70.0. The minimum recorded was a close second to S03 with a value of 8.25, which suggested that the waters were generally turbid at this site an impression confirmed by visual observation. The median of 42.5 at C2 was almost double the median value of S06. This indicated that C2, which had higher SS and turbidity values, contributed to a higher SS load and therefore turbid waters at the receiving site S06.

Conductivity

Data variability

The conductivity data is shown in table 6.34 and 6.35. The conductivity at C2 was higher than at C1 with the the minimum at 300.0 μmhos/cm, maximum at 1200.0 and the median at 725.0. The 90^{th} percentile fell at 1090.0. The range was 900.0 and the standard deviation 254.5. These indicated both the strength of the waste waters and the nature of the discharges, which were highly variable.

Relationships and effects

The conductivity at C2 was higher than at C1. This may be due to the concentration of dissolved salts in the fat trap which are contained in the the oil based products. The conductivity at C2 was low when compared to some of the other industries.

The conductivity at the receiving site S06 had values that were lower than at the factory site. The minimum recorded at the site was 400.0, maximum 1585.0, median 615.0, and the 90^{th} percentile fell at 828.0. Although the median was higher at C2, S06 still had higher minimum and maximum conductivities. It showed that the canal site was receiving continued discharges of dissolved solids which made the

water conductive. This discharge was obviously from factory site C2 which had a higher median value than site S06.

pH

The data variability in pH can be seen in table 6.34 and 6.35 and the daily concentrations in figures 6.26 and 6.27.

The pH had a wider range at C1 than at C2, although the median was lower in comparison. The pH at C1 ranged from an acidic value of 5.0 to an alkaline value of 8.9. The median was 8.3. The 90^{th} percentile fell at 8.9. The range had a value of 3.9 and the standard deviation was 1.1. Thus the variability of the data was higher at C1 although the concentration was comparatively lower.

Relationships and effects

It is understandable that the margarine wastes have acidic waste waters. This is due to the acidic nature of certain production processes. The alkaline values may be due to the cleaning operations in the factory which used detergents. This factory used detergents (mainly washing powder) freely as it is a product manufactured at the factory. On a few occasions it was observed that there were spillages of detergents in the factory premises, which would enter the waste water drains.

The median pH at S06, the receiving site, was alkaline with a value of 8.67. The minimum was 8.0 and the maximum reached 10.1. These high pH values recorded on certain days could be due to factory waste waters. It has to be taken into consideration that there are other products (toiletries) manufactured in this factory with other waste water streams that enter the canal. These could contribute to values usually not associated with the food industries.

Water temperature

Data variability

The data variability for water temperature can be seen in table 6.34 and 6.35.

The water temperature at the site C1 recorded a minimum of 30 °C, a maximum of 45.0 and a median of 31.5 °C. This was higher than at C2. Both the range and the standard deviation indicated high variability.

Relationships and effects

Although the median water temperature was low at C1, high water temperatures of 40.2 to 45.0 have been recorded on a few occasions (appendix F). These high levels could be due to the effluent process water or washing of mixing vats, which requires water with a high temperature as it is oil based.

The water temperatures at C2 were near or slightly above, the daily maximum air temperatures recorded (possibly more stabilised on standing), but it did not record exceptionally high water temperatures.

The water temperature at S06 was very similar to C2 with the median at 34.0 and the maximum at 36.5. The water temperature at the receiving site S06 with a median of 33.0 was higher than the sites which were free from industrial discharges such as S01 and S02, which had median water temperature of 31.0 and 31.1. This indicated that the industry contributed to a higher water temperature at the receiving site.

Total P

Data variability

The data variability can be seen in table 6.34 and 6.35.

Factory site C2 had similar, but slightly higher total P values than C1. The minimum was 0.6, the maximum 8.8 and the median 4.25. The 90^{th} percentile was 8.25. The median indicated fairly moderate values although the the maximum value was high. The range was 8.25 and the standard deviation 2.5. These indicated the variable nature of the effluent.

Relationships and effects

In comparison with the other industries, the phosphates values were moderate. The total P in the waste waters could be from the product itself and from the detergents used for cleaning purposes. The receiving canal site S06 had phosphate levels higher than the other canal sites, as its highest median level recorded had a value of 3.25. The minimum was 0.0 and the maximum 6.25. The 0.0 phosphate level could be an error in the measurement or the concentration too low to be detected. The total P in the canal site was obviously from the factory sites, since there were no immediate domestic waste water sources. This could be due to the phosphate based detergents that entered the canal from the other production departments in the factory through

other waste water drains.

Total N

Data variability

The data variability in total N can be seen in table 6.34 and 6.35 and the concentrations in figure 6.26 and 6.27 for C1 and C2 respectively.

The total N at C1 had a minimum recorded value of 6.84, a maximum of 27.3 and a median of 15.61. The 90^{th} percentile fell at and 26.36. These values were higher than the values at C2. The range was high with 20.46 and the standard deviation was 6.19. These indicate that the variability of the effluent was high.

Relationships and effects

The higher total N values at C1 may be due to the nitrogeneous vegetable oil based (oils and fats) products such as margarine. In comparison with the other industrial groups monitored, the margarine effluents had moderate total N levels. They were higher than for the soft drinks group and the confectioneries but lower than in meat processing industries.

The total N level at S06 had a median value of 12.56 which was close to C1, with 15.61. The maximum recorded at C1 was higher than at S06. The total N discharges into the canal are from the factory sites which have a higher total N content. This becomes obvious since there are no domestic sources in the immediate vicinity to contribute total N into the canal, although there could be total N flow from upstream sites S04 and S05, which had both industrial and domestic sources. On the other hand the flow in the canal was very low (except during the rainy season), therefore the bulk of the total N that enter the canal at this site had to come from industrial site C1 (other waste water outlets of the factory might contribute). Since total N and total P were moderately high at S06, it was surprising that aquatic plants were not observed at this site, other than the aquatic plants which floated during rainy weather. It is possible that the canal near the factory C area were scooped and manually cleaned from plant material and the canal at this point was kept visually clean although chemically and physically polluted. This could be surmised from the general cleanliness observed even in the backyard of the factory with plants grown within the industrial limits along the canal. The canal sites above and below such as S03, S04 and S07 had aquatic plants.

Sulphate

Data variability

The data variability can be seen in table 6.34 and 6.35 and the daily concentrations in figures 6.26 and 6.27.

The sulphate values at C1 and C2 were fairly high. The sulphates at C2 had higher values than at C1 with the minimum at 63.1, maximum at 1077.2, the median at 169.0 and the 90^{th} percentile at 1030.7. The range at C2 was very high with 1014.1 and the standard deviation 392.36. As with the other pollutants the variability was high.

Relationships and effects

The high sulphates at C1 and C2 may be due to the use of sulphuric acid in the production process of margarine and other edible fats. The receiving site S06 had the highest sulphate median recorded for the San Sebastian canal with a value of 170.6 mg/L. The maximum recorded was 511.0, although this was not the highest value recorded in the canal. The sulphates at S06 were higher than at S05 and S07. This makes it clear that the canal receives sulphates from these factory sites.

6.7.7 Other food effluents

Jam factory effluents

A1, the jam factory of the A group of industries, was also monitored on 20.01.86. The data can be seen in appendix F. After the first sampling this factory site was bombed and thus ceased production.

The sample was collected from the drain immediately outside the department but within the factory premises. Effluent sampling from each manufacturing process was not possible since access into the production area was not given. Therefore the sample may contain materials other than the raw materials used for production process, such as the detergents used in floor washing.

The results indicate a very high organic content in terms of the COD and the BOD. It also had a high SS concentration. The turbidity was also high. The effect on the receiving site was be highly detrimental on the DO demand.

Yeast extract effluents

A sample from factory K, a yeast extracting factory (marmite) was analysed once. The concentrations are given in appendix F. This sample was taken for a different research, but is included here since it is also food wastes. The sample was analysed on 13.06.86. The results gave a very high COD and BOD, a low DO, high SS and turbidity and a high conductivity. Both A1 and K show high organic waste from the food industries.

Raw water (A6)

A6, which is tap water from the A group of factories, was monitored once on 20.01.86. The analysed data can be seen in appendix F.

Water temperature, sulphate, total N and total P were not monitored. This can be used as the reference sample of unpolluted water. The monitored variables met all the standard specifications. This is the quality of the water supplied by the municipality.

Comparing the factory waste waters with the analysed tap water, it can be said that the water is used in the production process in most of the food industries is of a high quality, but leaves the factory outlets as highly polluted water.

6.8 Pollution from other industries

6.8.1 Natural oil based effluents (soapery)

The factory group B was monitored at two sampling points at a monitoring frequency of 14 during the research period. This factory was abbreviated B1 and B2, the former representing the soap effluent and the latter, the waste water from the cooling water tank. The monitoring was done on a monthly basis except in October when the sampling was carried out twice and in June when sampling did not take place. Total N was not monitored in January and February 1986. Samples were taken from effluent drains within the factory premises, but just outside the production departments. In soap manufacture (although not a food industry) most of the raw materials used are natural products such as coconut oil, palm oil and tallow. Therefore the effluent generated is organic. This factory was selected for monitoring for two reasons. Firstly it was originally an oil processing mill based on coconut copra and the largest oil mill in Asia (although by the time of the monitoring period the oil production had stopped completely). Only oil based products, such as soaps, and cooking oil based on oils from outside markets were manufactured. Secondly, it was directly discharging its waste waters into the San Sebastian canal (at S03). Although the factory was accessible, the data and a proper monitoring programme was hindered due to the lethargic attitude of the management.

COD, BOD and DO

Data variability

COD

The data variability at B1 and B2 for COD can be seen in tables 6.36 and 6.37. The concentrations at B1 can be seen in figure 6.28.

The COD at B1 was higher than at B2. The COD at B1 had a minimum of 437.0 mg/L and a maximum of 26,100.0. The median was 6429.0. The 90^{th} percentiles fell at 21850.0. This indicated very high concentrations. The very high variability in the data was evident in the range which was very high with 25663.0, and in the standard deviation of 7718.4. The COD at B2 also had fairly high concentrations.

BOD

The BOD data variability at B1 and B2 can be seen in table 6.36 and 6.37 and the concentration at B1 in figure 6.28.

The BOD was higher at B1. The BOD at B1 had a minimum of 165.0 mg/L a maximum of 13100.0 and a median of 2108.0. The 90^{th} percentile fell at 12717.5. Therefore the BOD in the factory site was very high. It was also very variable as the range had a value of 12935.0 and the standard deviation was 4421.0. The BOD at B2 also had fairly high concentrations.

Table 6.36 — Variability in data: factory site B1

Poll.	S.D.	Ran.	Min.	Max.	Med.	75th %	90th %
DO	1.64	4.4	2.1	6.5	4.0	5.9	6.4
W T	4.35	13.5	30.0	43.5	35.5	40.0	42.7
pH	1.45	4.4	8.4	12.8	9.6	11.6	12.3
CT	6720.30	20610.0	390.0	21000.0	925.0	3490.0	19550.0
TB	79.49	282.5	17.5	300.0	61.5	132.5	250.0
COD	7718.40	25663.0	437.0	26100.0	6429.0	13850.0	21850.0
BOD	4421.00	12935.0	165.0	13100.0	2108.0	5866.2	12717.5
SULF	822.36	2939.7	58.6	2998.3	188.1	454.0	2100.3
T N	2.07	6.3	0.0	6.3	2.4	4.3	5.8
T P	5.62	16.0	2.1	18.2	4.2	12.5	17.4
SS	2352.50	8826.0	98.0	8924.0	619.9	1444.5	6292.3

Source: Field monitoring.

Table 6.37 — Variability in data: factory site B2

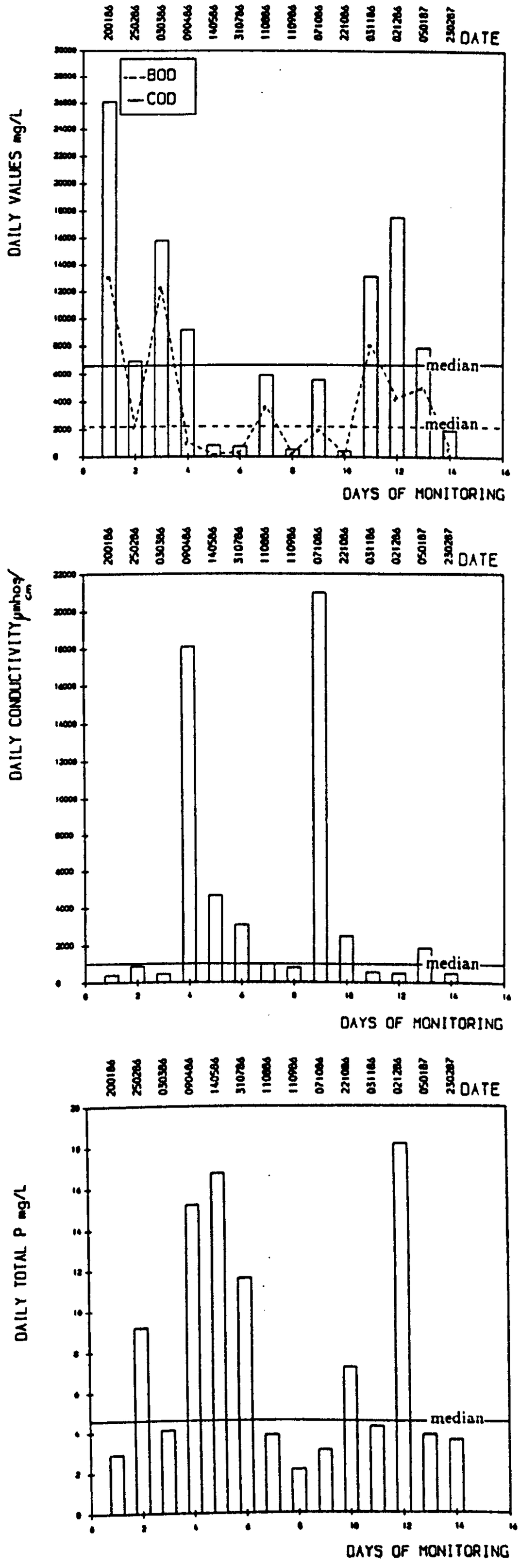
Poll.	Mean	S.D.	Ran.	Min.	Max.	Med.	75th %	90th %
DO	0.29	0.56	2.0	0.00	2.0	0.00	0.37	1.45
W T	37.17	3.40	12.0	32.00	44.0	37.25	39.12	42.50
pH	8.80	0.27	0.9	8.30	9.2	8.90	9.12	9.20
CT	616.00	457.50	1270.0	160.00	1430.0	382.50	1122.50	1325.00
TB	28.82	12.87	35.5	7.50	43.0	26.00	37.62	42.50
COD	282.16	184.13	549.0	88.00	637.0	250.00	4411.00	602.00
BOD	168.54	135.58	382.0	42.00	424.0	120.30	285.00	417.50
SULF	109.73	52.81	152.3	50.60	202.9	88.20	155.15	201.40
T N	2.67	2.08	5.5	0.80	6.3	1.69	5.10	6.09
T P	2.44	1.14	3.6	0.95	4.6	2.32	3.37	4.42
SS	138.91	98.92	329.0	10.07	339.0	122.90	203.80	302.60

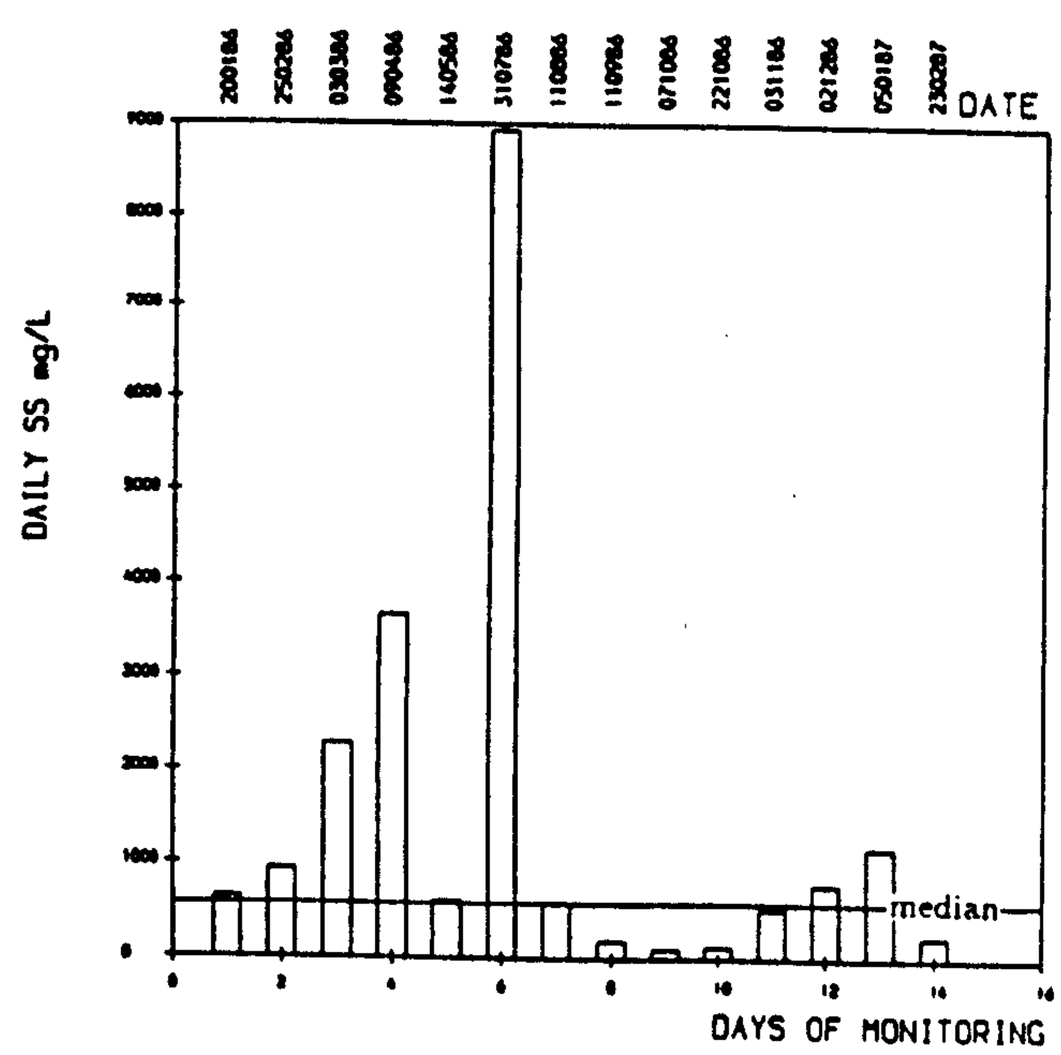
Source: Field monitoring

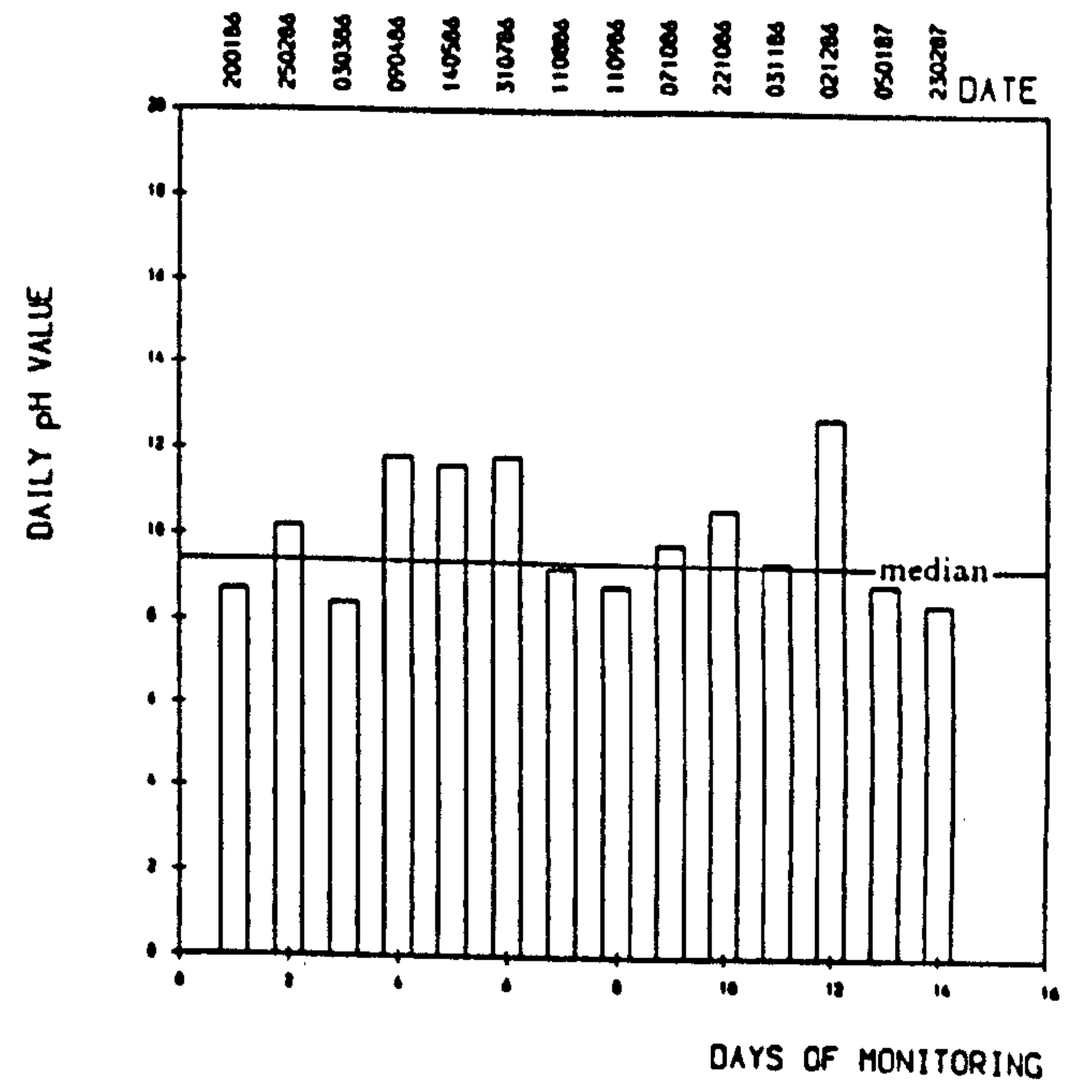
Relationships and effects

The COD and the BOD remained high in both sites, and and at B1 it was exceptionally high. This shows the high strength of the organic waste waters of this industry, which is mostly coconut oil based. Oil is an highly oxygen demanding waste. Among the monitored industries B1 had the highest median value of 6429.0 while the second highest median value was 4167.0 at F The highest recorded maximum value was 26100.0 for COD at B1. The BOD was also very high at B1. The second highest BOD maximum value of 13100.0 mg/L and the median value of 2108.0 were recorded at B1. The highest BOD for the industries was recorded at factory F.

The COD and the BOD were much higher at B1 than the receiving site S03 on San Sebastian canal. The COD at S03 had a median of 368.5, minimum of 38.0 and a maximum of 1322.0. The corresponding BOD values for the site was 226.5, 21.0 and 870.0 respectively. Therefore these indicated that the factory B1 was a contributory industry of a very high organic load into the canal site S03. This was reflected in the BOD of the canal.







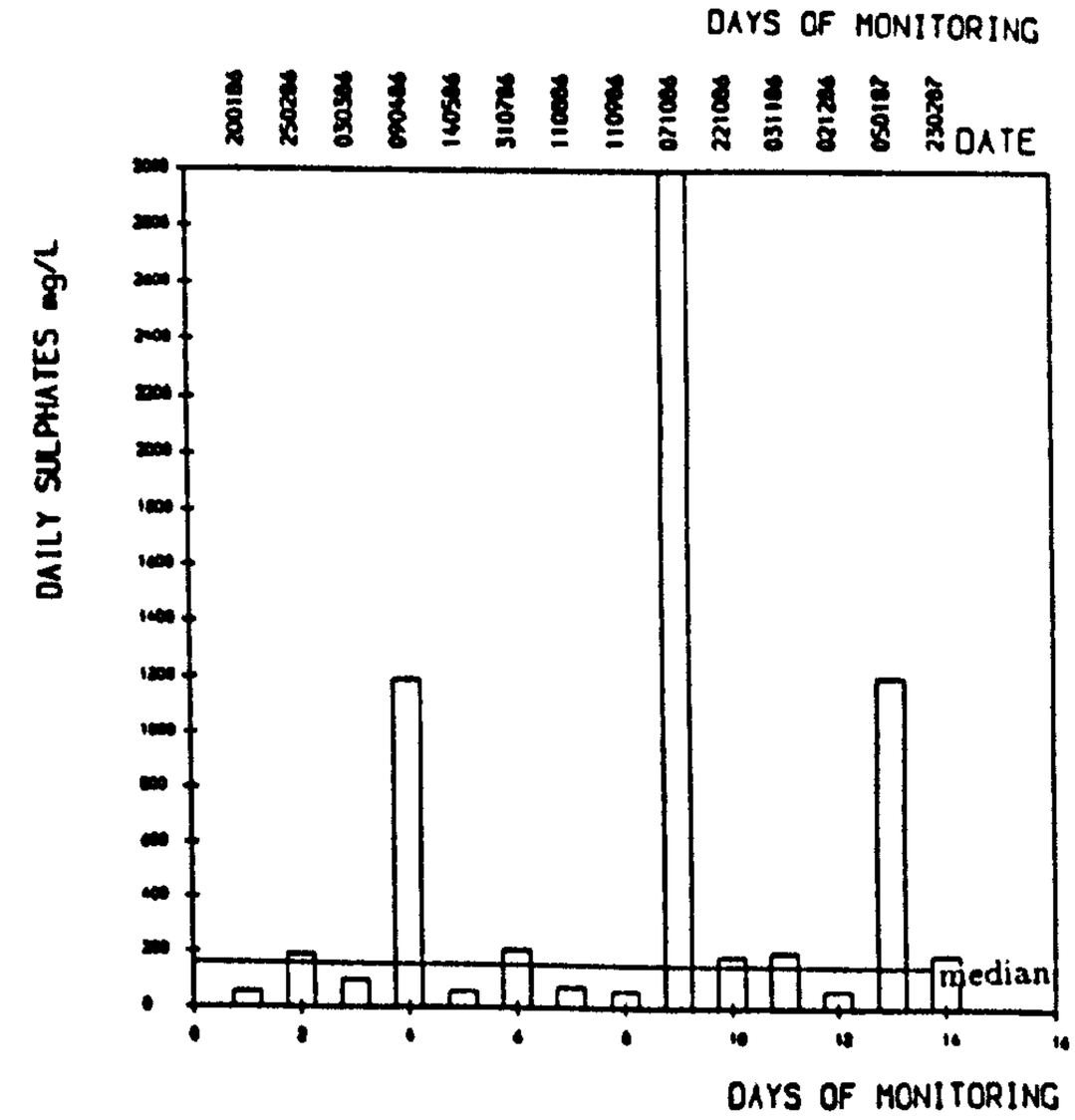


Figure 6.28 — Waste water concentrations in the soapery: B1

Source: Field monitoring

Site B2 had COD and BOD values similar to the receiving canal site S03. The COD median at S03 was 368.5, while at site B2 it was 250.0. The BOD median at S03 were 226.5 while at B2 it were 120.3. The COD minimum and maximum at S03 were 38.0 and 1322.0, while it was 88.0 and 637.0 at B2. The BOD minimum and maximum at S03 was 21.0 and 870.0 and at B2 42.0 and 424.0 respectively. These values indicated that the canal site S03 had higher COD and BOD values than B2, although the same canal water was used for cooling purposes. The higher organic content in the canal water in terms of the COD and the BOD was therefore due to the highly organic waste water that entered from B1. The high organic load from the factory was well reflected in the very low DO content of the canal water at the receiving site.

DO

Relationships and effects

The data variability in the DO at B1 and B2 can be seen in table 6.36 and 6.37.

At B1, the DO minimum was 2.1, maximum 6.5 and the median remained at 4.0. The 90^{th} percentile fell at 6.45. Thus the DO was not very low. The variability was high as seen in the range and the standard deviation. The range was 4.4 and the standard deviation 1.64.

At site B2, the DO had a minimum of 0.0 mg/L and a maximum of 2.0, with the median at 0.0. The 90^{th} percentile fell at 0.37 and 1.45. This indicated very low values. The variability in the DO was low as seen in the range and the standard deviation. The range was 2.0 and the standard deviation 0.56.

Relationships and effects

The DO ranged widely at B1. It is not clear as to why the DO remained moderate although the COD and BOD were very high at this site.

The DO at B2 resembled that at site S03. This may be due to the water being drawn from the canal for cooling purposes. Although the DO of the water did not directly affect the receiving site, it reflected the highly organic nature of the waste water that was discharged into the canal. The organic wastes deplete the DO of the receiving site. The DO level in the canal was very low at S03, with a minimum of 0.0, maximum of 0.9 and a median of 0.03 mg/L.

SS

The data variability at B1 and B2 can be seen in table 6.36 and 6.37 and the concentrations in figure 6.28.

The concentrations were higher at B1. The SS minimum recorded at B1 was 98.0 and the maximum 8924.0. The median fell at 619.9. The 90^{th} percentile was 6292.3. This indicated very high SS. The highly variable nature of the effluent is evident in a high range of 8826.0 and a standard deviation of 2352.5.

The SS at B2 had a minimum of 10.07, maximum of 339.08 and the median fell at 1229.9 with the 75^{th} and 90^{th} percentile falling at 203.8 and 302.6 respectively. The range was 329.01 and the standard deviation 98.92.

Relationships and effects

The SS is obviously higher at B1. This may be seen from the solids from the production drains which are led through the monitored site. Soap concentrates (referred to as nigger) was seen in the monitored site. The highest SS recorded among the industries monitored was at B1 with a value of 8924.0. The highest median of 619.9 was also recorded at this site.

The SS at S03 was lower than at B1. The median at S03 was 80.7, maximum was 483.6, and the minimum 29.0. This indicated that factory B1 contributed heavily to the SS load of the San Sebastian canal. This was further strengthened by the SS load of B2 with a median value of 122.9 which was higher than at S03, but both the minimum and the maximum SS recorded remained higher at S03. Therefore, it can be said that the higher contribution of SS at S03 is from the waste water of the factory site B1.

Turbidity

Data variability

The data variability at B1 and B2 can be seen in tables 6.36 and 6.37.

The turbidity at B1 was the highest recorded for the industries monitored with a minimum of 17.5 NTU, maximum of 300.0 and the median at 61.5. The 90^{th} percentile

was 132.5. The range was high with 282.5 NTU and the standard deviation 79.49. This indicated the highly variable nature of the data. In comparison the turbidity at B2 was lower.

Relationships and effects

The turbidity values reflected the SS at both B1 and B2. The waste water at B1 was very turbid, this is a reflection of the very high SS values recorded at this factory. B1 had the highest turbidity median of 61.5.

The turbidity at B2 had a higher median value than the receiving canal site S03. This indicated that the canal water that was used as cooling water left the industry more turbid than it entered. Therefore, the highly turbid waters of the soap effluent B1 and B2 contributed to a high turbidity at S03. In comparison with the other monitoring sites in the San Sebastian canal, this site had the highest minimum, maximum and the median values recorded. Both visual observation and the monitored values confirm this. Most of the time the canal water at this site was whitish and turbid.

Conductivity

The data variability at B1 and B2 are seen in table 6.36 and 6.37 and the concentration in figure 6.28.

The conductivity at B1 was one of the highest values recorded for the industries. It had a minimum value of 390.0 μmhos/cm, a maximum of 21.000.0, and median value of 925.0. The 90^{th} percentile fell at 19550.0. This indicated the very high conductivity values in the effluent. The very high variability in the industry is seen in the range which had a high value of 20610.0 and a standard deviation of 6720.0. The conductivity at B2 was lower than at B1.

Relationships and effects

The maximum conductivity of 21,000.0, recorded at B1 may have been higher than this value since, the maximum value the conductivity meter could read was 20,000 μmhos/cm. Therefore any value above 20,000 was recorded as 21,000.0. The conductivity at B2 was lower than B1, as mentioned earlier.

The conductivity at B1 was due to the dissolved salts present in the effluents. The conductivity at the receiving canal site S03 had higher conductivity values than B2, but was lower than B1. Thus the conductivity of the waters at at S03 is caused by the soap effluents B1. The conductivity at S03 had a median value of 600.0.

pH

Data variability

The data variability at B1 and B2 for pH can be seen in table 6.36 and 6.37 and the concentrations are seen in figure 6.28.

The pH at B1 was high and reached alkaline values. The minimum was 8.4, maximum 12.8 and the median 9.6. The 90^{th} percentile fell at 12.3. These indicated very high pH values. The data variability was fairly high as seen in the range, which was 4.4, and the standard deviation of 1.45. The pH at B2 was also high, but was lower than B1.

Relationships and effects

B1 had the highest pH value recorded among the industries. The pH at B2 was also high, but lower than B1. The soap effluents are strongly alkaline in nature, which was reflected in the higher pH values of B1. The B2 values were also high because of the nature of water drawn for cooling. The canal water at this point, i.e. S03 was already alkaline, and this is seen in the high pH at B2. The pH at the receiving site S03, recorded a minimum of 8.0, maximum of 10.1 and a median of 8.65. which indicated alkalinity.

Water temperature

The data spread at B1 and B2 can be seen in table 6.36 and 6.37.

The water temperature at B1 had a minimum of 30 °C maximum of 43.5 °C and a median of 35.5. The 90^{th} percentile fell at 42.7 °C. The median and the percentile indicated high temperatures.

The range was very high with a value of 13.5 and the standard deviation was 4.35 °C. The water temperature at B2 was also high as seen in the median value at 37.25.

The water temperature at the receiving canal site S03 was also higher than at sites which did not have industries directly discharging into the canal. The minimum

recorded water temperature was 30 °C, the maximum 42.7 and the median 33.25. The 90th percentile fell at 38.39. The maximum indicated a high value although the median was fairly low.

Relationships and effects

The high temperature at B1 was a result of the production process. The higher temperature at B2 due to water being used used for cooling purposes. The water temperature at both B1 and B2 was higher than at S03 and therefore these two industrial sites contributed to a warmer water in the canal at this site. This receiving site had warmer water than the upstream and the downstream sites S02 and S04.

Total P

The data variability at B1 and B2 can be seen in table 6.36 and 6.37, and the concentrations in figure 6.28.

The total P at B1 was obviously higher than at B2. The total P at B1 had a minimum value of 2.15, maximum of 18.2, and a median of 4.2. The 90th percentile fell at 17.47. The range of 16.05 and the standard deviation of 5.62 indicated the variable nature of the data.

Relationships and effects

Some of the highest total P values were recorded at B1. The maximum value of 18.2 was the highest at B1. This is due to the phosphate based detergents and soaps produced in this industry.

The total P in the canal receiving site S03 had a median of 2.3 mg/L and a maximum of 8.75. These values were much lower than at the discharging site B1. Therefore there appeared to be a contribution of total P from B1 into the canal site S03. Total P may also have entered from the domestic sources and the shanties bordering the site, but B1 was responsible for a greater proportion of the phosphates. The effects on the canal were visible. The site had an abundance of *Eichornia crassipes* and other aquatic plants which indicated nutrient enrichment.

Total N

Data variability

The data variability can be seen in table 6.36 and 6.37.

The total N levels in the factory site B1 had comparative lower total N values, the minimum being 0.05 mg/L, the maximum 6.35 and the median 2.49. The 90th percentile fell at 5.82. Although the concentrations were low the range and the standard deviation were fairly high with 6.3 and 2.07 respectively. This indicated the variable nature of the concentrations. B2 had lower values than B1.

Relationships and effects

B1 had some of the lowest total N values recorded in the industries. The total N level at the receiving site S03 had higher levels than both B1 and B2. The minimum recorded at S03 was 6.39, the maximum 12.13 and the median was 10.3. Therefore this indicates that the canal site S03, received total N from sources other than the industries. One positive source may be the shanties along the site. The makeshift toilets put up on the canal banks may contribute total N in the form of urine and faeces. Garbage is also emptied into the canal by the slum dwellers.

Sulphates

Data variability

The data variability at B1 and B2 can be seen in table 6.36 and 6.37 and the concentrations in figure 6.28.

The sulphates at B1 had a minimum recorded value of 58.6 and a maximum of 2998.3 and median of 188.1 The 90th percentile was at 2100.3. These indicated high values although the median was low. The high variability in the concentrations can be seen in the range of 2939.7 and the standard deviation of 822.36. Sulphates at B2 were much lower than at B1.

Relationships and effects

The sulphate at the receiving site S03 had a median of 156.2, and the 90th percentile fell at 376.2. This shows that the sulphates at the canal site were higher than B2, but lower than B1, which indicated that B1 contributed to a higher sulphate level in the canal. The concentrations at B2 indicated that the site had acquired some sulphates from the industry which in turn is discharged into the canal.

6.8.2 Chemical based industry

Factory D, although not a food industry, was monitored twice since it discharged waste water directly into the Dematagoda ela at T03, at which point the tributary canal enters the San Sebastian canal. The data for factory D can be seen in table 6.38.

Table 6.38 — Variability in data: factory D

Poll.	Mean	S.D.	Ran.	Min.	Max.
DO	0.32	0.03	0.05	0.30	0.32
W T	30.25	0.35	0.50	30.00	30.25
pH	7.57	0.38	0.55	7.33	7.57
CT	537.50	31.82	45.00	515.00	537.50
TB	33.25	23.68	33.50	16.50	33.25
COD	236.00	118.79	168.00	152.00	236.00
BOD	91.50	9.19	13.00	85.00	91.50
SULF	91.35	3.32	4.70	89.00	91.35
T N	3.51	0.65	0.92	3.05	3.51
T P	5.85	3.74	5.30	3.20	5.85
SS	604.68	737.39	1042.80	83.27	604.68

Source: Field monitoring.

Concentrations and effects

COD, BOD and DO

The median for COD at factory D was 236.0, minimum recording 152.0 and the maximum 320.0 mg/L. The minimum COD at T03 was 26.6 while the maximum reached 281.0 and the median fell at 114.6. The COD was higher at factory D than at site T03 in the canal.

The BOD in the canal recorded a median of 75.0, a maximum of 114.0 and a minimum of 11.0. The median BOD at factory D was 91.5, maximum 98.0 and the minimum was 85.0. The minimum and the median BOD values were higher for factory D than the relative values for canal, but the maximum value recorded in the canal is higher than the maximum BOD value for factory D.

When the overall effect of the COD and the BOD on the canal is considered, it can be said that, that the factory evidently contributed a high organic load into the canal. This high organic load depleted the DO in the canal, which was clear from the low DO levels. Thus this factory contributes to the pollution of Dematagoda Ela at T03.

To be fair to the factory it has to be mentioned that the point of sampling of factory D, although it was within the factory premises, was a sewer which was also used by a few other factories such as the textiles and hardware which were in the immediate neighbourhood. Therefore it is possible that the waste waters from these factories also entered this point. The factory waste water analysis was based only on two samples carried out on 20.08.86 and 06.01.87. Therefore it is not appropriate to draw definite conclusions.

Comparison of COD and BOD with food effluents

When the analytical results of D is compared with the food industries, the organic load reflected in the COD and BOD values is much lower in this factory than in the food industries. For example factory F discharging into the Main Drain had a COD minimum of 756.0 mg/L and a maximum of 29920.0, with the median falling at 4167.0. The BOD for this factory was 365.0, 22800.0 mg/L and 2137.0 mg/L respectively. These values were very much higher than recorded values for factory D. In one way it is inappropriate to compare the waste loads of D with food industries, since it is chemical based, while the food industries are not. But this simple comparison indicated the polluting strength of the food processing industries.

SS and Turbidity

The SS of the factory D recorded a minimum of 83.27 mg/L, maximum of 1126.1 and median of 604.68. The range was high with a value of 1042.8 and the standard deviation was 737.39. The corresponding values for T03 on the Dematagoda Ela was 8.65, 216.6, 70.4, 208.0 and 50.93 respectively . The turbidity showed a minimum of 16.5, maximum of 50.0 and median of 33.25, the parallel values for T03 were 4.0, 46.5 and 16.25 respectively. Both SS and turbidity indicated that the values were higher at the factory site D than at the corresponding canal site indicating that there is a polluting input into the canal site, by the factory.

Conductivity

The conductivity minimum for factory D was 515.0 μmhos/cm, and maximum 560.0 and median 537.8. The range was 45.0 and the standard deviation 31.82. The corresponding values at T03 was 300.0, 2500.0, 787.5, 2200.0 and 766.52 respectively. It can be seen that the canal conductivity was much higher than the factory values, although the factory also had high values. This indicated that either the canal had accumulated salts at T03 due to other factory discharges or it was being more conductive due to sea water that enters the canal to tides. As mentioned earlier, based on two analytical observations, it was difficult to come to a definite conclusion.

pH

The pH of factory D had a minimum of 7.3, maximum of 7.85 and median at 7.57. The range was 0.55, with the standard deviation at 0.38. The pH of canal at T03 had a minimum of 8.0, maximum of 9.22 and the median fell at 8.77. The range was 1.25 and the standard deviation 0.41. This indicates that factory D had more neutral wastes than the corresponding discharge point in the canal. Therefore the canal must be receiving more alkaline inputs from other sources.

Water temperature

The water temperature at factory D recorded a minimum of 30.0, maximum of 30.5 and a median of 30.25. The corresponding values for T03 was 30.0, 33.0 and 31.55 respectively.

Therefore the water temperature in the canal is higher than at factory site D. The water temperature in the canal was near the daily maximum temperatures recorded. As T03 is an industrial urban area, it is possible that warmer water enters at this point from some discreet source.

Total P

The total P in factory D had minimum value of 3.2 mg/L, maximum of 8.5 and a median value of 5.85. The range was 5.3 with standard deviation at 3.74. The corresponding value for site T03 was 0.30, 16.4, 3.7, 16.1 and 3.96 respectively.

Although a very high maximum value was recorded at T03, the median was lower than at the factory site. It is not surprising that factory D, a chemically based fertilizer producing factory (in addition to its other products), have high total P values. Thus it contributed to phosphate enrichment in the canal at T03. The maximum total P value of 16.4 in the canal may be either due to an outflow from the factory or from residences and shanties around the site.

Total N

The total N at factory site D recorded a minimum of 3.05 mg/L, maximum of 3.97 and a median of 3.51, range of 0.92, and standard deviation of 0.65. The corresponding values for the site T03 in the canal were 1.67, 7.35 and the median 4.82, 5.68 and 1.71. The total N level in the canal site T03 was higher than at factory site D, although a high total N value can be expected at factory D because urea is used for fertilizer production. There tends to be an accumulation of total N at T03 from factory discharges or nitrogeneous input from domestic sources. Nutrient enrichment has taken place at this site T03, which was evident from the aquatic plant growth in the site such as *Eichornia crassipes.*

Sulphate

The sulphates at factory site D had a minimum of 89.0 mg/L,maximum of 93.7 and a median of 91.35. The range was 4.7 and the standard deviation 3.32. The corresponding values at canal site T03 were 59.3, 278.4 and 142.5. The range recorded was 219.1, and the standard deviation 67.4 mg/L. The sulphate at the canal site was much higher than T03, which indicated that the canal had a sulphate entry at T03 from sources other than factory D. It is possible that other factories discharged these

wastes, or it entered from the domestic sources (which is only a minor source).

As far as factory D is concerned, the effluents have to be monitored for toxic pollutants as well. Although broad conclusions could be drawn from the analysis of factory D, a higher frequency of monitoring is necessary to arrive at a realistic conclusion. The fact that the analysis was based only on two sets of samples in this industry makes it unrealistic to draw decisive conclusions. The sampling days may not be even representative of the waste produced.

Summary

The analysis of the effluents from the food industries indicated some striking features. The strength of the food industrial wastes remained very high. This was seen in the high median values. The high base level concentrations was seen in the high minimum values. The highly variable nature of the effluents was evident in the high range and the standard deviation values. None of the industries had treatment facilities other than I, and a basic fat trap at C.

The organic strength in terms of the COD and the BOD of all the food industries remained very high. The highest values were recorded in the confectioneries E and F. The effect on the receiving sites on the Main Drain was detrimental. The DO at the receiving sites T11 and T13 were very low with 0.35 and 0.20 mg/L respectively. The meat processing industry A3, and the creamery A5, also had similar effects on the lake site U02, where the DO remained 1.3 mg/L. The effects of G1, and the soft drink plants are difficult to assess (as the receiving sites were not monitored in the former; while in the latter the discharges were either sent to the central sewage system or the receiving sites not monitored). But the effects at the receiving end may be detrimental. Factory sites C2 and B1 which discharged at S06 and S03 on the San Sebastian canal, had very degrading effects on the canal. The DO was 0.05 and 0.03 mg/L respectively. These two sites had the lowest DO levels in the water surfaces monitored. The other food effluents such as A1 and K also had very high organic waste waters. A non food industry (D) in comparison (although it had high COD and BOD values) had much lower values than the food processing effluents.

The SS also remained high in most of the food processing industries. The SS at A3 and G1; H1 and I1; A5; C1 and C2; B1; and, A1 and K were high. The SS contributes to the organic load. The SS was reflected in the turbidity values.

The conductivity at A3 and G1 was high. The soft drinks effluents also had fairly high values. A5 and C2 had moderately high values in comparison. The soap factory waste waters had the highest conductivity values. The values were above the maximum that the conductivity meter could read. This indicated the presence of large quantities dissolved salts in the effluents. The effect on the receiving sites other than the tidal discharge point of factory G is harmful.

The pH ranged from acidic to alkaline values in most of the industries. The alkalinity was very high in the soft drink plants, and the soapery (B1). This may be due to the detergent baths in the bottle washing operations in the former and the nature of the product in the latter. The pH was less alkaline at meat processing plants. Some acidic values were recorded at A5 and C1. The confectioneries also recorded some acidic values. At C1 it is due to the nature of the product while in the others it might be due to the waste waters turning acidic on standing.

The water temperature remained high in most of the industries. The confectionery F, soft drinks other than plant J, and soapery B1 all recorded very high values. The other industries too recorded very high maximum values, although the median remained lower. G2 recorded the lowest water temperature. The high temperatures are detrimental to the receiving sites where it affects aquatic life and decreases the DO of the receiving sites.

The total P varied according to the nature of the products. The meat processing industries had high values. The soft drinks group also had high total P values. The concentrations were high at B1, while the other industries had variable concentrations. This indicated both the nature of the raw materials and products; and the phosphate based detergents used for cleaning operations. The level of cleanliness that has to be maintained in the food processing plants is high and thus the washing operations are more frequent. The effect on the receiving water bodies is detrimental, as total P enhances the uncontrolled growth of aquatic plants.

The total N too reflected the nature of the products. The highest recorded con-

centrations were at the meat processing plants. The concentrations were also high at the creamery, A5. The C group also had high concentrations. These reflected the nitrogeneous content of the meat; milk; vegetable and animal fat based industrial effluents. It was lower at the confectioneries and the soft drink plants. The effect on the receiving water bodies is detrimental. Total N enhances the growth of aquatic plants. Thus the receiving sites which had high total P and N had an abundance of aquatic plants such as *Eichornia crassipes* and other species.

The sulphate concentrations varied widely among the industries monitored. The group C had very high ranging values although the median was not very high. B1 also recorded high values inspite of the variability. The soft drinks plants also recorded a few high values. This may be due to the use of this as a preservative in these industries. Sulphate corrodes the industrial and the municipal sewers.

The biological treatment plant at I was only partly installed at the time of the research. Thus the efficiency of the treatment was low. Although there was partial treatment by aeration, the concentrations of the effluents that were discharged into the river Kelani were high and detrimental. These discharges were very harmful as the receiving point in the river was above the water supply intake point for Colombo.

Thus the pollutants in the food industries monitored remained high in terms of the organic load discharged into the receiving water bodies. The DO content in the San Sebastian canal at the industrial waste water receiving sites S03 and S06 remained very low and anaerobic during the greater part of the year. The site U02 on the lake, which is receiving site to many food industries also had very low DO levels. The sites on the Main Drain also indicated the same. All these indicate the highly polluting nature of the food industrial waste waters. The high nutrient loading in terms of total P and N was reflected in the luxuriant growth of aquatic plants at the receiving sites which was evident in the San Sebastian canal and the other water bodies.

6.9 The correlation of pollutants in the industries

6.9.1 The correlation between the COD and BOD

Coefficient variation

The relationship between the COD and the BOD in the factory sites was essentially a positive relationship, although there was wide variation in the strength of the relationship, as seen in the variations in the coefficient. This is a marked difference from the highly positive relationships encountered in the water bodies.

The correlation coefficients for COD/BOD in the industries can be seen in table 6.39.

The coefficient varied from 0.02 at J to 0.94 at G1. At A2 the coefficient was 0.90, at A3 it was 0.83 and 0.87 at A5. The levels of significance was high at .001 in the sites. The correlation coefficient for C1 and C2 was 0.86 and 0.91 respectively. The level of significance was .001. At the factory sites E and F the coefficient was 0.79 and 0.91 respectively. The significance level was .001. Factory site G1 had a coefficient of 0.94 which was .001 significant while at G2 the coefficient was 0.65 which was not significant. The factory site I1 had a coefficient of 0.82 with the level of significance at .05. The correlation coefficient for the sites G1, G2, H1, I1 and J are based on 6 cases only and thus the lower number of cases might affect the coefficient.

Correlations

The observed positive correlation between the pollutants BOD and the COD is obvious and simple to comprehend. Both these pollutants give the oxidation capacity in the effluent of the industries with the only difference being the agent of decomposition or oxidation. The microorganisms oxidize the effluent in the BOD test while the dichromate (which is a strong oxidant), decomposes the organic matter in the effluent sample. Other than a small proportion of the non-organic degradation in the COD, the process of oxidation is essentially the same although by different media as mentioned earlier.

Therefore higher the COD values, the higher will be the BOD. It is impossible to have a negative correlation between these two variables. Except in a few isolated occurrences, the significantly high correlation between the COD and the BOD at most of the sites indicated the organic nature of the industrial waste waters.

Table 6.39 — Spearman's ρ between pollutants: industries

Fact.	COD/BOD	COD/DO	BOD/DO	TB/SS	DO/W T
A2	0.90***	0.27	0.21	0.91***	-0.31
A3	0.83***	-0.42*	-0.29	0.91***	-0.31
A5	0.87***	-0.35	-0.16	0.93***	0.01
B1	0.87***	-0.46*	-0.57**	0.96***	-0.39
B2	0.95***	-0.60**	-0.50*	0.95***	-0.11
C1	0.86***	-0.21	-0.36	0.68***	-0.33
C2	0.91***	-0.27	-0.49*	0.73***	0.19
E	0.79***	-0.26	0.01	0.78***	-0.57***
F	0.91***	-0.65***	-0.58**	0.97***	-0.77***
G1	0.94***	-0.88***	-0.94	1.0	0.30
G2	0.65	-0.55	-0.20	0.94***	-0.40
H1	0.94***	-0.54	-0.48	0.65	0.48
I1	0.82***	0.57	0.49	0.25	0.27
J	0.02	0.05	-0.51	0.94***	0.98***

Source: Field monitoring.

The very low coefficient at factory J which produces only food and drink is not very clear. It may be due to a high COD:BOD corresponding to a COD of 3200.0 mg/L and a BOD of 636.0 mg/L. The COD:BOD was 5:1 which is not a usual situation for a food industry with organic waste. This may be due to an inhibitor in the effluent or an error in the measurement. This may have affected the correlation, which resulted in the lowest value in the entire monitoring programme. Other than this factory, all the factories gave a high positive correlation.

6.9.2 The correlation between the COD, BOD and DO

Coefficient variation

The correlation coefficients for COD/DO and BOD/DO can be seen in table 6.39.

The correlation between the COD and DO in the factories was variable in strength, and ranged from a negative to a positive relationship.

Factory A3 had a COD/DO correlation coefficient of -0.42 and -0.29 for BOD/DO. The former had a significance of .05. A5 had -0.35 and -0.16 respectively. The correlation at B was much stronger with COD/DO coefficient at B1 being -0.46 and -0.60 at B2. The significance was .05 and .01. The BOD/DO correlation was -0.57 and -0.50 respectively. The significance was .01 and .05 respectively.

At factory C the strength was weaker with -0.21 at C1 and -0.27 at C2 for COD/DO, while -0.36 and -0.49 for BOD/DO respectively. Factory E had a weak correlation of COD/DO with a coefficient of -0.26 and BOD/DO of 0.01. Factory F had a stronger correlation with -0.65 for COD and -0.58 for BOD/DO. The significance was .001. G1 had the highest correlation with -0.88 for COD/DO and -0.94 for BOD/DO. The significance was .001 at both the sites. At G2 the correlation coefficient for COD/DO was -0.55 and -0.20 for BOD/DO. The level of significance was low at G2. At H1 the relationship was negative with COD/DO correlation coefficient at -0.54 and BOD/DO coefficient at -0.48. At J the COD/DO coefficient was 0.05 and the BOD/DO -0.51. The coefficient was insignificant.

Correlations

Therefore unlike in the water bodies the correlation between COD/DO and BOD/DO were not a perfectly negative relationship. But most of the industries had an expected negative trend. This may be due to the fact that, unlike in the surface water, where there is mixing and some degree of homogeneity in the industrial waste waters it is not so.

Another striking feature in the correlation of COD/BOD and DO in the industrial monitoring is that the correlation coefficient is not very high except at G1. Most of the industries had a coefficient of around -0.5. except at B2, F, G2, I1 and H1 which had coefficients stronger than this. The rest of the industries had lower correlation coefficients but they still remained negative. At J the relationship was striking in the fact that the COD/DO coefficient was positive, although the coefficient was very low with 0.05 while the BOD/DO was -0.51. These low correlations between COD/DO and BOD/DO may be due to the fact that in the industrial wastes the strength of the effluent is highly variable, and depends on the time of monitoring and the process involved at monitoring. Therefore the detection of the effluent strength is random. For example the effluent strength of COD at factory F varied from 756.0 to 29920.0 mg/L and BOD from 400.0 to 22800.0 mg/L. The lowest COD and the lowest BOD did not occur on the same day, although the maximum COD and BOD fell on the same day. The DO in factory F ranged from 0.0 to 3.2 mg/L. Although the DO levels were very low in this industry it does not necessarily mean that the lowest COD and the lowest BOD always had the lowest DO levels. For example at a COD of 910.0 mg/L the corresponding DO was 3.2 mg/L while at a lower COD of 833.7 mg/L the DO was 0.9 mg/L. This is true of almost all the industries.

Perhaps this gives an explanation to the lower and highly varying correlation coefficient in the industries between COD/DO and BOD/DO, i.e. the concentration of the pollutants is highly variable in the industry. The DO content in the food industry is also very low except at A2 which ranged from 2.6 to 5.9 mg/L and certain other industries on few occasions as seen in appendix F. But this does not necessarily mean that the lowest DO will have the highest COD or BOD values. Other than in the three industries the correlation between COD/DO and BOD/DO was negative. This means that if the COD and BOD are high, they lower the DO content of the waste water.

6.9.3 The correlation between the SS and turbidity

The correlation coefficient for SS/turbidity can be seen in table 6.39. In the factories monitored the relationship between the SS and turbidity ranged from a coefficient of 0.25 at I1 to a perfect correlation of 1.0 at G1. In most of the industries the correlation between these two variables was very high. At F the coefficient was 0.97, and at B1 it 0.96. The significance level was .001. The correlation was slightly lower in factory C with the coefficient of 0.68 at C1 and 0.73 at C2, the significance was high at .001. At H1 the coefficient was 0.65 and at I1 the correlation was poor with 0.25. The significance remained low. It is not clear as to why the correlation is poor at I1. The perfect positive linear correlation of 1.0 at G1 would be a rare occurrence under natural conditions. This may be due to a lower frequency of monitoring. The overall relationship between the SS and turbidity in all the industries was positive correlation. This indicates that when the suspended solids are high in the effluent the turbidity of the water is high.

6.9.4 The correlation between water temperature and DO

Coefficient variation

Table 6.39 shows the correlation coefficient between water temperature and DO. The correlation between water temperature and the DO in the industries ranged from -0.11 at B2 to 0.98 at J.

Correlations

In all the supplementary industries (except G2) the correlation was positive between the two variables.

Among the industries that discharge into the canals and the lake all the industries had a negative relationship except C2, where an isolated 0.19 correlation was observed, and A5 where the coefficient was 0.01. Although the correlation was a very weak one at C2 the positive coefficient is not comprehensible.

At A5, the very weak positive correlation may be attributed to the nature of

production processes in the factory where both boiling and chilling processes are done. This may be reflected in the water temperature of the effluent. The minimum temperature recorded at A5 was 28 °C while the maximum was 34.5 °C. The DO remained low with the maximum reaching 3.45 mg/L. Therefore, this **averaging** effect of the water temperature may have contributed to a near zero correlation at A5.

The strongest relationship was observed at F which had a coefficient of -0.77. The significance was .001. The water temperature of the effluent was very high which ranged between 36.0 °C and 45.5 °C. The DO remained very low throughout with the maximum at 3.2 mg/L. Therefore in this industry the important contribution of water temperature on a resultant low DO level becomes very clear. Factory E also had a fairly strong correlation between the variables. The coefficient was -0.57. The significance was .001. This industry had a very similar situation to that of F, except that the water temperature was much lower except on one occasion when it had reached 40.5 °C. The DO level was higher than at F with the maximum reaching 3.6 mg/L. Therefore, this situation would have made the relationship between these two variables slightly weaker than at F.

The coefficient remained within a comparable range at A2, A3, B1 and C1 which indicated that the water temperature had a negative effect on the DO levels. Although the correlation was not very strong the fundamental relationship remained the same.

Summary

The correlations in the monitored industries gave some significant relationships. There were significant correlations between some pollutants such as the COD, BOD and DO; SS and turbidity; and water temperature and DO.

The correlation between the COD and the BOD was positive, but the strength of the coefficients varied among the industries. This indicated the organic nature of the pollutants discharged from the industries. This is also useful for the treatability criteria used for the effluents. The higher the COD/BOD correlation coefficient higher is the organic content in the waste waters and the more suitable for biological treatment.

The COD/DO and the BOD/DO correlation had a negative relationship. This indicates the highly organic nature of the effluents and their capacity to deplete the DO. Thus highly organic waste waters with very low DO leave the industries into the receiving sites and will quickly deplete the DO of the receiving medium.

The correlation between water temperature and the DO in the industry was not a clear negative relationship as in the water bodies. The high water temperature in most of the food industries had the potential to deplete the DO. Thus in the food processing industries the high organic content in terms of the COD and the BOD; and the high water temperature depletes the DO. Although the water temperature exerts a negative effect on the DO, it is not **the** factor. The high BOD and COD in the industries contribute more to lower the DO levels.

The correlation between the SS and turbidity was positive and high. This shows that the SS load in the food industries contribute to the organic load and this is reflected in the turbidity. The highly turbid nature of the waste water that leave the industry is evident and this is deleterious to the receiving sites.

6.10 Correlation: industrial discharges and receiving sites

The correlation analysis done between the factory site and the corresponding receiving sites indicated some clear trends in the parameters monitored. This analysis also showed that the factories at least in part, were responsible for the pollutants discharged into the canal. In addition to this it showed the impact of the industrial discharge on the depletion of the DO content of the receiving waste water sites.

Five factories were selected for the analysis because they discharged waste waters directly into the waterways without any form of treatment (only factory C had a fat trap). The factories are A,B,C,E and F. Factory A had two departments i.e. A3 and A5, while B had two sampling points i.e. B1 and B2. A3 and A5 discharge untreated effluents directly into Beira lake at U02 while B and C (only C2) discharges into the San Sebastian canal directly at S03 and S06. Factory E and F discharge effluents into the Main Drain at T11 and T13. Sites S04 and S07 are the immediate downstream sites of factory B and C respectively. T12 and S10 are the downstream sites of factory

E and F. It has to be mentioned that the data for the industries and the receiving sites were collected on different days, which may affect the correlation.

6.10.1 BOD relationship: industrial and receiving sites

Coefficient variation

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

Table 6.40 — Spearman's ρ (mean monthly) between industries and receiving sites

Fact/ Site	BOD/ BOD	COD/ COD	BOD/ DO	COD/ DO	SS/ TB	SULF SULF	CT/ CT	T N/ T N	T P T P	W T/ W T	pH/ pH
1											
B1/SO3	.08	.09	-.33	-.22	.28	.31	.23	.45	-.57**	.04	-.14
B2/SO3	.70**	.29	-.72**	-.67**	.08	.36	.73**	-.36	-.12	.63**	.00
C2/SO6	.50*	.47	.04	.04	.55*	.27	.09	.21	-.22	-.12	-.32
2											
E/T11	.01	.29	.03	-.12	-.01	.55**	.14	.16	.31	.57**	.27
F/T13	.59**	.75***	-.18	-.21	.20	-.03	-.20	-.29	.21	.63**	.12
3											
A3/UO2	.30	.24	-.55**	-.29	.27	.23	.12	.28	.34	.57**	.01
A5/UO2	.45*	.68**	.31	.07	.39	.01	.55*	.58*	.65**	.53*	.80***

Sections: **1** = San Sebastian canal, **2** = Main Drain and **3** = Beira lake.

Source: Field monitoring.

Table 6.41 — Spearman's ρ between industrial discharges and downstream sites

Fact/ Site	BOD/ BOD	COD/ COD	BOD/ DO	COD/ DO	SS/ TB	SULF/ SULF	CT/ CT	T N/ T N	T P/ T P	W T/ W T	pH/ pH
1											
B1/SO4	-.01	-.20	.54*	.54*	.27	.14	-.05	.11	-.37	.12	-.21
B2/SO4	.41	.28	-.16	-.17	.23	.38	.46*	-.08	-.28	.44	-.05
C2/SO7	.61	.44	.28	-.18	.45	.06	.42	-.13	.18	.09	-.12
2											
E/T12	.11	.27	-.02	-.17	.27	.64**	-.01	-.02	-.01	.41	-.30
F/S10	-.13	.12	-.19	-.22	-.33	-.28	-.01	-.37	.30	.15	.44*

Sections: **1** = San Sebastian canal and **2** = Main Drain.

Source: Field monitoring.

As mentioned earlier the pollutants have a definite relationship between the factory sites and the corresponding waste water receiving sites. When the BOD load into the surface waters is considered, all the factory sites had a positive correlation with the corresponding receiving sites. The positive coefficients ranged from 0.01 at E/T11 to 0.70 B2/S03. The latter had .01 level of significance. The coefficients were fairly high and significant except at B1/S03 and E/T11 which had lower coefficients of 0.08 and 0.01. The correlations were higher and highly significant at B2/S03 with

0.70 (.01 level), 0.50 (.05 level) at C2/S06, 0.59 (.01 level) at F/T13 and 0.45 (.05 level) at A5/U02. Therefore this indicates that the higher the BOD at factories higher the BOD in the corresponding receiving sites. In other words, the higher the organic load discharged into the receiving sites, higher will be their BOD. The correlations can be explained with real values.

San Sebastian canal

B1, B2/S03

The site B2/S03 had a coefficient of 0.70 which was significant at .01 level. This can be explained in terms of the BOD discharged from the factories. When the BOD from factory B2 was 411.0 mg/L in February 1986, the corresponding BOD at S03 was 230.50 mg/L. Similarly in September 1986 the BOD were 280.0 mg/L and 223.67mg/L respectively. On the other hand there were occasions when the receiving site had a higher BOD than the factory site B2 such as in February 1987 the BOD at B2 was 424.0 mg/L while the site S03 had 664.0 mg/L. A small percentage of this receiving site BOD may be from domestic sources, (especially the shanties in the neighbourhood) but a large percentage is from the factory waste water itself. The high canal site BOD may be due to the continuous discharge of highly organic waste waters from the factory, although the factory BOD was only a monthly value. The factory B2 also had an impact on the site immediately downstream S04, which had a B2/S04 correlation coefficient of 0.41. Although S04 has organic loadings from the shanties and the motor spare garages at the site, a significant load may be contributed by the upstream factory sites.

Although the correlation coefficient of 0.08 was very low at B1/S03, the BOD discharges into the site was very high. The reason for a very low coefficient may be that the site S03 is so grossly polluted with zero or near zero DO levels that the sensitivity to a very high BOD from the site B1 was not felt.

C2/S06

The correlation coeffiecient between C2 and the receiving site S06 for BOD was 0.50 with significance level of .05. This correlation coefficient also indicates a high BOD loading from C2 into the site S06. For example in March 1986 the mean BOD at was 866.0 mg/L. The receiving site had 464.67 mg/L. of BOD. In June C2 loading was 430.0 while S06 had 163.67 mg/L. The BOD loading from the factory C2 not only had an impact resulting in a higher BOD in the immediate receiving site, but also on the down stream site S07.

The high organic load in terms of the BOD causes the rapid depletion of DO. The DO levels are the lowest at S03 and S06 in the entire San Sebastian canal. The high organic load also can be seen later in terms of the COD.

Main Drain

E/T11 and F/T13

In the Main drain F/T13 had the high correlation of 0.59, with a significance level of .01. This indicated that a higher organic input was discharged into the site T13, which resulted in a high BOD level in the receiving site T13. E/T11 had a positive, but a very low correlation.

The BOD input from factory F was very high. The BOD at F during May 1986 was 456.0 mg/L while the receiving site had a corresponding value of 103.0 mg/L. Factory F recorded a very high BOD in January 1987 with the BOD at 22800.0 mg/L, while T13 had 386.0 mg/L and in February 1987 the BOD was 1652.0 mg/L while the receiving site had 637.0 mg/L. The BOD at the receiving site was high throughout the period of monitoring. The site downstream of T13 after its confluence with the San Sebastian canal is S10. The negative correlation of -0.13 at F/S10 is not very clear, although it might be possibly be due to the effect of the diurnal tides which blurs the relationship or that S10 has inputs from elswhere which has a greater effect on the BOD than the Main Drain.

Beira lake

Coefficient variation

The coefficient variation can be seen in table 6.40. In the lake the correlation coefficient between A5/U02 was higher than A3/U02 for BOD, although both indicated a positive correlation. This indicated that the BOD of the factory sites increased the BOD level in the receiving site U02. The coefficients at A5/U02 and A3/U02 for BOD were 0.45 and 0.30 respectively. The former had .05 level of significance.

A5/U02

Being a creamery the BOD at A5 have been high which resulted in high BOD levels in the receiving site U02 (the discharge point was closer to U02 than A3). The BOD at A5 was the highest in May with a value of 2860.0 mg/L and the receiving site U02 recorded 1265.0 mg/L. In January 1987 the BOD at A5 was 1773.0 mg/L and the receiving site had 410.0. There were occasions when the lake had a higher BOD than the discharging factory such as in June 1986 when the factory A5 had a BOD of 595.0 mg/L while site U02 had 801.0 mg/L. This is quite possible because of the culvert that enters the site with raw sewage.

A lower factory waste water BOD may also be due to the production process going on at the time of monitoring. A floor wash water at the time of sample collection entering the canal may have a lower BOD than the process water. It is also difficult to generalise on a sample frequency of one per month. In such a situation the canal BOD is a better representative of a polluted situation.

6.10.2 COD relationship: industrial and receiving sites

Coefficient variation

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

The coefficient varied from 0.08 at B1/S03 to 0.75 at F/T13. The latter had a significance of .001. The COD relationship between the discharging industry and the receiving sites indicates a positive correlation. This indicates an organic loading into the canal.

San Sebastian canal

C2/ S06

The higher values in the canal site S06 is possibly due to a higher organic load from C2 which has a higher correlation coefficient of 0.47. For example a very high COD of 1216.0 mg/L has been recorded during March 1986 and the COD in the receiving site S06. The downstream S07 had too had a contribution from the upstream industry This can be seen in the positive coefficient of 0.44.

B1, B2/S03

The correlation coefficient at B2/S03 for COD gave a positive value of 0.29. Although the coefficient is low, it indicates some COD contribution into the site S03. The lower coefficient dampens the relationship between the factory site and the receiving site because the highest COD did not necessarily occur with the corresponding highest COD in the factory site. But the factory COD and the receiving site COD indicates the magnitude and the strength of the organic waste from the factory and the resulting high COD in the canal site. Further COD at B2 in some ways represent the canal water itself since it is drawn from the canal for cooling purposes.

The higher COD in the receiving site is mainly due to the input of highly organic waste water from B1. The corresponding base level COD at S03 was also high. The coefficient at B1/S03 for COD is lower with the values at 0.09. Even though the coefficient is low it still indicates a weak positive contribution from the factory site B1. The examination of COD values at B1 and S03 explains the low correlation coefficient. The COD values are very high at B1 and the corresponding changes in the COD at site S03 is not reflected due to these very high values. For example in January 1986 the COD at B1 was 26100.0 mg/L and the receiving site had only 160.0 mg/L. In March 1986, the COD at B1 was 15800.0 and the corresponding COD at the receiving site was 707.67 mg/L. In February 1987 the COD at B1 was 1962.0 mg/L while the receiving site had 916.0. The COD at the receiving site also depends on the other organic sources and the rainfall factor for higher or lower concentrations. But the basic relationship between the factory site and the receiving site remains i.e. a higher organic waste water input from the industrial sites make the COD of the corresponding receiving site high.

Main Drain

E/T11 and F/T13

The correlation between the factory site F and T13 for COD was higher at with 0.75, which had a significance of .001 than at E/T11 which had a correlation of 0.29, with a low significance. Both these indicate that the factory contribution of organic

wastes into the receiving sites are positive. Being two confectioneries the organic load is very high into the receiving sites, T11 and T13. The COD at F remained very high throughout the monitoring period. The highest COD was recorded in January 1987 with a value of 29,920.0 mg/L. Even the minimum recorded remained high at 756.0 in May 1986. These high organic wastes in terms of the COD had a high contribution to the receiving site T13. The COD at T13 remained very high for a canal site. The corresponding COD for January at T13 was 502.0 mg/L, while in May the COD was 209.0.

The lower concentration in May at the canal site was due to dilution effect resulting from the high rainfall received during this month. The highest COD at T13 was in February 1986, although the highest COD from F did not coincide with this. The corresponding COD at F was 6876.0 mg/L, which is a very high value although not the highest. Therefore the input of organic wastes into the receiving site from this industry has been very high.

Both factory F and E have impact on the sites down stream. The correlation coefficient at E/T12 for COD was 0.27 and 0.12 at F/S10. These positive correlations indicated an input of organic matter into the sites down stream, thus increasing the COD of the sites. The impact of the factory discharge F on the down stream site S10 is less clear, but the positive coefficient indicated contribution from the factory.

Beira lake

A3, A5/U02

The COD relationship between the factory sites A3 and A5 on the lake gave a coefficient of 0.24 at A3/U02 and 0.68 at A5/U02. The significance at A5/U02 was .01. The relationship was positive which indicated that the COD of the lake site increased with the increase in the organic discharges of the factories.

A5 had a stronger correlation. The highest COD was recorded at A5 in May 1986 with the value of 4733.0 mg/L. The corresponding COD for the site U02 was 1967.0 mg/L which was the highest recorded. The factory COD has been high throughout except in February and March 1986 when the COD has been lower with 351.0 mg/L and 308.0 mg/L. The corresponding values at U02 were higher with 773.0 and 701.0 mg/L. The higher COD at Lake site may be due to organic loading from A3 which had very high COD during these two months with 2080.0 and 1100.0 mg/L respectively. The lowest COD at U02 was recorded in December with the value at 168.0 mg/L, although the factory COD was high with 1280.0 mg/L. This may be due to the high rainfall experienced during this month with 203.45 mm, with the high rainfall contributing much to the dilution. The culvert that empties at this point also may have contributed with more diluted sewage. Other than on this occasion the COD remained high in the lake throughout.

6.10.3 DO relationship: industrial and receiving sites

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40, and that for the industrial discharges and the down-stream sites can be seen in table 6.41.

The high organic load of the industrial discharges is reflected in the DO of the receiving sites. Both the correlation between the BOD/DO and the COD/DO between the industrial discharge and the receiving sites gave a negative correlation coefficient. This can be seen in table 6.40. This indicated that the higher the organic load of the industrial waste water discharges lower is the DO of the receiving waters.

Coefficient variation

The BOD/DO correlation coefficient between the factories and the receiving sites ranged from -0.18 at F/T13 to -0.72 at B2/S03. The latter had a significance level of .01. The correlation was positive at C2/S06 and E/T11. Although the coefficient was positive it was very weak with 0.04 and 0.03 respectively. A5/U02 had a slightly higher correlation of 0.31.

These isolated coefficients occur not because there was no expected trend in the correlation between BOD and DO, but rather due to the very slight change in the DO to the fluctuation in the BOD discharged into the site from the factories. This situation holds true in all the industrial waste water discharge sites since the DO levels are very low due to the high organic content of the waste waters particularly from the food industries. Even with high rainfall the aeration capacity is very low due

to the continuous discharge of these highly organic wastes. Thus even if reaeration took place, the increase in the DO levels in the receiving sites were very low.

San Sebastian canal

COD/DO

The COD-DO relationship between the factories and the receiving sites also indicated a negative correlation. This strengthened the trend in the BOD-DO relationship. Since both the BOD and the COD indicate the organic strength of the waste, the relationship between these three variables have to be similar. This explains the basic relationship that more oxygen is required for oxidisation, when the wastes are highly organic in nature. Thus the depletion of oxygen at the industrial waste water receiving sites is higher in addition to the lower reaeration capacity at these sites. This situation was seen in the BOD/DO correlation at the factory waste water receiving sites and this holds the same for COD/DO.

Coefficient variation

The correlation coefficient is given in table 6.40. The correlation coefficient of COD/DO at the industrial waste water sites ranged from -0.04 at C2/S06 to -0.67 at B2/S03; the latter site had .01 level of significance. Site A5/U02 had a very weak positive coefficient with 0.07. All the sites except these two, therefore indicated the negative correlation which explain the oxygen depletion factor in the receiving sites due to highly organic industrial waste water discharges.

B1/S03

The coefficient at B1/S03 was -0.22. The DO values at S03 explains the impact of the highly organic wastes discharged to this site from B1. The DO of the site ranged from 0.0 mg/L to 0.57 mg/L. The mean monthly DO in March 1986 and February 1987 was 0.0 and it remained very low throughout the monitoring period. This is due to the direct result of strong organic wastes entering the site from the industry. As the highly organic waste water is continuously discharged, the DO remained near zero for major part of the year rising only to 0.32 mg/L and 0.57 mg/L during the high rainfall months of May and December 1986, which had 230.97mm and 203.45mm respectively. As discussed earlier the COD and BOD of the waste water from factory site B1 was very high, thus causing the depletion of oxygen in the receiving site S03. Even when the BOD fell to 165.0 mg/L in May 1986 at B1, the receiving site DO remained very low at 0.32 mg/L. The maximum BOD level discharged from B1 into the site was 13100.0 mg/L, while the COD was 26100.0 mg/L. Therefore this site occurs at the bottom of the oxygen sag curve. The downstream site appeared peculiar.

COD, BOD/DO

C2/S06

The impact on S06 by the high COD and BOD of factory site C2 is similar to the site S03 by factory B. The DO levels at S06 remained very low throughout the period of monitoring with the mean DO concentration ranging from 0.0 mg/L to 0.87 mg/L. The BOD and the COD from C2 were lower than at factory B1. The BOD ranged from 152.0 mg/L to 686.0 mg/L. Organic wastes also entered this site from the factory site C2 which had COD ranging from 216.0 mg/L to 1216.0 mg/L. The correlation coefficient was low at C2 with -0.04. The fluctuations in the corresponding DO levels in the receiving site is so low that it does not bring out the true trend in the relationship although a closer examination of the real value does.

Therefore the total organic load from the factory site is responsible for the very low DO level in the canal site S06. The factory site C2 also had impact on the DO of the downstream site S07. The correlation coefficient at C2/S07 for COD/DO was -0.18 while BOD/DO appeared isolated.

Main Drain

E/T11

The correlation coefficient is given in table 6.40. The sites on the Main Drain also gave weak negative correlation coefficients that indicated the contribution of industrial waste water discharges on the receiving sites. The correlation at E/T11 gave a value of -0.12 for COD/DO and 0.03 for BOD/DO. The relationship at F/T13 gave a correlation coefficient of -0.21 for COD/DO and -0.18 for BOD/DO. The DO levels at T11 remained very low ranging from 0.0 to 1.50 mg/L. The BOD ranged from 390.0 mg/L to 2443.0 mg/L. The DO did not necessarily follow the fluctuations

of the BOD. The BOD and the COD remained very high. The COD ranged from 660.0 mg/L to 3775.5 mg/L. These high BOD and COD kept the DO levels very low. This is due to a high uptake of oxygen by the bacteria to stablize the strong organic wastes, which results in a lower DO level in the site.

The factory waste water also had adverse effect on DO of the downstream site T12. The correlation coefficient at E/T12 was negative with -0.17 for COD/DO and -0.02 for BOD/DO. The DO levels remained higher than at T11, but overall the levels were very low.

F/T13

The factory site correlation at F/T13 also gave weak negative correlation for both COD/DO and BOD/DO with the coefficient at -0.21 and -0.18 respectively.

The COD and the BOD remained very high at F. The COD ranged from 756.0 mg/L to 29920.0 mg/L. The DO level at T13 was 0.0 to 1.20 mg/L. This site has some of the highest COD and the BOD recorded levels. This is due to the high content of sugar used in the confectionery. The waste water is thus highly organic. Thus the need for oxygen for biodegradation of these wastes is high.

The waste water discharges at F had a negative correlation at the downstream site S10. The coefficient for BOD/DO was -0.19 while the COD/DO was -0.22. The DO did not necessarily reflect the DO of the site T13 although it remained low. This could be possibly due to the tidal influence felt at the site.

The correlation coefficient for COD/DO and BOD/DO remained low with low significance levels. It is partly due to the grossly polluted nature of the receiving sites where the DO level was so low and the organic load in terms of the BOD and the COD were so high that the DO did not respond to the fluctuations in the organic input into the canal. The common limitation of factory sampling may have affected the analysis, but the basic negative trend between the variables remained. This indicated the degrading effects of high COD and BOD on the DO of the receiving sites.

Beira lake

A3, A5/U02

The factory-receiving site relationship on the lake gave a negative correlation coefficient of -0.29 for COD/DO and -0.55 for BOD/DO at A3/U02. The coefficient was 0.07 and 0.31 at A5/U02.

At A3/U02 the relationship indicated that a higher organic load from the factory resulted in a lower DO in the receiving site. The coefficient was .01 significant at A3/U02 for BOD. The BOD at A3 varied from 364.5 mg/L to 3136.0 mg/L while the DO levels ranged from 0.90 mg/L to 1.80 mg/L.

