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Land Evaluation Studies in the Mid-Wear Lowlands of County Durham

Abstract

This thesis is a statement of research into the use of various aspects of the science of land evaluation in a selected area of Eastern Durham, Great Britain. It has a dual purpose of both investigating the area under question and of developing new means of analysis in the light of present concepts and past research.

Two broad themes run through the study; that of consideration of methods of assessing the physical capability of land for various uses, and that of the development of natural resource information inventories for use where no specific land use is initially contemplated.

Two areas for research, suggested by deficiencies in the existing literature, are followed. The first is the use of point sample surveys to enable a rapid evaluation of an area's characteristics and land use capability at a "strategic" level of survey. The second is the development of quantitative information inventory procedures which reduce the elements of subjectivity that are inherent in composite unit analysis.

The three major underlying practical conceptual approaches to land evaluation of thematic, composite and parametric analysis are taken as the methodological basis for the research and only physical evaluations are considered. Soil receives particular emphasis throughout.

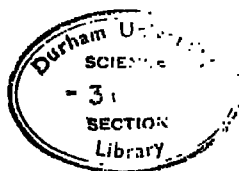
The work is divided into five parts. Part 1 discusses the concept of land evaluation, the contribution of previous workers and the rôle of natural resource attributes and parameters. Part 2 defines the study area, the survey methods, and a thematic description of the area's characteristics relevant to the study. Part 3 investigates parametric land capability classifications for selected land uses and Part 4, after a discussion of quantitative information analysis, outlines a series of quantitative methods for the development of site information inventories. Part 5 concludes the study.

Land Evaluation Studies in the
Mid-Wear Lowlands of County Durham

I.W. Brown, B.A. (Dunelm)

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A thesis submitted for the degree of Doctor of Philosophy,
Faculty of Science, University of Durham.





The Mid - Wear Lowlands

'Throughout history land has been the most sought-after and yet one of the least understood of the earth's phenomena. Nearly always it has been regarded as wealth and something to satisfy a demand for food and living-space. Rarely has it been treated both as a living entity and a resource in very limited supply.'

Robert Arvill, 1967

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Introduction

This thesis is a statement of research into the use of various aspects of the science of land evaluation in a selected area of Eastern Durham, Great Britain. It has a dual purpose of both investigating the area under question and of developing new means of analysis in the light of present concepts and past research.

Two broad themes run through the study; that of the consideration of methods of assessing the physical capability of land for various uses, and that of the development of natural resource information inventories for use where no specific land use is initially contemplated.

Land evaluation is a comparatively new discipline and there are many areas for research suggested by deficiencies in the existing literature, but two are of note. The first is the use of point sample survey to enable a rapid evaluation of an area's characteristics and land use capability at a "strategic" level of survey. "Strategic" is here defined in the planning sense of the term as a level of analysis enabling an overall investigation of an area to take place before specific policies regarding the use of land can be formulated, and before detailed surveys at individual site level take place on an areal basis. The second notable area for research is the development of quantitative information inventory procedures which reduce the elements of subjectivity that are inherent in composite unit analysis.

This study attempts to make a contribution towards filling these gaps by taking point sample methods at a strategic level as the survey procedure and, after basic thematic analysis, developing a) land capability classifications for a wide variety of land uses commonly encountered when planning an area, and b) quantitative natural resource site information inventories. The three major underlying practical conceptual approaches to land evaluation of thematic, composite and parametric analysis are taken as the methodological basis for the research. Only physical evaluations are to be considered, the complex web of socio-economic-political assessments being outside the scope of the study. The rôle of the major resource attribute of soil, as defined by Stewart (1968), receives special attention throughout.

The overall aim of the study may be defined as follows:

- i) To discuss the concepts of land evaluation and outline past workers' contributions to the discipline.
- ii) To investigate the rôle of natural resource attributes and their parameters in land evaluation procedure.
- iii) To investigate the physical characteristics of the selected area of Eastern Durham on a thematic basis.
- iv) To investigate the land capability for various land uses of the selected area of Eastern Durham using point sample parametric land capability systems developed at a strategic level of survey.
- v) To develop quantitative natural resource site information inventory systems for the selected area of Eastern Durham using point sample survey methods at a strategic level of survey.

At the end of the day it is the natural resource planner who has to use the information gleaned by using land evaluation techniques to achieve some practical end, and it is with this factor in mind that the research is oriented.

The work is divided into five parts. Part 1 discusses the concept of land evaluation, the contribution of previous workers and the rôle of natural resource attributes and parameters. Part 2 defines the study area in Eastern Durham, the survey methods, including the point sample procedures which form the data frame for further analysis, and a thematic description of the area's characteristics relevant to the study. Part 3 investigates parametric land capability classifications for selected land uses and Part 4, after a discussion of quantitative information analysis, outlines a series of quantitative methods for the development of site information inventories. Part 5 concludes the study.

CONTENTS

	<u>Page</u>
PART 1	
<u>Chapter 1. Land evaluation - Definition, concepts and approaches</u>	1
1.1 Land evaluation - definition of terms	1
1.2 The need for land evaluation	2
1.3 Land evaluation - concepts and approaches	4
1.4 Scale in land evaluation	8
1.5 Land evaluation procedures overseas	9
1.6 Land evaluation and the planning process in Great Britain	10
<u>Chapter 2. Previous Work</u>	15
2.1 Early regionalisation and genetic groupings	15
2.2 The composite unit idea	16
2.3 The development of parametric land evaluations	24
2.4 Summary	28
<u>Chapter 3. A review of the problems involved in determining the threshold levels of natural resource attributes and parameters for land use planning purposes</u>	29
3.1 Introduction	29
3.2 The threshold concept	29
3.3 Threshold analysis	31
3.4 Natural resource attributes, their parameters and thresholds as they affect selected land uses	33
3.5 Summary	60

	<u>Page</u>
PART 2	
<u>Chapter 4. Location of study area and procedures adopted in the collection of data for land evaluation analysis in succeeding chapters</u>	61
4.1 Introduction	61
4.2 Location of the study area	61
4.3 Survey procedure	65
<u>Chapter 5. Land evaluation - a thematic approach</u>	80
5.1 Physiographic units	80
5.2 Drainage	89
5.3 Geology	92
5.4 Glacial Deposits	96
5.5 Climate	100
5.6 Soils	105
5.7 Land use response to the physical environment	130
5.8 Conclusions	137
PART 3	
<u>Chapter 6. Land evaluation - a parametric approach</u>	138
6.1 Introduction	138
6.2 Land capability classification for agriculture	138
6.3 Land capability classification for forestry	172
6.4 Land capability classification for nature conservation	187
6.5 Land capability classification for housing development	194
6.6 Land capability classification for industrial development	215
6.7 Land capability classification for recreational development	231
6.8 Conclusions to Chapter 6	248

	<u>Page</u>
PART 4	
<u>Chapter 7. Land evaluation - an introduction to a numerical composite parametric approach</u>	250
7.1 Introduction	250
7.2 An approach to a composite parametric point sample land evaluation method for the transect sites	250
7.3 Data selected	251
<u>Chapter 8. The application of cluster analysis to land evaluation procedure</u>	254
8.1 Introduction	254
8.2 Site affinity determination	254
8.3 Definition of the term "cluster"	255
8.4 The clustering of transect sites on the basis of highest affinity	255
8.5 The clustering of transect sites by linkage analysis	271
8.6 Conclusions to chapter	282
<u>Chapter 9. The application of principal component analysis to land evaluation procedure - Part 1</u>	284
9.1 Introduction	284
9.2 The analysis	284
9.3 Transect principal component analysis discussion	286
<u>Chapter 10. The application of principal component analysis to land evaluation procedure - Part 2.</u>	312
10.1 Introduction	312
10.2 Definition of component scores	312
10.3 Analysis of the component scores of the transect sites	312
10.4 Conclusions	383
<u>Chapter 11. The application of principal component analysis to land evaluation procedure - Part 3 Site Clustering</u>	384
11.1 Introduction	384
11.2 Transect clustering procedures	384
11.3 Description of clusters and main site and soil characteristics of each and short outline of land potential	385

	<u>Page</u>
11.4 Conclusions	397
PART 5	
<u>Chapter 12. Summary and Conclusions</u>	397
 <u>Appendix 1 Soil profile descriptions</u>	 399
<u>Appendix 2 Soil analytical data</u>	471
<u>Appendix 3 The assessment of soil erosion potential</u>	490
3.1 Introduction	491
3.2 The quantitative assessment of erosion potential	492
<u>References</u>	507
Personal Communications	523

Overlays of Figures 4.5 and 5.1 are included inside the back cover for ease of reference.

FIGURES

	<u>Page</u>
1.1. The man-nature system (adapted after Chadwick, 1971)	3
1.2. Flow chart of the planning process including land evaluation procedures	12
2.1 Land systems and facets	21
3.1. Specific and gradational thresholds	30
3.2. The threshold triangle	30
3.3. Normal and threshold costs (after Barrell and Glasson, 1972).	32
3.4. Stepped housing (after Pollit, 1974)	48
4.1. Location of Eastern Durham	62
4.2. Topographical regions of Eastern Durham	62
4.3. Study transect location	64
4.4. Transect reference points	66
4.5. Transect sites	67
4.6. Organic carbon levels for humose materials (after Thompson).	76
4.7. Particle-size classes (International scale)	77
4.8. Particle-size classes (U.S.D.A. Scale)	77
5.1. Physiographic units	81
5.2. Drainage	91
5.3. Regional geology	93
5.4. Geology (solid-simplified)	95
5.5. Glacial deposits (after Maling, 1955)	98
5.6. Long-period mean temperature, with 10-year moving averages from Durham University Observatory. Annual temperatures ($^{\circ}\text{C}$), 1847-1968, (after Smith, 1970)	101
5.7. Mean annual precipitation, 1916-50 (after Smith, 1970)	101
5.8. Long-period precipitation amounts, with 10-year moving averages from Durham University Observatory. Annual precipitation (mm), 1886-1968 (after Smith, 1970)	103
5.9. Long-period Sunshine duration amounts, with 10-year moving averages from Durham University Observatory. Annual Sunshine duration in hours, 1886-1968 (after Smith, 1970).	103
5.10. Distribution of major soil groups	106

	<u>Page</u>
5.11. Distribution of soil groups	108
5.12. Distribution of soil subgroups	110
5.13. Land use	133
6.1. Sites with Wetness limitations - agriculture (subclass w)	144
6.2. Sites with soil depth to in-situ rock limitations - agriculture (subclass s)	145
6.3. Sites with soil stoniness limitations in topsoil - agriculture (subclass s)	147
6.4. Sites with soil texture and structure limitations in topsoil (5cm) - agriculture (subclass s)	148
6.5. Sites with soil texture and structure limitations in subsoil (40cm) - agriculture (subclass s)	149
6.6. Sites with soil acidity limitations in topsoil and for subsoil (5cm and 30cm) - agriculture (subclass s)	151
6.7. Sites with angle of slope and soil pattern limitations - agriculture - (subclass g).	153
6.8. Sites with soil erosion risk limitations - agriculture (subclass e)	155
6.9. Sites with altitude limitations - agriculture (subclass c)	157
6.10. Sites with exposure limitations - agriculture (subclass c)	158
6.11. Sites with site restrictions (subclass b)	160
6.12. Land capability classes for agriculture	162
6.13. Land capability subclasses for agriculture	165
6.14. Sites with soil drainage and texture limitations - forestry (subclass w)	178
6.15. Sites with pH limitations - forestry (subclass a)	179
6.16. Land capability classes for forestry	181
6.17. Land capability subclasses for forestry	184
6.18. Land capability classes for nature conservation	191
6.19. Sites with angle of slope limitations - housing (subclass g)	201
6.20. Sites with depth to in-situ rock limitations - housing (subclass d)	202
6.21. Sites with soil stoniness limitations - housing (subclass s)	203
6.22. Sites with topsoil quality limitations - housing (subclass s)	204
6.23. Sites with aspect and exposure limitations - housing (subclass c)	205
6.24. Sites with liability to mining subsidence limitations - housing (subclass m)	206
6.25. Land capability classes for housing development	208
6.26. Land capability subclasses for housing development	211

	<u>Page</u>
6.27. Sites with angle of slope limitations - industry (subclass g)	219
, 6.28. Land capability classes for small-scale industrial development	221
6.29. Land capability classes for large-scale industrial development	222
6.30. Land capability subclasses for small-scale industrial development	225
6.31. Land capability subclasses for large-scale industrial development	226
6.32. Sites with angle of slope limitations for recreation - camp sites and picnic areas (subclass g)	236
6.33. Sites with soil permeability limitation for recreation - camp sites and picnic areas (subclass s)	237
6.34. Sites with soil texture limitations for recreation - camp sites and picnic areas (subclass s)	238
6.35. Sites with aspect limitations for recreation - camp sites and picnic areas (subclass c)	239
6.36. Land capability classes for recreation - camp sites and picnic areas	241
6.37. Land capability subclasses for recreation - camp sites and picnic areas	244
8.1 Site correlation coefficients	256
8.2. Highest affinity clusters	257
8.3. Site dendrogram (Palmer, 1974)	273
8.4. Linkage coefficients graph	274
9.1. Correlation coefficients	291
10.1. Component 1	313
10.2. Component 2	324
10.3. Components 1 and 2	333
10.4. Component 3	338
10.5. Components 2 and 3	346
10.6. Component 4	351
10.7. Component 5	357
10.8. Component 6	365
10.9. Component 7	373
11.1. Site dendrogram (Mather, 1969)	386
11.2. Site dendrogram (Palmer, 1974)	387
11.3. Linkage coefficients graph	388

	<u>Page</u>
A.3.1. Sites within Morgan's (1974) Textural groupings	493
A.3.2. Soil erodibility nomograph (after Wischmeier, Johnson and Cross, 1971)	498
A.3.3. The relationship between erosion and angle of slope	499
A.3.4. The relationship between erosion and length of slope	501
A.3.5. Slope-effect chart (topographic factor LS)	501
A.3.6. Soil erodibility factor (K)	504
A.3.7. Soil loss in tons per acre without conservation practice (P)	506

TABLES

	<u>Page</u>
1.1. A scheme for local government land evaluation procedure in Great Britain	13
3.1. A.L.S. limits of altitude and rainfall as they affect agriculture	36
3.2. Altitude and rainfall thresholds of the land use capability classes (after Bibby and Mackney 1969 and Bendelow and Hartnup, 1977)	37
3.3. Effect of tree species on soil pH and base saturation (after Muckenhirn et al. 1949)	41
5.1. Mean monthly soil temperature at 30 cm depth 1963-68 (°C)	100
5.2. Soil major groups of the transect sites	105
5.3. Distribution of soil major groups within the transect	107
5.4. Soil groups of the transect sites	107
5.5. Soil subgroups of the transect sites	109
5.6. Transect point sample land use - 1971	132
5.7. Transect point sample land use by physiographic unit - 1971	132
6.1. Distribution of sites with soil wetness limitations by physiographic unit	143
6.2. Distribution of sites with soil stoniness limitations by physiographic unit	146
6.3. Distribution of sites with soil textural limitations by physiographic unit	150
6.4. Distribution of sites with soil fertility (nutrient status) limitations by physiographic unit	150
6.5. Distribution of sites with angle of slope limitations by physiographic unit	152
6.6. Distribution of sites with soil erosion limitations by physiographic unit	154
6.7. Land capability Classes for agriculture by physiographic unit	159
6.8. Land capability classes for agriculture	161
6.9. Dominant subclass by capability class - agriculture	164
6.10. Dominant subclass among the physiographic units by capability class - agriculture	166
6.11. Soil limitations dominant subclass s by capability class - agriculture	167

	<u>Page</u>
6.12. Combinations of subclasses by capability class - agriculture	168
6.13. Soil type, capability class and dominant subclass - agriculture	169
6.14. Percentage of sites in each land capability class according to land use - agriculture	170
6.15. Comparison of agricultural capability systems - A.D.A.S. (1971) and Brown (1971 Survey)	171
6.16. Land capability classes for forestry	180
6.17. Land capability classes for forestry by physiographic unit	183
6.18. Dominant subclass by capability class - forestry	183
6.19. Dominant subclass among the physiographic units by capability class - forestry	185
6.20. Combinations of subclasses by capability class - forestry	186
6.21. Soil type, capability class and dominant subclass - forestry	186
6.22. Land capability classes for nature conservation by physiographic unit	190
6.23. Land capability classes of the agricultural sites for nature conservation	193
6.24. Agricultural features - nature conservation	194
6.25. Land capability classes for housing by physiographic unit	200
6.26. Land capability classes for housing	207
6.27. Dominant subclass by capability class - housing	210
6.28. Dominant subclass among the physiographic units by capability class - housing	212
6.29. Combinations of subclasses-housing	213
6.30. Soil type, capability class and dominant subclass - housing	214
6.31. Land capability classes for small-scale industry by physiographic unit	218
6.32. Land capability classes for industry	220
6.33. Land capability classes for large-scale industry by physiographic unit	224

	<u>Page</u>
6.34. Dominant subclass by capability class - industry	227
6.35. Dominant subclass among the physiographic units by capability class for industry	228
6.36. Combinations of subclasses by capability class - industry	229
6.37. Soil type, capability class and dominant subclass - industry	230
6.38. Land capability classes for camp sites and picnic areas by physiographic unit	235
6.39. Land capability classes for camp sites and picnic areas	240
6.40. Dominant subclass by capability class - camp sites and picnic areas	243
6.41. Dominant subclass among the physiographic units by capability class - camp sites and picnic areas	245
6.42. Combinations of subclass by capability class - camp sites and picnic areas	246
6.43. Soil type, capability class and dominant subclass - camp sites and picnic areas	247
6.44. Land capability classes for the selected land uses	249
7.1. Site and soil variables	252
9.1. Elementary statistics	288
9.2. Run 1 eigenvalues and % variance explained	295
9.3. Component loadings of the computer runs	297
9.4. Original and final communalities for the three PCA computer runs	301
9.5. Run 2 eigenvalues and % variance explained	303
9.6. Run 3 eigenvalues and % variance explained	306
10.1. Component 1	314
10.2. Percentage of sites in each soil type by octile - component 1	321
10.3. % occurrence of land use types by octile - component 1	322

	<u>Page</u>
10.4. % site distribution among the physiographic units by octile - component 1	322
10.5. Component 2	326
10.6. % sites in each soil type by octile - component 2	330
10.7. % occurrence of land use types by octile - component 2	331
10.8. % site distribution among the physiographic units by octile - component 2	332
10.9. Component 3	334
10.10. pH (5cm)/Octile trend - Component 3	341
10.11. % base saturation (5cm)/octile trend - Component 3	341
10.12. % sites in each soil type by octile - Component 3	343
10.13. % occurrence of land use types by octile - Component 3	344
10.14. % site distribution among the physiographic units by octile - Component 3	345
10.15. Component 4	347
10.16. % sites in each soil type by octile - Component 4	354
10.17. % occurrence of land use types by octile - Component 4	355
10.18. % site distribution among the physiographic units by octile - Component 4	355
10.19. Component 5	358
10.20. Drainage status/octile trend - Component 5	361
10.21. % sites in each soil type by octile - Component 5	362
10.22. % occurrence of land use types - Component 5	363
10.23. % site distribution among the physiographic units by octile Component 5	363
10.24. Component 6	366
10.25. Depth to BC or C horizon/octile trend - Component 6	369
10.26. % sites in each soil type by octile - Component 6	370
10.27. % occurrence of land use types by octile - Component 6	371
10.28. % sites distribution among the physiographic units by octile Component 6	372

	<u>Page</u>
10.29. Component 7	374
10.30. % base saturation (30cm)/octile trend - Component 7	379
10.31. pH (30cm)/octile trend - Component 7	379
10.32. % sites in each soil type by octile - Component 7	380
10.33. % occurrence of land use types by octile - Component 7	381
10.34. % site distribution among the physiographic units by octile - Component 7	382
A.3.1. Conservation practice values	502
A.3.2. Results of the Universal Soil-Loss Equation	503

PLATES

		<u>Page</u>
Frontispiece	The Mid - Wear Lowlands	i
5.1.	Unit 1. Lowlands West of the River Wear	82
5.2.	Unit 2. Steep-sided stream section falling to the River Wear	83
5.3.	Unit 3. River Wear Gorge	84
5.4.	Unit 4. Lowlands East of the River Wear viewed from the Permian Escarpment (Unit 6)	86
5.5.	Unit 5. Coalford Vale	87
5.6.	Unit 6. Permian Escarpment rising from the Lowlands East of the River Wear	88
5.7.	Unit 6. Disused quarry in Magnesian Limestone at Pittington	89
5.8.	Unit 7. Permian (Magnesian Limestone) Plateau	90
5.9.	Unit 4. Pittington Village (left middle-distance) set among a broad agricultural landscape	131
5.10.	N.C.B. mixed woodland on the Permian Escarpment (Unit 6) at Elemore	134
6.1	Class 3ws for agriculture in the foreground on stagnogleyic brown earth soils of Unit 4, contrasts with 5 esg slopes of Pittington Hill, of predominantly brown calcareous and rendzina soils, in the distance	163
6.2.	Poorly drained cambic stagnogley land of Class 4ws at Site 11 near the base of the Permian Escarpment (Unit 6) at High Moorsley	163
6.3.	Typical brown earth soils on well drained land at Framwellgate Moor form Class 1 sites for forestry (near Site 16 in Unit 1)	182
6.4.	Class 2aw land for forestry near Carrville (Unit 4); cambic stagnohumic gley soils showing pH and drainage/texture limitations	182
6.5.	Class 1 site for nature conservation in the River Wear Gorge and Floodplain (Unit 3). Note the presence of deciduous woodland, water and luxuriant vegetation in combination to give the high score	192
6.6.	Agricultural sites such as this, with a combination of permanent grass, hedges and hedgerow trees can form valuable wildlife habitats. This example, of Class 3 standard, is in Unit 4 near Ramside	192
6.7.	Class 3ws land for housing, with poor drainage and stoniness limitations, near Site 7 at Moorhouse (Unit 4)	209

		<u>Page</u>
6.8.	Although flat, the effects of mining subsidence and exposure relegate this area near Hetton le Hill on the Permian Plateau (Unit 7) to Class 4 mc for housing.	209
6.9.	Poorly drained cambic stagnohumic gley soils, developed on laminated clay at Site 3 near Brasside (Unit 1), result in Class 3w status for small and large-scale industry	223
6.10.	Although Class 3w for small-scale industry, this location, near Site 36 in Unit 4, is 4gw for large-scale industry	223
6.11.	The effects of angle of slope and a stony profile relegate the location in the foreground (Site 54) at Pittington in Unit 6, on brown calcareous earths, to Class 2gs for camp sites and picnic areas. This passes to Class 3gs further up slope	242
6.12.	Soil drainage, exposure, soil texture and stoniness limitations restrict the use of this land, typical of the Permian Plateau (Unit 7) near Hetton le Hill, to Class 3wcs for camp sites and picnic areas	242

PART I

Chapters : I, 2 and 3

CHAPTER 1 - LAND EVALUATION - DEFINITION, CONCEPTS AND APPROACHES

1.1 Land Evaluation - Definition of Terms

"Land evaluation", is defined as "the assessment of the suitability of land for man's use in agriculture, forestry, engineering, hydrology, regional planning, recreation etc." (Stewart, 1968). The method makes it possible to gain a measure of the nature and potential of an area prior to plan formulation and implementation.

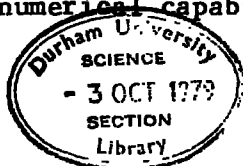
Land evaluation analyses and procedures have developed in response to the need for an understanding of the natural and cultural environment for practical land use purposes and are interdisciplinary in approach. Mitchell (1973), when referring to "terrain", an allied but not as wide a term as "land", proposes that the increasing variety of disciplines concerned with its practical use are both scientific; for example, geology, hydrology, geography, botany, zoology, ecology, pedology and meteorology, and applied; for example agriculture, forestry, civil and military engineering and urban and recreational landscape design. He surprisingly omits town and country planning which, although very slow to consciously adopt such procedures in Great Britain, is potentially the widest user.

Apart from "land evaluation", there exist a plethora of terms for what are essentially the same or similar techniques. "Land, terrain, resource, environment, environmental resource, and physiography" have all been used for the object of research whilst "evaluation, analysis, classification, assessment, appraisal and quantification" describe method. "Capability" and "potential" are also used to define aspects of "worth" and to define specific approaches more exactly.

Generally speaking, however, the most widely used terms are "land evaluation" or "terrain evaluation" and "land capability classification", the former two being wider in connotation than the latter and not defining the possibilities of land use as well.

The Concise Oxford Dictionary defines "land" as a "solid part of the earths' surface (opp. sea, water); ground; soil; expanse of country". This definition, however, is too narrow for that to which it is normally applied when considering land evaluation as a concept. Stewart (1968) defines land in a "comprehensive integrating sense" as a "wide variety of natural resource attributes in a profile from the atmosphere above the surface, down to some metres below the land surface"; the main natural resource attributes being climate, landform, soil, vegetation, fauna and water. Mabbutt (1968) suggests that land is "a complex of surface and near surface attributes significant to man".

To "evaluate" is defined by the Concise Oxford Dictionary as to "ascertain amount of; find numerical expression for" and in the New English Dictionary, "evaluation" is defined as the "act or result of expressing the numerical value of; judging concerning the worth of". Mitchell (1973) proposes that this double meaning, making the word "somewhat more inclusive", is preferable to terms such as "analysis, classification, quantification, assessment or appraisal". As an overall term this may be true but the author wishes to suggest that the process of "classification" inherent in so many "evaluation" exercises makes this former term invaluable in describing quantitative assessments; as in an "agricultural land capability classification". "Evaluation", in ascertaining the amount of "land", does not necessarily imply a numerical capability classification.



1.2 The Need for Land Evaluation

The evolution of land as we see it today has generally been a gradual process; any specific type of land being a reflection of the interaction between physical conditions, natural processes and living organisms (except man), superimposed upon which has been man's response to his environment in social and economic terms. This interaction has been called the "ecosphere" (Cole, 1958) which may be seen as being composed of numbers of ecosystems of increasing complexity; ecosystems being defined by Fosberg (1963), from the original concept of Tansley (1935), as a "functioning interacting system composed of one or more living organisms and their effective environment, both physical and biological..."

The activity of man in the evolution of land over the past centuries has been the dominant variable. Chadwick (1971) argues that "man is an animal amongst other animals, but being of a very special kind he competes in many ways with other animals and invariably wins." In common with other animals, man has had to adapt himself to changing natural phenomena, but, unlike most other animals, man is able to modify natural phenomena to a considerable extent. Thus, as a result of the study of natural systems, man contrives to produce modified systems or sub-systems within a context of natural ecosystems. This procedure is summarised in Figure 1.1.

In the study of land and its use, the concept of "optimization" is of importance; i.e. man is continually striving to achieve "optimum" results in his response to conditions and the actions that he takes; the optimum being defined as "the best result that can be obtained" (Chorley and Kennedy, 1971). Chadwick (1971) states that, "the optimisation activities of plants and animals are related to man's activities as they are part of the ecological system within which man finds himself...man, however, is capable of seeking optimisation by modification as well as self adjustment." In addition, "because of man's growing sophistication in exploiting his environment with the aid of technological change and with the problems of population pressures and the competition for land" the speed with which this process of optimization is capable of realisation is continually increasing.

Whether or not man is assuming an optimising role is open to question. However, Chadwick proposes that, "man appears as an optimising animal in that he optimises by consciously seeking to modify nature as well as adjusting himself to nature's phenomena".

It is likely that this clear attitude to an optimising role in man's response to his environment seldom, if ever, materialises. Chorley and Kennedy (1971) indicate that man, whether as an individual or as a group, does not achieve the "economic ideal of optimisation" but "tends to aim instead at satisficer behaviour". The decision-making process invariably involves elements of a political nature, rational and irrational, leading not necessarily to an optimum as Chadwick suggests.

In addition to the above, there are a large number of things that man can choose to optimise; for example, conservation, social needs, security etc. Invariably man requires an optimisation of several of these ideals (which are different from one society to another); a situation "mathematically impossible, even if one could define the "optimum" in each ideal satisfactorily" (Chorley and Kennedy, 1971).

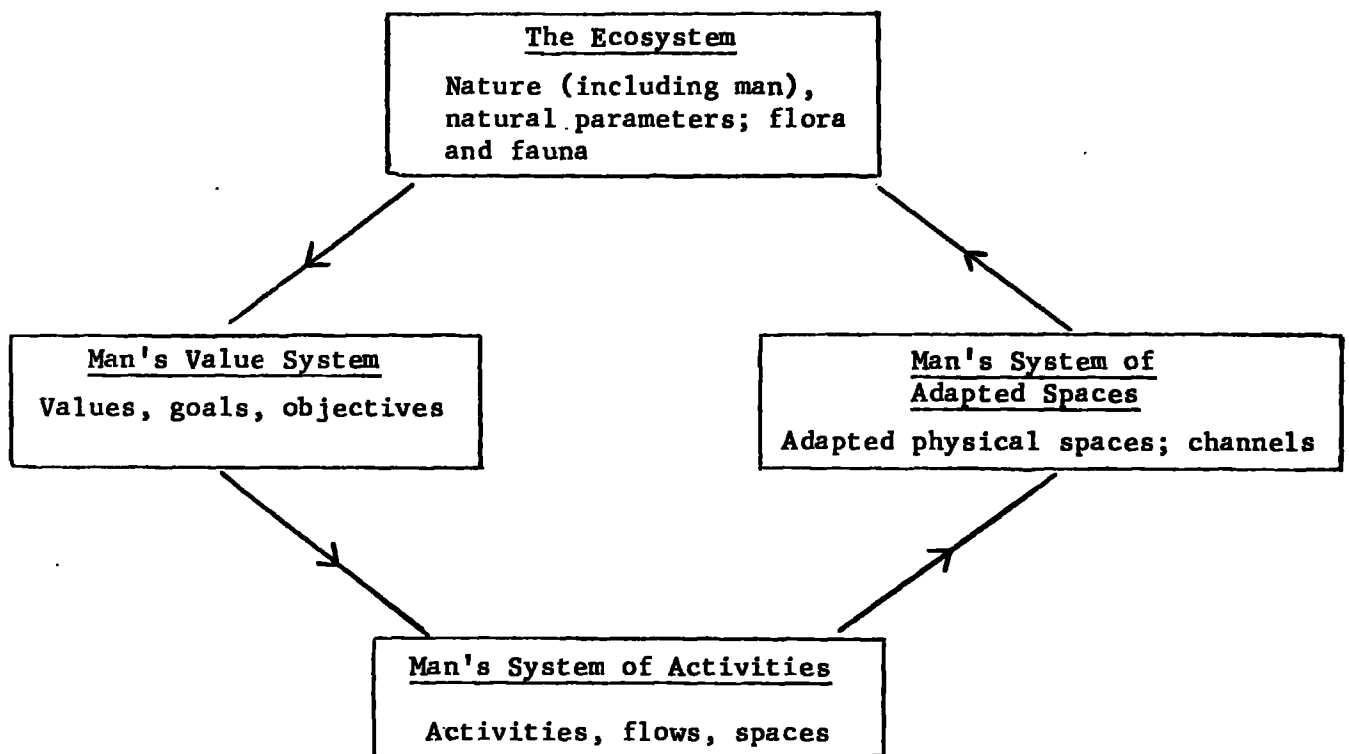


Figure 1.1 The Man-Nature System (adapted after Chadwick, 1971)

Likewise the law of diminishing returns is likely to operate, in that achievement of an optimum state usually requires a much larger input of energy than does the achievement of some "slightly sub-optimum state". Man will invariably follow the path of least resistance.

For the above reasons, most environmental decisions will involve the analysis of and choice between alternatives, but not necessarily the selection of optimal ones. Generally a compromise solution will be sought, embodying parts of differing alternative possibilities. Conflict between varying land uses and land use alternatives is, therefore, inevitable.

This conflict between different land uses occurs at two levels; namely, the allocation of land between competing activities and the management problems that arise when one land use impinges upon another (Keenleyside, 1970). The actual process of solution of such problems, if such a state is ever possible, involves precisely the situation of "alternatives decision" as outlined above.

It follows that any long term solution of these problems must work at both levels and that it is important, not only when identifying competitive land uses and potential problem areas, but also when undertaking land use projects and conservation measures, that an evaluation of the physical nature and potential, as well as of the socio-economic value, of land should be made.

1.3 Land Evaluation - Concepts and Approaches

Land evaluation procedures may be divided into two broad categories:

- (i) Physical
- (ii) Socio-economic-political

As the intricate web of social, economic and political land evaluation is beyond the scope of this study, only the first category of physical procedures will be discussed.

In the context of land evaluation, it is necessary to consider land itself as a basic resource capable of evaluation, and as such, it must be seen as a system; as being the result of a series of interactions among the "natural resource attributes" significant to man" (after Mabbutt, 1968 and Stewart, 1968) outlined on Page I .