The DO levels were higher than in the canal sites and this may be due to the larger volume of water in the lake which dilutes the waste waters to a certain extent, rather than due to the lower strength of the wastes. Although the DO levels were comparatively higher at U02, it remained very low for a surface water body, and this is primarily due to strong organic wastes from the food industries that enter this site from A3 and A5. The fluctuation in the DO is very low in relation to the fluctuation of the COD values. The BOD of the site A3 ranged from 76.0 mg/L to 2705.0 mg/L. Therefore the COD and the BOD of A3 are both high which depletes the DO of U02 when discharged into the site U02. The positive correlation of COD/DO and BOD/DO at A5/U02 appears isolated.

Thus high organic wastes from the food industries was responsible for the depletion of the DO in the receiving sites. This was seen in the very high COD and BOD values in the factory sites and the resulting low DO concentration in the receiving surface waters.

6.10.4 SS/turbidity relationship: industrial and receiving sites

Coefficient variation

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40 and the downstream sites can be seen in table 6.41.

The relationship between the SS discharged by the industries and the SS in the receiving sites gave a positive correlation at all the industrial sites. This indicated that the SS discharged by the industries contributed to the increased SS load in the receiving sites. The coefficient ranged from 0.08 at B2/S03 to 0.55 at C2/S06. The latter had a significance level of .01. The strength of the correlation coefficient varied

widely.

San Sebastian canal

B1, B2/S03

Although the correlation coefficient is weaker at B1/S03, the SS loaded into the receiving site is very high. As previously mentioned the correlation coefficient is affected by many factors such as time, day and frequency of monitoring. But the positive coefficient indicates loading of SS into the receiving site. High SS discharged by the factory was reflected in the high SS in the receiving site such as a high SS load of 3660.75 mg/L was reflected by a correspondingly high SS load of 208.6 mg/L at S03. On the other hand very high SS of 8924.0 mg/L at B1 was reflected by a lower SS of 40.59 mg/L. Similarly a low SS of 232.5 mg/L SS at B1 had a correspondingly low SS of 50.19 mg/L at S03. This is mainly due to the fact that the SS at B1 and S03 was monitored on different days. If it was monitored on the same day, the relationship may be higher.

The relationship between SS at factory site and the receiving site is reflected in the correlation coefficient between SS and turbidity. At B1/S03 this coefficient was 0.28 which indicates that a higher SS discharge from the factory site increases the turbidity of the receiving water.

The industrial site B1 also had an impact on the SS of the downstream site SO4. At B1/S04 it was 0.23. The SS and turbidity at S04 are lower than S03 but higher than S05. This indicates that SS is contributed by B1 to S04. The site B2 also contributes to the downstream site S04, indicated by the positive correlation coefficient of 0.23.

C2/S06

The positive correlation between C2/S06 for solids was reflected in the correlation between the SS and turbidity at C2/S06. The coefficient had a value of 0.55 with the significance at .05. This indicated that the higher the SS discharged from C2 the higher was the turbidity at the receiving site S06. The overall trend indicated a higher SS at C2 giving rise to higher SS at S06, which was reflected by higher turbidity.

The SS discharge of factory site C2 also had an impact on the site downstream S07. This can be seen in the coefficient of 0.45 at C2/S07.

F/T13

In the Main Drain the relationship between the industrial discharge site F and the receiving site T13 gave a higher correlation for SS than at E/T11. The coefficient had a value of 0.20. This indicated that the SS in site T13 increased with the discharge of high SS from the factory Site F.

The SS ranged widely at F with a minimum of 9.36 mg/L and a maximum of 693.10 mg/L. The highest SS at F was recorded in September 1986 with a value of 693.1 mg/L and a corresponding high value was recorded at T13 with the value at 177.0 mg/L when SS was low at F, such as 76.3 in February 1987, the SS was low at T13 with 62.4 mg/L. This pattern did not necessarily follow all the months. For example SS at T13 were higher than F in May and June 1986 and January 1987. The SS recorded were 211.66, 101.3 and 68.75 mg/L at T13, while the SS at the factory site F were 78.1 mg/L, 30.1 mg/L and 9.36 mg/L. This is obviously due to SS that enter the canal site from other sources.

The impact of factory F on the downstream site of S10 gave negative coefficients of -0.33 for SS-turbidity. This relationship is not very clear and may be due to the tidal effect felt at this station which dampens the relationship.

E/T11

The SS-turbidity correlation appeared isolated with -0.01. The contribution from E to the downstream site T12 is also positive indicated by the coefficient of 0.27 which again appears peculiar.

Beira lake

A3, A5/U02

The input of SS into the lake by the industries, A3 and A5 to site U02 indicated a positive relationships. The correlation coefficient was higher at A5 than at A3. The value was 0.39.

The positive correlation indicated that the SS at U02 increased with an increase in discharge from A3 and A5. At A5 the SS content ranged from 37.88 to 4145.96 mg/L. The highest SS at U02 was also recorded on the same month as the highest

SS at A5. The concentrations being 564.17mg/L and 4145.96 respectively in October 1986. The lowest SS at A5 was also reflected at U02 with 37.88 and 10.2 mg/L respectively. But a proportional increase or decrease of SS at U02 did not always occur. Overall, SS at U02 increased with the discharge SS from A5.

The same trend is also reflected in the SS-turbidity correlation with the coefficient at 0.27 for A3/U02. Therefore there has been an increase in the SS loading into the receiving site from the factory site A3.

6.10.5 Sulphate relationship: industry and receiving sites

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

The relationship between sulphate discharges from the industries and the sulphate concentration in the receiving sites indicated a positive relationship at all the industrial discharge sites except at F/T13 which gave a weak negative correlation coefficient of -0.03. The coefficient ranged from 0.01 at A5/U02 to 0.55 at E/T11. The latter had a significance level of .01. This indicated that there is a sulphate loading into most sites from the industrial discharges.

San Sebastian canal

B1, B2/S06

The sulphate discharges from factory sites in the San Sebastian canal gave a correlation coefficient of 0.36 at B2/S03 and 0.31 at B1/S03.

The sulphates at B1 ranged from 58.6 mg/L in January 1986 to 1592.0 mg/L in October 1986. High sulphate concentration were recorded at S03 in January 1987 when the corresponding discharge from the factory site B1 was high. The concentrations were 508.6 and 1202.4 mg/L respectively. Concentration of sulphates have also been higher in the canal site than in the industrial discharge site. This may be due to the lower frequency of monitoring of the industrial site, when the higher sulphate discharges were not detected, or it may be due to higher sulphates that enter the canal site from other sources. The former is more logical because the only other source which could discharge sulphates into the site S03 is domestic waste waters especially from the shanties in the neighbourhood, which cannot account for the concentrations at S03. Further there are no tributaries that discharge at this site.

The impact of the factory site discharge on the down stream site S04 can be seen in the positive coefficient which had a value of 0.14 at B1/S04 and 0.38 at B2/S04. The sulphates at S04 were lower than at S03 but the concentration at S04 were much higher than at S05. This indicates that there is contribution from B1 to the downstream site S04.

C2/S06

The table 6.40 gives the coefficient data.

The sulphates at factory C gave a correlation coefficient of 0.27 at C2/S06. This positive correlation also indicated a loading of sulphates from the factory sites into the receiving site S06.

The loading of sulphates from C2 into S06 is high. This may be due to concentration of sulphates at the fat trap before the waste water enters the canal. The sulphates at C2 ranged from 63.1 mg/L to 1077.2 mg/L. When the concentrations at C2 was higher such as in March 1986 and January 1987 with 961.0 and 832.4 mg/L the corresponding values at S06 also have been high with 216.0 and 235.47 mg/L respectively. With lower discharges of 187.3 mg/L such as in February 1987 the sulphates recorded in the canal site has been higher with a value of 337.33 mg/L. This is most probably due to concentration of sulphates in the canal due to a long spell of dry weather. The fact that there is a stable concentration in the receiving site indicates, that, there is a continuous discharge of sulphates into the site by C2.

The coefficient for the downstream site remained very weak, but positive. The sulphate concentration at the site downstream S07 indicated that there is a build up of sulphates discharged from C2.

Main Drain

E/T11 and F/T13

The sulphates in the Main drain gave a correlation of 0.55 at E/T11 which had a significance level at .01 at E/T11. The coefficient was -0.03 at F/T13.

The sulphates at E was higher than at the receiving site T11 and as indicated by the correlation contributed to the receiving site. The sulphates ranged from 62.3 mg/L to 297.3 mg/L at E. There was a higher concentration of sulphates at T11 in July 1986 with 312.3 mg/L while the factory site had only 66.5. This was probably due to an accumulation resulting from dry weather in July.

The contribution from E into the downstream site T12 can be seen from the coefficient which had a value of 0.64 with a significance of .01.

The relationship at F/T13 was more complicated. The coefficient was -0.03. The contribution was negative. The examination of sulphates at F and T13 shows other than a few discharges of high sulphate concentrations such as in January 1987 with a concentration of 1267.3 mg/L and in April with 307.20 mg/L, the concentrations at T13 have been generally higher. This may be due to sulphates that enter the site from the tidal waters which contain a higher sulphate content, in addition to the sulphate that enter the site from the factory site. There may also be a bottle neck effect at T13 with the sulphates accumulating at the site due to virtual stagnation and the blockage of the mouth of the canal due to siltation, weed growth and the diameter of the culvert through which it enters the San Sebastian canal.

The effect of F on the downstream site S10 gives a correlation coefficient of -0.33. It is possible that the tidal effect had a major influence at this site.

Beira lake

A3, A5/U02

The correlation between the sulphates at factory sites and the receiving site on the lake indicated a positive relationship with coefficient at A3/U02 with 0.23 and 0.01 at A5/U02. Contributions of sulphates into U02 may occur from other sources such as the raw sewage that enter the site from the culvert.

6.10.6 Conductivity relationship: industry and receiving sites

Coefficient variation

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

The conductivity relationship between the factory sites and the receiving sites indicated a positive correlation at all the sites except F/T13 which recorded a negative coefficient of -0.20. The coefficient at the other sites varied from weak, 0.12 at A3/U02 to 0.73, which was .01 significant at B2/S03.

This positive relationship indicates that with the higher conductivity levels at the factory sites, the conductivity levels at the receiving sites also went up, which means that the dissolved solid concentration at the receiving site increased with the higher input of dissolved solids from the discharging factories. Conductivity reflects the dissolved solid content in the waste waters.

San Sebastian canal

B1, B2/S03

The coefficient at B2/S03 was higher but this represents more of the canal water and is contributed by B1. The conductivity at B1/S03 was higher with levels ranging from 390.0 μmhos/cm to 18100.0 μmhos/cm. The canal site also had very high conductivity levels which was due to higher dissolved ions entering the site from B1. The highest levels at the discharge site did not result in the highest concentration in the receiving site. But the dissolved ions have been high at S03 which is undoubtedly due to the industrial discharge.

The impact on the downstream site S04 is not very clear since the coefficient was weakly negative. B1/S04 was -0.05. The conductivity levels tended to be higher than S05, which indicated a contribution from the upstream site. Therefore the coefficient appears peculiar.

C2/S06

The conductivity at factory C indicated a very weak positive relationship with that of the receiving site. The coefficient was 0.09 at C2/S06.

Though the correlation is weak it indicated a loading of dissolved solids into the receiving site. The dissolved ions discharged into the canal site is high at C2/S06.

The site downstream, S07 had a correlation higher coefficient of 0.44 at C2/S07 which indicated that there was a build up of dissolved solids from C2 to S07.

Main Drain

E/T11 and F/T13

The relationship of conductivity between the discharging and the receiving sites in the Main Drain was positive at E/T11 with 0.14 but negative with -0.20 at F/T13.

The conductivity relationship in the Main Drain appeared different to the other sites. The conductivity levels at T11 are higher than at E. The median at E and T11 are 296.2 μmhos/cm and 371.5 respectively. This indicates that in addition to dissolved solids discharged into the site by E, the site receives dissolved solids from other sources. The contribution to the downstream site was negative.

The coefficient at F/T13 was negative. The conductivity relationship at F/T13 was more complicated. The examination of the data indicated that there was input of dissolved solids into site T13 during certain months such as in April 1986 when conductivity of F was higher than T13 with levels of 1255.0 μmhos/cm and 561.0 respectively. But higher values of 1066.0, 1003.0, 1660.0 μmhos/cm were recorded when the corresponding values at F were much lower with 610.0, 480.5 and 320.5. Thus the factory contribution appears minimal.

The relationship of conductivity at F and the downstream site S10 is also complex. F/S10 had a correlation coefficient of -0.01. This indicated an isolated pattern. There appears to be more dissolved solids which enter from the sea from the tidal action.

Beira lake

A3, A5/U02

The conductivity relationship between the discharging sites and the receiving site in the lake showed a positive correlation with 0.12 at A3/U02 and 0.55 at A5/U02. The latter had a significance level of .01.

This indicated loading of dissolved solids into the receiving site U02 from both the industrial sites but higher At A5. The conductivity levels were higher at A5 than U02 which showed a clear loading of dissolved solids into U02. Higher conductivity levels at A5 had a correlation with higher conductivity levels in the receiving site such as 2600.0 in April at A5 had a corresponding high value of 600.0 μmhos/cm, and 2510.0 at A5, corresponding value of 1120.0 at U02.

The conductivity levels were not as high as that at the lake site U01 which was influenced by sea water mixing thus making the water very conductive. The dissolved solids entering the site U02 appears to be mainly from the industries.

The conductivity levels at A3 was also fairly high although the correlation coefficient remained lower.

6.10.7 Total N relationship: industry and the receiving site

Table 6.40 and gives the coefficient between the industrial discharges and the sites, and 6.41 between the industrial discharges and the downstream site. The relationship of total N between the discharging and the receiving sites indicated a positive correlation in all the sites except B2/S03 which had a coefficient of -0.36 and F/T13 which had a coefficient of -0.29. The coefficient ranged from 0.16 at E/T11 to 0.58 at A5/U02. The latter had a significance of .05. This indicated a total N loading into the receiving sites from the discharging industries.

San Sebastian canal

B1, B2/S03

Among the sites on the San Sebastian canal B1/S03 had a coefficient of 0.45 and -0.36 at B2/S03.

The total N at B1 ranged from 0.05 mg/L to 6.35 mg/L. The site S03 had a higher total N concentration than B1 such as in March 1986 when the total N in the factory site was 4.15 mg/L the receiving site had 12.13 mg/L and in February 1987 the concentrations were 6.35 mg/L and 11.2 mg/L respectively. Lower total N discharges from the factory sites also had corresponding lower concentrations in the receiving sites although the corresponding decrease in the concentration was slight. The higher concentrations in the receiving site than from the factory discharges is explainable since this site gets a heavy total N loading from the domestic source mainly from the shanties in the canal banks at this site. The negative correlation at B2/S03 may be due to no contributions from the cooling plant effluent.

The impact of B1 and B2 on the downstream site indicate a correlation coefficient of 0.11 at B1/S04 and -0.08 at B2/S04. Although weak B1 correlation indicates a

contribution to the total N at S04.

C2/S06

The nitrogen relationship at C2/S06 indicate a contribution into the receiving site, although the coefficient was low with a value of 0.21.

The concentration at C2 ranged from 5.3 mg/L to 32.31 mg/L. A high discharge of 23.63 from C2 corresponded with a high concentration at the receiving site of 16.36 mg/L in March 1986. The overall situations shows a contribution from the factory site.

The contribution to the downstream site S07 from C2 gave a negative coefficient of -0.13 at C2/S07. It is possible that there is loading from other input sources.

Main Drain

E/T11 and F/T13

The total N concentration in the Main drain gave a correlation coefficient of 0.16 at E/T11 and -0.29 at F/T13.

The total N at E ranged from 0.75 mg/L to 16.84 mg/L. The total N levels in the receiving site T11 was higher than the factory site with the median total N at T11 being 7.9 mg/L and the median at E being 3.56 mg/L. This can be expected in a confectionery, where the products were mostly hard boiled sweets, and therefore less nitrogeneous materials are used.

The contribution to the site downstream T12 does not appear to be clear. The correlation coefficient between E and T12 was -0.02. As indicated by the coefficient the contribution from E into the downstream site seems minimal. More nitrogeneous material may be entering the site from the domestic sources.

The relationship at F/T13 for total N show a contribution to the site T13. The contribution to the downstream sites were negative.

Beira lake

The total N relationship in the lake between A3/U02 and A5/U02 also indicated a positive correlation with the coefficient at 0.28 at A3/U02 and 0.58 at A5/U02, the latter with a significance level of .05. This indicated that both these factory sites contribute total N to the receiving site. The contribution from A5 into U02 was high. The corresponding concentrations at U02 also remained high. The highest concentration at A5 was 126.2 mg/L in December 1986 with the resulting concentration of 63.25 and U02. The lowest concentration was recorded in February 1986 with 30.37 and 10.6 mg/L at A5 and U02 respectively. High total N concentration at A5 can be expected since the nitrogeneous constituent in a dairy (creamery) waste water is high.

The total N concentration at A3 also remained high which can be expected in a meat processing industry. High discharge from the factory site A3 such as in December 1986 with a concentration of 286.0 mg/L can be associated with a higher concentration at the receiving site with 63.25 mg/L. This is the second highest concentration at U02. The concentration in April was also very high at A3 with the total N concentration at 236.7 mg/L. The concentration at the receiving site was 30.7 mg/L of total N. These two very high concentrations may be due to the seasonality of production with Christmas and the Sinhalese New Year season in December and April respectively. The median total N at A3 was 105.4 mg/L.

This increase in total N concentration during the two seasons can be seen at A5 also with the highest concentration in December with 126.2 mg/L and a high concentration of 96.81 mg/L in April, although a higher value of 116.75 mg/L was recorded in August.

Total N was the least monitored variable in the factories and also in the receiving sites. Therefore this shortcoming may affect the correlations between the factory and the receiving sites.

6.10.8 Total P relationship: industrial and receiving sites

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

The phosphate loading into the receiving waters by the discharging industries gave a negative correlation at the factory sites B and C while it was positive at the other sites. The coefficient ranged from -0.12 at B2/SO3 to 0.65 at A5/UO2. The

latter has a significance level of 0.01.

San Sebastian canal

B1, B2/S03

The total P correlation at B1/SO3 was negative with the coefficient at -0.57 and the -0.12 at B2/SO3. It is not clear why the coefficient is negative. B2 also gave a weak negative relationship. A possible reason at B1/SO3 may be due to the accumulation at the site than to a low discharge from the factory site that indicated a negative effect on the receiving site. It is also possible that the canal gets a higher loading from the domestic source especially from the shanties directly.

The correlation also could have been affected by the time, day and the factory operations at the time of monitoring. Being a factory which also produces detergents, the phosphate content in the waste water can be expected to be higher than the values detected during certain days at the factory.

The relationship at the factory C also resembled B. The coefficient at C2/SO6 was -0.22. The reason for the negative relationship is not clear.

Main Drain

E/T11 and F/T13

The total P relationship at the sites in the Main Drain indicate a positive correlation at both the sites. The coefficient was 0.31 at E/T11 and 0.21 at F/T13 which indicate a loading of total P into the receiving sites. The total P at E ranged from 0.90 to 8.25mg/L. The concentration at the receiving site T11 was lower than in the discharging site except in August when the factroy site had a lower concentration of 0.95mg/L while T11 had 1.20. Other than from fractory E, total P could enter the site from other factories in the area or even from the domestic sources.

The contribution from E to the site downstream T12 was a very weak negative coefficient of -0.01. Thus the contribution is not important.

The total P at F/T13 had a coefficient of 0.21 indicated a contribution to the receiving site. The concentration at F remained higher than a T13 except during November 1986 and February 1987 which had lower concentrations than at T13. The concentrations were 3.87 and 1.25mg/L and 4.3 and 3.6mg/L at F and T13 respectively. The concentration during May 1986 remained comparatively low at T13 with 0.95mg/L although the discharge from F was higher with 3.1mg/L which could be due to high rainfall and dilution at T13. 0.0mg/L total P were recorded at T13 in January 1987. This may be either due to a very low undetectable level or some error in the measurement. The total P discharged from F may be from the detergents used for cleaning purposes in the factory.

The contribution from F to the downstream site S10 can be assessed from the correlation coefficient of 0.30. This might be due to an accumilation effect or due to the complexity of the tidal action.

Beira lake

A3, A5/U02

The correlation data can be seen in table 6.40.

The total P relationship in the lake and the receiving sites gave a positive correlation of 0.34 at A3/UO2 and 0.65 at A5/UO2. The latter was .01 level significant. These indicated contribution to UO2 form both the sites.

The concentration at A5 ranged from 1.0 to 17.8 mg/L. The concentration at A5 was higher than the lake site. A higher value of 11.35 mg/L was recorded at UO2 in June although the factory site had a lower concentration of 8.9 mg/L. The total P at A5 enter the waste waters mainly from detergents used in the cleaning purposes. At A5 the vats used for making ice cream are washed in addition to the empty bottles of milk, as bottling dairy milk is also done in this factory site.

The factory site A3 had a concentration ranging from 1.5 to 10.0mg/L. The concentration at A3 was generally higher than at UO2 except in March and April 1986 when the concentrations were 4.35 and 5.15mg/L at UO2 and, 1.65 and 5.0 at A3. The concentrations at the lake site was very low with 0.45 mg/L in October 1986.

6.10.9 pH relationship: industry and receiving sites

The pH relationship between the factory and the receiving sites was more complex. The pH relationshiop in the factory site and the receiving water sites gave correlation of -0.32 at C2/SO2 to 0.80 at A5/UO2. The latter had a significance level of .001.

The pH relationship in the sites was a complex phenomena in water chemistry, which necessitates a deeper understanding of the chemical reactions particularly the hydrogen ion acitivity taking place in the waste water of the factory and the receiving sites.

San Sebastian canal

B1, B2/S03 and C2/S06

The correlation data is given in table 6.40.

The pH relationship in the San Sebastian canal appeared complicated. The relationship at B1 is not very clear. The pH at B1 remained very high and ranged from 8.7 to 12.8. Being waste waters from soap industry this is a normal range of pH encountered. A negative correlation although weak, -0.14 may be due to the rapid changing nature of pH, which would not have been detected due to the different times and days of monitoring in the factory sites and the receiving sites. Delay in measuring the sample pH on certain days due to unavoidable circumstances also may have affected the pH values which in theory should be measured insitu.

B2 is more or less the water of the canal site SO3 itself. The relationship was not comprehensible as the coefficient was zero.

The pH at C2/S06 was negative and thus the relationship was not clear. It is possible that other outlets influence the receiving site.

Main Drain

E/T11 and F/T13

Table 6.40 gives the correlation data.

The coefficient was 0.27 at E/T11. The level of significance was low. But the coefficient remained positive. At E the pH ranged from 6.1 to 9.1 with the median at 7.3. The high pH value of 9.1 was recorded only once, i.e in March 1986, possibly due to cleansing agents used in the factory. The waste water from E remained slightly acidic on many occasions with pH ranging from 6.1 to 6.3. This can be expected in a food industry, especially the waste water on standing becomes acidic. The receiving site T11 was usually slightly alkaline. The pH median was 8.2. Slighlty alkaline values were recorded in November and December 1986, and January 1987. The acidic waste water of the factory may be neutralized on entering the canal. The effect on the downstream site was negative.

The pH at F/T13 was a weak positive with the coefficient at 0.12 as seen in table 6.40. The discharge of both acidic and alkaline waters may have a neutralising effect (although slightly alkaline) on the receiving site which is indicated by the weak coefficient. The pH of the factory site F ranged from 6.2 to 10.1. The median pH at F was 7.9. The median pH at T13 was 8.4. This indicates that both acidic and alkaline waste waters have been entering the receiving site from the factory F. The acidity of the waste waters is due to the nature of the production in the industry and the alkalinity is due to the detergents used in the cleaning purposes, both the mixing vats and the floor. Being a food industry the factory floor is washed daily. The receiving site had slightly alkaline waters. This may be due to the factory waste water as indicated by the positive correlation coefficient.

Beira lake

A3, A5/U02

The correlation coefficient was weak at A3, but very strong at A5 as seen in table 6.40.

The pH in the lake site UO2 ranged from 6.2 to 9.0 with the median at 8.1. This range in pH may be due to the discharge of acidic to alkaline waste waters from the factory sites A3 and A5.

The pH at A5/U02 had a coefficient of 0.80, with the level of significance at .001. The pH at A5 ranged from 6.2 to to a very high alkaline value of 12.3. This can be expected in this industry since the waste waters from milk based products becomes acidic on standing, while the highly alkaline wasters from the same industry may be due to the cleansing agents used to wash the vats in the ice cream plants, and the bottles in the milk bottling section in the same premises, in addition to the

floor washing which is done daily. Thus this relationship with the receiving site was reflected in the coefficient.

6.10.10 Water temperature relationship: industrial and receiving sites

The correlation coefficient between the industrial discharges and the receiving sites can be seen in table 6.40. The coefficient between the industrial discharges and the downstream sites can be seen in table 6.41.

The water temperature relationship between the factory sites and the corresponding receiving sites gave a positive correlation in all the sites except C2/SO6 which had a negative coefficient of -0.12. The coefficient at the other sites ranged from 0.04 at B1/SO3 to 0.63 at F/T13 and B2/SO3 which had a significance level of .01. The positive correlation in the sites indicated an increase in water temperature with heated effluents entering the sites from the discharging sites.

San Sebastian canal

B1, B2/S03

The water temperature at B2/SO3 had a correlation of 0.63 which had a significance of .01, indicated an increase in the temperature of water at the receiving site. The water temperature at B2 ranged from 32 °C to 44 °C with the median at 37 °C. The water temperature at the SO3 appeared to reflect the temperature of B2 except during April and December 1986 when the water temperature at SO3 was slightly higher than B2. The water temperatures were 35 °C and 33 °C at SO3 and 35 and 32 °C at B2. The highest temperatures recorded during February 1987 with a high temperature of 44 °C was reflected in the higher corresponding water temperature of 37 °C at SO3. The lowest temperatures recorded at B2 also had a lower temperature of 31.27 °C at the receiving site.

The coefficient was weak with 0.04 at B1/S03, thus the relationship between water temperature at B1 and S03 appeared weak.

The effect of B1 and B2 on the downstream site SO4 can be seen in the correlation coefficient of 0.12 at B1/SO4 and 0.44 at B2/SO4. The former appeared weak, while B2/S04 indicated an influence on the downstream site. This indicates an increase of water temperature at the downstream site due to higher water temperature of the effluent discharge of the upstream factory.

C2/S06

The water temperature at C2/SO6 gave a correlation coefficient of -0.12.

The coefficient at C2/S06 was a weak negative. The water temperature at C2 was more stable. It also indicates a contribution from other outlets. Thus the impact on the receiving site directly from this site may be negligible. The coefficient at the downstream site appeared isolated.

Main Drain

E/T11 and F/T13

The water temperature in the Main Drain had a correlation coefficient of 0.57 at E/T11 and 0.63 at F/T13, which indicated a positive correlation at both the sites. The level of significance was .01 at both the sites.

The water temperature at E ranged from 30 °C to 40.5 °C with the median at 30.7 °C. Except for a very high water temperature value of 40.5 °C in March 1986 the temperature ranged between 30 and 33.5 °C. Thus the water temperature at E was not exceptionally high. It remained slightly above the ambient air temperature. The days which recorded high water temperatures at E are in March and November 1986 with 40.5 °C and 33.5 °C. The corresponding water temperature recorded in the receiving site was high with 33.5 °C and 32 °C.

The impact on the site down stream was positive with the correlation coefficient of 0.41 at E/T12. This indicates a contribution to the downstream site.

The water temperature at F/T13 had a correlation coefficient of 0.63 which had a significance of .01 which indicated an increase in the water temperature of the receiving site, due to heated effluents entering the site. The water temperature at F remained very high with the minimum at 36 °C and the maximum recorded at 45.5 °C. The median was 38 °C. The very high temperature at this factory is due to the site of monitoring which was within the factory and sample was collected from the drain which carried the boiling syrup effluent. The receiving site T13 had high temperatures which ranged from 32 to 40 °C with the median at 36.1 °C. The

temperature at T13 remained higher than the ambient temperature throughout, with high temperature at T13 corresponding to the higher temperature at the factory site, such as 45.5 °C at F and 40 °C at T13 in February 1987 and 36 °C and 32 °C in January 1986 at the respective sites.

The correlation between F and the downstream site S10 had a coefficient of 0.15 which indicated a very weak contribution.

Beira lake

A3 and A5/U02

The coefficient can be seen in table 6.40.

The water temperature relationship in the lake gave positive coefficients of 0.57 at A3/UO2 and 0.53 at A5/UO2. The level of significance was .01 and .05 respectively.

The site A3 had water temperature ranging from 30 to 33.5 °C. The median temperature was 32 °C. The corresponding water temperature at UO2 was lower than the discharge site with the median at 31 °C. There has been a corresponding increase in temperature at UO2 with an increase in the factory site temperature such as 32 °C and 33 °C respectively in the month of March 1986, while in February 1986, the temperature remained same at both the sites with 33 °C. In February 1987 the temperature at UO2 was higher than at A3 with 31 °C and 30 °C respectively. Overall there was response at UO2 to the water temperature at A3, although low water temperatures were recorded during certain times.

The relationship at A5 remained very similar to A3. The water temperature at A5 ranged from 28.0 to 34.5 °C, with the median at 32.5 °C, which was slightly higher than A3. Higher temperatures at A5 increased the water temperature of the receiving site such as in February 1986 the temperature was 34.5 °C at A5 and 33 °C at UO2 and in January 1986, the water temperatures were 34 and 30 °C at A5 and UO2 respectively. But this situation did not necessarily occur in all the months.

The overall impact of the factory sites A3 and A5 on UO2 appears contributory. The highly significant positive correlation coefficient between the factories and the receiving sites indicated that the higher temperatures of the effluent did increase the water temperature of the receiving site.

Summary

The correlation between the industrial discharges and the receiving sites indicated some important relationships. The coefficients varied widely and certain industries had lower coefficients which may have been due to the lower frequency of monitoring of the industries.

The correlation coefficient for BOD gave a positive coefficient for all the industries. This indicated that there was a clear relationship in the factory discharges and the receiving sites. The positive coefficient indicated a loading of organic wastes into the sites. The industrial sites (B2 and C2) on the San Sebastian canal contributed to the receiving sites. The coefficients also gave a positive relationship between the industrial discharges and the receiving sites. This indicated a positive effect on the downstream sites S04 and S07 respectively. The factory site on the Main Drain F/T13 also had a high correlation. The effect on the downstream site F/S10 was negative which indicated no contribution, due to the tidal impact at this site which supresses the contribution. The contribution to the downstrem site E/T12 was positive which indicates loading by E. The industrial sites on the lake too indicated positive contribution. A5/U02 had a higher coefficient.

The COD relationships were very similar to the BOD. The coefficient at B1/S03 remained low although the loading is very high. The reason for this is not clear. It may be possible that the organic load at the receiving site was so very high from the industrial discharge that it did not respond proportionately to the extremely high industrial discharges. At the downstream site F/S10 the coefficient was positive, thus there was contribution into the site, which was different to the BOD.

The COD/DO indicated a negative relationship except at A5/U02. This showed that the organic load in terms of the COD of the industries depletes the DO of the receiving water. In the San Sebastian canal the coefficient was low at C2. This was caused by the very low DO levels in the receiving site at S06. These hardly responded to the very high fluctuation in the COD. The downstream sites of S04 and S07 on the San Sebastian canal too had contributions from industries. Both the industrial sites on the Main Drain had negative coefficients which indicated the depletion of DO at

the receiving sites. The downstream sites E/T12 and F/S10 also had a negative effect on the DO. But it is less clear at the latter, possibly due to the tidal influence. The lake site A3/U02 had a negative relationship, but A5/U02 appeared isolated which is not clear.

The BOD/DO correlation coefficient gave similar relationship in all the sites except C2/S06 and E/T11. This showed that the organic load in terms of the BOD of the industries depletes the DO of the receiving water.

The SS/turbidity relationship gave a positive coefficient in all the sites except E/T11. In the San Sebastian canal B1/S03 appeared weak, but positive. The contribution into the downstream site S04 was positive. The industrial site C2/S06 too had the same relationship at both the receiving and the downstream sites. The coefficient was higher in the latter. In the Main Drain both the industries contributed to the receiving sites, but the coefficient was higher at F/T13. The contribution into the downstream site E/T12 was positive, but F/S10 was negative. Again this may be due to the tidal influence. Both the lake sites had positive coefficients, which indicated a contribution by the industries into the receiving site, a conclusion which was also strengthened by the values of the turbidity coefficient. Thus all the industries indicated a contribution of SS into the receiving sites.

The conductivity coefficient indicated a loading of dissolved solids from most of the industries into the receiving sites. In the San Sebastian canal the B2/S03 coefficient was higher: it represents the canal water. Although a higher coefficient can be expected from B1/S03 due to the discharge of dissolved solids, which was reflected in the very high conductivity values, the higher coefficient at B1 portrays this. The effect on the downstream site B2/S04 was contributory. The coefficient at C2/S06 was positive which indicated loading into the site. The contribution by C2 into the downstream site S07 was positive. In the Main Drain E/T11 indicated a contribution with a positive coefficient. F/T13 was negative. Thus the contribution to the receiving site was minimal. The conductivity at F/T13 appears to be influenced by the industries E and F to a certain extent. At the same time, the tidal effect from the Kelani River and the sea outlet to the Mutwal tunnel through which the sea water may enter the Main Drain by backflow seems to have a greater influence on the conductivity. In the downstream site the contribution by F appears minimal. In the lake both the industrial sites had a positive contribution, although the coefficient was higher at A5/U02.

The sulphates indicated a positive relationship at all the except at F/T13. This indicated a contribution of sulphates into the receiving sites. In the San Sebastian canal both the sites at B and C contributed to the receiving and the downstream sites. In the Main Drain E/T11 was positive and contributed to the downstream site E/T12 too. F/T13 was negative. This was reflected in the downstream site F/S10 as well. Thus the factory contribution to the sulphates of both the receiving and the downstream sites was minimal. In the lake sites, sulphate contribution appears to be more from A3/U02, although both are positive.

The total N was positive at all the sites except at B2/S03 and F/T13. In the San Sebastian canal the coefficient was positive at B1/S03 which indicates a loading. It also contributes to the downstream site although the coefficient is very weak. B2/S03 is not clear as the coefficient is negative. C2/S06 had a positive coefficient which indicated a contribution to the receiving site. In the Main Drain E/T11 had a weak contribution, but there appears to be no contribution to the downstream site E/T12. There was no contribution at F/T13. In the Beira lake both the sites had contributions. A5/U02 had a higher coefficient, which can be expected in a creamery.

The total P coefficients were positive in all the sites except B and C. The reasons for the negative coefficients at latter factory sites are not clear. In the Main Drain both the site had positive contributions. The appears no contributions to the downstream site E/T12 . The contributions into the downstream site F/S10 was positive. The industrial contribution into the lake was positive at both the sites, which indicates loading into the receiving site.

The pH relationship appeared more complex. The relationship at B1 and B2/S03 were not clear and neither was C2/S06. The downstream sites of B and C were negative. The sites in the Main Drain had positive coefficients, but it was very weak at F/T13. The relationship in the lake sites were positive and the coefficient was

strong at A5.

The water temperature coefficient was positive at all the sites except at C2/S06. This indicated an increase of the water temperature in the receiving sites from heated effluent discharges. In the San Sebastian canal the coefficients at both the sites at B were positive, but B1/S03 was very weak. There was also effect on the downstream site S04 indicated by the positive coefficients. C2/S06 had a negative effect which was not clear. In the Main Drain both the sites had high positive coefficients which indicated the response at the receiving sites. The downstream site E/T12 had a higher contribution from E. The downstream site F/S10 had a weak contribution. Both the lake sites had high positive contributions.

Thus although there were shortcomings in the frequency and the time of monitoring, the correlations between the factory discharges and the receiving sites indicated that there was a loading of pollutants into the receiving sites and that the effect was felt in the downstream sites. The detrimental effect on the DO was also clear at both the receiving and the downstream sites. This was true of most of the sites in the San Sebastian canal, the lake and the Main Drain.

Chapter VII

The rainfall-pollutant analysis

7.1 Limitations: water level readings in the monitored sites

The data for water levels in the canals show irregularities. Although the data were collected from two departments i.e the Irrigation Department, Colombo and the Low Lying Reclamation and Drainage Corporation (SLRDC) Colombo North, the information on water levels in the canals had many gaps in the data set. There was a good network of gauge posts in the canal network, which coincided with the monitoring sites, but the recordings were very poor from 1983, which may be due partly to the onset of civil disturbances and partly due to the reorganisation of government departments, with a change of functions from department to department and the creation of new departments to handle water data. In the event records were missing on the water levels, maintained by the SLRDC. The records maintained by the Irrigation Department was reliable and did not have missing values for the gauge stations maintained by them i.e. for RO2, while S10 had records only from mid July, 1986. The sites T11, TO9, TO3, SO4, TO4, T13, maintained by SLRDC had many missing values for all the sites with no records at all upto mid June in all the sites for 1986. Many stations were not functioning. SO4, TO4, and TO3 had only readings from January 1987.

As the data had many gaps during the period of monitoring, 1983 and 1984 water level data were used to see whether there were any correlations in the water levels between these years and 1986/87. Data for 1985 were non existent. Years prior to 1983 were not available. The 1986/87, did not correlate well with the daily and weekly values of 1983, 1984 or even the mean of the 1983/84, data. For example the daily correlation coefficient at 08.00 hours, at SO4 was -0.04 for 1983/86-7, 0.07 for 1984/86-7 and -0.31 for the mean of 1983-4/1986-7. The levels of significance were very low. Therefore, these analyses had to be rejected. As the water data were not useful to fill the missing values for 86/87, the 1986/87 daily rainfall was tried to fill the gaps, in the water data. A daily lag analysis was done, which too gave a very poor correlation coefficient. As a next step total rain lags were used to predict the missing values in the water data by means of a multiple regression analysis. This too did not prove a good measure of predictability. The predictability was good for the higher rainfall values, but where the rainfall was low (near or at zero mm) the predictability was poor and so the water levels could not be used to explain the pollutant concentration at the sites.

The water levels in the sites would have proved invaluable to interpret the pollutant concentration and the level of dilution, during high and low flows in the canal in the absence of flow measurements. Since water levels and flow measurements were not available, rainfall was used as a measure to interpret the pollutant concentrations. Rainfall also has its limitations, since not all the rain that fall enters the canal. Losses may occur due to evaporation and runoff, although more water will be retained in the canal due to its low gradient. Further the rainfall data collected from the Colombo Observatory was common to all the sites as the monitoring sites did not have their own rain gauges. The monitored sites were within a fair radius of the Observatory, hence the rainfall would be representative of the sites. This is especially true of the San Sebastian canal and the other surface waters monitored. The sites on the San Sebastian canal are very close to the Colombo observatory.

7.2 Meteorological conditions in Sri Lanka with reference to rainfall

The rain gauging stations and the rainfall data

There are 336 rain gauging stations in Sri Lanka of which 26 are principal meteorological stations. The stations closest to the research area are Angoda, Oruwala, Maligakanda, Fort and the Colombo observatory. Though Maligakande and Fort are closer stations, rainfall recordings are very irregular. Colombo Fort had rainfall readings upto 1984 February with a gap in data till 1987. It started refunctioning from February 1987. Angoda had data upto 1987 February, with many gaps in between, while Maligakande had observations only upto 1972. Oruwala had rainfall readings upto 1983, and refunctioned from 1987, but gaps in the data existed. Therefore, meteorological observations from the Colombo observatory were used for all sites for conformity.

The overall meteorological conditions

The latitudinal position of Sri Lanka subjects it to the tropical meteorological conditions. Though the temperatures are moderately high throughout the year, the climate is not marked by seasonal changes based on thermal characteristics. The mean annual range in temperature is around 4-5 °C. Although the thermal variation is low, the rainfall is an important parameter in the seasonality of the climate. Thus the seasons are based purely on rainfall. Rainfall in Sri Lanka is influenced by the tropical rainfall phenomena. It comes under the influence of the Inter Tropical Convergence Zone (ITCZ), which brings heavy spells of convectional, thunderstorm rainfall; the tropical cyclones; the SW and the NE Monsoons and orographic rainfall. The low pressure system which develops in the Bay of Bengal also causes heavy rainfall in the island. Parts of Sri Lanka receive rainfall practically throughout the year. The wet zone receives heavier rainfall due to the direction of the rainbearing wind flow and the topographic obstruction and shielding capacity of the central highland, and the wet zone receives rainfall practically throughout the year. The bulk of the rainfall is received during the SW monsoons. The two inter-monsoons in April and October also contribute heavily to the rainfall. The Inter-monsoon of October is much heavier in intensity. February is the driest month. On the other hand, the dry zone is a rainshadow area with lower rainfall.

Meteorological conditions in Colombo: January 1986 to February 1987

The weather conditions in Colombo during 1986 appeared to be distinctly different from the usual weather pattern observed in Colombo. This was clearly evident in the seasonal rainfall, which depicted a marked deviation from the typical situation. This trend can be observed in the monthly rainfall too. The SW monsoon which brings bulk of the rainfall to Colombo and the wet zone was weak, resulted in low rainfall during the seasonal NE monsoons. The Inter Monsoonal rainfall from the thunderstorm activities were predominantly active in 1986, while the cyclonic weather too was observed. Thus a re-classification of the seasonal rainfall was attempted.

Seasonality of rainfall

Classically, the rainfall is divided into four broad seasons. The north east monsoon occurs between December to February, Intermonsoon I, from March to mid May, SW monsoon from late May to mid September and the Intermonsoon II from late September to November. The Sri Lanka Economic Atlas classification of 1980 (Department of Census and Statistics, 1981a) is basically the same, except that the Intermonsoon II, is classified from October to November and the Southwest monsoon from mid May to September.

Peculiarities in the rainfall during the period of research

Figure 7.1 shows the total monthly rainfall in Colombo from December 1985 to February 1987.

The highest total monthly rainfall for 1986 was recorded in May with a total of 230.97mm of rainfall. April had the second highest with 216.84mm. The lowest was recorded in July with 10.39mm. Under normal circumstances the SW monsoonal flow develops its maximum depth in July with the intensification of the monsoon activities in the troposphere. This results in very heavy intensive rainfall during July which is the height of the SW monsoons. But as seen with the rainfall figure, July 1986, received the lowest monthly rainfall, with an amount of 10.39mm, which indicated a weak monsoonal rain or rather a failure of this seasonal rain which is very important phenomenon in the wet zone. On the other hand, February usually

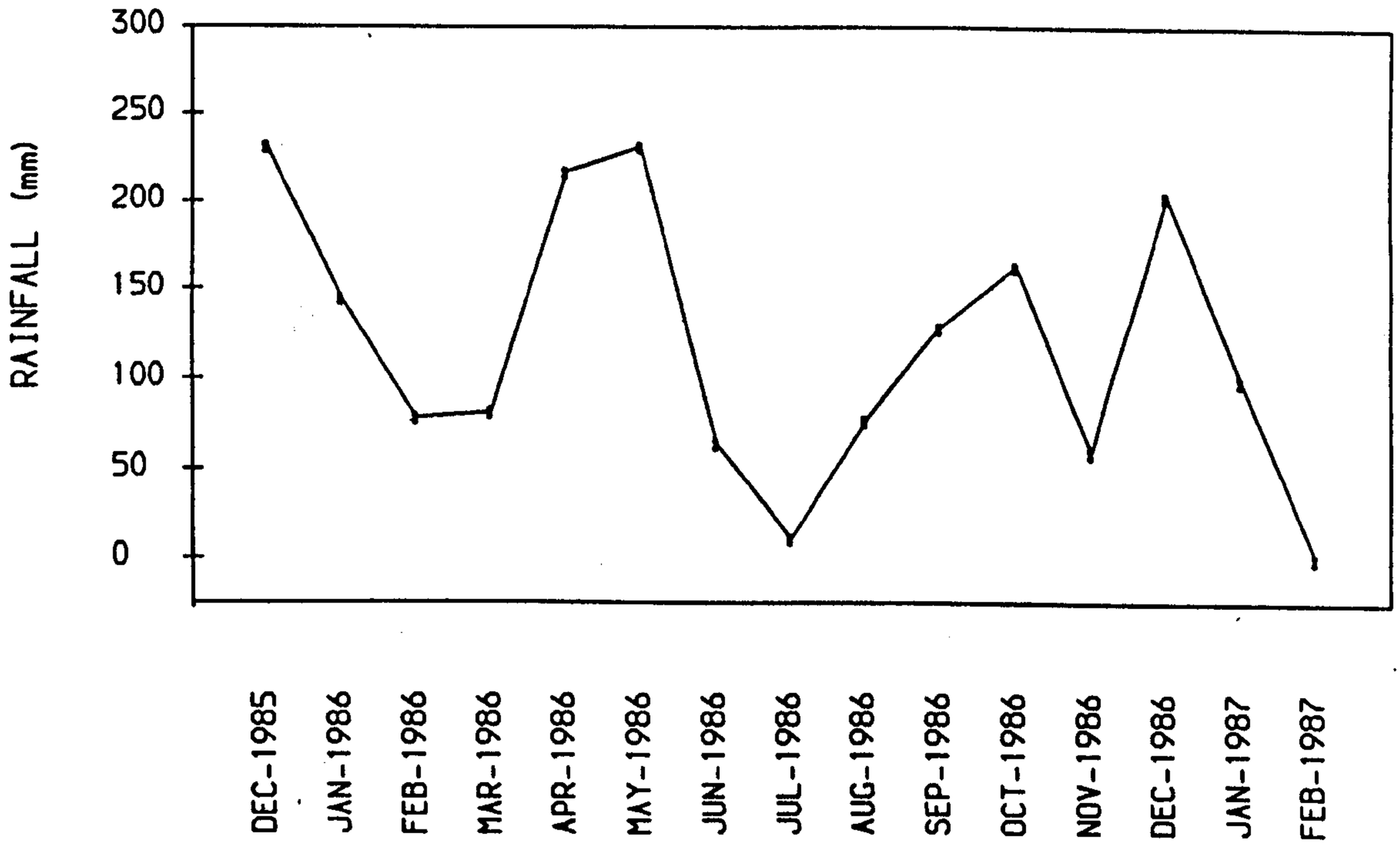


Figure 7.1 — Total monthly rainfall in Colombo: December 1985-February 1987

the driest month in the year received a fairly high monthly total of 78.4mm (mean 2.80 mm). In comparison February 1987 received 0.0mm. February received a higher monthly total than the usually high rainfall SW monsoonal months June and August which experienced 63.84 and 76.26mm respectively. This indicates the peculiarity of the rainfall in 1986. The rainfall peculiarity is seen further in the Intermonsoons, and the NE monsoonal rains. The Intermonsson I, the weaker of the two Intermonsoons had heavier and more intensive rainfall than in Intermonsoon II. In Intermonsson I, May received 230.97mm and April received 216.84mm, while in Intermonsoon II, September and October received only 128.43 mm and 163.02 mm. Further, rainfall in the NE monsoon month of December was 203.45mm was very much higher than the SW monsoonal months. The entire rainfall total for the SW monsoon season (June, July and August) of 150.49mm was only 73.9% of the monthly total of 203.45 mm in December alone. This itself indicates the peculiarity of the rainfall in 1986. The daily rainfall ranged from 0.0 - 100.2 mm in May 1986. 100.2mm was received on one single day, 7.5.86. The daily rainfall during the period of research can be seen in appendix I.

The number of days with 0.0 mm rainfall was 253, during the 14 months of monitoring. This indicated the magnitude of dry spells in between heavy showers. Therefore there was a negative deviation from the mean rainfall in the SW and IM II, while a positive deviation in IM I and the NE monsoons.

A closer examination of the monthly and the daily rainfall values revealed certain important features, such as the rainfall in May 1986 was an intensification of the intermonsoonal rainfall due to the activities of the ITCZ with accompanying convectional activity which resulted in thunderstorm rainfall rather than due to the SW monsoonal activity.

Similarly, September was the beginning of the IM II, rather than the the end of the SW monsoon and therefore May and September were classified as intermonsoonal months. This is a modification to the classical seasonal classification. This can be justified by the fact that 184.2 mm or 79.73% of the total rainfall in May was received during the first week of the month, which makes it akin to the intermonsoonal rains.

This is also supported by the atmospheric pressure conditions. The fact that a daily total of 100.2mm which is nearly 50% of the monthly total rainfall was received on 7.5.86 justifies this classification.

Therefore September was amalgamated with IM II. Therefore the two marginal months of May and September which are usually grouped with the SW monsoons were aligned with the intermonsoons.

This classification can be justified on the grounds that, May rainfall was an intensification of thunderstorm connectional rainfall due to ITCZ activity and other than SW monsoonal weather conditions. Over 75% of the rainfall was received during the first half of May, while less than 25% was recorded in the second half, therefore May was amalgamated with April as Intermonsoon I. September, another marginal month, usually classified as SW Monsoonal, was grouped with October as Intermonsoonal II. Similarly in September, the first 12 days of the month recorded zero rainfall for all but one day, which indicated the weakening of the SW monsoons. The rainfall during the second half of the month was steady starting with high daily rainfall which indicated the commencement of the second Intermonsoon. Nearly 98% of the rain was received in the second half of September. Most of the rain was received during the evening. Therefore September was classified as Intermonsoon II together with October. This classification proved very useful for the seasonal correlation analysis later.

Therefore the rainfall seasons were modified as follows:

January, February and March 1986:	NE Monsoon I	(Season I)
April and May 1986:	IM I	(Season II)
June, July and August 1986:	SW Monsoon	(Season III)
September and October 1986:	IM II	(Season IV)
November, December 1986; and January, February 1987:	NE Monsoon II	(Season V)

The modified mean seasonal rainfall can be seen in figure 7.2.

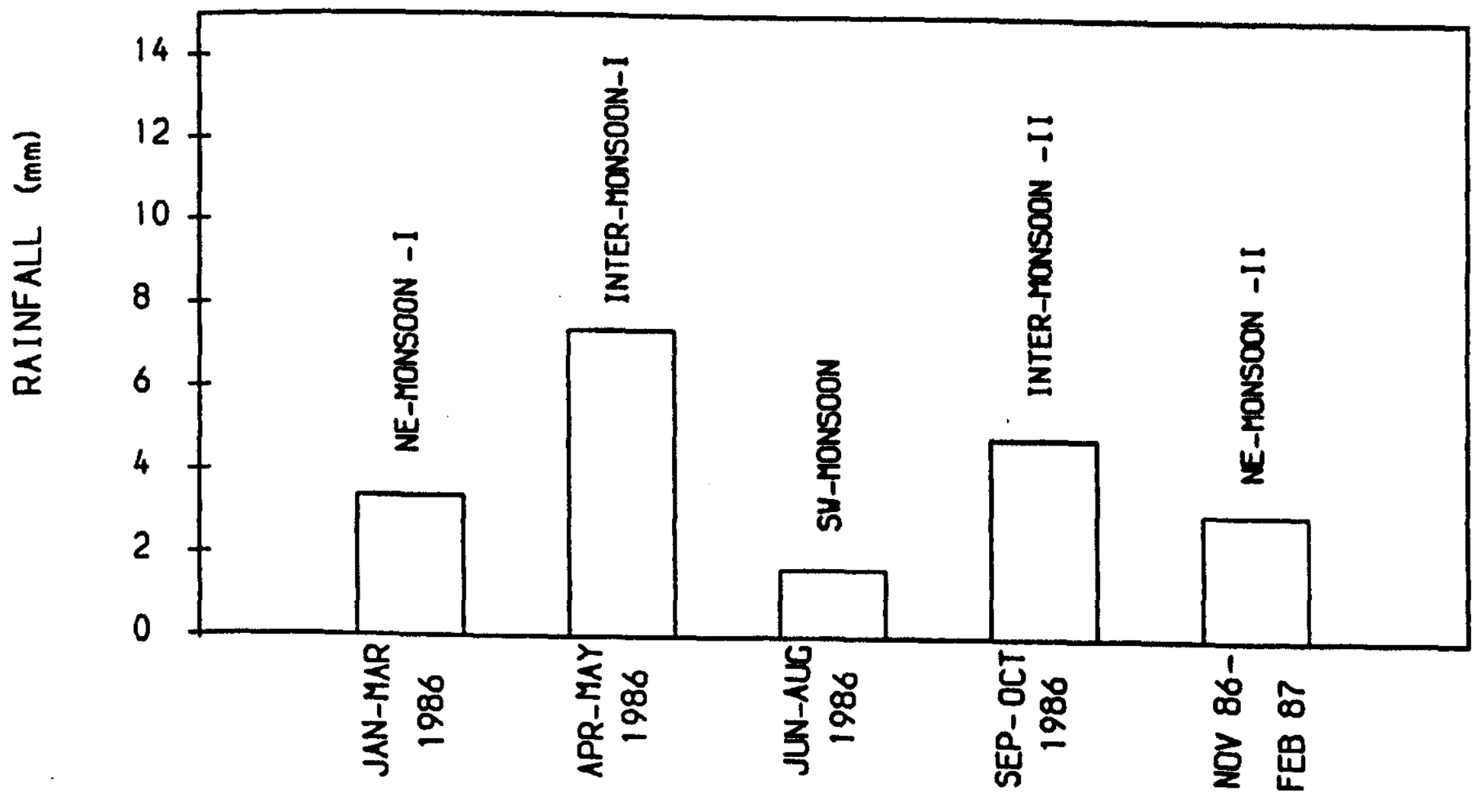


Figure 7.2 — Mean seasonal rainfall (modified) in Colombo: January 1986-February 1987

This modification to the seasonal rainfall was necessitated for the rainfall-pollutant

correlation analysis to see the relationship between the seasonal rainfall and the pollutants. This classification proved very useful as there was a good correlation with the pollutants. The unmodified seasons correlated poorly.

7.3 The rainfall-pollutant correlation analysis

In Sri Lanka as in the other tropical countries rainfall is an important parameter in water pollution studies. The rainfall determines the concentration and and dilution of the pollutants in the inland surface waters. As discussed earlier rainfall is high and can be expected throughout the year in the research area. The range in rainfall during the period of study was 100.2 mm, with zero rainfall as the minimum. Although rainfall can be expected throughout the year, it is influenced by the seasonal rainfall regimes. The seasons are well marked. Depending on the atmospheric development of the rainfall phenomena, the seasonal rainfall can vary in depth, intensity, and the distribution. It can range from a weak seasonal phenomenon to a well developed intense seasonal rainfall. It may even fail in certain years; but total failure is a rare occurrence. Dry spells with virtually no rain (or trace amount) is not rare. During the monitoring period, 1986 happened to be a peculiar rainfall year with the most important seasonal rainfall for the wet zone, i.e. the southwest monsoons, failing and July usually the height of the southwest monsoon received the lowest mean monthly rainfall of 10.59 mm recorded for the entire year. In 1987, February received zero rainfall. Intense rainfall alternating with marked dry weather has an important bearing on the pollutants in the inland surface waters. Low rainfall augments the pollutant concentration, while high rainfall has the capacity to dilute the pollutants under normal conditions. This relationship becomes more complex when industrial waste waters are discharged into low flow or stagnant inland surface water ways. To examine this relationship between the rainfall and the pollutants a rainfall-pollutant analysis was done on a daily, monthly, and a seasonal time scale. This indicated the effects of rainfall on the concentration and dilution of the pollutants in the surface water bodies.

Initially a correlation analysis was done on all the monitored pollutants with the rainfall on a daily basis. This analysis indicated some clear trends between the rainfall and the pollutants. Although the correlation coefficient was not very strong, some clear trends surfaced from this analysis. Thus the analysis was extended into a monthly and a seasonal analysis which indicated stronger relationships. This indicated that distinctive relationships between rainfall and the pollutants broadly existed on a time scale. It also indicated the importance of rainfall in the dilution and concentration of the pollutants in the inland surface waters. The seasonal analysis was a better representation since the rainfall was modified according to the rainfall pattern of the period of monitoring. Although the monthly analysis also proved useful to understand the relationships especially during the very high and very low rainfall months, the analysis was less clear in the marginal months. The fact that the months were arbitrarily broken down by the calendar months, or the peculiarity of the rainfall in the monitoring periods, may have affected this.

The conventional rainfall seasons was used initially in the seasonal rainfall pollutant analysis. This gave a lower correlation. The analysis done with the modified seasonal rainfall for 1986/87 indicated a higher correlation. Hence, this analysis was done for selected pollutants in all the waterways. The analysis on the tributary canals had its limitations due to lower monitoring frequency.

Although this analysis indicated the trends in the concentration and the dilution of pollutants, it did not give the precise relationship between the rainfall and the pollutants. It proved a good mechanism to explain the rainfall-pollutant relationship over a series of time defined by the natural phenomenon operative in the area of research. The analysis although very comprehensive and detailed also had its limitations since it represented only a mean situation between the rainfall and the pollutants. Thus to overcome this shortcoming a time series analysis based on the lag function was done on selected sites and pollutants in the San Sebastian canal.

Thus the rain based pollutant analysis gave some important insights and relationships in the trends over 14 months of monitoring with regard to rainfall and the pollutants. Being a tropical country where rainfall is important and the research area being located in the wet zone of the island, and the fact that the industrial discharges

monitored enter the inland water bodies without any form of treatment made this analysis very useful. Therefore, more emphasis was laid on the pollutant relationship with rainfall. Hence the importance of this least expensive natural dilutant with regard to the pollutant could be assessed on the waterways in the industrial and non-industrial sites.

7.3.1 The daily, monthly and seasonal rainfall - DO analysis

The relationship between DO and rainfall on a daily basis resulted in a positive correlation between these two variables which indicated that the higher the rainfall the higher is the DO in the surface waters. In other words, with rainfall reaeration takes place.(This makes available more DO for the bacteria to oxidize the organic matter in the surface waters). When there is more DO in the water the water is less polluted. On the other hand, when there is no rainfall the pollutants become concentrated and the DO in the surface water get depleted as no natural atmospheric re-aeration takes place. The daily rainfall-DO correlation analysis gave a clear relationship between these two parameters over the sites in the San Sebastian canal, the lake, river, and the tributary canals.

This analysis was not done for the industries as some of the sampling points were indoors. Further, the effect of the rainfall on the industrial discharges is clearly reflected in the industrial waste water receiving sites. In the tributary canals the correlation between rainfall and the pollutants was attempted mainly in the confluence sites. The monitoring frequency remained low in the tributary canals. Thus there are limitations.

San Sebastian canal

Coefficient variation: daily

The table 7.1 show the daily correlation coefficient between DO and rainfall. Figure 7.3 (A) shows the trend across the sites.

The daily coefficient was higher at S01 and S02 with 0.43 where the level of significance was .01. The sites S03 to S09 had lower correlation coefficients with 0.15 at S03 which is the industrial waste water reception site to factory B. The coefficients were 0.20 at S04, and 0.25 at S06 and S07. The correlation coefficient varied between 0.08 at S09, to 0.47 at S10. The latter had a significance level of .001.

Background factors

The coefficient was higher at S01 and S02 with 0.43 where the level of significance was .01. These two sites which are free from industrial and domestic discharges and exposed well to rainfall when compared to the other stations along the canal, cannot be expected to have a very high correlation between rainfall and the DO on a daily basis. A very high reaeration rate is not possible with a few millimeters of rainfall over 24 hours. But the coefficient indicates that reaeration is taking place. This becomes clear when the other sites along the canal are considered. Lower correlation at S05 which receives domestic waste waters from the shanties might be due to the daily values or the cumulative effect of the industrial waste waters from the upstream sites.

The sites S03 to S09 had lower correlation coefficients. The site S03 is an industrial waste water reception site to factory B. The site S04 receives waste waters from shanties and automobile repair shops, and S07 waste waters from an open laundry and the Kettarama drain.

The fact that the correlation is poorer from S03, with the same amount of rainfall that falls over the entire canal on the neighbouring sites to S02 which are spaced closely, indicates that there are factors that hinder the reaeration capacity of the canal. This is obviously due to the industrial discharges at S03, S04, and S06 which are highly organic, and, to a lesser extent from the domestic wastes waters. In addition to the organic matter in the waste waters, layer of oil was present at S04, S05, S06, and S07, and between S09, and S10 throughout the period of monitoring. Oil and grease enters from factory C which produces edible fats and soaps based on oil. These discharges enter the canal at S06. Oil and grease also enter the canal from the automobile spare shops. These waste waters enter the canal at S04. Factory B has most of its products based on coconut oil and palm oil such as soaps, and cooking oil. Disinfectants are also produced. These enter the canal at S03.

A drain from the State Petroleum Storage plant enters the San Sebastian canal

Table 7.1 — Spearman's ρ between the daily rainfall and pollutants

Site	DO	pH	CT	TB	COD	BOD	SULF	T N	T P	SS
1										
S01	.43**	-.13	-.35**	.36**	-.39**	-.36*	-.45**	.02	-.36*	.20
S02	.43**	-.17	-.18	.50***	-.37**	-.37**	-.62***	-.17	-.45**	.30*
S03	.15	-.07	-.08	.40**	-.12	-.13	-.34*	.11	-.08	.52***
S04	.20	-.12	-.19	.52***	-.13	-.14	-.33*	.35	.01	.48***
S05	.13	-.24	-.19	.46***	-.19	-.23	-.47***	.09	-.03	.48***
S06	.25*	-.20	-.19	.40**	-.25*	-.11	-.14	.41	-.31*	.49***
S07	.25*	-.21	-.15	.45**	-.21	-.003	-.36*	.19	-.39*	.49***
S08	.29*	-.39**	-.31*	.43**	-.04	-.12	-.56***	-.01	-.29	.31**
S09	.08	-.28*	-.11	.27*	-.17	-.13	-.44**	.23	-.37*	.25*
S10	.47***	-.21	-.34**	.10	-.10	-.01	-.43**	-.36	-.26	.07
2										
R01	.27*	-.56***	-.15	.34**	-.25	-.22	-.60***	.13	-.19	.26*
R02	.42**	-.46**	-.22	.40**	-.27**	-.24	-.51***	.22	-.16	.22
3										
U01	.56***	.01	.02	.38**	-.43**	-.39**	-.41**	.05	-.11	.21
U02	.01	-.37	.18	-.32	-.25	-.06	.36	.11	-.15	-.25
4										
T01	.69**	-.55*	.27	.06	-.34	-.24	-.23	.10	-.47*	.07
T02	.56**	-.56*	-.19	.17	-.35	-.09	-.32	.73**	-.57**	.05
T03	.28	.02	.41	.28	-.59**	-.46*	-.22	.21	-.27	.25
T04	.66**	-.44*	.16	.61**	-.51*	-.56**	-.05	.28	-.35	.57**
T05	.51*	-.52*	.32	.53*	-.35	-.32	-.07	.60**	-.44*	.48*
T06	.27	-.69**	.28	.20	.04	.15	.01	.42	.04	-.06
T07	.41	-.41	.002	.11	-.17	-.18	-.10	.71**	.24	-.01
T08	.35	-.44*	.41	.02	-.16	-.09	-.24	.37	.08	-.21
T09	.57**	-.47*	.15	-.11	-.32	-.09	-.36	.06	-.30	-.11
T10	.65**	-.31	.31	.36	-.55*	-.56**	-.26	.27	-.05	.44*
T11	.56**	-.14	-.28	.35	-.61**	-.43*	-.02	-.07	-.47*	-.13
T12	.46*	-.01	.00	.40	-.29	-.24	-.17	.39	.16	.30
T13	.62**	-.37	.22	.61**	-.57**	-.42	-.17	.67**	.29	.37

Sections: **1** = San Sebastian canal, **2** = Kelani river, **3** = Beira lake, **4** = Tributary canals.

S01 - U01 (40 values), U02 (15 Values), T01-T13 (14 Values).

Source: Field monitoring.

between S09 and S10 which brings oily waste waters. Oil has a double sided effect on the surface of the water. It is an organic waste that has a high oxygen demand, and it also forms a thin film on the surface of the water which hinder aeration at the atmospheric-water surface interface. Therefore, inspite of the same amount of rainfall received in the canal a lower correlation between DO and rainfall in these sites is obviously due to the high organic wastes and the oil present in the surface waters. The Kelani Tissa thermal power station also discharges waste waters into the canal between S09 and S10.

The coefficient was poor at S09. This area is one of the oldest industrial areas and thus may receive discharges from industries and domestic sources. The Kittampahuwa ela discharges into the San Sebastian canal just south of S09 while the Main Drain discharges just north of S09. Therefore, there may be an accumulation of pollutants at this site. It may also be due to a push back mechanism of the tides, thus concentration of pollutants takes place. This hinders aeration.

It is interesting to note that the correlation coefficient at S10 is high. This site is located at the extreme downstream end of the canal. This site may be receiving waste waters from the industries other than the food industries although direct discharges

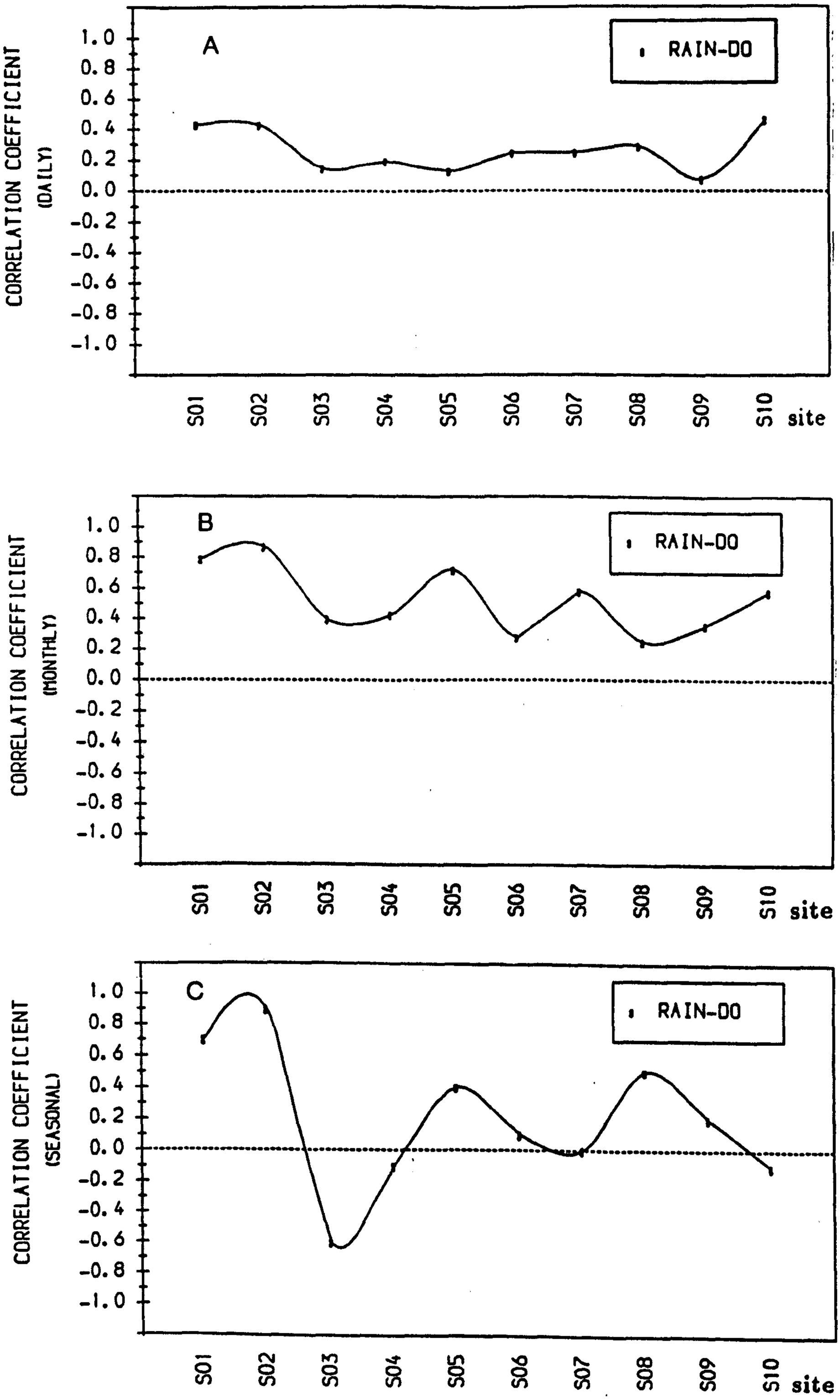


Figure 7.3 — Correlogram of daily, monthly, seasonal rainfall and DO in the San Sebastian canal

Source: Based on field monitoring

were not clearly visible. As seen from the coefficient the reaeration capacity in the site is higher on the monitored days. The mechanism is complex at this site since the highly significant correlation may be both due to reaeration by rainfall and the surface turbulence caused by the impact of rainfall on the site i.e. to a site where surface turbulence is already operative due to the diurnal tidal effect. Therefore, in addition to the reaeration from the rainfall turbulence may also have increased the DO.

Comparison: industrial and non-industrial sites

The daily DO data are in appendix D.

The examination of daily rainfall and the daily DO concentrations in an industrial site make the correlation between these two parameters clearer. For example, the DO concentration in the site SO2 at the daily rainfall of 0.3 mm on 29.04.86 was 14.0 mg/L. It increased to 14.8 mg/L with a daily rainfall of 100.2 mm on 07.05.86 which gives an increase of 0.8 mg/L. On the other hand, at S03 which is an industrial discharge site the DO on 29.4.86 was 0.1 mg/L while it increased to 0.3 mg/L on 07.05.86, i.e. an increase of only 0.2 mg/L. This explains the positive correlation between DO and daily rainfall. The rate of increase in the DO with the same amount of rainfall is not the same in both the sites. This could be explained further when the variables are considered on 15.05.86. The DO on 15.05.86 at S02 with a daily rainfall of 0.01 mm was 4.0 mg/L while at S03 the DO remained the same with 0.3 mg/L. The rate of fall in DO at S02 was 10.8 mg/L while at S03 there was no change in the DO level. At the site S02 which was relatively free of industrial and domestic sources of waste the highest recorded DO of 14.8 mg/L coincided with the highest daily rainfall of 100.2 mm on 07.05.86. This indicated that in a relatively pollutant-free site, the DO in surface water responds positively to rainfall with varying rates, but in a very polluted site the response is very slight or there may be no response.

When the correlation between these variables is considered in a dry month with 0.0 mm rainfall throughout the month such as in February 1987, the DO at S02 on 05.02.87 was 9.5 mg/L (the DO concentration was possibly influenced by the previous months which had a high total monthly rainfall of 203.45 mm in December and 98.4 mm in January 1987) fell steadily over the month to 5.0 mg/L on 24.02.87. At S03 the DO remained 0.0 mg/L throughout the month. These values give a spectrum of relationships on a daily basis, but the fact that monitoring was done on a daily basis where the interval of sampling differed, the rainfall in between the days of monitoring also may influence the base level of the DO concentration in the water bodies.

The extremes in the daily correlation is smoothed to a great extent in the monthly rainfall-DO analysis. With these extremes the basic fact remains that even on a daily basis the correlation between rainfall and DO is positive. Even with a slight increase in the amount of rainfall there was a positive increase in the DO which indicated the process of aeration takes place. This is very clear in an unpolluted site. But in the case of a very polluted site the rate of aeration is at best only minimal, although a continuously high rainfall for a longer period changes this situation by flushing out the pollutants.

Coefficient variation: monthly

Table 7.2 shows the monthly correlation between DO and rainfall. Figure 7.3 (B) shows the monthly trend across the sites.

The monthly correlation between DO and rainfall was essentially the same in all the sites in the San Sebastian canal, except the fact that total rainfall received at the sites had a bearing on the pollution level. Although the monthly rainfall DO analysis does not give an insight into the detailed mechanism of the DO-rainfall relationship, it gives a very good mean situation of the variability. The importance of the base level of the rainfall falling on the sites, or, in other words, the water levels in the sites and its effects on the concentration-dilution of pollutants mechanism can be assessed broadly. It also gives a good indication of the trend of pollutant behaviour in relation to rainfall during the months of the year. Thus the high rainfall, low rainfall months, and their relationship to pollutant concentration over a definite time scale can be assessd. This has an important bearing in understanding the pollutant concentration in the sites over the year and the reaeration capacity of the surface waters resulting from rainfall. Reaeration is important in reducing or neutralizing the organic wastes in the surface waters and rainfall acts as the medium of this

1										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
S01	.79***	-.53	-.23	.67**	-.76***	-.75***	-.50*	.73**	-.29	.57**
S02	.87**	-.33	-.05	.74***	-.75***	-.72**	-.72**	.22	-.12	.62**
S03	.40	-.39	-.16	.73***	-.49**	-.45*	-.78***	-.13	-.40	.70**
S04	.43	-.43*	-.06	.53*	-.59**	-.64**	-.68**	.17	.22	.62**
S05	.72**	-.59**	-.25	.58**	-.46*	-.55**	-.51*	-.27	.17	.71**
S06	.28	-.26	-.18	.72**	-.22	-.19	-.37	.19	-.20	.72**
S07	.58**	-.43	-.08	.69**	-.38	-.49*	-.56**	.30	-.22	.68**
S08	.25	-.24	-.62**	.41	-.27	-.20	-.77***	.18	-.45*	.60**
S09	.36	-.14	.002	.41	-.34	-.27	-.63**	.61**	-.19	.45*
S10	.58**	-.30	-.24	.20	-.56**	-.39	-.76***	-.02	-.28	.38
2										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
R01	.23	-.37	.11	.64**	.08	.06	-.72**	.30	-.10	.69**
R02	.66**	-.52*	.13	.67**	-.19	-.25	-.70**	.44	.12	.75***
3										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
U01	.26	-.01	.06	.64**	-.26	-.28	-.67**	.23	-.43*	.73***
U02	.16	.13	-.23	.52*	.14	.05	-.43*	.51*	-.02	.45*
4										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
T01	.55*	-.26	-.59**	.66**	-.75***	-.69**	-.68**	.53*	-.22	.49*
T02	.59**	-.15	-.30	.66**	-.76***	-.57**	-.70**	.46	-.21	.41
T03	.29	.24	-.19	.64**	.20	-.10	-.64**	.30	.23	.72**
T04	.47*	-.29	-.57**	.45*	-.14	-.17	-.78***	.38	-.02	.39
T05	.53*	-.33	-.38	.67**	-.34	-.38	-.70**	.25	.004	.74***
T06	.55*	-.32	-.36	.55*	-.33	-.32	-.83***	.75**	-.25	.58**
T07	.62**	-.40	-.48*	.88***	-.41	-.37	-.78***	.40	.06	.76***
T08	.65**	-.44*	-.34	.62**	-.45*	-.41	-.82***	.74**	-.28	.50*
T09	.51*	-.50*	-.52*	.60**	-.52*	-.51*	-.71**	.46	-.10	.49*
T10	.34	-.29	-.45*	.67**	-.58**	-.67**	-.78***	.58*	-.05	.33
T11	.53*	.03	-.61**	.26	-.55*	-.67**	-.80***	.27	-.51*	.24
T12	.49*	.27	-.61**	.64**	-.77***	-.80***	-.77***	.71**	-.53*	.31
T13	.38	.02	-.42	.36	-.60**	-.69***	-.66**	.16	-.53*	.47**

Sections: 1 = San Sebastian canal, 2 = Kelani river, 3 = Beira lake, 4 = Tributary canals.

Source: Field monitoring.

Table 7.2 — Monthly correlation between rainfall and pollutants

process of dilution or neutralization. This is also important in the understanding of the pollutant concentration under the most critical conditions which occur during the dry months or periods and in formulating pollution control strategies.

The monthly correlation coefficient at S01 and S02 remained high with 0.79 and 0.87 both of which were significant at .001 level. The correlation coefficient at the direct industrial discharge sites of S03, S04, and S06 gave a stronger correlation. At S03 the coefficient was 0.40, at S04 0.43, and at S06 0.26. The correlation coefficiant ranged from 0.25 at S08 to 0.87 at S02. The latter had a significance level at .001.

The correlation of total monthly rainfall with the mean monthly DO gave a stronger correlation between the two parameters than on the daily correlation analysis. The correlation trend over the sites remained the same except at S05 where the coefficient strengthened tremendously with the coefficient at 0.72 which was significant at the .01 level while in the daily analysis it was 0.13. It is free from direct industrial waste water discharges although it receives organic wastes from the domestic source. It is located between two industrial sites where some degree of aeration is possible although the accumulation effect of pollutant concentration from the upstream industrial sites could affect the site. This aeration effect or response of DO to rainfall in a positive direction is indicated by the coefficient of 0.72. This also shows that the base or background water level brought about by rainfall over a monthly span, or in other words, a longer period of time, influenced the dilution-concentration of pollutants. For example, a high rainfall month may be able to sustain a higher DO level than a low rainfall month because the base level DO will be higher in the former. Therefore, even if a lower rainfall month follows a higher rainfall month the higher DO level attained during the higher rainfall month will last through a longer period of time until the complete depletion of DO occurs. If there is no rainfall at all for a very long period, the reaeration capacity is virtually zero. This is true of an unpolluted situation and not necessarily true of a heavily polluted site. Even in a polluted site some aeration can occur in a rainy month than in a dry rainless month.

The coefficient fell from S03, with fluctuations between the sites, but the strength of the correlation had more than doubled at S03 (in comparison to the daily correlation) with the coefficient at 0.40 although the significance is low. At S06 it was almost the same while the coefficient became stronger at S09 with 0.36. These are in relation to the daily coefficients.

Comparison: industrial and non-industrial sites

The examination of the correlation coefficient at the direct industrial discharge sites of S03, S04, and S06 indicated, as mentioned earlier, gave a stronger correlation. At S03 the coefficient was 0.40, at S04 0.43, and at S06 0.26 (slight improvement). This indicated that on a monthly basis the DO has increased with an increase in rainfall even in the most polluted sites. In other words, rainfall has the capacity to dilute the pollutants concentration over a longer period of time, i.e. with rainfall the self regulatory process of pollution reduction is set in motion. Similarly, during the dry months with no rainfall, pollutant accumulation or concentration takes place. Thus gives rise to an oxygen sag at the most polluted sites.

The mean monthly DO data are in appendix I and the monthly rainfall data are in appendix K(i).