The surface of the earth is an "infinitely variable complex". At any one location it is composed of these series of lithologic, soil, moisture, biotic and climatic attributes each of which is made up of an association of secondary elements (Davis, 1969) which will be termed "parameters". The unique character of a natural resource attribute is, therefore, the result of an interaction between secondary "parameters". These divisions of an attribute form the basis of quantitative study and, like attributes, show great variations among themselves (Stewart, 1968). Thus soil, as an important attribute, is divided into many parameters, such as soil depth, structure, texture and drainage, whilst rainfall and evapo-transpiration are parameters of climate and rate of flow is a parameter of water. The above definitions of attributes and parameters will be used throughout this thesis.

Davis (1969) suggests that "no two point locations are exactly alike when subjected to fine enough analysis; each is unique". Uniqueness, however, cannot form a basis for evaluation and for any purpose in hand it is necessary to produce "meaningful categories into which the uniqueness of point locations may be placed for classification". These categories, which may be spatial as well as numerical, are generalisations of the facts and form the basis of all land evaluation analyses.

At present there are four broad approaches to land evaluation:

- (i) Thematic or Single Feature Mapping Approach
- (ii) Genetic Approach
- (iii) Composite Units Approach
- (iv) Parametric Approach

1.3.1 Thematic or Single Feature Mapping Approach

This approach deals with only one attribute at a time; the type of soil or vegetation, for example, being delineated, with only incidental attention being paid to other features. The boundaries constructed are defined by overall criteria relevant to the purpose in hand but do not involve the setting of numerical values or class limits. They are, therefore, qualitative in nature.

It is possible to compare a number of thematic maps of different components for the same area and if, according to Davis (1969), strong boundary correlations are observed, it may indicate a genetic correlation. This is a debateable point, much depending upon the type of variable under analysis and the effect of man's cultural response in terms of land use. However, maps of soil type, vegetation and drainage will, of course, show correlations to some degree.

Following on from this, it is feasible to carry out "multiple" thematic mapping with more than one characteristic being mapped simultaneously by a single mapper. There is, however, a possibility of disregarding minor boundary discrepancies or generalising to "make a single boundary serve multiple purposes" (Davis, 1969).

A major feature, and the biggest drawback to the thematic approach, is that each map is an end in itself and at no stage in production is the feasibility of a particular land use forwarded in concrete terms. This, for example, is true for much of the work of the Soil Surveys of England and Wales and of Scotland.

1.3.2 Genetic Approach

This is the least used of the four approaches but points the way towards the composite approach described in Section 1.3.3 below.

The basic premise of both of these analyses, however, is that any country may be divided into a finite number of physical regions each with its own characteristic landscape; for example "the Cotswolds or Chilterns". These regions are distinct from their neighbours (Mitchell, 1973 after Beckett, 1962) and are a result of a common tectonic and climatic history

acting upon a specific geologic base. Under similar environmental conditions regions in different parts of the world will show a similar landscape; sufficiently close for it to be possible to make predictions about unknown areas from a knowledge of the known.

Mill (1891) proposes that the most useful type of classification is that which permits the widest range of generalisations to be made. Thus, groupings should be genetic in character, separating land into natural units based on origin, process and form and should only be defined from fundamental and permanent characteristics of the landscape. In addition, their internal homogeneity should consist of a uniformity of natural properties rather than an organisation of unlike functions (Mitchell, 1973). A genetic approach in producing a sub-division of the landscape on the basis of causal environmental factors produces large-scale units but does not provide in its analytical base for a means of sub-division into smaller units within this overall framework. The method is, therefore, not hierarchical.

Mabbutt (1968) suggests that these broad genetic divisions have three practical advantages. Firstly they provide a framework for smaller units derived by other methods of classification. Secondly they provide an overall view of genetic relations so aiding the reconnaissance of large areas, thus rationalising field sampling, and thirdly they have educational value in explaining world patterns and are especially valuable to historians and planners. Genetic zones, however, do have a number of severe disadvantages. Because of their large size (often thousands of square kilometres) they have great internal complexity and vague boundaries, which must call into question Mabbutt's view of their usefulness to planners. In addition, the lower size limits to practicable genetic sub-division cannot be reduced to give units small enough to be "homogeneous for most types of land use" (Mitchell, 1973).

1.3.3 Composite Units Approach

The vagueness of large-scale genetic groupings coupled with the considerable drawbacks of interpretation for practical purposes using a thematic assessment prompted, from about the early 1930's, much speculation and research into the recognition and analysis of smaller land units derived for practical land use purposes. Such recurring boundaries are termed "composite units" by Davis (1969); "composite" to denote a "collapsing" of different types of information into one spatial whole. A fundamental land unit is recognised as a base (it may itself be subdivided into much smaller units) which fits into larger ones and so on to form a hierarchical system. Thus, information is held about the characteristics of each unit which, because of the nature of the unit as a recognisable entity, allows interpretation in land use terms. In addition, information pertaining to other features, apart from those by which the land unit is recognised, may be stored; for example, archaeological, wildlife or other land use details and the work of Brown et al. (1977-1978) suggests that this could be extended to the socio-economic sphere.

As no specific land use need necessarily be considered before composite units are defined, the practical use of the approach is for spatial information inventory purposes, which today, with the advances in computer plotting, V.D.U. and file handling facilities, allows a remarkably flexible approach to data storage and manipulation. Information may, therefore, be extracted by an investigator into the feasibility or not of a particular land use in an area and subsequently interpreted in capability terms.

Such a concept is very attractive but the author's experience is that it proves difficult for the layman to grasp and that this has tended to restrict its use. It also requires a "birds eye view" and prior to the extensive use of aerial photography composite mapping was virtually impossible; even though it is possible to analyse the environment at a particular point location, it is very difficult to ascertain boundary changes between changing composites of factors.

The composite approach has also been called a "landscape" or "physiographic" approach by varying researchers (notably in the book "Land Evaluation", Stewart (Ed.) (1968), but it is considered by the author that the term "landscape" involves too many aesthetic connotations whilst "physiographic" lays too much emphasis on physiography. The larger composite units, land systems for example, are basically morphogenetic units and not physiographic entities as are the smaller units such as land facets. The term "composite" is, therefore, preferred as it stresses the importance of relationships and interactions which are essential elements of this approach to land evaluation.

1.3.4 Parametric Approach

The "parametric approach" to land evaluation may be seen as a pragmatic development from both the thematic and composite approaches and involves the study of the parameters of land resource attributes. The division and classification of land is undertaken on the basis of specific parameter values. Although a parametric map may be drawn for a single factor using classes at certain critical levels to give a simple isarithmic map, for example average annual rainfall over a specific period (Mitchell, 1973), such a "thematic-parametric" method will yield little direct information about the feasibility of a particular land use. Therefore, for most practical purposes, a parametric map should be relevant to a particular land use and the parameters chosen as relevant to that land use must be capable of quantitative measurement.

Parameters are not necessarily discernible from aerial photographs and if they are, not necessarily quantifiable from them. Field survey is thus an essential ingredient in this approach.

The results of parametric field observations will initially be a set of quantitative statements or values together with point sample or area data. With the aid of statistical and/or cartographical techniques and the delineation of land capability "thresholds" (the concept and problem of thresholds is discussed in Chapter 3) a capability map or inventory for a land use under consideration may be drawn. Thus, a parametric evaluation for land capability purposes will entail the following:

- i) an initial statement of the purpose of the study.
- ii) the selection of parameters that can be measured quantitatively.
- iii) field investigation, aerial photograph interpretation and parametric analysis.
- iv) the selection of class intervals and threshold values specific to the land use in question.
- v) site or area classification and mapping.

Parametric evaluations have certain advantages over those approaches already discussed. Of most significance is the fact that, as the approach is quantitatively based, it is less dependent upon subjective interpretation, allows statistical methods to be employed and is tailored to the use of new remote sensing devices (in addition to traditional aerial photographs) and computer methods of data storage and analysis. Finally it tends to be more flexible in that, as the spatial boundaries drawn are parametrically based, they can be easily modified in the light of increasing knowledge about the selected parameters. For example, modern technology might modify slope thresholds for agricultural implement performance, so altering class boundaries.

However, as with all the approaches, there are disadvantages. The most detrimental is that it is extremely difficult to decide on which are the correct parameters and what are the correct threshold class limits to use for a particular land use. In the light of the paucity of present research into class limits for certain land uses this is a particular problem and will become manifest in Chapters 3 and 6 of this thesis. Likewise, whereas the composite approach allows a predictive element to be incorporated, physiographic analogy is severely limited in the parametric approach, requiring much more of a reliance on field survey and measurement. This can lead to costly delays if the research involves an area rather than point sample survey base.

However, despite these differences between the composite and parametric approaches, they should be seen as complementary to each other in their practical application to land use problems. Much depends on the type of project being undertaken, the individual research circumstances pertaining at the time and the scale of evaluation proposed. These factors will be discussed in the next section.

1.4 Scale in Land Evaluation

To what scale of area and detail a specific approach is best suited is fundamental to any practical use of land evaluation.

Mitchell (1973) suggests that the two approaches of composite (landscape) and parametric classification differ considerably in their practical value as the number of land uses under consideration increases. He argues that the first method is favoured when there are many land uses proposed or where resources are limited or access to the site is difficult. If information is required over a whole range of needs in agriculture, forestry, mining etc., the number of significant criteria becomes too large for it to be practicable to measure them all and this leads to a reliance on a single composite evaluation on inventory lines rather than on separate parametric classifications for each land use.

The parametric approach, on the other hand, with its emphasis on precise measurement, is according to Mitchell, most useful when only a few land uses are being considered and computing facilities are available. Because of the dependence on detailed measurements and the difficulty of extrapolating these into unknown areas by means of physiographic analogy (possible in the composite "facet" approach) it "tends to be better suited to the detailed analysis of small areas than to broad reconnaissance".

Very broadly speaking this is true, but it is suggested that the distinction is too vigorous and that a more flexible approach in terms of scale should be used.

Both composite and parametric approaches can be time consuming, especially if they are to be related to specific land uses which require a more detailed assessment of values than just a mere analysis of terrain

type. Depending upon the amount of detail required, parametric evaluations can nevertheless also be undertaken very rapidly. This is exemplified by the Ministry of Agriculture's Land Capability maps covering the Country. Although the speed with which these maps were produced was probably a major factor in their poor classificatory limits and inaccuracies, they nevertheless proved that the parametric approach is capable of rapid application. Parametric point sampling for soil survey and agricultural capability classification has also been undertaken with considerable success over a wide area of Pembrokeshire (Rudeforth and Bradley, 1972). Such classifications using purely point sample methods with no spatial boundary definitions are very rapidly undertaken and capable of use over very large areas.

Composite mapping techniques can also be used for detailed information inventory purposes for very small areas as well as being capable of reconnaissance use over very large areas (Brown et al., 1977; 1978). Computer methods are also desirable for holding composite evaluation information, especially if remote access and graph plotter facilities are available, but are by no means essential for parametric classifications.

It is therefore proposed that a flexible approach to scale should be utilised within an overall broad context of increasing detail from composite to parametric evaluation.

The approach selected, as well as considering scale, will also have to take into account such factors as the extent of the present development of the area concerned, its infrastructure and political development, the availability of financial and manpower resources and the use to which the study is to be put. This is illustrated by variations in procedures that have been adopted in the less developed or "third world" countries and those adopted in Great Britain.

1.5 Land Evaluation Procedures Overseas

Stobbs (1971), in describing survey procedures for development purposes overseas, considers that projects can be divided into five principal types of survey. These range from "reconnaissance surveys" involving national or regional inventories of areas in excess of 5,180 sq.km to "management problem studies" involving detailed studies of small areas. Land systems, or higher categories of physical subdivision, are used for surveys covering areas larger than 1,295 sq.km. and encompass "intensive" and "extensive" levels of survey as well as the reconnaissance level. At the intensive level, where the recognition and definition of specific projects is undertaken, land facets may also be utilised. From this level down to the "development study" and management problem study stages at areas below 130 sq.km a parametric approach is suggested.

The above implies a continuum of procedures from composite to parametric according to the area and project detail required. Yet, whilst such a systematic analysis is used where extensive tracts of undeveloped land are being studied, each type of survey may also be seen as an end in itself.

1.6 Land Evaluation Procedures and the Planning Process in Great Britain

In a developed country such as Great Britain, the same continuum of approaches to land evaluation proposed by Stobbs is not necessary, as nowhere is it possible to start with a comparatively "virgin" territory of large size requiring an inventory as it is in the undeveloped world. In addition, social, economic and political forces are far more influential in the decision making process in the developed nations.

Land evaluation procedure, as a part of local and national governmental planning in Great Britain has, therefore, with one or two notable exceptions, either been neglected as a form of analysis, or else used unwittingly. Thus, it has largely been up to the universities and research organisations to "develop the art".

It is not the purpose of this section to discuss the work of the latter bodies (to be discussed in Chapter 2) but, as this thesis is oriented towards land use planning, to place the various land evaluation approaches in the context of the planning process as it refers to local and central government departments, in particular those involved at the local level.

1.6.1 The Planning Process

In order to consider land evaluation in a planning context it is necessary to outline the basic elements of the plan-making process.

Basic to this process are the various ideals of society as embodied in the ideals of elected representatives. These may vary from one society or class to another and are invariably political in nature. An ideal, for example, may be the attainment or not of a socialist or capitalist state. It is the overall concept of ideals that forms the basis for the development of aims, goals and objectives of the planning process, the nature of which will affect the evaluation of land for aim and goal achievement and which in turn will be affected by the results of such a land evaluation.

Aims and goals are statements of directions in which planning or action is aimed, the former being of a broader nature than the latter. Lichfield argues (1968) when referring to goals (he uses the term "goals" to cover both aims and goals as used here), that being derived from human values they are ethical and therefore empirically untestable. "They are fundamental in that they stem from the apparently insatiable wishes of the human species for greater self-fulfilment". He goes on to suggest that they are unattainable "since progress towards them over time implies their reformulation in yet higher ideals".

Objectives, however, are specific steps towards the attainment of a goal and overall aim, and thus, although ends in themselves, are also the means of achieving a more distant goal. They are attainable and factual as opposed to ethical in "that the degree of attainment can be specified, measured and tested" (Lichfield, 1968). For example, an overall aim might be the conservation of natural resources. From this a particular goal could be to conserve agricultural land and so foster the agricultural economy. An objective would, therefore, be to recognise and hence, conserve such areas of highly graded agricultural land.

Before aims, goals and objectives can be formulated, however, problems must be identified. For example, taking the agricultural case again, one underlying problem leading to the formulation of the specific aims, goals and objectives so defined, might be the strong pressure for development which might lead to the undesirable spread of urban areas into the countryside to the detriment of agricultural and rural interests.

Problems are frequently defined by the general public at large (particularly in the form of pressure groups) as well as by elected representatives and permanent officials. Aims and goals, on the other hand, are normally set by elected representatives and objectives by permanent planning officers.

The above has to be put into practical terms in some form or other and land evaluation procedures can form a part of the means of attainment, the choice of which depends upon the context of study under consideration. Continuing with the agricultural example; having defined the objective as preserving grades 1 and 2 agricultural land for agriculture, by the use of land evaluation procedures and, in this case, a parametric approach, the grade may be evaluated (socio-economic evaluations might be used as well as physical evaluations). After this evaluation, with the resultant feasibility of the objectives being carried out or not being determined, strategies are generated and objectives may be incorporated into policy and put into action "on the ground". A generalised flow chart showing the place of land evaluation in the planning process is shown in Figure 1.2.

After the feasibility stage it might be found that the objective is not capable of implementation and, therefore, goals and/or objectives might have to be changed and new land evaluation procedures devised.

Likewise, after implementation, society might change its ideals; politicians might change their aims and goals and officials might alter objectives; the plan-making process is unending.

1.6.2 Land Evaluation Used as a Planning Technique

Land evaluation has been utilised by town and country planners in the past, either unwittingly, or comparatively recently, deliberately, in an attempt to include quantitative assessments of goals and objectives in physical evaluations (potential surface analyses).

The idea of "constraints" on development has been used by planners for years as has the technique of "sieving out" unsuitable areas, such as land liable to flood or areas of high landscape value. These simplified parametric approaches, together with the assistance of overall thematic maps, have been much used and even today form the basis of many development control decisions.

With the advent of sub-regional studies in the 1960's, together with the realisation that no county can be viewed in isolation, a major innovation in planning technique - the concept of the "potential surface" was introduced in the Nottinghamshire/Derby sub-regional study (1969). The concept is used to evaluate different strategies from an initial set of objectives, a potential surface being the means of evaluating in map form those areas having the best potential for development on the

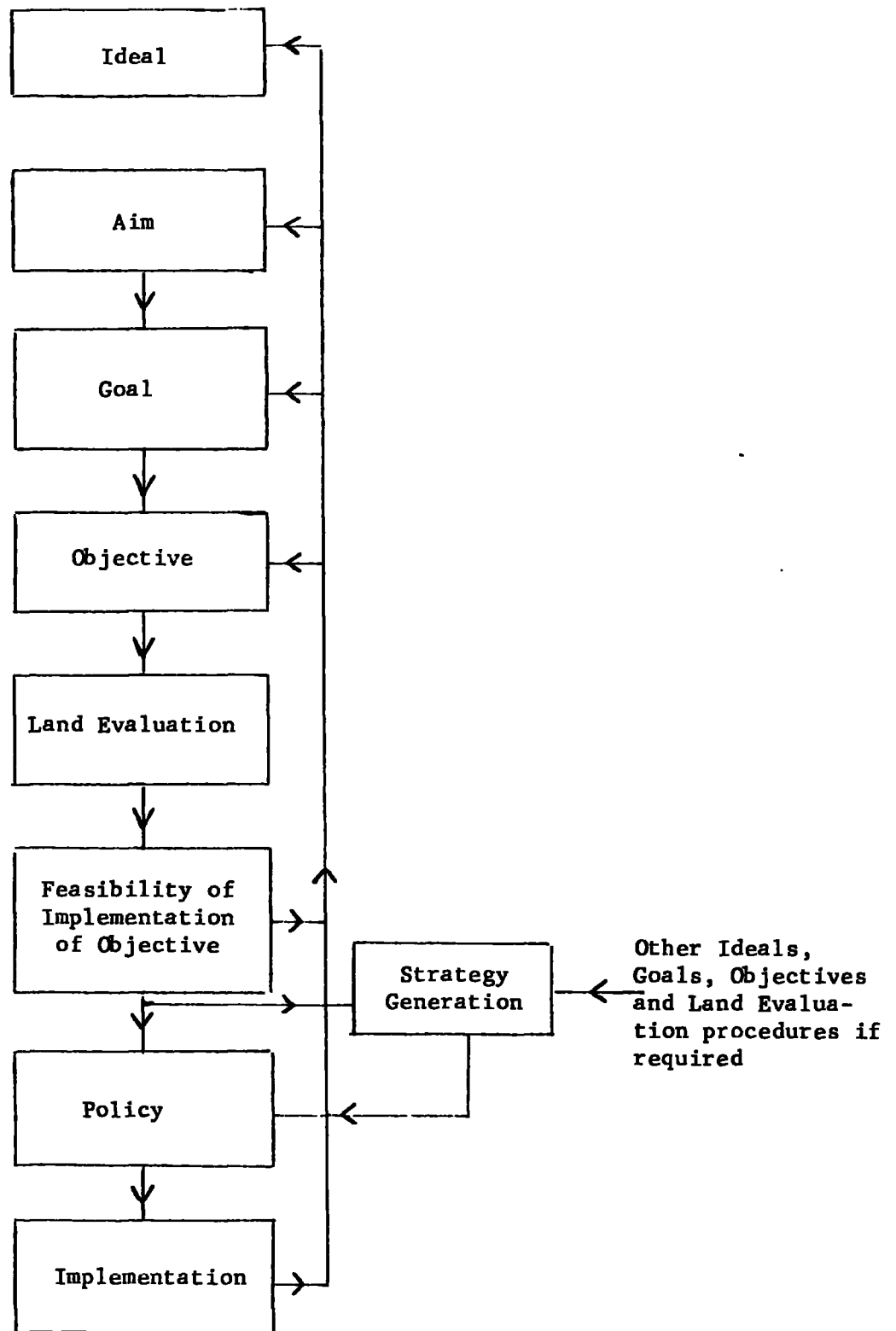


Figure 1.2 Flow Chart of the Planning Process Including Land Evaluation Procedures

basis of certain criteria. These criteria might be physical or socio-economic and related to the set of objectives that the plan must meet. Williams (1972) proposes that potential may be solely "intrinsic", for example, the physical suitability of land for the development of housing or industry, or "solely an expression of relative accessibility of one area to other areas containing a selected attribute such as jobs, shops or workers". Before the surfaces are generated, goals and objectives may be quantitatively generated by questionnaire.

Thus, the so-called "potential surface technique" is an approach to the plan-making process involving parametric land evaluation procedures to produce a series of capability maps for specific purposes and hence to produce various strategies. Goals and objectives, however, form the spinal column of the study.

1.6.3 Choice of Approach

The choice of a particular approach to land evaluation is dictated by the type of plan or study being undertaken, which itself is governed by the resources made available for such a study and time allowed.

The 1971 Town and Country Planning Act requires County Authorities to formulate Structure Plans for their areas, to supersede the Development Plans of the 1947 Act. Despite the widespread concern over the nature of the requirements for structure planning, land evaluation procedures have a place in the overall strategic planning process. Both composite and parametric approaches could be used to effect (the former at system and facet level) and an overall assessment made.

At a more detailed level, the Local Plan, which may cover any area, must produce specific "on the ground" proposals. Again both composite and parametric classifications could be undertaken but the former would be unlikely to be undertaken at land system level; facets and sub-facets forming the spatial base.

Apart from the statutory procedures outlined above, many ad-hoc plans are undertaken, particularly at a resource management level for comparatively small areas; for example, a management plan for a country park measured in hectares rather than square kilometres. Even at this scale a composite approach, particularly in forming a spatial data-bank base, may have advantages over a parametric study.

At all these levels the flexible adoption of approaches to suit the specific scale and conditions pertaining is necessary, but as a basis the following classification of approaches is proposed for local government planning in Great Britain (Table 1.1).

Table 1.1 A Scheme for Local Government Land Evaluation Procedure in Great Britain.

Type of Survey	Type of Study or Plan	Area	Land Evaluation Approach
Large Scale Surveys	Regional or Structure Plan	Square Kilometres	Composite (land systems) Parametric
Medium Scale Surveys	Structure Plan; General Study	Square Kilometres	Composite (land systems & facets) Parametric
Small Scale Surveys	1. Local Plan 2. Resource Management & other general studies	Square Kilometres Hectares	Composite (land facets & sub-facets) Parametric

Both the type of plan and the level of detail required will dictate the evaluation approach to be adopted and within an overall context of composite to parametric; of generalisation to detail, both approaches can be used to advantage at any scale of survey.

CHAPTER 2 - PREVIOUS WORK

Just as the techniques of land evaluation can show an overall continuum of approaches to survey, so past research has followed an "evolutionary" path from qualitative to quantitative analysis. This chapter traces this development but, naturally, does not extensively outline the work undertaken on thematic mapping as its applications are too numerous to consider in detail.

2.1. Early Regionalisation and Genetic Groupings

The embryonic formulation of the concept of land evaluation, lying in regional classification, goes back several hundred years. As Mitchell (1973) suggests in his book on "Terrain Evaluation" (from which this section is predominantly taken), within geography, the regional concept has had a long and complex development, generally combining physical and human factors into "general schemes". However, in the eighteenth century the customary political units were found to be inadequate and more "natural groupings" were sought. This led to the "pays" of France which were distinguished by a characteristic "genres de vie". In 1905 in England, Herbertson proposed his scheme of "natural regions" based primarily on climate and secondarily on configuration and vegetation and this, together with the Davisian interpretation of landforms as a function of structure, process and stage caused early morphological subdivisions to be based on genetic lines. This was exemplified by Fenneman (1916) in the United States with his "physiographic provinces", showing "unity or similarity of physiographic history" and in 1886 and 1900 Dokuchaiev suggested natural soil zones based on world climatic-vegetational divisions.

Workers in other sciences apart from geography, however, sought schemes based on simpler "single feature" regions away from an assumed cause; notable among which were de Candolle (1856) and Schimper (1903) for plants, Wallace (1876) for animals and Köppen (1931) for climate.

These three trends; the pays concept, the natural region and the single feature region, were further developed between the wars. In 1933 Thornthwaite refined Köppen's single feature climatic classification, and Unstead (1933) and Whittlesey (1936) attempted to regionalise cultural and agricultural factors respectively. Again in the thirties, a Committee of the Geographical Association (Unstead et al, 1937) distinguished "specific" and "generic" regions, the former being "unique" and the latter "recurrent", and in 1930 Dickinson and in 1933 Christaller proposed the idea of the "nodal region" based upon "interconnections between a central place and the surrounding countryside." Although designed primarily for the urban geographer, Mitchell states that "the latter concept has application in the physical field; for example, for regions in which there is a diffusion of a specific factor from a central source".

Large scale regional groupings have proved of little practical value outside the academic sphere, being deficient in the delineation of units and too large to produce meaningful subdivisions for land use projects. For example, Heath (1956) outlines how Bowman (1916) in his studies of Andean settlement found that genetically derived physiographic sub-divisions could only be used as a general background; for the study of practical land use problems site details were required.

2.2. The Composite Unit Idea

As Davis (1969) points out, in a detailed description of early composite unit groupings in the United States, from which the following analysis is adapted, in the early 1920's, in the days before the general availability of aerial photographs, the Michigan Land Economic Survey produced what was perhaps the first systematic attempt at regional land evaluation using a thematic approach to mapping. There was no intention at first of mapping composite units and Davis suggests that "probably the designers of the survey practices had never heard of composite units". It was only when the individual thematic maps were compared that such units appeared and were considered so obvious in the areas of glacial deposition that were studied that little attention was paid to them." Consequently they were used merely as "frameworks on which to arrange the specific data of the survey." It was the correlation of three principal maps of the economic inventory, those of land ownership, intent in ownership and assessed valuation, which together expressed the local opinion on the value of the land, that led to the first recognition of "natural districts."

In 1928 a paper by De Vries proposed the idea of expressing the economic assessments that had been made, in a spatial framework that would show their relations to the physical factors studied. As De Vries states "In order to make this correlation clearer the detailed farm-forest maps were combined into a more simple map of the natural districts which represent definite associations in nature of soil, drainage, topography and natural plant cover." This paper by De Vries appears to be the first definite statement of the "natural division concept," although it is feasible that the concept was established before De Vries' publication as part of the printed County maps, or possibly in an early paper by De Vries himself, published also in 1928.

The Michigan Survey became a casualty of the depression of the 1930's, but it was during this time that aerial photography, made for agricultural purposes, became generally available, although aerial photographs had been used by McMurray in the 1928-29 Isle Royale Survey.

During the 1930's the concept of the division of land into "land types" developed from a philosophical idea into practical use in land classification. In 1931, Schoenmann presented a paper to the Michigan Academy of Science whereby the natural district was used as a basis for land use planning. In 1933 Veatch published a paper on the land type, developing his ideas on the subject from an early 1930 paper. In it he attempted to express the agricultural value of Michigan through the delineation of "Major Land Types." Each of these he states "is a natural division based upon the intrinsic nature of the soil; the nature of the soil association; a uniformity or complexity of distinct types; the topography; the natural drainage and the native vegetation." He then assigned an agricultural value to each of the land types in three classes.

Veatch's last paper in which he used the land type pattern as a "framework for assembling land data" was in 1934, in a bulletin for fruit growers in south west Michigan. By the middle of the decade, however, the land type had been established as a tool in land research in the state, and similar ideas were developing elsewhere, often prompted by soil survey work. During the depression and "New Deal" years federal land projects, notably the Tennessee Valley Project and state agencies under the Sub-Marginal Land Programme attracted the attention of land researchers, but in the second half of the decade there was a general return to state supported research and the use of the land type, as indicated in papers by Veatch (1937) and Schneider (1939 and 1942).

During this period, the work undertaken by the Department of Geography of the University of Michigan is of note. Davis suggests that the ease with which "land typing" could be undertaken by students made it a popular part of the curriculum particularly under McMurray and the papers produced by students such as Stirling (1938), Dick and Ware (1939), Foster (1941) and Pearson (1955) are notable. The latter paper on recreational land use, uses the land type as a basis and is the last reference to the use of the land type in Michigan.

The work of the earlier survey team in Michigan and that of the University geographers shows a certain practical revolutionary approach to evaluation, superimposed upon which have been Veatch's theoretical writings on the subject. The first survey uses the land type merely as a "summary device", discovering the concept by boundary correlations of thematic maps. The University geographers, however, recognise the land type as a composite unit in the field and map it as such from direct observation.

It is impossible to state to what extent the work of Veatch on the land type diffused outside Michigan, since during the 1930's there was much discussion and speculation on composite units throughout the world. The transactions of the Third International Congress of Soil Science in 1935 contain a number of articles on the subject. Kellogg, for example, refers to a land classification system using composite units devised by himself and Ableiter. These "natural land types" (so devised) are "distinct combinations of climate, soil, relief, stoniness and vegetation." (natural) and are identical with the proposals forwarded in Veatch's 1930 paper. The 1937 Soil Survey manual of the U.S.D.A., indicates the importance of "natural land types" as the first step in soil mapping and Kellogg continued to suggest that the natural land types could be utilised to form "social land units", a concept similar to that outlined by De Vries and Schneider some years earlier.

There is little doubt that the work undertaken in Michigan in the 1920's and 1930's was pioneering, but because much of the literature was published in the Michigan Academy of Science, Arts and Letters transactions it probably did not greatly influence land research elsewhere in the U.S.A. or abroad. To substantiate this proposal Davis cites a letter received from Christian in 1966; the latter indicating that when the Northern Australia Land Survey was formulated in 1947, Veatch's work and the "land type" were unknown.

Similar work, therefore, was being undertaken elsewhere, both within and outside the United States and wherever land classification was required it seems a system of "breaking down" the land into composite units was devised. Thus work in Michigan was not an antecedent of similar concepts devised elsewhere.

The techniques developed for composite recognition outside Michigan were predominantly based on geomorphological differences, in that they were the most readily delineated features on aerial photographs, which were becoming available at the time. In addition the interest in composite units was fuelled by the "regional" concepts of geography; the idea being that the earth's surface was composed of a mosaic of small regional units of homogeneous nature.

In the United States two studies are of note. The first is the Montford study of Finch in southern Wisconsin in 1933, which reflects a continuation of the Land Economic Survey methodology of Michigan using the simultaneous thematic mapping of several components, with composite units not being recognised or mapped as such in the field. The second study is that of the Tennessee Valley by Hudson et al, begun in 1934. Each unit is recognised from some key component on aerial photographs and the characteristics seen in them are presumed to recur throughout the unit. This survey has certain essential qualities, particularly in the use of aerial photographs, that point the way to the Australian surveys of later years to be described below.

During the 1930's, research on composite units was being undertaken, seemingly independently, in Britain. In 1931 Bourne at Oxford, forwarded his ideas that major regions are composed of "sites", which are defined as areas which, for all practical purposes, provided throughout their extent "similar conditions as to climate, physiography, geology, soil and edaphic factors in general". In practice the concept is very similar to that of Veatch's land type or Finch's work without a land use factor. At the time, Bourne's work was not widely noted, but was to have great influence on the MEXE/Oxford studies of some thirty years later.

In 1933 Unstead produced an analysis, using the term "stow", to identify by unity of relief, characteristic structure, hydrology, plant cover and land use, primary units small enough for detailed scientific study, yet providing a distinctive geographical entity.

After World War II the most significant use of the composite unit approach was the development in 1946 of the "land system" method of analysis by Christian and Stewart of the Division of Land Research of the Commonwealth Scientific and Research Organisation (CSIRO); this being first applied in the Northern Australia Regional Survey. The origins of the land system are similar to those pertaining in Michigan in the 1930's in that a technique was required for the task in hand; viz. "to describe, classify, map and assess the land use, development possibilities and technical problems" of the vast area of the little known northern third of Australia. The traditional methods of land classification could not be used at this scale and although it was necessary to define the major soil and vegetation units and determine their relationships, these were not mapped because of time limitations and the large area to be covered. A broad composite unit was therefore required; one composed of "a number of land type units" (Christian and Stewart, 1952). This composite unit is the "land system" which, according to Christian, originated spontaneously from the necessity of the survey and is based upon the assumption that "each part of the land surface is an end product of an evolution governed by parent geological material, geomorphological process, past and present climates and time" (Christian, 1952).

Thus, the land system is defined as a grouping of "land units" that are "geographically and genetically related" and is "a composite of related units; an area, or a group of areas throughout which there is a recurring pattern of topography, soils and vegetation. A change in the pattern determines the boundary" (Christian, 1952). The land system boundaries were initially determined from aerial mosaics, and then checked by field traverses.