These become clear with examination of rainfall-DO values on a monthly basis. The total monthly rainfall in November 1986 was 59.06 mm.(The mean monthly rainfall was 1.97 mm). The DO at the site S02 was 9.13 when the rainfall increased to 203.45 in December, the mean monthly DO for the month increased to 12.40 mg/L and decreased to 7.80 mg/L in February 1987 which had received no rainfall. When these figures are compared with S03 the mean the monthly DO was 0.03 mg/L in November 1986 and it increased to 0.57 mg/L in December, and in February 1987 the DO at S03 was 0.0 mg/L. From these values it can be seen that the DO responds markedly at S02. There was a gradual decrease in the mean DO over the months which fell to 10.53 mg/L in January 1987. Although February recorded no rain throughout the month the mean monthly DO at S02 remained high with 7.8 mg/L. This is due to base level dissolved oxygen sustained in the canal at S02. With December 1986 and January 1987 receiving high rainfall totals the DO is sustained at a reasonable level in February even though zero rainfall was recorded. This situation is only true in an unpolluted site such as S02 where the DO is not depleted by the bacteria in the

process of biodegradation of organic matter.

In the case of S03 the mean monthly DO had increased by 0.54 mg/L from November to December 1986. It fell to 0.23 mg/L in January, thereby recording a decrease of 0.34 mg/L over the previous month. In February 1987 the mean monthly DO at S03 was 0.0. This shows that a polluted site responds very quickly to the decrease or failure in rainfall. Since the level of mean monthly DO in January 1987 was 0.23 mg/L a total failure of rainfall in February 1987 brought the mean monthly DO to zero. Although the rainfall had failed in February the factories continued to discharge highly organic waste water into the canal irrespective of the season. This means that what little mean monthly DO is available in the canal will be used up completely by the aerobic bacteria in the process of degradation. This is a basic difference between a non polluted and a polluted site, i.e a non polluted site can sustain a fluctuation in rainfall for a relatively longer time as its DO is not rapidly used up by the microorganisms in the aerobic process of waste degradation while in a very highly polluted site the situation is more delicate and, therefore, with a fall in rainfall for a longer period the site becomes completely devoid of oxygen. January and February 1986 were not generally used for comparisons in the analysis as the monitoring frequency was low.

Coefficient variation: seasonal

Table 7.3 shows the seasonal correlation between DO and rainfall. Figure 7.3 (C) shows the seasonal trend across the sites.

The seasonal correlation between the mean seasonal rainfall and mean seasonal DO in the San Sebastian canal gave high coefficients of 0.70 at S01 and 0.90 at S02. It ranged from 0.60 at S03 to 0.90 at S02. The latter had .01 level of significance. In both, the daily and the monthly correlations between these two variables discussed earlier the correlation coefficient was positive in all the sites. There is a deviation in the seasonal correlation. It ranged from negative to no correlation at S07, and a highly positive correlation at S02. But, out of the 10 sites on the canal 6 sites had a positive cofficients between these two variables. It is possible that the correlation coefficients were affected by the lower number of cases (5 seasons) or to the processes that operate within the sites.

At S02 (in comparison with S01) the coefficient was higher than the monthly correlation of 0.87 while, on a daily basis, it was only 0.40. Therefore, the trend in the DO becomes clearer on a time scale where the rainfall plays a very important role. The correlation remains fairly high in the sites which have no direct industrial waste water discharges such as S01, S02, S05, and S08. The zero correlation at S07 and S06, and negative correlations at S03 and S04 is obviously due to the industrial waste water that enter the sites. The DO at the industrial site was too low even to depict a fluctuation with the seasonal rainfall which was due to poor responses as a result of highly organic wastes.

The minor variations which took place at the site S03, as seen earlier, was not detected on a longer time span of the seasonal analysis. The correlation at S09 remained low both at the daily and monthly levels, and it remained so in the seasonal analysis. At the site S10 the correlation was negative with the coefficient at -0.10 although the correlation was positive in both the daily and monthly analysis. Although the negative strength of the correlation was very poor this effect could be possibly due to the tidal influence at the site. The same influence may also explain the low positive correlation at S09. Therefore, as the canal approaches the river the relationship between the variables became more complicated and less clear.

Comparison: industrial and non-industrial sites

The mean seasonal DO data can be seen in appendix L.

The seasonal correlation between the rainfall and DO can be explained in terms of S02 and S03. At S02 during the Intermonsoon I which had the highest mean seasonal rainfall of 7.34 mm, the highest mean sesonal DO was 12.43 mg/L. In the southwest monsoon season which followed the mean seasonal rainfall it was 1.64 and there was a corresponding fall in the mean seasonal DO which had a value of 7.17 mg/L. At Intermonsoon II there was an increase in rainfall to 4.78 mm which saw a corresponding increase in the DO of 10.47 mm while in the northeast II the mean seasonal rainfall fell to 3.03 mm which saw a fall in the DO to 9.97 mg/L. The effect of February 1987 which had zero rainfall was dampened by the higher rainfall months

1										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
S01	.70	-.90**	-.90**	.70	-.80	-.80*	-.30	.90**	-.30	.60
S02	.90**	-.80*	-.30	.70	-.90**	-.87*	-.80*	.60	.30	.70
S03	-.60	-.30	.70	.70	-.80*	-.20	-.90**	.50	-.30	.90**
S04	-.10	-.70	.10	.80*	-.90**	-.80*	-.70	.80*	.30	.80*
S05	.40	-.80*	-.30	.50	-.60	-.60	-.50	-.40	.30	.70
S06	.10	-.90**	-.10	.90**	.00	.00	-.30	.10	-.40	1.0
S07	.00	-.56	.30	.90**	-.70	-.70	-.60	.20	-.20	.90**
S08	.50	-.50	-1.0***	.10	.10	.10	-.90**	.20	-.80*	.60
S09	.20	-.80*	.40	.80*	-.70	-.60	-.90**	.70	-.10	.60
S10	-.10	-.90**	-.50	.60	-.60	-.30	-.90**	-.70	-.30	.70
2										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
R01	.00	-.70	.10	.50	-.20	-.20	-.80*	.30	-.40	.30
R02	.70	-.70	.10	.90**	-.20	-.60	-.80*	.90**	.00	.70
3										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
U01	.20	-.50	.70	.20	-.40	-.60	-.90**	.50	-.30	.20
U02	-.30	.15	-.50	.80*	.50	.30	-.70	.10	-.30	.80*
4										
	DO	pH	COND	TURB	COD	BOD	SULF	T N	T P	SS
T01	.70	-.90**	-.30	.70	-.70	-.70	-.70	.10	-.40	.50
T02	.70	-.50	-.60	.70	-.70	-.70	-.70	.60	-.20	.50
T03	-.30	.50	-.40	.90**	-.20	-.20	-.70	-.60	-.60	1.00
T04	.80	-.50	-.40	.30	-.60	-.60	-.70	.10	.10	.30
T05	.60	-.56	-.30	.90**	-.10	-.10	-.70	.30	-.41	.90**
T06	.60	-.30	-.40	.60	-.20	-.15	-.90**	.60	.10	.70
T07	.60	-.66	-.30	.70	-.50	-.70	-.70	.30	.50	.70
T08	.60	-.56	-.30	.90**	-.50	-.50	-1.00	.70	-.20	.10
T09	.56	-.87*	-.30	.60	-.50	-.80*	-.60	.20	.00	.10
T10	.40	-.90**	-.70	.70	-.70	-.70	-.60	.10	.70	.20
T11	.60	-.05	-.80*	.10	-.90**	-.70	-.70	.10	-.80*	-.10
T12	.50	.10	-.90**	.66	-.70	-.90**	-.70	.60	-.20	.50
T13	.30	.00	-.40	.60	-.90**	-.90**	-1.00	-.10	-.46	.60

Sections: **1** = San Sebastian canal, **2** = Kelani river, **3** = Beira lake, **4** = Tributary canals.

Source: Field monitoring.

Table 7.3 — Seasonal correlation between rainfall and pollutants

of December 1986 and Januray 1987.

At S03 the corresponding mean seasonal DO values were 0.18 mg/L, 0.21 mg/L, 0.14 mg/L, and 0.21 mg/L during the Intermonoon I, Southwest monsoon, Intermonsoon II, and the Northeast II respectively. This shows that although the seasonal effect of rainfall on the concentration-dilution mechanism was accentuated, and indicated a very good relationship at an unpolluted site such as S02 the small scale aeration that takes place in a polluted site such as S03 from rainfall is dampened in the longer seasonal trend.

Other surface waters

River Kelani

The data for the daily, monthly and the seasonal correlations can be seen in tables 7.1, 7.2 and 7.3 respectively.

The daily correlation between rainfall and DO in the sites in the river was positive at both the sites with 0.27 at R01, and 0.42 at R02, the latter being .01 significant. In the monthly correlation R01 had a coefficient of 0.23 and R02, 0.66. The latter had a significance level at .01. In the seasonal analysis R01 had a coefficient of 0.00 and R02, 0.70.

This shows that at R01 the strengh of the correlation had not increased over a longer period. R01 the more polluted site than R02, the lower correlation coefficient is understandable. R01 is downstream of the San Sebastian canal and, therefore, is a reception site to the waste load from the San Sebastian canal. This being the case even with an increase in rainfall the response of DO although positive, is small. Dilution of the wastes takes place to a certain extent, but not as much in the upstream site of R02 where the correlation between rainfall, on a daily, monthly, and seasonal basis, was stronger.

This indicates that the less polluted sites are more receptive to aeration. Even at R01 the seasonal correlation coefficient had increased although the significance level remained low which was mainly due to the lower number of cases.

Beira lake

The data for the daily, monthly and the seasonal correlations can be seen in tables 7.1, 7.2 and 7.3 respectively.

In the lake sites, the correlation between DO and daily rainfall was positive at both sites. The correlation was high at U01 with 0.56 which was .001 significant, and at U02 it was 0.01. In the monthly analysis the correlation fell at U01 to 0.26, but increased slightly at U02 to 0.16. In the seasonal correlation the coefficient was 0.20 at U01, and -0.30 at U02.

Therefore, as at the canal sites, the response of DO to rainfall was low at U02, which was the industrial waste water reception site. On a longer time scale such as the seasonal analysis, the coefficient indicated a negative relationship. This is due to the heavy load of organic wastes that enter from the industries such as A3 and A5, and the raw sewage from the culvert.

Tributary canals

The data for the daily, monthly and the seasonal correlations can be seen in tables 7.1, 7.2 and 7.3 respectively.

In the tributaries the relationship between rainfall and DO was positive in all sites. At T01, the daily correlation was 0.69 which was .01 significant. The monthly coefficient was 0.55 which was .05 significant. The seasonal correlation was 0.70. At T02, the coefficient was 0.56 which was .01 significant, 0.59 which was .01 significant, and 0.70 respectively. These correlation coefficients indicate that in the sites free of industrial waste water, the aeration process takes place.

In the Dematagoda ela, the daily correlation coefficient ranged from 0.27 at T06 to 0.66 which was .01 significant at T04. In the monthly analysis it ranged from 0.29 at T03 to 0.55 at T06. The latter had a .05 level of significance. In the seasonal analysis, the coefficient ranged from 0.30 at T03 to 0.80 at T04 which had a significance of .05.

The examination of the relationship between the rainfall and DO indicates that at site T03 (an industrial discharge site) in the Dematagoda ela the correlation coefficient remained low throughout. The coefficient remained positive in the daily and the monthly analysis, but gave a negative seasonal relationship. T03 is in a heavy industrial area where many industries discharge without treatment at T03 through a common sewer.

In short, with continuous rain there is a positive response of DO to rainfall, even in an industrial site. The rate of increase may be lower than in a non-industrial site, but a positive correlation exists. In the seasonal analysis this trend is dampened by the longer period under consideration in addition to the very low rate of aeration.

In the Kittampahuwa ela the daily correlation coefficient between rainfall and DO ranged from 0.35 at T08 to 0.65 at T10. The latter had a .01 level of significance. A positive correlation was maintained in all the sites in both the monthly and the seasonal analysis.

The lower monthly correlation and the seasonal correlation was observed at T10 with 0.34 and 0.40 respectively. This is an urban site with both industrial and domestic discharges in the vicinity.

In the Main Drain the relationship between rainfall and DO was positive in the daily and the monthly analysis. The coefficient ranged from 0.46 at T12 to 0.62 which was .01 significant at T13 in the daily and monthly analysis. In the seasonal analysis the coefficient fell to 0.30.

Being an industrial waste water reception site the lower correlation is understandable. Further, the organic load is very high from factory F which discharges at this point. The seasonal correlation also remained positive although the coefficient was the lowest in the canal. At T11 which is also an industrial waste water reception site to factory E, the correlation remained reasonably high throughout. The effluents that enter from E is lower in strengh than from F.

7.3.2 The daily, monthly and seasonal rainfall - COD analysis

Background factors

The daily rainfall and COD correlation was generally weak especially at the industrial waste water reception sites. But the correlation became stronger on the monthly and seasonal analysis.

In the daily analysis it is understandable that a few millimeters of rainfall on a certain day is not capable of diluting a waste stream which has very high organic waste in terms of the COD. This may be due to two factors. That is on a single day, or, to be specific, at the moment of monitoring the DO available for degradation of the high organic waste may not be high enough for the immediate oxidation of the waste, and secondly, the physical volume of water in terms of the few millimeters of rain that fall on the sites may be too small in terms of the high organic wastes for its dilution of wastes in a day.

This can be clearly seen in the rainfall daily totals received over the period of monitoring. Throughout the period of monitoring 100.2 mm of rainfall was received only on one day (07.05.86). This coincided with a day of monitoring. But the days receiving 0.0 mm rainfall, or a trace amount of rainfall was very high in 1986 and 1987 upto February 1987. For example, March 1986 had a total of 21 days of 0.0, or a trace amount of rainfall although 81.44 mm of the total monthly rainfall was recorded for the month. In January 1986 which received 144.94 mm of rain had 24 days with zero, or a trace amount of rain. May which recorded the highest rainfall for 1986 with 230.97 mm of rain had 16 days of zero, or trace amount of rainfall. February 1987 had the entire month with zero rainfall. With the exception of April and October 1986, all the other months had a greater number of days with zero, or trace rainfall. These have an important bearing on the dilution factor and the correlation coefficient in the daily analysis. If the days of monitoring fell on the days with zero, or a trace amount of rainfall (0.01mm), the dilution that takes place on such a day will be very poor which will result in a very poor correlation. This is especially the case in the industrial reception sites which have high COD.

The above situation is slightly different to the DO-rainfall relationship where the DO in the surface water is directly dependent on the rainfall for atmospheric reaeration. Oxygen has to be brought down from the atmosphere by means of rainfall although surface turbulence also contributes a little amount of oxygen. But the major part of dissolved oxygen in the surface waters is received from the atmospheric reaeration which takes place at the atmosphere-water surface interface. This holds more true for a stagnant water body where turbulence is minimal.

In the case of the rainfall-COD relationship although the DO is very important in the reduction of the organic wastes in the water in terms of a lower COD, the

physical amount of rainfall is also important in the direct dilution process where rainfall, independent of the biological process that takes place in the water, becomes important. This phenomenon can be explained in simple terms, such as 10 ml of waste waster diluted in a litre of water is obviously more diluted (thus less polluted) than 500 ml of waste water diluted in the same volume of water. The COD in the latter case will be much higher than in the former. This is the important relationship rainfall has on the dilution, or concentration of the waste water.

Therefore, in the COD-rainfall relationship as mentioned earlier although the DO is a major factor in oxidation of the waste and, thereby reducing the COD at the sites, rainfall in its physical volume also contribute in the dilution process. This is very true in the case of heavy, intensive rainfall, or well distributed rainfall spread over a long time scale. This factor explains the high monthly and seasonal correlations. That is, in the higher rainfall months the COD in the sites is low and in the low rainfall months the COD is high.

This analysis perhaps explains the direct COD-rainfall relationship more although the COD-DO relationship is an inherent biological and non-biological process within this relationship. That is, the more rainfall there will be in a certain month, the more diluted the wastes and therefore, the lower the COD will be at the site.

San Sebastian canal

Table 7.1 shows the daily correlation coefficient between COD and rainfall. Figure 7.4 (A) shows the trend across the sites.

The rainfall-COD correlation analysis in the San Sebastian canal gave a negative correlation in all the sites. The strengh of the correlation varied widely. This relationship was found in the daily, monthly, and the seasonal analysis. This meant that with an increase in the rainfall the strengh of the wastes decreased. The short-term and seasonal effect on the dilution-concentration mechanism was evident.

Coefficient variation: daily

The daily rainfall-COD correlation varied from -0.10 at S10 to -0.39 at S01. The latter had a significance level of .01. The coefficients were higher at S01 and S02.

At the industrial waste water reception sites the coefficients were lower. At S03 the coefficient was -0.12 and at S04 the coefficient was -0.13. This may be due to very high organic wastes that enter the site S03 from factory B. This influences the immediately dowstream site, S04. Site S05 which is a non-industrial site, but with domestic waste waters entering from the shanties around had a higher coefficient of -0.25 which had a level of significance at .05. This was higher than the industrial site of S06 and the site downstream, S07. The coefficients were -0.19 and -0.21 respectively. From site S08 to S10 the coefficient fluctuated again. This is possible due to tributary canals that bring organic waste loads and may also be due to the tidal effect felt on the sites nearer the river.

Thus in the industrial sites, sites receiving wastes from the tributary canals, and in the sites under the influence of more complex phenomena like the tidal effects, the correlation coefficient was lower than the relatively non-polluted sites of S01 and S02.

Comparison: industrial and non-industrial sites

The COD data are in appendix D.

The examination of COD - rainfall values make the situation clearer. In the site S02 and S03 in the rainfall-COD relationship from May to July 1986 (which covers both the highest and the lowest rainfall months for the year) it can be said that on 07.05.1986 which recorded the maximum daily rainfall of 100.2 mm, the COD at S02 was 4.0 mg/L, while at S03 it was 192.0 mg/L. In the previous month the COD at S02 was 4.0 mg/L, and at S03, 783.0 mg/L at a daily rainfall of 0.3 mm on 29.04.1986. In June on 19.6.86 the COD at S02 and S03 were 10.0 mg/L, and 304.0 mg/L respectively at a daily rainfall of 0.01 mm; in July the COD in the sites were 53.0 mg/L and 555.0 mg/L respectively at a rainfall of 0.00 mm. These values indicate that, on a daily basis, the COD is receptive to rainfall and has a negative relationship, but the rate of response, or dilution-concentration is not the same. A dilution of canal water at S03 can be seen in the low COD of 192.0 at 100.2 mm of rain, while the previous month recorded 783.0 mg/L at 0.3 mm of rain. The former value is obviously due to dilution resulting from an intense rainfall on a single day. It is not due to a waste water discharge from factory B with a lower COD. Although factory monitoring was not done on this particular day, the COD at factory B1 on

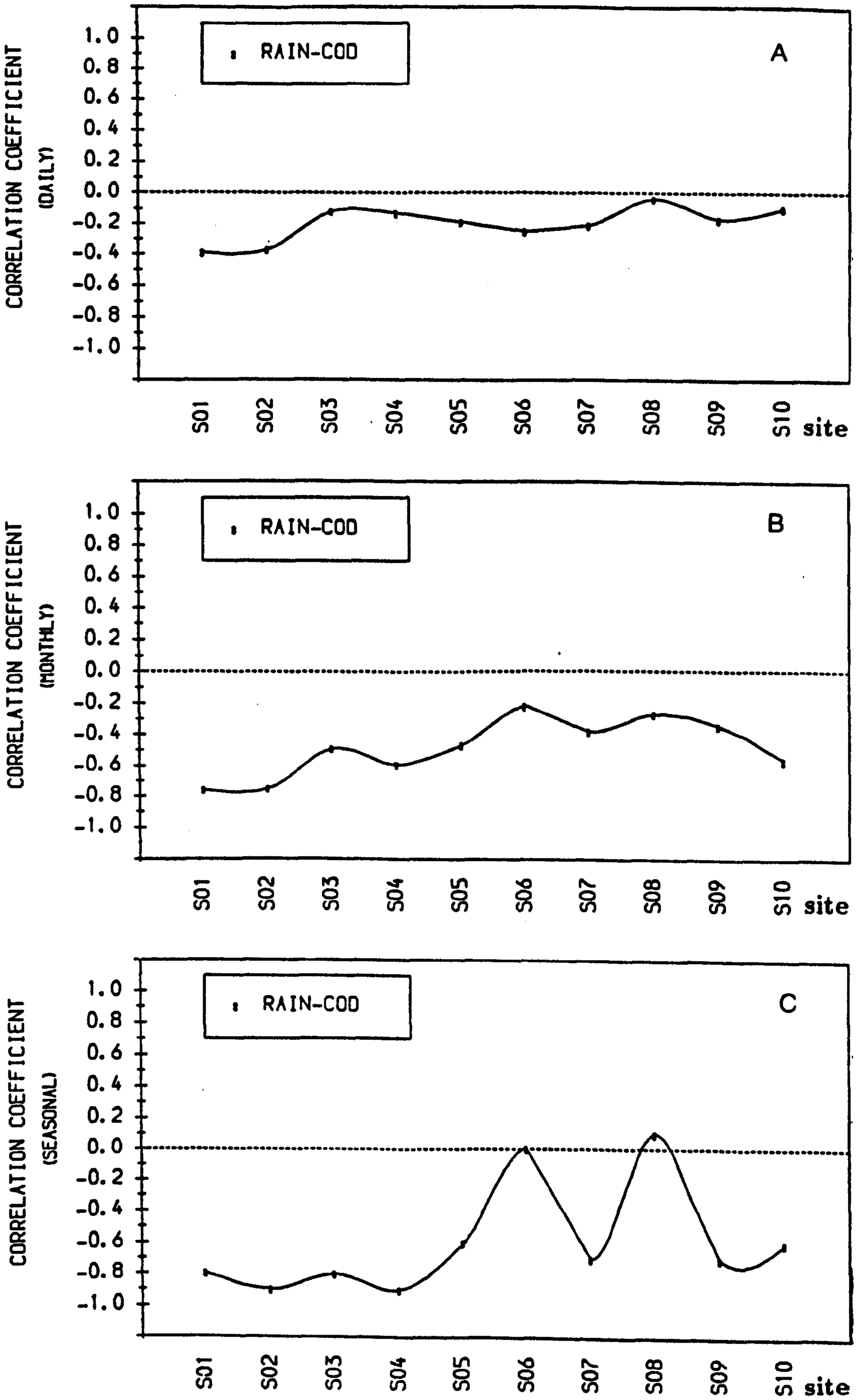


Figure 7.4 — Correlogram of daily, monthly, seasonal rainfall and COD

Source: Based on field monitoring

09.04.1986 and 14.05.1986 indicate a high COD of 9200.0 mg/L and 810.0 mg/L in the factory effluent. It is partly due to the oxygen from aeration, but mostly due to the physical volume of rainfall in the dilution process. When rain decreased in the following month the COD also increased in the sites at different rates.

Coefficient variation: monthly

Table 7.2 shows the monthly correlation coefficient between COD and rainfall. Figure 7.4 (B) shows the trend across the sites.

The mean monthly COD values can be seen in appendix I. In the monthly rainfall-mean COD analysis, the coefficient strengthened such as at S01 which had a higher coefficient of -0.76, S10 a coefficient of -0.56, and S08 a coefficient of -0.27. The level of significance at S01 and S10 were .001 and .01 respectively. These sites had weaker coefficients in the daily analysis. The correlation coefficient in the industrial sites such as S03 and S04 also strenghened.

These coefficients indicate that the extreme effects in the daily values are smoothened in the monthly analysis. Further, it shows that, over a longer period of time, the rainfall has the capability to dilute the strong organic wastes that enter the canal from the industries to a certain extent. Site S03 had a coefficient of -0.49 and S04, -0.59 which was .01 significant. The daily rainfall-COD coefficient was much lower. In general all the sites showed improvement in the monthly rainfall-DO analysis.

Comparison: industrial and non-industrial sites

In the monthly rainfall-COD relationship, the COD at S02 was 9.33 mg/L in May at a rainfall rate of 230.97 mm; 25.0 mg/L in June at a rainfall rate of 63.84 mm, and 53.33 mg/L in July when the total monthly rainfall was 10.39 mm. At S03, the mean COD was 243.00 mg/L, 389.33 mg/L, and 436.17 mg/L respectively. In August the mean COD at S03 had increased to 536.33 mg/L, probably due to the long period of very low rainfall from the first third of the month of May until the 04.08.1986. During this period 55 days recorded zero or 0.01 mm of rainfall. This situation clearly shows the COD-rainfall relationship. This high rainfall in May saw a lower COD at S03 and S02, although the latter half of the month was dry. The low COD in the sites could have been possible due to a high rainfall of 216.84 mm in the month of April. Therefore, a well distibuted highly intensive rainfall, a higher water level in the canal, and a flow in the canal would have contributed to a lower COD at S03 in May 1986.

Coefficient variation: seasonal

Table 7.3 shows the daily correlation coefficient between COD and rainfall. Figure 7.4 (B) shows the trend across the sites.

The monthly trend is also seen in the mean seasonal rainfall-mean COD analysis. In the unpolluted sites of S01 and S02 the relationship was the strongest with -0.80 which was .05 significant, and -0.90 which was .01 significant respectively. The coefficients were also high at S03 and S04. Other than at S06 and all the other sites gave a very high correlation. Therefore, these values indicate that there is a direct negative relationship between the rainfall and COD. The higher the rainfall, the lower is the COD.

Comparison between non-industrial and industrial sites

The mean seasonal COD data can be seen in appendix L.

In the seasonal COD-rainfall relationship the mean COD at S02 during the first intermonsoon season was 33.0 mg/L at a seasonal mean rainfall of 7.34, while during the drier southwest monsoon, the mean COD was 33.0 mg/L at a seasonal mean rainfall of 1.64 and the COD fell during the seasonal intermonsoon to 13.83 mg/L at a rainfall of 4.78 and increased to 17.67 mg/L COD during the northeast season with rainfall at 3.03 mm. At S03, the industrial waste water discharge is clearly evident. During the first intermonsoon the COD was 402.67 mg/L, during the southwest monsoon season the COD had risen to 453.94 mg/L, and during the second intermonsoon, the COD had fallen to 296.83 mg/L due to higher rainfall and during the northeast monsoon II the COD had risen to the maximum COD mean. Zero rainfall in February 1987 influenced the COD to a great extent when the monitored COD was the highest recorded at the site.

Therefore, these values clearly indicate the COD-rainfall relationship over a range of time scales, under different weather conditions, at two different sites, which was relatively less polluted and highly polluted due to industrial waste water discharge.

Other surface waters

River Kelani

The correlation coefficient for the daily, monthly and the seasonal values can be seen in table 7.1, 7.2 and 7.3 respectively.

In the COD-rainfall analysis the river sites R01 and R02 had a negative relationship on the daily basis with -0.25 and -0.27. The latter had a significance of .05. In the monthly correlation, the coefficients are 0.08 and -0.19, and in the seasonal correlation the coefficient was -0.20 at both the sites. The correlations were low at both the sites.

The lower correlation may be due to the fairly low COD in the river except on a few occasions. Also due to the larger volume of water in the river itself the dilution mechanism by the rainfall may be quite insignificant and may not be felt as in the canal. The COD load was higher at R01 than at R02 which may be due to the influence of the waste waters entering from the canal. During a normal rainfall year with marked dry and wet season, or a well defined monthly rainfall the dilution effect on the pollutants may be felt more. As the large volume of river water in itself is a dilution medium the little effect felt by the rainfall medium is not very clear. 1986 is a negative deviation from normal rainfall years. But, it must be mentioned that the upstream site R02 which is less polluted than R01 has a stronger correlation (although the coefficient is weak) among the two sites which indicates that the rainfall helps to dilute. Further, during the no-rainfall months such as February 1987, the COD concentration was the highest in the river which can be directly linked to the low rainfall.

Beira lake

The correlation coefficient for the daily, monthly and the seasonal values can be seen in table 7.1, 7.2 and 7.3.

The weaker coefficient at U02 indicates industrial discharges and the lower capacity of the rainfall to dilute the wastes in the water. As the lake is the larger body of water a below average rainfall such as in 1986 does not have a great impact. The correlation gives a peculiar coefficient at U02 in the seasonal analysis which to some extent explains the long term situation where abnormalities, or complexities can occur. U02 being an industrial discharge site does not show a very clear correlation between COD and rainfall as at U01 although the negative trend was clear in the daily analysis. The coefficient was -0.25 at U02 while it was -0.43 at U01. At U01 the significance level was .01. The correlation is positive in both the monthly and the seasonal analysis with 0.14 and 0.50 respectively which is not significant. This shows the overwhelming effect of a very high COD in the water body. The COD ranged from 440.0 mg/L in February 1987 to 1967.0 mg/L in May 1986. The COD values appear very independent of the time of the year with the highest in May 1986 and the lowest in February 1987. This may be due to the industrial effluents that enter at this site. The industrial waste water discharges are independent of the time of the year since waste waters of varying strengh can be discharged at any time of the year. Further the discharge is also continuous. The fact that U02 was monitored monthly leaves a gap in assessing the comparative relationship between the two variables.

Tributary canals

The correlation coefficient for the daily, monthly and the seasonal values can be seen in table 7.1, 7.2 and 7.3.

The tributary canals depicted the same negative correlation between rainfall and COD in all the sites, except at T06 which had a coefficient of 0.04 which was not significant in the daily analysis. The coefficient ranged from 0.04 at T06 to -0.61 at T11. The level of significance was .01. In the Dematagoda ela the correlation was high at T03 and T04 with -0.59 and -0.51 with significance levels at .01 and .05 respectively. In the Kittampahuwa ela the coefficient varied from -0.16 at T08 to -0.55 at T10. The significance level at T10 was .05. In the Main drain the correlation coefficient ranged from -0.19 at T12 to -0.61 at T11. The level of significance at T11 was 0.01.

In the monthly analysis the correlation improved on many sites. It ranged from 0.20 at T03 to -0.77 at T12, the latter was .001 significant. The only difference between the daily and the monthly correlation is that the computations were done using the coresponding daily rainfall in the daily COD in the former, while the COD was correlated with the monthly rainfall in the latter. This is due to monthly monitoring

of the sites. But this makes the relationship clearer as seen in the monthly correlation coefficient is higher with a value of -0.75 and -0.76 respectively. Both the sites had significance at .001 level. In the Dematagoda ela, the industrial waste water reception site T03 had a positive correlation of 0.20 which was not significant. This is the only site in the monthly analysis that deviates from the pattern. This is probably due to the industrial discharges at the site. The correlation between COD and rainfall in the Kittampahuna ela improved on the monthly analysis. It ranged from -0.41 at T07 to -0.58 at T10. The coefficient was significant at .01 level. The Main drain saw an improvement in the relationship at all the sites. Although the COD was high at these sites the dilution and concentration effect of the monthly rainfall becomes apparent. In the site which had no direct industrial discharge such as at T12, the coefficient was high with a value of -0.77 which was .001 significant.

In the seasonal analysis the relationship between COD and the rainfall increased in most of the sites. In the Maligawatte and Kettarama drains, the coefficient was -0.70. In the Dematagoda ela, it remained low in all the sites except T06. In the Kittampahuwa ela, the coefficient was -0.50 in all the sites except T10 which had -0.70. In the sites which are closer to the urban center the COD are higher although there are no direct industrial discharges, but the higher correlation coefficients in this ela on a monthly and seasonal basis indicates that the dilution-concentration mechanisms of rainfall on the COD is operative.

The seasonal relationship in the Main drain shows a very high correlation between the variables in all the sites. This is an extreme situation in that both the industrial sites have a very high negative correlation with the coefficient at -0.90 which is .01 significant. This could perhaps be due to an influence of the tides as both T11 and T13 are accessible to tidal influence. The Main drain is connected to the sea through the Mutwal tunnel, while T13 is very close to the tidal river. It is also possible that a flushing out effect is operative at these sites during the high rainfall seasons as this canal is a major drainage outlet during high water levels in the Kelani river. This becomes a possible explanation to high rainfall months and seasons. The opposite effect of concentration is also true for the COD, possibly due to malfunctioning of the drainage outlet at Mutwal, due to the formation of sand bars. For example, the COD at T11 was 133.0 mg/L in May 1986 and 209.0 mg/L at T13, and 201.0 mg/L and 260.0 mg/L in October while, in December 1986, the COD were 316.0 mg/L and 444.0 mg/L respectively (though December was a high rainfall month, the day of monitoring was 03.12.1986, which may have been influenced by the drier low rainfall of the previous month, i.e. November, and therefore, higher COD. In February 1987, the COD increased to 415.0 mg/L and 811.0 mg/L respectively. In the seasonal analysis, the COD at T11 during the higher rainfall intermonsoon I the mean seasonal COD was low with a value of 183.0 mg/L, while it increased to a 311.33 mg/L in the drier southwest monsoon, again and decreased to 284.80 mg/L during the second intermonsoon and had the highest seasonal mean of 329.75 mg/L during the northeast monsoon II which was influenced by 0.0 rainfall in February. The mean seasonal rain was 3.03 mm. At T13, the same trend is seen with 254.5 mg/L, 488.33 mg/L, 341.0 mg/L, and 515.0 mg/L respectively. These values indicate that there is some flushing out of pollutants during the higher rainfall seasons and the concentration of pollutants during the lower rainfall seasons indicated by the higher COD.

7.3.3 The daily, monthly, seasonal rainfall - BOD analysis

Background factors

As discussed earlier in the COD/BOD relationship, the movement of these two variables are in the same direction and therefore the relationship with rainfall also should have the same trend. The negative coefficient as in the rainfall-COD analysis indicates that when rainfall is high the corresponding BOD is low and vice versa. Therefore, dilution, or concentration of wastes in terms of the BOD was taking place depending on the rainfall. Unlike the COD, the BOD is a bioassay procedure which is dependent entirely on the bacterial activity. It is the amount of oxygen required by the bacteria for oxidation during the stabilisation of decomposable organic matter under aerobic conditions. Therefore, unlike the COD, the BOD is directly related to the availablility of dissolved oxygen in the surface water. The bacteria need oxygen

for biodegradation of the wastes and this oxygen is supplied from the atmosphere through rainfall. Therefore in BOD, the DO and the rainfall are equally important in assessing the relationship. Further, BOD degrades only organic wastes which becomes more relevant to food industries. Thus it is not only the physical rainfall which is important. The atmospheric reaeration that takes place by the amount of rainfall received is also important to understand the relationship. Temperature also plays a very important part in the biodegradaion proceedure, as the aerobic activity of the bacteria is increased in higher temperatures which means more oxygen is required under a tropical condition for the decomposition of wastes. And this oxygen is supplied by rainfall.

San Sebastian canal

Coefficient variation: daily

The correlation coefficient for the daily BOD - rainfall can be seen in table 7.1. This is also portrayed in figure 7.5 (A).

The BOD-rainfall daily correlation in the San Sebastian canal was very similar to the rainfall-COD relationship, except in the variation in the strengh of the correlation. The strongest daily correlation was at the sites S01 and S02 with -0.36 and 0.37 respectively. The level of significance was .001. This is very similar to the rainfall-COD coefficient in the same sites. The strength of the coefficient decreased from site S03 to S10. The coefficient was -0.13 at S03 and -0.01 at S10 with minor fluctuations in the sites in between. Site S05 which was between two major industrial sites had a comparatively higher correlation of -0.23. This indicates the higher negative correlation between rainfall and BOD in the non-industrial sites compared to the industrial sites.

Even among the non-industrial sites, the strength of the coefficient varied. For example, the daily correlation coefficient was stronger at S02 with -0.37 than at S05 which had the coefficient at -0.23. This indicates the influence of industrial discharges on the downstream sites in addition to the domestic waste waters that enter the sites. The strengh of the coefficient varied in terms of the COD, but the essential feature of a negative correlation remained.

Comparison between non-industrial and industrial sites

The daily BOD data is in appendix D. The comparison of rainfall-BOD values in a non-industrial and industrial site further explains the relationship. On 07.05.1986 with 100.2 mm of rainfall, the BOD at site S02 was 2.0 mg/L while on 29.04.1986 the BOD at S02 remained 2.0 with a very low rainfall of 0.3 mm. The BOD of 2.0 mg/L on the latter date was due to a very high rainfall during April. Examination of the equivalent DO values showed that they similarly remained high (14.8 and 14.0 mg/L). This indicates a situation where with the same low BOD trend with two extreme daily rainfall values the DO had increased by 0.8 mg/L. The 100.2 mm of rainfall has not diluted the 2.0 mg/L of BOD that was prevalent although 0.8 mg/L of extra DO has been supplied by the heavy rainfall. When you consider the BOD at S03 or S06, in the former the BOD was 389.0 mg/L on 29.04.1986 with a rainfall of 0.3 mm. On 07.05.1986, with 100.2 mm, the BOD fell to 144.0 mg/L. The increase in the DO level was 0.2 mg/L. Therefore, in this industrial site with an increase of 99.9 mm of rain, resulting in an increase of 0.2 mg/L of DO, had reduced the waste in terms of the BOD by 245.0 mg/L. This is both due to the volume of water in terms of the rainfall and oxygen supplied by the rain. When the site S06 is considered the large increase in rainfalll from 29.04.1986 to 07.05.1986, there has been no increase in the DO. The DO was 0.02 mg/L in April and 0.0 mg/L in May. The BOD has fallen to 139.0 in May from 368.0 mg/L in April. This shows a situation where dilution of waste water has taken place purely in terms of the volume of rainfall with the increase in the atmosphere supplied. This could be due to the film of oil found at S06 which hinders atmospheric oxygen diffusion. When the driest month, i.e. February 1987 with zero rainfall is considered, the BOD at S02 had increased to 59.0 mg/L, the DO was 5.0 mg/L, but at S03 the BOD had a high concentration of 870.0 mg/L. The DO level was zero. At S06 the BOD was 400.0 mg/L with zero DO and zero rainfall. This shows that the BOD had fluctuated with daily rainfall on different scales at the different sites.

Coefficient variation: monthly

Table 7.2 shows the monthly correlation coefficient between BOD and rainfall.

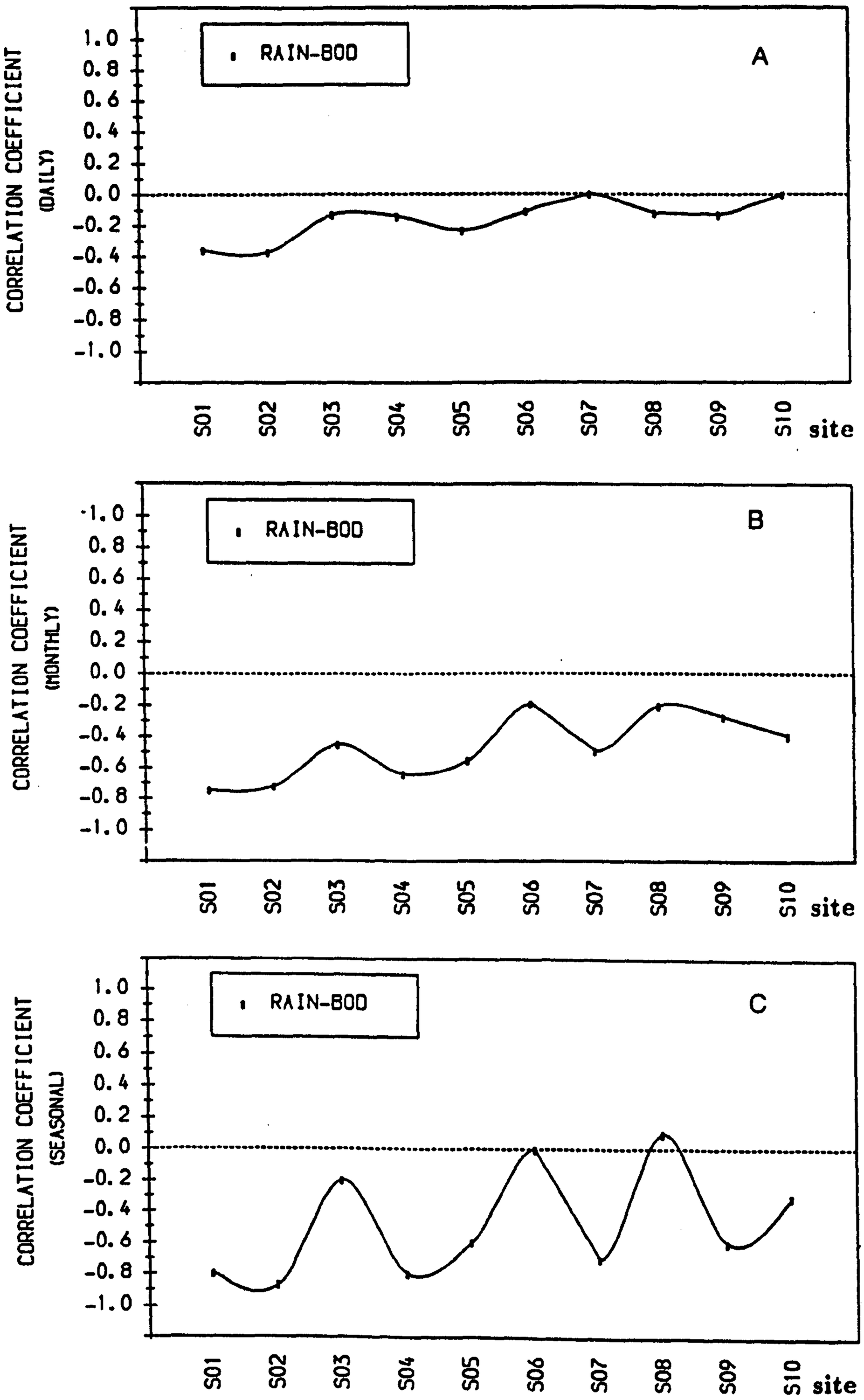


Figure 7.5 — Correlogram of daily, monthly, seasonal rainfall and BOD

Source: Based on field monitoring

Figure 7.5 (B) shows the trend across the sites.

The relationship of rainfall-BOD on a monthly basis improved in most of the sites, except at S06 which remained low at -0.19. The monthly coefficient improved at the industrial waste water reception sites such as at S03 with -0.45 at .05 level of significance. Site S05 and S07 also saw an increase with the coefficients at -0.55 and -0.49 with significance levels at .01 and .05 respectively. The relationship between rainfall and BOD improved over the daily coefficient from the sites S08 to S10, but the strength between the variables was low in comparison with the other sites. The sites S01 and S02 also had higher correlation coefficients with -0.75 and -0.72, which were .001 and .01 significant.

Comparison: industrial and non-industrial sites

There was a general improvement in the coefficient which indicated the impact of the monthly rainfall on the pollutant dilution, but the level of significance remained low from S06 downstream. This indicated the complexities as the canal progressed due to the tributary discharges, tidal influence, agricultural runoff and certain industrial discharges.

Other than a few extremes and complexities, on the monthly basis there was a clear relationship between the rainfall and the BOD. When the rainfall is high the corresponding BOD was low and when the rainfall is low the BOD was high. In the industrial waste water reception sites the correlation coefficient was lower , other than at S03 which indicated that the organic wastes are high and, therefore, the dilution capacity of the rainfall was lower. This is clearly evident when the values were compared with the non-industrial sites such as S01 and S02 where the relationship is less complex and more direct between the variables.

On a monthly scale the BOD and rainfall at S02 had moved in the opposite direction depending on the amount of rainfall. In April 1986 with a monthly rainfall of 216.84 mm, the mean BOD was 6.33 mg/L. In May with 230.97 mm it decreased to 5.67 mg/L and then increased to 32.67 mg/L in the low rainfall month of July (10.39 mm). In December the lowest mean monthly BOD was recorded with 3.67 mg/L at a rainfall of 203.45 mm. In February 1987 the mean BOD was high with 26.67 mg/L. These figures indicate that during the high rainfall months the BOD has been low and during low rainfall months the mean was high; but the lowest BOD did not coincide with the highest rainfall month of May, nor did the highest mean COD coincide with the lowest rainfall month of February 1987. At S03 the BOD in April was 343.33 mg/L, it fell to 157.67 in May, increased to 216.67 mg/L in July, and fell to 201.67 mg/L in December, and recorded the highest mean monthly BOD of 664.0 mg/L in February 1987. The corresponding DO at S03 was 0.05 mg/L, 0.32 mg/L in May, 0.30 mg/L in July, 0.57 mg/L in December 1986, and 0.0 mg/L in February 1987. The mean monthly BOD which was very much higher than at S02 also has moved in an opposite direction to the rainfall.

Coefficient variation: seasonal

Table 7.3 shows the seasonal correlation coefficient between BOD and rainfall. Figure 7.5 (C) shows the trend across the sites.

In the seasonal analysis the high mean seasonal rainfall and the mean seasonal BOD was maintained. The correlation coefficient was very high at S01 and S02 with -0.80 and -0.87 respectively. The level of significance was .05 at both sites. The correlation fell at S03 to -0.20. It strenghened at S04 and S05. There was no correlation at S06 and a positive correlation at S08 with the coefficient at 0.10. The coefficient was higher (-0.60) at S09 than on the monthly analysis. At S10 it fluctuated again slightly. Other than the extreme correlation coefficients at S06 and S08, the general negative relationship between rainfall and the industrial sites were lower than the monthly analysis.

Therefore, even on a seasonal basis, the negative relationship between these variables were maintained. This indicates that in the high rainfall season, the BOD concentration is lower and vice versa. This shows that rainfall dilutes the high BOD concentration in the canal sites by its physical volume of rainfall and by the aerobic bacteria at the sites. The dilution capacity of the rain varied with lower dilutions which was evident from the higher BOD at the industrial sites. At the less polluting sites of S01 and S02 there was a direct relationship between rainfall and BOD. The BOD was very low during the high rainfall months and the DO content in these sites

was very high.

Comparison: industrial and non-industrial sites

The mean seasonal BOD data are in appendix L.

The seasonal rainfall-BOD values show that at S02, in the second intermonsoon with the highest mean seasonal rainfall of 7.34 mm, the mean seasonal BOD was 6.0 mg/L. The BOD increased to 20.61 mg/L during the southwest monsoon which recorded the lowest mean seasonal rainfall of 1.64 mm. At the second intermonsoons the BOD rose to 6.0 mg/L with a higher seasonal rain of 4.78. During the northeast monsoon II, a higher BOD of 11.08 mg/L was recorded at a mean seasonal rainfall of 3.03 mm. At S03 the mean seasonal BOD values were 250.5 mg/L, 247.89 mg/L, 180.5 mg/L, and 375.5 mg/L respectively. The fluctuations in the BOD at this site also show that the BOD are lower during higher rainfall seasons and high during the lower rainfall seasons. The BOD was obviously higher at this industrial site than at S02 which is free from industrial and domestic discharge.

Other surface waters

River Kelani

The correlation coefficient for Kelani river is given in table 7.1, 7.2 and 7.3 for the daily, monthly and seasonal values.

In the river sites the daily rainfall-BOD correlation had a negative trend. At the site R01 the correlation coefficient was -0.22 while at R02, the coefficient was -0.24 in the daily analyis.

The correlation was lower at R01 than at R02, obviously due to more waste loads that enter from the San Sebastian canal than the upstream site R02. Further, the organic waste load is higher at R01 due to untreated sewage that enter from the Madampitiya sewage works at this site. Therefore, the waste load in terms of the BOD is higher at R01 which dampens its relationship with the rainfall.

In the monthly rainfall-mean BOD analysis the coeficient is 0.06 at R01 which is a deviation from the normal rainfall-BOD relationship. This may be due to more organic load that enter this site, or the insignificance of rainfall as a dilutant in the river. The negative correlation, although lower, is maintained at the site R02. In the seasonal analysis, the correlation is negative at both sites. The correlation improved to -0.60 at R02. Although the correlation improved the level of significance was low.

Beira lake

The correlation coefficient for the lake is given in table 7.1, 7.2 and 7.3 for the daily, monthly and seasonal values.

In the lake sites the daily correlation between rainfall and BOD at U01 was -0.39 with a significance level of 0.01 while the correlation was poor at U02 which had a correlation of -0.06. The monthly correlation was higher at U01 than at U02. On the seasonal basis, the correlation improved at U01 with a correlation coefficient of -0.60 while it gave an isolated correlation of 0.30 at U02.

The rainfall-BOD correlations indicate that at U01 the relationship between these two variables was comparatively stronger, while at U02, which is the industrial waste water reception site to highly organic food wastes from A3 and A5, and untreated sewage from the city, the correlation was very low. It depicted peculiar behaviour with positive correlation coefficients. This trend is difficult to comprehend in terms of the correlation coefficient, but in term of real values the situation is clearer. U02, a highly polluted site from organic waste water discharged from the meat industry, creamery, and the culvert that discharge raw sewage from the domestic sources are too strong for the rain to dilute. Although dilution does take place, the capacity of the rain water to dilute the wastes to a significant degree is not prevalent at this site. The BOD at site U02 on 14.05.1986 was 1265.0 mg/L at a daily rainfall of 0.0 mm, on 31.07.1986 it was 799.0 mg/L at 0.1 mm, on 02.12.1986 at 0.0 mm it was 100.0 mg/L, and on 24.02.1987 at 0.0 mm it was 165.0 mg/L.

In the seasonal analysis the rainfall-BOD relationship indicates that even during the high rainfall season such as the intermonsoon I, the BOD has been high with 897.50 mg/L at a seasonal mean rainfall of 7.34 mm. During the low rainfall southwest monsoon with 1.64 mm of rain, the BOD was lower with 640.33 mg/L. During the second intermonsoon and the second northeast monsoon the mean BOD has fallen to 322.3 mg/L and 321.25 mg/L. This indicates that at site U02, the BOD concentration in the lake has been independent of rainfall. The dilution effect of rainfall is minimal

at this site.

Tributary canals

The correlation coefficients for tributary canals are given in tables 7.1, 7.2 and 7.3 for the daily, monthly and seasonal values.

The rainfall-BOD in the tributary canal indicated a negative correlation in all the sites except at T06 in the Dematagoda ela which had a coefficient of 0.15 on the daily rainfall-BOD analysis. The coefficient ranged from 0.15 at T06 to -0.56 at the tributary site T10. The level of significance was .01 at T10. In the Dematagoda ela it ranged from 0.15 at T06 to -0.56 at T04. The significance at T04 was .01. In the Kittampahuwa ela it ranged from -0.09 at T08 to -0.56 at T10. In the Main drain it ranged from -0.24 at T12 to -0.43 at the site T11 which had a significance level of .05.

In the monthly analysis all the sites on the tributary canals had a negative correlation. The correlation significantly improved at T01 and T02 with -0.69 and -0.57 respectively. They had .05 and .01 levels of significance. In the Dematagoda canal the correlation improved at T06 to -0.32, but fell at T03 to -0.10. In the Kittampahuwa ela the correlations improved at all the sites. In the Main drain the monthly correlation improved remarkably with a significantly high correlation of -0.80 with a .001 level of significance at T12. The correlations were also high at T11 and T13 with -0.67 and -0.69 which were .05 significant. Both of these are industrial effluent discharge sites from food industries.

In the seasonal analysis the correlation between the two parameters improved in most of the sites, although the significance was low, except in the Dematagoda ela where the correlation weakened at all the sites with the exclusion of T04 which had -0.60. The coefficient in the Kittampahuwa ela also increased in all the sites with a significantly high correlation of -0.80 at T09. The Main drain also experienced an increase in the rainfall-BOD seasonal relationship in all the sites. The correlation was very high with -0.70 at T11 to -0.90 at site T13.

The behaviour of rain-BOD relationship in the sites of T11 and T13 in the Main drain was different to the other industrial reception sites. There is a significant relationship in the rainfall capacity to dilute and concentrate the pollutants at these two sites, whereas in the other industrial sites, such as S03 and S06, the dilution capacity of the high concentration of wastes by rainfall has been comparatively low. Rainfall being a common factor in all the sites the only possible reason could be the dilutions that take place due to the flushing out effect through the Mutwal tunnel during the high rainfall seasons when the sand bar at the mouth is cleared due to high flow. This initial flushing out effect may have a secondary, but a direct effect on the rains capacity to dilute the otherwise very strong wastes. The closure of the outlet during dry weather may have the opposite effect with highly organic wastes concentrating at the sites. The concentration may also be high during the dry weather due to virtual stagnation which is augmented by the blockage at the entry point of the Main drain to San Sebastian through the culvert.

The situation at the sites on the Main drain can be explained further by real values. The daily BOD on 15.04.1986 at a daily rainfall of 30.4 mm at T11 and T13, was 136.0 mg/L and 223.0 mg/L. On 24.06.1986, the BOD was 191.0 mg/L respectively at a daily rainfall of 0.0 mm while in the driest month of February 1987, the BOD on 12.02.1987 was 302.0 mg/L and 637.0 mg/L respectively. These figures indicated a relationship between the high rainfall, low rainfall, and zero rainfall months at the sites. The monthly relationship was similar although the correlation obviously improved due to the fact that the rainfall computations were based on monthly totals. The seasonal values indicated the same trend. The seasonal mean BOD during the Intermonsoon I was 107.0 mg/L at a mean seasonal rainfall of 7.34 mm, 228.67 mg/L during the second intermonsoon of 4.78 mm and, 200.0 mg/L at the northeast monsoon season at 3.03 mm at site T11. At the site T13 the values were 163.0 mg/L, 358.67 mg/L, and 395.5 mg/L respectively. The longer term monthly and seasonal relationship between rainfall and BOD perhaps explains the flushing out effect on the lowering of BOD values during high rainfall. The blockage of the outlet at Mutwal during the dry season is explained by the corresponding higher concentrations.

7.3.4 The daily, monthly and seasonal rainfall - SS analysis

San Sebastian canal

Coefficient variation: daily

Table 7.1 shows the daily correlation coefficient between SS and rainfall. Figure 7.6 (A) shows the trend across the sites.

The rainfall-SS relationship at the San Sebastian canal shows a positive correlation at all the sites in the daily analysis. The coefficient varied from 0.07 at S10 to 0.52 at S03. The level of significance at S03 was .001. The correlation coefficient is higher between S03 and S07 which has two important industrial dischare points at S03 and S06. The coefficient is lower at site S01 and S02 which are non-industrial sites and virtually free from domestic waste waters too. The daily coefficient was 0.20 and 0.30 at S01 and S02 respectively. The correlation fell from site S08 to S10 with the lowest correlation for the canal being recorded at S10. The lower correlation at S10 may be due to the tidal effect felt at this site. Both the correlation coefficient and the level of significance is higher at the sites between S03 and S07. A significant amount of SS enters the canal between these sites from industry B, C, and motor spare garages at S04. Maligawatte ela drain also contributes at S04. At S07 SS enters from the Kettarama drain. At S05 and S04 SS enters from domestic sources especially from the shanties.

In addition to these sources, a large amount of silt, sand, and other construction material entered the canal from the construction site at the new courts complex at Hultsdorf which is near S03. Heaps of sand were piled up near the canal. In 1986 dredging of the San Sebastian canal was done after a lapse of three years. The dredged material was piled up on the bank. The fact that dredging was done after a long time may have contributed to a large quantity of silt and other materials. The dredged materials being dumped along the canal banks in the canal reservations may have contributed to the large proportion that re-enter the canal during high rainfall. The dredging was done from S03 to midway between S08 and S09 during the period of monitoring. This may explain the higher correlation between rainfall and the SS. The level of significance was high at the sites.

Coefficient variation: monthly

Table 7.2 shows the monthly correlation coefficient between SS and rainfall. Figure 7.6 (B) shows the trend along the sites.

In the monthly SS-rainfall analysis the correlation improved at all the sites. It ranged from 0.38 at S10 to 0.72 at S06. In the sites between S03 and S08 the correlation coefficient ranged from 0.60, with a significance level of .01 at S08, to 0.72 at S06. The correlations were significantly high which indicated that in the rainfall months the suspended matter in the canal is high.

Coefficient variation: seasonal

Table 7.3 shows the seasonal correlation coefficient between SS and rainfall. Figure 7.6 (C) shows the trend along the sites.

The seasonal correlation in the SS-rainfall analysis showed an improvement in the relationship both in the SS and tubidity in most of the sites. In the SS-rainfall correlation, the coefficient ranged from 0.6 at S08 S09, and S01 to 1.0 at S06, but it may explain the current situation. This is a very rare situation and is not encounterd, except at this site on the San Sebastian canal. The coefficient increased to 0.7 at S10 and to 0.60 at S08 and S09. Though the correlation improved over the longer period, the level of significance remained low.

The overall salient feature in the SS-rainfall correlation analysis is that even in the industrial sites the correlation remained high. This is perhaps due to the high SS the industrial discharges and the direct washing away effect of the desilted material piled up along the canal into the canal at these sites during rainly seasons.

Comparison: industrial and non-industrial sites

The SS data are in appendix D,J and L for the daily, monthly and seasonal SS data.

The SS-rainfall monitored values explain the above discussed situation. On 10.04.1986 three days after a daily rainfall of 20.1 mm the SS at S01, S03, and S10 were 23.44 mg/L, 212.60 mg/L, and 12.27 mg/L and respectively. The corresponding daily rainfall was 0.01 mm. On 07.05.1986 they were 156.23 mg/L, 483.61, and 281.38 mg/L respectively with a daily rainfall of 100.2 mm. In the drier month

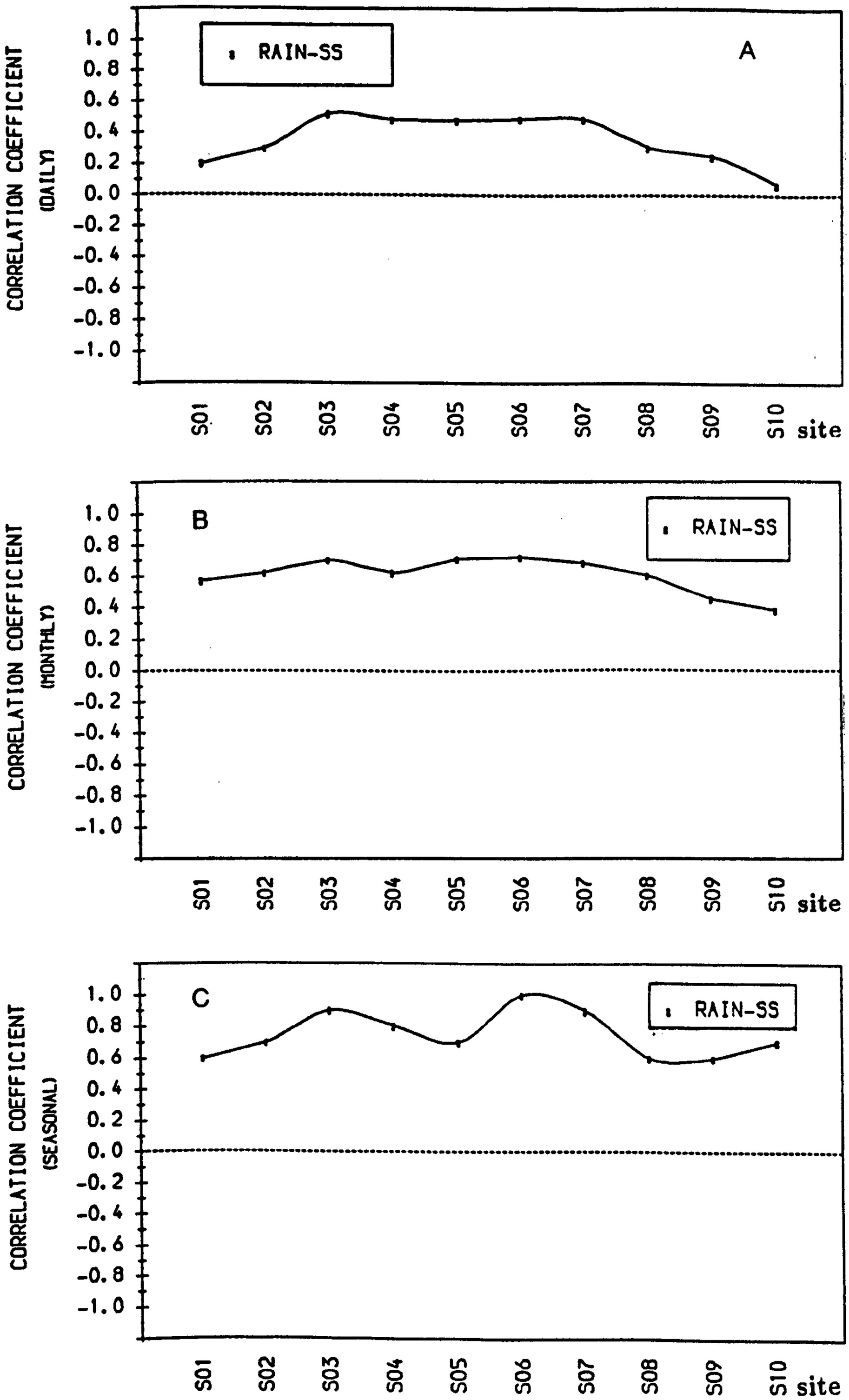


Figure 7.6 — Correlogram of daily, monthly, seasonal rainfall and SS

Source: Based on field monitoring

of July (17.07.1986) the values at S01, S03, and S10 were 15.61 mg/L, 32.51 mg/L, and 40.23 mg/L respectively. The daily rainfall was 0.0 mm. In the drier July (10.39 mm) SS was higher at S10.

In the monthly analysis in the sites S01, S03, and S10 at a monthly total rainfall of 216.84 mm the mean monthly SS in April was 25.36, 208.0 mg/L, and 15.74 mg/L. In July at a rainfall of 10.39 mm the respective values were 13.57 mg/L , 40.95 mg/L, and 41.0 mg/L. This indicates that at S10 even with a heavy rainfall the SS remained low while in July the behaviour of SS was very similar to S03.

In the seasonal analysis the SS values at S01, S03, and S10 during the first intermonsoon was higher with a rainfall of 7.34 mg/L mean seasonal SS were 41.58 mg/L and 61.83 mg/L and 15.94 mg/L respectively. In the drier southwest season, at a rainfall of 1.64 mm they were 23.75 mg/L, 50.34 mg/L, and 33.33 mg/L respectively. The figures in the seasonal analysis indicate that in these sites a more normal picture of SS-rainfall relationship. This indicates that even in a tidal site rainfall has the effect of accentuating, or dampening SS, although it is not the major factor.

Other surface waters

River Kelani

The daily, monthly and the seasonal correlations for SS are shown in the tables 7.1, 7.2 and 7.3 respectively.

In the river sites the daily correlation between SS and rainfall at R01 was 0.26 while at R02 it was 0.22. In the monthly basis, the relationship improved with 0.69 and 0.75 respectively at R01 and R02 for the SS-rainfall. The significance level was .01 at both sites. On a seasonal basis the correlation decreased to 0.30 at R01 while the relationship strengthened at R02 with 0.70. Except on the daily basis, the SS-rainfall had a lower coefficient at R01.

This indicates that at R01 which gets effluents from the San Sebastian canal and the site being close to the Madampitiya municipal sewage disposal site had a higher load of SS. This indicates that although rainfall contributed to a certain extent other sources were responsible for the SS load. Although the monthly rainfall-SS had a significantly high positive relationship which indicates the importance of rainfall in the high rainfall/low rainfall months, over a longer period, the other sources for SS become important thus dampening the influence of rainfall on SS.

Beira lake

The daily, monthly and the seasonal correlations for SS are shown in the tables 7.1, 7.2 and 7.3 respectively.

In the lake sites, the daily correlation between rainfall-SS-turbidity, a positive correlation was found between rainfall and SS at U01 with the coefficient at 0.21 while at U02, the correlation was negative with the coefficient at -0.25. In the monthly correlation the rain-SS coefficient improved significantly at both U01 and U02 with 0.73 and 0.45 respectively. The SS-rainfall level of significance was .001 and .05. In the seasonal correlation the relationship at U01 remained positive but low with the coefficient at 0.20 in the SS-rain analysis. At U02 the coefficient was 0.80 with a significance of .05.

The negative daily correlation at U02 may be due to high waste water discharges from the factories and the gully which enters at this point. Therefore, although a very high SS load enters the lake at this point it is not atttributable to daily rainfall. Further, the rainfall on the day of the monitoring also may have influenced the correlation in this analysis. Except on 25.02.1986, 03.03.1986, and 11.08.1986 all the other monitoring days had zero or very low rainfall. These extremes in the daily values improved in the monthly analysis more than in the seasonal analysis and thus indicated that high rainfall and low rainfall months had a bearing on the SS load and the resulting turbidity. More than the other variables, the SS load depends on the water movement arising from the rainfall. Although this does not affect the lake in the same manner as a river or canal, the impact of rain on the lake can cause matter to be in suspension, and disturb the bottom sediments and wash away the shores. The impact of SS load from the culvert which empties here can be affected due to higher rainfall which results in a higher flow rate causing more suspended matter to be brought into the lake. Although there were isolated occurences the overall rain-SS relationship remained positive in the lake.

Tributary canals

The daily, monthly and the seasonal correlation for SS is shown in the tables 7.1, 7.2 and 7.3 respectively.

The rainfall-SS daily correlation in the tributary canals ranged from -0.13 at T11 to 0.57. The relationship was just positive in the Maligawatte and the Kettarama drain with 0.07 and 0.05 respectively. In the Dematagoda ela all the sites remained positive exept T06 with -0.06 while the highest SS-rainfall daily correlation coefficient was recorded at T04 with 0.57. The significance level was .01. The Kittampahuwa ela had a very weak negative correlation in all the sites except T10 which had a positive correlation of 0.44. In the Main Drain the correlation was posotive in all the sites, except T11 which had a negative correlation.

At the sites near the confluence of the San Sebastian canal which are industrial receiving sites in nature, at site T03, the daily correlation is weak both in the SS-rainfall analysis. This may be due to the direct amount of rainfall on the sites which were very low during the days of monitoring of the tributary canal in addition to its monthly sampling. Further, a heavy load of SS may be discharged from the industries at this site in addition to the SS resulting from rainfall. For example, on 29.05.1986, the SS at T03 was 46.65 mg/L at a higher rainfall of 28.7 mm. On 13.11.86 at a rainfall of 0.01mm the SS was 86.33 mg/L. This indicates that although during high rainfall days the SS has increased due to rainfall on lower rainfall days too, the SS remains high because of industrial waste water discharges.

In the monthly analysis, the relationship increased at T03 in the SS-rain analysis with 0.72 which was .01 significant on rain-SS. The seasonal correlation was a further improvement in the relationship with the SS which indicated very high coefficients. The monthly and the seasonal correlations smooth out the extremities in the daily values. Further, it also indicates a positive correlation between SS-rainfall which means the SS load is high during the rainfall months and lower during the drier months.

In the seasonal analysis the SS during the first intermonsoon with a higher mean seasonal rainfall of 7.34 mm the SS was 158.14 mg/L. In comparison, during the lower rainfall southwest monsoon season of 1.64 mm of seasonal mean rain, the mean seasonal SS was 26.64 mg/L. This indicates in a longer time scale the SS has moved positively with rainfall.

The Main Drain site T11 had a negative daily correlation in the SS-rainfall analysis with the coefficient at -0.13 while at T13 it was higher with 0.37. The coefficient improved on the monthly and the seasonal analysis, except at T11 where the rain-SS correlation was -0.10. But the significance of this correlation is very low. Thus, although the sites on the Main Drain show an overall positive correlation between SS and rainfall, the fact that the correlations are lower and do not significantly improve on the monthly and seasonal basis may be due to the sea outlet at Mutwal and the tidal influence felt at T13. This may be a possible explanation because the conductivity values are also very high at T13.

7.3.5 The daily, monthly, seasonal rainfall-conductivity analysis

The San Sebastian canal

Correlation variation: daily

Table 7.1 shows the daily correlation coefficient between conductivity and rainfall. Figure 7.7 (A) shows the trend along the sites.

The rainfall-conductivity analysis indicated a negative correlation between these two parameters in all the sites in the San Sebastian canal. The correlation coefficient ranged from -0.08 at S03 to -0.39 at S08 in the daily analysis. At S08 the significance was 0.01. The rainfall-conductivity correlation remained very low at the indistrial waste water receiving sites of S03 with the coefficient at -0.08. Although the correlation was generally very low it improved a little from S04 with the coefficient at 0.19. S10 and S08 marked slight improvement. It is also interesting to note the site S02 had a very low correlation between the daily rainfall and conductivity. The coefficient was -0.18. The significance level was low in all the sites except S01, S08 and S10.

Correlation variation: monthly

Table 7.2 shows the monthly correlation coefficient between conductivity and rainfall. Figure 7.7 (B) shows the trend along the sites.

In the monthly rainfall-mean conductivity analysis, except at site S05 and S08,

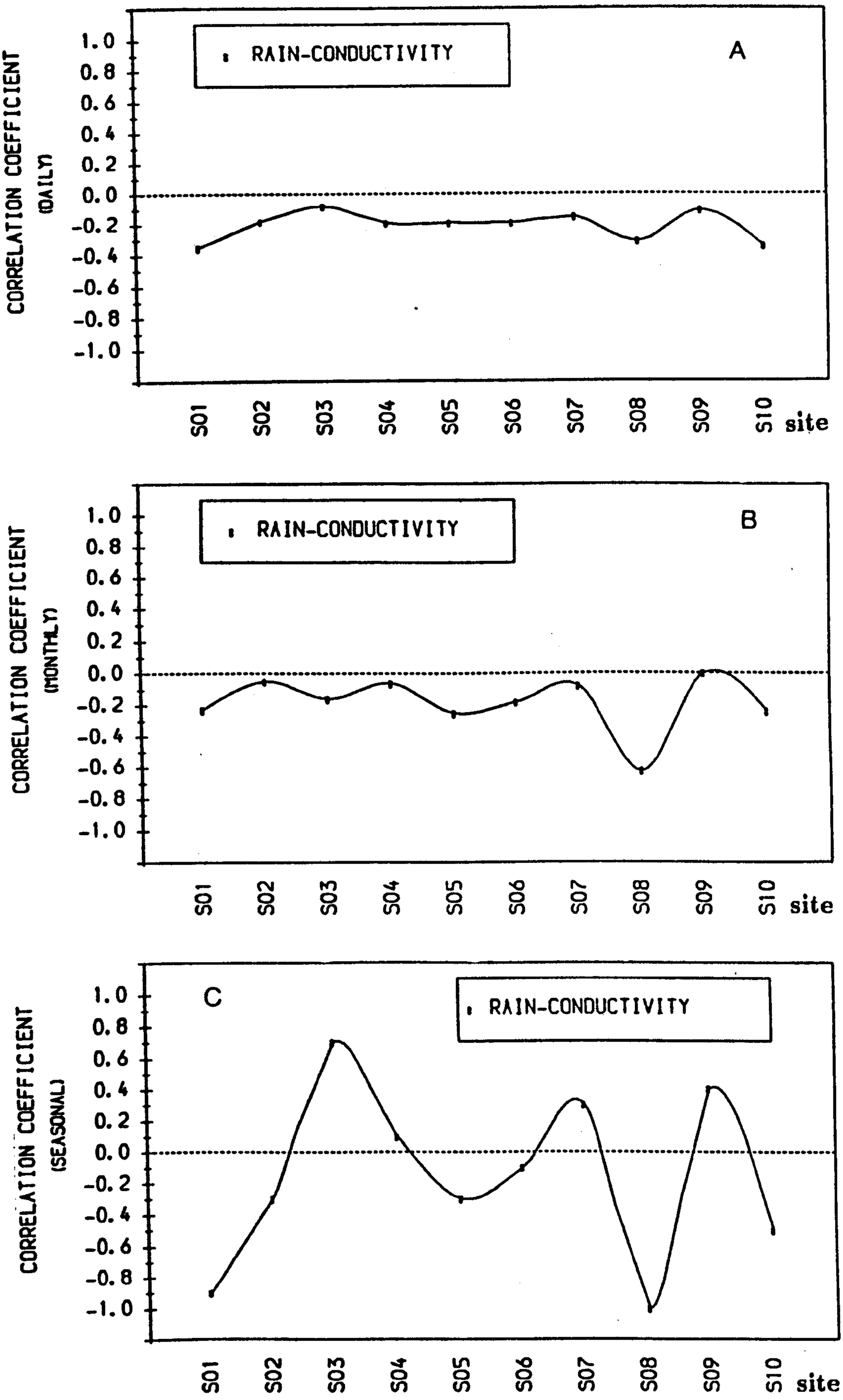


Figure 7.7 — Correlogram of daily, monthly, seasonal rainfall and conductivity

Source: Based on field monitoring

the correlation did not improve although the negative correlation was maintained. The correlation coefficient was lower than in the daily analysis in most of the sites. The correlation was .00 at S09. The coefficient was -0.25 at S05 and -0.62 at S08. The latter was .01 significant. There was a slight improvement at S03 with the coefficient at -0.16.

Correlation variation: seasonal

Table 7.3 shows the seasonal correlation coefficient between conductivity and rainfall. Figure 7.7 (C) shows the trend along the sites.

The rainfall-conductivity seasonal analysis on the San Sebastian canal gave a range in the coefficient from -1.0 at S08 to -0.90 at S01, the latter was .01 significant. At the industrial sites of S03, S04, and S07 the conductivity gave a positive correlation with 0.70, 0.10, and 0.30 respectively, although the level of significance was low. The correlation at S10 improved. There was contrasting relationships between the sites with regard to rainfall-conductivity in the monitored sites.

Comparison between non-industrial and industrial sites

The conductivity data for the daily, monthly and the seasonal values are in appendix D, J and L respectively. The conductivity-rainfall correlation although negative in all the analyses at S02 remained very low without much response to the seasonal or monthly rainfall. This is a contrast to other variables at this site which had more response to rainfall on a monthly or seasonal basis. This may be due to the low dissolved solids present at the site which did not show much variation over the monitored period. Fluctuations are sharp at polluted river sites (Greenberg *et al* 1980). The conductivity values changed very little with minimum recorded 145.0 μmhos/cm on 26.11.1986 to 370.0 recorded on 04.08.1986. The range in the site is very narrow compared to the industrial waste water receiving sites and the tidal sites. Further, the lowest conductivity level did not occur in the high rainfall months. At this site the low conductivity levels indicate that the dissolved solids are low. This is also seen in sulphate concentrations. The slight increase in conductivity may be due to atmospheric carbon dioxide which increases conductivity since there are no immediate domestic sources that discharge waste water or industries at the site. Although the relationship of rainfall and conductivity were not highly significant, the negative correlaiton was maintained in all the analyses.

At site S03, the correlation between rainfall and conductivity was the weakest recorded with an isolated occurrence in the seasonal analysis. The weak relationship between conductivity and rainfall is acceptable in an industrial waste water receiving site. This indicates that the dissolved solids are high in this site with continuous input of dissolved ions discharged from the factory B. The waste water discharges take place irrespective of the time and since the input is high and continuous into the site the rainfall is unable to dilute the high concentration of dissolved ions at the site. If the rainfall is very heavy and continuous it may have a direct relationship in the dilution of the dissolved solids. On the other hand, a drier period with no rainfall will help to concentrate the dissolved solids. Although dilution occurs to some degree, as seen in the correlation, it is very low and this is purely due to the very high concentration in industrial wastes. This applies to most of the pollutants in the canals with low flow to a stagnant waterways. The situation may differ in the surface waterways with flow characteristics influenced by other factors such as the tides and other outflow outlets. The highest conductivity recorded at S03 was 1600.0 on 22.09.1986 when 12.0 mm of rainfall was received. An equally high conductivity was recorded on 07.05.1986 with a conductivity at 1230.0 at a rainfall of 100.2 mm. The conductivity value at S03 was the highest among the industrial receiving sites on the San Sebastian canal. The conductivity at S06 was also high, the maximum recorded at this site was 1585.0 μmhos/cm on 19.03.1986, at a daily rainfall of 0.01 mm. The conductivity values from S03 downstream was high in all sites with minor fluctuations in the non-industrial sites and this is a sharp contrast to the non-industrial site of S02. The conductivity at S01 was higher throughout the monitoring period. This may be due to the influence of the lake where the conductivity level at U01 was very high.

The sites closer to the river such as S10, S09, and S08 recorded some of the highest conductivity values. At S09 and S10, the influence of the tides may be the reason. The highest conductivity levels recorded at S09 and S10 in 1986 were on 20.02.1986 with the concentrations of 2050.0 and 2400.0 μmhos/cm respectively, while

in 1987, towards the end of January and February, the conductivity remained very high. The conductivity at S08 also remained high. This could be either due to tidal water reaching the site, or due to dissolved solids entering the canal from the industries discharging to the Dematagoda ela. The conductivity at S09 and S10 generally reflected the conductivity of the river sites R01 and R02, but even though a fall in conductivity of the river sites occurred during the rainy months of April, May, October and December, the conductivity levels at canal sites S09 and S10 remained high. Therefore, the buffering effect at the site is acutely felt here. This is possibly due to the influence of the industries upstream and around the site discharging waste waters with dissolved ions such as sulphates and chlorides. Further, the lower volume of water in the canal would have a higher concentration with continuous input than a larger volume of water such as the river. This situation is clearer in the higher rainfall months. In the dry months when the rainfall was very low, or zero, the conductivity remained very high in the sites S09 and S10 reaching over 1500.0 in both of these sites. The seasonal correlation was fairly high at S10 with -0.50 although it was peculiar at S09. The peculiar seasonal occurrence of a higher positive correlation coefficient of 0.70 at S03 and lower although positive occurenrces at S04 and S07 is understandable. These are the industrial waste water receiving sites, or the sites immediately downstream.

Other surface waters

River Kelani

The correlation coefficient for the daily, monthly and the seasonal values are given in the tables 7.1, 7.2 and 7.3 respectively. In the river sites R01 and R02 the conductivity-rainfall relationship was negative although the relationship was weak. R01 had a lower coefficient with -0.15 and R02 slightly higher coefficient of -0.22. In the monthly analysis the correlation was a weak positive one with 0.11 and 0.13 respectively. The significance level remained very low. In the seasonal analysis too the correlation coefficient remained low with 0.1 at both the sites. Although there has been no response to rainfall on a seasonal basis, the daily correlation indicates a weak negative response of conductivity to daily rain.

The low correlation in the river sites may be due to low conductivity in the low rainfall southwest monsoon months. Conductivity was very high in the beginning of 1986 reaching 2950.0 μmhos/cm at R01, and 2600.0 mhos on 20.02.1986 when the daily rainfall was 0.90 *mm*. February 1986 has been a very low rainfall month recording 0.0 mm rainfall on most of the days, except two heavy showers on 13.02.1986 and 25.02.1986 with 53.10 mm and 22.77 mm of rainfall respectively. The conductivity continued to fall in the high rainfall months of April and May which is a normal situation. It is difficult to explain why the conductivity level in the river continued to fall during the lower rainfall months of June and July. July recorded only 10.39 mm of rainfall for the month. In July (17.07.1986) a conductivity of 45.0 and 39.0 mhos/cm was recorded at R01 and R02 respectively. This would have affected the correlation coefficient to a great extent. The only possible explanation could be either that the tidal influence would have been minimal, or that there would have been a large volume of water input into the river from the neighbouring areas during the low rainfall southwest monsoon period, or that a complex mechanism in the water chemistry was operative as far as a dissolved ions were concerned. The sulphate concentration at R01 and R02 does not explain the lower conductivity levels during the lower rainfall months of June, July, and August because the sulphate concentrations at R01 and R02 during these months have been comparatively higher than the higher rainfall months. Therefore, the behaviour of the dissolved solids other than sulphates may be the cause. Similarly, there has been a sudden change in the conductivity levels in these sites with the level rising at R02 in relation to R01 during mid-December. From January 1987 the conductivity levels increased at R01. From January conductivity increased steadily until February, both at R01 and R02 during the lower rainfall months, and the maximum was reached on 24.02.1987 with 3375.0 and 2500.0 at R01 and R02 respectively. The increase was very sharp from 75.0, on 24.12.1986, to 1980.0 μmhos/cm on 07.01.1987. Sharp fluctuations in the conductivity in polluted river sites is not an abnormal phenomenon (Greenberg *et al* 1980).