The Australian system is by nature hierarchical, in that the land system is divided into "land units" and "sites". The land unit, as defined by Christian, is not necessarily a homogeneous unit such as the "site" of Bourne, but rather is identified by the similarity of such of its characteristics as are of "consequence to land use". He considers that "parts of the land surface having similar genesis can be described similarly in terms of major inherent features of consequence to land use, namely, topography, soils, vegetation, and climate, and are regarded as being members of the same land unit". The site is recognised as a component of the land unit with a homogeneous entity. In fact, because of the vast areas involved, only the land system was utilised in the field.

During the twenty five years or so since its inception and despite criticisms of the scale, the limited point sample methods used and the geomorphological-genetic base units, the concept of land systems has been much utilised and extended.

The land unit has been particularly criticised by ecologists on the premise that the basic unit should be "one of similar intrinsic qualities and that genetic origin is subject to individual interpretation" (Davies, 1969). To meet this criticism, in the studies of soils and vegetation by Gibbons and Downes (1964) in S.W. Victoria, a basic homogeneous unit is added, and this small soil/vegetation unit, the "land component" sub-divides the former land unit of the earlier studies. At the other end of the scale the term "land zone" is included and defined as an association of land systems with "significant differences in climate, parent materials or vegetation".

It is remarkable that the Australian work, at least in the early years, appears to have been undertaken in isolation from both Veatch's and Bourne's work.

The research of the Military Engineering Experimental Establishment (MEXE)/Oxford University team in England in the 1960's under Beckett and Webster, however, was not undertaken in such isolation. This work was initially carried out for military purposes, the objective being to develop a method whereby terrain types would be recognised from aerial photographs, analysed and the resultant data stored in machine readable form to be retrieved by non-specialist personnel.

The basic premise is that a thematic map is only of limited use when attempting to overcome practical land use problems; landform and soils, for example, are only two of a whole series of attributes which may merit attention. The method developed envisages a series of compartments, one for each land type, each holding all the information required for that particular type irrespective of which part of the world it comes from (MEXE, 1964). Underlying the definition of these land types is the concept of prediction whereby, by obtaining a knowledge of one particular unit, prediction can be made "not only from one occurrence of the unit to another, but also about parts of the unit from one's understanding of the unit as a whole" (Brink, Mabbutt, Webster, Beckett, 1966). Thus, information gleaned in one area may be used to guide particular operations in another area with no need to carry out comprehensive surveys in subsequently delineated areas. The system of compartments, however, depends upon a prior land classification that groups together all land of analogous attributes, wherever it occurs, into specific types or units. The usefulness of statements on sites about which there is little known information, apart from their location and broad environmental details, will depend upon the accuracy of recognition of land types at the new unknown sites and just how much information is available about these sites.

A specific land type is defined by certain "definitive" features which must be common to all occurrences of a given unit; for example, slope, water regime and depth to rock; with the principal spatial unit in this classification system being termed the "land facet". This is an area which is fairly homogeneous and which is distinct from surrounding terrain. It is the "largest portion of terrain that can be conveniently treated as one block for the purpose of moderately extensive land use; for example, its physical properties and relief, etc., should be sufficiently uniform for a prudent arable farmer to manage the whole extent of one facet in the same way" or a road engineer to adopt common specifications (MEXE, 1964).

Facets are sub-divided into units called "sub-facets" and for practicable purposes these are the simplest part of the landscape, being "uniform" in lithology, form, soil and vegetation. They are equivalent to Bourne's "site" (1931) and Linton's "site" (1951) and are also called "land elements" (MEXE, 1964).

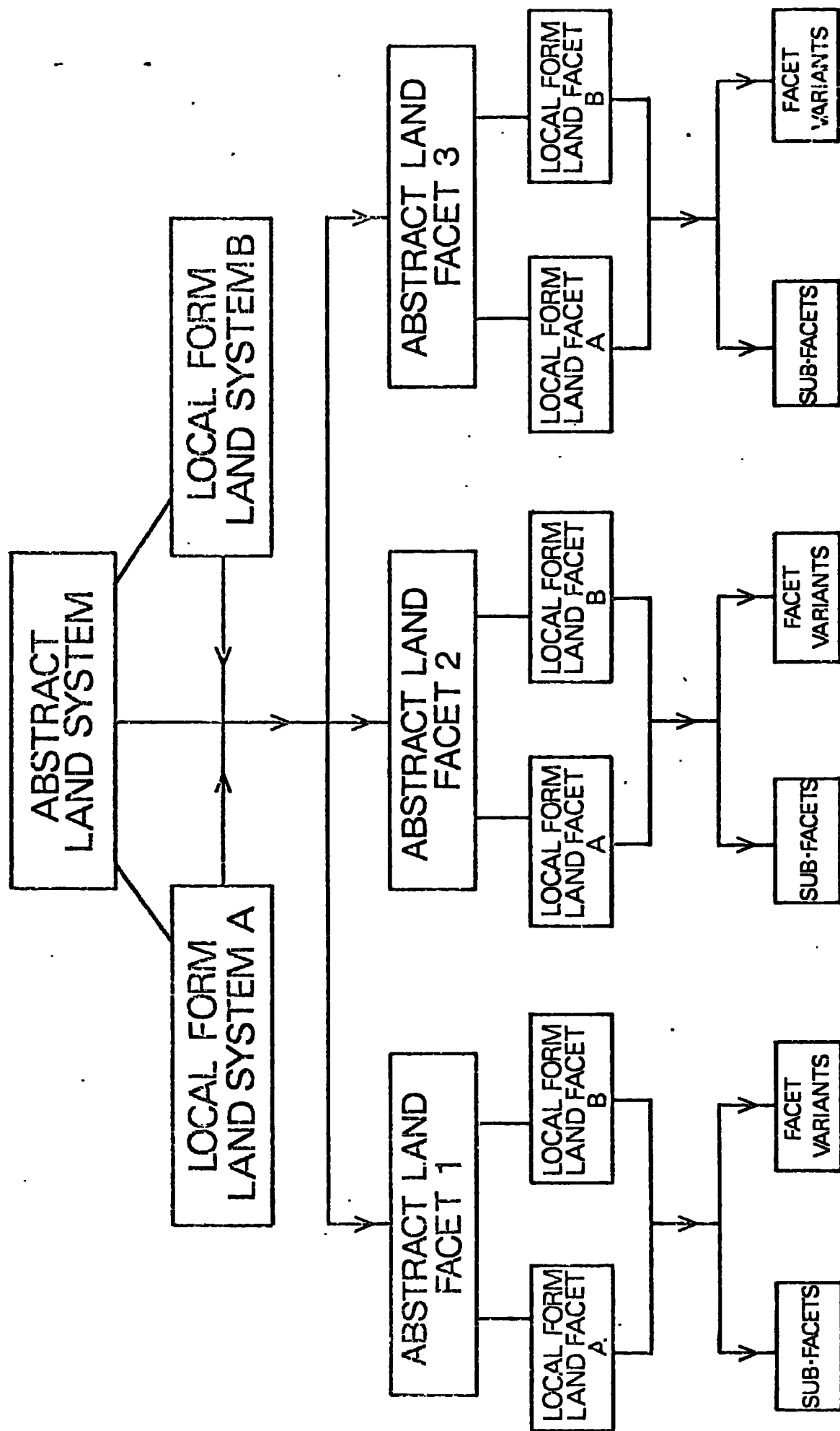
Within a facet differences may occur which are unpredictable, having no surface expression; for example, different types of superficial deposit. Such variations are called "facet variants". Variations may also occur between land systems and facets in different areas, but not enough to justify a separate category; for example, differences in the type of sandstone substrata. These units are called "local forms" of the overall "abstract" land system or facet.

At the other end of the scheme under consideration is the "land system" which is a recurrent pattern of genetically linked land facets and is defined on its constituent facets and their inter-relationships. Like facets, "local forms" of "abstract land systems" occur.

Land systems are themselves grouped, in order of increasing size into "land regions" "land provinces", "land divisions" and "land zones" with the possibility of an overall world classificatory system envisaged (Brink, Mabbutt, Beckett, Webster, 1966). Figure 2.1 shows the system in flow chart form (as interpreted by the author) from land systems downwards.

Apart from the major research projects, outlined above, work has been undertaken elsewhere using composite approaches, in particular influenced by the early Australian studies. Condon (1961 and 1968) utilises a land system procedure in an estimation of the grazing capacity of arid lands in New South Wales. Aitchison and Grant (1967 and 1968), developing the P.U.C.E. (Pattern, Unit, Component, Evaluation) method of terrain description and evaluation for engineering purposes, use "a readily definable terrain unit" as the key entity in the system; defined as "an area occupied by a single physiographic feature formed of a characteristic association of earthen materials with a characteristic vegetative cover". Dowling (1968) uses the land system and facet to evaluate large areas of northern Nigeria for road construction purposes, whilst Robertson, Jewitt, Forbes and Law (1968) describe how the land system and facet can be used for a first stage regional survey in the assessment of land quality for the production of pasture, field or tree crops.

FIG.2.1 LAND SYSTEMS AND FACETS



In the United States since the last war, composite units appear to have only been used for practical purposes in recent years. During the late 1950's and early 1960's landscape architects began to respond to the increasing problems associated with urban decentralisation. As a result of their efforts a planning procedure was adopted which is described by Fabos and Caswell (1977) as the "landscape approach". This, in fact, is a compilation and evaluation of characteristics such as landform, soils and vegetation on thematic lines. In 1963, however, McHarg and his associates in their "Plan for the Valleys" (reported in 1969) used a composite assessment of an area near Baltimore which divided the area into five smaller types of "landscape units"; valley floors, wooded valley walls, unwooded valley walls, wooded plateaux and unwooded plateaux". By evaluating these composite units "development and protection recommendations were prepared". For example, in connection with the unwooded plateaux it was proposed that: "forest and woodland sites on the plateaux should not be developed at densities in excess of one house per acre".

Elsewhere since the war the development of composite units has continued. Mitchell (1973) outlines in some detail work that has been undertaken in Canada, Russia, Germany and Japan and this is discussed in the following paragraphs. Hills (1942, 1949, 1950) and Hills and Portelance (1960) mapped "land types" in Ontario as a basis for planning future land developments, the concept for which is defined by Lacate (1961). Criteria for defining land types involve soils, bedrock and vegetative patterns and types and, where applicable, the species within the forest ecosystem. In 1959 Hare described a reconnaissance survey of Labrador - Ungava, where sample areas were studied on aerial photographs to obtain a key of surface types and then large areas were mapped using the key. An attempt was made, to sub-divide the types rather than to "merely to recognise and map them as complexes."

In the Soviet Union work on composite evaluations proceeded on lines similar to the Australian approach and was derived from the pioneer work of Dokuchaiev, Beng, Ramensky and others, as described by Solntsev (1962) and Vinogradov et al. (1962). Criteria used for land type recognition are relief, soil, bedrock, microclimate, together with such habitat conditions as moisture, salinity and vegetation.

Rather like the early American approaches, though probably not affected by them, is the fact that economic significance is also noted. The basic unit is the "facies" which is the "smallest elementary physical geographic sub-division of the landscape, having constant site and habitat conditions and a single "biocoenosis" and which is, therefore, homogeneous genetically, physiognomically and morphologically". In 1962, however, Prokaiev proposed that the definition of "facies" was too rigid because of the variety of land uses concerned and their internal variability. Following on from the facies, in order of increasing size, are "zvens, sub-urochishche and mestnost". The urochishcha are clearly recognisable on aerial photographs and are associations of facies with homogeneous substrata, common drainage, transfer of solid material and chemical elements.

In Germany the earlier concepts of "fliese, physiotop and landschaftszelle" have been more recently systematised into a hierarchical system by the Institute Für Landeskunde at Bad Godesberg (Schneider, 1966). The smallest basic unit is the "ecotope complex" followed by the "fliesengefuge" or "microchore" which is the principal natural geographic unit and this in turn is followed by higher levels.

In Japan, units on similar lines have been developed by using morphological development and genetic features, in order of increasing size, landform type, series, association, section and province.

Apart from the MEXE research, the practical use of composite units expressly for planning purposes has been slow to develop in Great Britain, although it is much used by the Overseas Development Administration of the Ministry of Overseas Development (King, 1970 and Stobbs 1970). The only work being undertaken at present appears to be that of a small team at the Planning Department of Clwyd County Council in North Wales (Brown, Ratcliffe and Hawkes, 1977, 1978). They are using a facet system based on the MEXE approach as a basis for resource inventory assessment for County Park planning purposes in some 861 hectares of the Clwydian Hills. Greater attention is being focussed on sub-facets, as it has been found that at a detailed level, when planning such factors as path networks, the finer detail gives a more realistic analysis. A comprehensive computer-based information retrieval and storage system is also being developed, the facet and sub-facet boundaries being digitised to enable graph-plotter output. The approach is very much oriented towards a spatial information system with a potential to include data on factors not necessarily pertaining to the selection of individual land types; for example, wildlife, visitor numbers and archaeological details.

Whilst the above developments of land unit recognition directly related to land use planning were taking place, certain researchers were suggesting theoretical schemes or models of groups of land units which occur regularly in association over large and small areas. In 1919 Passarge proposed his hierarchical classification scheme for the understanding of landforms over a wide area and Mitchell (1974) suggests that this was followed by schemes of Howard and Spock (1940) and Von Engeln (1942). For military intelligence purposes Putnam et al. (1960) classified the coastal environments of the world and Perrin and Mitchell (1970) classified world deserts.

At a smaller-scale level, in 1935 Milne, working in East Africa, proposed the use of the term "catena" to delineate a recurring association of soils of widely differing morphologies which are found together in similar situations, but it is to the classification of hillslopes that most attention has been focussed. The most notable schemes are those of Penck (1927), King (1962) and more recently the nine-unit land surface model of Dalrymple, Blong and Conacher (1968) and Conacher and Dalrymple (1977). This latter research will undoubtedly have a direct effect on practical land evaluation procedure in the future.

During the past twenty years or so, two major advances have been made in terms of the utility of resource data which have altered the course that land evaluation has taken. Firstly, as a result of improvements primarily in the technology of remote sensing and field survey analysis, much more detailed information about land attributes (for example, soils, landform) has become available, with a corresponding increase in accuracy of interpretation. This has meant that many more items of information are available for application when considering a particular problem. Secondly, and parallel to this data improvement, have been advances in computer technology. Thus it has become possible for numerous pieces of data, once identified on a numerical basis, to be rapidly manipulated.

These improvements have given rise to a new quantitative "parametric approach" to land evaluation especially designed to meet the new criteria. Although rising out of the underlying concepts of the composite approach, the new method has run parallel to, and largely independently of it.

2.3 The Development of Parametric Land Evaluations

There are a great number of parametric evaluations and it would not be feasible to list all of these in the context of the work. The ones chosen for mention, therefore, are those which the author considers, in the context of practical land use planning, to be either "milestones" in the "state of the art" or demonstrate the progression of the approach particularly well.

The approach has been most fully applied for military planning and agricultural land capability classification purposes, although it is the latter type of analysis which has, naturally, disseminated most widely amongst workers outside the strategic services. Mitchell (1973) indicates that as far as military planning is concerned, the United States Army Engineer Waterways Experiment Station at Vicksburg has been the chief agent in using parametric evaluations, although they have also been used by the Quartermaster Research and Engineering Centre at Natick, Mass. (Wood and Snell, 1959), the Air Force Cambridge Research Laboratories (for example, Ta Liang, 1964), the Office of Naval Research (Melton, 1958), and Cornell Aeronautical Laboratory Inc. (1963). They have also been developed for military purposes by the Canadian Army (Parry et al., 1968).

Of particular significance, however, over the past fifteen years have been the parametric evaluations derived for the assessment of agricultural quality, the principal advance being made in the early 1960's with the land capability classification of the Soil Conservation Service of the United States Department of agriculture (Klingebiel and Montgomery, 1961). As with all interpretative groupings it begins with the individual soil mapping units which are building stones of the system. The soils are grouped into 8 classes according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialised site conditions or treatment. Non-arable soils, defined as "soils unsuitable for long term sustained use for cultivated crops" are grouped according both to their potentialities and limitations for the production of permanent vegetation and to their risks of soil damage if mismanaged. In order to determine these classes, the soils are studied on the basis of the following parameters:- inherent potentiality or defect, shallowness, drainage, stoniness, erodability, structure and workability, moisture-holding capacity and hazard of overflow. Slope and climate factors are also considered. Class I land has "few" limitations to crop production whilst "severe" limitations come as far down the gradings as Class III; but although Class V is "impracticable" only Class VIII "precludes" use.