R01 had higher conductivity levels than R02 throughout the monitoring period with a few exceptions. This is understandable due to the location of the site which

is downstream of the San Sebastian canal closer to Madampitiya sewage works and closer of the two sites in relation to the sea. Other than these extreme situations, the conductivity-rainfall relationship depicted a negative correlation, even though it was very weak at most of the sites. This indicated that the rainfall has the ability to dilute and concentrate the ionic components of the water.

Beira lake

The correlation coefficient for the daily, monthly and the seasonal values are given in the tables 7.1, 7.2 and 7.3 respectively.

The correlation between rainfall and conductivity at the lake sites shows a very positive correlation in both the daily and the monthly analyses, with 0.02 and 0.06 respectively in the lake site U01. The seasonal correlation coefficient was 0.70. The site U02 also had a weak positive correlation with the coefficient at 0.18. In the monthly analysis the correlation had a negative value with -0.23 and in the seasonal analysis the correlation coefficient increased to -0.50.

The behaviour of conductivity-rainfall relationship at U01 was very different from the other sites. This is the only site which had a positive correlation in all three analyses, although the daily and the monthly coefficients were very weak. The weak correlation at U01 may be due to the location of the site. As it is on the entry point to the harbour, large volume of sea water enter the lake at this point. Therefore the conductivity levels have been exceptionally high at this site throughout the period of monitoring. The lowest conductivity recorded at this site was 16910.0 μmhos/cm on 8.12.86. The conductivity recorded on 7.5.86 at which the maximum daily rainfall of 100.2 mm was over 20000.0 μmhos/cm. The monthly mean conductivity for the highest rainfall month of May 1986 which received 230.97 mm was also over 20000.0 μmhos/cm. The mean seasonal conductivity recorded at U01 during the high rainfall Intermonsoon I season was 20833.3 μmhos/cm at a mean seasonal rainfall of 7.34mm. The mean seasonal conductivity during the low rainfall SW monsoon season was a close 19849.44 μmhos/cm at a mean seasonal rainfall of 1.64mm. The conductivity would have been higher at this site because the maximum unit the conductivity meter could read was 20000.0. Therefore any value above 20000.0 was recorded as 21000.0. Most of the conductivity recordings at this site were over 20000.0. Therefore it is obvious that rainfall did not have any significant impact on the conductivity at U01. The reason for this as mentioned earlier is that it is a sea water mixing point. As sea water is high in dissolved solids, it makes the site highly conductive. At site U02, an industrial waste water receiving site the conductivity levels fluctuated widely which is a common feature in the waste water receiving sites.

Tributary canals

The correlation coefficient for the daily, monthly and the seasonal values are given in the tables 7.1, 7.2 and 7.3 respectively.

The conductivity-rainfall relationship in the tributary canals ranged widely. The correlation coefficient was 0.0 at T12 and ranged to 0.41 at T03, and -0.28 at T11 in the daily analysis. The nature of correlation at these sites on the daily analysis may be due to the daily rainfall received on the days of monitoring. As mentioned earlier except in April and May 1986 all the other months had either zero or very low raifall. Since the computations were based on the monthly monitoring, the fluctuations that took place at a shorter interval was not accounted for. The level of significance remained low in these canals. In the Dematagoda canal and the Kittampahuwa ela all the sites recorded positive correlations while in the Main Drain T11 had -0.28, and 0.22 at T13. In the monthly analysis all the sites recorded negative coefficients ranging from -0.19 at T03 to -0.61 at T11 and T12. The level of significance at T11 and T12 was .01. This indicates that at a higher rainfall total, the correlation had increased considerably in a negative direction. In the seasonal analysis the correlation was stronger in the Main Drain than in the other canals.

In the tributary sites at the confluence of the San Sebastian canal, the correlation coefficient at T03 remained low, but negative with the coefficient at -0.19, in the monthly analysis and -0.40 in the seasonal analysis. This is fairly typical in the industrial waste water receiving sites. Although the daily coefficient was more isolated, the monthly and the seasonal correlation indicate that over a longer time scale the rainfall has the ability to dilute the dissolved solids. The degree of dilution is lower at these sites as large amount of dissolved solids enter from the discharging factories (the

concentration of the factories as seen earlier is high at this particular site). Therefore a large volume of dissolved solids may be be entering the San Sebastian canal from the Dematagoda canal near site S08. The conductivity was also high at S08 which possibly could be from this canal. The highest recorded conductivity at T03 was 2500.0 on 3.7.86. This was the driest month in 1986. A high value of 2090.0 μmhos/cm was recorded in February 1987, although it was not the highest. Although there were fluctuations in the conductivity values with rainfall in the high rainfall months, the levels still remained appreciably high. For example in May 1986 the conductivity was 1655.0 μmhos/cm. Therefore in the industrial waste water receiving sites, because of high concentrations the dilution capacity remained low.

In the Main Drain the site T13 had a positive correlation coefficient in the daily analysis with the coefficient at 0.22. In the monthly analysis the coefficient was -0.42. The seasonal correlation remained at -0.40. The level of significance remained low. The conductivity levels remained higher than the neighbouring sites T11 and T12. Higher conductivities may also be due to the tidal influence which may be felt at this site. The conductivity on 15.4.86 was 561.0 μmhos/cm against a daily rainfall of 30.4mm and a monthly rainfall of 216.84mm which indicated the value has been lower during high rainfall days and month. On the other hand 29.5.86, the conductivity was 1066.0 μmhos/cm against a daily rainfall of 28.7 mm and a monthly total of 230.97 mm. This indicates a typical industrial input into the canal site, where inspite of a higher daily rainfall the dilution of the dissolved solids has been low. In July 1986 and February 1987 the conductivity remained high at 1006.0 μmhos/cm with a daily rainfall of 2.4 mm and a monthly total of 10.39 mm in July, and 0.0 mm at both daily and monthly rainfall in February. These were the low rainfall months. These values indicate that at the industrial waste water receiving sites, although there is dilution by rainfall the continued discharge of waste water with variable strength makes the correlation between the these two factors weak. As mentioned earlier this may be also due to the high base level conductivity at the site as a result of sea water influence. Thus the dilution was weaker.

7.3.6 The daily, monthly, seasonal rainfall-total N analysis

San Sebastian canal

Coefficient variation: daily

Table 7.1 shows the daily correlation coefficient between total N and rainfall. Figure 7.8 (A) shows the trend along the sites. The data are in appendices D, J and L.

The total N-rainfall, daily correlation analysis gave a positive correlation in all the sites in the San Sebastian canal except at S02, S08 and S10. The daily correlation was poor in all the sites except at S04 and S06 which had slightly higher coefficients of 0.35 and 0.41 respectively. The level of significance was low. The positive coefficient in the sites ranged from 0.02 at S01 to 0.41 at S07. Total N-rainfall correlation computation was based on 14 samples since it was monitored only once a month. No monitoring of total N was done in January and February 1986. Therefore computation is based on smaller numbers of samples than the other pollutants.

Coefficient variation: monthly and seasonal

Tables 7.2 and 7.3 show the monthly and seasonal correlation coefficient between total N and rainfall. Figures 7.8 (B and C) show the trend along the sites.

In the monthly analysis the correlation improved at S01. The coefficient was 0.73, which had .001 level of significance. The correlation also improved at S09 to 0.61, with a .01 level of significance. S08 which was a very weak negative in the daily analysis had a positive value of 0.18. S03 which had a positive value in the daily analysis had a weak negative correlation in the monthly analysis. Except the sites S03, S05 and S10, which had weak negative correlations. All the other sites had positive coefficients.

In the seasonal analysis all the sites except S05 and S10 had positive correlations.

Comparison: industrial and non-industrial sites

Therefore in the rainfall-total N analysis most of the sites had positive relationships. This indicated that when the rainfall was high the total N level was also high. Therefore there is no dilution effect, rather the total N levels tended to increase with the corresponding increase in rainfall. This may be due to supply of total N

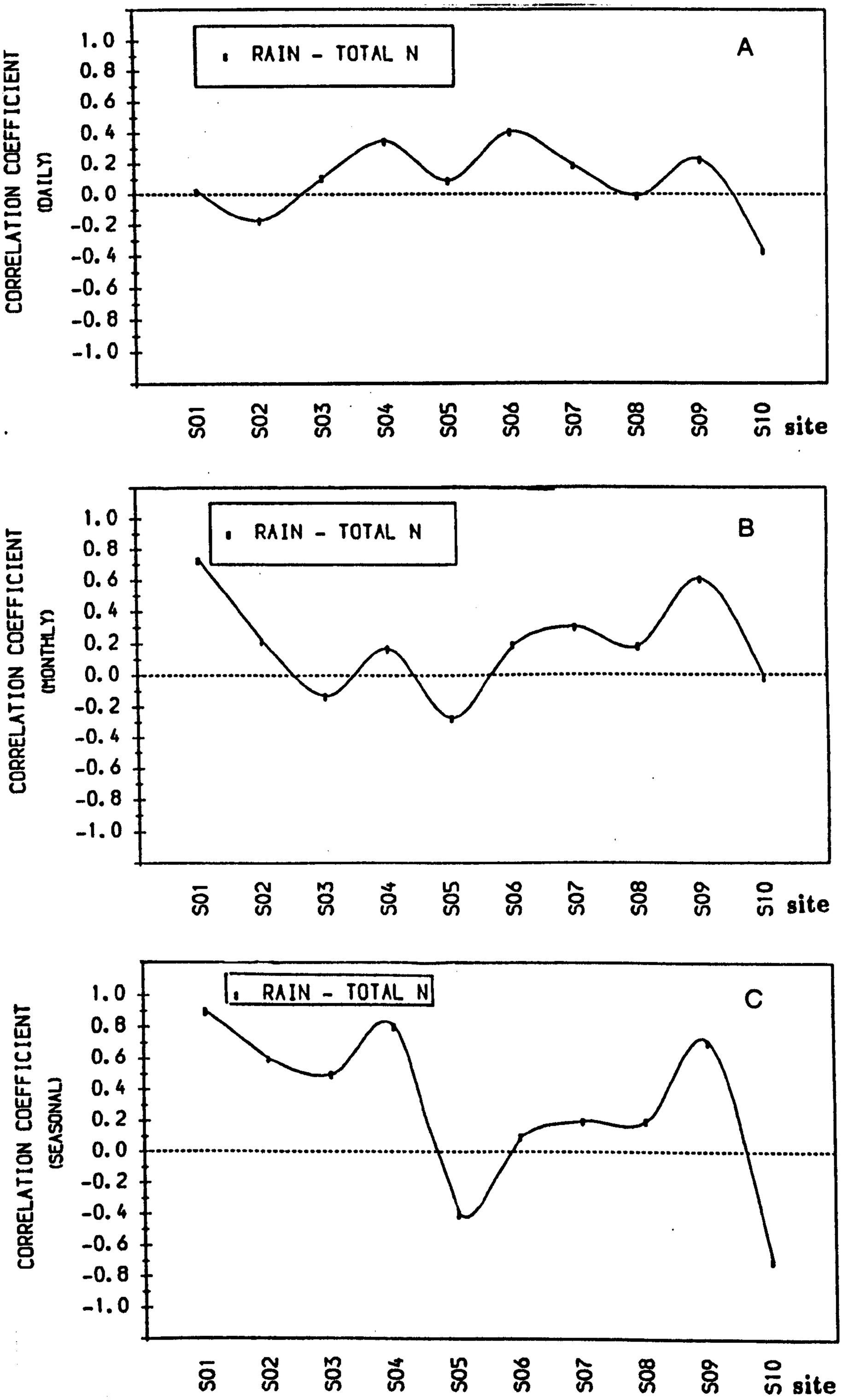


Figure 7.8 — Correlogram of daily, monthly, seasonal rainfall and total N

Source: Based on field monitoring

to the canal water with rainfall, as total N is constantly removed from the atmosphere by electrical charges. Atmosphere is the main reservoir for nitrogen. Further during electrical storms, large amounts of nitrogen is carried to the earth in rain. Therefore lightening and thunderstorm activities which are important in the tropics may be contributing to large amounts of total N to the surface waters. During the Intermonsoons the rainfall received in Sri Lanka is from the activities of the ITCZ which causes the thunderstorm activities. During rainfall total N also enter the canal via land drainage from domestic agricultural and other sources (washing off effect). Therefore a positive correlation between total N and rainfall in the sites is mainly due to nitrogen carried to the canal in rain and washing away of nitrogeneous matter into the canal. This situation aggravates the higher levels of total N that enter the canal from the industries and some domestic sites.

The examination of the daily correlations and the total N values in the sites indicated that the daily correlation coefficient was higher at S06 and S04 with 0.41 and 0.35 respectively among the industrial sites. The other sites which have lower correlations are S07 with 0.19 and S03 with 0.11. The examination of total N values shows that the level of total N was higher at S06 and continued to be the highest recorded value except on one occasion. The maximum recorded at this site was 16.36 mg/L. High total N level at this site may be due to the nitrogenous matter that enter from the organic wastes of the food industry C and also total N that enter the canal site in the form of nitrite used as corrosion inhibitor in the industrial process water of this industry in addition to the nitrogen supplied by atmospheric and land sources by direct rainfall. Although the total N-rainfall positive relationship is maintained at S06, it did not necessarily mean that the highest total N levels corresponded to the highest daily rainfall levels. For example a high level of total N with the concentration at 10.35 mg/L was recorded on 17.04.86 with a daily rainfall of 3.20 mm. But the highest total N level recorded was on 19.03.86 at a daily rainfall of 0.01 mm. There was a fall in the total N level in February 1987 with 5.0 mg/L recorded at zero rainfall. The seasonal correlation gave a coefficient which is weak, although positive.

Very broadly it can be said that the monthly and seasonal analysis higher total N levels have been recorded during the high rainfall month of May 1986 with 13.2 mg/L at 230.97mm of rain and a lower total N level of 5.0 mg/L during Februrary 1987 with 0.0mm of rainfall for the month, but a higher nitrogen level of 11.92 mg.L was recorded for the low rainfall month of July 1886 which had 10.39 mm of monthly rainfall. Similarly in the seasonal correlation, during the second intermonsoon at a mean seasonal rainfall of 4.78 mm, the total N level was 15.36 and during the lower rainfall season of the second northeast monsoon with 3.03 mm of rainfall the total N concentration was lower with 8.32 mg/L. On the other hand during the first intermonsoon, and the southwest monsoon this situation did not hold true.

The site S04 also had a higher correlation coefficient, the contributions to this site being from both industrial and domestic sources (shanties) in addition to the atmospheric and land sources brought about by rainfall. Site S07 has contributions from the tributary canal Kettarama drain in additon to factory C. S01 had higher total N levels than S02, possibly due to the influence of the lake.

The site S09 had a correlation of 0.23 which improved to 0.61, which is .01 significant and 0.70 in the monthly and seasonal analysis. Although S09 had a positive correlation, the site downstream, S10 had a negative correlation in all the analyses. It is possible that S10 is an isolated occurrence or may be due to the tidal influence which is felt more at this site. On the other hand, although the tidal influence may be felt at S09 too, the contributions of total N from other sources such as urea from commercial fertilizers drain into the site from the leafy vegetable plots and the contribution from the Main Drain may influence the background total N levels. The daily rainfall-total N correlation coefficient at S08 too may be an isolated occurrence because over the monthly and seasonal time scale the correlations improved to a positive correlation. Total N at S09 was 4.03 mg/L in the high rainfall month of May 1986 and it fell to 3.56 mg/L in the low rainfall month of July 1986 and in the dry November it fell to 0.28 mg/L although the rainfall in November was higher than in July. In December it had increased to 3.49 mg/L and in February 1987 falling to 1.02. This indicated that at S09, although fluctuation in the total N concentration did not proportionally correspond to the increase and decrease of rainfall in all the months.

The concentrations fairly followed the rainfall pattern in a positive direction.

The behaviour of total N and rainfall may have been understood better if the monitoring frequency was higher, but due to limitations in the monitoring programme, this was not so.

Other surface waters

River Kelani

The tables 7.1, 7.2 and 7.3 give the correlations for the daily, monthly and the seasonal values. In the river sites the total N gave a positive correlation with rainfall in both the sites in all the analyses. The correlation was weaker at R01 than at R02 with 0.13 and 0.22 respectively. This is seen in the monthly and the seasonal analysis.

The total N concentration at R01 and R02 remained lower than most of the canal sites. The concentration at R01 was higher than at R02. Nitrogen is naturally present in surface water from the organic nitrogen containing compounds derived from animal and vegetable matter. The fact that total N was higher at R01 than R02 indicated that it receives nitrogen containing discharges from the surrounding domestic sources, the San Sebastian canal and the industries situated nearby. Another possible contributor is the untreated sewage from the municipal sewage plant at Madampitiya . As indicated by the positive correlation, the rainfall too contributes total N to the river during high rainfall periods. This may be direct from the atmospheric reservoir which is supplied through the rainfall and the washing away of nitrogeneous matter from the land surface. During the high rainfall month of April with 216.84 mm of rainfall the total N content was 3.86 mg/L at R01 during May it was slightly lower with 3.26 mg/L. In June the concentration had fallen to 1.90 mg/L and 1.23 mg/L in July. In February 1987 although it was the driest month, the total N concentration was slightly higher than in the low rainfall month of July with the value at 1.30. In the mean seasonal concentration the highest mean seasonal total N concentration was in the first intermonsoon period which had 3.56 mg/L. The convectional thunderstorm activity is at its height during this period, which is also reflected in the total N concentration at R01.

Beira lake

The tables 7.1, 7.2 and 7.3 give the correlations for the daily, monthly and the seasonal values. The total N-rainfall correlation in the lake sites gave a positive coefficient at both the sites in all the analyses. The daily correlation coefficient at U01 was 0.05 and 0.11 at U02. On the monthly and seasonal analyses the total N-rainfall coefficient improved, which indicated that with more rainfall over a longer time scale the total N concentration also increased. The total N concentration at U01 was higher than at most of the sites in the San Sebastian canal, other than in the industrial waste water receiving sites. It was also higher than the river sites R01 and R02. At site U02, the total N levels were very high. Although there was a positive correlation between rainfall and total N at U02, which also increased on a monthly scale, more total N must be entering the site from the two food industries which discharges nitrogeneous waste water and the culvert which brings raw sewage from the city. A3 which is the meat processing industry and A5, the creamery discharge waste water directly into the lake at this site. The rainfall-total N correlation indicates the contribution of rainfall towards the total N content. On a daily basis even though the correlation coefficient was very low, there was a concentration of 7.01 mg/L at U01 in April. It was slightly lower in the highest rainfall month of May. It may be due to a relatively higher daily rainfall of 3.20 mm on 17.04.86 and a lower daily rainfall of 0.01 on 15.05.86 (which were the days of monitoring). In July, the other low rainfall month, the concentration was lower with 4.16 mg/L. In February 1987 the concentration was 2.11 mg/L at 0.0 mm of rainfall. Even at U02 in May the total N content was high with 43.2 mg/L, although the drier June concentration was higher than the higher April rainfall with the value of 30.7 mg/L and 23.0 mg/L respectively.

In the seasonal rainfall total N analysis in both the intermonsoons the nitrogen levels were high at U01. In the first intermonsoon the concentration was 6.01 mg/L and the in second intermonsoon it was higher with 7.38 mg/L. The lowest recorded was in the low rainfall southwest monsoon with 3.04 mg/L. The total N level has been higher during the second northeast monsoon with a concentration of 6.71, which may be due to the influence of the high rainfall month of December 1986. At U02 the trend was less sharp. The highest total N mean seasonal concentration during the second

intermonsoons was 55.74 mg/L. During the first intermonsoon, the concentration was very similar to both the low rainfall south west monsoon and the second north east monsoon, with a value of 33.10 mg/L. Although the pattern is not clear at the industrial waste water receiving site, it still indicates the nitrogen content was highest during the convectional, thunderstorm rainfall season of the second intermonsoons. This is clear in both the intermonsoons at U01.

Tributary canals

The tables 7.1, 7.2 and 7.3 give the correlations for the daily, monthly and the seasonal values. The rainfall-total N coefficient in the tributary canals was a positive relationship except at T11 in the Main Drain. The Kettarama drain had a significantly (0.01) high daily correlation of 0.73. In the Dematagoda ela the correlation coefficient ranged from 0.21 at T03 to 0.60 at T05. The latter had .01 significance level. In the Kittampahuwa ela it ranged from 0.06 at T09 to 0.71 at T07. Site T07 had a significance level of .01. In the Main Drain it ranged from -0.7 at T11 to 0.61 at T13. The significance level at T11 was .01. In the monthly analysis, the coefficient improved at all the sites except T02, T05, T07 and T13. The negative correlation at T11 in the daily analysis was a positive correlation coefficient in the monthly analysis. In the seasonal analysis all the sites maintained the positive correlation except at T03 which had a coefficient of -0.60 and T13 which had -0.10.

Of the sites that get industrial discharges, site T03 on the Dematagoda canal had a positive correlation in the daily and the monthly analysis with 0.21 and 0.30, while the seasonal analysis indicated a negative correlation of -0.60. The level of significance was low.

The examination of total N values at site T03 indicates that it has the highest nitrogen concentration in the Dematagoda ela. The maximum recorded was 7.35 mg/L. This may be due to the industrial discharges that enter the site, especially from factory D which produces agricultural fertilizers. Urea is a nitrogeneous fertilizer produced, which may find its way to the canal. In addition to these the shanties near the sites dispose of organic wastes which contain nitrogeneous matter. When the total N and the rainfall at T03 are considered the daily and the monthly correlation was very similar as mentioned earlier, with 0.21 and 0.30 respectively. This means that rainfall too contributes nitrogen directly to the canal site. Examination of rainfall and total N values showed this relationship. In May (29.05.86) the nitrogen level at T03 was 5.65 mg/L at a daily rainfall of 28.7 mm, while in August (20.08.86) the concentration was lower with 1.67 mg/L at a rainfall of 0.0 mm. Although February was the driest month with no rainfall, the concentration was higher with 4.6 mg/L of nitrogen. This is a fairly common feature in the industrial waste water receiving sites. In the monthly analysis in the thunderstorm rainfall months of April and May the mean monthly total N concentration were 4.25 and 5.73 mg/L respectively, and the highest total N level recorded was in the second intermonsoon month of October 1986 with a concentration of 7.35 mg/L. As in any other industrial waste water receiving site, the low rainfall month of July had a high concentration of 5.3 mg/L of total N. The high rainfall month of December also had a high concentration of total N with 6.88 mg/L. The other months had comparatively lower total N concentrations. This shows that total N has been higher in the higher rainfall months and the concentration generally lower in the lower rainfall months with a few exceptions.

In the Main Drain, site T13 gets industrial waste water from factory E. This site is also at the confluence of the Main Drain with the San Sebastian canal. The daily correlation of rainfall and total N was high with the coefficient at 0.67, which is also highly significant at .01 level. The monthly correlation was positive although the coefficient was weaker with a value of 0.16. The seasonal coefficient gave a weak negative correlation of 0.10. The examination of total N values indicate that site T13 had high levels of total N. The sites T11 and T12 also had higher total N levels compared to the other canals. This may be due to the fact that the Main Drain runs through a highly industrial and residential area. The shanties along the canal may be another cause. It also has adjoining marshy areas and during the rainy season the excess water drains into the Main Drain. The relationship between rainfall and total N at site T13 shows that there is a good relationship between these two variables. On 25/05/86 with a daily rainfall of 28.7 mm, the total N concentration at T13 was 11.50 mg/L. May is a high rainfall month. In June and July, although

the monthly rainfall was low with 63.84 mm and 10.39 mm respectively, the total N level was high with 12.75 and 11.71 mg/L due to the rainfall which fell on these particular days, which wase 4.0 mm on 24.06.86 and 2.4 mm on 03.07.86. In the dry rainfall month of February 1987, the lowest total N level of 2.38 mg/L was recorded. This indicates that there is higher total N concentration during the rainfall days and months and lower concentration during the low rainfall months. This is the general trend, although, as discussed earlier, being an industrial waste water discharge site it does not necessarily follow this pattern as the industrial discharges vary in strength and volume, depending on the production that takes place at that particular moment of waste water discharge. The seasonal correlation was a weak negative correlation of 0.10 which was not significant. This may be due to a lower number of cases in the tributary canal each season having between 2-4 cases. The seasonal analysis may be a reflection of these disconformities. But even with all the shortcomings, the general positive trend indicates a supply to total N with rainfall.

Others

As turbidity reflects the SS it was not attempted. The sulphates were not attempted as conductivity reflects the sulphate ion to some extent. The pH and water temperature were not attempted as they are insitu conditions. The total P was not attempted as one nutrient was examined. All the coefficients for these variables are given in table 7.1, 7.2 and 7.3. Other than turbidity all the other pollutants generally indicated a negative trend, with varying strength in the coefficient.

Summary

The rainfall-pollutant analysis indicated certain important features. The daily correlation between the rainfall and the DO indicated a positive trend which implied that reaeration took place during rainfall. The coefficients gave a positive values, although not all of them were high. The coefficients were higher at the non industrial sites such as S01 and S02 while the coefficients at the industrial sites of S03 and S06 remained relatively poor. The monthly correlations indicated an improvement in the coefficient even at the industrial sites. This showed that during the high rainfall months the rainfall had the capacity to dilute and reaerate the strong industrial wastes in the receiving sites. Similarly the low rainfall months had lower DO, which indicated the concentration of pollutants. This augments anaerobic activity in the industrial sites if there is no supply of DO. Although the monthly correlation indicated an improvement in the coefficient the seasonal correlation at the industrial sites appeared poor or isolated. This indicates that over a very long period with continued industrial discharges, DO gets depleted in the receiving sites, and therefore the dilution by rainfall is also poor. But in the non-industrial sites the coefficient remained high, which showed continuous reaeration and the good response at the site. Even in the lake, river and the tributary canals the relationships appeared similar.

The COD-rainfall indicated a negative relationship in the daily, monthly and the seasonal analyses. This meant that there is a dilution of the waste waters. The negative correlation at the industrial sites were weaker than at the non industrial sites of S01 and S02. In the monthly correlation the coefficients increased in most of the sites, but in the seasonal correlations the industrial site such as S06 appeared isolated. This indicated there was less dilution at the industrial sites. In the lake the relationship at the industrial site was the same with a lower coefficient at U02. The relationship was different in the Main Drain where the coefficient significantly improved. This indicates that there was dilution of the waste waters. This is probably due to the secondary effect of the rainfall i.e the flushing out of the pollutants through the Mutwal tunnel into the sea.

The BOD was very similar to the COD, but it depicted the importance of the DO in the re-aeration. The coefficients were high at S01 and S02 but decreased from S03. S05 also had a higher coefficient but was lower than S03. The monthly relationships improved except at S06. In the seasonal correlation the coefficients fell at the industrial site of S03 and there was no correlation at S06. Thus the dilution in the industrial sites was poor. Thus the organic load at the industrial sites were too high for the rainfall as a natural dilutant. The relationships at the river and the lake and the tributary canals appeared similar.

The SS/rainfall coefficients were positive in all the sites in all the analyses. The coefficients were higher from S03 to S07. This was a deviation from the other pol-

lutants. This may be due to the high base level input from the industrial sites and the re-entry of the dredged materials from the canal banks due to rainfall. In the river sites R01 had lower coefficients in the monthly and the seasonal analyses which indicated that there were other sources of inputs, example the San Sebastian canal. In the lake the relationships in the daily values were generally positive other than a negative occurrence at U02. In the tributary canals other than a peculiar occurrence at E/T11 all the values were positive. Thus the rainfall increased the SS load in the surface waters. This was marked at the industrial sites due to its high base level load. The conductivity coefficient indicated negative values in the daily correlations, the correlations were low in the industrial sites. The site S02 also had lower coefficients. The lower coefficient at S02 may be due to the low concentrations which did not show much with the rainfall. The monthly coefficients did not improve much. In the seasonal analysis the industrial sites had positive coefficients. This appeared isolated and indicated that the dilution of the dissolved solids at the industrial sites were poor. At the river sites the coefficients were negative at both the sites. R01 was weaker of the two sites. Seasonally too there was no response to rainfall. Thus the dilution of the dissolved solids was poor. This is due to the higher conductivity levels due to the tidal waters. The lake site U01 also appeared isolated. The rainfall did not have any effect on the conductivity. The site U02 had some response to the rainfall over the longer period. The coefficients at the tributary canals ranged widely. Dilution was indicated at T03. At T13, it appeared isolated in the daily but over the longer period there was improvement. The fact that the significance was low indicated the dilutions at this site was low. This may be due to the high base level conductivity.

The rainfall-total N coefficients were positive in all the analyses in the San Sebastian canal except at S03, S05 and S10 in the monthly analysis and the latter two in the seasonal analysis. Thus the general trend was the contribution of total N into the water way from rainfall. This may be due to the supply of nitrogen from the electrical charges especially during the thunderstorms. High base level total N at the industrial site S06 was reflected in the higher coefficients. The coefficients remained high at S04 and S09. The former had industrial and domestic discharges while the latter had tributary and agricultural contributions. These high base levels were reflected in the coefficients. The river and the lake sites also indicated loading from the rainfall. The seasonal component in the total N loading was clear especially in the lake sites. In the tributary canals the Main Drain had a good relationship, but the seasonal loading was not clear.

The site S10 was different from the other sites in most of the analyses. The coefficients at this site differed both from the relatively unpolluted sites and the industrial sites. This may be due to the difference in the behavior of the pollutants under the influence of the tidal river. The importance of rainfall as a dilutant was not remarkable at this site.

7.4 The rainfall lag-pollutant analysis

The rainfall-pollutant analysis (daily, monthly and seasonal) indicated the relationships between the rainfall and the pollutants. The correlation coefficient improved significantly in most of the sites progressively from the daily to the seasonal analysis, though not at the industrial and the tidal sites. The analysis, though comprehensive, had certain shortcomings since it indicated only the mean situation in the dilution and the concentration of the pollutants, especially in the monthly and the seasonal analysis. In the daily analysis the correlation was computed only on the single value of the corresponding day of the monitoring, the rainfall of which date may not be the true representative of the month. In the monthly analysis computation was based on the definition of the calendar month. The monitored dates of the pollutants hardly coincided with the first and the last day of the particular month such as the 1^{st} or the 31^{st} day of January. But each analysis had its own advantage. The daily correlation gave the spontaneous response of the pollutants to the current day's rainfall, while the monthly and the seasonal correlation indicated the response of the pollutants to the nature of the rainfall for the particular month and the seasons over a longer time scale. To overcome the minor shortcoming in the previous analysis a rainfall lag-pollutant analysis was done on the monitored pollutants.

Three sites in the San Sebastian canal were selected per pollutant for the analysis, i.e. a relatively unpolluted site at the origin of the canal which was free from industrial and domestic wastes such as S02, a highly polluted industrial waste water receiving site such as S03/S06 which was at the bottom of the oxygen sag in the canal and the terminal site of the canal, S10 which was near the confluence with the river Kelani. The sites selected gave a good representation along the length of the canal. The pollutants used in this analysis were COD, DO, SS, conductivity and total P. As the BOD fairly represented the COD and as turbidity represented the SS, they were not used. The pH and water temperature being more an in situ condition were also not done. The total N was not analysed because the monitoring frequency was low and thus was wide apart (between n and n-1) in addition to not being monitored in January and Februry 1986. For the interpretation of analysis, values representing minimum, median and the maximum concentration of pollutants were selected to give a wide range of situations. Extreme situations in the period of monitoring influenced by extreme rainfall conditions were avoided as far as possible. This was done to representant a realistic situation as far as possible.

The rainfall lag-pollutant analysis works on the principle that the past rainfall influences the current level of the pollutant concentration. Therefore, a lagged correlation was worked out to see the relationship between the lagged rainfall and the pollutants. It gave a precise relationship between the current day's and the immediately previously days monitoring, n and n-1.

The lagged rainfall has a bearing on the receptive or the assimilative capacity of the the stream for the pollutants discharged. If the lagged or the previous rainfall was higher, the ability to receive a pollutant load is more. If the lagged rainfall is less, the tendency of the pollutants to concentrate is higher, and therefore the stream's ability to assimilate additional pollutants is less. Thus a situation of gross pollution can occur. This can be seen by the very high concentration of pollutants in the canal. On the other hand if the assimilative capacity due to higher rainfall is high, the pollutants that enter the canal will be diluted at the receiving sites. Therefore the lag analysis gives the condition and explains the ability of the receiving water to assimilate pollutants.

The lag analysis also served as a relative measure to express the pollutant concentrations in a body of water in a situation where the flow rates were not available, although a precise unit concentration of the pollutants could not be given at a particular value of rainfall. Indirectly using the rain lags the water levels in the canal were worked out. It has to be accepted that every millimetre of rainfall does not reach the canal but there will be a proportionate increase in the volume of water that enters the canal due to rainfall. This is a fair asssumption since the gradient of the canal is very low in addition to the low flow. Therefore it is a relative surrogate measure to express the water level in the canal which has a very important bearing on the concentration or the dilution of the pollutant.

In a tropical country like Sri Lanka where the most important deciding envi-

ronmental parameter is rainfall for many economic activities such as agriculture, irrigation and hydro-electricity generation, this potential resource also can be used as an alternative to treatment, since it is a natural dilutant which is freely available under normal weather conditions in the south western part of Sri Lanka. To use this resource a rain lag analysis becomes important as it gives an insight into the necessity of treatment or pollution control.

7.4.1 Computation of the rainfall lags

Initially, individual rainfall lags using only the daily rainfall were correlated with the pollutant concentration. The pollutant concentration was correlated with the individual lags upto lag 16, 16 days being the maximum range in the pollutant monitoring, which occurred on the 19.6.86 in the San Sebastian canal. The individual lagged rainfall did not correlate well with the pollutant concentrations. As the lagged correlation coefficient was weak in the individual lags, the rainfall lag was computed for the total lags. Here the rainfall was aggregated which started from the previous days rainfall (the day previous to the current day of monitoring). Thus lag 1 to lag 16 was computed so that,

$$lag1 = R_{t-1}$$

$$lag2 = (R_{t-1}) + (R_{t-2})$$

where,
R_{t-1} was the rainfall on the day previous to monitoring
R_{t-2} was the rainfall on the second day before monitoring

The above computation did not include the rainfall of the current day of monitoring. This was done to see the effect of the rain lags on the pollutant concentration excluding the current day's rainfall. A parallel computation was also done in the same way which included the rainfall of the current day of monitoring. This was done to see whether there was any bearing of the current day's rainfall on the level of concentration of the pollutants. These lags were then correlated with the pollutants. The lagged correlation in both the analyses gave a good relationship between the rainlags and the pollutants, but the latter computation gave a relatively higher correlation with a higher significance levels which indicated that the current days rainfall had a bearing on the pollutant concentration in relative terms (This also explains the daily rainfall-pollutant analysis done previously). The significant improvement in the lagged correlation coefficient in the computation which included the current days rain can be seen in table 7.4. As the lag analysis which included the current days rainfall proved more satisfactory this was done for the selected sites and the pollutants on the San Sebastian canal.

The rain lags may not only necessarily explain the dilution or concentration of pollutant, although it does indirectly. It rather explains the condition of the canal to the reception of a pollution load. That is, if the assimilative capacity of the canal is high the dilution capacity is also high.

The relationship between the rain lags and the pollutant concentration can be written functionally as,

$$Z_t = f(lag1, lag2, lag3.....lagn);$$

where,
Z_t = pollutant concentration Z in the site at time t, and,

$$lag1 = R_t + (R_{t-1})$$

$$lag2 = R_t + (R_{t-1}) + (R_{t-2})$$

$$lagn = R_t + ...(R_{t-n})$$

Table 7.4 — Spearmans's ρ between DO and rainlag: a comparison

Lags	S02		S03		S10	
	1	2	1	2	1	2
14	.56***	.52***	.35**	.29*	.56***	.49***
9	.47***	.49***	.25*	.22	.49***	.49***
8	.46***	.45**	.27*	.22	.47***	.48***
7	.52***	.43**	.14	.25*	.42**	.46***
6	.49***	.52***	.17	.10	.47***	.41**
5	.50***	.48***	.17	.12	.47***	.44**
4	.49***	.45***	.21	.13	.46***	.40**
3	.54***	.46***	.18	.14	.43**	.40**
2	.45***	.47***	.27*	.08	.42**	.36**
1	.34**	.37**	.28*	.20	.39**	.21

Columns: 1=total rainlag with current days rain and 2=total rainlag excluding current days rain
Source: Field monitoring.

$$R_t = current\ monitoring\ day's\ rainfall\ at\ time\ t$$

$$R_{t-1} = rainfall\ the\ previous\ day\ before\ monitoring$$

$$R_{t-n} = rainfall\ n\ days\ before\ monitoring$$

$$lag1x = R_{t-1}\ (which\ was\ computed\ for\ comparison)$$

7.4.2 The rainlag-COD relationship

The rainfall lag-pollutant analysis indicated a negative lagged correlation between the COD and the rain lags across the sites in the San Sebastian canal with minor deviations at certain sites. This indicated that the rainfall prior and on the day of monitoring had influence on the concentration of the pollutant. This indicated that the if the rainfall was high before or on the monitoring day, the concentration of the COD was low and vice versa.

S02

Table 7.5 gives the coefficient for COD and lagged rainfall for S02. Figure 7.9 (A) shows the relationships.

At site S02 the rainlag-COD relationship indicated a negative lagged correlation. The COD at S02 recorded a minimum of 4.0 mg/L. The minimum of 4.0 fell on two consecutive days of monitoring i.e 29.4.86 and 7.5.86. The day 29.4.86 was selected for the interpretation of the effects of the rainlags on the pollutant concentration as the concentration on 7.5.86 may have been highly influenced by the very high rainfall of 100.2 mm. The number of lags between n, which is the current day of monitoring and n-1, which is the previous day of monitoring was 11. The highest lagged correlation coefficient between the concentration and the rainlags occurred at lag 11. The coefficient was -0.42, which was significant at .01 level. A very high daily rainfall of 85.4mm at the upper limit of lag 11 may have influenced the coefficient. This indicated that a very high rainfall lowers the pollutant concentration by improving the assimilative capacity of the canal. The rainfall was also high with 30.5mm on 26.4.86, which was on lag 3 and this had a coefficient of -0.38. The level of significance was .01. The coefficients fluctuated between lag 4 and 10 i.e from 25.4.86 to 19.4.86. This is due to very low rainfall ranging from 0.0 to 2.0mm. The rain at lag 11 although it was the furthest may have influenced the lower concentration

Table 7.5 — Spearman's ρ between COD and rainlags

Lags	S02	S03	S10
Lag 16	-	-	**-.49*** **
Lag 15	-	-	-.48**
Lag 14	-	-	-.45**
Lag 13	-	-	-.41**
Lag 12	-	-	-.36**
Lag 11	**-.42****	-	-.36**
Lag 10	-.40**	-	-.36**
Lag 9	-.37**	-	-.32*
Lag 8	-.37**	-	-.32*
Lag 7	-.34**	-	-.15
Lag 6	-.31*	-.09	-.23
Lag 5	-.33**	-.08	-.21
Lag 4	-.34**	**-.11**	-.22
Lag 3	-.38**	-.08	-.20
Lag 2	-.28*	-.03	-.11
Lag 1	-.19	-.05	-.11
Lag 1x	-.003	.06	-.11
Lag 0 (Rndaily)	-.37**	-.12	-.10

Source: Based on field monitoring. Coefficients in boldface represent the best lag for the sites

because the high total of 85.4mm would have compensated for the very low rainfall in the upper two-thirds of the lags. Thus the aeration may have been higher which brought about a lower COD concentration.

S03

Table 7.5 gives the coefficient for COD - rainlag at S03. Figure 7.9 (B) shows the relationship.

The situation in a polluted site is more complex as the COD tend to remain high with not much reception to rainfall. This can be seen at the site S03 which is an industrial discharge receiving site from industry B. The examination of the COD concentration at S03 indicated that the lowest COD level recorded during the monitoring period fell on 19.11.86 with the concentration at 38.0mg/L. The maximum lags between n and n-1 was 6. The relationship between the concentrations and the lagged rainfall was well explained by lag 4 which also had the highest lagged correlation coefficient of -0.11 within the monitoring days n and n-1. Although the coefficient was the highest, the level of significance was low. The rainfall corresponding to this lag was 0.71mm which was the highest between n and n-1, with 0.0mm rainfall being recorded on all the other days except 0.01mm on the current day of monitoring. The coefficient was lower at lag 6 with -0.09 because the proportionate increase in the aggregate rainfall was trace with a value of 0.01mm. Thus lag 4 with the corresponding highest coefficient of -0.11 explains the impact of the the rain lags on the COD concentration. Thus even within a very low rainfall period between two monitoring days the lag analysis explains the impact of slightly higher rain lag on the resultant low concentration of the pollutant. Being a highly polluted industrial waste water receiving site this is a remarkable feature of the lag analysis.

The correlation coefficient remained very low in all the lags, but it indicated a negative trend. The level of significance also remained low which indicated that in an industrial waste water discharge site the rainfall does not have much importance in diluting even a comparatively low concentration as the assimilative capacity is low. This is mainly due to the continuous injection of highly organic waste waters.

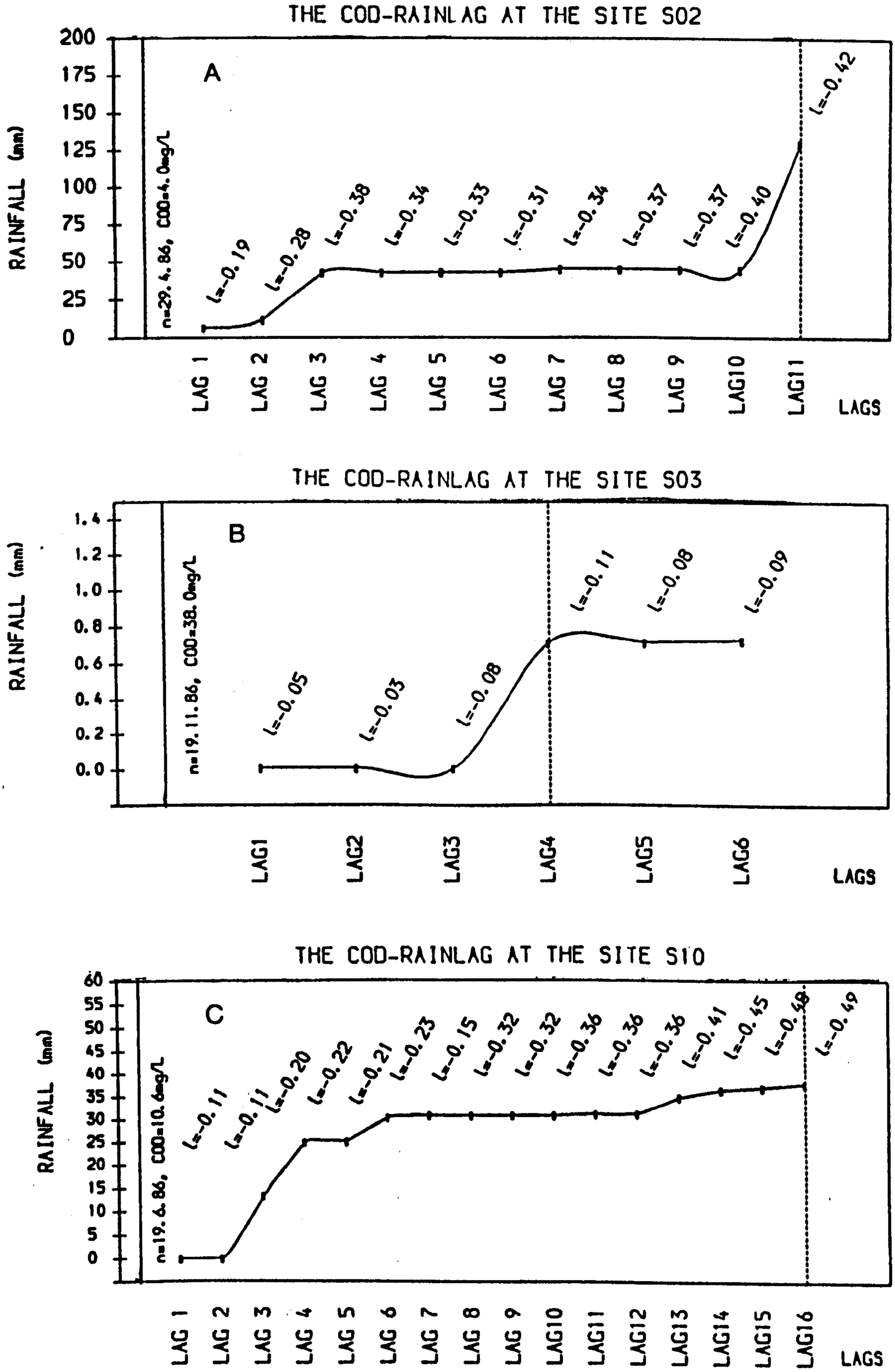


Figure 7.9 — Time-lag relationships between COD and rainfall for selected sites in the San Sebastian canal

Source: Based on field monitoring

A typical situation encountered in an industrial site is the occurrence of an isolated coefficient. This occurred at lag 1x with a coefficient of 0.06. This indicated that even the immediate past rainfall (within the past 24 hours) did not have a diluting effect in an industrial site.

S10

Table 7.5 gives the coefficient for COD - rainlag at S10. Figure 7.9 (C) shows the relationship.

At the site S10, which is the terminal site and which comes under the influence of the tides the lagged correlation remained higher than the industrial site S03, but lower than the relatively non polluted site, S02. The coefficient varied from -0.11 at lag 1 to -0.49 at lag 16. The coefficient fluctuated at lag 7 with the coeffficient at -0.15, and above this the lags had high significance levels (above .05) and below which the significance was low. Therefore the site S10 varied widely from S02 and S03. The situation becomes clear by the examination of the COD concentration and the lags. The lowest COD concentration recorded during the monitoring period fell on 19.6.86 at S10 with a value of 10.6mg/L. The best lag which explained this relationship was lag 16. The highest lagged correlation coefficient of -0.49 also occurred at lag 16 which had a significance of .001. The maximum lag between n and n-1 was 16, and the aggregate rainfall was 37.93mm. As mentioned earlier the coefficient at lag 7 fluctuated markedly with the coefficient at -0.15. The rainfall data showed zero rainfall on 11.6.86 which may have affected the lag, thus resulting in a lower coefficient. The vagaries in a site influenced by the tides can be seen in the lower lags. Even with a comparative higher rainfall at lag 3 and 4 coefficient and the level of significance remained low which indicated that the rainfall was not the major influence on the pollutant concentration at a tidal site. Therefore a realistic rainfall-COD relationship can be discerned in the lag analysis where the impact of the individual lag is felt on the concentration even in a tidal site, while it was difficult to disassociate the tidal effect from the rainfall effect on the pollutant concentration in the rainfall pollutant analysis.

7.4.3 The rainlag-DO relationship

The rainlag-DO analysis indicated a positive correlation in all the sites in the San Sebastian canal (except in lag 1x at site S04 and S09). Other than these two isolated occurences the analysis indicated a positive lagged correlation between the rainfall lags and the DO concentration. The sites near the canal origin such as S02 had significantly high coefficients in all the lags. The level of significance ranged from .05 to .001 at S02.

S02

Table 7.6 gives the coefficient for DO - rainlag at S02. Figure 7.10 (A) shows the relationship.

To interpret the rainlag-DO relationship at S02 the monitoring day 26.5.86 was selected to minimize the effect of the current days rainfall. This day was also selected as it had the second highest DO concentration with 14.7mg/L (the highest was 14.8mg/L on 7.5.86). The lag which explained the best relationship between n and n-1 was lag 3 which had the highest correlation coefficient of 0.54 within the 10 lags that fell between n and n-1. This had a significance level at .001. The examination of rainfall values within the lags indicated that lag 3 had a total rainfall of 1.12mm. The high monthly rainfall in April may have obviously influenced the high base level concentration of DO, since it is illogical to expect a high DO of 14.7mg/L at 1.12mm of rainfall. The site may have been already aerated with the past heavy rainfall, and with relatively no organic pollutants entering this site the DO may not have been depleted even with a decrease in the rainfall towards the end of the month. Thus on the monitoring day of 26.5.86 a high level of DO was maintained in the canal. The range in rainfall between n and n-1 was very low. In this particular instance it is the aerated condition at this site which would have influenced the DO concentration, brought about by the rainfall conditions in April and May. The high correlation coefficient at lag 3 may be a magnification of this condition at the site. Although the correlation coefficient was slightly at the higher at lag 3, the coefficient at the other lags also remained high.

It has to be mentioned that all the lags other than lag 1 had significance levels

Table 7.6 — Spearman's ρ between DO and rainlags

Lags	S02	S06	S10
Lag 12	-	-	.48***
Lag 11	-	.27*	.47***
Lag 10	.50***	.27*	**.50*** **
Lag 9	.47***	.27*	.49***
Lag 8	.46***	.30*	.47***
Lag 7	.52***	.23	.42**
Lag 6	.49***	.17	.47***
Lag 5	.50***	.17	.47***
Lag 4	.49***	.19	.46***
Lag 3	**.54*** **	.16	.43**
Lag 2	.45***	.32*	.42**
Lag 1	.34**	**.33** **	.39**
Lag 1x	.27*	.31*	.12
Lag 0 (Rndaily)	.43**	.25*	.47***

Source: Based on field monitoring. Coefficients in boldface represent the best lag for the sites

at at .001. Lag 1 had a significance level of .05. This indicates that all the lags between n and n-1 had a highly significant effect on the very high DO concentration. Although the daily rainfall was low between n and n-1, the little rain that fell on the already aerated site had a significant contribution to the high DO, thus bringing it to a saturated condition.

S06

Table 7.6 gives the coefficient for DO rainlag at S06. Figure 7.10 (B) shows the relationships.

In the industrial waste water receiving site S06 the maximum DO occurred on 4.3.86 with the concentration of 2.5mg/L. The maximum lags between n and n-1 was 11 and the correlation coefficient ranged from 0.33, with the significance level at .01 at lag 1 to 0.27 at lag 11 which had a significance level of .05. The highest correlation coefficient was at lag 1. The rainfall at lag 1 was 29.4mm. This high rainfall may have certainly influenced the DO concentration of 2.5mg/L. Although the value was very low, the DO concentration was high for this site, the median being only 0.03mg/L. Thus there is justification in the highest correlation coefficient which correspond to lag 1. The rainfall between n and n-1 was 0.0mm except on 3.3.86 and 25.2.86 which had 29.0 and 22.7mm respectively. The high rainfall of 29.4mm at lag 1 may have helped slight aeration at the site, thus resulting in a comparatively higher DO of 2.5mg/L. This rainfall was received after 5 days of zero rainfall. The higher coefficient which was significant thus explains the higher DO concentration. Lag 2 which had a slightly lower coefficient of 0.32 which was significant at .05 level may have been influenced by the rainfall on 3.3.86. Although a relatively higher daily rainfall of 22.7mm was received on 25.2.86 which was at the upper limit of lag 7 the coefficient was lower with 0.23 which had a low level of significance. This indicates that in the industrial site aeration which may have taken place with this rainfall may have been reduced with days (5 days) followed by zero rainfall, with the continuous polluting industrial waste water discharges into the site. Thus lag 7 with slightly lower rainfall did not have any contributory effect on the higher DO concentration at the site. The higher rain of 29.0mm complemented by 0.4mm on the current day, certainly had a contributory effect on a higher DO at an industrial site, although in absolute terms it was a very low concentration. Other than this, the very low coefficients with corresponding low significance levels, explain the relative insignificance of rainfall in an industrially polluted site.

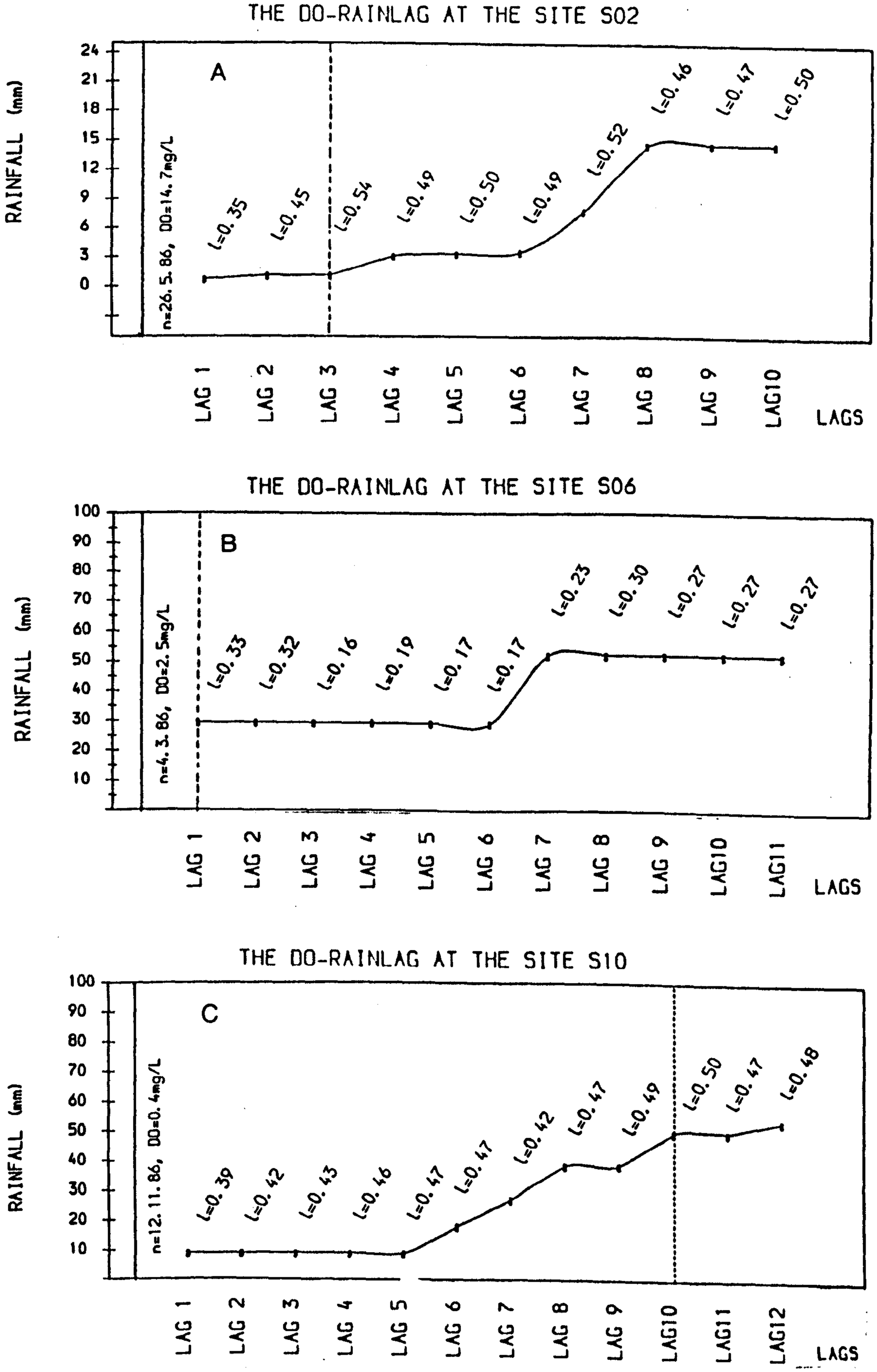


Figure 7.10 — Time-lag relationships between DO and rainfall for selected sites in the San Sebastian canal

Source: Based on field monitoring

S10

Table 7.6 gives the coefficient for DO - rainlag at S10. Figure 7.10 (C) shows the relationships.

At the tidal site S10 the DO concentration ranged from 0.0 to 6.6mg/L, with the median falling at 0.35mg/L. A DO concentration nearest to the median was selected to investigate the impact of the rain lag on the DO. A concentration of 0.4mg/L of DO occurred on 12.11.86. This was done to see the impact of rain lag on a median rather than on an extreme situation. The number of lags between n and n-1 on this day of monitoring was 12. The highest correlation coefficient at S10 ranged from 0.39, with the significance level at .01 at lag 1 to 0.50, with the significance at .001 at lag 10. The highest correlation coefficient within the 12 lags occurred at lag 10. The coefficient was 0.50 and the level of significance was .001. The rainfall at this lag was 49.83mm. The rainfall at the the upper limit of lag 10 which was 11.4mm on 4.11.86 may have significantly contributed to the DO concentration and to the coefficient. The rainfall within n and n-1 was also fairly distributed. The high rainfall in October and September (fairly high) may have contributed to the median condition in addition to the surface turbulence which plays an important role at this site. Although the rainlags have been significant in explaining the DO concentration, the very low median value of 0.4mg/L of DO suggests that in absolute terms the insignificance of the lagged rainfall in aerating a polluted tidal site (which gets an accumulated high load of pollutants from the upstream industrial sites, the tributary canals and from sources of pollutants localised to the site). But the lag analysis explains the rainfall situation clearly and its impact on the DO concentration. From this it can be seen that even in a tidal site the response of DO to rainfall (although other factors such as surface turbulence can cause a higher DO) is discernible. Even at a very low median DO concentration at this site, the impact of rainfall on the DO concentration becomes clear in this analysis while it was less clear in the rainfall-pollutant analysis.

7.4.4 The rainlag-SS relationship

The rainlag-SS depicted a positive correlation in all the sites in the San Sebastian canal. In comparison with the other pollutants SS had a highly significant correlation with the rain lags in most of the sites except S10 which had a lower correlation and a lower significance levels.

S02

Table 7.7 gives the coefficient for SS - rainlag at S02. Figure 7.11 (A) shows the relationship.

In the site S02 which is free from industrial discharges the coefficient ranged from 0.30 at lag 1 to 0.48 at lag 3. The level of significance was .05 and .001 respectively. The median SS concentration of 18.3mg/L was used to examine the effect of the rain lag on the SS concentration at S02. This was done to minimise the effect of a very high rainfall-SS relationship and to see the implication of the rainlag in a normal situation. The median SS of 18.3mg/L occurred on 19.6.86. The maximum lags between n and n-1 was 16. The daily rainfall was fairly distributed, but alternated with days of zero rainfall. Thus this proved a good situation to see the impact of the rainlag on the SS concentration than a very high SS corresponding to a high rainfall period. The highest coefficient of 0.48 with a significance level at .001 fell at lag 3. Examination of data indicated that the rainfall at lag 3 was 13.31mm. Comparing this with the highest lag 16, which had a rainfall of 37.93mm but a lower correlation coefficient of 0.41 (significant at .05), indicated that lag 3 which had a high rainfall prior to days of zero rainfall (from the day of monitoring SS) had more impact on the SS concentration than lag 16, which had equally high rainfall, but days with previous rainfall. This may have revitalilalised the canal. Therefore in this relatively unpolluted site the SS was very receptive to the the fluctuation of rainfall.

S06

Table 7.7 gives the coefficient for SS - rainlags at S06. Figure 7.11 (B) shows the relationship.

The SS concentration in an industrial site remained high irrespective of rainfall, but the high rainfall situation aggravated the situation. At site S06 the rainlag-SS remained a positive relationship. Being an industrial discharge site, a SS concentra-

Table 7.7 — Spearman's ρ between SS and rainlags

Lags	S02	S06	S10
Lag 16	.41**	-	-
Lag 15	.45**	-	-
Lag 14	.47***	-	-
Lag 13	.41**	-	-
Lag 12	.40**	-	-
Lag 11	.42**	-	-
Lag 10	.42**	-	-
Lag 9	.39**	-	-
Lag 8	.36**	.53***	-
Lag 7	.39**	.54***	-
Lag 6	.47***	.51***	.11
Lag 5	.45**	.56***	.12
Lag 4	.46***	.56***	.13
Lag 3	**.48*** **	**.58*** **	.11
Lag 2	.38**	.53***	**.20**
Lag 1	.30*	.44*	.15
Lag 1x	.22	.25*	.01
Lag 0 (Rndaily)	.30*	.49***	.07

Source: Based on field monitoring. Coefficients in boldface represent the best lag for the sites

tion was selected which was near the median value, but occurred during the drier period of the year so that the greater percantage of the SS at the site would be from the industrial discharge. The rainfall was very low from 0.01 to 0.1mm and the SS concentration was 73.61mg/L which occurred on 29.1.87. The maximum number of lags between n and n-1 was 8 and the correlation coefficient between SS and the lags ranged from 0.25 at lag 1 to 0.53 at lag 8. The highest coefficient occurred at lag 3 which was 0.58, which had a level of significance at .001. The examination of rainfall values indicated that the highly significant coefficient was influenced by the 0.1mm of rainfall which occurred on 26.1.87. The high SS concentration of 76.61mg/L is obviously due to the industrial discharge, but the 0.1 and 0.01mm of rainfall on the previous days had a significant relationship with the SS concentration which may be due to the washing up of the dredged material from the canal banks on a near zero rainfall situation. This indirectly indicates that even in an industrial site which obviously has a comparatively higher SS load than a non industrial site even a low rainfall especially in the immediate past as indicated by the lags can aggravate the SS load in the canal.

S10

Table 7.7 shows the coefficient for SS - rainlags at S10. Figure 7.11 (C) shows the relationships.

The rainlag-SS at the tidal site S10 gave a poor correlation. The level of significance also remained low. An SS that approached the median value of 33.3mg/L was chosen for the interpretation. A SS concentration of 33.5mg/L occurred on 26.11.86. The lags between n and n-1 was 6, and the rainfall within the period ranged from 0.0 to 4.0mm. The correlation coefficient ranged from 0.01 at lag 1 to 0.11 at lag 6 with fluctuations in the lags. The highest correlation coefficient of 0.20 occurred at lag 2. A positive correlation between SS and the lags may have occurred because of two positive daily rainfall values occuring within lag 2. But the low correlation coefficient with low levels of significance indicated that the rainfall did not significantly influence the SS concentration, although the positive correlation indicated that the rainlags did

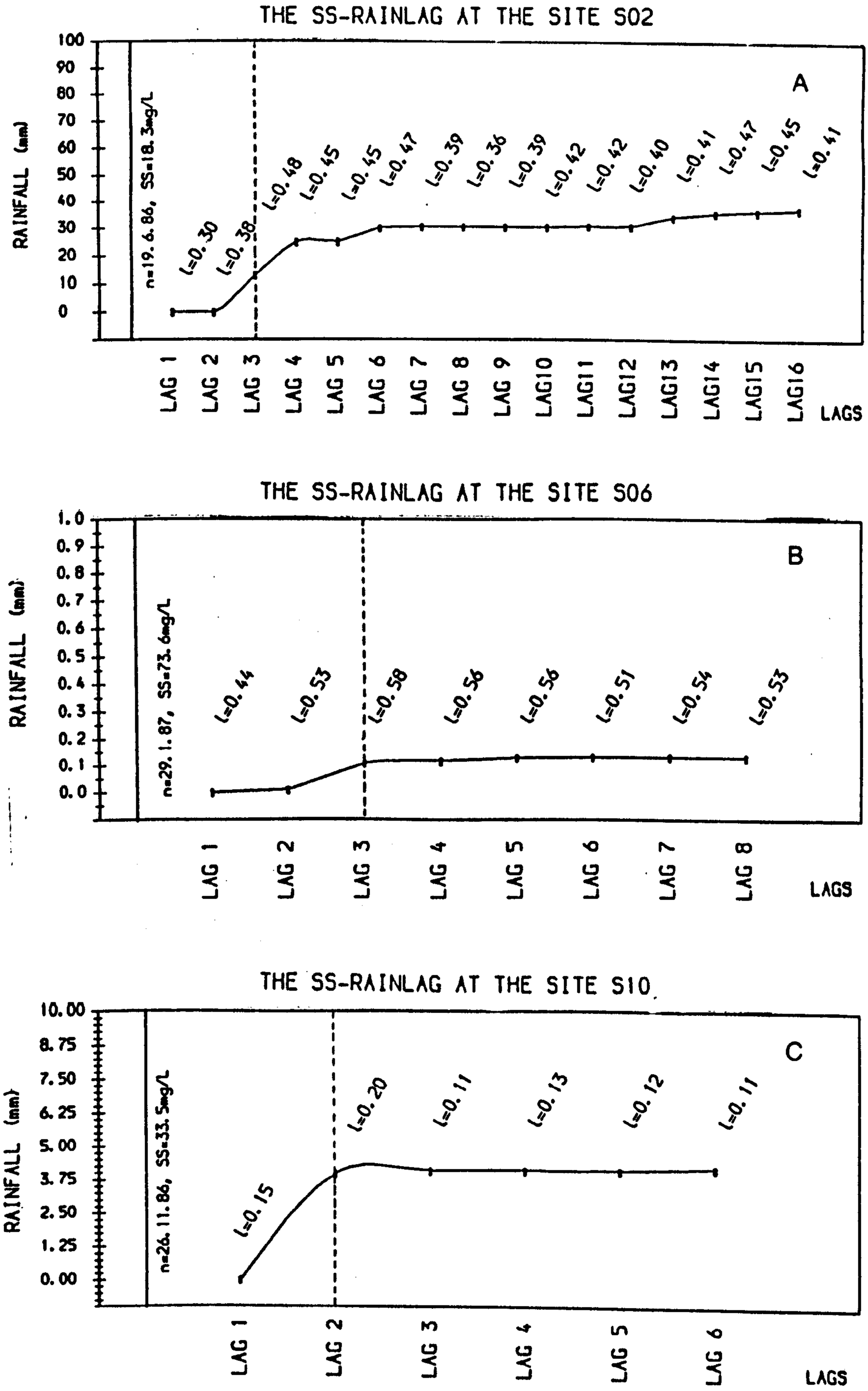


Figure 7.11 — Time-lag relationships between SS and rainfall for selected sites in the San Sebastian canal

Source: Based on field monitoring

have a contributory impact on the SS. Being a tidal site, the tidal effect would have had a significant impact on the SS concentration. The diurnal flow of tidal waters would certainly move the SS backwards and forwards.

7.4.5 The rainlag-conductivity relationship

The conductivity-lag analysis indicated a negative relationship at all the sites.

S02

Table 7.8 gives the coefficient for conductivity - rainlag at S02. Figure 7.12 (A) shows the relationship.

Table 7.8 — Spearman's ρ between conductivity and rainlags

Lags	S02	S03	S10
Lag 8	-	-.01	-
Lag 7	-	-.23	-
Lag 6	-.35**	-.24	-.34**
Lag 5	-.35**	**-.27***	-.33**
Lag 4	**-.36****	-.24	-.29*
Lag 3	-.34**	-.19	-.24
Lag 2	-.22	-.25*	-.29*
Lag 1	-.13	-.17	**-.37*****
Lag 1x	.00	-.19	-.08
Lag 0 (Rndaily)	-.18	-.08	-.34**

Source: Based on field monitoring. Coefficients in boldface represent the best lag for the sites

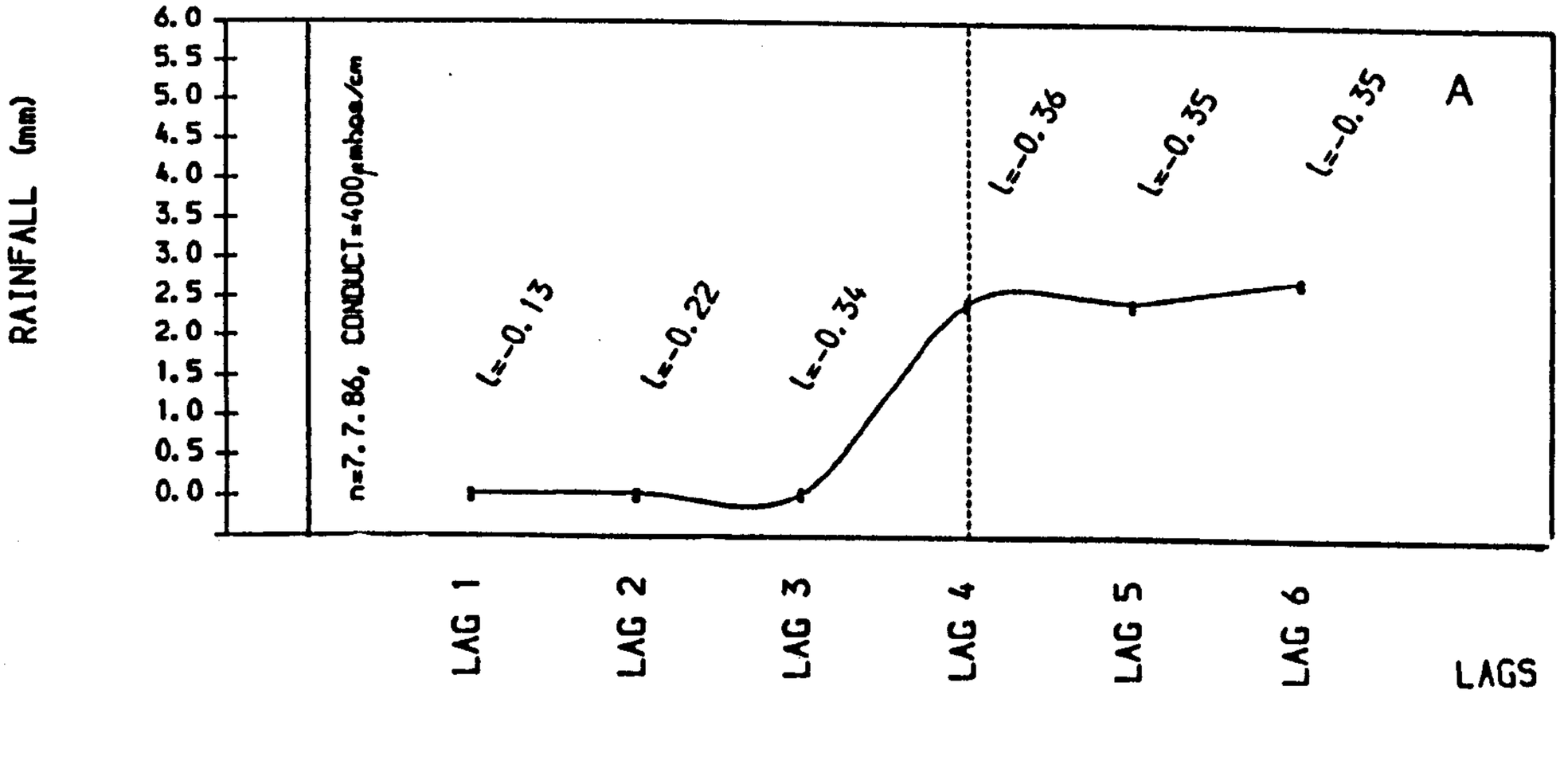
At lag 1x in site S02 the coefficient was .00. This was the only deviation.

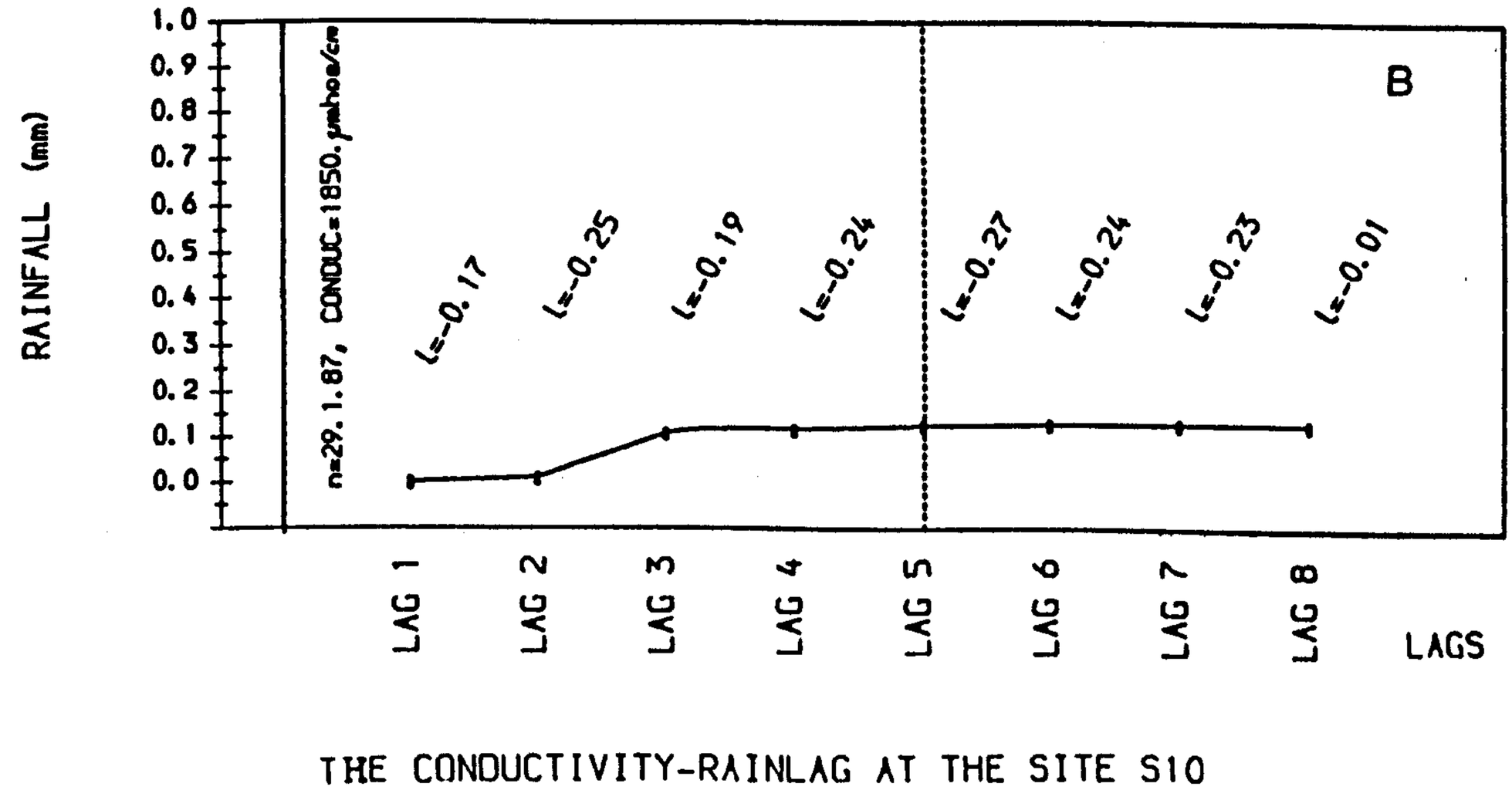
The conductivity had a maximum value of 400.0 μmhos/cm. The highest concentration occurred on 7.7.86 which was one of the driest months. The lags between n and n-1 was 6. The coefficient ranged from -0.13 at lag 1 to -0.35 at lag 6. The highest coefficient of -0.36 which had .01 level of significance fell at lag 4. The rainfall was 2.44 mm at lag 4. Further being a non-industrial site the assimilative capacity of the site was high. Even a little amount of lagged rainfall will make the site receptive to a higher pollutant concentration. The lagged correlation coefficient improved away from lag 1. This also explains the influence of the rainlags on the conductivity levels because comparatively higher rain was received in the upper limits of the higher lags 4 and 6.

S03

Table 7.8 gives the coefficient for conductivity - rainlag at S03. Figure 7.12 (B) shows the relationships.

The conductivity at S03, which is the industrial site had a maximum of 1850.0 μmhos/cm. The maximum value was selected to see the effect of rainlags on the concentration of dissolved solids which the conductivity represent. This concentration occurred on 29.1.87. The total lags within the period was 8. The highest coefficient of -0.27 occurred at lag 5. The level of significance was .05. The examination of data indicated that at lag 5 the rainfall was 0.13, which was the highest during the period of monitoring n and n-1. This indicated that although the low rainfall between the lags did not lower the dissolved solids concentration, even a trace amount of rainfall has some effect on the pollutant concentration. Other than the lag 2 which has a coefficient of -0.27 and lag 5, the other lags within the period of monitoring had very low significance levels, which indicated that in a highly polluted industrial site the rainlags do not have a significant lowering impact of the pollutant concentration. The impact of the lags decreased towards the higher lags indicating that the lagged effect on the concentration decreased with the rainfall approaching zero. Therefore in an industrial site unless a very high rainfall is received the lowering impact by the





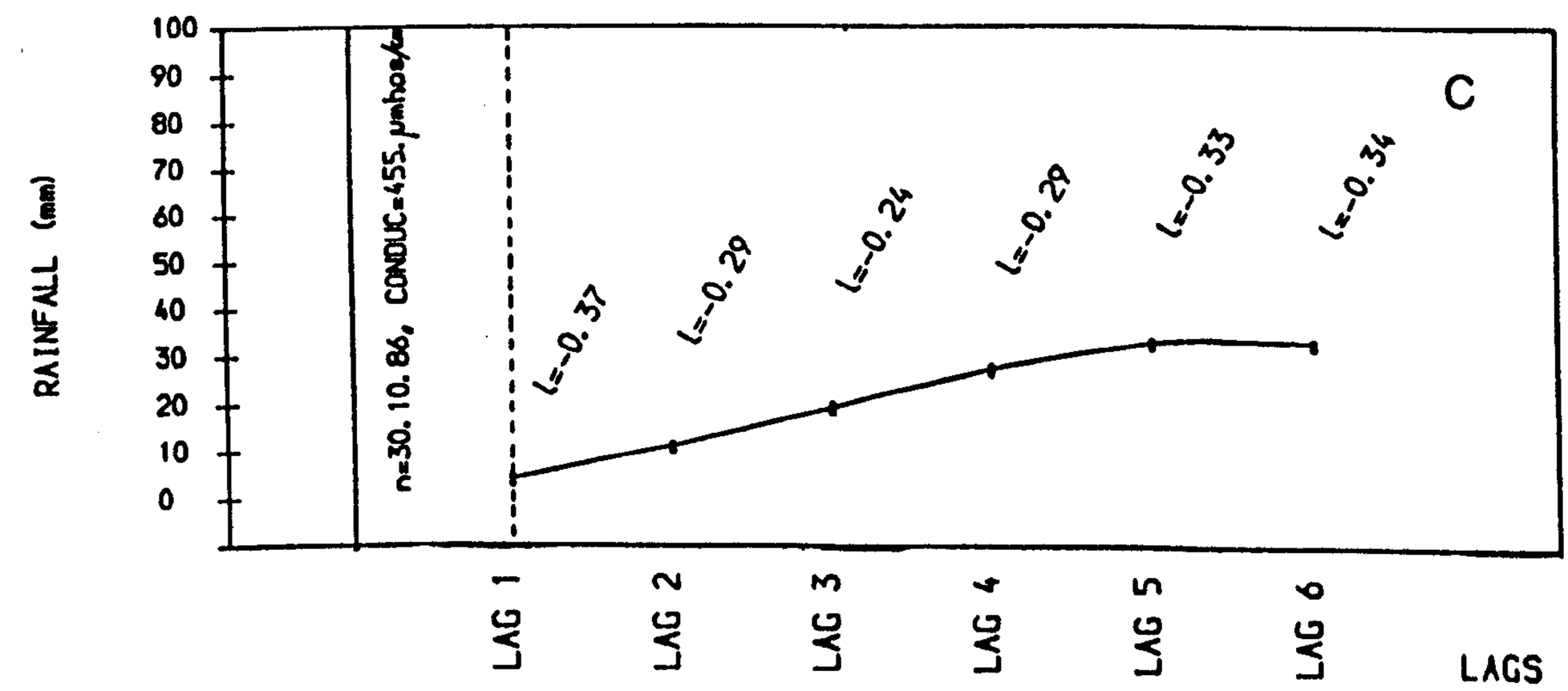


Figure 7.12 — Time-lag relationships between conductivity and rainfall for selected sites in the San Sebastian canal

Source: Based on field monitoring

rainlags on the concentration at the receiving site is very poor. On the other hand a low rainfall has the opposite effect of aggravating the situation by contributing towards concentration of the pollutant. In the site as a whole, the correlation between the concentration of dissolved solids and the rainlags was poor which indicated the inadequacy of previous rainfall in lowering the concentration.

S10

Table 7.8 shows the coefficient between conductivity and rainlags at S10. Figure 7.12 (C) shows the relationship.

The conductivity-rainlag at the tidal site S10 indicated a negative relationship. The level of significance fluctuated between the lags such as at lag 3 indicating the importance of factors other than rainfall on the dissolved solids concentration. The conductivity at S10 remained high with the median at 455.0 μmhos/cm and the maximum at 2800.0. A concentration nearest to the median was chosen for the interpretation. The conductivity level of 455.0 was recorded on 30.10.86. The number of lags that fell between n and n-1 was 6. The correlation coefficient ranged from -0.24 at lag 3 to -0.37 at lag 1. The significance was higher in the latter with the level at .001. The highest lagged correlation coefficient fell at lag 1. The higher correlation at lag 1 may have been more influenced by the rainfall on the day of monitoring, where an amount of 3.8mm was recorded, while on the previous day the rain was only 0.5mm. This is also indicated by lag 1x which had a poor correlation coefficient of -0.08 which was not significant. Being a tidal site the dissolved solids are high at S10 and the lags indicate that the rainfall had a lowering impact on the concentrations during the higher rainfall and a concentrting effect during the low rainfall periods. The tidal effect was felt at lag 3 as indicated by the low coefficient with no appreciable significance between the rainlag and and the conductivity. Thus the impact of lag 3 on the concentration of dissolved solids was insignificant. The other lags had significant impact on the concentration. Therefore even in a tidal site where factors other than rainfall affect the concentrations, the lag analysis showed that the rainfall improves the assimilative capacity of the canal. The significant negative lagged correlation coefficient showed this dilution effect on the pollutants.

7.4.6 The rainlag-total P relationship

The lag analysis indicated a negative trend at all the sites (except at S04 in the upper lags, and lag 1 at S09). Peculiarities were also evident at many sites in lag 1x. The lower frequency may affect the results.

S02

Table 7.9 gives the coefficient for total P - rainlag at S02. Figure 7.13 (A) shows the relationship.

A concentration was selected for the interpretation from the month of October 1986, which had the highest frequency of monitoring. The median value of 0.95 at S02 occurred on 8.10.86. The maximum number of lags between n and n-1 was 8 and the highest coefficient fell at lag 4. The coefficient was -0.42 with the level of significance at .01. The difference between lag 4 and lag 5 was very narrow with the coefficient at -0.417 at lag 4 and -0.415 at lag 5. The level of significance at both the lags was .01. The rainfall at lag 4 was 5.0mm. The examination of the lags indicated that lag 4 was the upper limit of the unevenly distributed rainfall although the amount received was low. This may have resulted in a lower concentration of total P on 8.10.86 which was also a representative situation as the value was the median. At lag 5 the correlation was slightly lower because of the 0.0mm rainfall at its upper limit.

S06

Table 7.9 gives the total P - rainlag coefficient for S06. Figure 7.13 (B) shows the relationship.

The total P at S06, the industrial site had a higher median than the site S03. The median concentration was 3.25mg/L and the maximum 6.25. As at S02, there were limitations due to the frequency of monitoring. Due to this limitation a value close to the median, but also a date that had subsequent monitoring had to be selected. Other than in October the only other period which had consecutive total P monitoring was between 31.3.86 and 17.4.86. Within this period a value that approached the median occurred on 17.4.86. The total P concentration was 3.15mg/L. The number of lags between n and n-1 was 6. The correlation coefficient ranged from -0.10 at lag 6 to -0.28

Table 7.9 — Spearman's ρ between total P and rainlags

Lags	S02	S06	S10
Lag 14	-	-	-.27
Lag 13	-	-	-.25
Lag 12	-	-	-.23
Lag 11	-	-	-.24
Lag 10	-	-	-.28
Lag 9	-	-	-.31
Lag 8	-.23	-	-.29
Lag 7	-.40**	-	-.28
Lag 6	-.34*	-.01	-.35*
Lag 5	-.41**	-.10	-.41**
Lag 4	**-.42****	-.11	**-.43****
Lag 3	-.40**	-.12	-.42**
Lag 2	-.29	-.27	-.30
Lag 1	-.37*	**-.28**	-.20
Lag 1x	-.10	.02	.16
Lag 0	-.45**	-.31*	-.26
(Rndaily)			

Source: Based on field monitoring. Coefficients in boldface represent the best lag for the sites

at lag 1. The highest coefficient occurred at lag 1. The level of significance was low in all the lags. The coefficient progressively decreased towards the upper lags. Lag 1x had an isolated coefficient of 0.02. This and the lower coefficient with low significance levels is a typical occurrence in an industrially, highly polluted site. The examination of the lags and the total P concentration indicates that fairly well distributed rainfall throughout this period would have contributed to this lower concentration, with the canal site having more receptive conditions to assimilation of a pollutant input. There were no zero rainfall days. The rainfall at lag 1 was 9.5mm. The level of significance was low in all the lags. This indicated that although the lagged rainfall have a dampening effect as seen by the negative coefficient on the pollutant concentration, the impact at the industrial site is very poor.

S10

Table 7.9 shows the total P - rainlag coefficient for S10. Figure 7.13 (C) show the relationships.

The total P concentration at S10 had a maximum of 6.1 mg/L. The limitations at sites S02 and S06 also applies to S10. The highest concentration was taken for the interpretation which occurred on 23.10.86. The number of lags within n and n-1 was 14. The correlation coefficient ranged from -0.20 at lag 1 to -0.27 at lag 14. The highest coefficient occurred at lag 4 with the coefficient at -0.43, which was .01 level significant. The level of significance was very low at all the lags except between lag 3 and lag 6. There was no progressive decrease in the coefficient from the lowest to the highest lags, rather there was fluctuation between the lags with low levels of significance. This exemplifies the situation in a tidal site where the rainfall has very little importance. The examination of rainfall values indicate that at lag 4 the rainfall was 6.5mm. Although higher rainfall was received at lags 6, 7 and 8 the coefficient was lower with -0.35, -0.28 and -0.29. Lag 6 had a .05 level of significance while the other two had lower significance levels. This illustrates the mechanism in a tidal site. The lower rainfall in the first few lags may have contributed to a higher total P concentration, but the higher lags which had higher rainfall did not have much effect on lowering the concentration as indicated by the lower coefficients and significance levels. Therefore the diurnal tidal flow may be the important force in

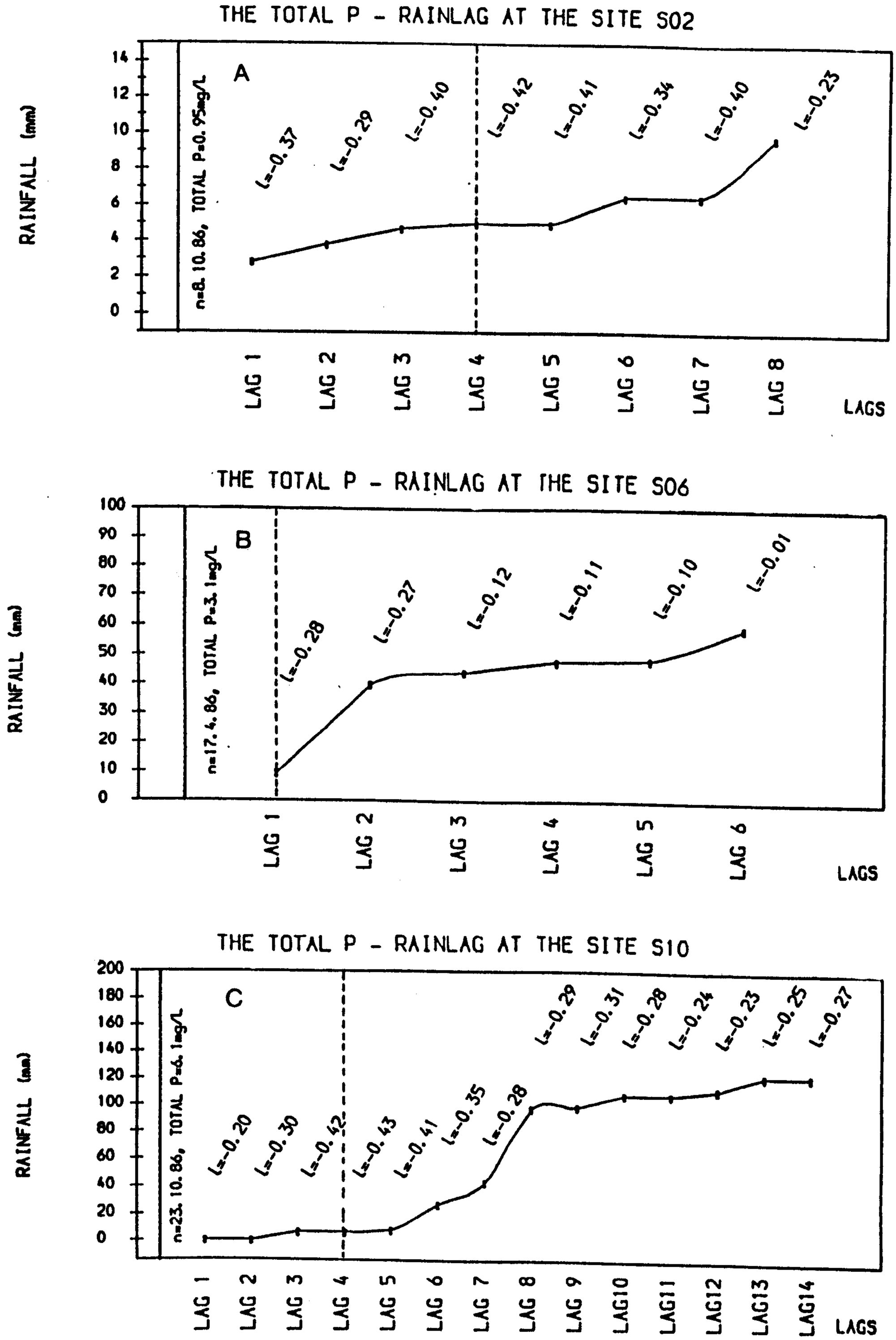


Figure 7.13 — Time-lag relationships between Total P and rainfall for selected sites in the San Sebastian canal

Source: Based on field monitoring

the concentration of the pollutant than the rainfall in the tidal site, but it has to be acknowledged that the lag analysis depicts the impact of the lagged rainfall on the concentration. The coefficient at lag 1x had a positive correlation of 0.16, which appeared isolated and more in common with the industrial site or due to the influence of the tidal flow.

Summary

The lag analysis explained the lagged rainfall relationship with the pollutants between two consecutive days of monitoring. The COD-rainlag gave a negative correlation in the San Sebastian canal. The coefficient remained high at the relatively unpolluted site, S02. This indicated that the assimilative capacity of the site was high. At the industrial waste water discharge site of S03 the coefficient was comparatively low which indicated the lower dilution of waste waters and the lower assimilation capacity of the receiving site. Thus the poor response of the pollutant to the previous rainfall was clear. The site S10 differed to both S02 and S03. Although the rainfall did not have much impact on this site, the difference between the tidal and the rainfall effect on the pollutant was clearer.

The DO-rainlag was positive at all the sites. The coefficient was high at S02 which indicated a higher aeration and the assimilative capacity at the site. This was even clear under the very low rainfall period under consideration. At the industrial site S06, the significance of a high lagged rainfall was clear which resulted in higher aeration. This explained the higher assimilative capacity due to past rain in a polluted site. Other than this significant lag, all the others indicated the low assimilation at this site. At S10 the significantly high coefficient explained the relative importance of rainfall in assimilation even in a tidal site.

The SS-rainlag coefficient was positive. The coefficient was high at S02. At S06, even during a low rainfall period the lag analysis indicated the relationship between a slightly higher rainfall on the resulting concentration. At S10 the coefficient was low and insignificant, which indicated that the lagged rainfall was not the major cause for the SS concentration.

The conductivity-rainlag indicated a negative relationship. At S02 the assimilation remained higher than at S03. Even at S03 the importance of the slightly higher rainfall on the resultant concentration was explained by the coefficient. There was a wider fluctuation of the coefficient at S10, but the general trend indicated a dampening of the concentration. This indicated some degree of assimilation capacity at the site.

The total P-rainlag relationship was negative. The site S02 indicated a higher assimilation capacity. At S06 the coefficient was lower which showed that the assimilation was low at the industrial site. But even in the industrial site the dampening effect on the concentration was indicated by the negative coefficient. The coefficient at S10 was higher than at S06 but lower than at S02, which indicated the difference among the sites. Although the rainfall was not the important factor at this site, the dilution capacity indicated some degree of assimilation.

As the previous analysis (rainfall-pollutant), and present lag analysis show the dilution effect by the rainfall at the industrial waste water discharge sites is very poor, treatment of waste water becomes mandatory to maintain the San Sebastian canal water in good quality. This can be compared with the non-industrial sites of the canal such as the S02, where the natural rainfall was responsible for the relatively better quality water at the site.

Chapter VIII

Standards

8.1 Standard criteria used for the surface waters and industries

The availability of standards in Sri Lanka to test the fresh water quality was poor. This was mainly because the San Sebastian canal, the tributary canals and the lake were not put to any particular use, specified in the standard criteria. Although certain parts of the lake have some amenity value the uses of the monitored sections is not specified. The canal system is nothing but a public, industrial and a municipal sewer for untreated waste water discharges. Thus the water bodies had to be tested for their actual water quality rather than a use specific testing. Hence finding the water quality criteria for such a purpose was difficult, as most of the standards were formulated for a particular use of inland fresh water surface. The only available standard specification to test the basic water quality of the monitored water bodies was the Indian standards 2296:1973 modified by the CEA - Sri Lanka, (Central Environmental Authority, 1985b). This set of standards called the Quality of Inland Surface Waters (fresh water norms) or the CEA Interim standards (1985) was used to test the water quality of the San Sebastian canal, the tributary canals and the lake sites. The relevant standards can be seen in Appendix M(i). Not all the pollutants monitored had the required standard specifications. Where Sri Lankan standards were not available, the next priority was to use the available standards from the other tropical countries, and when nothing was available certain European standards were used. These were resorted to sparingly and only as a last measure because the climatological, hydrological and the water chemistry may not suit the tropical Sri Lankan conditions. Further, it may not be economically feasible to adopt them as the European standards are too stringent in the total socio-economic context of Sri Lankan water pollution control.

The COD standard specification for water quality of the inland surface water was not available. Therefore Parker's (1971) recommended standard for the COD was used. This specified a maximum of 10.0 mg/L of COD. This did not provide any distinction between the standards to test the water quality of the canal system and the river water, for which the Sri Lankan Standards of 1983 for Potable Water Quality (Sri Lanka Standards Institution, 1983) was used (Appendix Mii). The COD specification in the latter was also a maximum of 10.0 mg/L. There was no alternative for the former. The potable water quality standards were used for the Kelani river since drinking water is abstracted from this river. Although the absraction point is about 13 km upstream the tides may carry polluted water upstream. In addition the residents along the river near the monitored sites use the river for bathing, domestic purposes and sometimes even for drinking.

As far as the industries were concerned the Sri Lankan Standards of 1984 for the Industrial Discharges into the Inland Surface Waters, 1984 (Sri Lanka Standard Institution, 1984) was used (Appendix Miii). Not all the specifications for the pollutants were available. Thus, where available standards from the other tropical countries for food industries were used. The main specifications used are the COD, BOD, pH, SS and water temperature in the food industries. There was no specific set of standards for the food industries in the tropical countries (industry-wise). Pollutants were monitored according to the waste water characteristics of the individual food industry concerned. No standard publications are available for the food industries (Not even the WHO 1983 guidelines had all the specifications for the food industries) in the tropics. The few available data were widely scattered. The Sri Lankan standards themselves had their limitations, as they were a common set of standardards for all the industrial discharges into the inland surface waters irrespective of the industrial group. Standards other than the available Sri Lankan and the relevant industrial standards from other tropical countries were not used as they were inappropriate for the Sri Lankan situation.

8.2 Standard specifications met: surface waters

The San Sebastian canal

The percentage (DO) standards met in the canal can be seen in table 8.1. The standard specifications for the Quality of Inland Surface Water can be seen in Appendix M(i).

Table 8.1 — Percentage standards met in the San Sebastian canal

Site	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	% for canal	Std.
DO												4.0
Comp	100.	100.	-	-	-	-	-	-	2.5	2.5	20.5	
Ex	-	-	100.	100.	100.	100.	100.	100.	97.5	97.5	79.5	
COD												
Comp	40.	35.	-	-	-	-	-	-	-	-	7.5	10.0
Ex	60.	100.	100.	100.	100.	100.	100.	100.	100.	100.	92.5	
BOD												
Comp	15.	20.	-	-	-	-	-	-	-	-	3.5	3.0
Ex	85.	80.	100.	100.	100.	100.	100.	100.	100.	100.	96.5	
SS												
Comp	60.	75.	-	7.5	15.	-	-	62.5	35.	30.	28.5	25.0
Ex	40.	25.	100.	92.5	85.	100.	100.	37.5	65.	70.	71.5	
T N												
Comp	57.1	100.	-	-	7.1	-	-	64.3	28.6	50.	30.7	3.0
Ex	42.9	-	100.	100.	92.9	100.	100.	35.7	71.4	50.	69.3	
T P												
Comp	66.7	88.9	29.6	48.1	74.1	14.8	11.1	55.6	59.3	74.1	52.2	2.0
Ex	33.3	11.1	70.4	51.9	25.1	85.2	88.9	44.4	40.7	25.9	47.8	
pH												
Comp	77.5	77.5	42.5	40.	52.5	35.	40.	85.	67.5	75.	75.	8.5
Ex	22.5	22.5	57.5	60.	47.5	65.	60.	15.	32.5	25.	25.	
COND												
Comp	100.	100.	80.	97.5	100.	95.	95.	75.	72.5	85.	90.	1000.0
. Ex	-	-	20.	2.5	-	5.	5.	25.	27.5	15.	10.	
SULF												
Comp	84.6	100.	69.2	66.7	76.9	71.8	82.1	100.	92.3	92.3	83.6	250.0
Ex	15.4	-	30.8	33.3	23.1	28.2	17.9	-	7.7	7.7	16.4	

Comp = complied, Ex = exceeded

Source: Field Monitoring.

None of the DO standards were complied from S03 to S08. Other than S01 and S02, all the other sites had a higher percentage not conforming to the standards. In the canal as a whole 79.5% of the standards were exceeded.

None of the COD and BOD standards were met from S03 - S10. In the entire canal 92.5% and 96.5% of the samples exceeded the COD and the BOD respectively.

The SS sample were not complied at S03, S06 and S07. Among the other sites S04, S05, S09 and S10 had a higher percentage not complying with the standards. In the entire canal 71.5% exceeded the standards.

All the total N standards were exceeded from S03 - S07 with a slight fluctuation at S05. Sites S09 and S10 also had a fair percentage exceeding the standard. In the entire canal 69.3% exceeded the standards.

A very high percentage of total P standards was exceeded at S03, S06 and S07. In the entire canal 47.8% exceeded the standards.

A higher percentage of pH standards were not complied at S03 - S07 and S09. In the entire canal 25.0% exceeded the standards.

A high percentage of conductivity specification was complied with. Of this S03, S08 and S09 had a higher percentage not conforming. In the entire canal 90.0% complied with standards.

A higher percentage of sulphate samples were complied with. Of this S03 to S06 had a fair percentage not meeting the standards. In the entire canal 83.6% complied with the standards.

Among the sites S01 and S02, had a higher percentage conforming to most of the standards.

Specifications and water quality

The percentage of samples conforming and non conforming to the standards for the pollutants discussed above indicates certain discernible trends. The sites S01 and S02 had a higher percentage of samples conforming to the specification, thus indicating a lower pollution level and therefore better water quality. Among these two sites S02, appears to have better water quality than S01. This may be due to the fact that this site is not influenced by the connecting lake. Hence, this site is free from the external influences.

The sites S03 to S07 had a higher percentage of values not conforming to the specified standards. This indicates the higher degree of pollutants entering the sites thus contributing to very poor water quality. The site S05 which is a non industrial site had slight fluctuations in the percentage among these sites, the nature of a domestic site with a high shanty concentration. The sites S08 to S10 gave a complicated picture with varied percentages falling above and below the standards. This group of sites was entirely different to S01 and S02, which had better water quality. The sites S03 to S07 had poor water quality. The tributary canals entering from S08, and the the tidal waters from river Kelani influence the site S10 in addition to the agricultural land use towards the end of the canal may have made the situation more complicated. The site S08 was also a domestic site with a high shanty population on either side of the bank, which added further implications. On the whole the entire length of the canal had poor water quality except at S02 and S01 to a lesser extent which indicated that the canal is grossly polluted with poor water quality along its entire length. The deterioration of the water quality started at the industrial site S03 and continued through S04, S06 and S07 until it reached Kelani river, with a slight degree of improvement that occurred from S08.

The river Kelani

The percentage standards met in the river Kelani can be seen in table 8.2 (25A). Appendix M(ii) gives the Standard Specifications for Potable Water Quality.

The DO standards were complied at both the sites. A higher percentage of COD and BOD were not conformed at R01, which are 92% and 90% respectively. Of the SS, 42.5% was exceeded at R02. The percentage was same for turbidity. These were higher than at R01. The non conformity at R02 was higher for total P with 29.6%. A high percentage of pH was conformed to at both the sites. A high percentage of conductivity standards were not complied to at R01. The percentage of non-conformity for sulphates was higher at R01.

In the entire river 80% of COD and 81.3% of the BOD failed to meet the standards. Non conformity for total N was also high.

Standards and water quality

In the river Kelani as a whole (in the monitored stretch), most of the pollutants had a higher percentage of samples not conforming to the specified standards at R01 than at R02. The DO indicated that the river water was of fair quality and was capable of supporting flora and fauna. (though the standard was met the DO was generally lower at R01 than at R02). Although the DO was met at the sites, the fact that a higher percentage of COD and BOD did not comply with the standard, clearly spells a warning that the river water quality was falling. The examination of monitored data indicated marginal conditions on many occasions. The nutrient loading as indicated by total N, particularly in the downstream site R01, was evident by the presence of *Eichornia crassipes*. This indicated that the San Sebastian canal

Table 8.2 — Percentage of standards met in the River Kelani

Pollutant	R01	R02	% for river	Standard
DO				4.0
Comply	100.0	100.0	100.0	(mg/L)
Exceed	-	-	-	
COD				
Comply	7.5	32.5	20.0	10.0
Exceed	92.5	67.5	80.0	(mg/L)
BOD				5.0
Comply	10.0	27.5	18.7	(mg/L)
Exceed	90.0	72.5	81.3	
SS				25.0
Comply	75.0	57.5	66.2	(mg/L)
Exceed	25.0	42.5	33.8	
TB				8.0
Comply	60.0	57.5	58.8	(mg/L)
Exceed	40.0	42.5	41.3	
T N				1.0
Comply	28.6	35.7	32.1	(mg/L)
Exceed	71.4	64.3	67.9	
T P				2.0
Comply	81.5	70.4	75.9	(mg/L)
Exceed	18.5	29.6	24.1	
pH				9.0
Comply	92.5	92.5	92.5	
Exceed	7.5	7.5	7.5	
CT				750.0
Comply	72.5	75.0	73.8	(μmhos/cm)
Exceed	27.5	25.0	26.2	
SULF				200.0
Comply	84.6	87.2	85.9	(mg/L)
Exceed	15.4	12.8	14.1	

Source: Field monitoring.

contributes to the pollution of the river Kelani which is clearly evident by the higher percentages not conforming to the standard at the downstream site R01 than at R02 which is at the upstream of the confluence.

The Beira lake

The table 8.3 shows the percentages conforming to the standards in the Beira lake. The standard specifications are given in appendix L(i).

Table 8.3 — Percentage of standards met in the Beira lake

Pollutant	U01	U02	% for lake	Std.
DO				4.0
Comply	25.0		18.2	
Exceed	75.0	100.0	81.8	(mg/L)
COD				
Comply	-	-	-	10.0
Exceed	100.0	100.0	100.0	(mg/L)
BOD				3.0
Comply	-	-	-	(mg/L)
Exceed	100.0	100.0	100.0	
SS				25.0
Comply	-	6.7	1.8	(mg/L)
Exceed	100.0	93.3	98.2	
T N				3.0
Comply	7.1	-	3.7	(mg/L)
Exceed	92.9	100.0	96.3	
T P				2.0
Comply	40.7	33.3	38.1	(mg/L)
Exceed	59.3	66.7	61.9	
pH				8.5
Comply	92.5	66.7	85.5	
Exceed	7.5	33.3	14.5	
CT				1000.0
Comply	-	93.3	25.5	(μmhos/cm)
Exceed	100.0	6.7	74.5	
SULF				250.0
Comply	-	86.7	24.1	(mg/L)
Exceed	100.0	13.3	75.9	

Source: Field monitoring.

In the lake sites none of the samples conformed to the the standards at U02. All the samples for COD and BOD were exceeded at both the sites. SS saw a higher non conformity at U01, but U02 was also high. None of the samples met the total N standards at U02 and 92.9% did not comply at U01. The total P standards not conformed to at both the sites were similar, but slightly higher at U02. A higher percentage (33.3) did not conform to the pH specifications at U02. All the samples at

U01 exceeded the conductivity and the sulphate standards. In the lake as an entity, a higher percentage in most if the pollutants other than pH exceeded the standards.

Standards and water quality

The lake sites indicated a very polluting situation at both the sites. Except for the total N and total P at U02, the other pollutants indicated a fairly similar situation in the lake. A higher nutrient loading was evident at U02, both from the industrial discharges of A3 and A5; and raw sewage that enter the lake at this site from the culvert. This was evident from a higher samples not conforming to total N and total P standards at U02. This was also clearly evident from the luxurious growth of *Eichornia crassipes* and *Salvinia* at U02. Eutrophication had taken place at U02. The DO was very low at both the sites. This is obviously due to the industrial waste water discharges although domestic sewage also may have contributed. None of the BOD or the COD samples at U01 and U02 conformed to the standards. This indicated a very high organic loading into the lake mainly in the form oil at U01 and industrial disdcharges from A3 and A5 at the site U02. The non conformity to conductivity and sulphate specifications at U01 showed the influence of the sea. These indicate very poor quality water.

The tributary canals

The table 8.4 gives the percentages for the standards met in the tributary canals. Appendix M(i) gives the relevant standards.

In the tributary canal system none of the samples met the specification for DO in the Maligawatte, Kettarama, Kittampahuwa ela and the Main Drain. In the Dematagoda ela 96.4% of the samples did not meet the standards. None of the confluence sites (T10 and T13) met the standards. At T03 92.9% did not meet the specifications. The percentage standards met in the individual sites in the tributary canals can be seen in appendix N. In the entire tributary canal system 98.9% fell short of the standards.

None of the canals met the met the COD and the BOD standards.

A high percentage of SS did not meet the specification in the Main Drain, Dematagoda ela and the Kittampahuwa ela. The percentage in the Main Drain was 95.2. In the entire tributary canal system 74.7% fell short of the standards.

In the Maligawatte drain 83.3%, and 91.7% in the Kettarama and the Main Drain did not meet the specification for total N. The confluence sites T03, T10 and T13 had a higher percentage that failed to meet the standards. In the entire tributary canal system 55.8% fell short of the standards.

The percentage not meeting the standards for for total P was not very high. The highest was at Kittampahuwa ela with 42.9%. The confluence sites had a high percentage not conforming to the standards. In the entire tributary canal system 31.9% fell short of the standards.

The pH in the canals showed showed a high percentage conforming to the standards. The Dematagoda ela had the highest non conformity with 26.8%. Among the confluence sites T03 with 64.3%, T10 with 50% and T13 with 35.7% did not conform to the standards. In the entire tributary canal system 16.5% did not meet the standards.

The conductivity in the tributary canals complied with the standards to a great extent. Kittampahuwa ela had the highest non-conformity to the standards with 10.7%. A higher percentage of the samples did not meet the specification at the confluence sites. They are 28.6%, 35.7%, and 21.4% at T03, T10 and T13 respectively. In the entire tributary canal system 92.3% met the standards.

The sulphate standards in the tributary canals indicated that a higher percentage in the Kittampahuwa ela and the Main drain did not conform to the standard. Among the confluence sites T10 and T13 had comparatively higher percentages with 21.4% and 28.6% failing to meet the standards.

Standards and water quality

In the entire tributary canal system 98.9% of the samples fell short of the standards. This indicated the gravity of the pollution in the canals. The sites which are at the confluence of the San Sebastian canal thus makes a very poor contribution to the reaeration of the San Sebastian canal. The situation is one of deoxygenation rather than reaeration. This can be further substantiated with the COD and the BOD load that enter from these tributary canals. None of the samples in the entire tributary

Table 8.4 — Percentage standards met in the tributary canals

Canal/ % Exceed	Entire canal system	Mali. Ela	Ket. Ela	Main Drain	Kitt. Ela	Dem. Ela	Std.
DO							
Comply	1.1	-	-			3.6	
Exceed	98.9	100.0	100.0	100.0	100.0	96.4	4.0 mg/L
COD							
Comply	-	-	-	-	-	-	10.0 mg/L
Exceed	100.0	100.0	100.0	100.0	100.0	100.0	
BOD							
Comply		-	-	-	-	-	3.0 mg/L
Exceed	100.0	100.0	100.0	100.0	100.0	100.0	
SS							25.0 mg/L
Comply	25.3	57.1	50.0	4.8	26.8	25.0	
Exceed	74.7	42.9	50.0	95.2	73.2	75.0	
T N							
Comply	44.2	16.7	8.3	8.3	72.9	58.3	3.0 mg/L
Exceed	55.8	83.3	91.7	91.7	27.1	41.7	
T P							2.0 mg/L
Comply	68.1	85.7	64.3	71.4	57.1	73.2	
Excced	31.9	14.3	35.7	28.6	42.9	26.8	
pH							
Comply	83.5	92.9	100.0	83.3	87.5	73.2	8.5
Exceed	16.5	7.1	-	16.7	12.5	26.8	
CT							
Comply	92.3	100.0	100.0	92.9	89.3	91.1	1000.0 μmhos/cm
Exceed	7.7	-	-	7.1	10.7	8.9	
SULF							
Comply	87.4	100.0	100.0	88.1	71.4	96.4	250.0 mg/L
Exceed	12.6	-	-	11.9	28.6	3.6	

Source: Field monitoring.

canal system conformed to the standard specification for COD and BOD. The causes are both industrial and domestic discharges from shanty areas. Sites T01 and T02 represent more of domestic discharges from the shanties although illegal industrial discharges may also be diverted to these canals. The sites T03, T10, T11 and T13 are mainly industrial discharges. At these sites COD and the BOD are very much higher than at T01 and T02. The DO was much lower in the former sites.

The SS standard shows that the SS percentage not conforming to the standards were higher at the industrial sites of T03, T10, T11 and T13. The Main Drain which flows through a densely populated and a well established old industrial area has the highest percentage of SS not conforming to the standards.

Both the domestic and the industrial sites discussed earlier had higher percentages not conforming to the total N standards. The Main Drain had the highest percentage while the Kittampahuwa ela had the lowest. The industrial sites which are also located at the confluence contribute directly to the nutrient loading into the San Sebastian canal.

A higher percentage of pH was also not complied at the confluence sites. It was the highest at T03 with the manufacture of detergents at the factory D. The industrial site T13 also had a high percentage.

The conductivity at T10 and T03 may be due to more dissolved solids, while at T13, in addition to this the tidal waters may have contributed. The non industrial sites in these canals had most of the samples conforming to the standards.

The industrial sites of T03, T10 and T13 had comparatively higher percentages of sulphate that exceeded the standards.

Hence the tributary canals enter the San Sebastian canal with poor quality water. The situation is aggravated since the industrial sites are located at the confluence in most of the tributary canals.

8.3 Aesthetic conditons in the surface waters

Aesthetically, none of the monitored sites in the water bodies met the specification of **no visible floating matter of sewage or industrial waste water origin** in the Water Quality Criteria for the Inland Surface Waters - Interim standards (CEA, 1985b).

San Sebastian canal

In the San Sebastian canal all the sites except S02 had floating material of some nature. The site S01 had aquatic plants. Sites S03 and S04 had solid soap wastes (which is known colloquilly in the trade as 'nigger'). Foam and froth was clearly visible, emanating from the factory B. The canal site S03 and the site downstream was in this situation for most part of the year except during the very heavy rainfall months. At the site S04 skeletons of motor spares and assemblages with blackish oily water were clearly visible. In addition to these, domestic garbage which ranged from plastic cans and fabric to cut banana trunks floated or stagnated in the site. Heaps of sand and other construction material which ranged from sand and bricks to iron rods was visible near S03, both in the canal reservation and in the canal itself. At the site S05 oil, domestic garbage and some soap wastes were found to float. Between S03 and S05 mosquito breeding was clearly evident throughout the year except during the very high rainfall periods. The site S06 appeared clean most of the time, but a thick film of oil was visible throughout the period of monitoring. Foam and froth was visible during certain days of monitoring. This can be seen in plate 8.1(a). This originated from the industry C. This was also a mosquito breeding ground during the dry period. The site S07 also had a film of oil. It was a continuity from the site S06. Laundry waste water with soapy froth was visible at this site as seen in plate 8.1(b). Domestic garbage was also visible. This may be from the Kettarama drain which enters at this site. Site S08 had domestic garbage in the canal site and the banks and was a breeding ground of the mosquitoes. At the site S09 and S10 black oily streams of water in addition to domestic garbage was clearly visible. In addition to the particular conditions in the individual sites, almost all the sites had floating aquatic plants except at S06. *Eichornia crassipes* and occasionally *Salvinia* were visible.

Other surface waters

In the the tributary canal sites which were at the confluence with the San Sebastian canal, sites T01 and T02 had floating material which were mainly of domestic origin. At the site T03 on the Dematagoda ela black mucky tar-like formation was clearly visible at the factory D waste water discharge point. Coloured water too was seen. The tar formation was seen only in the factory discharge entry side of the canal. The site T10 on the Kittampahuwa ela had unsightly garbage and thick slimy mossy formation. This point was stagnant for most part of the year. At the site T13 thick black tar-like deposit was clearly visible at the edge of the canal at the entry point of the factory E waste water drain during the dry period. This can be seen in plate 8.2. Aquatic plants such as *Eichornia crassipes* were present. In the river Kelaniya at both the sites, R01 and R02 sawdust floated in the river along the edges. This was particularly visible in the left bank of the river. A difference in the colour of the water in the river was clearly evident at the entry of the San Sebastian canal. The demarcation of the dark blackish oily water from the San Sebastian canal and the comparatively cleaner water of the river was clearly visible downstream of the San Sebastian canal. Freely floating *Eichornia crassipes* was seen in the river very fre-

Plate 8.1 — (a) Foam and froth near factory C (b) Laundry waste entering San Sebastian canal

Plate 8.2 — Black tar-like deposit at the discharge point of factory F in the Main Drain

quently. In the lake sites, there was a thick blackish film of oil at U01. At the site U02 both domestic garbage and milky or coloured waste water streams from the factory A5 were clearly visible. Aquatic plants, both *Eichornia crassipes* and *Salvinia* were luxuriant in this site. Thus the aesthetic specification for the inland surface waters was not met in the surface waters.

8.4 Standard specifications met: industrial discharges

The percentage of the samples that met the standards can be seen in table 8.5 [25E]. The relevant standards are shown in appendix M(iii)

A1: Jam factory effluent

Only one set of sample was monitored in this factory. The COD did not conform to the specification for discharges from the industries into the inland surface waters of 250.0mg/L (Sri Lanka Standard Institution, 1984). The factory sample did not conform to the BOD of 30.0mg/L. The SS standard of 50.0mg/L was exceeded. The effluent sample complied with the total N effluent standard of 50.0 mg/L (Ministry of Science, Technology and the Environment - Malaysia, 1982). The pH sample of the industry with the standard specification of 6.0 to 9.0 (WHO, 1983b) and the water temperature of the effluent (Sri Lanka Standards Institution, 1984) fell within the standards.

A2: Soft drinks, bottle washer effluent

In this industry none of the samples complied with the standards for the COD and the BOD. Of the samples 80.0% were above the specification for SS, while the total N complied with the standard. The pH was exceeded by 93.3% and 26.7% of the water temperature samples exceeded the specified standards.

A3: Meat processing industry effluent

Of the samples 93.3% fell short of the standards for the COD, while non of the

Table 8.5 — Percentage standards met in the industries

% Exceeded	A1	A2	A3	A4	A5	B1	B2	C1	C2	E	F	G1	G2	H1	H2	I1	I2	J	K	Std.
COD																				250.0 mg/L
Comply	-	-	6.7	100.0	-	-	50.0	30.8	7.7	-	-	-	-	16.7	33.3	16.7	16.7	-	-	
Exceed	100.0	100.0	93.3	-	100.0	100.0	50.0	69.2	92.3	100.0	100.0	100.0	100.0	83.3	66.7	83.3	83.3	100.0	100.0	
BOD																				30.0 mg/L
Comply	-	-	-	66.7	-	-	-	-	-						33.3					
Exceed	100.0	100.0	100.0	33.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	66.7	100.0	100.0	100.0	100.0	
SS																				50.0 mg/L
Comply	-	20.0	6.7	100.0	13.3		28.6	30.8	7.7	5.9	17.6	-	-		66.7	-	-	-		
Exceed	100.0	80.0	93.3	-	86.7	100.0	71.4	69.2	92.3	94.1	82.4	100.0	100.0	100.0	33.3	100.0	100.0	100.0	100.0	
T N																				50.0 mg/L
Comply	-	100.0	25.0	not	25.0	100.0	100.0	100.0	100.0	100.0	100.0	-	83.3	100.0	-	100.0	100.0	100.0	-	
Exceed	-	-	75.0	done	75.0	-	-			-		100.0	16.7							
pH																				9.0
Comply	100.0	6.7	80.0	66.7	73.3	35.7	50.0	100.0	84.6	88.2	76.5	83.3	50.0	16.7	33.3	33.3	66.7	33.3	100.0	
Exceed	-	93.3	20.0	33.3	26.7	64.3	50.0	-	15.4	11.8	23.5	16.7	50.0	83.3	66.7	66.7	33.3	66.7		
W T																				40 C
Comply	100.0	73.3	100.0	-	100.0	71.4	85.7	69.2	100.0	94.1	58.8	100.0	100.0	50.0		50.0	100.0	100.0	-	
Exceed	-	26.7	-	100.0	-	28.6	14.3	30.8	-	5.9	41.2			50.0	100.0	50.0		-	-	

Columns: A1 - K are factory sites.

Source: Field monitoring.

samples complied with the BOD standard. The SS specification was not complied by 93.3% of the samples and 75.0% of the total N samples did not comply with the effluent standard. Of the pH samples 20.0% were above the specification. All the samples complied with the specification for water temperature.

A4: Carbon dioxide plant effluent

All the samples complied with the COD standards, while 33.3% of the BOD did not meet the specification. All the samples met the standards for SS, while 33.3% of the samples exceeded the pH standard. The water temperature always exceeded the standard specified.

A5: Creamery effluent

Both the COD and the BOD samples did not meet the standard. The SS was exceeded by 86.7%, total N by 75.0%. and pH by 26.7%. The water temperature samples complied with the effluent standard.

Summary for A1 - A5

Industries A3 and A5 discharge directly into the the Beira lake. The standard specifications indicated that the organic load in terms of the COD and the BOD discharged is very high. Only 6.7% of the COD samples complied with the standard, while 93.3%of the COD and the none of the BOD samples met the standards. This is a contributory cause for the very low DO levels at the site U02 in the Beira lake. None of the COD or the BOD samples at the site U02 complied with the standards for the inland surface water. Thus the effect of these industrial discharges is very harmful to the receiving site particularly the depletion of the DO. Measurements of total N indicated that 75% of the samples did not meet the specification in both the industries, which meant that a high load of nutrient was discharged into the lake. As mentioned earlier the receiving site showed evidence of eutrophication with the high growth of *Eichornia crassipes* and *Salvinia* and other floating aquatic plants. The very high percentage of SS in the A group exceeded the standards which indicated a high input of suspended matter into the receiving site.

B1: Soap industry effluent

None of the samples for COD, BOD and SS complied with the standards. All the total N samples complied with the standards. 64.3% of the pH samples exceeded the specification and 28.6% of the samples for water temperature exceeded the limits.

B2: Cooling plant effluent

Of the samples 50.0% did not meet the specification for the COD standards while

none of the samples met the BOD standards. 71.4% did not meet the SS standards. Whilst the total N samples complied with the standards. Of the pH samples 50 % fell above the standards and 14.3% of the water temperature samples exceeded the limit.

Summary for B1 and B2

The COD and the BOD samples exceeded the limit at both B1 and B2. The percentage of SS exceeding the standards at both the monitoring sites were high. Thus this factory discharges a very high organic loading into the receiving site. The high pH percentage at B1 and B2 exceeded the standards. It is appropriate to mentioned that the oxygen sag in the San Sebastian canal starts at the receiving site (S03) of this factory's waste water discharges.

C1: Margarine factory effluent

The COD indicated that 69.2% of the samples did not comply with the specification. None of the BOD samples complied with the standards and 30.8% of the SS samples did not comply. The total N and the pH complied with the standards. The water temperature samples were exceeded by 30.8% the specification.

C2: Fat trap effluent

All the COD, 92.3% of the BOD, and 92.3% of the SS exceeded the standard specification. The total N fell within the specification while 15.4% of the pH exceeded the limit. The water temperature fell within the specified limit.

Summary for C1 and C2

The organic loading in terms of the COD and the BOD is very high as seen from the percentage exceeding the specified standards. The SS loading into the canal is also high from both the monitored sites as seen from the percentages exceeding the standard specification. The water temperature exceeded the standard at C1. The oxygen sag continued through this site in the canal. Factory C discharges a heavy pollution load into the San Sebastian canal which is evident both from the percentage exceeding the effluent standards in the factories and the percentages not conforming with the standards in the receiving sites.

D: Chemical effluent(fertilisers, pesticides)

Only two sets of samples were monitored. The COD was exceeded by 50.0%. None of the BOD samples complied with the standards. The SS exceeded the specification, while total N, pH and water temperature samples complied with the specification. Since the frequency of monitoring is very low it is difficult to make a realistic assessment of the input of the pollutants into the receiving site.

Summary

Even with the small scale of monitoring of this factory the organic loading into the receiving site appears high. This becomes evident from the standards exceeded by the pollutants in the receiving sites.

E: Confectionery effluent

The COD and the BOD exceeded the specifications in all the samples. The SS samples did not comply with the standards for 94.1% of the samples. The total N was within the specified standard. 11.8% of the pH did not meet the range specified by 11.8% and 5.9% of the samples for water temperature exceeded the specification.

F: Confectionery effluent

None of the BOD and the COD samples met the specified effluent criteria. The SS samples were exceeded by 82.4% of the specification. The total N samples complied with the standards. Of the pH 23.5% and 41.2% of the water temperature exceeded the required specification.

Summary for E and F

The organic loading in terms of the COD and the BOD is very high as seen both from the factory effluents discharged with all the samples exceeding the specification and the condition of the receiving sites T11 and T13 both of which had low DO levels. The SS load from both the factories has a very high percentage which exceeds the specification. Since the factories were confectioneries the nutrient loading in terms of total N is low.

G1: Meat processing effluents

All the samples exceeded the COD, BOD, SS and the total N standard specification. Of the pH samples 16.7%, were above the specification. All the samples complied with the water temperature standard.

G2: Meat packing effluents

The COD and the BOD samples did not conform to the specification. The SS also exceeded the limits in all the samples and 16.7% of the samples exceeded the total N specification. The pH specifications was exceeded by 50% of the samples but the water temperature complied with the standards.

Summary for G1 and G2

In the meat processing and packing plant all the samples exceeded the specification for COD, BOD and SS. The total N specification was exceeded in all the samples at G1. The organic loading into the receiving site, the river Kelani would be very high, had it been monitored. The SS also exceeded the limits in all the samples. Although the impact of the meat processing factory would be detrimental to the receiving river, as it is a large flowing river it may be able to cope with the effluents than in any of the industrial receiving sites of the canal which are small water courses with low flow and little volume of water to dilute the effluents. The percentage of the pollutants that exceed the standards show the highly polluting nature of this food industry.

H1: Soft drinks-bottle washer effluent

All the BOD, 83.3% of the COD and all SS samples exceeded the specifications. The total N conformed to the standards. Of the pH 83.3% did not meet the standard and 50% of the water temperature samples were above the standards.

H2: Carbon dioxide plant effluent

Only three set of samples were monitored throughout the period. For the COD and the BOD 66.7% of the samples did not comply with the standards. For SS 33.3%, of the samples fell short of the specification. For pH 66.7% of the samples were above the specification while none of the samples conformed to the water temperature specification.

Summary for H1 and H2

The effluent from the H group is discharged into a drain which flows through a paddy tract into the tributary of the Kelani ganga. The receiving site was not monitored. The percentage of the pollutants not conforming to the standards indicates the highly polluting nature of this industry. The organic load is very high at H1, in terms of the COD and the BOD. The SS is also very high. The pH percentage indicated the high alkalinity of the effluent. The impact of the effluent on the receiving site will be very harmful.

I1: Soft drinks factory bottle washer effluent

All the BOD, 83.3% of the COD and the SS samples were above the specification. The total N samples complied with the standard. A value of 66.7% for the pH and 50% of the water temperature samples did not meet the standards.

I2: Aeration tank

83.3% of the COD and all the BOD and the SS samples did not meet the specifications. The total N standards were complied with, 33.3% of the pH did not meet the specification while the water temperature standards were complied with.

Summary of I1 and I2

The COD and the BOD indicated a high organic loading into the receiving from I1. The pH standards indicated a highly alkaline waste water and the water temperature indicated hot effluent discharges. The treatment plant I2 was not fully functioning since it was in the initial stage of installation and so the performance was poor (This can be seen from the COD and the BOD not meeting the specifications). Even the pH correction of the waste water was not efficient as the samples showed 33.3% falling above the specification. The plant may be functioning now which means that treated effluents are being discharged into the Kelani river.

J: Fruit and milk, bottle washer effluent

None of the COD, BOD and the SS met the standard specification. The total N and water temperature samples complied with the standard. The pH was above by 66.7% of the specification.

Summary

The standards indicated a highly polluting organic load and an alkaline waste water discharge which are sent into bare land initially. Towards the end of the monitoring, a septic tank was built for the collection of the waste water.

K: Marmite effluent

One sample each was analysed for the COD, BOD, SS and pH, although the factory itself was neither visited nor monitored. None of the samples met the specifications. The pH fell within the specification.

8.5 The COD:BOD ratio and treatability

The percentages of the pollutants not conforming to the standards indicated the gravity of the waste water discharges from the industries. Thus the consideration of the treatability of the wastes becomes important.

The COD:BOD indicates the type of treatment necessary for the waste water discharges. The COD:BOD of any waste water will vary depending on the extent of its biodegradability, the presence or absence of the toxic materials and bactericides. The presence or the absense of the biologically inert material gives an indication of the treatment to be decided by the industries. When the character and the composition of the waste water does not fluctuate very much a good relationship between the COD and the BOD can be expected. When the difference between the COD and the BOD is high which is indicated by the ratio, the presence of biologically inert matter is indicated. Such a situation indicates treatment other than biological is necessary to treat the waste water. A lower ratio around 2:1 or 3:1 (personal communication - Anderson,1990) indicates the sufficiency of biological treatment.

The COD:BOD of the monitored food and drink industries indicated a higher ratio depicting a stronger organic waste than the domestic waste. The COD:BOD for domestic waste waters range from 0.53 to 0.62 (Archeivala - 1981, as reported by Wijeyesekera *et al* 1987).

Table 8.6 — The COD:BOD of the food and drink industry

Day of sampling	A2	A3	A5	B1	B2	C1	C2	E	F	G1	G2	H1	I1	I2	J
1	2:1	2:1	2:1	2:1	3:1	1:1	1:1	2:1	1:1	1:1	2:1	4:1	1:1	1:1	2:1
2	1:1	2:1	2:1	3:1	1:1	4:1	1:1	2:1	1:1	2:1	1:1	1:1	2:1	1:1	2:1
3	1:1	1:1	1:1	1:1	1:1	2:1	1:1	3:1	1:1	1:1	2:1	1:1	2:1	1:1	1:1
4	2:1	1:1	3:1	9:1	1:1	1:1	2:1	2:1	2:1	1:1	2:1	2:1	2:1	2:1	5:1
5	2:1	1:1	2:1	5:1	3:1	1:1	5:1	1:1	2:1	1:1	1:1	1:1	1:1	2:1	2:1
6	1:1	1:1	6:1	2:1	2:1	2:1	1:1	2:1	3:1	2:1	2:1	2:1	1:1	1:1	1:1
7	4:1	3:1	2:1	2:1	2:1	2:1	2:1	1:1	2:1	-	-	-	-	-	-
8	1:1	6:1	2:1	2:1	2:1	2:1	1:1	1:1	1:1	-	-	-	-	-	-
9	1:1	2:1	2:1	3:1	2:1	2:1	1:1	2:1	1:1	-	-	-	-	-	-
10	1:1	3:1	2:1	2:1	2:1	3:1	2:1	2:1	1:1	-	-	-	-	-	-
11	1:1	2:1	1:1	2:1	2:1	2:1	2:1	2:1	1:1	-	-	-	-	-	-
12	1:1	2:1	2:1	4:1	2:1	5:1	2:1	2:1	1:1	-	-	-	-	-	-
13	1:1	2:1	2:1	2:1	2:1	1:1	1:1	9:1	1:1	-	-	-	-	-	-
14	5:1	2:1	1:1	3:1	2:1	-	-	1:1	1:1	-	-	-	-	-	-
15	2:1	2:1	2:1	-	-	-	-	1:1	1:1	-	-	-	-	-	-
16	-	-	-	-	-	-	-	1:1	1:1	-	-	-	-	-	-
17	-	-	-	-	-	-	-	1:1	4:1	-	-	-	-	-	-
COD:BOD (Mean)	2:1	2:1	3:1	3:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1

Columns A2-J are factory sites

Source: Field monitoring

The table 8.6 shows the ratio for the industries. In the monitored industries the highest COD:BOD ratio was 5:1 in A2, 6:1 in A3, 3:1 in A5, 9:1 in B2, 5:1 in C1 and C2, 9:1 in E, 4:1 in F, 2:1 in G1 and G2, 4:1 in H1, 2:1 in I1 and I2, and 5:1 in J. A1

and K, which were analysed once gave a ratio of 1:1 and 2:1. Although there were higher COD:BOD in most of the factory sites the mean COD:BOD indicate that the highest ratio is only 3:1 at A5 and B1. All the other factories had mean COD:BOD of 2:1. This corresponds to the COD:BOD of 2:1 in milk-bottling waste water in India (Subrahmanyam and Mohanrao, 1972). The higher COD:BOD ratios may indicate the presence of non-biodegradable matter. This may be due to inhibitors in the raw materials used or accidental occurrences of biologically inert material. As seen in the table, occurrences of high COD:BOD is rare. The mean COD:BOD indicates values which are normal to the food and drink industrial waste waters. These are biologically amenable to treatment. Therefore the COD:BOD indicates that biological treatment is suitable for the food industries. B1 the soap industry waste water indicated a higher percentage of the COD:BOD ratio showing the implications in a non food industry even though it was based on an organic product. In such a situation treatment other than biological such as chemical treatment may become important.

The COD-BOD correlation coefficient is related to the COD:BOD ratio. The COD:BOD correlation coefficient in the food industries gave a significantly high correlation coefficient in most of the industries. This is a good index used to decide the type of treatment necessary for the industry. A higher correlation coefficient between the COD and the BOD indicates the organic nature of the wastes. If the coefficient is lower, the relationship between the variables is poor which indicates lower degradability. This is analogous to the COD:BOD ratio. Thus a higher correlation coefficient indicates a simple biological treatment of the waste waters is sufficient to treat the waste waters. Therefore at the monitored industrial sites A2, A3, A5, B2, C1, C2, E,F, G1, H1 and I1 the correlation coefficient is very high and significant. At G2 and J, although food wastes, the correlation was poor and the significance was low. This could be due to inhibitors or lower frequency of monitoring. Therefore other than the negligible deviations in the industries monitored both the high COD-BOD correlation coefficient and the COD:BOD ratio indicated that the waste water from the food and drink industry may be easily treated with simple biological methods (either in the factory before the release of waste water or in a municipal treatment plant).

Chapter IX

Conclusion

9.1 Surface water pollution

The pollutant concentrations along the San Sebastian canal indicated certain important features. Based on the results the canal can be broadly divided into three sections. The sites S01 and S02 at the origin of the canal appeared less polluted with higher DO levels and lower pollutant concentrations. Of the two sites, site S01 had higher concentrations, although the difference was negligible. These two sites were free from direct industrial and domestic waste water discharges.

The sites S03 to S07 had very high concentrations of the polllutants. The DO of the canal at this stretch was very low and often reached zero level during most of the monitoring period. The very high concentrations of the pollutants between these sites is due to the two large scale industries B and C. Industry C, a food processing industry and B an oil based industry discharge very strong organic waste waters at S06 and S03 respectively. The downstream sites S07 and S04 were affected by the upstream sites. Therefore the canal at this stretch was at the bottom of the oxygen sag curve. The shanties along the stretch (none at S06) also contribute to the pollution of the canal. But their contribution compared with the industrial discharges appears to be very low. The domestic site S05, which is between two major industries experienced fluctuations in the pollutants and slight aeration was evident. But the background level of the pollutants remained very high. This is clearly evident when the concentrations are compared with the site S08 which is downstream, but not influenced by direct industrial discharges, although it has tributary canal contributions.

The stretch from S08 to S10 had lower concentrations of the pollutants than between S03 to S07, but the relationships were less clear. This may be due to the contributions from various sources such as the tributary canals, agriculture, domestic, indirect industrial discharges and the commercial sector. The influence of the tidal river in the eastern end of the canal also contributes to the complexity. Further, the proximity and the exposure of the canal to the sea near and through the Main Drain may have added to this. This was clear in the conductivity values.

The tributary canals too contributed to the pollution of the San Sebastian canal. This was clearly evident in most of the pollutants that entered from the Dematagoda ela, the Kittampahuwa ela and the Main Drain. This is mainly due to the entry points which have strong organic discharges from the large scale industries. Although there were contributions from the Maligawatte and the Kettarama canals the loadings into the receiving sites appeared minimal. Of the tributary canals the Main Drain appeared to be the most polluted water way. This is due to the presence of two confectioneries that discharge into this canal. The organic loading into the San Sebastian canal at the confluence point of the Main Drain in terms of the BOD and the COD was the highest in the entire monitoring programme. This illustrates the strength of the food wastes. The Dematagoda and the Kittampahuwa canals also had industries near the confluence of the San Sebastian canal. Thus the tributary waters were of equally poor quality with very low DO levels and aggravated the pollution of the San Sebastian canal.

The results indicated that the San Sebastian canal in turn polluted the river Kelani downstream of the confluence. This can be seen in the concentration of the pollutants at the upstream and the downstream sites of the confluence with the river i.e. R01 and R02. The concentration of the pollutants was higher at R01 which is the downstream site. The DO level was lower at this site of the two monitored in the river. The San Sebastian canal water which flowed into the river was blackish and oily. There was a clear demarcation between the water of the San Sebastian canal and the clearer river Kelani water as seen in plate 9.1. Due to a larger volume of water in the river the concentration of pollutants were lower than in the San Sebastian canal.

But the DO level at R01 indicated that the river was at a marginally dangerous level of being polluted. Similarly at the other end of the canal, the entry of the canal water into the lake by means of pumping has a high potential to pollute the lake waters. The two monitored sites in the lake indicated gross pollution.

Plate 9.1 — The water quality difference at the confluence of San Sebastian canal with the river Kelani

Source: Ministry of Physical Planning, Housing and Environment (1986)

The industrial discharge sites on the canal indicated that they did not meet the standard specifications for the COD, BOD, DO and SS. A higher percentage of the total N and total P were not met at the industrial receiving sites. The pH standards were not met at these sites. A higher percentage of the conductivity and the sulphate were also not complied with at these sites. Aesthetically, most of the sites did not meet the specifications. Nutrient enrichment had taken place in many of the sites, which was clearly visible in the luxuriant growth of *Eichornia crassipes* and other aquatic plants. In the tributary canals, the industrial discharge sites did not conform to the specifications. In the river Kelani the downstream site (R01) of the San Sebastian canal had a higher percentage of the pollutants not conforming to the standards than at R02. In the lake the industrial site U02 had the same trend other than the conductivity. The aesthetic condition and the nutrient enrichment were similar to the San Sebastian canal in the lake and the tributary canals. In the river Kelani floating aquatic plants and other materials were visible on many occasions

Based on the standard criteria for inland surface water quality (CEA, 1985) the canal can be classified according to the river classification adopted by the National Water Council of the U.K (Toms, 1985). Appendix O gives the U.K. river classification. According to this classification the sites along the San Sebastian canal other than S01 and S02 fell between Class 3 and 4. The sites S03 to S07 fall into class 4, while S08 to S10 fell between 3 and 4. Sites S01 and S02 met the DO specifications

but did not meet the COD and the BOD at certain times of the year. The DO level in the canal alone is sufficient to designate the canal as grossly polluted. This is clearly seen in the oxygen sag from the site S03 to S07 and the slight aeration that took place at from S08. This situation can be seen in Figure 9.1. Thus in accordance with the class 4 of the classification the water quality in the canal is inferior in terms of the DO and the BOD and is anaerobic at times. Between S03 and S07, which were mostly industrial waste water receiving sites the canal water was anaerobic during most part of the year. This is particularly true of the sites S03, S04 and S06. Thus the waters were grossly polluted and at nuisance level. This is also true of the other water bodies monitored, particularly the industrial waste water receiving sites. Hence the water bodies were incapable of supporting fish life.

The San Sebastian canal, overall presented an example of a grossly polluted canal. Although the water was relatively clean at the origin of the canal (possibly due to the pumping station), it became heavily polluted as it progressed. The contrast between the sites S02 and S03 was very sharp. As the industrial discharges entered at the latter site the DO level fell from a maximum of 14.8 mg/L at S02 to 0.0 at S03 (median of 9.65 at S02 to 0.03 at S03). Thus from S03 downwards till S07 the pollutants were very high with slight fluctuations. Although there was a fall in the pollutant concentrations from S08, a high level was still maintained by the upstream industrial sites and the tributaries that discharged into the San Sebastian canal. The San Sebastian canal in turn discharged highly polluted waters into the receiving river Kelani. Although there was a buffered effect at the terminal site on the canal due to low flow (or even stagnation), lockage and the tidal effect (which also may have helped to contain the pollutants within the canal), it discharged highly polluted waters to the Kelani river. At the other end of the canal the pumping of the water into the Beira lake potentially polluted the lake. Therefore, the San Sebastian canal polluted the receiving waterways at both ends.

9.2 Industrial pollution

The industrial discharges indicated that the food industrial waste waters are highly organic, strong and therefore highly polluting. This was clearly evident in the water quality of the receiving sites. The organic strength in terms of the COD and the BOD in the industries were very high with the maximum at the confectionery F, with a COD of 29,920.0 mg/L and a BOD of 22,800.0 mg/L. The COD and BOD were also very at factory B. he receiving waters were the Main Drain and the San Sebastian canal respectively. The SS was also high in the factories, which was also reflected by the turbidity. The SS contributes to the organic load. This high organic loading is reflected in the very low DO levels in the receiving sites. The nutrient loading into the canal by the factories varied with the different products. The total N was higher in the meat processing and the creamery than in the other factories. The total P was high at A5. The detrimental effects of a high nutrient loading into the canal was evident in the luxurious growth of aquatic plants such as *Eichornia crassipes*, and *Salvinia molesta* was present at some sites. This was evident in all the monitored water bodies. The pH ranged from acid to alkaline. The pH was very high at the carbonated soft drinks and low in the margarine waste waters. The water temperature remained high in most of the industries. The high water temperature has detrimental effects on the receiving sites in a two-fold manner on the receiving sites. The heated effluents raises the water temperature of the receiving stream whereby it is directly harmful to the aquatic fauna and the flora in addition to lowering the DO. This effect was felt at the receiving sites where the DO was low and there was no fish life. It was revealed by the residents along the San Sebastian canal that the fish entered the canal from the river only during the floods in the river Kelani.

The correlation between the industrial discharges and the corresponding receiving sites indicated positive contributions into the receiving sites. There was a high positive organic loading which had a detrimental effect on the DO. Even the loading of the other pollutants by the industries into the receiving sites were high. The industrial discharges also had detrimental effect on the downstream sites. The results although very clear, were dampened by the lower monitoring frequency in the industries.

The study also indicated that there were no proper treatment facilities in any of the industries monitored along the water bodies. Factory C, had only a fat trap which

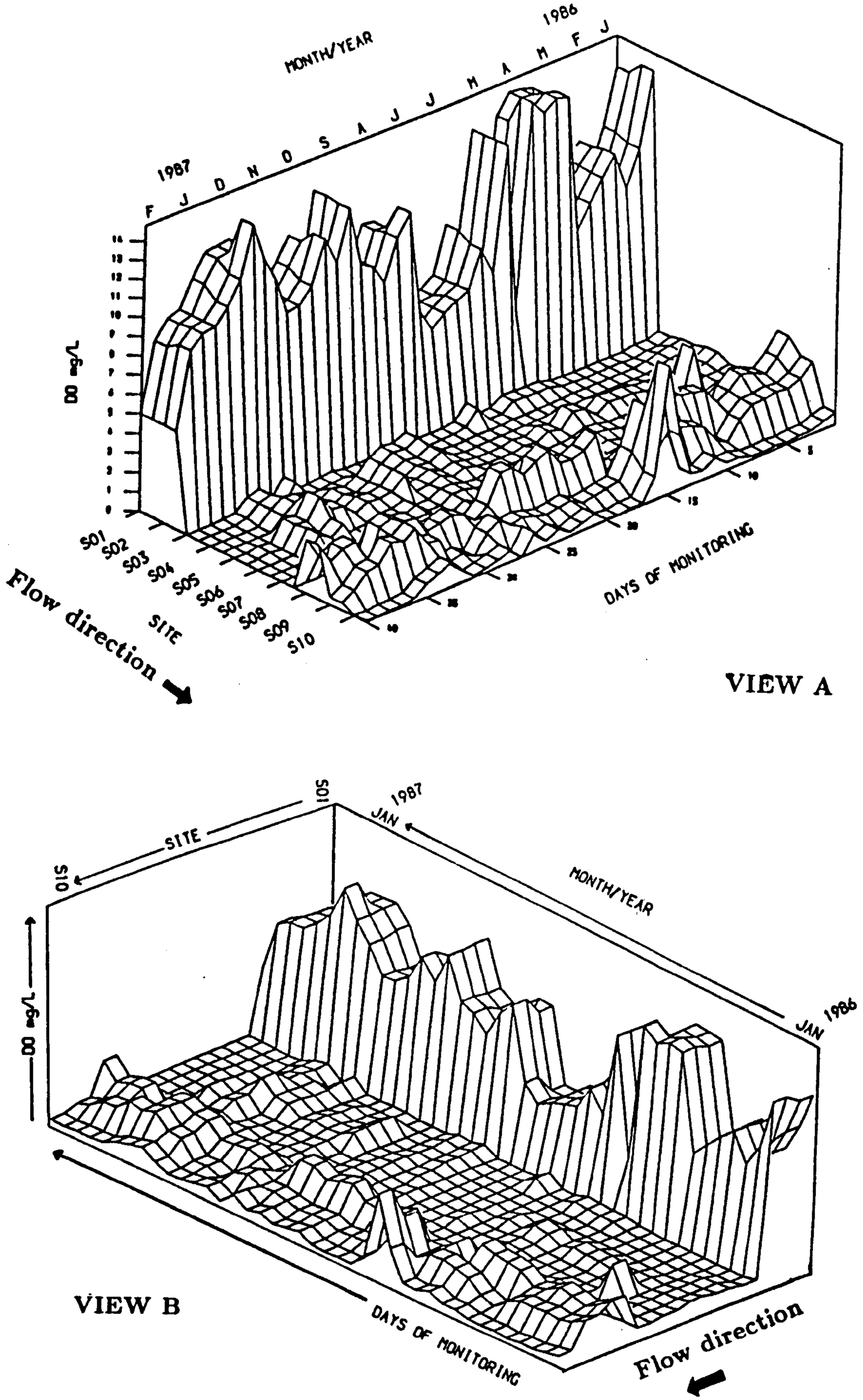


Figure 9.1 — The DO sag along the San Sebastian canal

Source: Field monitoring

was for the recovery of the fats and oils, but the entry of oil into the canal at this point was evident. Among the supplementary industries only factory I had installed proper treatment facilities. Factory J had a sedimentation tank constructed after the research period. Factory F had a sump to collect the waste water, but the waste water was sent to the canal without any form of treatment. Thus all the factories other than these were discharging untreated highly organic waste waters into the receiving sites.

The correlation between the pollutants in the industries indicated certain striking relationships. There was a high positive relationship between COD and the BOD, while both these had a negative relationship with DO. The SS and the turbidity was positively correlated. The water temperature and the DO were negatively correlated. These relationships indicated the organic strength of the pollutants and the detrimental effects on the DO content of the receiving waters.

The compliance with the standards in the industries were poor. In the soft drinks (A2), creamery, soapery, confectionery and the meat processing (G1) the COD and the BOD standards were not met. Even in the other industries a high percentage of these standards were not met. None of the samples met the SS specifications at the fruit and drink industry (J) and the meat processing (G1 and G2) . In the other industries a high percentage did not comply. In the soft drinks and the soapery a high percentage did not meet the pH standards. The total N specifications were not complied at the meat processing (A3 and G1) plants. A fair percentage of the water temperature standard was not complied at most of the industries.

The COD:BOD ratio of the industrial waste waters indicated that most of the industries had ratios suitable for biological treatment. The significantly high correlation between the COD and the BOD in the industrial waste waters substantiated this. Therefore, for the food and drink industries monitored, the sufficiency of simple biological treatment was indicated.

9.3 Biological pollution

The biological analysis done for one set of samples in the San Sebastian canal for faecal coliforms indicated that the entire length of the canal was heavily polluted. This indicates pollution from domestic sources. The shanty population along the canal in addition to the domestic outlets of the industries in the form of toilet waste waters are responsibile for this.

9.4 Rainfall-pollutant relationships

The rainfall-pollutant analysis which investigated the relationship between the variables and the rainfall, indicated some important relationships.

The rainfall-DO gave a positive correlation in most of the sites, but the strength and the level of significance varied widely from the relatively non-polluted site S02 to the industrial sites. The strength of the correlation was stronger at the non industrial sites which indicated the aeration capacity, while the reaeration in the industrial sites remained low. Over the monthly and the seasonal time scale the correlation significantly improved in the non industrial sites while in the industrial sites, although the correlations improved which indicated the dilution of the pollutants due to reaeration, the correlation remained lower than the former sites. There were peculiarities in the industrial sites especially in the seasonal analysis which showed that over a long period (due to continued discharge of pollutants) the relative unimportance of rainfall as a dilutant. The industrial sites in the San Sebastian canal, the lake and the tributary canals had a similar trend.

The rainfall-COD indicated a negative trend. The correlation was high and significant at S01 and S02, while at the industrial sites the correlation was lower and insignificant. In the monthly analysis certain industrial sites improved, but in the seasonal analysis the correlation in the industrial sites did not improve at S03 and S04. At S06 the seasonal correlation was isolated. But, the general negative trend remained in most of the sites. Thus higher the rainfall lower was the COD other than in the industrial sites where the dilution due to rainfall tended to remain weaker. In the industrial sites of the other water bodies too, virtually the same trend prevailed with the insignificant correlations at these sites.

In the rainfall-BOD analysis the relationship was similar to the COD with highly significant correlations at the non industrial sites and lower correlations at the industrial sites. In the monthly analysis the correlations improved in most of the sites, but in the sites S06 downwards the level of significance was low. In the seasonal analysis the coefficients improved at S01 and S02 but fell at the industrial sites such as S03 and a zero correlation at S06. Other than at S10, the negative trend was maintained. Basically there was dilution of organic pollutants in terms of the COD and the BOD during rainfall and concentration at the drier periods. As the organic load at the industrial sites were too high there was a weaker correlation at certain sites, although there was some improvement in the relationship over time that indicated dilution to a some extent. Virtually the same trend at the industrial sites of the other water bodies prevailed.

The rainfall-SS correlation was positive in most of the sites. The correlation between SS and the rainfall was higher between S03 and S07. The level of significance also remained high. Comparatively the correlation at the sites S01 and S02 remained lower. The monthly and the seasonal correlation also remained high. This may be both due to the high base level SS that entered the canal from the industries and the SS that re-entered the canal from the dredged materials of the canal banks. Although the correlation improved at S08-S10, the significance remained low. Thus the significance of rainfall was lower at the sites closer to the tidal river. In the lake sites the industrial waste water receiving site U02 appeared isolated with a negative correlation in the SS-rainfall analysis.

The rainfall-conductivity relationship in the San Sebastian canal was negative. In the monthly analysis the coefficient did not improve in many sites, but the seasonal correlation indicated significant improvement in the non industrial sites. At the industrial site S03 it was the weakest in the seasonal analysis. Among the other water bodies the correlation at R01 in the river and U01 in the lake remained weak. This may be due to the influence of the sea felt at these two sites with higher conductivities and thus lower dilution by rainfall. Among the industrial sites, at U02 the correlation was weak in both the daily and the monthly analysis, but improved in the seasonal analysis. But the level of significance remained low. In the tributary canals the coefficient ranged widely. In the monthly analysis it improved to a negative trend indicating dilution. Sites in the Main Drain improved significantly. Site T03, an industrial site remained weak. In the seasonal analysis the correlation was negative in all the sites indicating dilution of the dissolved salts over a longer period. In the industrial sites of T03 and T13, although the correlation improved the significance remained low.

The total N-rainfall was similar to the DO-rainfall. The relationship was positive. The correlation improved in the monthly and the seasonal analysis, but the significance remained low. This may be due to the lower number of cases. The positive correlation indicated that there was a supply of total N with rainfall to the sites. The industrial sites had a higher coefficient that indicated a higher base level total N input into the sites such as at S04 and S06. The former site also had domestic inputs from the shanties. Site S10 was different with a negative correlation in all the analyses that may be due to the tidal influence at this site, which makes the situation more complex. As the data is sparse for the total N definite conclusions cannot be made. The relationships in the other water bodies also indicated a positive relationship at most of the sites. In the industrial waste water receiving sites such as at U02 the correlation improved from the daily to the seasonal coefficient. But the correlation was lower in the seasonal than in the other sites which indicates that there was a higher contribution from the industrial discharges than from the rainfall. The positive correlation also indicates there was a contribution of total N from rainfall. In the tributary canals all the sites had positive relationships except T11 which was negative.

Therefore according to the results of the rainfall-pollutant analysis the San Sebastian canal sites may be broadly categorised into three distinct segments. The sites S01 and S02 appeared less polluted with more dilution that took place during the rainy periods and therefore the pollutant concentrations were less. Sites S03 to S07 which had the industrial waste water discharges had lower dilutions which is due to higher and continuous discharges of pollutants by the industries and thus the rain-

fall as a natural dilutant appeared very weak at these sites. The sites S08 to S10 appeared distinctly different from the former two groups and more complex with less clear relationships. This is due to the entry of tributary canals, industrial and the agricultural runoff, openness to the sea outlet and the tidal waters particularly at site S10.

9.5 Rainlag-pollutant relationships

The rainlag-pollutant analysis which was a more specific and time related analysis, aimed at understanding the dilution-concentration effect of the lagged rainfall on the pollutant concentrations and the examination of the assimilation capacity of the receiving canal sites indicated some precise relationships between two consecutive days of monitoring (n and n-1). The lag analysis showed clear trends in the non polluted, the polluted industrial waste water receiving sites and the more complex downstream sites in the San Sebastian canal. The assimilation capacity of the canal was higher in the non polluted sites. The lagged correlation coefficient remained significantly high in these sites. In the polluted sites with industrial waste water discharges the lagged coefficient remained low and insignificant which indicated that the previous rainfall did not have much effect on the concentration due to the lower assimilation capacity of the canal. But the highest coefficient in the lags between n and n-1 indicated that even slightly higher rainfall within the monitoring periods had effect on the pollutant concentrations. Similarly the low rainfall within n and n-1 had a resultant higher concentration of pollutants. This is due to the lower assimilation capacity of the industrial waste water receiving sites. In the tidal site the rainlag had been less effective in the fluctuations of the pollutant concentrations, the precise relationship between the concentrations and the lags were magnified and thus clear.

Both the rainfall-pollutant and the lag analysis indicated that in the industrial waste water receiving sites the concentration of the pollutants were too high for the rainfall to dilute. The lag analysis also indicated that the assimilative capacity of the industrial waste water receiving sites were low. Thus the treatment of the food and drink wastes becomes mandatory to maintain the San Sebastian canal as a polllution-free waterway. As the canal is a relatively small waterway it cannot cope with the heavy input of pollutants from the industries as the volume of water in the canal is too low for dilution of the high organic wastes. Further the self purification and reaeration are impeded because the pollution load is buffered both due to the locks at both the downstream end of the canal and the tidal river.

9.6 Recommendations

The chemical and physical monitoring in addition to the visual observations indicated the gravity of pollution. The monitored industries indicated the discharge of highly organic waste waters which caused the depletion of DO in the receiving sites. This was very conspicuous in the San Sebastian canal. The pollutant concentrations tested against the relevant available standards both in the canal sites and the industrial discharges indicated a situation where most of the effluents failed to meet the standards. The industries indicated a gross polluting situation. Only one industry had proper treatment facilities. The rainfall-pollutant and the lag analysis indicated that at the industrial discharge sites, rainfall was not an important dilutant of the pollutant in the receiving sites. The lag analysis also indicated the poor assimilative capacity of the San Sebastian canal at the industrial sites. The failure of the SW monsoons indicated the vagaries of the rainfall. Thus the confidence placed on a high tropical rainfall situation as a dilutant is debatable. The COD:BOD ratio of the food industries indicated the highly organic nature of the waste waters and the amenability to biological treatment.

Thus from the results of the research it becomes important to control the industrial waste water discharges that enter the canal and to take steps to protect the San Sebastian canal and the the other water bodies. This is important to revitalise the canal system in the future so that the much needed DO is restored. This will revive the nearly dead system into life.

Thus to revitalise the canal system certain measures may be recommended. The shortcomings in the pollution control mechanism in Sri Lanka and the appropriate

lessons from the other countries, both from the East and the West are referred to in the recommendations. A spectrum of situations and altrernatives may prove useful for the country in the decision-making process.

9.7 Industrial discharge control measures

9.7.1 Control measures for the older existing industries

Pollution control was virtually non-existent in the industries before the Ennvironmental Act of 1981 was enacted. The existing older industries were not sentitive to the existing pollution problem. Even if these industries felt the pressure of pollution, it was regarded as external to the normal functioning of the industries. These industries had not even determined the nature and the characteristics of their discharges. Not having incorporated measures at the time of planning, they were concerned about the technical and the cost aspects of pollution control. Most of the existing factories in the study area were situated in highly urbanised areas and faced the shortage of land for the installation of waste treatment facilities. These physical limitations might compel them to resort to highly sophisticated and energy intensive treatment units that involve high capital and operational costs. In the case of smaller industries it may even force them out of business.

Under these conditions a compromise in the approach to pollution control has to be considered regarding these industries. With the view to accommodate the genuine difficulties faced by the industries a 'grace period' has to be given to commission and install treatment plants. If for any reason the industry is not able to meet these conditions for genuine reasons, they may contravene these conditions with a licence from the CEA. These industries may be charged a fixed rate per metric tonne of BOD discharged into the inland surface waters. The rate of charge may vary according to the use of the inland surface water. The rationale for the charge should be to bring these older industries in the direction of pollution control. But at some stage an ultimatum has to be met, with compliance to the quality standards set by the regulatory body.

An example may be taken from Malaysia, where 100 dollars (Malaysian) are charged per metric tonne of BOD discharged into the inland surface waters within the water catchment areas and $100-500 per kilogramme of toxic chemicals discharged. This approach is very important for improving the water quality of the San Sebastian canal as all the industries are the older industries that existed before the enactment of the law. Without a positive, firm and uncompromising attitude backed by punitive measures to bring these industries in line with pollution control, the cleansing of the waters of the San Sebastian canal and the other water bodies can never be achieved. To begin with the large scale industries in the area need this approach. If the installation of the treatment facilities is too expensive for the smaller plants a central municipal treatment plant may be installed or these industries may be moved out to industrial zones which have such facilities.