In addition to land capability surveys for agriculture, the U.S.D.A. has also published soil surveys which incorporate land capability classifications for uses such as forestry, engineering etc. Two examples may be cited (after Casson, Hartnup and Jarvis, 1973). The soil survey of Tompkins County in New York State (U.S.D.A., 1965) discusses slope stability, soil compaction, winter embankment construction and frost action and evaluates each soil type for highway location, highway cut conditions, embankment foundations, building foundations, infiltration systems, dikes and levees, farm ponds and agricultural drainage and irrigation. Another survey of San Benito County in California (U.S.D.A., 1969) outlines the permeability, shrink-swell capacity, and potential corrosiveness of the soils mapped and describes their capability as a source of topsoil, sand and gravel and road fill and discusses their potential in affecting road location, water retention structures, irrigation and septic tanks.

As Casson et al. state, American soil survey/capability surveys are "numerous and they are difficult to obtain in Britain" but the principals are adequately summed up in a book edited by Bartelli, Klingebiel, Baird and Heddleson (1966) on "Soil Survey and Land Use Planning".

As far as town and country planning is concerned in the United States, the parametric approach to land evaluation began to take hold in the late 1960's and it is reported by Fabos and Caswell (1977) that even McHarg's early work presented in "Design with Nature" in 1969 (described in the Section 2.2. on Page 22) "gives some evidence of the trend towards parametric planning while much of the later work of his planning group has actually adopted parametric methods"; for example, in the study of Staten Island, New York in the late 1960's.

At about the same time as McHarg was adopting parametric methods, several other groups within landscape architecture programmes also began to develop such an approach. One such group was that undertaking the METLAND study which began in 1971 at the University of Massachusetts in "response to the hypothesis that the metropolitanisation of eastern Massachusetts was causing a needlessly high depletion of its environmental resources (Fabos and Caswell, 1977). In effect a highly organised integrated land evaluation system for planning purposes, the study embodies capability analyses for a wide variety of urban and countryside developments - agricultural, wildlife, water resources, mineral resources, landscape, highways and residential construction, with special emphasis being placed upon natural and man-made hazards.

In Europe the parametric approach has progressed on similar lines to those followed in the United States. Nowhere in Europe has the pressure of population on land been so clearly manifest as in the Netherlands, a direct result of which has been the increasing number of surveys classifying land in relation to planning. One third of the annual effort of the Dutch Soil Survey is directed towards commissioned soil surveys for non-agricultural land use purposes (Casson et al., 1973). Haans and Westerveld (1970) state that detailed soil maps (i.e. thematic); derivative maps showing water table levels, and interpretative maps showing capability for agriculture, horticulture and landscaping (i.e. parametric) are used by planners in Holland. Such maps have been used in rural reconstruction schemes (Int. Institute Land Reclam. and Improvement, 1960) and the development of urban areas (Steegh and Westerveld, 1971).

As part of the interpretation of the soil map of Portugal, Salgueiro (1966) modified the U.S.D.A. system of land capability classification to fit the Portuguese situation. Five classes, A to E, were established, with three sub-classes denoting risks of erosion, wetness, drainage or overflow and root-zone limitations. Classes A to C are suitable for cultivation and "other uses" whilst classes D and E are not suited to cultivation but with possible use for range pasture, woodland or wildlife.

In Great Britain during the early and mid sixties, as a result of the realisation by the agricultural community of the increasing use of agricultural land for urban and industrial development, and in particular the use of farmland at the edge of existing urban centres for housing development, the then Agricultural Land Service implemented a rapid survey of the agricultural resources of England and Wales, using a five grade classification. Hilton (1968) states the case for such a classification as i) "it may be essential to locate and therefore help conserve the maximum area of actual or potential agricultural value in cases where maximum food production is required", ii) "an evaluation is needed where there is a need for a more selective process in agricultural location and where the net social and economic advantage lies in taking land out of agricultural use", iii) "in urban areas agricultural land is often recreational land" (the case is also true for agricultural land in many rural areas, particularly in the upland zone, although Hilton does not mention this) "and in rural areas there is an added incentive of conserving good agricultural land because of the local economy".

The classification as developed by the A.L.S. and now used by A.D.A.S. is a modified U.S.D.A. system using five instead of eight categories. These are selected "according to the degree to which their physical characteristics impose long-term limitations on agricultural use". (A.L.S., 1968). The physical characteristics of each grade include thresholds of slope, drainage, soil depth, stoniness, water holding capacity, chemical deficiencies or toxicities, altitude and climate. The A.L.S. explanatory note (1968) states that the limitations operate in one or more of four principal ways- "they may affect the range of crops which can be grown, the level of yield, the consistency of yield and the cost of obtaining it".

The survey was undertaken very rapidly and has met with severe criticism especially concerning the classificatory groupings and the scale of application. It is now being updated with memoirs being produced for each map. This is discussed in Chapter 6, Pages 170 - 172.

In association with the physical classifications as outlined above, the A.L.S. also experimented with economic classifications, particularly using the Standard Net Output concept but these have not proved as acceptable as the physical classification.

Although soil surveys of selected areas of the British Isles were undertaken in the 1930's, it was not until 1939 that the Soil Survey of England and Wales was established, whilst the Soil Survey of Scotland was not established until 1948. Even then little attempt was made to adapt the resultant maps and soil classification schemes to practical land use planning. The approach was thus thematic in concept, with resultant severe limitations and somewhat academic approach. However, since the late 1960's, possibly as a result of the increasing pressure on government research organisations to show their practical worth by more obvious means, the Soil Survey has given land capability assessment a high priority. This has been a wise move, as a traditional soil map means little to a non "soil man"; for example, although soil scientists may extol the worth of thematic soil maps to planners they have been little used at central or local government level.

There remains, however, within the Soil Survey a bias towards agricultural applications of soil survey owing to the fact that it is funded by various agricultural organisations (administered by the Lawes Agricultural Trust Committee, financed by the Ministry of Agriculture, Fisheries and Food and advised by the Agricultural Research Council). This agricultural bias, coupled with the use of thematic soil maps, has been a major contributing factor in the ignorance and apathy of town and country planning to soil in general. Even where land capability assessments for other land uses have been used, for example, in the Castleford area, their full worth has not been realised by the planning authorities concerned. (Hartnup, pers.comm., 1976).

In partial response to the above criticisms and in line with its agricultural sponsors, the Soil Survey of Great Britain proposed its own land capability classification for agriculture (Bibby and Mackney, 1969). The system, which is heavily influenced by the U.S.D.A. classification, grades land into seven groupings according to the properties of soil, site and climate of each mapping unit (soil series), which are summarised and briefly discussed in relation to land use and management problems in the memoir for each sheet surveyed. Class 1 land has no limitations to agriculture whilst Class 7 land has very severe limitations to agriculture. Spread over these seven classes are twelve "sub-classes," showing the exact nature of the limitations.

The Soil Survey is actively engaged in agricultural land capability assessment research and in 1975 it was reported that it was co-operating with A.D.A.S. soil scientists on the classification of land according to the Bibby and Mackney method, for agricultural and horticultural purposes (Le Grice, 1975).

Other bodies have also undertaken agricultural capability surveys; notable examples being in the Deeside and Donside conservation study of north east Scotland (Walton et al., 1969), using the U.S.D.A. system, and also in 1969 McVean and Lockie used a modified version of this approach as part of an ecological and land use study of upland Scotland. Recently Aitken (1977) reports their use in preliminary investigations for sand and gravel extraction.

However, despite this emphasis on agricultural capability classification, soil maps have been made for non-agricultural purposes by the Soil Survey. The first maps were produced in the late fifties for the Lancashire County Council in connection with new town and other development at Skelmersdale, Ormskirk, Formby and Culcheth and some years later for the new town of Milton Keynes in Buckinghamshire. Even so, this non-agricultural application of soil survey for land evaluation purposes is still in its infancy in Great Britain (Casson et al., 1973), although research on the applications of soil survey for recreation and ecological evaluation is actively being pursued by the Soil Survey (Thompson, T.R.E., pers. comm., 1976).

In recent years the Soil Survey has produced a number of specialised studies on a contract or experimental basis. For example, Rudeforth and Thomasson (1970) produced a report on the Hydrological properties of the soils of the River Dee catchment area, and a drainage map of the North Berkshire Downs has also been published (Thomasson, 1975). Mackney (1973) describes soil survey applications for hydrology, planning and forestry evaluation and Jarvis (1976) describes the use of soil survey for playing field management.

The most significant project for integrated multiple land use planning undertaken so far by the Soil Survey (under contract from the former West Riding County Council) has been the study of the land capability of the Castleford area (Hartnup and Jarvis, 1973 and Casson, Hartnup and Jarvis, 1973). This study was designed to aid the planning of a suggested major growth area of some 88 sq.km. based upon the towns of Castleford, Featherstone, Knottingly, Normanton and Pontefract. Soil was the predominant attribute used, being mapped at the series level. The suitability of the soil was then assessed for agriculture and amenity use; building development, road construction and services.

During the past ten years or so, apart from those systems devoted to the assessment of agricultural capability and the limited special surveys, the principal use of land capability in Britain has centred on the development of ecological evaluations for nature conservation purposes. The motivation behind this has been the realisation that the country's flora and fauna is rapidly becoming depleted as a result of complex socio-economic forces requiring in some cases devastating environmental change; for example, the impact of modern farming on the countryside (Nature Conservancy Council, 1977). Thus, as Goldsmith (1975) outlines, "the problem that concerns the naturalist and ecologist is to identify the exact number, extent and spacing of various habitats for the survival of each species of plant, animal and fungus (Hooper, 1971). The problem for society is to decide how many such species are required, their abundance, and how they should be distributed, and the problem for the planner is to interpret the wishes of society and to ensure that their requirements are accommodated in competition with other demands on land". Evaluation procedures are, therefore, a medium for the transference of information on worth of particular areas of land for the sustenance of wildlife.

Notable evaluation studies have been those of Tubbs' and Blackwood (1971) in Hampshire; the Coventry-Solihull-Warwick sub-regional study (Warwickshire County Council, 1971) and West Sussex Council's survey (Burrows, 1973), all of which determined the extent of semi-natural habitats and graded them accordingly.

Heiliwell (1969, 1971) attempted to place an economic value on ecological resources but this has not been developed to any extent, the principal attention being put on developing indices of value, as with the projects of the University College London's Conservation Course (1972 and 1975), as reported by Goldsmith (1975) and the studies of Yapp (1973), Ranwell, (1969) and Scott (1972). In most studies it is habitat that forms the basis for evaluation.

Land evaluation procedures as practised by the Soil Survey, being based upon the soil series, are in essence soil capability analyses, although site factors such as slope and elevation and climate are also considered. It has been up to other bodies and researchers to attempt a wider view and to integrate land evaluation procedures into the planning process.

In 1972 Statham reported his work on a pilot study of land capability in the North York Moors National Park. Parametric assessments of capability for agriculture, forestry, recreation in the private and public sectors and nature conservation are described, taking economic as well as physical parameters into consideration. After these capability analyses, conflicts between competing potential land uses are analysed and "optimum" use patterns investigated on the grid square basis.

Much of Statham's research is based upon the work of the Agricultural and Rural Development Administration of the Canadian Land Inventory (examples of the Canadian work are the 1973 published land capability maps for the East Kootenay and Prince George areas, for multipurpose land use planning where "composite" mapping of these capability maps to evolve optimum uses for the areas were also undertaken).

The development by various local authorities of "potential surface" analyses have been outlined in Chapter 1 on Page II, the method was first used in the Nottinghamshire-Derby sub-regional study of 1969 as a means of a quantitative planning assessment from goals to final strategy generation. This work was further refined by the Coventry-Solihull-Warwickshire study team with extensive use being made of weighting factors as a means of strategy generation. The approach was also being undertaken by Glamorgan County Council (Williams, 1972) as a means of Structure Plan analysis and the Worcestershire Structure Plan published in 1974 also uses the method. Since then, however, there has been a move away from such a definite quantitative assessment to a less specific analysis using more intuitive methods as exemplified by the 1975 output from East Sussex County Council.

2.4 Summary

Land evaluation has developed from early regional groupings and has followed an "evolutionary" path from qualitative to quantitative analysis as a result of advancements in technological data manipulation. The two major approaches to evaluation, of composite and parametric analysis are now being actively developed side by side, although it is towards the latter that greater attention is now being focussed.

CHAPTER 3 - A REVIEW OF THE PROBLEMS INVOLVED IN DETERMINING THE THRESHOLD LEVELS OF NATURAL RESOURCE ATTRIBUTES AND PARAMETERS FOR LAND USE PLANNING PURPOSES

The principal natural resource attributes of climate, landform, soil, vegetation, fauna and water, as defined by Stewart (1968), were mentioned in Chapter 1. They are discussed in greater detail in this Chapter.

3.1 Introduction

J. A. Mabbutt (1968) states, that the more closely man attempts the definition of land character in specific and numerical terms, "the more necessary it is for the land classifier to grapple with the complex variations of land attributes from place to place". Soil, for example, not only exhibits vertical, but also horizontal variability and these variations may be abrupt or gradational. In addition, many important soil parameters, structure for example, do not lend themselves to "conventional surface scanning".

As well as within-attribute variability, certain between-attribute variations are of note. Landform, soil and vegetation are fixed in their location and extent and, in general, are exploited by man at that location. Water, however, may be transported long distances to meet man's needs. Other attributes may have a temporal as well as spatial distribution; for example, climate, water and vegetation. Some are directly usable, as with natural building materials; others must be combined, as with soil and water for irrigated agriculture, whereas mineral resources and, to a lesser extent, soil resources may be worked out, although the latter may be improved if degradation has not progressed too far.

3.2 The Threshold Concept

In any type of land capability analysis there is the problem of setting limiting values or "thresholds" to parameters, above or below which the feasibility of a specific land use or activity being undertaken increases or decreases. Such thresholds may be divided into two broad categories as shown in Figure 3.1.

3.2.1 Specific Thresholds

In this case there is a definite quantifiable barrier, above or below which a specific land use or activity is definitely possible or not. For example, the maximum angle of slope for special bank mowing machines is 27° (British Standards Institution, 1969) and up to this specific threshold figure an increasing angle does not detrimentally affect operations.

3.2.2 Gradational Thresholds

For such thresholds there is no definite single quantifiable barrier, but rather a gradational range of values within which the possibility of a specific land use being undertaken increases or decreases. For example, a slope of 7° may be considered the maximum for house building on a large scale (Williams, 1972), whereas 2.9° is considered the maximum for housing without "special provisions" (Holmes, 1968).

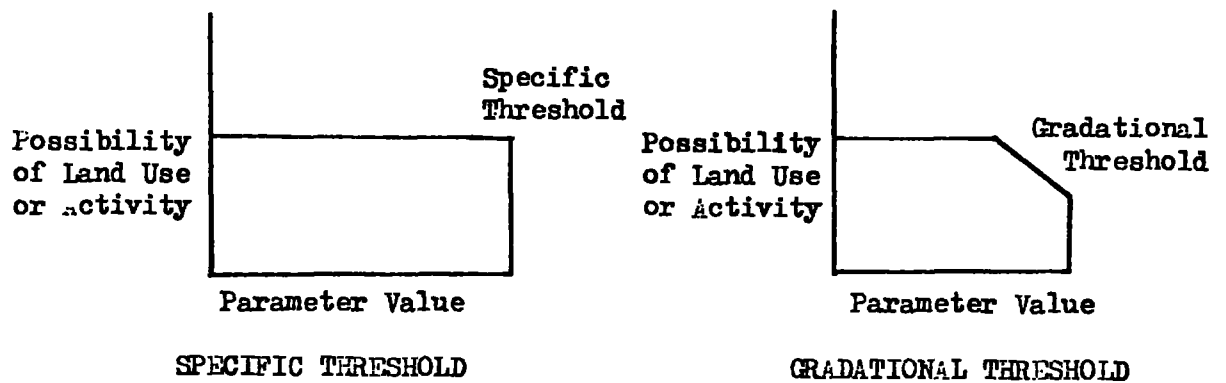


Figure 3.1 Specific and Gradational Thresholds

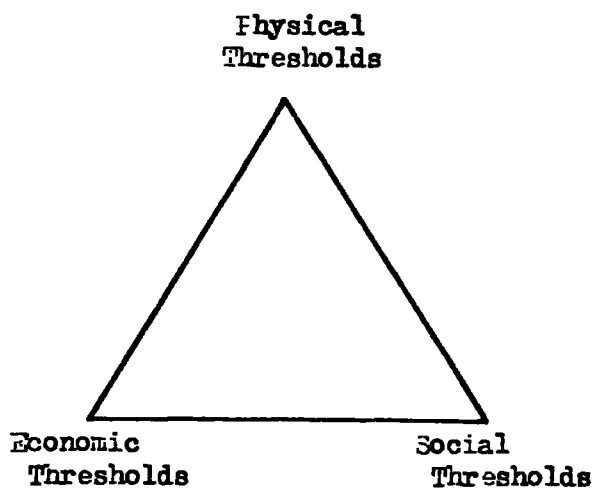


Figure 3.2 The Threshold Triangle

In practice, both specific and gradational thresholds occur and they may be sub-divided into three distinct types, all of which are linked (Figure 3.2).