9.7.2 Incentive and financial help for the industries

The economic costs of pollution damage is estimated to vary between 3-5% of the GNP in the developing countries and the pollution abatement cost estimated is 0.5-1.0%. The effects of water pollution control on plant operations is not projected to be significant. It is 1-5% of the manufacturing costs (Hinnawi, 1982). The pollution control expenditure by industry is sizeable. The industrial capital expenditure spent on pollution control is 5% in the food industries. In several industries it ranges from 1-17% (Marshall, 1979).

This cost is borne by the industry in three ways i.e passing to consumers, reducing profits or by government subsidy. If the plants face a critical pollution cost (or critical control cost) which causes a plant to go out of business, (assuming no price increase) the government should step to help these industries threatened by closure due to additional pollution cost (Oslon, 1979). In the USA the Federal government helps the industries with these pollution control costs in the form of tax benefits for the

industrial plant equipment expenditure, rapid amortisation(the period for pollution control equipment being 5 years) which also covers process changes that avoid the creation or the discharge of pollutants, and investment tax credit for all types of equipment, which is an incentive to buy capital equipment for pollution control by the industries in the first year. There are also four significant Federal programmes to help finance pollution control expenditure i.e. Industrial Development Bonds, Small Business Admininistrative Direct Compliance Loans, Small Business Administration Lease Gurantees and Farmers' Home Administration Loans which are mainly for the food processing industries (Marshall, 1979). In Brazil, bank loans are given to cover part of the capital requirements and to assist industries that install water pollution control systems. Assistance is also given to local pollution control equipment manufacturers. In Malaysia a rebate on pollution charges is given to the industries which engage in pollution control research.

The old and the new industries in Sri Lanka which might be threatened by closure due to pollution control costs may be helped by the government in the form of loans, tax incentives or other means of funding to stay in business as practiced in some of the countries discussed.

9.7.3 Charging mechanism for the industries

The current methods by which industrial waste waters are controlled in many countries is by the consent given to discharge to public sewers or receiving streams. In the UK, former FRG, USA, France and Malaysia a charging system is operative in relation to both the volume and waste water characteristics. In the UK and in many other countries a charging system is also used to pay for the municipal costs in operation and maintenance of sewers and treatment works. Thus the public authorities are compensated for the efforts in disposing the waste waters. The scales of charges ensure that the plant has an economic incentive to improve the quality of the effluent. Therefore the industries can opt for either discharging to a municipal treatment plant or discharge treated wastes to a municipal sewer or discharge treated or acceptable wastes to a river directly.

The charges imposed on the industry discharging into a municipal sewer by the Regional Water Authorities in the UK is based on the following formula,

$$C = R + V + \frac{O_t}{O_s} * B + \frac{S_t}{S_s} * S$$

where,

C=standard unit charge
R=reception and conveyance charge
V=volumetric treatment
B=biological treatment
S=sludge treatment and disposal
Ot=COD in mg/L of the trade effluent after one hour of quiescent settlement. In rare cases where COD is not applicable an alternative oxidation parameter will be applied
Os=regional weighted average COD in mg/L of settled sewage. In rare cases where COD is not applicable an alternative oxidation parameter will be applied
St=total suspended solids (TSS) in mg/L settled in one hour from the trade effluent
Ss=regional weighted average of TSS in mg/L removed from crude sewage by primary settlement

There is an additional charge of R+3.50 for discharges through the sea outfalls (Anderson, 1987).

Trade effluent charges are payable half yearly in arrears. If it is only practicable to sample a combined discharge of trade and domestic effluent, Ot and Os will be adapted to reflect the trade effluent component only. Any domestic sewage component will be assumed to be of average strength. If an industry makes a capital contribution towards the expenses of disposing of the discharge then the authority will agree to an

appropriate adjustment to the effluent charges.

In Sri Lanka a similar or a modified charging system might be adopted by the regulatory authorities to levy a fee for the pollutants discharged into the receiving waters. This will enhance water quality in the receiving streams by directing the industries towards pollution control. Of the industries monitored, factory C is a multinational company, which should be able to have its own treatment plant, while B (a large scale industry which was in financial difficulties due to mismanagement) should be able to install at least primary treatment with some government assistance. An effluent charge therefore will direct the industries in the path towards reduction or the control of waste water discharges. As there are many other industries which are agro based with high polluting loads in terms of BOD discharges an efficient and strict charging system could eliminate a good percentage of the organic loading into the canal, which will naturally revive the DO of the canal. This is also true of the other water bodies.

9.7.4 Industry based and time specific discharge limitations

In the USA a technology-based effluent control system was designed to limit the quantity of discharges of pollutants from the point sources into any body of water with the ultimate aim of zero discharge. This was effected through the National Pollutant Discharge Elimination System (NPDES). Permits are issued to the industries to achieve this. There are stepwise regulations on the effluent limitations with specific industrial category related limitations. Under this system all classes and categories of industrial point source discharges of pollutants are required to meet the effluent limitations based on the Best Practical Control Technology (BPT). This technology has been defined by the US EPA to represent the average of the best existing waste treatment performance within each industrial category or sub category. The Best Conventional Pollution Control Technology (BCT) set forth a new technology based requirement for effluent limitations where conventional pollutants are regulated. The conventional pollutants defined are the BOD, SS, pH and faecal coliform. There is a set of effluent guidelines for these and were meant to be achieved by 1984. The food processing industrial group falls under the BCT. Similarly for non conventional pollutants such as toxic wastes, the Best Available Technology Economically Achievable (BAT) was applicable. The allowed pollutant discharge is based on the production capacity and the product processed. The technology based pollution control system came into being with the Federal Water Pollution Control Act (Amendment) 1972. The specific industry based effluent control system also exists in India (WHO, 1983b). This system has the advantage of identifying the effluent characteristics of a common group of industries which could be controlled by a common set of standards.

To this mechanism may be added a specific time factor for regulating the effluent discharged such as in the system operative in Malaysia. Malaysia has a six generation set of effluent standards for palm oil effluents and a four generation set of standards for the rubber industry based on economically viable technology. This came into effect with the Environmental Quality (Prescribed Premises)(Crude Palm oil) Regulations of 1977 (Warta Keranjaan, 1977). During the first year of implementation (1978), the compliance with the discharge standards of 5000.0mg/L of BOD was not mandatory. Therefore a sufficient lead time for the building and the commissioning of treatment system and development of technology was given. But to give the industry a push in the direction of installing the treatment facilities an effluent related fee was charged on the 'polluter pays' principle. Over a discharge of 5000 mg/L of BOD 100 dollars (Malaysian) per metric tonne of BOD load was charged, but only 10 dollars for 5000 mg/L or less of the BOD discharged. But during the second year of the enforcement of the law it was mandatory for the mills to reduce the BOD to 2000 mg/L. The specific time phase varied between 6 months and one year over the entire period. Thus the desired target of 100 mg/L of BOD for the palm oil mills and 50 mg/L for the rubber mills was achieved. By 1983, 80% of the palm oil mills were in full compliance with the specified standards (Singham and Maheswaran, 1985).

Therefore, such an approach based on the specific industry and time related effluent control to achieve a desired goal is essential for a Sri Lankan pollution control strategy. Although Malaysia and Sri Lanka started pollution control strategies simultaneously i.e after the Stockholm Conference of 1972, Malaysia is far ahead in the

the pollution control mechanism. This is mainly due to clear identification of the two most polluting (also the economically most important) industries, the palm oil and the rubber mills together with a clearly well phased and stringent regulations.

9.7.5 The concept of zero discharge

Another approach towards the industrial water pollution control is the ideal state of 'zero discharge'. Much of the waste water generated is unnecessary. Large amount of money is spent on waste removal and investment in the treatment plants. Investment in pollution should be looked upon as research and development, and pollution control should be looked upon positively and constructively. New products and processes often emerge with such an approach. Efforts or change in the attitude by the industries from a conventional pollution control to pollution prevention approach is important. This may be achieved by use of the most rational use of the resources to improve the water quality. This means the elimination of the causes of pollution before spending the money and resources to clean up afterwards. Therefore the aim of the industry should be to use the resource conservation technology where ever possible and practicable. This entails the creation of non-waste or low-waste technologies and learning to create valuable resources from the waste waters. Resolute steps should be taken to minimise the amount of waste that originate in the industrial processes.

9.7.6 Specific industry based practices

The advantages are evident as one considers the financial implications, the natural resources, manpower and energy required to build a pollution control plant and operate it throughout its life span. This could be achieved by proper inplant measures such as modification or replacement of raw material input, modification or replacement of production processes, segregation of strong waste streams, in-plant recirculation of water, changing product output and good housekeeping. Even with all these precautions some waste waters will be generated in production. The wastes produced after production could be reduced to a considerable degree by materials recovery, by-product production, waste utilisation and effluent reuse. The wastes generated after all these considerations and applications may be subjected to some form of treatment before it is discharged into the receiving water.

In-plant practices

Simple in-plant practices in the food industries will reduce the pollution load discharged into the receiving water. The minimisation of the solids by screening all the sewer openings especially in a meat preparation area not only reduces the SS but also the BOD and the fat and grease content. The collection of the grease near the source of production also guarantees a saleable quality product. This same practice can be extended to the confectioneries which have high SS and grease. A simple fat trap also can help, but a problem in such a situation will be the synthetic detergents used for cleaning purposes which will emulsify any grease and oil present. In the soft drink industry screening or settling may reduce the SS. Alkalinity of the waste waters which is mainly due the synthetic detergents may be neutralised by adding alum or lime. The change of the phosphate-based detergents to low or non-phosphate based detergents will reduce the nutrient content discharged into the receiving water. A change in the detergent use will also reduce the foaming and frothing. Process modification in the edible fats industry is a useful technique. A barometric scrubber will reduce the volatile materials and the fatty matter. The oil recovered is also of a higher grade than in a fat trap. Although there is a general reluctance to plant modification and manufacturing processes due to additional cost, if it is viewed as an integral part of manufacturing the total operating cost can be minimised. Plant practices such as the use of food colour from a lighter to a darker shade reduces the waste water volume generated (as the water use for washing of the mixing vats after every operation is greatly reduced). This reduces the polluting load. This system for example is practised at Rowntree Mackintosh, U.K (personal communication, Coates P. - 1985).

Waste stream segregation

The principal sources of pollutants are limited to special plant operations. If these are segregated from the major plant effluent, the pollution load will be consid-

erably reduced. In the meat industry blood is very polluting with a BOD of about 100,000mg/L. The colour also persits even in high dilutions. In the confectioneries bulk of the pollution emanates from the washing and cleaning of storage vats, dissolving vessels, cookers, shaping and cutting areas, and from floor washing. In the soft drinks plants mixing vats and the first bottle wash effluent are the most polluting operations. In the edible fats, milk preparation vessels, mixing tanks and rotators, and in the creamery, the mixing vats and the milk bottle wash operations have high polluting loads.

In some processes the effluents have high temperatures, such as the soft drinks, dairies and the confectioneries. These waste waters may be intercepted and kept standing for a few hours before finally discharged into the receiving water.

Good housekeeping

Good housekeeping practices can minimise the polluting load discharged into the receiving waters. The first rinses of the tanks and equipment that contain the most residual organic matter could be restricted in volume, and the residue can be collected for separate disposal or even incorporated into the next stage of production if hygienically done. Overflows of tanks can be prevented by larger tanks or by an alarm system which will reduce the floor spillage. Even if these occur it can be carefully gathered before hosing which will reduce the pollution load. Dry cleaning techniques will also reduce the pollution and the hydraulic load, and efficient use of water without wastage will reduce the the pollution load discharged into the receiving waters. Good housekeeping practises due to the combined efforts of the management and the operators may minimise bad housekeeping. A waste manager would be an asset in controlling pollution.

Reuse and by-product recovery

Reuse and by product recovery has to be viewed as an ultimate measure in pollution control while the disposal of liquid effluent into an aquatic environment has to be seen as an interim measure until a product recovery system is found. In the soft drink industry the final rinse water can be reused in successive operations such as for the first bottle wash, since it will have only have a slight detergent carry over. It can also be treated for further use without serious difficulties. Recycling of cooling water is another possibility. Reuse of remnant sweets is done at the factory F, where the recovered chips are reused in the next stage of production. Recycling of water is practised to a certain extent at factory C and F. By product recovery is not practised in any industry other than in C where the fats and oils are recovered in a fat trap. This is done as a raw material recovery rather than a by-product recovery. But in the food processing industries by-product recovery has good potential as there is no danger of toxicity.

The advantages of by-product recovery are evident when some examples are considered. In the palm oil mills in Malaysia, fertilisers are produced in the form of pottash by incinerating fresh fruit bunches, fibre and shells; and mulching materials from the leaf fronds, fruit and fibre. After the oil extraction the kernel is converted into animal feed. Partially treated effluent from the anaerobic digestion process is used in land applications as fertiliser. One establishment, Ajinomoto Berhad (Malaysia), which produces monosodium glutamate converted its liquid effluent into a new product line producing fertilisers. This earns the Malaysian company $ 500,000/year (Sundaram, 1984). From separated milk, cream and cottage cheese; cream butter and lactose from whey; and concentrates for use in the confectioneries, bakeries medicines and animal feed are products recovered from the dairy industry. Protein is dried and the lactose liquor further concentrated to recover sugar by crystallisation. This reduces the BOD from 35,000.0 to 1000.0 mg/L (Borne, 1974).

Protein is a potential by-product that may be tapped in the Sri Lankan food processing industries. Experiences in the other countries show that it is recovered from the meat processing plants. Feeding trials on pigs and poultry indicated high nutrition values. Microbial protein production offers a method of recovery of some of the organic materials discharged from food wastes. This is a cheap source of protein second only to soya flour concentrate and nutrition supplement. Single cell protein (SCP) and fermentation products from the vegetable processing wastes, whey products from the dairy wastes chitin and chitosan from the crustacean and shellfish processing wastes, microbial media peptones from the fishery wastes are other possibilities (Green *et al*

1979). Liquid stillage is produced as a by product of fermentation in the distillation process in the distillery (one distillery can produce the BOD of a sewage from a city). All sugar based stillages are high in organic content, and in the US, grain alcohol stillage is evaporated and sold as high protein additive for animal feed, stock feed, fodder yeast and fertilisers. It is also an irrigant and crop fertiliser for sugar cane (Willington *et al* 1982).

9.7.7 Treatment of waste waters

Food processing waste waters are highly organic in strength either in colloidal or in dissolved form. Their strength is very high but are amenable to biological treatment. Pre-treatment is usually required to produce an equivalent effluent. Among the aerobic and the anaerobic biological treatment available the major and the more effective methods make use of activated sludge, biological filtration, anaerobic digestion, oxidation ponds, lagoons and spray irrigation.

In the meat processing industry the primary treatment used is the vibrating screen, grit channels, flocculation, sedimentation and dissolved air floatation. These processes reduce 80% of the SS and 42% of the BOD. Trickling filters are used in packing house wastes and 95% of the BOD reduction is achieved (Nemerow, 1978). In the dairy industry a pretreatment plant which includes screening, grease traps, pH control and settlement tank is used with partial treatment. At the Chard creamery U.K, a rotating biological filter was used to treat the creamery wastes. It also requires less space which is suitable for an urban environment (Jerrard, 1984). In the confectioneries any conventional biological treatment designed on the basis of volumetric and the BOD load can be used. In some cases where the biodegradability is poor due to inhibitory constituents such as menthol used in cough sweets, chemical treatment may be used. In the edible fat industry, biological treatment is necessary to reduce the BOD and the COD but sometimes chemical treatment is also necessary for acid and the barometric water. If the barometric water is small due to a recirculation system hydrochoric acid may be used instead of sulphuric acid which will reduce the sulphate concentration at a low cost.

Lagoons, spray irrigation and conventional filters which require large land area are not usually suitable for developed areas with land shortages such as Colombo where the industries are concentrated. Factories A, B, C, E and F are located in highly urban areas which requires in-plant pretreatment, common municipal treatment or some treatment facility which requires little land.

For example the Taunton Cider Company U.K, used a BOC Vitox Oxygenation pretreatment system to reduce its COD. This system uses a minimum of land (Bradstock, 1983). Pescod M.B. (personal communication, 1985) recommends evaporative lagoons in the tropical countries for wastes which can be segregated from the main effluent. Such a system was used in Thailand for soft drinks effluent treatment with a BOD of 8000 mg/L, isolated from the first bottle wash. Anaerobic lagoons are also strongly recommended for high strength agro-industrial wastes in hot climate, but these need land (personal communication - Pescod, 1985). Aerated lagoons require less land and suitable for food waste treatment, with a COD reduction capacity of up to 90%, but the operating costs are high. Where land is at a premium this is a useful treatment system. Anaerobic treatment systems are useful for strong organic wastes. This also occupies less land. Anaerobic digestion is widely used in sewage treatment works. Anaerobic contact process and anaerobic filter is very suitable for strong industrial wastes. Food processing waste water such as meat packing waste water which are hot on release is frequently treated by anaerobic contact process or by anaerobic filters in the USA. These techniques will be economical in an urban tropical situation where strong organic effluents are produced. The more recently developed anaerobic upflow sludge blanket offers practical and simple technology for large volumes of dilute effluents with short retention times of less than a day. Pilot scale trials showed 90% COD removal in a synthetic food processing effluent (931 mg/L COD, initial); 90-95% COD removal from industrial carbohydrate effluent (10,000 mg/L, initial); 90% COD removal from piggery manure effluent; 86% COD removal from dairy wastes (6000 mg/L COD, initial) and 71-81% COD removal from a synthetic starch processing (480 mg/L COD, initial), all at tropical temperatures (Lane, 1984).

The oxidation ditch, which is an aerated activated sludge system, has been

adopted in many urban areas in the tropical countries. This is simple to operate. Effluents from the condensed milk factory and soft drinks bottle washing plants in Thailand are found to use this. Rotating biological contactors are also used effectively under the tropical situations. These are simple to operate and can handle fluctuating waste water load common in the food processing and the drink industry. 80% BOD removal in the tapioca starch industry and 99% BOD removal in the rubber effluents were achieved in this system. Oxidation ponds are effective but costly.

An area treatment plant could be constructed to serve the industries clustered around the canal area. As the concentration of industries is high along the San Sebastian canal and the other water bodies an area treatment plant might may be a useful consideration. This will serve the older industries in the region. This may be a rational alternative to shifting the plants to an industrial zone. As the food processing wastes are amenable to biological treatment, a municipal treatment plant with suitable facilities may be helpful to the industrialists especially the small scale ones. In many advanced countries food wastes are usually treated in the municipal plants. The large scale industries may be requested to have pretreatment to avoiding overloading of the area plant. Even with the new sewerage project under construction, illegal discharges from the industries into the water bodies is bound to continue at least from the smaller and the backyard industries in the area. Therefore connection to a common municipal plant may eliminate such a situation. The municipal plant may supply the treated water for some industrial purposes to the industries of the area as most of the industries are dependent on the municipal water for production purposes. The installation cost of the municipal plant may be met by the government or the industries themselves or met partially by both parties. A service charge may be levied for the treatment. In the USA most food processors use the public system and over 42% of the food processes use the municipal plants for treatment (Cooper and Denit, 1979). In the USA the municipality or the publicly owned treatment works has an industrial cost recovery system, whereby the industries have to share the cost of construction and the user charges, whereby each recipient of the water treatment services has to pay the proportionate cost of operation and maintenance. The use of land is encouraged for food waste water treatment i.e the conventional pollutants.

Recent investigations have used *Eichornia crassipes* as a depollutant. It is a simple inexpensive biological method for treatment of various industrial waste waters. This aquatic plant thrives in most of the sites in the San Sebastian canal and the other water bodies. In Malaysia water hyacinth is successfully used for final treatment of mixed rubber effluents pretreated by anaerobic digestion before the final discharge. Effluents from the block rubber factory and latex concentrate factory in the Johore State in Malaysia treated with *Eichornia crassipes* indicated a substantial reduction in the total and ammoniacal nitrogen. The treatment of piggery wastes in Malaysia and tannery effluents in India with water hyacith is also successful.

In Sri Lanka the Rubber Research Institute has clearly shown the possibility of treatment of the effluents in the crepe rubber factory. Here the *Eichornia crassipes* improved the efficiency of the conventional ponding system by 50%. The non availability of sufficient land for construction of the ponding system in the urban area is the biggest problem for this simple treatment system, both in Sri Lanka and in many other conntries. The 50% reduction in the land requirement by using the depollutant is quite significant (Yapa, 1989). Thus this system which uses a pollutant as a depollutant appears economically viable as a simple, inexpensive biological treatment for the the food industries monitored which have high organic wastes.

9.7.8 Coordination: government, research bodies and industries

For a sustained and far reaching pollution control programme coordination, consultation and good relationship among the government, research institutes, universities, industry and the public sector agencies is important. Regular dialogue sessions and consultations with the industrial sector in formulation and implementation of the regulations, cooperation from the industries and commitment by the industries in funding the pollution abatement research with particular emphasis on breakthrough in the development of the low cost waste treatment technology suitable to the local situation is important. The development of the technical and economic data bases for appropriate treatment technologies and effluent limitations should involve substan-

tial programme for data collection, analysis and review both by the governmental and non-governmental bodies.

9.8 Stream protection measures

Pollution of the receiving stream can be either controlled by stream or water quality standards, or industrial discharge or effluent standards.

9.8.1 Industrial discharge standards

By the industrial discharge standards or the effluent standards the waste water discharged is kept below a fixed percentage or a certain maximum concentration. The effluent standards are based on the economic and practicability of treatment rather than on the absolute stream protection. Discharge standards have been introduced in many countries sometimes in isolation and sometimes in conjunction with general quality standards or other control mechanisms. In its simplest form the discharge covers the entire industries of the country. This approach is adopted in Italy and in Singapore. In both the countries separate sets of standards for different types of receptors were found necessary to be established (WHO, 1983b). In India, the Indian Standards Institution has published discharge standards for a number of industries. Although they are only suggested levels they are adopted and enforced by many state boards responsible under the Water (Prevention and Control of Pollution) Act of 1974. Standards for specific industries both conventional and non-conventional pollutants have been introduced by the US-EPA by laying down effluent limitations for waste waters from point source categories. The most specific means of establishing standards is on a case by case basis in the U.K. Effluent standards for industrial plants are fixed by the local regional water authorities. Non-mandatory guidelines are also used in certain cases either by the governmental authority such as Swiss National Environmental Protection Board in Switzerland or by a non- governmental body such as Landerarbeitsgemeinschaft Wasser in Germany. As the guidelines are non-mandatory the cooperation of the industry becomes important in this case. The discharge standards is a good control mechanism from point sources. A disadvantage to this approach is that there is normally no control over the total volume of polluting substance added to the stream. The best usage of the stream is not the primary consideration too. When the combined load of several industrial discharges exceed the self purification capacity of the receiving stream the regulatory agency may be required to set the effluent standards. This standard should be strict enough to protect the quality of the receiving which is tailored to the characteristics and volume of waste waters at each point of discharge.

9.8.2 Water quality standards

When the combined pollution load of several discharges exceeds the assimilative capacity of the receiving stream, water quality standards for the receiving water becomes important. The stream standard system is based on establishing classifications or standards of quality for a stream and the regulating any discharges in order to maintain the established stream classification or quality. The primary motive of the stream standard is to protect and preserve each stream for its best usage. The streams are classified in a manner set forth by state laws, sampled and analysed for existing pollution and surveyed for the present and potential usages. Formal notification is served on each polluter. No discharge shall create conditions that violate the receiving water quality standards. The main advantage of stream standard is the prevention of excessive pollution regardless of the type of industry, municipality or other sources. The pollutant load is limited to what the stream can assimilate. It may be that any given river or stream would have several categories of the the standards applied along the different stretch of the river in accordance with the highest beneficial use being applied at that time. The aim of the regulatory bodies is to enhance the quality of the receiving waters.

9.8.3 Other procedures

Procedures other than water quality standards are becoming important for improving the stream water quality. These are stream specialisation, stream aeration, low flow stream augmentation and pumped storage.

Stream specialisation

Stream specialisation works on the principle of allowing one stream to become degraded so that the others in the area are preserved in a pristine state. This system is similar to that of a stream classification except that it encourages the use of one stream as an 'open sewer'. This system operates in Germany where the river Emscher is used as an industrial sewer and is converted into a single purpose stream without stream standards to serve the concentration of the industries which provides employment in the region. Before the Emscher discharges into the river Rhine it is subject to primary treatment. A similar system to the open sewer of Germany operates in the Phillipines where the water usage of the river falls into class E i.e. with has a DO minimum of 1.0mg/L (Pescod, 1974).These streams are used for navigation and waste disposal to the extent that they do not cause a nuisance. The waters can accommodate the waste disposal within the limits of the prescribed specification for this class. This class is not assigned to waters with a use such as agriculture, industrial water supply, fishing, bathing or a source of domestic water supply.

This approach is not applied in Sri Lanka, and in the tropical countries in general, but should not be overlooked. This approach will have wider applications and minimal disruption to the environment when the government has to maintain a balance between the industrial development and pollution control, especially in a developed urban area, which also provides employment to many. The San Sebastian canal is centrally located in such an area. Therefore this approach may be viable for the canal. If the canal could be kept clean from floating materials and is desilted regularly it could be still used for recreation such as boating. This has great potential in a city like Colombo. It will also earn an income to the authorities. The treated water before its entry into the Kelani river can be used to replenish the Beira lake by a pipeline. Otherwise, as the gradient of the canal is negligible treatment could be done at the western end of the canal (at the Beira lake end) and the San Sebastian pumping station used to pump the canal water in to the lake to maintain the lake level. The lock gates (North lock gates) and the flood gates at the eastern end of the canal may be operated according to the water level in the river. By this means the Kelani river water may also be used to maintain the lake level during the low flow in the canal. The cost entailed will also be minimal, with only the construction of a treatment plant. The lake will also receive cleaner treated water. Further structural changes in the area will be minimal with virtually no changes.

Stream aeration

Stream aeration is a novel approach used to dispose waste waters for organic decomposable type of waste where the receiving stream is supplied with oxygen by artificial means. Although a very useful measure it is very costly. It is found less expensive to aerate the wastes than the streams. If the cost could be reduced it is a very useful technique particularly for the food industries which are found to have high organic, but decomposable wastes waters.

Stream augmentation

Low flow stream augmentation is a mechanism by which water is stored for diluting large amounts of pollutants. Dams or reservoirs built on upland of the main or tributary stream can store water during high flow periods to be released when the stream flow diminishes below critical values.

The pumped storage mechanisms is quite similar to stream augmentation. This has a great potential for protecting the stream from the excessive contamination during the low flow. Here the water is pumped during the maximum stream flow and stored away from from the main stream.

These may be useful mechanisms by which the Kelani flood waters (Kelani floods virtually annually) may be stored and used during the critical low flow conditions in the San Sebastian canal to flush out the pollutants in the canal periodically particularly in the dry critical months, through the Main Drain and the Mutwal tunnel into the sea outfall at Mutwal. This might entail only the construction of a reservoir to store the water.

As far as Sri Lanka is concerned both the discharge standards and the water quality standards may be important to control the pollution of the inland surface waters. Effluent standards are important to control the discharges from the industries which surround the San Sebastian and its tributary canal banks, the Beira lake and the Kelani river. The industrial waste water discharges are the primary cause for the pitiful conditions to which these fresh water bodies have fallen today. Effluent discharges will greatly reduce the pollution loads discharged into the inland surface water from the point source discharges, but the stream quality standard criteria is equally important to achieve this. It will provide a basis for evaluation of the effectiveness of the discharge standards. It will also operate as a surveillance mechanism to see whether the water quality is maintained at the desired level. If the water quality standards are not met at some particular point near an industrial discharge, the effluent standard for that particular industry can be made more stringent in order to improve the water quality of the receiving stretch of the water. The water quality standards also incorporates the concept of the receiving body which makes it more difficult to achieve than the effluent standards. In the state of Rio de Janeiro, Brazil, the approach to water pollution control has taken into account the assimilative capacity of the receiving bodies (WHO, 1983b).

Thus both the discharge standards and the water quality standards have to be seen as complementary to each other in order to regulate the industrial discharges while simultaneously maintaining the pristine water quality of the receiving waters and not in isolation as two different control mechanisms. This approach is very important to bring back the San Sebastian canal and the other water bodies to an acceptable state.

9.8.4 Standards: improvements and modifications

There are discrepancies and shortcomings in the Sri Lankan standards. The Interim Standards of the CEA (1985b) and the standards formulated by the Sri Lanka Standards Institution (1985) are subject to these.

The BOD standard specification for potable water (SLS-722:1985) is 5.0mg/L, while the Inland Surface Water Quality (fresh water) Norm i.e the modified Indian standards (2296:1973) modified by the CEA in 1985 is 3.0mg/L. The potable water which requires a higher pristine water quality which should have stringent standards has a higher BOD specification than the inland water quality norm. This indicates that there has been no clear coordination between the standard formulating authorities, and a lack of thorough and careful investigation into all the standards available in the country. Obviously the potable water requires a lower BOD specification than the inland water quality norms. Therefore either the BOD specification for the potable water has to be lowered or the stream quality norm has to be modified. If the latter is no longer meant to be used it has to be made redundant, by stating so precisely. Similarly the BOD in the standard specification (SLS-722:1985) does not appear clear. The 5-day incubation at 20°C is used as the reference method on which the 5.0 mg/L standard specification is recommended to be adopted, yet a 3-day incubation period at the ambient temperature is given as the routine method. At 20°C (which is the mean situation under the temperate conditions) and at the Sri Lankan ambient temperature with incubation for 3 days the metabolic rate, and therefore, the oxygen uptake by the degrading microorganisms may be different. Thus the 5.0 mg/L standard specification may not probably be quite an accurate specification for the routine method for the use in the laboratories. Although the routine method has to be commended for the recognition of importance of the ambient temperature in the biological degradation and thus the analytical method itself, the standard specification itself does not appear a natural equivalent. Therefore it would be more appropriate to base the standard specification on the 3-day BOD at ambient temperature and make it the reference method itself, thus clearing the ambiguity in the analysis. Further the 3 day BOD at ambient temperature recognised by Sri Lanka Standard Institution should be made the standard analytical method adopted in all the laboratories as some waste water monitoring laboratories still use the 5 day BOD at 20°C. This has to be enforced by the law, as in Malaysia.

In the Sri Lankan Standards (SLS-721:1985) i.e. the standard specification for industrial waste water discharged into the marine coastal areas the specification for pro-

cess water (100.0mg/L, maximum) and for cooling water effluent (100.0mg/L+10% influent) is clearly specified for the SS. There is no such definite specification for industrial discharges into the inland surface waters (SLS-652:1984). Only a fixed specification of 50.0mg/L is recommended. There is no specification for SS at all in the SLS Standard 722:1985, which is the criterion used for inland surface waters used as raw water for public water supply. The fresh water quality has to be given more or at least equal weightage. Further the industries discharge directly into the inland surface waters in Sri Lanka rather than into the marine coastal waters. Even if more industries discharge into the marine waters the assimilative capacity of the sea is greater than the inland fresh waters. Thus the assimilative capacity of the receiving water is not clearly not taken into consideration. This situation has to be rectified.

The Sri Lankan standards relating to the industrial discharges into surface waters have to be modified on a definite industrial group based standard. The Sri Lankan standard SLS 652:1984 for pH is 6.0-8.5. The Indian Standard IS:2490/1974 (Part II) has a range from 5.5-9.0 and the UK standards (Yorkshire Water Athority) has a range from 6.0-9.0 for discharges from the distilleries, cane sugar and the breweries (WHO, 1983b). Both in the Indian and the UK standards a pH range more suitable for the food industrial wastes which ranges from very acidic to alkaline conditions is recognised. But the Sri Lankan standard does not recognise this. The range is narrower in addition to the basic shortcoming of a fixed standard for any group of industry whether it is a food industry such as soft drinks or an industry producing toxic wastes such a pesticide industry.

Similarly the SS limit for the brewery waste waters specified by the Yorkshire Water Authority is 30.0 mg/L (WHO, 1983b) while in the SLS 652:1984 it is 50.0 mg/L for any industrial discharges into inland surface waters. The UK standards also indicate a regional component in the standards which may be a good approach to adopt in order to make the standards more stringent in the highly industrial urbanised industrial areas like Colombo.

The BOD standard also may be modified on a industry based criteria such as in Malaysia where, the BOD_3 standards the for palm oil mill discharge of 100.0 mg/L effective from 1.1.84 is different from the the BOD standard for rubber mills (latex concentrates) waste water discharges which has an additional specification of 50.0 mg/L effective from 1.4.1983 (Singham and Maheswaran, 1985).

9.8.5 Legislation: shortcomings and stronger enactments

Legislation to protect the inland surface water ways from pollution was enacted long before the National Environmental Act of 1980. The latter was the first comprehensive legal mechanism to protect the environment.

The pollution of inland fresh water bodies specially the San Sebastian canal and the Beira lake were mentioned in the Sessional Papers of 1946, with punishment meted out for violation of the law. The Municipal Council Ordinance of 1956 (Government of Sri Lanka, 1983) imposed a fine of Sri Lankan Rupees 50/- and an additional 10/- for the continuation of the offence on any person polluting the streams and watercourses which fed the municipal reservoir by bathing, washing or any other activity. The Municipal Councils and Urban Councils (Amendment) Act Number 2 of 1979 deals clearly with pollution from the industries within the Colombo municipal limits. If a factory within the Colombo Municipal limits causes pollution to endanger or prejudice the health of the neighbouhood a fine equivalent to twice the fee payable for a licence issued under the provisions of this ordinance has to be paid or, depending on the degree of pollution, the factory shall cease to operate. There are many relevant clauses in the legislation, but they are scattered and not codified into a single act.

The National Environmental Act of 1980 made provisions to establish a Central Environmental Authority which was given the powers as the chief coordinating and the regulatory body to matters pertaining to the protection and the management of all the sectors of the environment. But the experience in the past few years showed that the CEA did not possess sufficient enforcement powers particularly to stop the factories discharging untreated effluents into the inland surface waters. A paltry fine of Rupees 10,000/- charged by the CEA did not have effect on the factories. Because of the weak regulations an amendment to the 1980 act was proposed in 1988. The objective of the 1988 Ammendment Bill was to increase the powers of

the CEA, to cordinate all the activities of pollution and to protect the environment, to make environmental impact assessment (EIA) mandatory on all the new projects, and to give regulatory powers to the local government authority within its area of jurisdiction. With this amendment the CEA could issue consent conditions to the discharges of industrial effluents based the standard criteria.

The punishment by means of imprisonment upto six months for the violators especially the plant managers or the chairman, and the shifting of certain polluting industries were proposed in the Amendment Bill. A National Environmental Conservation and Management Plan; independent public participation and inquiry into the environmental problems (as in the Coast Conservation Act of 1981); to make publicly available pollution documents from the industries; the cooperation between the public, the supreme court and the regulatory bodies; and separate acts for water and air were proposed. The National Environmental (Amendment) Act was passed at the end of 1988 (Government of Sri Lanka, 1988). The second reading of this Environmental Bill appeared weak with no specific deadline to meet the discharge standards for the industries. The standards themselves were not specified. If the relevant clauses are clearly specified in the act itself like in the Malaysian environmental act the implementation and the achievement of the goal may become easier.

The Sri Lanka Land Reclamation and Development Corporation (Amendment) Act 1982 relates to the control, maintenance and the management of the canal system in Colombo. The Sri Lanka Land Reclamation and Development Corporation is the authority for the maintenance of the canals in Colombo. The legal powers vested in this corporation are weak. The powers to prevent the shanty and industrial encroachments into the canal banks and the water ways, (which impedes proper maintenance and enhances canal water pollution) is vested in the local bodies and other government departments. Therefore the limitations in the statues as to the powers of the corporation should be rectified so that it has full legal authority and jurisdiction to take all steps and measures to eliminate these drawbacks. The corporation should be vested with full legal powers to eject squatters and prevent squatter encroachments on the canal banks and to prevent obstruction to waterways and prosecute polluters. Steps may be also taken to demarcate canal reservations. No local body or department may be given permission to construct bridges or other structures over the canal without the approval of the corporation so as to ensure minimum waterway width and headroom requirement.

The National Science Policy for Sri Lanka 1986 (Ministry of Plan Implementation, 1986) which is an action plan for development recognised the major problems facing the environment. The problems of the urban industrial region of Colombo is particularly stressed. It specially highlighted the problems of the canal system of Colombo as the major health hazard and as a focus of pollution. The problems such as low flow capacity, little flow from the catchment areas, siltation, garbage dumping, and the discharge of chemical effluents into the canals were highlighted. The organic pollution of the river Kelani caused by the untreated city sewage outfall was also sited.

The Science Policy also stressed the zoning of industries, submission of EIA reports, relocation and upgrading the existing old industries, installation of treatment facilities by the industries, recycling and reuse of wastes, industrial discharges to comply with the standards, a common treatment plant for industries with common problems, a directory of industries with potential pollution hazard, a complete set of Sri Lankan standards for the pollutants and setting up of facilities for pollutant monitoring was recommended at a macro level.

The Policy recommended urgent action to revitalise the canal system and bring it to an acceptable state. The control of chemical industrial discharges, regular desiltation and removal of silt away from the canal banks, prevention of garbage dumping and investigation of methods to make the canal flow, a single authority to control the pollution of the canal system, canal reservation and reforestation along the canals was recommended. In addition to these cleaning up of the Beira lake was also recommended.

The National Science Policy, although fairly comprehensive, it has its shortcomings. A clearly defined implementation strategy was lacking in the policy. Further as far as the canals are concerned, although the importance of the canal system was

recognised and recommended measures to revitalise it, it failed to take into account the organic pollutants that enter the canal from the food processing industries, which is the largest in Colombo and heavily responsible for the depletion of DO. Although the chemical effluent discharges are also important due to its potential toxicity all polluting industries have to be given equal weighting and measures recommended for combating the pollutants.

9.8.6 Monitoring, baseline studies and surveillance

An essential part of the pollution control programme which is also complementary to the enforcement of the regulations should be baseline studies in the water quality monitioring and surveillance such as in Malaysia where 350 water quality monitoring stations that fall into 94 water quality control regions on a nationwide basis was established by the Environmental Quality Act of 1974. In the UK there are national river surveys to assess the water quality. For example the 1980 survey showed the improvement of the overall water quality of the rivers especially in the grossly polluted non-tidal rivers from 2250 km in 1958 to 810 km in the 1980 survey. By 1980 310 km of Class I rivers were produced with the total length of grossly polluted rivers being reduced by 50% (Toms, 1985).

Thus in Sri Lanka it would be appropriate to undertake baseline studies and surveillance based on water quality control regions, as such an approach is not prevelant at present. As the first phase of monitoring and surveillance the water quality has to be monitored in the water ways running through the urban and the industrial areas as these are the most highly polluted regions in the country. This has to be backed by national surveys to assess the quality and make comparisons, with the main objective of the authorities being to ensure that the inland surface waters are improved with successive surveys and not to allow it to deteriorate below the existing quality.

There has to be a long range target to improve the water quality to at least to class 2 of the river classification of the U.K., which will support reasonably good coarse fisheries and will have moderate amenity value, but as an immediate short term target to improve the quality of water stepwise, the canal water has to be brought at least to class 3 which has the quality criteria of not allowing the water to become anaerobic. This waters will still be polluted to an extent but fish may at least be sporadically present. The waters still could be used for low grade industrial abstraction purposes with considerable potential for further use if cleaned up.

In addition to all the precautionary and the pollution control measures the shanty population in the canal banks have to be relocated or rehoused, if to maintain the canal in an acceptable state. Inspite of the government aim of rehousing the shanty population it was observed that new shanty units are being put up and rented to new dwellers on the canal reservations. Such illegal acts have to be dealt firmly by legal actions. These measures may ensure a systematic approach to water pollution control in the research area.

9.9 Problems encountered in the research

The laboratory provided by the Division of Occupational Hygiene for the project was found to be adequate in size but with considerable restrictions of both necessary equipment for pollution monitoring (it was a good self-contained laboratory with all the necessary equipment, but was poorly maintained) and basic support services such as power points, power load, water supply, chemicals and cooperation. This gave it a very limited capability for monitoring. But for whatever being achieved in the study sincere and heartfelt gratitude goes to the laboratory and the staff, without the facilities given and the cooperation extended nothing would have been achieved, as none of other laboratories extended their welcome to a situation without funds for chemicals. This included certain Universities other than the Departments mentioned earlier.

There were many problems encountered during the period of study. Obtaining the necessary chemicals for the analyses proved very difficult in the beginning of the research, although they existed in the departmental stores in the same building. Therefore initially about three months was lost due to this. During this period some

of the chemicals were borrowed from some other laboratories, but the frequency of monitoring was severely restricted in January and February 1986. Monitoring was not done in November and December due to the same fact. Sampling days and thus the frequency of monitoring was lost due to the unavailability of a vehicle since the funding body promised but never sent the vehicle on many occasions.

On many occasions distilled water had to be transported to the laboratory in the bus from the University of Colombo (Chemistry and Geography Departments) due to electricity failure or unavailability of water for distillation as there was a leak in the overhead tank. This was not repaired till the end of the research. This entailed changing two buses or walking about half a kilometre with the water cans.

Although well equipped, due to the breakdown of the necessary equipment in the laboratory some important measurements like the flow rates in the canal and certain analyses could not be done. A flow meter was not available. The Kjeldahl apparatus for the nitrogen, the spectrophotometer for the measurement of absorbance for the phosphates, apparatus for determining grease and oil, the muffle furnace for the measurement of sulphates (gravimetric method) and the solids were unavailable. A more time-consuming volumetric sulphate determination was resorted to. Grease and oil was not tested although it was an important analysis in some of the food industries monitored. Total nitrogen was carried out in three laboratories i.e. preparation of the sample for the Occupational Hygiene laboratory, digestion at the Nuffic laboratory, Department of Geography and the distillation and titration in the Chemistry Departmental laboratory of the Colombo University. No nitrogen samples were analysed in January and February 1986, and for the rest of the period it was only analysed once a month due to the difficulty of working in three laboratories at the same time. The total phosphates were done in a similar way with the sample preparation at Occupational Hygiene and the absorbance at the Chemistry Department (only two samples per month was analysed for total phosphates due to the same problems as nitrogen) . Therefore time was lost between sample preparation and the other procedures in the analysis. This may have affected the results to a certain extent, although every precaution was taken to do as soon as possible. The operation of the Kjeldahl also depended on the Departmental laboratory technicians time at the Chemistry Department. As far as possible they did it as soon as possible with their own work load. There were also electricity failures in the middle of certain analyses in the Occupational Hygiene laboratory. Both the water and the electricity failure affected the COD analysis on certain days during refluxing.

The fact that the research was done at the height of the civil disturbances had its own additional problems and being a staff member of a University located in a core problem area in the South of Sri Lanka made it worst. Access was not given to the library of the Central Bank of Ceylon due to the latter reason. Any information from maps and aerial photographs was patchy. Certain maps were unobtainable and certain areas (including the neighbouring areas) were dubbed from the air photos completely for security reasons. This affected the research as the San Sebastian canal flowed through urban Colombo and had high security posts, the harbour, and the petroleum storage in the immediate neighbourhood. At certain monitoring sites such as at S02, U01, near S10 and R01, I was constantly checked and questioned as these were security points of the pumping station; lockgates and the main access into Colombo harbour; check point of the Petroleum storage and the Colombo city respectively. Sudden closure of the laboratory due to curfew and frequent bomb blasts and working hours only till 16.00 hours with no possibility of working extra hours were further restrictions. This affected the industrial sampling too, as industries were suddenly closed due imposition of the curfew. Transport from my home town to the laboratory also proved difficult frequently. Both the public and the private transport services were frequently stopped for several days. Industrial sampling could not be fitted into a plan, due to both the uncoperativeness of the industry and to the civil disturbances.

No baseline data existed regarding the research in Sri Lanka. There were few pilot surveys and short term reports on the canal as discussed before, but research on the food industries was virtually none existent. Even the few available reports were inaccessible even for pure academic research as pollution monitoring in the industries was confidential. Research material from the tropical countries was scarce, and the

available material was widely scattered and unavailable.

In addition to all these difficulties funding for the research was a limitation.

9.9.1 Limitations in the research

The research undertaken has several limitations and thus by itself is incomplete. It is only a baseline study and may serve as a stepping stone into future studies. Some of the basic limitations are,

1. The frequency of monitoring especially in the tributary canals and the industries is low due to the problems encountered in the research which makes it difficult to draw definite conclusions. Although the tributary canals were not the major objective of the research, more monitoring in the tributary canals may provide a good understanding of the pollution in the entire canal system.

2. In the industrial monitoring sampling was not designed on the flow characteristics and the different processes of production. Thus the most polluting process could not be examined. This is not only important for the detrimental effects on the receiving stream but also for the design of the treatment plant. Flow rates were not measured due to the unavailability of a flow meter which was a severe limitation in the industrial monotoring. Thus the pollutant load discharged into the canal could not be calculated. Owing to the limitations in the laboratory facilities especially the working hours during the week days and non-availability of working facilities during the weekends, the time of monitoring in the industries could not be changed. Therefore the discharges at the end of the day were never monitored. Thus the factory discharges may have escaped a high polluting load which may take place at the end of the day, hence the samples monitored may not be the truly representative samples of the factory discharges.

The correlation analysis between the factory sites and the receiving sites also had its limitations. These were mainly due to limitations in the factory monitoring. The inadequate factory monitoring dampened the analysis, although the positive pollutant contribution was very clear. Further the factory and the receiving sites were never monitored on the same days except on a very few occasions. Thus the mean pollutant concentration of the canal was correlated against the factory waste water discharges. If the factory monitoring frequency was higher the coefficient may be much higher. In addition to this factory sampling did not have certain pollutants monitored during certain months. This was either due to limitations with the chemicals, laboratory facilities, inaccessibility or civil disturbances.

3. Due to the restrictions in the laboratory facilities the results of certain analytical tests may have been affected. This is also true of analysis done during electricity failures and water shortages.

4. Only the organic pollutants were monitored in the San Sebastian canal and the other water bodies as the industries dealt with were the food and the drink group. But many sites such as S04 had other pollutants, e.g. from deisel oil in the motor spares workshops at the Pancikawatte bridge and its neighbourhood, S10, which has oil discharges from the petroleum storage, and T03 where toxic discharges from pesticide manufacture at factory D and other products from the factories in the neighbourhood.

5. Oil and grease in the canal especially at the sites S03, S04, S06, S10 and U01 needs to be monitored, it was not monitored as there was limitations in the equipment and glassware for the analysis.

6. No proper biological monitoring was done. The canal is obviously faecally polluted. This was again due to the restrictions in the laboratory facilities.

7. Domestic waste water monitoring was not done as it was outside the scope of the research, but domestic waste water monitoring is particularly important along the canals in Colombo as there is a high shanty population which pollutes the canal, in addition to the location of the canal in a highly urban area. Domestic waste water monitoring for the total N, BOD, COD and SS may be useful.

8. There were also limations in the factories selected. Only factories close to the laboratory were selected for the analysis. Thus the diversity of the factories were less. Finding the same group of, or any food industry directly discharging into the canal which were also located within a fair radius of the laboratory was a difficult criteria to be met.

9. In the rainfall-pollutant analysis the monthly analysis (paticularly the tributary canals and the site U02 in the lake) has limitations. The computations for the correlations were based only on one value per month as the monitoring was done only monthly. Therefore although it explained the basic relationships it has basic shortcomings due to the insufficiency of data.

Future usefulness of the research

The research undertaken has certain usefulness inspite of the limitations discussed earlier. But future research is a basic necessity.

As to the usefulness of the research, the data results from a routine sampling programme of the San Sebastian canal and the other water bodies. Thus it serves as an initial data base even with its own limitations. This may provide a long term record of water quality information at specific points on the canal and the other water bodies. The data may be used as a reference point for future comparison. It may be used to maintain surveillance over water quality and to provide supporting data used in the analysis and prediction of water quality for planning and other purposes.

The industrial data obtained from this project may be used as an initial guideline for any future study on the Sri Lankan food industrial waste waters and on a broader scale to any future design of waste water treatment plant for food processing waste waters. The food industries monitored are wide and varying and thus fairly represent the strength of the waste waters of this group of industries. The industrial waste water data may also serve as data base for recovery of by products from this group of industry which is non toxic in nature. Some of the food industries are rich in nitrogeneous wastes and these could be used in protein recovery. This would provide a useful dietary supplement for a country faced with many economic problems.

Further, the strength of the monitored food and drink industrial wastes demonstrate the nature of the effluents entering the receiving waters. The potentiality of oxygen depletion is very high in these industries. The chemical industries, specifically mentioned in the National Science Policy of Sri Lanka, 1986, have potential toxic industrial discharges, and the food group is important for its organic strength. If unchecked and untreated the dissolved oxygen essential for the sustenance of aquatic life will be depleted. This is the current situation in the San Sebastian canal as far as fish life is concerned. The very low DO level (anaerobic, most of time in the receiving sites) in the canal arising from the untreated industrial waste water discharges may serve as an eye-opener for the industrial water pollution control.

The rain-based analyses demonstrate that even in a tropical situation too much confidence cannot be placed on rainfall as a natural dilutant. The seasonality of rainfall which is an important phenomena in the tropics, and is believed to have a degree of regularity, was a failure in the research period in Sri Lanka. Even during the other rainfall seasons the dilution of the pollutants in the industrial receiving sites was poor. Thus the research has applicability in a local scale, and broadly in a tropical situation.

The shortcomings highlighted in the standards may be useful in the future to formulate guidelines to suit the industries on a much broader industry based and and time specific perspective.

The bibliography on industrial water pollution in Sri Lanka and the tropics may serve as a useful index for future research. As far as possible most of the research material available on water pollution in Sri Lanka is covered by the bibliography. The research organisations, universities, government bodies and other institutions dealing with pollution work and material from the libraries which is relevant, both old and new is covered upto January 1989 for Sri Lanka.

With all its limitations, it is a compact study which starts from monitoring of the water-ways and the industrial discharges and ends with an analysis which attempts to understand dilution and assimilation. Thus the research serves as a simple baseline study and a stepping stone to industrial water pollution studies in Sri Lanka.

Appendix A

San Sebastian canal: sampling points and identification codes

NAME OF SAMPLING POINT	IDENTIFICATION CODE	SAMPLED FROM	REMARKS
200m UPSTREAM OF S02	S01	MID STREAM-SAMPLED FROM BANK	SAN SEBASTIAN CANAL SAMPLING ORIGIN POINT EAST OF EAST BEIRA LAKE
SAN SEBASTIAN HILL	S02	MID STREAM-SAMPLED FROM BRIDGE	-
INDUSTRY B DISCHARGE POINT	S03	MID STREAM-SAMPLED FROM BANK	ENTRY OF DISCHARGES FROM INDUSTRY B
PANCHIKAWATTE ROAD BRIDGE (SANGARAJA MAWATHA)	S04	MID STREAM-SAMPLED FROM BRIDGE	SHANTIES AND MOTOR SPARES WORK SHOPS
100 METRES UPSTREAM INDUSTRY C	S05	MID STREAM-SAMPLED FROM BANK	SITE BETWEEN TWO LARGE SCALE INDUSTRIES
INDUSTRY C DISCHARGE POINT	S06	MID STREAM SAMPLED FROM BANK	ENTRY POINT OF FACTORY C DISCHARGES
KETTARAMA BRIDGE	S07	MID STREAM-SAMPLED FROM BRIDGE	OPEN LAUNDRETTE, CONFLUENCE OF KETTARAMA DRAIN
STACE ROAD BRIDGE	S08	MID STREAM-FROM BRIDGE	SHANTIES, UPGRADING SCHEMES
ALUTHPALAMA BRIDGE	S09	MID STREAM FROM BRIDGE	
THOTALANGA PLANK BRIDGE	S10	MID STREAM-FROM BRIDGE	END OF SAN SEBASTIAN CANAL CONFLUENCE WITH RIVER KELANI

Source: Field monitoring.

Appendix B

Sampling points and identification codes: other water bodies

NAME OF SAMPLING POINT	IDENTIFICATION CODE	SAMPLED FROM	REMARKS
BEIRA LAKE LAKE HOUSE BRIDGE (MaCALLUM LOCKS)	U01	BRIDGE/LOCKS	LAKE CONFLUENCE WITH HARBOUR CANAL
BEIRA LAKE/CREAMERY	U02	LAKE BANK	INDUSTRY A3,A4,A5 DISCHARGE ENTRY; CULVERT ENTRY WITH RAW SEWAGE
RIVER KELANI VICTORIA BRIDGE	R01	MID STREAM-FROM BRIDGE	DOWNSTREAM OF SAN SEBASTIAN CANAL CONFLUENCE
NEW KELANI BRIDGE	R02	MID STREAM-FROM BRIDGE	UPSTREAM OF SAN SEBASTIAN CANAL CONFLUENCE
TRIBUTARY CANALS MALIGAWATTE DRAIN	T01	MID STREAM-FROM BANK	
KETTARAMA DRAIN	T02	MID STREAM-FROM BANK	
DEMATAGODA ELA BASELINE ROAD BRIDGE (LANKEM)	T03	MID STREAM-FROM BRIDGE	INDUSTRIAL DISCHARGE ENTRY POINT
KOLONNAWA BRIDGE	T04	MID STREAM-FROM BRIDGE	
MEETOTAMULLA BRIDGE	T05	MID STREAM-FROM BRIDGE	
VIVEKARAMAYA	T06	MID STREAM-FROM BANK	
KITTAMPAHUWA ELA KOLONNAWA/GOTHATUWA BUND	T07	MID STREAM-FROM BANK	
BRANDYWATTE BRIDGE	T08	MID STREAM-FROM BRIDGE	
DEMATAGODA RAILWAY BRIDGE	T09	MID STREAM-FROM BRIDGE	
BASELINE ROAD BRIDGE (TOYOTA)	T10	MID STREAM-FROM BRIDGE	
MAIN DRAIN INDUSTRY E DISCHARGE POINT	T11	MID STREAM-FROM BANK	INDUSTRY E DISCHARGE POINT
BLOEMENDAL BRIDGE POINT	T12	MID STREAM-FROM BRIDGE	
PRINCE OF WALES STREET BRIDGE	T13	MID STREAM-FROM BRIDGE	INDUSTRY F DISCHARGE POINT

Source: Field monitoring

Appendix C

Industrial sampling points and identification codes

INDUSTRIAL DEPARTMENT	SAMPLING POINT	IDENTIFICATION CODE
JAM	DRAIN OUTSIDE FACTORY ENTRANCE	A1
SOFT DRINKS (BOTTLING PLANT)	MANHOLE WITHIN FACTORY	A2
MEAT PROCESSING	DRAIN OUTSIDE FACTORY ENTRANCE	A3
CARBON DIOXIDE PLANT	DRAIN OUTSIDE PLANT OUTLET	A4
CREAMERY (DAIRY)	DRAIN OUTSIDE PLANT OUTLET	A5
RAW WATER	FACTORY TAP	A6
SOAPERY	DRAIN OUTSIDE PLANT OUTLET	B1
COOLING WATER	PLANT OUTLET DRAIN	B2
MAGARINE	DRAIN OUTSIDE FACTORY	C1
FAT TRAP	FAT TRAP OUTLET	C2
CHEMICAL	EFFLUENT DRAIN WITHIN FACTORY (COMMON SEWER)	D
CONFECTIONERY	EFFLUENT DRAIN WITHIN FACTORY	E
CONFECTIONERY	EFFLUENT DRAIN WITHIN FACTORY	F
MEAT PROCESSING	EFFLUENT DRAIN WITHIN FACTORY	G1
MEAT PACKING	EFFLUENT DRAIN WITHIN FACTORY	G2
SOFT DRINKS (BOTTLING PLANT)	BOTTLE WASHER EFFLUENT DRAIN	H1
CARBON DIOXIDE PLANT	PLANT OUTLET DRAIN, OUTSIDE	H2
SOFT DRINKS- CARBONATED (BOTTLING PLANT)	BOTTLE WASHER EFFLUENT DRAIN	I1
AERATION TANK	TANK EFFLUENT	I2
SOFT DRINKS (FRUIT AND MILK)	EFFLUENT DRAIN, WITHIN FACTORY	J

Source: Field monitoring

Appendix D

Daily monitored values for surface waters (Sites S01-S10, R01-R02 and U01)

St	Date	DO	W.T	pH	Cond	Turb	COD	BOD	Sulf	TN	TP	SS
		mg/L	°C		µmhos/cm	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
U01	090186	4.30	28.55	7.80	17400.0	18.05	337.0	200.0	1802.6	.	.	183.20
S01	090186	13.20	27.00	7.65	415.0	12.00	7.0	3.0	135.1	.	.	28.30
S02	090186	13.90	27.05	7.80	200.0	13.30	8.0	3.0	73.2	.	.	36.20
S03	090186	0.30	32.50	8.00	590.0	32.20	158.0	81.0	130.6	.	.	168.16
S04	090186	0.50	32.50	8.05	520.0	20.10	168.0	87.0	200.0	.	.	133.12
S05	090186	0.70	30.50	7.95	510.0	21.20	108.0	69.0	187.2	.	.	66.30
S06	090186	0.40	29.50	8.15	555.0	24.00	133.0	52.0	97.2	.	.	128.24
S07	090186	0.30	29.50	8.20	565.0	24.00	116.0	61.0	188.0	.	.	102.11
S08	090186	3.30	28.00	7.20	250.0	10.80	40.0	20.0	58.3	.	.	19.10
S09	090186	2.60	28.50	8.00	465.0	14.10	59.0	26.0	121.7	.	.	21.32
S10	090186	0.60	29.00	8.15	465.0	16.20	93.0	78.0	62.1	.	.	26.14
R01	090186	7.00	29.50	7.00	950.0	9.20	18.0	12.0	93.2	.	.	18.80
R02	090186	8.60	29.50	7.00	855.0	10.80	6.0	3.0	101.0	.	.	29.30
U01	220186	3.10	30.50	8.20	16350.0	7.00	605.0	438.0	2011.4	.	1.70	61.33
S01	220186	10.30	29.50	8.00	405.0	6.00	8.0	4.0	163.5	.	0.95	12.30
S02	220186	10.00	29.00	8.00	175.0	6.70	6.0	2.0	97.3	.	0.50	13.81
S03	220186	0.10	33.00	8.30	580.0	22.00	162.0	91.0	139.5	.	2.35	77.26
S04	220186	0.40	33.50	8.55	550.0	24.30	183.0	112.0	275.3	.	2.30	76.06
S05	220186	0.40	31.15	8.65	435.0	23.10	115.0	79.0	262.1	.	1.90	62.35
S06	220186	0.30	32.00	8.95	650.0	22.50	121.0	72.0	200.7	.	2.85	78.36
S07	220186	0.30	31.65	8.45	590.0	25.60	123.0	107.0	236.1	.	2.50	83.20
S08	220186	2.50	30.05	7.95	580.0	7.30	48.0	25.0	87.3	.	0.95	13.60
S09	220186	2.00	31.50	8.20	525.0	14.00	71.0	30.0	140.1	.	1.85	26.30
S10	220186	0.40	31.50	8.30	460.0	15.30	110.0	61.0	82.3	.	1.00	31.61
R01	220186	6.60	25.00	8.00	1600.0	6.70	23.0	16.0	130.0	.	1.70	12.46
R02	220186	7.10	25.50	7.90	1335.0	6.40	10.0	4.0	169.4	.	1.75	12.30
U01	050286	1.50	30.50	8.00	21000.0	3.90	623.0	516.0	1938.7	.	1.85	38.65
S01	050286	8.10	30.90	8.20	600.0	5.20	16.0	13.0	167.3	.	1.00	9.36
S02	050286	8.10	31.00	8.30	275.0	5.20	14.0	10.0	101.2	.	0.65	10.60
S03	050286	0.10	32.50	8.60	725.0	24.30	336.0	231.0	103.1	.	2.00	78.30
S04	050286	0.30	32.00	8.85	635.0	20.70	291.0	180.0	301.7	.	2.10	65.12
S05	050286	0.35	32.05	8.70	600.0	23.00	138.0	97.0	277.6	.	1.95	62.01
S06	050286	0.30	33.00	8.90	750.0	21.50	396.0	188.0	139.3	.	2.35	68.90
S07	050286	0.20	32.65	8.40	710.0	19.30	274.0	174.0	222.7	.	2.95	56.25
S08	050286	1.90	31.40	7.30	1225.0	6.40	151.0	99.0	97.2	.	1.30	9.74
S09	050286	1.70	31.65	7.80	2985.0	10.20	163.0	92.0	155.0	.	1.65	12.34
S10	050286	0.20	32.00	8.00	2800.0	14.30	192.0	100.0	111.7	.	1.00	20.02
R01	050286	5.40	30.65	7.90	3100.0	5.10	33.0	21.0	159.3	.	1.85	10.60
R02	050286	6.20	30.00	7.80	2900.0	6.00	27.0	20.0	158.0	.	1.86	12.35
U01	200286	1.00	31.00	8.00	21000.0	4.80	576.0	411.0	1817.0	.	2.00	48.02
S01	200286	10.00	30.00	7.85	535.0	5.30	17.0	11.0	153.2	.	1.20	8.33
S02	200286	10.20	30.05	7.80	290.0	6.00	16.0	11.0	96.7	.	.80	8.00
S03	200286	0.00	33.00	8.15	600.0	20.00	350.0	230.0	187.3	.	2.65	63.22
S04	200286	0.10	33.00	8.15	595.0	18.00	367.0	226.0	298.6	.	2.70	55.12
S05	200286	0.15	32.50	8.20	580.0	18.20	208.0	93.0	217.3	.	3.24	52.35

S06	200286	0.10	33.50	8.40	710.0	21.60	387.0	296.0	270.0	.	4.25	61.37
S07	200286	0.00	33.00	8.55	680.0	23.70	305.0	261.0	239.2	.	2.80	67.48
S08	200286	2.20	32.00	7.35	935.0	10.00	209.0	100.0	100.6	.	2.25	13.53
S09	200286	1.80	32.50	8.05	2050.0	11.30	233.0	180.0	153.2	.	3.25	18.60
S10	200286	0.20	33.00	8.15	2400.0	15.20	233.0	190.0	162.7	.	1.30	26.30
R01	200286	5.80	29.50	7.95	2950.0	5.00	40.0	31.0	123.6	.	2.05	10.51
R02	200286	6.80	29.00	8.00	2600.0	5.70	30.0	15.0	131.7	.	2.85	10.90
U01	040386	0.70	31.50	8.50	21000.0	14.00	611.0	461.0	1653.2	.	1.20	180.20
S01	040386	9.30	31.50	7.90	650.0	11.00	12.0	9.0	93.0	.	1.11	21.66
S02	040386	9.20	31.60	7.90	300.0	10.80	15.0	10.0	86.3	.	0.85	23.21
S03	040386	0.00	33.50	8.50	710.0	42.00	910.0	603.0	253.0	.	2.15	288.22
S04	040386	0.01	33.65	8.70	680.0	51.00	850.0	482.0	265.1	.	1.75	297.30
S05	040386	0.20	33.00	8.50	635.0	39.70	483.0	391.0	211.3	.	1.30	152.08
S06	040386	2.50	33.80	8.75	620.0	40.30	681.0	581.0	323.2	.	3.05	268.39
S07	040386	0.10	34.00	8.90	600.0	41.10	512.0	412.0	250.6	.	2.50	177.30
S08	040386	2.40	32.60	8.10	720.0	12.80	330.0	269.0	97.6	.	2.04	26.30
S09	040386	1.70	32.80	8.55	800.0	17.50	298.0	261.0	137.5	.	2.00	20.66
S10	040386	0.10	33.00	8.70	975.0	16.30	299.0	186.0	76.2	.	0.95	18.36
R01	040386	5.70	31.00	8.00	1155.0	12.00	66.0	41.0	80.3	.	1.50	24.32
R02	040386	6.90	31.00	7.95	925.0	14.60	30.0	16.0	93.2	.	1.75	28.41
U01	190386	0.60	29.50	8.20	21000.0	5.60	986.0	688.0	1399.0	4.62	.	67.62
S01	190386	7.90	32.00	7.90	595.0	6.20	33.0	27.0	112.6	2.01	.	13.66
S02	190386	8.10	32.00	7.80	255.0	5.60	28.0	16.0	83.3	0.96	.	12.30
S03	190386	0.00	33.50	8.20	700.0	24.10	612.0	519.0	199.6	12.13	.	88.30
S04	190386	0.00	33.50	8.00	600.0	20.20	587.0	460.0	238.7	10.06	.	76.55
S05	190386	0.20	33.00	7.95	610.0	20.60	567.0	419.0	179.3	3.85	.	69.38
S06	190386	0.10	34.00	8.10	1585.0	31.00	412.0	306.0	156.0	16.36	.	87.49
S07	190386	0.10	34.00	8.20	530.0	32.00	412.0	201.0	167.3	11.88	.	93.21
S08	190386	1.80	32.50	7.85	390.0	6.30	296.0	181.0	98.7	2.05	.	19.81
S09	190386	1.70	33.00	8.05	535.0	13.50	237.0	160.0	101.6	2.73	.	27.30
S10	190386	0.20	33.50	8.25	360.0	14.00	248.0	151.0	63.2	4.22	.	26.20
R01	190386	5.20	30.50	8.00	140.0	6.00	69.0	40.0	59.3	3.02	.	10.30
R02	190386	6.20	30.90	8.10	140.0	5.30	33.0	15.0	42.8	2.36	.	9.01
U01	310386	0.60	31.00	8.20	21000.0	4.50	931.0	744.0	1220.3	.	1.25	39.01
S01	310386	7.00	32.50	8.00	640.0	5.20	48.0	36.0	112.6	.	1.02	10.33
S02	310386	6.90	32.60	7.90	235.0	5.20	44.0	27.0	73.1	.	0.95	9.23
S03	310386	0.00	34.50	8.30	250.0	20.00	601.0	511.0	187.2	.	1.55	76.36
S04	310386	0.00	36.00	8.60	560.0	21.70	632.0	571.0	163.3	.	1.60	72.68
S05	310386	0.25	34.00	8.55	535.0	18.30	600.0	470.0	124.0	.	1.30	63.28
S06	310386	0.00	34.50	8.80	1335.0	21.00	603.0	507.0	170.6	.	3.65	72.33
S07	310386	0.00	34.00	8.25	600.0	24.00	590.0	493.0	183.2	.	3.51	82.30
S08	310386	1.50	32.60	7.85	400.0	5.60	296.0	172.0	93.6	.	1.25	12.35
S09	310386	1.20	33.00	8.05	510.0	8.30	253.0	161.0	82.3	.	1.55	10.14
S10	310386	0.15	33.00	8.25	365.0	10.20	301.0	208.0	61.7	.	1.00	26.71
R01	310386	5.10	32.50	8.20	135.0	5.70	81.0	59.0	48.9	.	1.55	12.76
R02	310386	6.30	32.00	8.20	125.0	5.90	56.0	37.0	38.3	.	1.65	16.08
U01	100486	0.60	29.00	8.10	21000.0	5.90	799.0	632.0	1165.0	.	0.75	103.65
S01	100486	13.90	31.00	7.80	635.0	7.20	11.0	8.0	89.7	.	0.90	23.44
S02	100486	14.30	31.00	7.70	245.0	7.10	12.0	9.0	46.8	.	1.00	22.88
S03	100486	0.00	34.00	8.05	600.0	45.50	456.0	275.0	111.6	.	1.25	212.60
S04	100486	0.00	34.00	7.90	520.0	49.50	456.0	285.0	101.2	.	2.10	335.00
S05	100486	0.40	34.00	7.95	540.0	39.90	424.0	270.0	97.6	.	5.40	193.07
S06	100486	0.00	34.05	8.00	540.0	35.60	538.2	427.0	210.6	.	5.60	100.00
S07	100486	0.30	33.00	8.25	550.0	37.25	272.0	65.0	163.7	.	6.75	125.36

S08	100486	2.30	33.00	7.95	395.0	6.65	128.0	80.0	83.2	.	0.75	18.36
S09	100486	0.30	35.00	8.05	500.0	7.60	90.6	60.0	91.6	.	1.15	19.11
S10	100486	0.20	35.05	8.25	510.0	6.30	102.0	77.0	53.0	.	0.95	18.60
R01	100486	5.80	32.00	8.00	120.0	5.95	84.0	40.0	31.7	.	1.50	20.25
R02	100486	8.50	31.00	8.55	125.0	8.30	12.0	10.0	26.8	.	1.65	39.35
U01	170486	1.20	29.00	8.05	20000.0	11.00	600.0	481.0	836.0	7.01	0.75	206.10
S01	170486	14.10	31.50	7.90	530.0	9.60	16.0	11.0	75.3	3.98	0.65	28.35
S02	170486	14.50	31.00	8.00	240.0	9.50	12.0	8.0	37.6	1.10	0.75	21.15
S03	170486	0.05	32.50	8.20	560.0	45.00	448.0	366.0	100.7	10.37	2.10	212.60
S04	170486	0.01	33.00	8.20	515.0	55.50	487.0	352.0	98.0	11.26	1.90	377.33
S05	170486	0.40	33.05	8.40	540.0	43.20	430.0	316.0	87.3	4.08	1.10	265.12
S06	170486	0.00	33.65	8.60	520.0	42.60	492.0	401.0	93.6	10.35	3.15	232.14
S07	170486	0.00	34.00	8.75	535.0	38.00	363.0	287.0	93.0	11.23	3.00	211.24
S08	170486	2.50	32.00	8.00	370.0	9.60	126.0	82.0	52.5	3.25	0.70	26.64
S09	170486	0.70	33.60	8.85	515.0	10.20	132.0	94.0	69.0	3.89	1.25	27.00
S10	170486	0.40	33.75	8.90	525.0	6.40	141.0	86.0	43.7	2.75	0.75	12.27
R01	170486	6.30	30.60	7.90	110.0	7.80	61.0	49.0	26.7	3.86	1.35	18.63
R02	170486	8.40	30.20	7.60	95.0	9.20	16.0	9.0	19.3	3.18	1.50	29.33
U01	290486	2.70	29.80	8.07	21000.0	8.30	538.0	407.0	1008.3	.	.	112.23
S01	290486	14.20	30.40	7.80	515.0	7.10	4.0	3.0	81.6	.	.	24.30
S02	290486	14.00	31.40	7.75	200.0	7.20	4.0	2.0	42.6	.	.	21.60
S03	290486	0.10	38.60	8.30	655.0	41.20	783.0	389.0	92.2	.	.	200.61
S04	290486	0.03	40.00	8.30	500.0	47.30	502.0	203.0	90.5	.	.	352.35
S05	290486	0.50	33.10	8.60	525.0	41.60	402.0	209.0	81.0	.	.	206.05
S06	290486	0.02	33.25	8.65	580.0	38.05	419.0	368.0	106.3	.	.	163.11
S07	290486	0.03	33.00	8.65	550.0	37.60	294.0	200.0	87.8	.	.	187.02
S08	290486	2.60	33.60	8.90	320.0	7.85	113.0	71.0	43.8	.	.	23.17
S09	290486	1.60	31.00	8.00	510.0	8.90	80.0	65.0	59.6	.	.	29.67
S10	290486	0.40	32.10	8.10	505.0	6.75	138.0	81.0	33.7	.	.	16.36
R01	290486	7.00	31.00	7.60	100.0	7.60	48.0	31.0	30.6	.	.	22.09
R02	290486	8.60	30.00	7.70	85.0	6.50	16.0	9.0	18.7	.	.	19.23
U01	070586	2.80	31.00	8.10	21000.0	29.60	521.0	407.0	1186.1	.	0.95	367.25
S01	070586	13.20	30.00	7.90	595.0	23.00	4.0	2.5	87.0	.	0.75	156.23
S02	070586	14.80	30.10	7.90	270.0	22.60	4.0	2.0	42.3	.	0.65	162.34
S03	070586	0.30	32.00	8.30	1230.0	65.20	192.0	144.0	116.2	.	1.50	483.61
S04	070586	0.00	34.50	8.20	605.0	62.80	181.0	137.0	93.2	.	1.65	409.80
S05	070586	0.10	31.70	8.40	435.0	60.30	101.0	76.0	61.7	.	1.00	366.25
S06	070586	0.00	32.50	8.05	430.0	70.00	286.0	193.0	87.3	.	1.75	472.31
S07	070586	0.04	33.00	8.00	925.0	71.60	183.0	135.0	43.8	.	1.35	488.32
S08	070586	2.90	31.40	7.90	160.0	21.00	96.0	62.0	40.3	.	0.05	183.41
S09	070586	1.90	32.00	7.60	1880.0	52.35	83.0	65.0	66.3	.	0.50	266.60
S10	070586	0.90	31.20	7.65	280.0	59.30	110.0	81.0	26.7	.	0.25	281.38
R01	070586	7.20	30.60	7.70	75.5	23.40	21.0	13.0	31.0	.	0.65	106.50
R02	070586	8.40	30.00	7.50	35.0	29.60	16.0	11.0	16.2	.	1.35	125.23
U01	150586	1.90	31.00	8.20	21000.0	2.70	544.0	350.0	1333.9	5.01	1.20	26.36
S01	150586	6.00	33.00	8.00	400.0	3.80	20.0	16.0	100.2	3.07	1.00	6.85
S02	150586	4.00	34.00	7.98	275.0	4.50	18.0	12.0	62.3	1.64	1.25	7.25
S03	150586	0.30	34.00	8.25	1150.0	35.00	176.0	106.0	96.3	10.05	1.70	181.01
S04	150586	0.00	36.00	7.95	600.0	22.50	152.0	106.0	80.0	9.62	1.92	101.30
S05	150586	0.60	35.00	7.65	475.0	20.50	122.0	47.0	79.0	3.33	1.55	97.30
S06	150586	0.20	33.00	8.90	465.0	19.00	64.0	39.0	90.0	13.20	0.00	88.60
S07	150586	0.00	33.00	8.75	1000.0	22.00	122.0	65.0	96.3	9.11	1.40	110.10
S08	150586	0.50	32.00	7.85	180.0	5.50	117.3	70.0	52.0	2.01	0.20	23.20
S09	150586	2.10	32.00	7.65	1950.0	6.40	10.6	6.0	61.8	4.03	0.75	24.20

S10	150586	0.50	31.00	7.65	225.0	5.00	48.0	30.0	60.7	2.17	0.40	19.35
R01	150586	6.20	30.50	7.80	400.0	2.75	24.0	4.0	75.6	3.26	0.75	5.80
R02	150586	6.70	30.00	7.75	65.0	5.15	28.0	6.0	20.3	2.93	2.40	18.60
U01	260586	1.70	31.00	8.10	21000.0	4.30	607.0	510.0	1396.2	.	.	78.25
S01	260586	13.00	32.00	7.90	585.0	5.20	4.0	2.0	101.6	.	.	10.32
S02	260586	13.00	32.00	7.75	260.0	5.35	6.0	3.0	56.9	.	.	9.67
S03	260586	0.35	35.00	8.25	1005.0	31.65	361.0	223.0	86.2	.	.	199.62
S04	260586	0.01	35.60	8.60	560.0	30.05	343.0	107.0	92.3	.	.	183.30
S05	260586	0.80	33.60	8.50	430.0	27.30	130.0	101.0	90.2	.	.	100.02
S06	260586	0.30	34.00	8.40	415.0	33.10	220.0	108.0	98.3	.	.	91.31
S07	260586	0.20	34.20	8.55	1005.0	24.00	107.0	89.0	83.1	.	.	110.02
S08	260586	2.10	32.30	7.85	195.0	5.20	100.0	73.0	59.6	.	.	28.62
S09	260586	2.00	33.30	8.10	1700.0	8.30	69.5	48.0	63.0	.	.	29.10
S10	260586	0.60	33.50	8.25	215.0	11.90	123.0	101.0	56.3	.	.	23.05
R01	260586	5.80	30.00	7.90	70.0	3.65	36.0	19.0	40.6	.	.	18.70
R02	260586	6.40	29.50	7.60	65.0	5.35	31.0	16.0	20.8	.	.	21.60
U01	020686	1.80	31.50	8.10	19230.0	9.10	613.0	507.0	1507.2	.	2.15	60.33
S01	020686	7.10	33.60	8.26	565.0	6.25	34.0	21.0	111.3	.	0.36	18.31
S02	020686	6.50	34.00	8.25	198.5	5.00	32.0	21.0	85.6	.	0.20	17.38
S03	020686	0.40	34.00	8.65	490.0	28.00	232.0	185.0	176.3	.	1.75	115.62
S04	020686	0.00	34.00	8.45	430.0	21.50	256.0	170.0	86.0	.	0.96	93.26
S05	020686	0.10	33.30	8.25	435.0	20.40	238.0	154.0	80.0	.	0.50	90.30
S06	020686	0.05	31.50	8.15	460.0	24.00	232.0	96.0	143.9	.	3.25	101.73
S07	020686	0.10	31.00	8.45	400.0	17.00	53.3	40.0	136.2	.	2.17	77.80
S08	020686	0.75	31.50	8.40	150.0	7.50	21.3	15.0	162.2	.	0.65	24.30
S09	020686	1.30	31.50	8.70	225.0	15.00	37.3	17.0	133.8	.	1.05	40.36
S10	020686	2.80	31.00	7.85	155.0	13.50	48.0	21.0	97.1	.	0.90	38.20
R01	020686	7.00	31.00	8.70	30.0	4.60	8.0	4.5	53.0	.	0.65	12.00
R02	020686	6.70	31.50	8.70	47.0	5.80	8.0	5.5	39.6	.	0.65	20.60
U01	190686	2.00	30.20	7.85	18810.0	11.00	513.0	419.0	1772.0	4.23	2.40	63.10
S01	190686	8.40	32.00	8.30	500.0	9.50	32.0	17.0	139.9	1.35	0.20	21.60
S02	190686	8.00	32.00	8.20	180.0	6.00	10.0	4.5	87.3	0.97	0.20	18.30
S03	190686	0.00	34.00	8.35	720.0	12.00	304.0	215.0	174.9	7.00	1.80	43.27
S04	190686	0.00	37.00	8.35	640.0	17.00	399.0	265.0	94.9	6.21	0.30	48.29
S05	190686	0.30	36.00	8.30	650.0	16.10	130.0	73.0	83.0	3.61	0.90	47.15
S06	190686	0.00	35.00	8.45	700.0	16.50	352.0	105.0	139.9	14.32	6.25	52.00
S07	190686	0.00	33.00	8.40	820.0	13.50	373.0	236.0	149.9	10.05	2.35	43.63
S08	190686	0.40	31.50	8.30	2250.0	6.00	62.0	25.0	204.8	2.15	0.25	19.11
S09	190686	4.00	30.50	7.95	460.0	7.50	117.3	60.0	147.4	3.71	0.30	25.78
S10	190686	6.60	30.00	7.85	40.0	2.05	10.6	3.0	112.4	2.92	0.20	3.12
R01	190686	7.00	30.20	7.90	39.0	3.50	8.0	4.0	57.4	1.90	1.10	6.92
R02	190686	6.90	30.00	7.90	36.0	2.00	4.0	3.0	52.4	1.30	1.20	3.60
U01	300686	1.10	30.00	8.00	19900.0	9.60	776.0	662.0	1806.0	.	.	53.16
S01	300686	6.00	32.00	8.20	510.0	8.30	38.0	26.0	146.0	.	.	20.35
S02	300686	6.10	32.05	8.10	185.0	7.25	33.0	23.0	89.6	.	.	15.36
S03	300686	0.00	39.00	8.95	680.0	15.20	632.0	491.0	231.5	.	.	43.82
S04	300686	0.00	39.50	8.90	625.0	18.00	688.0	243.0	186.0	.	.	116.30
S05	300686	0.00	35.00	8.50	580.0	16.70	283.0	186.0	112.1	.	.	146.23
S06	300686	0.00	34.60	8.65	610.0	15.95	409.0	290.0	122.5	.	.	58.00
S07	300686	0.00	35.00	8.80	735.0	12.60	481.0	401.0	142.9	.	.	140.60
S08	300686	0.30	32.90	8.00	2110.0	6.20	62.5	35.0	198.0	.	.	14.37
S09	300686	1.90	33.20	8.15	430.0	7.90	102.0	63.0	151.6	.	.	23.67
S10	300686	1.20	33.30	8.40	95.0	8.35	266.0	172.0	121.4	.	.	9.26
R01	300686	6.60	30.10	7.90	56.0	5.00	12.0	9.0	97.6	.	.	6.30

R02	300686	6.80	30.00	7.60	48.0	5.25	8.0	5.0	148.8	.	.	4.57
U01	070786	1.10	30.00	7.90	18750.0	9.00	802.0	719.0	1896.0	4.16	2.35	97.61
S01	070786	5.50	30.00	8.20	520.0	4.50	61.4	37.0	175.2	1.11	1.65	12.30
S02	070786	5.80	29.40	8.01	400.0	5.00	48.0	27.0	106.3	0.13	1.10	10.31
S03	070786	0.80	30.00	8.25	450.0	10.60	299.5	195.0	276.7	10.26	1.20	39.90
S04	070786	0.00	29.00	8.30	410.0	16.00	384.4	270.0	458.9	9.35	1.10	123.42
S05	070786	0.10	30.00	8.35	415.0	14.70	321.0	261.0	210.8	8.12	1.05	43.20
S06	070786	0.30	30.00	8.20	425.0	15.00	345.6	215.0	16.1	11.92	1.65	86.70
S07	070786	0.00	29.00	8.20	490.0	22.25	360.9	230.0	262.9	10.67	2.40	112.10
S08	070786	2.40	29.50	8.30	2000.0	6.00	199.6	130.0	175.2	2.67	6.50	17.23
S09	070786	0.60	30.00	8.10	1400.0	18.35	112.6	70.0	106.0	3.56	3.40	92.41
S10	070786	0.10	29.00	8.25	640.0	14.10	168.9	95.0	129.6	3.87	2.15	47.70
R01	070786	9.30	29.30	8.20	40.0	4.10	26.8	16.0	295.2	1.23	0.15	13.20
R02	070786	7.00	29.00	8.30	45.0	6.50	34.5	20.0	221.4	1.33	1.35	35.60
U01	170786	0.90	30.30	7.80	19955.0	8.75	859.0	769.0	1936.6	.	3.15	83.26
S01	170786	5.40	31.00	8.00	540.0	5.20	61.0	32.0	196.3	.	1.85	15.61
S02	170786	5.40	31.00	8.10	210.0	5.35	53.0	25.0	133.0	.	1.60	12.31
S03	170786	0.10	31.80	9.15	480.0	10.65	555.0	89.0	428.7	.	5.25	32.51
S04	170786	0.00	36.30	8.75	405.0	21.00	491.0	396.0	456.7	.	2.00	48.37
S05	170786	0.00	31.60	8.70	420.0	14.20	461.0	330.0	282.6	.	1.95	40.00
S06	170786	0.00	32.00	8.45	550.0	28.10	397.0	287.0	422.3	.	3.67	39.27
S07	170786	0.00	32.10	8.90	1560.0	26.20	416.0	273.0	359.4	.	4.15	52.60
S08	170786	1.90	29.00	7.60	1340.0	5.00	207.0	190.0	183.6	.	2.10	18.21
S09	170786	0.50	30.00	7.95	600.0	12.70	215.0	106.0	139.6	.	1.85	87.36
S10	170786	0.10	32.20	8.00	430.0	15.80	231.0	83.0	156.4	.	1.15	40.23
R01	170786	6.30	30.50	8.00	45.0	4.00	26.0	18.0	230.6	.	1.85	10.61
R02	170786	6.70	30.00	8.00	39.0	6.90	21.0	15.0	189.0	.	1.95	21.32
U01	280786	0.70	29.60	8.10	19000.0	6.00	941.0	816.0	2301.7	.	.	66.25
S01	280786	4.50	31.00	8.00	535.0	4.20	70.0	47.0	222.0	.	.	12.62
S02	280786	4.80	31.20	8.02	189.0	4.25	59.0	46.0	159.7	.	.	10.37
S03	280786	0.00	32.00	8.40	675.0	18.70	454.0	366.0	267.3	.	.	49.35
S04	280786	0.00	32.00	8.45	400.0	15.30	512.0	420.0	450.0	.	.	93.22
S05	280786	0.00	32.50	8.30	420.0	15.00	505.0	401.0	296.2	.	.	30.80
S06	280786	0.00	33.00	8.65	435.0	19.30	568.0	493.0	430.7	.	.	40.01
S07	280786	0.00	33.60	8.90	530.0	21.60	586.0	381.0	368.6	.	.	100.30
S08	280786	1.70	32.30	8.10	1900.0	4.90	220.0	100.0	201.6	.	.	12.23
S09	280786	0.40	33.00	8.55	1360.0	8.30	220.0	101.0	168.7	.	.	19.56
S10	280786	0.00	33.00	8.45	620.0	8.90	293.0	189.0	183.9	.	.	35.06
R01	280786	5.60	29.60	8.00	47.0	4.20	37.0	20.0	367.3	.	.	10.00
R02	280786	5.50	28.90	8.10	40.0	5.00	30.0	18.0	329.8	.	.	12.60
U01	040886	1.00	29.00	8.95	21000.0	6.20	382.0	262.0	1750.1	.	1.00	60.12
S01	040886	4.50	31.60	8.80	595.0	5.00	62.0	46.0	168.6	.	1.05	12.07
S02	040886	6.00	32.00	8.90	370.0	6.10	38.0	27.0	99.3	.	0.97	11.07
S03	040886	0.00	32.00	9.40	510.0	19.30	862.0	170.0	125.4	.	4.15	36.25
S04	040886	0.00	32.50	9.50	560.0	18.10	882.0	613.0	101.3	.	1.70	35.32
S05	040886	0.00	32.00	9.10	600.0	16.60	315.0	251.0	77.0	.	4.65	31.26
S06	040886	0.00	36.50	9.00	625.0	19.25	300.0	201.0	86.0	.	3.35	59.02
S07	040886	0.00	35.80	9.45	595.0	22.00	307.0	253.0	93.3	.	2.60	46.23
S08	040886	1.80	31.60	8.70	595.0	5.10	81.0	49.0	92.0	.	1.18	10.30
S09	040886	0.30	32.30	8.95	510.0	8.30	113.0	66.0	130.2	.	1.20	23.62
S10	040886	0.10	32.00	8.75	435.0	10.60	187.0	100.0	101.5	.	1.20	27.50
R01	040886	5.40	27.80	9.30	45.0	4.95	21.0	16.0	156.1	.	1.46	9.32
R02	040886	5.60	27.00	9.20	40.0	5.20	21.0	15.0	139.6	.	1.40	11.27
U01	120886	4.10	30.20	8.40	21000.0	9.25	272.0	151.0	1513.7	.	.	133.00

S01	120886	10.10	32.00	8.80	685.0	7.10	18.0	12.0	121.8	.	.	37.65
S02	120886	11.50	32.00	8.60	325.0	6.75	16.0	8.0	68.4	.	.	36.20
S03	120886	0.00	33.00	9.30	500.0	27.30	611.0	404.0	362.3	.	.	63.35
S04	120886	0.10	33.60	9.45	520.0	26.90	701.0	333.0	311.0	.	.	60.37
S05	120886	0.10	33.00	9.60	510.0	21.00	321.0	199.0	41.5	.	.	57.82
S06	120886	0.20	36.50	9.35	700.0	34.00	192.0	145.0	237.2	.	.	98.26
S07	120886	0.01	33.50	8.60	585.0	31.20	198.0	148.0	72.1	.	.	86.15
S08	120886	2.70	31.60	8.10	580.0	29.00	93.6	56.0	83.0	.	.	111.30
S09	120886	0.70	31.90	8.55	520.0	16.80	106.0	68.0	126.2	.	.	42.62
S10	120886	0.60	31.80	8.50	545.0	21.00	140.0	93.0	93.0	.	.	49.70
R01	120886	6.20	27.90	8.00	55.0	7.60	18.0	7.0	97.1	.	.	16.37
R02	120886	7.00	27.20	8.10	40.0	8.75	10.0	6.0	53.5	.	.	23.25
U01	260886	4.30	30.00	8.90	21000.0	8.10	272.0	65.0	1623.0	0.72	0.90	196.20
S01	260886	10.20	31.80	8.60	675.0	6.25	10.0	6.0	126.0	0.23	0.60	63.20
S02	260886	10.40	32.00	8.90	365.0	8.00	8.0	4.0	78.4	0.14	0.00	31.67
S03	260886	0.60	32.80	9.30	490.0	8.50	136.0	116.0	89.9	11.32	6.20	29.00
S04	260886	0.50	32.00	9.00	515.0	8.00	330.0	310.0	63.3	11.32	5.00	22.35
S05	260886	0.30	32.00	8.70	520.0	9.10	218.0	160.0	40.0	10.80	1.20	18.67
S06	260886	0.00	32.50	9.20	650.0	16.00	208.0	130.0	62.2	14.30	0.90	121.81
S07	260886	0.00	33.00	8.60	590.0	10.00	218.0	115.0	71.1	13.65	3.60	93.51
S08	260886	2.40	31.50	8.75	595.0	7.50	48.0	22.0	92.2	3.79	3.10	18.21
S09	260886	0.60	32.00	8.65	520.0	11.00	70.0	22.0	110.7	3.69	1.35	15.07
S10	260886	0.40	31.50	8.70	565.0	12.00	80.0	25.0	92.2	3.98	1.10	40.20
R01	260886	6.30	28.10	9.40	55.0	5.50	18.0	10.0	63.1	1.00	1.20	12.80
R02	260886	11.60	28.00	9.45	48.0	5.00	8.0	5.0	11.5	0.01	1.35	26.81
U01	120986	4.00	30.10	8.50	21000.0	8.50	301.0	221.0	1666.3	.	.	99.00
S01	120986	8.00	31.00	8.70	550.0	5.00	12.0	9.0	175.3	.	.	18.36
S02	120986	8.30	31.20	8.60	255.0	5.60	12.0	7.0	72.6	.	.	16.23
S03	120986	0.30	32.60	8.90	600.0	21.00	259.0	166.0	79.6	.	.	97.02
S04	120986	0.20	32.80	8.90	585.0	23.00	294.5	189.0	127.2	.	.	68.39
S05	120986	0.10	32.70	8.60	530.0	21.25	211.0	100.0	95.1	.	.	59.26
S06	120986	0.10	32.90	8.85	610.0	14.00	258.0	186.0	97.9	.	.	63.25
S07	120986	0.00	33.00	8.80	585.0	16.70	271.0	200.0	76.3	.	.	69.10
S08	120986	2.00	31.80	7.90	520.0	8.10	69.0	37.0	53.1	.	.	21.88
S09	120986	0.50	32.00	8.20	535.0	16.50	102.0	68.0	99.7	.	.	67.55
S10	120986	0.20	32.30	8.40	310.0	11.30	112.0	71.0	72.0	.	.	39.16
R01	120986	5.90	30.10	8.30	60.0	8.50	18.0	10.0	41.3	.	.	12.80
R02	120986	8.00	30.00	8.00	50.0	9.20	6.0	3.0	17.6	.	.	24.50
U01	220986	6.10	29.00	8.30	21000.0	10.60	500.0	271.0	1603.0	.	3.95	112.50
S01	220986	8.90	30.00	8.20	455.0	5.60	10.0	8.0	136.2	.	0.65	126.01
S02	220986	9.40	30.50	8.30	200.0	6.70	6.0	3.0	70.1	.	0.25	29.52
S03	220986	0.40	40.00	9.40	1600.0	21.40	525.0	322.0	156.2	.	5.65	152.37
S04	220986	0.30	38.50	8.25	395.0	22.10	631.0	466.0	123.1	.	3.05	152.01
S05	220986	0.40	32.00	8.20	410.0	19.60	185.0	98.0	92.4	.	1.40	111.30
S06	220986	0.30	33.00	8.30	550.0	15.30	239.0	160.0	127.0	.	2.15	93.60
S07	220986	0.00	32.00	8.35	530.0	14.10	260.0	239.0	101.1	.	3.25	92.75
S08	220986	2.60	31.00	7.90	460.0	6.30	85.0	53.0	50.3	.	3.00	21.70
S09	220986	0.70	31.50	8.05	595.0	23.70	101.0	69.0	82.1	.	1.85	171.33
S10	220986	0.60	31.50	8.00	230.0	10.20	107.0	70.0	51.2	.	1.26	80.44
R01	220986	6.30	29.80	7.80	55.0	7.50	13.0	8.0	30.0	.	1.35	21.00
R02	220986	8.20	30.00	8.00	60.0	7.60	7.5	3.0	18.6	.	1.57	28.65
U01	290986	6.40	27.00	8.35	19800.0	8.00	531.0	317.0	1526.2	6.73	4.95	77.22
S01	290986	9.60	30.00	8.30	395.0	4.10	8.0	4.0	159.0	2.26	1.15	13.26
S02	290986	9.80	30.50	8.30	160.0	5.60	6.0	2.0	86.0	0.36	0.75	14.10

S03	290986	0.01	32.00	10.10	495.0	15.20	236.0	183.0	163.2	11.03	8.10	57.00
S04	290986	0.01	32.50	9.30	480.0	17.00	211.0	170.0	159.1	11.58	5.65	65.16
S05	290986	0.20	32.00	8.20	480.0	17.00	267.0	163.0	103.3	9.36	1.37	62.30
S06	290986	0.30	33.00	8.30	500.0	19.80	197.0	103.0	200.7	15.36	2.10	89.46
S07	290986	0.30	33.00	8.35	490.0	20.25	254.0	138.0	139.0	13.14	2.00	115.70
S08	290986	2.60	31.00	7.90	420.0	6.20	136.0	87.0	69.0	3.06	1.27	16.30
S09	290986	0.90	32.00	8.10	435.0	14.50	66.0	10.0	93.2	3.61	3.25	44.00
S10	290986	0.30	31.50	8.00	205.0	10.10	73.0	43.0	82.1	3.71	3.00	12.70
R01	290986	6.30	27.00	8.00	40.0	7.00	13.0	6.0	37.0	1.36	0.90	15.60
R02	290986	8.10	27.10	8.10	35.0	7.50	7.0	4.0	10.0	1.17	1.85	21.30
U01	081086	6.30	31.00	8.45	21000.0	11.50	760.0	550.0	1209.7	7.52	2.40	201.00
S01	081086	13.10	30.50	8.60	610.0	8.40	4.0	2.0	682.6	3.41	2.40	32.10
S02	081086	13.00	30.00	8.75	250.0	6.95	40.0	18.0	92.2	0.65	0.95	26.30
S03	081086	0.00	33.00	9.20	645.0	29.50	301.0	208.0	132.6	10.46	2.05	133.38
S04	081086	0.00	33.50	9.15	700.0	22.00	217.3	90.0	66.8	8.93	1.76	55.07
S05	081086	0.10	30.50	8.70	720.0	22.50	129.0	100.0	58.0	7.81	1.45	129.36
S06	081086	0.00	32.60	8.90	890.0	23.00	410.0	311.0	221.7	16.35	4.35	140.30
S07	081086	0.00	33.00	8.45	950.0	22.50	280.0	131.0	96.8	13.65	3.10	42.75
S08	081086	1.20	31.00	8.10	680.0	7.50	63.0	41.0	93.6	4.62	3.06	18.66
S09	081086	0.80	31.50	8.30	655.0	15.00	75.0	56.0	102.8	4.43	5.70	51.33
S10	081086	1.00	32.00	8.30	520.0	12.50	40.0	24.0	66.4	1.45	4.75	41.65
R01	081086	7.30	27.00	9.80	600.0	15.00	4.0	2.0	9.2	0.14	2.60	55.00
R02	081086	7.80	27.50	9.60	380.0	17.25	4.0	2.5	6.3	0.11	2.80	62.12
U01	231086	6.40	30.00	8.00	21000.0	10.50	726.0	616.0	1351.3	7.90	2.35	199.50
S01	231086	8.20	31.00	7.60	515.0	9.00	16.0	10.0	200.2	3.50	2.00	43.00
S02	231086	10.40	31.00	7.90	225.0	6.00	12.0	4.0	110.7	0.68	1.00	21.30
S03	231086	0.00	32.50	8.10	790.0	8.50	225.0	102.0	139.3	10.87	3.93	30.60
S04	231086	1.20	32.00	8.35	700.0	6.00	228.0	65.0	93.4	9.36	3.62	18.27
S05	231086	1.20	32.00	8.30	695.0	5.00	210.0	98.0	72.6	7.91	1.05	9.56
S06	231086	0.00	33.00	8.30	665.0	54.00	552.0	400.0	356.4	14.36	4.15	251.63
S07	231086	0.00	33.00	8.40	700.0	59.50	357.0	131.0	100.3	13.25	1.80	262.30
S08	231086	0.70	32.00	8.30	500.0	18.00	21.0	15.0	197.1	3.93	0.00	492.70
S09	231086	1.30	32.50	8.40	465.0	26.00	76.0	59.0	150.2	3.64	6.20	121.08
S10	231086	0.00	31.50	8.15	450.0	19.00	56.0	13.0	117.6	2.57	6.10	26.15
R01	231086	5.80	29.00	8.20	76.0	14.00	36.0	11.0	41.5	1.83	0.60	51.23
R02	231086	6.80	28.00	8.50	62.0	10.10	4.0	2.0	10.3	1.62	1.40	48.60
U01	301086	6.00	30.20	8.20	21000.0	8.60	810.0	771.0	1259.3	.	.	101.05
S01	301086	11.20	31.50	7.60	440.0	9.00	6.0	3.0	161.3	.	.	52.60
S02	301086	11.90	31.00	7.90	205.0	7.30	7.0	2.0	96.2	.	.	27.35
S03	301086	0.15	34.00	8.20	310.0	18.30	235.0	102.0	113.4	.	.	83.62
S04	301086	0.50	34.50	8.35	435.0	21.80	298.0	187.0	98.0	.	.	90.32
S05	301086	0.60	32.00	8.30	635.0	6.30	273.0	186.0	63.0	.	.	18.10
S06	301086	0.50	32.50	8.55	660.0	32.10	526.0	488.0	296.1	.	.	206.25
S07	301086	0.40	32.00	8.60	685.0	38.60	400.0	291.0	136.4	.	.	333.80
S08	301086	1.20	31.00	7.60	520.0	12.30	49.6	16.0	93.8	.	.	87.99
S09	301086	0.90	31.50	8.00	535.0	27.00	87.2	59.0	162.5	.	.	111.36
S10	301086	0.60	31.60	8.25	455.0	18.20	36.0	22.0	106.4	.	.	63.54
R01	301086	5.90	29.50	7.90	070.0	13.70	31.0	14.0	39.7	.	.	42.72
R02	301086	6.80	29.00	7.80	060.0	10.60	14.0	9.0	10.6	.	.	39.33
U01	121186	5.50	30.00	8.30	17200.0	12.00	473.0	373.0	1416.2	5.23	2.10	84.44
S01	121186	10.10	32.00	8.30	420.0	8.00	9.0	6.0	207.6	1.39	2.00	16.53
S02	121186	9.70	32.30	8.05	200.0	8.00	8.0	4.0	97.2	0.10	0.87	18.31
S03	121186	0.10	36.50	8.60	320.0	24.50	911.0	633.0	133.0	8.30	2.15	138.01
S04	121186	0.20	36.00	8.70	560.0	25.50	509.0	300.0	164.2	7.23	1.10	73.80

S05	121186	0.50	33.60	8.50	510.0	20.00	293.0	189.0	70.8	4.21	0.85	61.30
S06	121186	0.30	33.50	8.80	625.0	28.25	410.0	311.0	281.0	9.02	2.60	148.67
S07	121186	0.40	32.00	8.60	500.0	27.50	383.0	299.0	160.1	8.13	2.60	170.35
S08	121186	1.50	31.00	8.00	285.0	14.00	111.0	62.0	106.3	1.35	1.35	58.26
S09	121186	0.00	34.00	8.20	170.0	26.50	21.3	12.0	107.2	0.28	0.75	49.98
S10	121186	0.40	34.00	8.40	185.0	21.30	104.0	68.0	93.7	0.23	0.65	32.35
R01	121186	5.20	29.00	7.90	55.0	12.30	41.0	30.0	41.3	.95	1.10	26.22
R02	121186	6.10	28.10	7.80	55.0	11.00	16.0	12.0	12.7	1.02	1.25	21.30
U01	191186	3.80	31.00	8.30	18025.0	9.00	600.0	402.0	1400.3	.	.	76.35
S01	191186	9.00	32.00	8.40	465.0	6.30	12.0	6.0	186.0	.	.	14.23
S02	191186	8.90	32.10	8.30	205.0	5.70	13.0	6.0	99.7	.	.	15.31
S03	191186	0.00	34.00	8.70	585.0	24.00	38.0	21.0	256.0	.	.	160.00
S04	191186	0.40	33.70	8.70	550.0	22.50	310.0	251.0	161.2	.	.	66.25
S05	191186	0.60	33.60	8.60	500.0	18.50	306.0	266.0	96.3	.	.	59.37
S06	191186	0.30	34.80	8.90	610.0	20.30	393.0	300.0	139.0	.	.	60.36
S07	191186	0.10	33.20	8.40	450.0	24.60	387.0	165.0	93.2	.	.	201.27
S08	191186	1.30	31.20	8.00	400.0	9.00	103.0	52.0	96.0	.	.	32.40
S09	191186	0.40	31.90	8.20	410.0	24.30	106.0	67.0	112.0	.	.	123.46
S10	191186	0.20	31.90	8.40	340.0	20.00	133.0	81.0	91.2	.	.	49.20
R01	191186	6.10	31.00	8.00	75.0	10.00	38.0	26.0	57.0	.	.	22.95
R02	191186	6.10	31.20	8.10	45.0	11.10	20.0	10.0	29.6	.	.	23.67
U01	261186	2.70	30.20	8.00	17000.0	8.00	791.0	641.0	1507.6	.	2.65	68.30
S01	261186	8.60	30.90	7.90	400.0	6.20	18.0	11.0	203.6	.	2.35	10.30
S02	261186	8.80	30.80	7.80	145.0	7.10	18.0	9.0	126.0	.	0.95	12.88
S03	261186	0.00	34.00	9.20	310.0	24.50	376.0	259.0	140.4	.	1.85	63.75
S04	261186	0.10	33.00	8.90	405.0	21.30	402.0	311.0	169.1	.	1.15	59.10
S05	261186	0.30	33.20	8.95	420.0	16.10	400.0	301.0	138.2	.	1.00	46.27
S06	261186	0.05	30.50	8.80	400.0	15.50	486.0	385.0	100.3	.	2.78	44.39
S07	261186	0.00	31.60	8.55	400.0	16.30	478.0	367.0	99.7	.	2.15	51.50
S08	261186	1.20	30.00	8.00	360.0	7.25	93.0	56.0	103.2	.	1.90	12.36
S09	261186	0.30	31.00	8.20	365.0	13.10	106.0	63.0	118.0	.	1.15	27.99
S10	261186	0.10	32.00	8.60	320.0	17.70	151.0	70.0	76.2	.	0.85	33.50
R01	261186	6.20	30.20	8.20	60.0	8.50	36.0	21.0	89.6	.	1.35	16.17
R02	261186	6.10	30.00	8.90	55.0	7.90	18.0	9.0	56.3	.	1.95	12.80
U01	081286	2.00	31.20	8.20	16910.0	17.80	768.0	600.0	1501.3	.	2.25	236.77
S01	081286	11.10	30.00	8.30	440.0	7.60	10.0	6.0	137.3	.	1.00	26.32
S02	081286	10.80	30.60	8.40	185.0	8.20	11.0	7.0	76.6	.	0.65	21.81
S03	081286	0.90	32.00	9.20	310.0	21.50	183.0	93.0	151.7	.	3.50	139.16
S04	081286	0.70	33.00	8.70	420.0	19.30	256.0	162.0	106.7	.	4.05	83.67
S05	081286	0.90	33.00	9.00	425.0	18.20	252.0	131.0	100.3	.	4.15	63.00
S06	081286	0.05	32.50	8.80	400.0	26.50	510.0	433.0	192.8	.	2.10	238.01
S07	081286	0.30	32.50	8.90	525.0	27.65	521.0	451.0	163.0	.	2.00	281.50
S08	081286	2.10	31.00	8.00	560.0	8.30	97.0	47.0	70.0	.	1.90	63.30
S09	081286	1.60	31.60	8.70	575.0	11.10	102.0	61.0	91.4	.	1.00	87.63
S10	081286	0.60	31.80	8.50	450.0	12.30	157.0	73.0	85.6	.	0.95	71.85
R01	081286	6.00	30.50	8.10	80.0	12.30	64.0	41.0	36.7	.	1.25	74.65
R02	081286	6.30	30.00	8.00	75.0	16.25	51.5	37.0	42.0	.	1.80	81.06
U01	171286	0.00	32.10	8.30	17200.0	17.50	944.0	513.0	.	6.24	2.50	220.30
S01	171286	12.30	31.90	8.25	545.0	12.60	8.0	4.0	.	2.62	2.25	29.36
S02	171286	12.20	32.00	8.30	210.0	12.30	5.0	2.0	.	0.10	1.10	30.70
S03	171286	0.00	34.00	8.80	480.0	26.80	697.0	352.0	.	7.26	2.92	83.25
S04	171286	0.90	31.00	8.65	445.0	13.50	224.0	102.0	.	5.95	2.55	36.60
S05	171286	1.00	31.00	8.40	475.0	17.30	200.0	100.0	.	2.63	2.40	80.33
S06	171286	0.00	32.00	8.60	525.0	23.00	696.0	450.0	.	9.59	4.25	109.10

S07	171286	0.20	31.80	8.65	585.0	28.00	621.0	497.0	.	10.36	4.09	162.75
S08	171286	2.20	31.00	8.60	650.0	5.50	101.3	75.0	.	2.47	2.50	35.07
S09	171286	1.70	31.50	8.70	630.0	19.70	110.0	71.0	.	3.49	2.65	49.88
S10	171286	1.30	31.00	8.25	660.0	10.00	101.3	55.0	.	3.41	0.25	28.63
R01	171286	5.60	31.50	8.20	75.0	23.50	80.0	67.0	.	0.28	1.30	93.40
R02	171286	6.80	30.50	6.00	190.0	14.00	72.0	34.0	.	1.38	2.10	57.21
U01	241286	0.50	32.00	8.40	18660.0	18.00	813.0	701.0	1390.3	.	.	296.30
S01	241286	12.20	30.00	8.00	540.0	10.50	4.0	2.0	101.0	.	.	36.82
S02	241286	14.20	30.50	8.20	195.0	9.00	4.0	2.0	82.6	.	.	21.66
S03	241286	0.80	33.00	8.60	495.0	27.00	207.0	160.0	120.3	.	.	136.70
S04	241286	1.00	34.00	8.65	455.0	30.20	189.0	165.0	100.9	.	.	167.60
S05	241286	1.90	33.00	8.50	460.0	21.50	188.0	96.0	73.6	.	.	301.22
S06	241286	1.10	34.00	8.70	525.0	23.00	337.0	281.0	193.0	.	.	100.05
S07	241286	0.60	32.80	8.40	575.0	28.75	432.0	316.0	78.0	.	.	249.37
S08	241286	2.60	30.20	7.90	620.0	12.20	99.0	62.0	59.0	.	.	68.77
S09	241286	2.70	31.80	8.10	610.0	15.00	107.0	59.0	62.8	.	.	71.33
S10	241286	1.00	31.90	8.10	595.0	11.60	148.0	81.0	51.7	.	.	68.85
R01	241286	6.00	30.30	8.00	75.0	16.80	59.0	40.0	16.3	.	.	62.20
R02	241286	7.00	29.70	7.60	140.0	17.20	32.0	18.0	23.7	.	.	69.30
U01	070187	0.00	31.00	8.10	19400.0	11.00	728.0	600.0	1562.2	4.36	0.25	207.50
S01	070187	12.10	30.00	8.00	665.0	7.30	4.0	1.0	231.2	3.15	3.65	22.76
S02	070187	11.60	31.20	8.00	325.0	8.10	7.0	2.0	199.0	1.91	1.20	26.20
S03	070187	0.60	32.50	8.60	1005.0	21.20	344.0	216.0	306.2	7.10	3.65	100.23
S04	070187	0.60	32.00	8.30	935.0	23.00	369.0	137.0	193.0	6.62	3.00	116.08
S05	070187	0.90	33.00	8.65	920.0	23.00	101.0	51.0	101.3	5.37	1.90	105.36
S06	070187	0.70	34.00	8.30	810.0	14.20	180.0	71.0	277.0	8.36	3.70	39.37
S07	070187	0.40	33.70	8.60	700.0	16.20	92.0	45.0	83.6	7.93	3.98	46.05
S08	070187	2.40	32.00	8.10	475.0	7.00	49.0	36.0	81.8	2.36	2.65	32.63
S09	070187	2.30	32.30	8.60	495.0	8.10	53.0	20.0	113.6	2.84	2.90	36.00
S10	070187	0.70	32.50	8.50	520.0	12.30	53.0	27.0	73.5	3.17	1.85	43.75
R01	070187	6.40	30.60	8.00	1980.0	10.20	30.0	16.0	97.3	1.69	1.45	41.23
R02	070187	7.00	30.70	8.10	785.0	10.00	18.0	9.0	77.4	0.93	2.36	36.80
U01	200187	0.00	31.00	8.40	17700.0	11.50	296.0	75.0	1636.3	9.37	2.50	174.60
S01	200187	11.00	29.50	8.60	605.0	7.90	6.0	2.0	293.0	4.32	5.00	38.35
S02	200187	10.40	29.00	9.20	250.0	7.50	16.0	12.0	200.1	1.74	6.25	27.44
S03	200187	0.10	33.00	9.20	920.0	18.70	484.0	369.0	633.3	6.39	6.10	31.27
S04	200187	0.00	32.00	8.80	880.0	9.00	466.0	235.0	522.7	5.66	2.32	48.33
S05	200187	1.00	31.60	9.10	890.0	8.70	211.0	107.0	367.3	3.31	2.30	28.60
S06	200187	1.15	33.00	10.10	700.0	12.50	455.0	306.0	169.1	5.88	5.75	30.55
S07	200187	0.30	32.50	9.70	660.0	14.00	69.0	55.0	224.0	8.35	3.75	36.90
S08	200187	0.50	30.50	8.95	445.0	25.00	58.6	35.0	141.4	1.16	9.25	101.60
S09	200187	2.50	31.30	9.00	520.0	28.50	41.0	20.0	167.2	3.02	6.50	167.93
S10	200187	0.20	30.50	8.90	510.0	26.00	58.6	35.0	67.6	4.43	4.50	61.80
R01	200187	6.10	31.50	8.70	2300.0	10.00	80.0	52.0	178.3	1.67	6.25	38.80
R02	200187	6.20	30.00	8.80	690.0	7.50	4.0	2.0	181.4	0.36	2.10	28.07
U01	290187	0.20	32.00	8.40	21000.0	7.60	629.0	436.0	1880.3	.	.	162.06
S01	290187	9.60	31.00	9.20	720.0	4.20	12.0	9.0	358.6	.	.	30.25
S02	290187	9.60	31.20	9.20	270.0	4.50	11.0	9.0	237.1	.	.	19.00
S03	290187	0.00	36.50	9.50	1850.0	21.60	536.0	411.0	586.3	.	.	67.35
S04	290187	0.00	37.00	8.70	900.0	9.80	463.0	263.0	432.0	.	.	31.26
S05	290187	0.01	32.00	8.60	750.0	7.60	249.0	181.0	386.6	.	.	22.88
S06	290187	0.00	33.00	9.60	760.0	23.30	407.0	163.0	260.3	.	.	73.61
S07	290187	0.01	32.60	9.65	745.0	13.10	493.0	39.0	249.6	.	.	32.39
S08	290187	2.20	31.50	8.90	1500.0	18.20	50.0	37.0	166.2	.	.	60.00

S09	290187	1.60	31.60	9.15	1620.0	21.00	63.0	49.0	183.0	.	.	69.53
S10	290187	0.10	32.00	8.85	1550.0	22.90	64.0	51.0	162.5	.	.	68.03
R01	290187	5.90	32.00	8.70	2560.0	9.20	40.0	23.0	199.0	.	.	22.20
R02	290187	6.20	31.50	8.80	2110.0	10.00	12.0	6.0	183.0	.	.	26.06
U01	050287	0.10	32.50	8.50	21000.0	6.10	948.0	798.0	2003.0	.	.	143.85
S01	050287	9.40	30.20	8.60	595.0	4.00	16.0	12.0	341.2	.	.	27.30
S02	050287	9.50	30.30	8.60	250.0	4.10	11.0	6.0	219.3	.	.	17.66
S03	050287	0.00	34.20	8.90	1120.0	12.30	418.0	318.0	376.2	.	.	56.12
S04	050287	0.00	34.00	8.70	1005.0	7.00	410.0	206.0	301.3	.	.	30.00
S05	050287	0.10	33.00	8.70	715.0	8.25	391.0	300.0	280.0	.	.	27.20
S06	050287	0.00	34.50	9.00	830.0	15.50	481.0	373.0	293.0	.	.	68.75
S07	050287	0.00	34.00	8.80	800.0	10.30	407.0	361.0	273.2	.	.	50.10
S08	050287	2.10	32.00	8.30	1595.0	3.20	133.0	100.0	191.2	.	.	16.81
S09	050287	1.50	32.90	8.70	1680.0	6.00	141.0	72.0	268.6	.	.	23.59
S10	050287	0.10	32.80	8.90	1650.0	9.30	203.0	101.0	291.5	.	.	29.06
R01	050287	5.70	31.00	8.20	2775.0	5.30	55.0	26.0	372.5	.	.	14.83
R02	050287	6.10	31.50	8.30	2285.0	5.70	40.0	28.0	306.2	.	.	16.75
U01	160287	0.00	31.60	8.30	21000.0	5.00	680.0	518.0	2900.0	.	2.90	96.35
S01	160287	8.50	31.00	8.00	590.0	5.00	29.0	18.0	287.0	.	2.40	23.50
S02	160287	8.90	31.20	8.20	255.0	4.20	28.0	15.0	206.1	.	3.90	18.32
S03	160287	0.00	34.30	8.70	915.0	19.50	1322.0	804.0	322.1	.	5.65	65.70
S04	160287	0.00	35.00	8.80	920.0	7.20	928.0	631.0	300.0	.	1.95	21.85
S05	160287	0.00	33.00	8.70	735.0	4.00	402.0	396.0	266.7	.	1.85	12.51
S06	160287	0.00	32.00	9.00	700.0	21.65	612.0	516.0	511.0	.	6.25	106.66
S07	160287	0.00	32.00	8.70	685.0	8.00	563.0	483.0	433.2	.	3.80	28.25
S08	160287	1.70	31.50	8.40	2000.0	3.20	196.0	107.0	197.8	.	5.20	10.50
S09	160287	0.80	32.60	8.30	1560.0	6.25	197.0	100.0	286.0	.	5.75	12.30
S10	160287	0.00	32.80	8.60	1535.0	7.10	259.0	177.0	306.3	.	3.75	11.60
R01	160287	5.30	31.80	8.20	3300.0	4.30	51.0	27.0	347.0	.	4.05	11.06
R02	160287	5.80	31.60	8.10	2450.0	2.60	37.0	21.0	369.0	.	4.35	11.73
U01	240287	0.00	31.80	8.70	21000.0	7.50	1028.0	811.0	2907.8	8.36	2.75	33.00
S01	240287	5.00	30.30	8.60	670.0	7.00	69.0	49.0	306.6	2.11	2.65	28.00
S02	240287	5.00	30.00	9.00	260.0	5.50	80.0	59.0	215.2	1.62	6.90	21.50
S03	240287	0.00	42.70	9.00	1010.0	16.00	1008.0	870.0	267.5	11.20	8.75	43.76
S04	240287	0.00	37.50	8.70	765.0	17.50	881.0	422.0	398.3	9.03	4.60	49.07
S05	240287	0.00	32.50	8.90	720.0	6.30	427.0	288.0	301.2	4.01	2.76	12.30
S06	240287	0.00	32.00	8.70	660.0	8.25	679.0	400.0	208.0	8.73	5.00	58.67
S07	240287	0.00	34.00	9.00	735.0	6.90	731.0	556.0	276.0	6.25	6.15	46.23
S08	240287	2.80	32.00	8.50	2000.0	5.00	112.0	85.0	184.5	2.30	5.00	10.37
S09	240287	0.40	32.60	8.40	1600.0	6.20	203.0	108.0	299.0	1.02	5.79	19.33
S10	240287	0.10	33.00	8.60	1510.0	5.00	144.0	85.0	301.3	1.65	3.65	12.49
R01	240287	5.30	31.60	8.75	3375.0	2.00	62.0	50.0	362.2	1.30	4.20	10.77
R02	240287	6.60	31.30	8.55	2500.0	2.50	104.0	67.0	335.1	0.94	2.60	11.62

Appendix E

Daily monitored values for the tributary canals

Site	Date	DO mg/L	WT °C	pH	Cond µmhos/cm	Turb NTU	COD mg/L	BOD mg/L	Sulf mg/L	TN mg/L	TP mg/L	SS mg/L
T01	280186	0.70	30.05	8.00	235.0	10.00	106.0	59.0	60.0	-	0.75	14.20
T02	280186	0.80	30.00	8.10	215.0	9.50	101.0	61.0	62.3	-	0.60	15.63
T03	280186	0.70	31.50	8.60	620.0	26.50	133.6	88.0	106.7	-	7.80	78.32
T04	280186	1.20	30.50	8.40	210.0	14.50	80.0	51.0	43.9	-	0.30	26.30
T05	280186	0.60	30.00	8.35	435.0	10.00	93.0	72.0	36.1	-	0.10	16.01
T06	280186	0.65	30.05	8.30	460.0	27.00	91.0	73.0	70.7	-	1.35	91.23
T07	280186	1.05	30.00	8.10	215.0	12.00	77.0	42.0	39.0	-	0.95	70.64
T08	280186	0.70	30.00	8.10	510.0	29.00	133.0	69.0	69.3	-	2.60	88.34
T09	280186	0.90	30.00	8.20	390.0	15.50	98.0	58.0	408.1	-	0.10	22.90
T10	280186	0.60	31.00	8.25	735.0	23.00	100.2	79.0	127.3	-	3.65	62.85
T11	280186	0.25	30.50	8.20	295.0	18.50	283.0	188.0	97.0	-	0.40	55.60
T12	280186	0.40	31.00	8.00	480.0	16.00	200.0	107.0	63.2	-	0.75	37.60
T13	280186	0.10	32.00	8.30	575.0	20.50	324.0	206.0	100.2	-	0.60	109.40
T01	110286	0.30	31.50	8.20	310.0	5.00	200.0	106.0	112.3	-	0.90	7.26
T02	110286	0.35	31.50	8.20	345.0	4.50	203.0	106.0	122.6	-	1.00	6.90
T03	110286	0.40	33.00	8.75	855.0	16.50	169.0	89.0	181.6	-	3.85	50.00
T04	110286	1.60	31.50	8.40	365.0	10.00	101.0	59.0	85.5	-	0.35	30.51
T05	110286	0.30	31.00	8.45	470.0	7.50	171.6	93.0	67.0	-	0.20	11.30
T06	110286	0.30	30.50	8.20	555.0	23.00	161.3	87.0	109.2	-	2.15	76.25
T07	110286	0.25	30.00	8.05	300.0	6.00	183.0	112.0	69.4	-	1.60	8.31
T08	110286	0.40	30.00	8.15	610.0	22.30	160.0	98.0	96.5	-	4.35	73.05
T09	110286	0.70	31.00	8.20	430.0	6.50	136.0	85.0	731.1	-	0.45	10.07
T10	110286	0.40	33.50	8.60	810.0	18.00	141.0	76.0	258.3	-	5.30	51.61
T11	110286	0.20	32.50	8.20	290.0	14.50	307.0	179.0	187.3	-	0.80	41.33
T12	110286	0.40	32.00	8.05	395.0	9.00	216.0	141.0	166.2	-	2.00	16.66
T13	110286	0.10	36.50	8.20	580.0	18.00	432.0	318.0	219.0	-	1.10	59.35
T01	270386	0.50	31.00	8.10	331.0	10.50	267.0	177.0	164.5	2.35	2.80	10.42
T02	270386	0.45	30.50	8.05	400.0	12.00	242.0	176.0	161.3	4.65	2.00	16.00
T03	270386	0.00	32.00	9.10	900.0	28.50	184.0	98.0	265.3	4.03	4.20	69.81
T04	270386	3.80	33.00	7.40	187.0	80.00	102.6	69.0	121.0	0.06	2.10	269.33
T05	270386	0.10	31.50	8.10	601.0	14.50	189.0	103.0	83.5	0.08	0.25	30.66
T06	270386	0.30	31.00	8.00	630.0	14.50	170.0	99.0	165.2	3.16	2.00	23.00
T07	270386	0.10	30.00	8.25	195.0	08.00	196.2	112.0	89.6	0.59	1.95	11.80
T08	270386	0.20	30.00	8.20	677.0	16.00	199.0	122.0	130.1	0.56	3.05	63.77
T09	270386	0.50	30.50	8.35	361.0	8.50	162.0	93.0	859.3	0.37	0.35	19.31
T10	270386	0.30	32.05	8.60	820.0	17.50	164.0	93.0	347.7	2.37	4.65	67.08
T11	270386	0.00	33.55	8.25	297.0	20.00	301.0	231.0	201.0	5.15	0.65	58.11
T12	270386	0.30	32.50	8.20	381.0	12.50	206.3	101.0	178.3	7.37	1.65	40.00
T13	270386	0.00	37.50	8.40	733.0	22.50	391.0	302.0	266.0	8.65	2.20	169.20
T01	150486	2.00	32.00	8.00	330.0	13.50	90.0	51.0	39.0	6.31	0.85	19.90
T02	150486	2.10	31.50	8.05	365.0	13.50	96.0	68.0	41.3	7.40	0.70	23.65
T03	150486	1.00	33.00	9.25	917.0	39.50	111.0	81.0	103.0	4.25	2.15	99.63
T04	150486	2.80	32.50	8.30	261.0	36.00	76.0	38.0	55.0	0.15	0.40	101.20
T05	150486	3.30	32.00	8.35	600.0	18.50	89.0	60.0	27.6	0.76	0.30	49.88
T06	150486	0.90	31.00	8.10	507.0	24.00	93.0	62.0	73.5	4.16	1.35	81.30
T07	150486	1.90	30.60	8.05	201.0	15.50	33.0	26.0	30.1	1.87	1.00	37.11

T08	150486	0.90	31.00	8.10	676.0	32.00	59.0	38.0	62.0	1.65	2.00	91.91
T09	150486	1.20	31.60	8.25	381.0	12.00	56.0	40.0	367.5	0.90	0.20	26.80
T10	150486	1.80	33.60	8.40	821.0	34.00	47.0	32.0	97.0	5.39	3.80	89.08
T11	150486	0.95	31.50	8.30	230.0	23.00	233.0	136.0	72.6	6.37	0.30	92.65
T12	150486	1.10	31.60	8.25	265.0	17.50	132.0	97.0	56.7	8.10	1.00	46.30
T13	150486	0.80	36.00	8.50	561.0	40.00	300.0	223.0	95.6	8.85	2.35	139.32
T01	290586	3.45	31.20	8.10	260.0	20.50	87.0	47.0	24.3	7.36	0.55	96.22
T02	290586	3.05	30.80	8.15	187.0	19.00	91.0	53.0	24.7	7.91	0.60	98.37
T03	290586	3.90	31.60	8.80	1655.0	46.50	90.0	46.0	59.3	5.65	4.60	216.65
T04	290586	3.95	30.80	8.30	260.0	26.00	61.0	34.0	36.1	0.90	0.15	92.00
T05	290586	4.10	31.00	8.30	291.0	20.50	15.0	8.0	14.2	1.65	0.00	81.41
T06	290586	1.30	30.00	8.00	305.5	36.50	36.0	23.0	47.8	6.20	0.50	139.00
T07	290586	2.70	30.00	8.00	201.0	19.00	18.0	13.0	23.4	3.71	0.90	77.67
T08	290586	1.10	29.80	8.00	375.0	37.00	41.6	25.0	40.7	2.96	1.65	117.25
T09	290586	1.60	30.40	8.05	350.5	16.50	49.0	35.0	207.3	1.60	0.26	61.00
T10	290586	2.10	31.20	8.35	1007.0	51.00	39.0	26.0	66.2	6.30	3.90	276.10
T11	290586	1.50	30.10	8.10	355.0	27.50	133.0	79.0	67.0	7.80	0.60	100.50
T12	290586	1.60	30.20	8.15	501.5	24.50	90.0	64.0	43.1	10.07	0.80	93.10
T13	290586	1.20	36.30	8.30	1066.0	43.00	209.0	103.0	71.1	11.50	0.95	211.66
T01	240686	1.20	31.80	7.90	333.0	8.00	130.0	81.0	100.3	6.81	0.65	18.50
T02	240686	1.10	31.10	8.00	193.0	7.50	121.6	82.0	113.1	7.63	0.60	16.76
T03	240686	1.00	32.50	8.00	2350.0	5.60	26.6	11.0	214.8	5.73	6.00	10.30
T04	240686	1.80	31.00	8.10	580.0	18.00	100.3	62.0	134.0	0.85	0.30	93.10
T05	240686	2.90	31.20	8.15	660.0	8.00	18.0	13.0	93.5	1.30	0.10	16.36
T06	240686	0.70	31.00	8.05	596.0	26.00	53.0	40.0	136.8	4.01	1.35	83.52
T07	240686	1.30	31.00	8.00	443.0	7.50	20.0	11.0	97.6	3.82	1.00	9.30
T08	240686	0.80	31.10	7.90	656.0	18.00	47.0	29.0	100.6	1.65	2.60	78.36
T09	240686	1.30	31.30	8.10	687.0	10.00	53.6	37.0	497.2	0.94	0.45	19.90
T10	240686	1.60	31.60	8.30	1390.0	20.50	46.7	36.0	209.7	5.07	4.50	95.26
T11	240686	1.00	30.50	8.25	388.0	28.00	266.0	191.0	211.6	6.70	1.20	98.30
T12	240686	1.20	30.00	8.00	727.0	16.50	206.0	122.0	131.5	9.60	1.30	71.80
T13	240686	0.90	35.00	8.20	981.0	33.50	302.0	268.0	263.1	12.75	2.05	101.30
T01	030786	0.70	30.00	8.20	400.0	7.50	233.0	166.0	131.6	7.09	0.85	17.60
T02	030786	0.55	30.30	8.25	362.0	7.00	203.3	178.0	130.0	6.90	0.75	12.40
T03	030786	6.20	30.00	9.00	2500.0	15.00	34.3	16.0	219.1	5.30	3.60	37.30
T04	030786	1.00	30.30	8.50	607.0	13.00	51.0	29.0	151.6	0.96	0.35	56.55
T05	030786	2.10	30.00	8.60	1000.0	7.50	63.0	49.0	93.3	1.25	0.25	15.90
T06	030786	0.50	30.10	8.30	1026.0	23.00	199.0	123.0	191.1	4.00	1.60	77.36
T07	030786	0.90	29.80	8.10	566.0	7.00	152.6	88.0	108.2	2.75	0.80	8.88
T08	030786	0.15	30.10	8.30	1310.0	18.00	173.0	111.0	190.6	1.00	2.00	69.81
T09	030786	0.80	30.60	8.45	703.0	8.00	207.6	183.0	563.8	1.37	0.00	19.30
T10	030786	0.80	31.90	8.60	1400.0	19.00	203.0	137.0	233.4	8.62	3.60	92.00
T11	030786	0.30	31.00	8.00	433.0	28.50	357.0	217.0	312.3	8.36	1.60	101.30
T12	030786	0.60	30.50	8.25	681.0	14.00	259.0	204.0	139.6	8.00	1.30	66.25
T13	030786	0.40	37.80	8.40	1003.0	31.50	611.0	407.0	371.1	11.71	2.90	189.39
T01	200886	1.40	29.00	8.60	321.0	8.50	127.0	67.0	99.9	6.90	0.80	21.16
T02	200886	1.30	29.10	8.15	330.0	10.00	110.0	69.0	96.2	6.30	0.60	36.00
T03	200886	3.80	31.00	9.15	500.0	7.50	142.6	80.0	87.6	1.67	2.15	32.33
T04	200886	1.30	30.00	8.40	406.0	12.00	109.0	71.0	107.2	0.80	0.10	51.55
T05	200886	2.30	30.60	8.35	697.0	9.00	38.2	22.0	96.4	0.00	0.20	19.00
T06	200886	1.80	29.30	8.05	675.0	30.50	71.0	39.0	111.6	3.51	1.35	89.12
T07	200886	1.90	29.00	8.00	360.0	12.00	66.0	30.0	96.2	1.67	0.60	16.65
T08	200886	0.95	28.00	8.10	706.0	31.00	86.0	62.0	115.3	1.30	2.60	107.50
T09	200886	1.20	29.50	8.35	591.0	15.00	55.0	31.0	407.7	0.88	0.00	29.70

T10	200886	1.30	28.50	8.65	1001.0	22.00	76.3	49.0	166.5	5.36	2.00	101.10
T11	200886	0.60	31.00	8.20	401.0	20.50	311.0	278.0	160.6	8.00	1.20	106.51
T12	200886	1.20	30.20	8.05	550.0	17.50	206.0	175.0	111.3	7.10	1.20	67.44
T13	200886	0.65	34.60	8.60	770.0	23.00	534.0	401.0	188.5	10.37	1.65	81.24
T01	030986	0.60	30.00	8.30	300.0	9.50	110.0	55.0	81.2	8.31	0.95	30.17
T02	030986	0.65	30.20	8.40	306.0	10.00	100.0	50.0	86.3	7.26	0.90	30.66
T03	030986	1.00	32.60	9.05	500.0	20.50	98.0	26.0	107.3	3.60	4.25	83.61
T04	030986	1.30	31.00	8.35	336.0	13.00	66.6	39.0	101.3	0.85	0.35	58.50
T05	030986	2.40	30.00	8.40	561.0	10.50	30.0	16.0	80.0	0.25	0.40	27.73
T06	030986	1.85	30.50	8.30	607.0	30.00	78.3	39.0	91.0	3.88	1.80	94.46
T07	030986	1.95	30.00	8.05	388.0	12.50	63.7	27.0	76.5	1.71	1.40	16.20
T08	030986	0.95	29.50	8.10	600.0	32.50	81.0	57.0	103.2	1.20	2.50	129.51
T09	030986	1.00	30.90	8.35	402.0	17.50	41.6	20.0	391.6	0.64	0.35	39.22
T10	030986	1.35	32.80	8.60	639.0	21.00	68.0	42.0	146.9	6.07	5.30	66.09
T11	030986	0.65	29.60	8.10	391.0	31.50	368.6	282.0	156.1	8.67	1.35	160.33
T12	030986	1.50	31.00	8.20	399.0	19.50	258.0	163.0	81.2	8.11	1.50	68.80
T13	030986	0.35	34.30	8.70	600.0	36.00	422.0	351.0	170.0	9.22	2.00	177.00
T01	141086	1.80	30.10	8.00	201.0	14.00	100.0	83.0	61.3	8.62	1.00	50.60
T02	141086	1.90	30.00	8.00	193.0	13.50	90.0	90.0	59.7	8.33	0.80	61.00
T03	141086	1.20	31.00	8.20	370.0	16.00	37.0	23.0	121.0	7.35	0.30	79.25
T04	141086	1.45	30.80	8.20	166.0	13.50	59.0	25.0	86.4	1.30	0.25	59.10
T05	141086	2.60	30.00	8.20	240.0	13.50	27.3	14.0	66.5	0.91	0.30	62.72
T06	141086	2.00	30.50	8.10	265.0	32.50	69.0	46.0	82.3	5.75	1.10	125.61
T07	141086	1.95	30.20	8.00	101.0	16.00	32.0	16.0	67.2	3.70	0.80	68.10
T08	141086	1.10	30.00	8.10	360.0	25.00	69.6	38.0	90.4	2.94	2.00	116.00
T09	141086	1.20	30.60	8.15	227.0	20.50	36.0	16.0	406.3	1.70	0.15	101.50
T10	141086	1.05	31.80	8.30	400.0	27.50	60.0	32.0	127.4	10.34	4.30	120.20
T11	141086	0.75	30.00	8.20	201.0	31.00	201.0	139.0	126.7	9.64	1.30	158.10
T12	141086	1.65	30.40	8.25	210.0	22.50	155.0	100.0	107.0	10.72	0.90	81.25
T13	141086	0.35	37.80	8.40	390.0	37.50	260.0	148.0	161.3	11.30	2.40	181.43
T01	131186	0.50	30.00	8.10	230.0	15.00	198.0	125.0	97.3	5.46	0.96	72.60
T02	131186	0.50	30.00	8.00	250.0	15.50	266.0	186.0	131.2	6.34	2.30	70.50
T03	131186	0.40	30.00	8.25	300.0	21.50	112.0	70.0	126.0	2.06	0.75	86.33
T04	131186	0.00	29.00	8.20	110.0	12.50	21.3	13.0	64.8	0.01	0.12	59.35
T05	131186	2.00	31.00	8.35	225.0	4.00	37.3	23.0	51.8	0.06	0.00	10.07
T06	131186	0.40	30.00	8.30	245.0	26.00	21.3	14.0	96.8	2.83	0.60	120.55
T07	131186	0.90	30.00	8.10	110.0	10.00	16.0	10.0	55.3	0.57	0.45	51.00
T08	131186	0.20	29.00	8.10	290.0	34.50	32.0	21.0	93.4	0.50	2.10	168.75
T09	131186	0.80	31.00	8.25	190.0	17.00	76.0	37.0	747.2	0.21	0.12	107.70
T10	131186	0.01	33.00	8.30	750.0	32.50	105.2	95.0	197.1	2.10	1.60	139.36
T11	131186	0.30	32.00	8.55	425.5	16.50	288.0	173.0	127.8	8.57	4.65	101.00
T12	131186	0.40	30.50	8.40	405.0	14.50	209.0	157.0	162.6	6.02	1.20	88.15
T13	131186	0.30	34.50	8.65	465.0	20.00	303.0	262.0	143.2	7.11	4.30	106.50
T01	031286	0.60	30.50	8.30	160.0	18.50	155.0	87.0	103.0	9.95	0.90	83.20
T02	031286	0.50	30.00	8.20	355.0	18.00	149.0	125.0	126.8	6.24	2.80	47.80
T03	031286	2.70	31.00	8.50	720.0	16.00	117.3	65.0	175.2	6.88	6.401	71.00
T04	031286	0.60	30.50	8.30	100.0	12.00	103.0	76.0	60.2	0.87	0.75	63.09
T05	031286	2.70	30.50	8.40	160.0	6.50	32.5	20.5	57.0	0.36	0.30	18.37
T06	031286	0.60	30.00	8.30	205.0	27.00	21.0	10.0	79.3	6.81	0.60	139.25
T07	031286	1.05	30.05	8.00	165.0	16.50	13.5	08.0	56.2	0.98	0.35	70.20
T08	031286	0.30	29.50	8.10	245.0	38.00	26.5	15.0	81.6	3.80	1.60	233.00
T09	031286	0.90	31.50	8.30	215.0	20.50	79.0	36.3	516.2	2.90	0.30	110.25
T10	031286	0.10	32.50	8.45	760.0	37.50	111.0	89.0	142.0	9.43	2.10	169.68
T11	031286	0.50	30.50	8.40	412.0	18.50	316.0	116.0	101.3	10.06	1.96	133.02

T12	031286	0.60	30.00	8.60	390.0	16.00	161.0	101.0	110.7	9.69	0.75	88.00
T13	031286	0.45	34.50	8.60	425.5	22.50	444.0	297.0	126.3	8.61	1.05	146.72
T01	060187	0.40	31.00	8.20	273.0	14.50	163.6	99.3	99.3	4.36	2.65	52.20
T02	060187	0.60	31.30	8.30	300.0	12.00	146.3	93.3	121.7	4.32	2.30	46.72
T03	060187	2.00	31.00	9.20	420.5	11.00	160.0	91.0	159.0	5.05	2.25	47.09
T04	060187	0.65	31.00	8.60	265.0	10.00	161.0	89.0	67.0	0.16	0.75	55.24
T05	060187	2.10	31.50	8.65	300.5	6.00	72.0	47.2	53.8	0.42	0.45	12.00
T06	060187	0.65	30.00	8.50	185.0	22.50	58.3	37.0	77.4	3.60	0.60	106.25
T07	060187	0.60	30.05	8.30	215.0	12.50	46.0	30.0	59.7	0.73	0.35	67.11
T08	060187	0.30	30.00	8.35	355.0	21.00	62.2	36.3	96.3	0.86	0.75	219.31
T09	060187	0.70	32.00	8.40	260.0	12.00	93.0	71.5	518.6	2.63	1.60	63.00
T10	060187	0.00	28.00	9.20	1000.0	17.00	191.0	135.0	215.2	4.87	3.75	70.50
T11	060187	0.35	31.50	8.45	305.0	27.50	300.0	209.0	137.0	5.87	4.00	180.51
T12	060187	0.55	31.50	8.40	320.0	14.00	150.0	93.0	112.7	7.36	0.30	51.60
T13	060187	0.30	38.00	8.55	400.0	15.00	502.0	386.0	439.6	8.13	0.00	68.75
T01	120287	0.00	31.80	8.30	380.0	6.50	261.6	163.0	131.2	1.03	1.65	10.30
T02	120287	0.00	32.00	8.40	400.0	7.00	295.0	112.0	127.6	1.21	2.35	19.20
T03	120287	0.20	33.00	8.40	2090.0	4.00	281.0	144.0	278.4	4.60	3.65	8.65
T04	120287	0.00	32.00	8.65	566.0	7.20	196.0	120.0	161.6	0.02	1.60	12.10
T05	120287	1.30	31.20	8.70	410.0	3.00	224.0	163.0	87.1	0.40	0.95	7.60
T06	120287	0.00	31.30	8.60	385.0	6.50	136.0	63.5	155.4	0.30	1.05	13.75
T07	120287	0.05	30.50	8.20	280.5	4.00	102.7	52.0	101.2	0.56	0.85	8.01
T08	120287	0.01	30.90	8.35	560.0	5.50	161.0	98.0	197.0	0.54	1.80	10.72
T09	120287	0.10	32.00	8.45	475.0	6.00	211.2	141.0	796.0	0.83	3.20	12.70
T10	120287	0.35	33.60	8.60	1400.0	6.00	238.6	185.0	265.3	1.26	6.25	15.80
T11	120287	0.00	32.00	8.20	665.0	10.60	415.0	302.0	169.6	2.86	3.75	26.35
T12	120287	0.02	31.00	8.00	750.0	5.00	237.0	185.0	160.3	3.00	1.21	10.27
T13	120287	0.00	40.00	8.40	1660.0	25.00	811.0	637.0	200.8	2.38	3.60	62.40

Appendix F

Daily monitored values for the factories and site U02

Fac	Date	DO	WT	pH	Cond	Turb	COD	BOD	Sulf	TN	TP	SS
		mg/L	C		umhos/cm	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A1	200186	5.00	32.0	8.80	700.0	72.5	5360.0	4436.0	193.1	-	2.50	877.32
A6	200186	5.20	-	7.40	94.0	0.6	4.0	0.0	-	-	-	8.70
A2	200186	5.90	30.0	10.50	1200.0	12.0	1865.0	1156.0	-	-	2.50	46.15
A2	250286	5.25	38.0	10.70	1160.0	34.0	2160.0	1608.0	147.6	-	3.75	286.55
A2	030386	5.00	37.5	9.90	840.0	25.5	252.0	207.5	69.3	0.81	4.20	176.80
A2	090486	4.00	36.0	9.50	450.0	6.7	384.0	185.0	59.3	1.62	3.85	21.65
A2	140586	3.80	41.5	11.90	1050.0	26.0	1560.0	984.0	66.0	1.03	6.50	211.00
A2	180686	2.60	43.0	9.80	855.0	20.5	3280.0	2687.0	131.8	2.60	7.65	106.11
A2	310786	4.25	33.5	8.90	320.0	10.0	2330.0	1350.0	152.3	1.30	5.00	43.27
A2	110886	4.10	30.6	9.85	960.0	29.0	921.0	209.0	84.5	-	7.90	220.50
A2	110986	5.60	37.4	10.60	1350.0	43.0	2053.0	1686.0	103.4	-	8.55	497.06
A2	071086	5.00	36.5	11.00	1005.0	25.0	1668.0	920.0	26.8	1.06	8.10	139.29
A2	221086	4.50	38.0	12.05	2400.0	28.0	896.0	700.0	20.7	1.09	0.90	101.86
A2	031186	5.00	39.5	12.00	2150.0	36.5	1833.0	1364.0	91.3	0.96	7.60	306.65
A2	021286	4.10	37.0	12.40	4000.0	26.0	872.0	600.0	806.0	6.73	5.90	186.40
A2	050187	5.10	40.8	11.60	3805.0	52.5	1627.0	354.0	93.1	3.15	8.10	561.32
A2	230287	2.30	40.0	12.55	4050.0	16.0	1344.0	750.0	396.0	1.42	5.00	144.60
A3	200186	5.50	32.0	6.50	780.0	52.5	1806.0	976.0	40.0	-	3.65	751.20
A3	250286	5.00	33.0	8.20	1850.0	30.5	2080.0	1380.0	18.6	-	4.80	216.50
A3	030386	2.00	33.0	8.35	1225.0	25.0	1100.0	972.0	91.2	167.85	1.65	110.67
A3	090486	0.60	30.5	7.80	3000.0	56.5	3136.0	2705.0	86.3	236.70	5.00	863.35
A3	140586	5.70	31.5	8.20	1108.0	36.5	1010.0	775.0	16.6	62.35	5.00	331.07
A3	180686	1.80	32.0	9.00	525.0	38.0	2581.0	1821.0	26.6	183.60	7.00	296.50
A3	310786	1.60	30.0	8.75	2075.0	44.5	1775.0	651.0	85.6	45.75	6.90	462.62
A3	110886	2.30	30.5	8.60	600.0	10.0	1963.0	338.0	76.5	15.60	6.35	28.30
A3	110986	0.10	33.5	8.85	1330.0	58.0	754.0	462.0	19.5	133.20	2.30	509.24
A3	071086	5.10	32.0	9.00	1130.0	53.5	196.0	76.0	17.6	112.30	8.55	507.20
A3	221086	5.60	30.0	7.60	480.0	38.0	533.0	266.0	37.3	98.50	1.40	186.00
A3	031186	5.60	32.0	8.90	3255.0	46.0	502.0	276.0	123.6	-	2.60	720.25
A3	021286	1.90	33.0	8.20	1125.0	56.0	1096.0	450.0	17.2	286.00	1.50	1250.00
A3	050187	4.60	32.5	8.10	1350.0	38.5	1860.0	1005.0	36.7	18.60	6.70	307.20
A3	230287	5.60	30.0	9.05	600.0	12.5	1520.0	975.0	95.3	53.70	10.00	57.00
A4	030386	0.00	45.0	9.10	440.0	4.6	63.0	20.0	-	-	3.00	12.60
A4	310786	0.00	51.0	8.00	805.0	2.5	40.0	18.0	41.3	-	0.90	8.31
A4	050187	0.10	48.5	7.60	900.0	1.8	116.0	52.0	32.7	-	1.25	4.05
A5	200186	2.60	34.0	8.10	705.0	072.0	2916.0	1988.0	118.3	-	2.50	565.30
A5	250286	3.60	34.5	6.50	420.0	65.0	351.0	186.0	276.9	-	1.00	590.00
A5	030386	3.40	33.0	6.20	175.0	40.1	308.0	245.0	71.0	-	1.50	296.39
A5	090486	3.35	31.5	10.20	2600.0	30.0	1227.0	437.0	281.6	96.81	9.35	118.77
A5	140586	3.30	32.0	9.15	1250.0	60.0	4733.0	2860.0	101.2	79.20	7.60	567.60
A5	180686	2.40	31.0	11.00	490.0	60.5	3360.0	595.0	82.6	53.02	8.90	580.00
A5	310786	3.50	29.0	8.30	730.0	155.0	2008.0	1320.0	96.7	79.11	5.00	1906.26
A5	110886	3.45	32.0	5.30	2510.0	12.5	0665.0	346.0	138.0	116.75	2.00	30.30
A5	110986	3.00	34.5	8.40	710.0	39.0	701.0	323.0	251.3	73.20	2.50	369.65
A5	071086	3.10	32.5	7.80	2110.0	73.5	265.0	111.0	130.9	10.30	1.10	684.02
A5	221086	3.40	34.0	8.45	710.0	635.0	896.0	700.0	265.0	131.05	1.40	7607.90

A5	031186	3.30	33.5	8.60	750.0	70.5	1675.0	996.0	204.1	92.70	2.30	625.05
A5	021286	3.40	28.0	12.30	2100.0	72.5	1280.0	606.0	235.2	126.20	17.80	1951.00
A5	050187	3.40	34.0	7.90	560.0	39.6	2350.0	1773.0	107.0	37.10	2.60	311.61
A5	230287	2.40	32.0	8.30	410.0	10.0	1600.0	800.0	119.9	30.37	2.90	37.88
B1	200186	3.10	42.0	8.70	390.0	65.5	26100.0	13100.0	58.6	-	2.90	637.11
B1	250286	4.00	36.0	10.20	860.0	70.0	6928.0	2216.0	190.2	-	9.20	927.62
B1	030386	2.10	39.5	8.40	450.0	146.0	15800.0	12335.0	100.3	4.15	4.10	2273.00
B1	090486	2.70	35.0	11.80	18100.0	200.0	9200.0	1026.0	1193.6	1.70	15.20	3660.75
B1	140586	6.40	40.0	11.60	4660.0	57.0	810.0	165.0	59.1	2.61	16.75	602.73
B1	310786	6.50	30.0	11.80	3100.0	300.0	726.0	360.0	207.5	0.05	11.60	8924.00
B1	110886	4.10	33.5	9.20	990.0	50.0	5930.0	3673.0	76.3	4.60	3.85	574.44
B1	110986	4.60	33.0	8.80	800.0	17.5	520.0	260.0	59.9	4.06	2.15	178.70
B1	071086	2.10	31.0	9.80	21000.0	22.0	5600.0	2000.0	2998.3	0.07	3.10	98.00
B1	221086	4.00	40.0	10.60	2500.0	22.5	437.0	200.0	186.0	0.90	7.25	118.08
B1	031186	2.10	43.5	9.40	560.0	58.0	13200.0	8165.0	201.1	0.35	4.30	510.33
B1	021286	6.20	34.0	12.80	490.0	65.0	17600.0	4333.0	62.3	4.36	18.20	778.63
B1	050187	3.00	38.0	8.90	1865.0	128.0	7927.0	5100.0	1202.4	2.37	3.90	1168.40
B1	230287	5.90	31.0	8.45	490.0	50.0	1962.0	662.0	190.6	6.35	3.65	232.50
K	130686	2.10	.	7.50	3400.0	53.0	5280.0	3400.0	.	.	.	500.00
B2	200186	0.10	36.0	9.20	210.0	36.0	139.0	51.0	60.7	.	3.75	190.22
B2	250286	0.00	38.5	8.80	1490.0	15.0	567.0	411.0	167.0	.	1.10	46.00
B2	030386	0.00	39.0	8.30	350.0	16.0	420.0	300.0	76.3	0.80	0.95	37.00
B2	090486	0.00	35.0	8.80	420.0	43.0	301.0	211.0	81.9	4.11	4.60	339.08
B2	140586	0.20	35.5	9.00	1100.0	26.5	116.0	42.0	151.2	5.60	3.20	112.60
B2	310786	0.00	32.0	9.00	300.0	25.5	88.0	48.0	202.9	1.00	4.25	133.20
B2	110886	2.00	35.0	8.80	160.0	7.5	88.0	52.0	94.5	2.36	2.15	26.60
B2	110986	0.00	39.0	8.60	1190.0	15.0	504.0	280.0	69.1	1.10	1.20	111.80
B2	071086	0.00	35.0	8.55	1000.0	36.5	296.0	140.0	64.5	5.44	2.40	200.60
B2	221086	0.00	39.0	8.80	385.0	38.0	160.0	83.0	50.6	1.62	2.35	213.41
B2	031186	0.30	39.5	9.10	170.0	42.0	285.0	161.0	110.3	0.96	1.85	266.20
B2	021286	0.90	32.0	9.20	310.0	14.5	133.3	56.0	140.0	6.30	1.50	61.66
B2	050187	0.60	41.0	9.20	380.0	8.5	216.0	100.6	200.0	1.77	2.60	10.07
B2	230287	0.00	44.0	9.00	1220.0	37.5	637.0	424.0	67.3	1.06	2.30	196.30
C1	200186	1.30	40.2	8.10	200.0	29.5	686.0	526.0	111.3	.	5.00	137.60
C1	250286	2.60	30.5	8.90	315.0	8.0	366.0	97.0	181.7	.	7.25	9.91
C1	030386	5.20	31.5	6.70	412.5	10.5	390.0	169.0	27.1	15.77	2.00	20.08
C1	090486	0.10	45.0	7.90	632.5	12.0	467.0	337.0	99.2	6.84	3.20	53.68
C1	140586	3.00	31.5	7.80	336.0	20.5	500.0	398.0	93.2	10.33	1.90	91.10
C1	180686	4.20	30.0	5.00	520.5	26.5	350.0	153.0	36.3	15.91	0.40	102.27
C1	110886	0.80	43.5	7.90	675.0	15.5	159.0	87.0	108.6	22.60	2.55	43.60
C1	110986	0.70	42.0	8.70	550.0	11.0	368.0	190.0	27.6	15.61	4.25	78.56
C1	071086	2.60	30.0	8.90	650.0	27.5	160.0	100.0	87.6	14.01	1.80	83.00
C1	221086	2.70	30.5	8.30	750.0	13.0	197.0	63.0	400.3	18.35	5.00	29.55
C1	021286	4.90	30.5	8.60	360.0	14.0	152.0	80.0	193.7	7.66	5.00	106.30
C1	050187	4.80	32.5	8.90	525.0	11.5	463.0	100.0	117.0	10.70	6.25	87.29
C1	230287	0.60	30.0	8.70	390.0	14.0	397.0	292.0	186.0	27.30	1.80	73.65
C2	200186	0.00	32.0	8.80	910.0	40.0	398.0	269.0	63.1	.	6.15	300.70
C2	250286	0.60	35.0	6.90	385.0	45.0	665.0	492.0	163.1	.	1.15	223.16
C2	030386	0.00	32.0	8.60	675.0	15.0	1216.0	866.0	961.0	23.63	5.25	122.70
C2	090486	2.30	36.5	8.80	300.0	35.0	485.0	297.0	93.0	32.31	5.00	195.60
C2	140586	1.60	32.4	9.10	925.0	50.5	356.0	76.0	169.0	21.67	7.35	495.60
C2	180686	0.00	31.0	8.70	825.0	43.0	633.0	430.0	159.1	6.70	3.35	296.13
C2	110886	1.70	32.0	8.50	650.0	42.0	216.0	140.0	1077.2	5.30	2.20	362.00
C2	110986	0.00	35.0	8.70	900.0	7.5	384.0	275.0	69.1	20.77	4.10	10.22

C2	071086	0.00	34.0	8.80	725.0	50.0	344.0	240.0	931.1	5.80	0.90	467.15
C2	221086	0.10	35.0	8.60	820.0	50.0	465.0	261.0	268.3	5.92	5.00	238.00
C2	021286	2.80	31.0	8.70	375.0	45.0	357.0	230.0	159.1	9.30	4.25	935.20
C2	050187	3.10	35.0	9.10	1200.0	37.0	384.0	199.0	832.4	5.80	8.85	104.16
C2	230287	0.20	36.5	7.20	685.0	42.5	478.0	339.0	187.3	20.63	0.60	169.28
E	200186	3.10	31.0	6.70	260.0	35.0	660.0	390.0	117.3	.	0.90	271.05
E	250286	3.20	31.5	6.50	310.0	47.5	1576.0	1001.0	260.1	.	1.25	367.80
E	030386	1.60	40.5	9.10	340.0	35.0	3718.0	1137.0	297.3	1.20	8.25	201.67
E	090486	2.80	32.0	7.20	255.0	32.0	2610.0	1626.0	62.3	7.10	3.60	111.20
E	140586	2.90	30.5	7.50	205.0	49.5	2922.0	1998.0	73.1	15.60	3.80	506.15
E	180686	3.60	30.0	6.25	320.0	20.0	1856.0	1032.0	337.0	0.75	2.00	46.30
E	310786	0.40	31.5	7.25	125.0	30.0	5931.0	4186.0	27.0	0.60	3.50	181.26
E	110886	3.00	32.0	6.10	435.0	58.0	887.0	436.0	269.0	1.40	0.95	589.61
E	110986	2.80	30.0	6.10	255.0	35.0	1952.0	1300.0	106.0	16.84	1.20	308.20
E	071086	2.80	30.0	7.25	260.0	47.5	1344.0	600.0	110.7	0.36	3.20	104.60
E	221086	2.70	31.0	8.10	235.0	46.7	607.0	385.0	113.6	1.78	4.00	367.20
E	031186	2.60	32.0	9.30	250.0	31.5	1993.0	217.0	96.5	10.50	9.15	161.33
E	021286	2.80	30.0	6.30	365.0	37.5	2140.0	1718.0	107.6	6.30	2.15	416.06
E	050187	3.40	30.5	7.90	340.0	32.0	1226.0	900.0	184.5	1.52	5.00	196.20
E	230287	3.20	30.0	7.60	310.0	30.0	3100.0	2310.0	193.0	5.60	5.25	92.16
E	131186	1.80	35.0	6.70	315.0	36.0	1150.0	960.0	186.3	8.30	1.00	322.77
E	030786	2.70	33.0	8.30	270.0	47.0	1620.0	700.0	106.1	0.96	0.90	468.16
F	200186	0.90	36.0	6.20	437.5	45.0	833.7	652.0	151.1	.	1.00	300.62
F	250286	0.10	38.5	7.25	623.0	37.5	4269.0	2966.0	136.7	.	2.50	181.27
F	030386	0.00	40.0	7.90	780.0	29.0	2636.0	1810.0	100.3	4.25	2.35	101.30
F	090486	2.60	34.5	8.10	1255.0	50.0	1527.0	776.0	307.2	10.70	5.00	629.26
F	140586	2.00	36.5	7.30	610.0	27.0	756.0	456.0	110.7	0.95	3.10	78.10
F	180686	0.30	37.0	8.90	730.5	10.0	967.0	365.0	92.3	2.66	4.00	30.80
F	310786	0.00	41.5	9.60	725.0	47.0	6120.0	4201.0	271.6	1.21	8.75	469.26
F	110886	0.00	38.0	9.10	255.0	8.0	7000.0	5288.0	60.2	19.36	3.70	10.85
F	110986	0.20	38.0	7.60	610.0	60.5	8113.0	6910.0	115.3	3.97	5.00	693.10
F	071086	0.10	40.0	7.90	160.0	36.0	5661.0	4633.0	130.0	3.20	5.15	162.60
F	221086	3.20	36.0	7.95	560.0	35.5	910.0	400.0	41.2	0.40	5.10	176.30
F	031186	1.30	39.5	7.80	320.5	38.0	1388.6	610.0	193.2	3.93	3.60	222.20
F	021286	0.60	37.0	6.30	665.5	55.0	15360.0	11266.0	107.2	1.70	1.50	497.60
F	050187	0.00	40.0	7.90	645.0	5.0	29920.0	22800.0	1267.3	3.50	5.25	9.36
F	230287	0.00	45.5	10.20	320.5	28.0	6876.0	1652.0	57.1	3.80	1.25	76.30
F	131186	0.90	40.0	8.90	670.0	49.5	3006.0	2137.0	267.0	2.70	4.15	386.12
F	030786	0.00	43.5	9.10	296.0	35.0	4167.0	2700.0	105.8	3.60	3.25	193.94
D	200886	0.35	30.5	7.30	560.0	16.5	320.0	98.0	93.7	3.97	8.50	83.27
D	060187	0.30	30.0	7.85	515.0	50.0	152.0	85.0	89.0	3.05	3.20	1126.10
G1	170986	0.30	23.0	8.75	3000.0	30.6	2660.0	1850.0	41.5	266.00	6.50	284.70
G1	090686	0.60	23.5	6.70	1680.0	56.0	1860.0	1200.0	49.3	187.60	4.50	936.75
G1	150187	6.00	24.0	7.00	2500.0	70.5	801.0	710.0	52.7	276.37	12.00	1386.70
G1	101286	0.20	23.0	6.70	910.0	20.0	3280.0	2710.0	16.7	97.60	5.00	96.30
G1	120386	0.10	23.5	9.00	3150.0	29.6	2807.0	2000.0	.	301.30	6.25	180.70
G1	190287	0.70	23.0	8.40	1800.0	49.0	1932.0	1007.0	.	281.40	3.60	623.25
G2	170986	4.70	27.0	9.10	1350.0	31.6	688.0	450.0	23.0	11.40	3.60	298.70
G2	090686	6.00	27.0	6.90	1300.0	37.5	733.0	493.0	20.1	9.35	4.15	367.20
G2	150187	5.10	27.5	9.00	1250.0	35.0	621.0	426.0	37.0	15.60	8.40	277.30
G2	101286	4.60	27.5	8.00	400.0	38.5	1551.0	981.0	12.7	38.70	5.30	368.90
G2	120386	4.90	27.0	9.00	1900.0	48.0	1500.0	736.0	.	110.60	5.20	510.30
G2	190287	4.70	26.5	8.50	860.0	52.0	827.0	401.0	.	11.80	1.35	607.80
H1	190287	2.70	43.0	12.90	6500.0	12.5	184.0	100.0	590.0	1.30	1.30	112.20