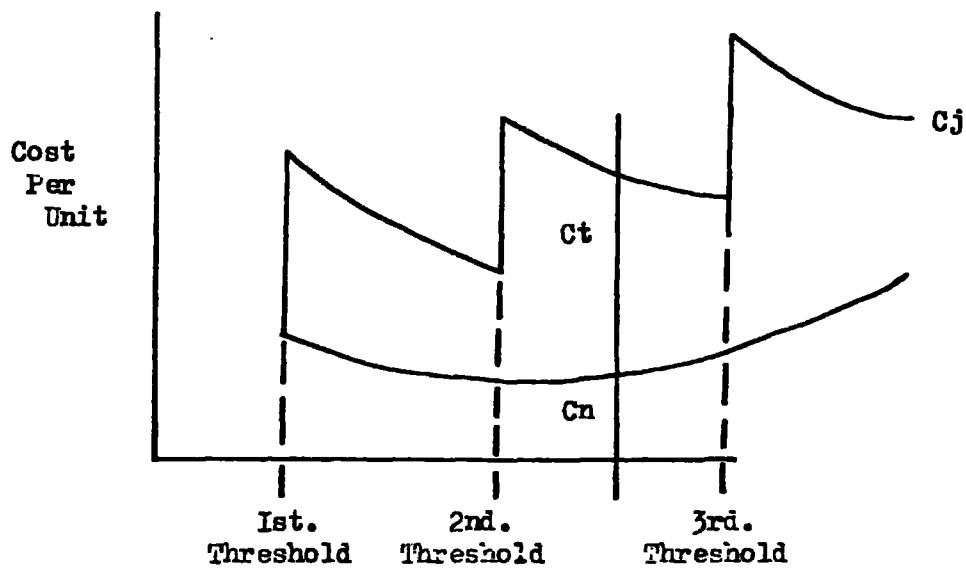
- i). Physical thresholds which involve the actual physical value of a parameter above or below which a land use or activity is affected.
- ii). Economic thresholds which involve the economic limits above or below which a land use or activity is affected.
- iii). Social thresholds which involve the social limits above or below which social desirability is affected.

For example, a physical threshold to development for housing may be put into economic terms, whereby certain threshold costs will be met in overcoming the physical limitation to development. Likewise a physical and/or economic threshold to development for housing may be put in social terms. For example, a housing development for the elderly will have a physical threshold of an angle of slope above which economic and social thresholds will come into effect.

3.3 Threshold Analysis

As an indication of how the concept of thresholds, as suggested above, has been used in a planning system, the technique of "threshold analysis" developed by Malisz of the Polish Academy of Science (1963) is cited. This has been used extensively in Poland, in the Moscow region and in Italy (Barrell and Glasson, 1972). In Britain the technique, which may be seen as a "practical way of ensuring greater co-operation between economists and physical planners in the planning process", has been developed further by the Planning Research Unit at Edinburgh and used in the Lothian Regional Survey and Plan (1966); the Grangemouth/Falkirk Regional Survey and Plan (1968) and the Central Borders Study (1968).

The basic concept is that towns encounter some physical limitations to their expansion due to one or more factors of - topography, public utility networks or existing land uses. These limitations may only be overcome by high capital investment, and the "threshold costs" are those necessary to overcome the threshold factors limiting physical development. This is represented schematically in Figure 3.3. For example, an expanding urban centre may be faced with a large demand for housing but a negligible supply of flat land, i.e. it becomes faced with a physical threshold and associated threshold costs. Three courses may be open. Firstly, it could decide not to meet any extra demand to the normal density capacity of the flat land. Secondly, it could attempt to meet the demand by increasing existing densities or by using land that would not normally be used; for example, derelict land (although extra threshold costs might be met here, due to reclamation or foundation problems). Thirdly, the authority might decide to cross the threshold and in this case there may be the question of several alternative slopes on which to develop and these may in turn involve social thresholds. Other things being equal, threshold theory, by costing these thresholds would indicate the least cost alternative.



- C_n = normal investment costs not connected with a particular location.
- C_t = threshold or abnormal costs heavily bound to the existing conditions and characteristics of a particular area.
- $C_j = C_n + C_t$ = total costs per unit (the peaks on the C_j curve represent the thresholds as they occur).

Figure 3.3 Normal and Threshold Costs (after Barrell and Glasson, 1972)

3.4 Natural Resource Attributes, their Parameters and Thresholds as they Affect Selected Land Uses

It is not intended in this section to discuss every aspect of natural resource attributes and parameters, but to concentrate on the general characteristics and threshold values of those parameters that will be encountered in later chapters. Where appropriate, each parameter will be discussed in terms of agriculture, forestry, nature conservation, housing development, industrial development and recreation. Road construction will be mentioned only briefly, owing to the considerable problems involved in defining engineering thresholds and, as a result of these problems, this land use will not be analysed in succeeding chapters (see Chapter 6, Page 138). Landform parameters will be discussed first in each section as they are often the most significant to development.

3.4.1 Agriculture

There are a number of parameters that influence agriculture which may be considered pertinent to land capability analysis. Each will be discussed in turn with respect to threshold limits as applicable to the British scene.

3.4.1.1 Slope

Slope is a parameter of Stewart's (1968) landform attribute and affects agriculture, both directly through the angle of slope and the form or configuration of slope influencing operations and indirectly through the influences it has on soil, drainage and climate; the latter being influenced by the type of aspect pertaining at a particular location.

The angle of slope not only influences the performance of farm machinery but also their stability and hence the safety of their operators. The thresholds involved are discussed by Spoor and Muckle (1974) and Bibby and Mackney (1969), from which the following discussion is taken.

The side stability of a tractor is dependent upon wheel or track spacing and the height of the centre of gravity above the ground. Although theoretically it would be possible for tractors to traverse slopes of 45° , this would be unwise, for any "differential wheel slip or running into a slight hollow could cause immediate overturning"; a more realistic threshold is indicated at 15° . The situation is further complicated by tractor attachments, for example, if a raised mounted implement swings when moving across slopes, instability could be caused because the centre of gravity is altered.

Apart from movement across slopes, movement up slope is affected by steepness, as a greater amount of weight is transferred to the back wheels, giving a tendency for the front wheels to lift and so overturn the machine. The extent to which this rearing occurs is also dependent upon whether an implement is mounted on the vehicle or is trailed. A mounted implement in work will prevent rearing, but the risk of the rearing of a trailed implement not only depends upon the angle of slope but also on the height of the hitching point and the more inclined upwards the line of pull, the greater the risk. With mounted implements, dangerous situations occur particularly when the implement is lifted from the ground whilst still on

the slope, with resultant weight transfer to the rear. In addition, the tractive performance of vehicles is less when travelling upslope. Allowing for many design differences, the following threshold values are suggested by Spoor and Muckle (1974):

Standard Wheeled Tractor	13°
Four Wheeled Drive Tractor	17°
Tracklaying Tractor	17°
Tractor working with plough	11°
Tractor working with Rotary Cultivator	30°

There are no traction problems when working downhill but braking problems can occur particularly with loaded tractors.

Combine harvesters are seriously affected by slope and Spoor and Muckle's work shows that travelling across a slope has been found to approximately double the total loss from the machine, in the form of unseparated material, when compared with losses on the flat. In addition, a build-up of material on the grain pan can be dislodged as the machine is turned quickly off the slope to more level ground with subsequent loss. An angle of slope of between 10-12° is the upper limit to prevent excessive losses (Finkenzteller, 1957) and between 7° and 15° the use of harvesters becomes very restrictive (Bibby and Mackney, 1969) unless the most modern machines are used. Morrison and Idle (1972) suggest that an 8.5° slope is the threshold for a forage harvester and trailer, as even though actual cutting performance may not be impaired, stability and safety are.

Fertilizer distribution is also affected and although, apart from hopper overflowing, the performance of full width distributors is little altered by slope angle, the centrifugal or broadcasting types are severely affected. Some broadcast up to three times more on one side than on the other when working across a 10° slope whilst others give a - 10% distribution under similar conditions.

Some muck spreaders are inoperable at slopes in excess of 6-7° and the performance of certain thinners, gappers and precision seeders falls off rapidly when working on slopes of 4° or more and towards 15° loading difficulties with trailers are encountered.

The form of the slope and configuration of the ground also has an effect. Two-way ploughing reaches a limit around 11°, although if there is a turning space at the head and foot of the slope and a short 15° angle, this might be undertaken, whereas a uniform 15° slope would call for one-way ploughing only (Bibby and Mackney, 1969).

In general, severe problems exist on all slopes in excess of 15° for all machines, but problems decrease with angle and few are encountered below 7°.

Angles of slope above 15° are, therefore, not suitable for normal rotations, are frequently down to grass and threshold costs can be large. Greater than 20° slopes are very difficult to plough, lime and fertilize, costs are large and normal rotations impossible. Between 20-25° occasional tillage for pasture improvement is sometimes undertaken but above 25° the formation of paths across slopes by animals starts (Ruhmann, 1957) and special machinery is necessary if mechanised farming is to be carried out (Bibby and Mackney, 1969).

Aspect is significant to agricultural production as a result of its influence upon climate. Northwards-facing slopes (NNW-ENE) receive the most inclement conditions in the form of smaller amounts of insolation, most frost and snow and wind blast and greater amounts of rainfall than slopes facing other quarters. Much depends upon the type of crop being contemplated, but in general terms, steep north-facing slopes are unsuitable for agricultural and horticultural production.

Curtis (1971; 1976) working on moderately steeply to steeply sloping land on Exmoor has revealed marked differences in soil temperatures at different aspects. On opposing north and south-facing slopes under conditions of strong and continuous sunshine, differences of 21.7°C at the surface, 7.5°C at 5 cm depth and 5.4° at 10 cm depth were recorded and on opposing east and west facing slopes differences of 6.9°C at the surface and 2°C at 5 cm depth were found.

In addition, Curtis points out that the greater insolation received by south and west facing slopes also affects the drying out of soil and that observations over a three year period showed that on north and east-facing slopes, mean gravimetric moisture contents were 79.2% compared with 59.4% for south and west-facing slopes. These moisture content differences "partly reflect and explain" the soil temperature differences found.

Smith (1969) states that at Tideswell in Derbyshire in April, the increase in total radiation on a south facing slope of 6° , over that received on a horizontal surface, is of the order of 6 cal. $\text{cm}^{-2} \text{ day}^{-1}$ and both in April and July on such a south-facing slope, the total radiation received is about 3% greater than on the level.

3.4.1.2. Climate

The effect of climatic factors on different land uses is profound and well documented and because of its complexity it is not intended to undertake a comprehensive analysis here. Only the essential outlines will be discussed with particular reference being made to various classificatory systems in use.

Climate is the principal characteristic of the physical environment that affects agricultural capability and the application of climatic limitations to classification procedures is outlined by Bendelow and Hartnup (1977). They place emphasis on those factors which have the greatest effect on plant growth, which are predominantly, radiant energy and soil moisture balance. These parameters are reflected by air temperature, precipitation and transpiration and light in the form of direct and diffuse insolation; whilst wind and, to a lesser degree, humidity are also important. The situation is complicated by seasonal variation. Stations in East Anglia for example, have higher accumulated temperatures than those in Pembrokeshire, but because winter and early spring temperatures are higher in west Wales the growing season begins earlier and early crops can be grown as a result.

Bendelow and Hartnup outline an early assessment of climate for land classification purposes by Osmond (1944), who divided England and Wales into 28 climatic regions based on the variation of the monthly April to September mean air temperature and mean rainfall from the national monthly means. Also noted was whether the March mean air temperature was above 5.6°C (i.e. the threshold growing temperature for grass).

The first application of climatic thresholds to agricultural land classification, however, was the work of the A.L.S. Study Group on Agricultural Land Classification (Ministry of Agriculture, Fisheries and Food, 1966). A grading scheme was proposed using altitude and rainfall thresholds for certain grades of land, with attention also being given to other important features, such as the length of the growing season, irrigation need and wind exposure. Table 3.1 shows the overall guidelines used.

Table 3.1 A.L.S. Limits of Altitude and Rainfall as they Affect Agriculture

- 1). Land over 607 m is generally above the tree line and provides only poor rough grazing.
- 2). Land between 305 m and 607 m with more than 1,524 mm of annual rainfall gives only rough grazing and pasture improvement is usually not feasible.
- 3). Land between 183 m and 305 m with over 1,270 mm of annual rainfall allows pasture improvement but is not suitable for arable cultivation.
- 4). Land between 122 m and 183 m with more than 1,016 mm of annual rainfall (1,143 mm in western Britain) is mainly suitable for grass and limited arable cropping.

In the Soil Survey of England and Wales before 1969, climatic assessments were not generally used, but in the work of Rudeforth (1970), Mackney and Burnham (1966) and Green (1968) references are made to climate. The break-through came with the Bibby and Mackney land capability system of 1969 which used the two climatic parameters of average mean daily maximum temperature ($^{\circ}\text{C}$) and potential water deficit (ins) for the appropriate growing season of April to September, to indicate thermal and moisture conditions. Table 3.2 shows the thresholds of the parameters according to capability class, with altitude and rainfall limits being a further aid to identification.

These broad zones work tolerably well, but naturally do not consider local mesoclimatic or microclimatic effects such as slope or wind exposure, which often alter markedly over small areas. The guidelines may also be difficult to use in uplands where there is a need to indicate areas suitable for improvement and where the rainfall criteria alone causes land to be downgraded in capability

According to Bendelow and Hartnup this current scheme has been used, sometimes with modifications, by Hodgson and Palmer (1971), Harrod (1971), Johnson (1971), Palmer (1972), Green and Fordham (1973), Clayden and Evans (1974), Hollis (1975) and Bendelow and Carroll (1976).

At the Macaulay Institute, Aberdeen the work of Birse, Dry and Robertson between 1970 and 1971 produced three climatic maps of Scotland at a scale of 1:625,000 and in 1971 Birse applied the various assessments used to land capability classification, giving a table showing the best land capability class possible under combinations of accumulated temperature above 5.6°C , potential water deficit and wind exposure. In 1976, Birse and Robertson produced a table of "moisture divisions" using the work of Birse (1971), as part of a study of plant communities and soils of the Lowland and Southern Upland regions of Scotland. The value of this work, however, has yet to be proved in practical terms.

Table 3.2 Altitude and Rainfall Thresholds of the Land Use Capability Classes (after Bibby and Mackney 1969 and Bendelow and Hartnup, 1977).

		Rainfall			
		<1016 mm	1016-1270 mm	1270-1524 mm	>1524 mm
Land Use Capability Class	7				
	6	← 610 m →			
	5	← 533 m → 305 m			
	4			183 m	
	3	← 381 m →		sea level	sea level
	2	229 m	122 m		
	1	152 m			

In England and Wales it is reported that work on climatic parameters for land capability classification is in progress by the Soil Survey (Bendelow and Hartnup, 1977). The principal aim is that "capability classes be specified as being found only under certain groups in the climatic classification." A secondary aim is to provide a simplified illustration of the English and Welsh climate for pedological purposes. Accumulated temperature above 5.6°C (Birse and Dry, 1970) is being calculated and used as a measure of "thermal conditions during the growing season". Potential transpiration, which relates to sunshine and windiness, has been demonstrated to give the best indication of grass crop production potential (Penman, 1962; Smith, 1967) in lowland areas over the growing season, when soil fertility and moisture status are satisfactory. A straight line regression has been calculated between total potential transpiration over the growing season and accumulated temperature above 5.6°C.

Although soil moisture is adequate for the most part in the uplands, an added indication of its variation in the lowlands is desirable. The measure of "average maximum potential cumulative soil water deficit" is being used by the survey in place of the previously used "potential water deficit", as being more accurate in the drier eastern parts of England.

An assessment of wind exposure, by observing the size of trees and dwarf shrubs as used by Birse and Robertson (1970), is being applied and the importance of oceanicity is being checked.

Thus, when maps have been prepared of the variations in these important parameters, isopleth maps showing critical values for capability will be produced.

3.4.1.3 Soil

As soil is the medium for plant growth, its parameters figure widely in capability classifications for agriculture. Relationships, as with climate, are complex and again only the broadest outlines will be discussed here.