H1	150187	2.00	40.0	12.10	1885.0	25.6	2109.0	1652.0	100.7	1.67	5.60	437.60
H1	101286	2.60	36.0	11.50	490.0	36.5	1831.0	897.0	37.6	6.21	2.65	360.30
H1	170986	0.10	33.5	9.60	4630.0	40.5	3111.0	2503.0	63.3	1.07	8.15	397.30
H1	090686	1.60	38.0	11.90	2150.0	29.0	800.0	596.0	.	3.65	7.35	200.60
H1	120386	1.20	41.0	8.90	3500.0	46.5	1338.0	301.0	.	1.07	9.25	735.20
H2	190287	0.00	50.0	9.60	3500.0	10.5	277.3	184.0	46.0	.	5.00	58.00
H2	150187	0.00	45.0	7.20	960.0	4.0	36.0	20.0	39.0	.	1.20	10.60
H2	090686	0.20	48.0	9.10	440.0	4.6	520.0	315.0	42.6	.	4.25	8.70
I1	190287	0.00	43.0	8.80	190.0	22.0	816.0	750.0	37.6	1.09	5.00	368.00
I1	150187	0.00	34.0	7.80	850.0	26.5	190.0	142.0	73.1	0.91	5.50	116.30
I1	101286	2.80	37.6	11.90	2000.0	36.0	1065.0	506.0	91.6	1.32	8.10	257.10
I1	170986	1.60	38.0	10.50	1860.0	44.0	2631.0	1456.0	.	1.01	5.60	967.30
I1	090686	4.10	40.0	11.60	4100.0	29.5	1857.0	1001.0	171.6	0.73	6.50	208.00
I1	120386	3.90	43.0	12.00	3650.0	28.0	900.0	761.0	163.0	0.87	7.10	259.60
I2	190287	0.20	34.0	9.20	1600.0	36.0	624.0	500.0	86.1	1.00	5.00	337.00
I2	150187	0.80	32.0	7.70	1200.0	35.0	165.0	87.0	83.4	1.67	5.00	234.60
I2	101286	4.10	33.0	8.90	3610.0	41.0	1000.0	434.0	161.3	2.35	7.65	760.00
I2	170986	1.80	33.5	8.00	1600.0	56.0	1639.0	1107.0	.	1.95	5.10	1352.10
I2	090686	4.80	34.5	9.30	4000.0	37.0	933.0	625.0	186.2	0.74	5.30	265.00
I2	120386	4.30	34.5	8.10	4200.0	37.5	411.0	302.0	106.3	0.96	6.00	311.70
J	190287	1.70	34.0	11.60	3500.0	34.5	920.0	800.0	126.0	2.17	15.10	138.10
J	150187	1.60	33.5	9.60	1220.0	30.0	1600.0	925.0	101.0	16.10	6.30	103.67
J	101286	2.00	36.0	10.20	3000.0	36.5	3200.0	636.0	116.2	20.60	8.10	209.44
J	170986	1.70	34.5	11.50	925.0	27.0	1200.0	810.0	97.3	10.70	8.00	122.03
J	090686	0.70	26.0	6.80	480.0	60.0	1360.0	800.0	716.5	.	6.20	366.90
J	120386	0.80	28.0	7.20	525.0	40.0	2880.0	1772.0	87.8	26.50	2.15	307.20
U02	200186	1.00	30.0	8.00	250.0	65.0	1916.0	865.0	132.0	.	3.50	441.37
U02	250286	1.00	33.0	8.30	290.0	14.0	773.0	466.0	268.3	.	1.20	36.12
U02	030386	1.20	32.0	7.00	200.0	30.0	701.0	536.0	237.2	18.36	4.35	147.21
U02	090486	1.20	30.5	8.95	600.0	25.0	896.0	526.0	182.0	23.00	5.15	79.80
U02	140586	1.60	31.0	8.60	310.0	70.0	1967.0	1265.0	96.2	43.20	3.00	477.81
U02	180686	0.90	30.6	9.00	400.0	45.0	1360.0	801.0	106.7	30.70	11.35	222.33
U02	310786	1.80	29.0	8.30	710.0	40.0	996.0	799.0	290.7	16.25	5.00	211.30
U02	110886	1.60	30.5	6.20	1120.0	20.5	522.0	321.0	196.8	56.11	1.25	70.08
U02	110986	1.10	31.0	7.90	630.0	20.0	760.0	301.0	163.0	39.20	2.00	100.10
U02	071086	1.30	31.5	7.80	800.0	62.0	329.0	216.0	101.1	72.03	0.90	537.00
U02	221086	1.40	31.0	7.60	675.0	70.0	736.0	450.0	162.6	56.00	0.00	591.34
U02	031186	1.40	31.5	7.90	700.0	15.0	823.0	610.0	103.3	41.60	1.75	39.99
U02	021286	1.60	31.0	8.65	300.0	30.0	168.0	100.0	190.2	63.25	2.10	79.98
U02	050187	1.50	32.0	7.50	500.0	22.0	783.0	410.0	187.4	13.82	3.65	97.80
U02	230287	1.00	31.0	8.60	440.0	8.5	440.0	165.0	239.8	10.60	2.50	10.20

Appendix G

Percentage DO concentrations in the surface waters

G(i)- Percentage concentration of DO in the San Sebastian canal

Site	0.0mg/L	0.0 - <1.0mg/L	>1.0mg/L	Max DOmg/L
S01	-	-	- (min, 4.5)	
S02	-	-	- (min, 4.0)	
S03	47.5	52.5	-	
S04	45.0	52.5	2.5	
S05	15.0	80.0	5.0	
S06	42.5	52.5	5.0	
S07	45.0	55.0	-	
S08	-	17.5	82.5	
S09	2.5	40.0	57.5	
S10	7.5	77.5	15.0	

G(ii) - Percentage concentration of DO in the Beira sites

Site	0.0mg/L	0.1- <1.0mg/L	>1.0mg/L	Max. mg/L
U01	12.50	30.00	57.50	6.40
U02	-	26.60	73.33	1.80

G(iii) - Percentage concentration of DO along the tributary canals

Site	0.0mg/L	0.1- <1.0mg/L	>1.0mg/L	Max DO mg/L
T01	7.14	64.28	28.57	3.45
T02	7.14	57.14	35.71	3.05
T03	7.14	50.00	42.80	6.20
T04	14.20	21.40	64.28	3.95
T05	-	21.40	78.57	4.10
T06	7.14	57.14	35.71	2.00
T07	-	42.85	57.14	2.70
T08	-	85.71	14.28	1.10
T09	-	64.28	35.70	1.60
T10	7.14	57.14	35.70	2.10
T11	14.28	71.42	14.28	1.50
T12	-	57.14	42.85	1.62
T13	14.28	78.57	7.14	1.20

Appendix H

Carbon dioxide plant effluents

Poll	Mean	S.D	Ran	Min	Max	Med	75%	Indus
DO	0.03	0.05	0.10	0.00	0.1	0.00	0.10	A4
DO	0.06	0.115	0.20	0.00	0.20	0.00	0.20	H2
COD	73.0	38.97	76.0	40.0	116.0	63.0	116.0	A4
COD	277.76	242.0	484.0	36.0	520.0	277.3	520.0	H2
BOD	30.0	19.07	34.0	18.0	52.0	20.0	52.0	A4
BOD	173.0	147.8	295.0	20.0	315.0	184.0	315.0	H2
SS	8.32	4.27	8.55	4.05	12.6	8.31	12.6	A4
SS	25.76	27.93	49.3	8.7	58.0	10.6	58.0	H2
TURB	2.96	1.45	2.8	1.8	4.6	2.5	4.6	A4
TURB	6.36	3.59	6.5	4.0	10.5	4.6	10.5	H2
COND	715.0	242.8	460.0	490.0	900.0	805.0	900.0	A4
COND	1633.3	1637.35	3060.0	440.0	3500.0	960.0	3500.0	H2
PH	8.2	0.77	1.5	7.6	9.1	8.0	9.1	A4
PH	8.63	1.27	2.4	7.2	9.6	9.1	9.6	H2
WAT T	48.16	3.01	6.0	45.0	51.0	48.5	51.0	A4
WAT T	47.66	2.51	5.0	45.0	50.0	48.0	50.0	H2
PHOS	1.71	1.12	2.1	0.9	3.0	1.25	3.0	A4
PHOS	3.4	2.01	3.8	1.2	5.0	4.25	5.0	H2
SULF	37.0	6.0	8.6	32.7	41.3	37.0	-	A4
SULF	42.53	3.5	7.0	39.0	46.0	42.6	46.0	H2

Appendix I

Daily rainfall (mm) in Colombo (Colombo Observatory)

Date	Rain	Date	Rain	Date	Rain	Date	Rain	Date	Rain
011285	5.80	230186	12.20	170386	2.20	090586	0.01	010786	0.30
021285	1.10	240186	0.00	180386	0.00	100586	0.00	020786	0.00
031285	4.90	250186	0.00	190386	.01	110586	0.01	030786	2.40
041285	0.01	260186	0.00	200386	6.40	120586	0.00	040786	0.01
051285	66.60	270186	0.00	210386	0.00	130586	0.01	050786	0.01
061285	47.20	280186	0.00	220386	.01	140586	0.00	060786	0.02
071285	1.00	290186	0.00	230386	0.00	150586	0.01	070786	0.00
081285	0.00	300186	0.00	240386	0.00	160586	0.01	080786	0.00
091285	0.00	310186	0.00	250386	0.00	170586	0.10	090786	0.00
101285	0.00	010286	0.00	260386	2.60	180586	6.80	100786	.01
111285	0.00	020286	0.00	270386	0.01	190586	4.30	110786	.00
121285	8.50	030286	0.00	280386	0.00	200586	0.20	120786	.01
131285	0.00	040286	0.00	290386	0.00	210586	0.20	130786	1.50
141285	35.40	050286	0.00	300386	0.00	220586	2.00	140786	0.01
151285	0.50	060286	0.00	310386	0.00	230586	0.01	150786	1.60
161285	38.80	070286	0.00	010486	0.00	240586	0.40	160786	0.10
171285	0.00	080286	0.00	020486	0.00	250586	0.70	170786	0.00
181285	0.01	090286	1.40	030486	0.00	260586	0.01	180786	0.00
191285	0.00	100286	0.00	040486	2.30	270586	0.00	190786	0.00
201285	0.00	110286	0.01	050486	1.70	280586	0.00	200786	0.00
211285	0.00	120286	0.00	060486	1.00	290586	28.70	210786	0.01
221285	0.00	130286	53.10	070486	20.10	300586	0.00	220786	0.00
231285	0.00	140286	0.00	080486	0.00	310586	3.40	230786	0.01
241285	0.00	150286	0.20	090486	0.20	010686	19.00	240786	0.00
251285	6.80	160286	0.00	100486	0.01	020686	0.00	250786	2.20
261285	13.70	170286	0.00	110486	11.00	030686	0.80	260786	0.00
271285	0.60	180286	0.01	120486	0.60	040686	0.60	270786	0.00
281285	0.00	190286	0.10	130486	3.60	050686	1.60	280786	0.00
291285	0.00	200286	0.90	140486	4.20	060686	3.60	290786	0.00
301285	0.00	210286	0.00	150486	30.40	070686	0.01	300786	2.10
311285	0.00	220286	0.00	160486	6.30	080686	0.30	310786	0.10
010186	0.00	230286	0.00	170486	3.20	090686	0.01	010886	0.20
020186	0.00	240286	0.00	180486	85.40	100686	0.00	020886	0.01
030186	0.00	250286	22.70	190486	0.01	110686	0.00	030886	0.40
040186	0.01	260286	0.00	200486	0.01	120686	0.50	040886	0.01
050186	37.80	270286	0.00	210486	2.00	130686	5.20	050886	3.30
060186	76.20	280286	0.01	220486	0.01	140686	0.20	060886	11.90
070186	7.40	010386	0.00	230486	0.00	150686	11.80	070886	27.70
080186	7.20	020386	0.00	240486	0.00	160686	13.30	080886	7.40
090186	3.80	030386	29.00	250486	0.00	170686	0.00	090886	0.01
100186	0.30	040386	0.40	260486	30.50	180686	0.00	100886	0.20
110186	0.01	050386	0.00	270486	5.30	190686	0.01	110886	10.30
120186	0.01	060386	0.00	280486	6.80	200686	0.00	120886	13.30
130186	0.00	070386	4.60	290486	0.30	210686	0.00	130886	1.50
140186	0.00	080386	20.70	300486	1.90	220686	0.01	140886	0.00
150186	0.00	090386	1.50	010586	24.40	230686	0.00	150886	0.00
160186	0.00	100386	.01	020586	0.00	240686	4.00	160886	0.00
170186	0.00	110386	5.70	030586	53.60	250686	1.00	170886	0.00

180186	0.00	120386	0.00	040586	4.20	260686	1.00	180886	0.00
190186	0.00	130386	0.00	050586	0.00	270686	0.30	190886	0.00
200186	0.00	140386	0.00	060586	0.00	280686	0.00	200886	0.01
210186	0.00	150386	0.00	070586	100.20	290686	0.00	210886	0.00
220186	0.01	160386	8.30	080586	1.70	300686	0.60	220886	0.00

230886	0.01	221086	0.00	211286	35.50	190287	0.00
240886	0.00	231086	0.00	221286	11.30	200287	0.00
250886	0.00	241086	0.00	231286	0.00	210287	0.00
260886	0.00	251086	5.60	241286	0.01	220287	0.00
270886	0.00	261086	8.10	251286	0.01	230287	0.00
280886	0.00	271086	8.20	261286	29.50	240287	0.00
290886	0.00	281086	7.10	271286	0.00	250287	0.00
300886	0.00	291086	0.50	281286	0.00	260287	0.00
310886	0.01	301086	3.80	291286	4.30	270287	0.00
010986	0.00	311086	0.01	301286	9.50	280287	0.00
020986	5.60	011186	11.20	311286	0.00		
030986	0.00	021186	0.00	010187	0.00		
040986	0.00	031186	0.01	020187	0.00		
050986	0.00	041186	11.40	030187	0.00		
060986	0.20	051186	9.00	040187	0.00		
070986	0.00	061186	9.20	050187	0.00		
080986	0.00	071186	0.00	060187	0.00		
090986	0.00	081186	0.01	070187	0.00		
100986	0.00	091186	0.10	080187	3.80		
110986	0.01	101186	0.01	090187	51.60		
120986	0.01	111186	0.00	100187	8.70		
130986	16.80	121186	8.90	110187	0.00		
140986	45.60	131186	0.01	120187	4.20		
150986	8.50	141186	0.00	130187	0.01		
160986	0.00	151186	0.70	140187	22.70		
170986	6.20	161186	0.00	150187	0.01		
180986	0.80	171186	0.00	160187	2.40		
190986	2.60	181186	0.00	170187	0.00		
200986	0.00	191186	0.01	180187	1.30		
210986	0.70	201186	0.10	190187	3.60		
220986	12.00	211186	0.00	200187	0.00		
230986	0.01	221186	0.00	210187	0.00		
240986	2.40	231186	00.10	220187	0.00		
250986	6.80	241186	4.00	230187	0.00		
260986	1.00	251186	0.01	240187	0.01		
270986	1.10	261186	0.00	250187	0.01		
280986	3.00	271186	2.00	260187	0.10		
290986	11.80	281186	1.60	270187	0.01		
300986	3.30	291186	0.70	280187	0.00		
011086	0.00	301186	0.00	290187	0.00		
021086	1.50	011286	26.00	300187	0.00		
031086	0.00	021286	0.00	310187	0.00		
041086	0.30	031286	0.00	011087	0.00		
051086	0.90	041286	0.00	020287	0.00		
061086	1.00	051286	0.60	030287	0.00		
071086	0.60	061286	9.80	040287	0.00		
081086	2.20	071286	0.01	050287	0.00		
091086	0.00	081286	19.40	060287	0.00		
101086	10.40	091286	5.10	070287	0.01		
111086	4.00	101286	17.30	080287	0.00		
121086	0.00	111286	0.01	090287	0.00		
131086	9.30	121286	0.00	100287	0.00		
141086	1.20	131286	0.00	110287	0.00		
151086	54.80	141286	5.70	120287	0.00		

161086	16.30	151286	1.00	130287	0.00
171086	19.30	161286	0.00	140287	0.00
181086	1.40	171286	0.00	150287	0.00
191086	0.00	181286	0.00	160287	0.00
201086	6.50	191286	0.01	170287	0.00
211086	0.01	201286	28.40	180287	0.00

Appendix J

Mean Monthly Pollutants

	DO	COD	BOD	SS	Cond	Nit
Site:S01						
1986						
J	11.35	07.50	03.50	20.30	410.00	-
F	09.05	16.50	12.00	08.84	567.50	-
M	08.07	31.00	24.00	15.22	628.33	2.21
A	14.07	10.33	07.33	25.36	560.00	3.98
M	10.73	09.33	06.83	57.80	526.67	3.07
J	07.17	34.67	21.33	20.09	525.00	1.35
J	05.13	64.38	38.67	13.51	531.67	1.11
A	08.27	30.00	21.33	37.64	651.67	0.23
S	08.83	10.00	07.00	52.54	466.67	2.26
O	10.83	08.67	05.00	42.57	521.67	3.45
N	09.23	13.00	07.67	13.69	428.33	1.39
D	11.87	07.33	04.00	30.83	508.33	2.62
1987						
J	10.90	07.33	04.00	30.45	663.33	3.73
F	07.63	38.00	26.33	26.27	618.33	2.11
S02						
1986						
J	11.95	07.00	02.50	25.00	187.50	-
F	09.15	15.00	10.50	09.30	282.50	-
M	08.07	29.00	17.67	14.91	263.33	0.96
A	14.27	09.33	06.33	21.88	228.33	1.10
M	10.63	09.33	05.67	59.75	268.33	1.64
J	06.87	25.00	16.17	17.01	187.83	0.97
J	05.33	53.33	32.67	11.00	266.33	0.13
A	09.30	20.67	13.00	26.31	353.33	0.14
S	09.17	08.00	04.00	19.95	205.00	0.36
O	11.17	19.67	08.00	24.98	226.67	0.66
N	09.13	13.00	06.33	15.50	183.33	0.10
D	12.40	06.67	03.67	24.72	196.67	0.10
1987						
J	10.53	11.33	07.67	24.21	281.67	1.82
F	07.80	39.67	26.67	19.16	255.00	1.62
S03						
1986						
J	00.20	160.00	086.00	122.71	585.00	-
F	00.05	343.00	230.50	070.76	662.50	-
M	00.00	707.67	544.33	150.96	553.33	12.13
A	00.05	562.33	343.33	208.60	605.00	10.37
M	00.32	243.00	157.67	288.08	1128.33	10.05
J	00.13	389.33	297.00	067.57	630.00	07.00
J	00.30	236.17	216.67	040.59	535.00	10.26
A	00.20	536.33	230.00	042.87	500.00	11.32
S	00.24	340.00	223.67	102.13	898.33	11.03
O	00.05	253.67	137.73	082.53	581.67	10.66
N	00.03	441.67	304.33	120.59	505.00	08.30

D	00.57	362.33	201.67	119.70	428.33	07.26
1987						
J	00.23	454.67	332.00	066.28	1258.33	06.74
F	00.00	916.00	664.00	055.19	1015.00	11.20
304						
1986						
J	0.45	175.50	099.50	104.59	535.00	-
F	0.20	329.00	203.00	060.12	615.00	-
M	0.00	689.67	504.33	148.84	613.33	10.06
A	0.01	481.67	280.00	354.89	511.67	11.26
M	0.00	225.33	116.67	231.47	588.33	09.62
J	0.00	447.67	226.00	085.95	565.00	06.21
J	0.00	469.47	362.00	088.34	405.00	09.35
A	0.20	637.67	418.67	039.35	531.67	11.32
S	0.17	378.83	275.00	095.19	486.67	11.58
O	0.57	247.77	114.00	054.55	611.67	09.14
N	0.23	407.00	287.33	066.38	505.00	07.23
D	0.87	223.00	143.00	095.96	440.00	05.95
1987						
J	0.20	432.67	211.67	062.22	905.00	06.14
F	0.00	739.67	419.67	033.64	896.67	09.03
305						
1986						
J	0.55	111.50	074.04	064.32	472.50	-
F	0.25	173.00	095.00	057.18	590.00	-
M	0.22	550.00	426.67	094.91	593.33	03.85
A	0.43	418.67	265.00	221.41	535.00	04.08
M	0.50	117.67	074.67	187.86	446.67	03.33
J	0.13	217.00	137.67	094.56	555.40	03.61
J	0.03	429.00	330.67	038.40	418.33	08.12
A	0.13	284.67	203.33	035.92	543.33	10.80
S	0.23	221.00	120.33	077.62	473.33	09.31
O	0.63	204.20	128.00	052.32	683.33	07.86
N	0.47	333.00	252.00	055.65	476.67	04.21
D	1.27	213.33	109.00	148.18	453.33	02.63
1987						
J	0.64	187.00	113.00	052.28	853.33	04.34
F	0.03	406.67	328.00	017.34	723.33	04.01
306						
1986						
J	0.35	127.00	062.00	103.30	602.50	-
F	0.20	391.50	242.00	065.13	730.00	-
M	0.87	565.33	464.67	142.74	1180.00	16.36
A	0.01	483.47	398.67	165.08	546.67	10.35
M	0.17	190.00	113.33	217.41	436.67	13.20
J	0.02	331.00	163.67	070.58	590.00	14.32
J	0.10	433.87	331.67	055.33	470.00	11.92
A	0.07	233.33	158.67	093.03	658.33	14.30
S	0.23	231.33	149.67	082.10	553.33	15.36
O	0.17	496.00	399.67	199.39	738.33	15.35
N	0.22	429.67	332.00	084.47	545.00	09.02
D	0.38	414.33	388.00	149.05	483.33	09.59
1987						
J	0.62	347.33	180.00	047.84	756.67	07.12

F	0.00	590.67	429.67	078.03	730.00	08.73
S07						
1986						
J	0.30	119.50	084.50	092.65	577.50	-
F	0.10	289.50	217.50	061.86	695.00	-
M	0.07	504.67	368.67	117.60	576.67	11.88
A	0.11	309.67	184.00	174.64	545.00	11.23
M	0.08	137.33	096.33	236.15	976.67	09.11
J	0.03	302.43	225.67	087.34	651.67	10.05
J	0.00	454.30	294.67	088.33	860.00	10.67
A	0.00	241.00	172.00	075.30	590.00	13.65
S	0.10	261.67	192.33	092.52	535.00	13.14
O	0.13	345.67	184.33	212.95	778.33	13.45
N	0.17	416.00	277.00	141.04	450.00	08.13
D	0.37	524.67	421.33	231.21	561.67	10.36
1987						
J	0.24	218.00	046.33	038.45	701.67	08.14
F	0.00	567.00	466.67	041.53	740.00	06.25
S08						
1986						
J	2.90	044.00	22.50	16.35	415.00	-
F	2.25	180.00	99.50	11.62	1080.00	-
M	1.90	307.33	207.33	19.49	503.33	2.05
A	2.47	122.33	77.67	22.72	631.67	3.25
M	1.83	104.43	68.33	78.41	178.33	2.01
J	0.48	048.60	25.00	19.46	1503.33	2.15
J	2.00	208.87	140.00	15.89	1746.67	2.67
A	2.30	074.20	42.33	46.60	590.00	3.79
S	2.40	096.67	59.00	19.96	466.67	3.06
O	1.03	044.53	24.00	199.78	566.67	4.27
N	1.33	102.33	56.67	34.34	348.33	1.35
D	2.30	099.10	61.33	55.71	610.00	2.47
1987						
J	1.70	052.53	36.00	64.74	806.67	1.76
F	2.20	147.00	97.33	12.56	1865.00	2.30
S09						
1986						
J	2.30	65.00	28.40	23.81	495.00	-
F	1.75	198.00	136.00	15.47	2517.50	-
M	1.53	262.67	194.00	19.37	615.00	2.73
A	0.87	100.87	73.00	25.26	508.33	3.89
M	2.00	54.37	39.67	106.63	1843.33	4.03
J	2.40	85.53	46.67	29.94	371.67	3.79
J	0.50	182.53	92.33	66.44	112.00	3.56
A	0.53	96.33	52.00	27.10	516.67	3.69
S	0.70	89.67	49.00	94.29	521.67	3.61
O	1.00	79.40	58.00	94.59	551.67	4.03
N	0.23	77.77	44.33	67.14	315.00	0.28
D	2.00	106.33	63.67	69.61	605.00	3.49
1987						
J	2.13	52.33	29.67	91.15	878.33	2.93
F	0.90	180.33	93.33	18.41	1613.33	1.02
S10						
1986						

J	0.50	101.50	069.50	28.87	0462.50	-
F	0.20	212.50	145.00	23.16	2600.00	-
M	0.15	282.67	181.67	23.76	0566.67	4.22
A	0.33	127.00	081.33	15.74	0513.33	2.75
M	0.67	093.67	070.67	107.93	0240.00	2.17
J	3.53	108.20	065.33	16.86	0096.67	2.92
J	0.07	230.97	122.33	41.00	0563.33	3.87
A	0.37	135.67	072.67	39.13	0515.00	3.98
S	0.37	097.33	061.33	44.10	0248.33	3.79
O	0.53	044.00	019.67	43.78	0475.00	2.01
N	0.23	129.33	073.00	38.35	0281.67	0.23
D	0.97	135.43	069.67	56.44	0568.33	3.41
1987						
J	0.33	058.53	037.67	57.86	0860.00	3.80
F	0.07	202.00	121.00	17.72	1565.00	1.65
U02						
1986						
J	1.06	1916.00	865.00	441.37	250.00	-
F	1.00	0773.00	466.00	036.12	290.00	-
M	1.20	0701.00	536.00	147.21	200.00	18.36
A	1.20	0896.00	526.00	079.80	600.00	23.00
M	1.60	1967.00	1265.00	477.81	310.00	43.20
J	0.90	1360.00	801.00	222.33	400.00	30.70
J	1.80	0996.00	799.00	211.30	710.00	16.25
A	1.60	0520.00	321.00	070.08	1120.00	56.11
S	1.10	0761.00	301.00	100.10	630.00	39.20
O	1.35	0532.00	333.00	564.17	737.00	64.01
N	1.40	0823.00	610.00	039.99	700.00	41.60
D	1.60	0168.00	100.00	020.10	300.00	63.25
1987						
J	1.50	0783.00	410.00	097.80	500.00	13.82
F	1.00	0440.00	165.00	010.20	440.00	10.60
T10						
1986						
J	1.60	100.20	079.00	062.85	0735.00	-
F	1.40	141.00	076.00	051.61	0810.00	-
M	1.30	164.00	093.00	067.08	0820.00	02.37
A	1.80	047.00	032.00	089.08	0821.00	05.39
M	2.10	039.00	026.00	276.10	1007.00	06.30
J	1.60	046.70	036.00	095.26	1390.00	05.07
J	0.80	203.00	137.00	092.00	0140.00	08.62
A	1.30	076.30	049.00	101.10	1001.00	05.36
S	1.35	068.00	042.00	066.09	0639.00	06.07
O	1.05	060.00	032.00	120.20	0400.00	10.34
N	0.01	105.20	095.00	139.36	0750.00	02.10
D	0.10	111.00	089.00	169.68	0760.00	09.43
1987						
J	0.00	191.00	135.00	070.50	1000.00	04.87
F	0.35	238.60	185.00	015.80	1400.00	01.26
T13						
1986						
J	0.10	324.00	206.00	109.46	0675.00	-
F	0.10	432.00	318.00	059.35	0580.00	-
M	0.00	391.00	302.00	169.20	0733.00	08.65

A	0.80	300.00	223.00	139.32	0561.00	08.85
M	1.20	209.00	103.00	211.66	1066.00	11.50
J	0.90	302.00	268.00	101.30	0981.00	12.75
J	0.40	611.00	407.00	189.39	1003.00	11.71
A	0.65	534.00	401.00	081.24	0770.00	10.37
S	0.35	422.00	351.00	177.00	0600.00	09.22
O	0.35	260.00	148.00	181.43	0390.00	11.30
N	0.30	303.00	262.00	106.50	0465.00	07.11
D	0.45	444.00	297.00	146.72	0425.00	08.61
1987						
J	0.30	502.00	386.00	068.75	0400.00	08.13
F	0.00	811.00	637.00	062.40	1660.00	02.38

Appendix K

Monthly and seasonal rainfall

APPENDIX K(i)

Monthly Rainfall (mm)

Year	Month	Monthly Total	Monthly Mean
1986	January	144.94	4.86
	February	78.43	2.80
	March	81.44	2.63
	April	216.84	7.23
	May	230.97	7.45
	June	63.84	2.13
	July	10.39	0.34
	August	76.26	2.46
	September	128.43	4.28
	October	163.02	5.26
	November	59.06	1.97
	December	203.45	6.56
1987	January	98.45	3.18
	February	0.00	0.00

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APPENDIX K(ii)

Seasonal Rainfall(mm) Modified)

Year	Month	Season	Seasonal Mean
1986	January	NE Monsoon I	3.39
	February		
	March		
	April	Inter -	7.34
	May	Monsoon I	
	June	SW Monsoon I	1.64
	July		
	August		
	September	Inter -	4.78
	October	Monsoon II	
	November	NE Monsoon II	3.03
	December		
1987	January		
	February		

Appendix L

Mean seasonal pollutants

Site	Season	DO	COD	BOD	SS	COND	NIT
S02	NEI	9.49	18.11	11.29	16.19	247.14	0.96
	IMI	12.43	9.33	6.00	40.81	248.33	1.37
	SWI	7.17	33.00	20.61	18.11	269.17	0.41
	IMII	10.47	13.83	6.00	22.47	215.83	0.56
	NEII	9.91	17.67	11.08	20.90	229.17	1.09
S03	NEI	.07	447.00	323.71	119.97	593.57	12.13
	IMI	.18	402.67	250.50	248.34	866.67	10.21
	SWI	.21	453.94	247.89	50.34	555.00	9.53
	IMII	.14	296.83	180.50	92.33	740.00	10.79
	NEII	.21	543.67	375.50	90.44	776.67	8.05
S04	NEI	.19	439.71	302.57	110.85	591.43	10.06
	IMI	.01	353.50	198.33	293.18	550.00	10.44
	SWI	.07	515.93	335.56	71.21	500.56	8.96
	IMII	.37	313.30	194.5	74.87	549.17	9.96
	NEII	.32	450.58	265.42	65.30	686.67	6.90
S05	NEI	.32	317.00	231.14	75.39	557.86	3.85
	IMI	.47	268.17	169.83	204.63	490.83	3.70
	SWI	.10	310.22	223.89	56.16	505.56	7.51
	IMII	.43	212.50	124.17	64.98	578.33	8.36
	NEII	.60	285.00	200.50	68.36	626.67	3.91
S06	NEI	.53	390.43	286.43	109.30	886.43	16.36
	IMI	.09	336.53	256.00	191.24	491.67	11.77
	SWI	.06	333.73	218.00	72.98	572.78	13.51
	IMII	.20	363.67	274.67	140.75	645.83	15.36
	NEII	.30	470.50	332.42	99.85	628.75	8.32
S07	NEI	.14	333.14	244.14	94.55	610.11	11.88
	IMI	.09	223.50	140.17	205.34	760.83	10.17
	SWI	.01	332.58	230.78	83.66	700.56	11.46
	IMII	.12	303.67	188.33	152.73	656.67	13.35
	NEII	.19	431.42	302.83	113.05	613.33	8.20
S08	NEI	2.23	195.71	123.71	16.35	642.86	2.05
	IMI	2.15	113.38	73.00	50.57	270.00	2.63
	SWI	1.59	110.56	69.11	27.25	1280.00	2.87
	IMII	1.72	41.50	92.82	109.87	516.67	3.87
	NEII	1.88	100.24	62.83	41.84	907.50	1.93
S09	NEI	1.81	187.71	13.00	19.52	1124.29	2.73
	IMI	1.43	77.62	56.33	65.95	1175.83	3.96
	SWI	1.14	121.47	63.67	41.16	669.44	3.65
	IMII	.85	84.53	53.50	94.44	536.67	3.89
	NEII	1.32	104.19	58.50	61.58	852.92	2.13
S10	NEI	.26	210.86	139.14	25.05	1117.86	4.22
	IMI	.50	110.33	76.00	61.83	376.67	2.46
	SWI	1.32	158.28	86.78	32.33	391.67	3.59
	IMII	.45	70.67	40.50	43.94	361.67	2.58
	NEII	.40	131.32	75.33	42.59	818.75	2.58
U02	NEI	1.07	1130.00	622.33	208.23	246.67	18.36
	IMI	1.40	1431.50	895.50	278.80	455.00	33.10

	SWI	1.43	959.33	640.33	167.90	743.33	34.35
	IMII	1.27	608.33	322.33	409.48	701.69	55.74
	NEII	1.37	553.50	321.25	56.99	485.00	32.32
T10	NEI	.43	135.07	82.67	60.51	788.33	2.37
	IMI	1.95	43.0	29.00	182.59	914.00	5.84
	SWI	1.23	108.67	74.00	96.12	1263.67	6.35
	IMII	1.20	64.25	37.00	93.14	519.50	8.20
	NEII	.11	161.45	126.00	98.83	977.58	4.41
T13	NEI	.07	382.33	257.33	112.65	629.33	8.65
	IMI	1.00	254.50	163.00	175.49	813.50	10.17
	SWI	.65	482.33	358.67	123.98	918.00	11.61
	IMII	.35	341.00	249.50	179.21	495.00	10.26
	NEII	.26	515.00	395.00	96.09	737.63	6.56

Appendix M

Standard Specifications

APPENDIX M(i)

Standards Specification for The Quality of Inland Surface Waters

Parameter	Units	Tolerence limit	Code
DO	mg/L	minimum of 4.0	1
BOD, 5 days at 20 °C	mg/L	maximum of 3.0	1
pH		6.5-8.5	1
Electrial conductivity at 25 °C	µmhos/cm	maximum of 1000.0	1
Total N	mg/L	3.0	2
Sulphates as SO_4	mg/L	less than 250.0	2
Total P as PO_4	mg/L	2.0	3
SS	mg/L	less than 25.0	4
COD	mg/L	10.0 (maximum recommed limit)	5
Aesthetics		no visible floating matter of sewage or industrial origin	1

Source:

1. CEA modified Interim Standards of 1985, based on the Indian Standards, 2296:1973
2. EEC Standards, 75/440/EEC
3. Sri Lanka Standards Institution, SLS 614:1983, Part I
4. EEC Standards, 78/659/EEC
5. Parker, 1971

Appendix M(ii)

Standard Specification for Potable Water Quality

Parameter	Units	Specification	Code
DO	mg/L	4.0	a
BOD, 5 days at 20 °C	mg/L	5.0	a
pH		6.0-9.0	a
Total P as PO_4	mg/L	2.0, maximum permissible level	b
Turbidity	Jackson Turbidity Units	8.0	b
Electrical conductivity	µmhos/cm	750.0, maximum desirable level	b
COD	mg/L	10.0, maximum permissible level	b
Sulphates as SO_4	mg/L	200.0, maximum desirable level	b
Total N	mg/L	1.0	c
SS	mg/L	less than 25.0	d

Source:

a. Sri Lanka Standard Institution, SLS 722:1985

b. Sri Lanka Standard Institution, SLS 614:1983, Part I

c. EEC Standards, 75/440/EEC

d. EEC Standards, 78/659/EEC

Conversion:

1 Jackson Turbidity Unit=1 NTU, if formazin standard is used
(Source: Sawyer and MacCarty, 1978)

APPENDIX M(iii)

Standard specification for discharges from the industries into the inland surface waters

Parameter	Units	Specification	Code
BOD	mg/L	30.0, maximum	I
COD	mg/L	250.0, maximum	I
SS	mg/L	50.0, maximum	I
Water temperature	°C	40.0, shall not exceed this limit in any section of the stream within 15m downstream from the effluent outlet	I
pH, at ambient temperature		6.0-9.0	II
Total N	mg/L	50.0	III

Source:

I. Sri Lanka Standard Institution, SLS 652:1984

II. Compendium of Environmental Guidelines and Standards for Industrial Discharges (WHO, 1983)

III. Environmental Quality (Prescribed Premises)(Crude Palm Oil) (Ammendment) Regulations-1982, Ministry of Science, Technology and Environment (Malaysia)

Appendix N

Percentage standards met in the sites of the tributary canals

	TO3	TO4	TO5	TO6	TO7	TO8	TO9	T10	T11	T12	T13	Standard
DO												4.0
Comply	7.1	-	7.1	-	-	-	-	-	-		-	(mg/L)
Exceed	92.9	100.	92.9	100.	100.	100.	100.	100.	100.	100.	100.	
COD												
Comply	-	-	-	-		-	-	-	-		-	10.0
Exceed	100.0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	(mg/L)
BOD												3.0
Comply	-	-	-	-		-	-	-	-		-	(mg/L)
Exceed	100.0	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	
SS												25.0
Comply	14.3	7.1	64.3	14.3	50.	7.1	42.9	7.1	-	14.3	-	(mg/L)
Exceed	85.7	92.9	35.7	85.7	50.	92.9	57.1	92.9	100.	85.7	100.	
T N												3.0
Comply	16.7	100.	100.	16.7	75.	91.7	100.	25.	8.3	8.3	8.3	(mg/L)
Exceed	83.3	-	-	83.3	25.	8.3	-	75.	91.7	91.7	91.7	
T P												
Comply	14.3	92.9	100.	85.7	100.	28.6	92.9	7.1	78.6	92.9	42.9	2.0
Exceed	85.7	7.1	-	14.3	-	71.4	7.1	92.9	21.4	7.1	57.1	(mg/L)
pH												
Comply	35.7	85.7	78.6	92.9	100.	100.	100.	50.	92.9	92.0	64.3	8.5
Exceed	64.3	14.3	21.4	7.1	-	-	-	50.	7.1	7.1	35.7	
CT												
Comply	71.4	100.	100.	92.9	100.	92.9	100.	64.3	100.	100.	78.6	1000.0
Exceed	28.6	-	-	7.1	-	7.1	-	35.7	-	-	21.4	(µmhos/cm)
SULF												250.0
Comply	85.7	100.	100.	100.	100.	100.	7.1	78.6	92.9	100.	71.4	(mg/L)
Exceed	14.3	-	-	-	-	-	92.9	21.4	7.1	-	28.6	

Source: Field monitoring.

Appendix O

River classification - U.K

Class 1: Rivers unpolluted and recovered from pollution

1. All lengths of the rivers whatever their composition, which are known to have received no significant polluting discharges.
2. All rivers which though receiving some pollution, have a BOD less than 3 mg/L, are well oxygenated and are known to have received no significant discharges of toxic materials or of suspended matter which affects the condition of the river bed.
3. All rivers which are generally indistinguishable biologically from those in the area known to be quite unpolluted, even though the BOD may be somewhat greater than 3 mg/L.

Class 2: Rivers of doubtful quality and needing improvement

1. Rivers not in class 1 on BOD grounds and which have a substantially reduced oxygen content at normal dry summer flows or at any other regular times.
2. Rivers irrespective of BOD, which are known to have received significant toxic discharges which cannot be proved either to affect fish or to have to be removed by natural processes.
3. Rivers which have received turbid discharges which have had an appreciable effect on the composition of the water or character of the bed but have no great effect on the biology of the water.
4. Rivers which have been the subject of complaints which are not regarded as frivolous but which have been substantiated.

Class 3: Rivers of poor quality requiring improvement as a matter of some urgency

1. Rivers not in class 4 on BOD grounds but which have a dissolved oxygen saturation, for considerable periods, below 50%.
2. Rivers containing substances which are suspected of being actively toxic at times.
3. Rivers which have been changed in character by discharge of solids in suspension but which do not justify being placed in Class 4.
4. Rivers which have been the subject of serious complaint accepted as well found.

Class 4: Grossly polluted rivers

1. All rivers having a BOD of 12 mg/L or more under average conditions.
2. All rivers known to be incapable of supporting fish life.
3. All rivers which are completely deoxygenated at any time apart from times of exceptional drought.
4. All rivers which are the source of offensive smells.
5. All rivers which have an offensive appearance, neglecting for these purposes any rivers which would be included in this class solely because of the presence of detergent foam.

Source: Toms (1985)

BIBLIOGRAPHY

Ahmad, G. and Srivastava, G. (1983) The toxicity of 'Kharnewala soap' to catfishes *Heteropneustes fossilis (Bloch) and Mystus vittatus (Bloch). Journal of Environmental Biology.* 4 (2), pp 69-76.

Amuzu, A.T. (1975) *Survey of Water Quality of the River Densu.* Water Resources Research Unit. Accra, Ghana.

Anderson, G.K. (1979) Occupational health and industrial hygiene, Sri Lanka (Industrial waste waters). *Project SLR HWP 001.* World Health Organization, Geneva.

Anderson, G.K. (1987) Industrial waste treatment. *The Management of Hazardous Waste, and Solid Waste from Domestic and Industrial Sources With Reference to Problems in the Developing Countries.* Seminar proceedings, 18th-21st April 1987. Session 3. Department of Civil Engineering, University of Moratuwa, Sri Lanka.

Anil, D.K. *et al* (1985) Pollution profile of river Damodar sediment in Raniganj - Durgapur industrial belt, West Bengal, India. *Environment International.* 7 (5), pp 453-459.

Aoki, M. (1983) *Notes on Economic Time Series Analysis: System Theoretic Perspective.* Lecture notes in economics and mathematical systems - 220. Springer-Verlag, Berlin.

Arambewela, D. (1980) *The Significance and Potential of the Canals in the Development of the Colombo Metropolitan Region.* Unpublished M.Sc Thesis. Department of Town and Country Planning, University of Moratuwa, Sri Lanka.

Bandaratilleke, K.G.D. (1984) GCEC and the environmental programme. *Environmental Analysis and Assessment.* Seminar Proceedings, 29th February - 2nd March, University of Moratuwa, Sri Lanka. pp 3-1.

Basu, A.K. *et al* (1981) Hoogly estuarine pollution and its impact on the water quality near the major bathing places. *Paper presented at the National Water Council/Water Industry 1981.* International Conference, June 1981, U.K. pp 83-92.

Bennet, R.J. (1979) *Spatial Time Series Analysis: Forecasting and Control.* Pion, London.

Best, G.A. and Ross, S.L. (1977) *River Pollution Studies.* Liverpool University Press, Liverpool.

Blalock, H.M. (1972) *Social Statistics.* McGraw-Hill, Tokyo.

Borkar, M.D. and Paul, A.C. (1984) Pb and ^{210} Pb in a total environment, *Science of the Total Environment.* 34 (3), pp 279-289.

Borne, B.J. (1974) By-product recovery and waste disposal in the dairy industry. *Treatment of Food Wastes from the Food and Drink Industry* Symposium, Newcastle University/Institute of Water Pollution Control, 8-10th January. Newcastle-upon-Tyne, U.K. pp 17-23.

Bradstock, N. G. C. and Jeffries, C. F. (1983) Consent compliance: A flexible approach adopted by Taunton Cider Company Limited. *Journal of Water Pollution Control.* pp 348-354.

Brohier, R.L. (1947) The Dutch canal system between Kalutara and Colombo: A review. *Journal of the Dutch Burgher Union.* 37 (2), Dutch Burgher Union, Colombo. pp 37-43.

Brohier, R.L. and Paulusz, J.H.O. (1951) *Land, Maps and Surveys.* Volume 2, Ceylon Government Press, Colombo.

Brohier, R.L. (1954) The Dutch canals. *Ceylon Fortnightly Review.* 7 (5), Dutch Burgher Union, Colombo. p 23.

Brohier, R.L. (1965) Vignettes from the past : Colombo's water front. *Journal of the Dutch Burgher Union.* 55, December-January, Dutch Burgher Union, Colombo. pp 25-27.

Brohier, R.L. (1978) *Links between Sri Lanka and Netherlands: A Book of Dutch Ceylon.* Lake House Publishers, Colombo.

Brohier, R.L. (1984) *Changing Face of Colombo: 1505-1972.* Lake House Publishers, Colombo.

Calley, A.J. *et al* (1977) *Treatment of Industrial Effluents.* Hodder and Stoughton, London.

Central Environmental Authority (CEA) of Sri Lanka, (1983) *Industrial Pollution in the Ratmalana and Moratuwa Areas: A Preliminary study.* CEA, Colombo.

Central Environmental Authority of Sri Lanka, (1985) *Industrial Pollution in the River Kelani: Preliminary Survey and Interim Report.* Volume 1 and 2. CEA, Colombo.

Central Environmental Authority of Sri Lanka, (1985) Quality of Inland Surface Waters (Fresh Water Norms) *CEA Interim Standards.* (Based on Indian Standard 2296:1973, with modifications) CEA, Colombo.

Chang, L.V. (1982) Sau Paulo waste water pollution control project. In, *Management of Industrial Waste Water in Developing Nations.* (Stuckey, D. and

Hamza, A. eds.) Proceedings of the International Symposium, March 1981, Alexandria. pp 3-13.

Colombo Municipal Council Polyclinic, (1987) *Patient Record Register.* Unpublished. Slave Island, Colombo.

Colombo Municipal Council, (1987) *Vector Control Project.* Unpublished. City Microbiologist Laboratory, Colombo.

Cooper, J.L. and Denit, J.D. (1979) Federal water pollution control programs affecting the food processing industry. In, *Food Processing Waste Management.* (Green, G.H. and Kramer, A. eds.) Avi Publishing Company, Connecticut. pp 499-516.

Costa, H. H. and De Silva, S.S. (1978) Hydrobiology of the Colombo lake. *Spolia Zeylanica.* 32 (2), pp 83-92.

Daily Observer (1984) *Fish Kills in the Beira.* (20.9.84) Independent Newspapers Limited, Colombo. p 4.

Dart, M.C. (1974a) Waste water from the manufacture of edible oils and magarine. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January, Newcastle-upon-Tyne. pp 45-48.

Dart, M.C. (1974b) Treatment of waste water from the meat industry. *Treatment of Wastes from the Food and Drink industry* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January, Newcastle-upon-Tyne. pp 51-58.

Dayaratne, P. (1981) *A Methodology in Urban Renewal: A case Study of Panchikawatta, Colombo.* Unpublished M.Sc. Thesis. Department of Town and Country Planning, University of Moratuwa, Sri Lanka.

Department of Census and Statistics, (1981a) *Sri Lanka Economic Atlas, 1980.* Department of Census and Statistics, Ministry of Plan Implementation, Colombo.

Department of Census and Statistics, (1981b) *Basic Population Data for the Wards and Gramasevaka Divisions: Colombo District.* Unpublished, File Number 01. Ministry of Plan Implementation, Colombo.

Department of Census and Statistics (1986) *Statistical Pocket book of the Democratic Socialist Republic of Sri Lanka: 1986.* Ministry of Plan Implementation, Colombo.

Department of Census and Statistics, (1987a) *Sri Lanka Census of Industries- 1985: Preliminary Report.* Department of Census and Statistics, Colombo.

Department of Census and Statistics (1987b) *Annual Survey of Industries - 1985:*

Preliminary Report. Department of Census and Statistics, Colombo.

Department of Environment Welsh Office, (1978) River quality and the discharges of sewage and industrial effluents. *River pollution survey of England and Wales: updated 1975.* HMSO, London.

Department of Irrigation, (1966) *Technical Report on the Reclamation and Drainage of Swamps in and Around the City of Colombo.* (Sessional Papers 26). Government Publication, Colombo.

Department of Irrigation, (1972) Wellawatte canal pollution control. *Report of the Special Committee appointed by the Minister of Irrigation, Power and Highway.* Irrigation Department, Colombo.

Department of Meteorology, (1985-1987) *Daily Weather Charts for Colombo.*(December 1985 - March 1987) Unpublished. Department of Meteorology, Colombo.

Department of Meteorology, (1985-1987) *Three Hourly Rainfall Record for Colombo.* (December 1985 - March 1987). Unpublished. File Number, ROB 1985-1987, Department of Meteorology, Colombo.

Department of Meteorology, (1988) *Monthly Weather Summary: Colombo, 1986-1987.* Department of Meteorology, Colombo.

Department of National Archives, (n.d.)a Dutch canals. *Correspondence Letters between Director (PWD) and Government Agent (WP).* Unpublished, File Number RW-1876 (1.11.48-7.8.62). Department of National Archives, Colombo.

Department of National Archives, (n.d.)b *San Sebastian Canal. Correspondence Letter Numbers, 145(1955), 144(20.4.1953), 143a(1.4.1953), 143(21.3.1953), 141(7.3.1953), 128(27.9.1952), 127(9.8.1952), 69(14.3.1950), 48(17.5.1948).* Unpublished. Departmental File Number RW-43/608A (27.2.46-3.10.55). Department of National Archives, Colombo.

Dissanayake, D.A. (1985) *Pollution of River Kelani with Respect to Industrial Effluents.* Unpublished M.Sc Thesis. Department of Botany, University of Kelaniya, Sri Lanka.

Dissanayake, C. B. *et al* (1980) Distribution of copper ions in water and potable waters in Sri Lankan cities. *Water, Air and Soil Pollution.* 13, pp 275-286.

Dissanayake, C.B. *et al* (1983) Environmental impact of polluted city canals: a case study from Colombo, Sri Lanka. *Environment International.* 9, pp 401-407.

Dissanayake, C.B. *et al* (1985) The heavy metal pollution of river Kelani in Sri Lanka. *Aqua.* 2, pp 79-88.

Dutch Burgher Union, (1955) Water ways which have made history. *Journal of the Dutch Burgher Union.* 45 (4), pp 5-6.

EEC, (1975) Council Directive on the quality of surface water intended for the abstraction of drinking water in the member states. 75/440/EEC, Number L-194, (27.7.75) *Official Journal of the European Communities.* pp 26-29.

EEC, (1978) Council Directive on the the Quality of Fresh Water needing protection or improvement in order to support fish life. 78/659/EEC, Number L-222, (14.8.78) *Official Journal of the European Communities.* pp 1-10.

Ehrlich, P.R. *et al* (1977) *Ecoscience: Population, Resources and Environment.* Freeman and Company, San Francisco.

ESCAP (1985) *Coastal Environmental Management Plan for the West Coast of Sri Lanka - Preliminary Survey and Interim Action Plan.* ESCAP, Bangkok.

Evison, L.M and James, A. (1977) Microbial criteria for tropical water quality. In *Water, Wastes and Health in Hot Climates.* (Feachem, R., McGarry, M., Mara, D.D. eds.) John Wiley, London. pp 30-49.

Fatoye, G.A. (1982) Industrial development and environment - Nigeria looks ahead to the year 2000. *Industry and Environment.* Special Issue Number 3. pp 6-8.

Fernando, A.D.N. (1976) *Physical Planning for Agriculture.* Special International Sessions, Scientific and Technical Co-operation among the Non-aligned Countries, Sri Lanka Association for the Advancement of Science, Colombo.

Fernando, P.L.A.M.S.K. (1982) *Utilisation of Land for Integrated Urban Development: A Case Study of Colombo North.* Unpublished M.Sc Thesis. Department of Town and Country Planning, University of Moratuwa, Sri Lanka.

Freedman. D. *et al* (1978) *Statistics.* Norton and Company, New York.

Friends of the Earth, (1981) The state of the Malaysian environment. *A World Environment Day Report.* Kuala Lumpur, Malaysia.

Gilad, A. (1979) Planning and execution of comprehensive environmental pollution control projects. *Progress in Water Technology.* Volume 4, Pergamon Press, Oxford. pp. 113-128.

Gilardi, E.F. (1982) Surveillance and monitoring of industrial effluents. In, *Management of Industrial Waste Water in Developing Nations.* (Stuckey, D. and Hamza, A. eds.) Proceedings of the International Symposium, Alexandria, March 1981.

Gopalakrishnan, K. (1985) The Ganga: India's poisonous pilgrimage. *Earth Scan.* 8 (4), London. pp 8-9.

Government of Ceylon, (1923) San Sebastian canal: Report of the Committee appointed to investigate the question of the improvement of the San Sebastian

canal. *Sessional Papers* 30, Government Publication, Colombo.

Government of Ceylon, (1957) Report on the Reclamation and Utilisation of Swamps in and Around Colombo. *Sessional Papers 21.* Government Publication, Colombo.

Government of Sri Lanka, (1983) Municipal Council Ordinance 1956 - Revised. *Legislative Enactments: Government of Ceylon.* Government Publication, Colombo.

Government of Sri Lanka, (1988) *The National Environmental (Amendment) Act - 1988.* Government Publication, Colombo.

Green, J.H. and Kramer, A. (eds.) (1979) *Food Processing Waste Management.* Avi Publishing Company, Connecticut.

Greenberg, A.E., Connors, J.J., Jenkins, D., Franson, M.H. (1980) (eds.) *Standard Methods for the Examination of Water and Waste Water.* (15th ed.) American Public Health Association, Washington D.C.

Hill, R. (1984) A total capability in water treatment. *Water Services.* 88 (1059), pp 178-179.

Hinnawi, E.E. and Hashmi, M.U.H. (eds.) (1982) *Global Environmental Issues.* Tycooly International Publishers, Dublin.

Hoather, R.C. *et al* (eds.) (1960) *Approved Methods for Physical and Chemical Examination of Water.* (3rd ed.) Institute of Water Engineers, U.K.

Hobday, S.R. (1952) *The Law of Waters and Drainage.* (6th ed.) Sweet and Maxell, London.

Hodges, L. (1973) *Environmental Pollution: A Survey Emphasising Physical and Chemical Principles.* Holt Rinehart and Winston Inc., New York.

Holdgate, M.W. (1979) *A Perspective of Environmental Pollution.* Cambridge University Press, Cambridge.

Holdgate, M.W., Kassas, M. and White, G.F. (eds.) (1982) *The World Environment: 1972-1982.* Tycooly International Publishers, Dublin.

Holdsworth, S.D. (1970) Effluent from fruit and vegetable processing. *Effluent and Water Treatment Journal.* 10, pp 131-137.

Hughes, J.D. (1975) *Ecology in Ancient Civilizations.* University of New Mexico Press, Alburquerque.

Humitake, S. (1982) *Organic Materials in Aquatic Ecosystems.* CRC Press, Florida.

Isaac, P.C.G. and Anderson, G.K. (1974) Waste disposal problems in the food and drink industry - A review. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January, Newcastle-upon-Tyne, U.K. pp 7-11.

James, G.V. (1971) *Water treatment: A Survey of Current Methods of Purifying Domestic Supplies and of Treating Industrial Effluents and Domestic Sewage.* Technical Press, Edinborough.

James, A. (1974) By-product recovery from food waste by microbial protein production. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January, Newcastle-upon-Tyne, U.K. pp 149-155.

Jayatissa, P.M. (1981) *A Survey of Industrial Pollution in the Moratuwa Area.* Report I-13/5/1981. Ceylon Institute of Scientific and Industrial Research, Colombo.

Jerrard, R. (1984) Cleaning at a creamery. *Water Services.* 88 (1059), pp 176-178.

Jones, M.B. (1984) Carbonated beverages. *Encyclopaedia of Chemical Technology.* Volume 24, John Wiley Inter Science, New York. pp 710-725.

Karan, P.P. and Bladen, W. A. (1976) Geographical aspects of environmental pollution in India. *Geoforum.* 7 (1), pp 51-57.

Karan, P. P. (1980) Changes in environmental pollution in the Culcutta-Hooglyside industrial strip of India. *International Journal of Environmental Studies.* 15, pp 185-189.

Karunaratne, G. (1984) *A Steady State Water Quality Model for River Systems.* Unpublished M.Sc Thesis. Department of Civil Engineering, University of Moratuwa, Sri Lanka.

Kendall, M. (1976) *Time Series.* (2nd ed.) Charles Griffin, London.

Klein, L. (1966a) *River pollution - Causes and Effects.* Volume 1. Butterworths, London.

Klein, L. (1966b) *River Pollution - Chemical Analysis* Volume 2. Butterworths, London.

Klein, L. (1972) *River pollution - Control.* Volume 3. Butterworths, London.

Kurukulasuriya, S.B. (1982) Sri Lanka. *Seminar cum Study Tour on Inland Water Ways, Terminals and Landing Facilities* Country paper, 16-28th Decenber, ESCAP, Bangkok.

Lane, A.G. (1982) Prospects for anaerobic treatment of food processing effluent in Australia. *Food Technology in Australia.* 34 (9), pp 410-411.

Lane, A.G. (1984) Pilot scale anaerobic digestion of waste fruit solids. *Environmental Technology Letters.* 5, pp 141-150.

Lankaputhra, W.E.V. (1986) A physical-chemical and limnological survey of water in the Beira lake. *Sri Lanka Association for the Advancement of Science.* Proceedings, 42nd Annual Sessions. Part 1 (December). SLAAS, Colombo.

Lawrence, G.K (1976) 100 years of progress in the food processing industry *Food Quality and Safety - A Century of Progress.* (Ministry of Food and Fisheries) HMSO, London.

Lee, J.E. and Prasad, R.A (1982) *Well Water Quality in the South Pacific Islands.* Research paper, Institute of National Resources, University of South Pacific, Fiji.

Liyanage, A.M. (1980) *Mineral Resources of the Colombo District.* Mineral information series: Number - 4. Department of Geological Survey, Colombo.

Ludwig, H.F. (1979) Design of marine waste disposal system for industrial waste water. *Progress in Water Technology.* 4, pp 223-226.

Ludwig, R.G. (1980) *Industrial Waste Water Pollution Control Management.* Industrial Environment Division, Ministry of Industry, Bangkok, Thailand.

MacAndrews, C. and Sien, C.L (1979) (eds.) *Developing Economies and the Environment - the Southeast Asian Experience.* MacGraw-Hill International, Singapore.

MacDonald, D. (1974) Water reclamation and effluent treatment in the soft drink industry. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control, 8-10th January. Newcastle-upon-Tyne, U.K. pp 59-68.

MacDonald, N. (1978) *Time Lags in Biological Models.* Lecture notes in bio-mathematics: 27. Springer-Verlag, New York.

Madeley, J.R. and Reynolds, L.F. (1974) Aerobic biological treatment of food and drink industry wastes. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January. Newcastle-upon-Tyne, U.K. pp 96-112.

Singham, G. and Maheswaran, A. (1985) *Water Pollution and its Control in Malaysia.* Unpublished paper, Ministry of Science, Technology and Environment, Malaysia.

Mara, D.D.(1977) Waste water treatment in hot climates. In, *Water, Wastes and Health in Hot Climates.* (Feachem, R., McGarry, M., Mara, D.D. eds.) John Wiley, London. pp 264-283.

Margola, A. (1984) *Management and Waste Water Pollution Control in the Petro-Chemical and Plastic Processing Industry.* Proceedings: Petro-chemical and polymer consultation week, UNIDO. Paper number ID/WG.430/4, 6-16th October 1984, Jeddah, Riyadh and Dammam, Saudi Arabia.

Marshall, C. (1979) Unique Federal Pollution Control Financial Programs. In *Food Processing Waste Management.* (Green, G.H. and Kramer, A. eds.) Avi

Publishing Co., Connecticut. pp 544-570.

Menasveta, P. (1987a) Fish, fisheries, aquatic macrophytes and water quality in inland waters. *Water Quality Bulletin.* 12 (3), pp 121- 124.

Menasveta, P. (1987b) Effects of water pollution on aquaculture development in Thailand. *Water Quality Bulletin.* 12 (3), pp 116-118, 129-130.

Mensah, G.A. (1976) *Water Quality and Pollution Survey of Inland and Coastal Waters of Ghana.* Water Resources Research Unit. Accra, Ghana.

Meyer, G. (1984) Water - sources and utilisation. *Encyclopaedia of Chemical Technology.* Volume 24, John Wiley Inter Science, New York. pp 257-273.

Middlebrooks, J.E. (1979) *Industrial Pollution Control: Agro-Industries.* Volume 1. John Wiley, Canada.

Miller, J.P. (1982) Industrial pollution control in developing countries. In, *Management of Industrial Waste Water in Developing Nations.* (Stuckey, D. and Hamza, A. eds.) Proceedings of the International Symposium, Alexandria, March 1981. pp 14-18.

Ministry of Environment, (1983) *Ontario Drinking Water Objectives - Revised.* Ministry of Environment, Ontario.

Ministry of Housing, Physical Planning and Environment (1986) *Water Pollution Survey with an Ultra Light Aircraft - Colombo:.* Final Report - March, Ministry of Housing, Physical Planning and Environment, The Netherlands.

Ministry of Housing, Physical Planning and Environment (1987) *Water Pollution Survey with an Ultra Light Aircraft - Colombo: Phase 2.* Final Report - June, Ministry of Housing, Physical Planning and Environment, The Netherlands.

Ministry of Local Government, Housing and Construction, (1971) *Colombo Synthesis Report.* 4, Colombo Master Plan Project, Ministry of Local Government, Housing and Construction, Colombo.

Ministry of Culture, (1984) River taken on new life. *The Mirror.* Information Division, Ministry of Culture, Singapore. pp 14-15.

Ministry of Environment (1989) *Water Quality Data for Ontario Lakes and Streams.* Water Resources Branch, Ministry of Environment, Ontario.

Ministry of Health (1986) *Annual Health Bulletin.* Colombo, Sri Lanka.

Ministry of Industries (1986) *Classification of Industries.* Reference Government Gazette Number 14/979/11 (13.10.1971). Ministry of Industries and Scientific Affairs, Colombo.

Ministry of Industries and Scientific Affairs (1988) *Review of Activities 1985-1986.* Ministry of Industries and Scientific Affairs, Colombo.

Ministry of Plan Implementation, (1986) *National Science and Technology Policy for Sri Lanka.* Special Report Integrating the Nine Sectoral Policy Documents. Ministry of Plan Implementation, Colombo.

Ministry of Science, Technology and Environment (1982) *Environmental Quality Act 1974: Environmental Quality (Prescribed Premises) (Crude Palm Oil) Amendment Regulations 1982.* Her Majesty's Government Gazette, P.U.(A) 182-183, Malaysia.

Mohanrao, G.J (1972) Dairy waste characteristics, with reference to ISI standards. *Indian Journal of Environmental Health.* 14 (3), pp 218-223.

Morrison, R.J and Brodie J. E. (1983) *Pollution Problems in the South Pacific with Particular Reference to Fertilisers, Biocides, Water Supplies and Urban Wastes.* UNEP Symposium on Regional Co-operation on the Protection of the Environment, 1-11.2.83, 15th Pacific Science Congress, Dunedin, New Zealand.

Motha, M.S. (1985) *Beira Lake: Some Critical Aspects of Biological and Chemical Quality.* Unpublished B.Sc Dissertation. Department of Chemistry, University of Colombo, Sri Lanka.

Muers, M.M. (1968) Wastes from the processing of milk and milk products. *Water Pollution Control.* 6 (67), 644-645.

Mukerjee, S. (1977) Variations in the hepato-pancreatic A-Amylase activity in fishes exposed to some industrial pollutants. *Water Research.* 2 (1), pp 71-75.

Muller, C. M. and Stumm, W. (1984) Water properties. *Encyclopaedia of Chemical Technology.* 24, John Wiley Inter Science, New York. pp 276-293.

National Housing Development Authority, (1986) *Preliminary Census of Shanties and Slums (Tenements) within the Colombo City.* Departmental File Number 9/01/00/31. Unpublished. Division of Slum and Shanty, NHDA, Colombo.

National Building Research Organization, (1988) *Environmental Assessment Procedure for Development Activities in Urban Areas.* Ministry of Local Government Housing and Construction, Colombo.

National Development Bank, (1987) *Annual Report - 1986.* National Development Bank, Colombo.

National Water Supply and Drainage Board, (1981) *Sri Lanka Sewerage Project: Final Design Report.* NWSDB, Ratmalana, Sri Lanka.

National Water Supply and Drainage Board, (1982) *Solid Waste Management Plan for Colombo.* Final Report. NWSDB, Ratmalana, Sri Lanka.

Nemerow, N. L. (1978) *Industrial Water Pollution: Origin, Characteristics and Treat-*

ment. Addison-Wesley Publishing Company, London.

Nemerow, N.L. (1984) Wastes, industrial. *Encyclopaedia of Chemical Technology.* 24, John Wiley Inter Science, New York. pp 227-256.

North of England Development Council, (1983) *Food and Soft Drinks Industry.* Newcastle-upon-Tyne.

Northumbrian Water Authority, (1986) *Effluent Charges: Equation.* Unpublished. Newcastle-upon-Tyne.

Norusis, M.J. (1983) *SPSS- X: Introductory Statistical Guide.* McGraw-Hill, New York.

Olson, N.A. and Lyons, D.N. (1979) NPDES Compliance Monitoring. In, *Food Processing Waste Management.* (Green, G.H. and Kramer, A. eds.) Avi Publishing Company, Connecticut. pp 517-526.

Ostrom, C.W. (Jnr.) (1978) *Time Series Analysis: Regression Techniques.* Sage Publications, London.

Overcash, M.R. *et al* (1983) *Livestock Waste Management.* Volume 1. CRC Press, Florida.

Padmaperuma, C.I. (n.d) *Water Quality Monitoring in the Colombo Canal Systems.* National Science Council, Colombo.

Parker, C.D. (1971) *Recommended Standards for Rivers, Lakes, Irrigation Canals, Klongs and Waste Water Effluent.* Department of Health, Bangkok.

Peoples' Bank, (1977) Irrigation and Multipurpose Development in Sri Lanka. *Economic Review.* 2 (12), p 4.

Peoples' Bank, (1981) Canal development. *Economic Review.* 7 (5), pp 13-17.

Perera, A.L.S. (1976) *Location of Industry,* Unpublished M.Sc. Thesis, Department of Town and Country Planning, University of Moratuwa, Sri Lanka.

Pescod, M.B. (1974) *Investigation of Rational Effluent and Stream Standards for Tropical Countries.* Annual Report Number FE-476-2. Asian Institute of Technology, Bangkok.

Pescod, M.B. (1977) Surface water quality criteria for tropical developing countries. In, *Water, Wastes and Health in Hot Climates.* (Feachem, R., McGarry, M., Mara, D.D. eds.) John Wiley, London. pp 30-49.

Pescod, M.D. (n.d) *Industrial Waste Water in the Developing Countries.* Unpublished. Department of Civil Engineering, University of Newcastle-upon-Tyne, U.K.

Petr, T. (1987) Fish, fisheries, aquatic macrophytes and water quality in inland waters. *Water Quality Bulletin.* 12 (3), pp 103-106, 128-129.

Pollution Control Board (1985) *A Decade of Achievements.* Kerala State Pollution Control Board. Kerala, South India.

Porter, E (1973) *Pollution in Four Industrialised Estuaries.* (Four case studies undertaken for the Royal Commission on Environmental Pollution). HMSO, London.

Portillo, M.L. (1982) Industry and environment in Mexico. *Industry and Environment.* Special Issue Number 3. pp 33-35.

Pravdic, V. (1987) Environmental capacity: an approach for prevention of water pollution. *Water Quality Bulletin.* 12 (4), pp 137-140, 166.

Rahman, A.A. (1984) Effect of distillery waste water on the biota of river Cauvery, India. *Monograph - The Biosphere: Problems and Solutions.* Proceedings of the Miami International Symposium on the biosphere. 23-24th April, Miami Beach, Florida.

Raman, V. (1978) *Environmental Management of the Area of Authority under the GCEC.* Assignment Report. UNEP, Bangkok.

Ramanathan, M. (1984) Water Pollution. *Encyclopaedia of Chemical Technology.* 24, John Wiley Inter Science, New York. pp 295-314.

Rao, S.V.R. and Singh, V.P (1979) The effect of sewage and industrial waste water discharges on the primary production of a turbulent river. *Water Research.* 13 (10), pp 133-147.

Rao, S.V.R. and Mull, L.P. (1981) Effects of sewage and industrial waste on floristic composition and distribution of macrophytic vegetation in the river Khan. *Water Research.* 15 (2), pp 287-289.

Ratasuk, S. (1981) Philosophy of pollution control: water quality monitoring and management. *ASEAN/UNEP Technical Workshop on Urban Water Quality Monitoring and Management.* 14-19th December, Ministry of Environment, Singapore.

Rosenwinkel K.H. and Ruffer, H.M.(1982) Waste water from the juice industry. In *Management of Industrial Wastewater in Developing Nations.* (Stuckey, D. and Hamza, A. eds.) Proceedings of the International Symposium, Alexandria, March 1981. pp 426-444.

Rowley, C. and Beavis, B. (1974) *The Control of Industrial Discharges into Tidal Rivers and Estuaries: Long Range Planning.* Department of Economics, University of Newcastle-upon-Tyne, U.K.

Sandanam, S. (1984) *Study of Some Characteristics of Domestic Waste Water.* Unpublished M.Sc Thesis. Department of Civil Engineering, University of Moratuwa,

Sri Lanka.

Satomi, Y. and Takayanagi, K. (1987) Water quality criteria for fisheries in Japan: total phosphorous and total nitrogen. *Water Quality Bulletin.* 12 (4), pp 163-165.

Sawyer, C.N. and McCarty P.L. (1978) *Chemistry for Environmental Engineers.* (3rd ed.) McGraw-Hill, New York.

Sharma, A.K. (1983) Environmental pollution in India. *Mazingira.* 7 (1), pp 2-14.

Sidwick, J.M. (1974) Review of waste water from confectionery, preserves and pickle industry. *Treatment of Wastes from the Food and Drink Industry* Symposium, Newcastle University/Institute of Water Pollution Control. 8-10th January, Newcastle-upon-Tyne, U.K. pp 28-37.

Siegel, S. (1959) *Non-parametric Statistics for the Behavioural Sciences.* McGraw-Hill, London.

Silva, K.M.(1973) (ed.) *History of Ceylon.* Volume 3. University of Ceylon, Colombo. p 309.

Simmons, I.G. (1981) *The Ecology of Natural Resources.* (2nd ed.) Edward Arnold, London.

Singh, L.R., Singh, *et al* (1983) *Environmental Management.* Allahabad Geographical Society, Allahabad.

Singh, S.N. and Bhargava, A.K. (1984) Plant distribution as affected by the confluence of a polluted stream with a clean stream. *Indian Journal of Ecology.* 2 (2), pp 342-344.

Singham, G. and Maheswaran, A. (1985) *Water Pollution and its Control in Malaysia.* Unpublished paper, Ministry of Science, Technology and Environment, Malaysia.

Sivalingam, P.M. *et al* (1978) *Aquatic Pollution Effects of Discharges from a Sugar Refinery in Malaysia.* Proceedings: International Conference on Water Pollution in Developing Countries. 21-25th February. Bangkok, Thailand. pp 203-215.

Smart, R.B. and Mancy, K.H. (1984) Water analysis. *Encyclopaedia of Chemical Technology.* 24, John Wiley Inter Science, New York. pp 315-326.

Sprent, P. (1989) *Applied Non-parametric Statistical Methods.* Chapman and Hall, London.

Sri Lanka Lowlying Reclamation and Development Board, (1981) *New Capital City Drainage Project: Final Report.* Sri Lanka Low Lying Reclamation and Development Board, Colombo.

Sri Lanka Lowlying Reclamation and Development Board, (1987) *Canals Maintenance*

Cost: San Sebastian Canal - 1986/1987. File Number 24 RE/CN. Unpublished. Sri Lanka Lowlying Reclamation and Development Board, Colombo North.

Sri Lanka Standards Institution, (1983) *Sri Lanka Standard Specification for Potable Water: Part I - Physical and Chemical Requirements. SLS 614:1983.* (Council approved copy) Sri Lanka Standards Institution, Colombo.

Sri Lanka Standards Institution, (1984) *Tolerance Limits for Industrial Discharges into Inland Surface Waters. SLS 652:1984.* (Council approved copy) Sri Lanka Standards Institution, Colombo.

Sri Lanka Standards Institution, (1985) *Tolerance Limits for Industrial and Domestic Effluent Discharges into Marine Coastal Areas. SLS 721:1985.* (Council approved copy) Sri Lanka Standards Institution, Colombo.

Sri Lanka Standards Institution, (1985) *Tolerance Limits for Inland Surface Waters for use as Raw Water for Public Water Supply. SLS 722:1985.* (Council approved copy) Sri Lanka Standards Institution, Colombo.

Sri Lanka Lowlying Reclamation and Development Board, (1987) *Labour Distribution and Progress of Canal Works.* Departmental File Number RE PR/CO-057. Unpublished. Sri Lanka Lying Reclamation and Development Board, Colombo North.

Sri Lanka Ports Authority, (1986 and 1987) *Charges for the Use of the McCallum Locks.* Departmental File Number EW/8/262. Unpublished. Ports Authority, Colombo.

Stavenger, P (1970) The food industry and pollution. *Food Technology* . 24 (121), 15-20.

Subash-Rele, J. and Chaudri, N. (1985) Ganga the most polluted today, and how to clean the Ganga. *Yojana.* 29 (10), pp 4-10.

Subrahmanyam, P.V.R. and Mohanrao, G.J. (1972) Sources, flows and characteristics of dairy wastes. *Indian Journal of Environmental Health.* 14 (3), pp 207-216.

Subrahmanyam, P.V.R. and Mohanrao, G.J. (1972) Treatment of dairy wastes by unmechanised methods. *Indian Journal of Environmental Health.* 14 (3), pp 232-236.

Sumathipala, M.D. (1984) *Beira Lake, an In-depth Study as an Urban Resource in Colombo: A Case Study in East Beira Lake and its Surronding.* Unpublished Dissertation, Diploma in Urban Development, Department of Town and Country Planning, University of Moratuwa, Sri Lanka.

Sundaram, S.T. (1984) Environmental strategies for industrialisation. *Chemistry and*

Environment. Symposium, 29th-31st March. Ministry of Science, Technology and Environment, Malaysia.

Sunderasan, B.B. and Blinde, A.D. (1983) An overview of toxic and hazardous wastes in India. *Industry and Environment.* Special Issue Number 3. UNEP, Paris.

Tebbutt, T.H. Y. (1973) *Water Science and Technology.* John Murray, London.

The National State Assembly, (1980) *The National Environmental Act: Number 47.* (Published as supplement to the Government Gazette of 31st October 1980) Government Publication, Colombo.

The National State Assembly, (1988) The National Environmental (Amendment) Bill - Second Reading. *Hansard: Parliamentary Debates.* 54 (9), 6th October 1988. Uncorrected official Report. Government Publication, Colombo.

The National State Assembly, (1988) The National Environmental (Amendment) Bill - Third Reading. *Hansard: Parliamentary Debates.* 54 (23), 25th November 1988, Government Publication, Colombo.

Toms, R.G. (1985) River pollution control since 1974. *Water Pollution Control.* 84 (2), pp 178-186.

Urban Development Authority, (1981) *Ward Profiles for 1978.* Unpublished. Ministry of Local Government, Housing and Construction, Colombo.

UNEP, (1985) Food processing industries and the environment. *Industry and Environment.* 8 (4), UNEP, Paris.

UNIDO, (1985) *Round Table Ministerial Meeting on Co-operation among Developing Countries in the Food Processing Industry.* 7-11th May. Novi Sad, Yugoslavia.

US Department of Interior, (1966) *Delaware Estuary Comprehensive Study.* The preliminary report to findings. Federal Water Pollution Association, US Department of Interior, Washington D.C.

Venu, P. *et al* (1984) Indicatory and functional role of phytoplankton in the effluents of Rangpo distilleries of Sikkim Himalayas. *Phykos.* 23 (1-2), pp 38-44.

Verma, S.R. *et al* (1978) Studies on the sugar factories and their wastes in Western Uttar Pradesh. *Indian Journal of Environmental Health.* 20 (3), pp 204-218.

Vowles, P.D. *et al* (1980) *Experiments in Environmental Chemistry: A Laboratory Manual.* Pergamon Press, Oxford.

Wadley, J. and Bell, J.(1974) Treatment of waste water from canning, freezing and drying of fruits and vegetables. *Treatment of Wastes from the Food and Drink Industry.* Symposium, Newcastle University/Institute of Water Pollution Control UK. 8-10th January, Newcastle-upon-Tyne, U.K. pp 12-16.

Warta Keranjaan, (1977) Environmental Quality Act 1974: Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations 1977. *Government Gazettte.* 22, November. Government Publication, Malaysia.

Wigneswaran, T. (1983) *Studies on the Benthic Environment, Benthic Sediments and Benthos of Colombo Beira Lake.* Unpublished M.Sc Thesis. Department of Botany, University of Kelaniya, Sri Lanka.

WHO, (1972a) *Draft Reconnaissance Report on the Surface Water and Main Drainage of the City of Colombo.* WHO, Geneva.

WHO, (1972b) *South West Coastal Area Water Supply, Sewerage and Drainage Project.* Preliminary Engineering and Feasibility Study - Part 1. WHO, Geneva.

WHO, (1982) *Rapid Assessment of Sources of Air, Water and Land Pollution.* WHO Offset Publication Number 62. WHO, Geneva.

WHO, (1983a) *GEMS/WATER Data Evaluation Report.* WHO, Geneva.

WHO, (1983b) *Compendium of Environmental Guidelines and Standards for Industrial Discharges.* Number EPF/83.49. WHO, Geneva.

Wijeyesekera, D.S. and Pathinather, S. (1987) Performance of a high loaded deep primary waste stabilisation pond. *The Engineer.* June 1987, Colombo. pp 10-20.

Willinton, I.P. and Marten, G.G. (1982) Options for handling stillage waste from sugar-based fuel ethanol production. *Resources and Conservation.* 8, pp 111-129.

Wright, P. (1985) Coping with waste - 2. *The Times.* (5.2.1985), London.

Wright, A. (1907) *Twentieth Century Impressions of Ceylon: Its History, People, Commerce, Industries and Resources.* Lloyds Greater Britian Publishing Company, London.

Yapa, A.P.J. (1989) Water Hyacinth: eradicate or cultivate it? *Ceylon Daily News.* (25.1.89), Associated Newspapers of Ceylon, Colombo. p 4.

Zeigler, D.J. *et al* (1983) *Technological Hazards.* Association of American Geographers, Washington, D.C.

Zoetman, B.C.J. (1980) *Sensory Assessment of Water Quality.* Pergamon Series in Environmental Science. Pergamon Press, Oxford.