Mackney (1974) states that both crop yield and crop management are directly influenced by the amount of water and air in soils and by the ease with which water is extracted by plants or removed by drainage. In the determination of capability thresholds it is, therefore, on these two parameters that most attention has been focussed. Widespread field measurements of air and water in soils are, however, "at present either

expensive or impracticable", with resultant problems for threshold determination. Thus, thresholds are derived from the more easily assessed, but less satisfactory indicators of the soil/moisture regime. Mackney (1974) indicates that these relevant properties are predominantly, soil texture, structure, stoniness, depth and wetness.

Salter (1969), in examining the influences of soil on moisture characteristics, concludes that soil texture, structure and soil depth are important; whilst a shortage of water for plant growth may limit crop production and, without irrigation procedures, directly affect land capability.

Soil texture influences the ease by which plants extract water from the soil. Mackney (1974) states that sands release most at most suctions, silt loams and related textures release it steadily over a range of suctions and clays retain much of their available moisture at large suctions. Millar, Turk and Foth (1965) indicate that up to a certain point an increase in the amount of clay in the subsoil is desirable, as it can increase the amount of water and nutrients stored in that zone and, by slightly reducing the rate of water movement through the soil, it will reduce the rate of nutrient loss through leaching. However, if the accumulation of clay is great, the movement of air and water will be restricted, as will the penetration of roots in the B horizon. The amount of run-off on sloping land will also increase. Brown (1974) outlines in detail the agricultural significance of clays and Edwards (1974) states that when insecticides were applied to different soils in field experiments, they were absorbed least in sand and progressively more in silty clay loam, light sandy clay loam, coarse silt, silty clay, sandy loam, clay loam and peat.

Davies (1974) states that to a large extent the texture of a soil determines its structural properties, and so in practice it is not possible to separate clearly which are textural and which are structural effects, particularly when cultivations are involved. However, structural defects of agricultural significance are more often found in topsoils than in subsoils because of the greater stress imposed upon them, since many of the forces responsible for disruption and the formation of structure, including wetting and drying, biological activity, freezing and thawing and cultivation practice, are more intense and occur more frequently in the topsoil.

Ideally, according to Davies, the topsoil should have a strongly developed crumb or granular structure, "in which forces within peds are well in excess of forces between peds". As a result, this encourages good working properties, helps to keep the soil open against compacting forces and facilitates loosening of the soil if compaction does occur. It also helps to have a structure that is stable in water and a friable consistence at field capacity. In the subsoil the requirements are less and Davies proposes that "what is needed is a matrix that is not too compact but has a well developed network of larger fissures and/or pores through which gravitational water can pass freely, roots may grow readily and through which are sufficient smaller pores to provide for adequate water storage". The types of structure suggested to provide these requirements include porous blocky, porous prismatic and porous non-fissured structures.

These combinations of topsoil and subsoil structural optimal conditions are most likely to be found in medium textured soils, i.e. loams, sandy loams and lighter textured clay loams with medium to high levels of organic matter. Sands, silt loams and clays are those textures where structural problems are most likely to be found.

The amount of stones found in a soil will directly affect crop performance, as in profiles with hard rock, plough pans or other barriers to root penetration, the amount of water available is proportional to the thickness of soil exploitable by roots. Non-porous stones also reduce the available water capacity (the volume of water held between field capacity and the wilting point) in proportion to their volume. The presence of solid rock near to the surface also affects the available soil moisture to some extent. Thompson (1975), for example, suggests that the scorching patterns occurring in dry periods in the grasslands of the Carboniferous Limestone plateau of east Clwyd in North Wales, reflect the distribution of sub-surface rock outcrops at depths of less than 30 cm. Crompton and Matthews (1970), on the other hand, suggest that the rendzina soils of the Wetherby Series on the Magnesian limestone of Yorkshire are, "like most shallow soils over limestone.....not so droughty as might be expected because crops appear to be able to extract some water from the rock itself".

Generally, however, shallow soils have detrimental effects upon crop performance which are normally expressed through low available water capacity, restricted rooting range and inadequate nutrient uptake. The limiting effects of some of these properties also depend on external factors such as rainfall. Shallow depth also presents problems to management, particularly when mechanical implements are involved and their use may be impracticable in certain cases (Bibby and Mackney, 1969).

Thomasson (1974) states that "over much of Britain poor or indifferent soil-water conditions are probably the major barrier to improving crop yield;" defects varying markedly from "phase to phase and include both too much and too little water". An optimum drainage is the complete removal of waterlogging from the upper metre of soil at any time of year, but drainage measures to achieve this state are not economic with present techniques on most of the heavier soils. Thomasson continues that severe waterlogging during December, January or February is unpleasant, but does not interfere with farming to the same extent as waterlogging does in Spring, when the need to start drilling or grazing is critical. Excessively well drained soils, particularly with sandy profiles, may show a soil-water deficit (the measure of the dryness of the soil relative to field capacity). Davies (1974) states that the depth of root penetration in the arable areas of England is a crucial factor in moisture supply and drought may occur through root penetration being checked by layers of strength or a compact non-porous nature. Over compaction may also produce anaerobic conditions, which similarly restricts crop performance.

Thomas (1974) suggests that soil structure problems may arise when the soil organic matter falls below 3% in fine sand, very fine sand or silt soils. In some loamy sands and sands, less than 2% organic matter has been found and such soils in low rainfall districts are very prone to wind blow. He also states that organic matter improves the physical condition of heavy textured soils, helps water retention, nutrient content, microbiological activity etc.

The reaction of soils is significant to crop-production and soil management practices and is useful in diagnosing the "fertility" (nutrient status) of soils. In general, when the pH is about neutral most nutrients (if present) are usually available in adequate quantities to satisfy plant requirements and there is enough calcium to counteract acidity, maintain the stability of the clay humus complex and promote a crumb structure. Allied to pH, the percentage base saturation is a very useful criterion in indicating the nutrient conditions in the soil-colloid-root environment. A fertile soil has an abundance of exchangeable bases readily available for plant growth, as most of the exchange sites in the horizons are occupied by bases rather than hydrogen. In general, the exchange capacity increases as soils become more clayey and/or richer in organic matter. Sands and sandy loams are low in colloidal clay and likely to be deficient in humus also and hence have a low base saturation.

As far as the properties of soil most related to machinery performance, Spoor and Muckle (1974) suggest that soil texture, structure, wetness and stone content figure highly and that these affect "draught, penetration, scouring, traction, sinkage, local and general compaction, wear, breakage, and implement effectiveness"....."Actual performance on any one soil type depends particularly upon its moisture state".

For most mechanized agricultural operations, in terms of the maximum number of monthly working hours available at vital times of the year (September to March), the optimum soil condition is one of friable consistence and this is dependent upon interactions between soil type and climate. The greatest problems occur on heavy, clayey soils during October to December, coinciding with the autumn cultivations and potato and sugar beet harvests.

Abrasion and breakage of machinery may be caused by jamming and wear by stones, especially where the rock is near to the surface. In stone-free soils, the greater the soil shear strength and sand content the greater the wear; hence sandy soils cause more wear than clays.

Landform, climate and soils are the most important attributes influencing the type and success of agricultural production, but the remaining principal attributes of vegetation, water (in the form of flooding), and fauna also have an effect.

3.4.1.4. Vegetation

The fourth natural resource attribute, that of vegetation, is of particular significance to the capability of land for agriculture in two ways. The first is the actual physical presence of vegetative growth on land to be brought into agricultural use and the second is the effect of vegetation on the soil itself.

Costs of production increase substantially if the clearing of areas of tree growth is necessary. This may not only require the removal of trunks and branches but the grubbing up of extensive root systems, the latter often necessitating the use of explosives.

The reclamation of marginal land to provide tolerable pasture requires considerable expense, particularly in the clearing of heather (Calluna and Erica spp) and the eradication of bracken (Pteridium aquilinum). The latter is particularly persistent even after using Asulan and without subsequent management improved pasture will invariably revert back to bracken.

When grassland and timbered soils are brought into cultivation, one of the most notable differences between them is the colour of the surface layer. Under similar drainage conditions, grassland soils are much darker, owing to a higher humus content; when the entire profile is considered, soils developed under grass are found to contain about twice as much humus as nearby soils developed under trees (Millar, Turk and Foth, 1965).

Because of the intense nature with which the grass roots ramify the soil substrata and the annual habit of growth, great quantities of minerals are carried up to the leaves and stems and returned to the soil each year. This return of minerals to the soil results in a larger supply of available nutrients for a succeeding crop than there would be if the land was initially under trees and it also delays the tendency of the colloids to become base unsaturated. Grassland also decreases the leaching away of soluble nitrogen compounds and hence leads to a further build-up of humus through increased plant growth. Under woodland, however, much of the mineral and nitrogenous nutrient content of the leaves of trees is translocated to the woody parts before the leaves fall and hence the heavy nutrient uptake of trees is stored and not returned to the soil until the death of the tree.

Wide differences in the uptake of ions and consequently in the chemical composition of plant tissues occurs and even between tree species there are large differences and this is reflected in soil fertility. Muckenhirn et al. (1949) confirm that hardwoods maintain a higher pH and percentage base saturation than spruce when grown on parent material with the same mineralogical composition (Table 3.3).

Table 3.3. Effect of Tree Species on Soil pH and Base Saturation (After Muckenhirn et al. 1949).

<u>Forest Type</u>	<u>Horizons</u>	<u>pH</u>	<u>% Base Saturation</u>
Spruce	O2	3.45	13
	A2	4.60	20
	B1	4.75	27
	B2	4.95	27
	C1	5.05	23
Hardwood	O2	5.56	72
	A1	5.05	47
	B1	5.14	36
	B2	5.24	34
	C1	5.32	34

From the above discussion it is suggested that the capability for agricultural production is much greater at sites under grass than under woodland.

3.4.1.5. Fauna

It is only in recent years that attention has been paid, both at an academic and practical level, to the effects of differing land uses on fauna and, as a result, how this attribute affects land use capability in other than sporting terms. The most recent appraisal of the problems for agriculture, in a British context, has just been published by the Nature Conservancy Council (1977).

In Great Britain, before fauna (other than pests and disease carriers and "sporting" animals and birds) can have an effect on the capability of land for any use, a conscious decision has to be made on the part of the land user towards species conservation. If he decides on conservation measures, his choice of the amount and kind of land use which will produce a conventional economic return will be restricted. If on the other hand, there is no such conscious decision for conservation, development of most kinds will be invariably unaffected in terms of economic return, but wildlife will suffer.

A limited form of protection is afforded to certain sites by their designation as Sites of Special Scientific Interest under Section 23 of the National Parks and Access to the Countryside Act, 1949. This requires local authorities to consult with the Nature Conservancy Council if development is proposed, but even so does not form a complete statutory protection even in areas within local authority control. Conservation is even more difficult to enforce if the S.S.S.I. is situated in private hands.

Thresholds to development, although capable of definition in terms of the numbers or rarity of species etc., are in effect, virtually impossible to define in practical terms without statutory provision, as all depends upon the specific instance and attitude of the landowner concerned.

3.4.1.6. Water

The role of water has been discussed, where appropriate, in previous sections, as it is related to the other attributes. Throughout this chapter, water as a natural resource attribute in itself, will only be considered in relation to flooding and the considerable problems that this poses to land use.

Flooding may be both beneficial and destructive to agriculture. Alluvial deposits are frequently scattered in narrow irregular strips along the borders of streams and rivers and most alluvium is carried and deposited during floods, since it is at this period that erosion is most active and the carrying capacity of water courses is most effective. Alluvium deposited on flood plains is often rich in plant nutrients (although this depends on the geology of the catchment) and comparatively rich in organic matter. Such soils tend to warm up quickly and have good drainage, allowing free root development. Where terraces develop as streams cut deeper channels, the resultant soil may be coarse textured sands and gravels with a well drained and droughty profile and suitable for specialised crops such as vegetables and fruits (Millar, Turk and Foth, 1965).

Flooding may be destructive, however, especially if it occurs in the growing season, when damage to crops will result. Severe soil erosion may occur and livestock be at risk.

In general, intermittent flooding will not deter agriculture but persistent waterlogging will be more significant and, if frequent, flooding may rule out arable agriculture altogether.

3.4.2. Forestry

3.4.2.1. Slope

The increasing afforestation of upland areas, resulting from the intense competition for land in the lowlands, has increased the significance of the angle of slope in limiting forestry activities. For large-scale afforestation the limits set by tracklaying vehicles, as suggested by Spoor and Muckle (1974) at 17° , may be noted but specialist machines are capable of operating at slopes in excess of 25° . Toleman (1974), however, suggests that slopes of up to 35° are acceptable for forestry.

Steep slopes cause more surface run-off and this may be of benefit to soil conditions especially where the slope is convex and where there is a net loss from the site. There is, therefore, a greater likelihood of better drained soils occurring in these situations than on gentle slopes where run-off is slow; particularly on concave slopes where water tends to accumulate (Pyatt, Harrison and Ford, 1969).

The effects of the shape and steepness of slope on soil-moisture and micro-climate are considerable, but the effects on tree growth resulting from the interplay of these factors depends almost entirely on the species of tree.

Aspect, as it affects the intensity of exposure and insolation, which in turn partly controls the amount of evapotranspiration and thus the amount of precipitation, is an important factor in tree culture, but again much depends upon the species of tree. South-western slopes, being the warmest and driest are generally the best areas for forestry.

However, turning from theoretical to more practical aspects, commercial forestry requires an infrastructure of buildings and roads. Whilst buildings may be located on strongly sloping land (as will be discussed in Section 3.4.4), forestry roads are subject to vehicular requirements. As a general rule, Huggard (1958) suggests a ruling slope of 5.7° with a maximum of 7° .

3.4.2.2. Climate

Both macro and micro-climate are the most important environmental parameters for tree cultivation and, as with slope, thresholds are different according to species. Thus, when considering afforestation, an attempt must be made to plant the species best suited to the environment of the planting area (Edlin, 1964).

An exposed situation together with an unstable site may lead to widespread windthrow when crops reach a susceptible height. In individual cases, the causes of windthrow are often complex, but analysis has led to the general conclusion that, where rooting is shallow owing to poor subsoil aeration or a mechanical restriction, the crop is almost inevitably predisposed to premature windthrow (Pyatt et al. 1969). This susceptible height varies with location and species, decreasing as the degree of exposure increases. Windthrow is irregular in occurrence both in terms of time and area and thus may lead to a very variable annual production; depending as it does upon the strength and frequency of the winds and on the distribution of susceptible plantations during a particular period. However, the variation in yield is unlikely to present an insurmountable problem in small forests, particularly when these areas lie in areas of moderate population density where excess volume can be worked by men living locally (Robertson, 1970).

Certain tree species will withstand exposure more than others. For example, Corsican pine (Pinus nigra) is not suitable for upland areas and will be most successful in low rainfall areas. Mountain pine (Pinus mugo), on the other hand, will stand great exposure and, although not a timber tree, will provide useful shelter belts. Beech (Fagus sylvatica) likes a mild sunny climate and frost hollows should be avoided, whilst, sycamore (Acer pseudoplatanus) is fairly frost hardy and stands exposure well (Edlin, 1964). Leyton (1960) related the growth of forest trees to monthly site temperatures, but one aspect of the windthrow problem about which there is still much to be learnt is the extent to which the velocity of damaging gusts is related to the topography. (Pyatt et al., 1969).

3.4.2.3. Soil

It is suggested by Toleman (1973) that climatic and topographic factors probably play a greater part in classification for forestry than soil factors. Stoniness or boulder content will have little effect on forest utilization, unless a very high frequency is encountered, and organic or organo-mineral soils do not represent as severe limitation to forestry as they do to agriculture. However, wetness associated with a heavy clay texture and low or nil potential water deficit, may cause a serious limitation to growth and stability. Depending on the species of tree, three days waterlogging may drastically alter a yield.

On soils derived from limestone and associated till, soil conditions alter tree growth and performance markedly. In the Leeds district of Yorkshire deciduous trees, notably sycamore and beech are predominant with pine and larch (Larix spp.) grown as a "catch crop". These conifers are usually planted at about the same time as the deciduous trees and provide an early return from thinnings. The growth of trees on limestone soils is restricted by the dearth of water and a high lime content which is inimical to conifers over about 30-40 years old. Scots pine, (Pinus sylvestris) although tolerant of a wide range of soils, does not grow well in highly calcareous soils (Crompton and Matthews, 1970). A shallow soil over limestone is particularly limiting for many conifer species, although these soils can be "utilized quite productively by intelligent agricultural practice" (Toleman, 1974).

Soil depth is a critical factor to optimal tree growth. 45 cm is considered a minimum depth to rock for a good crop and less than 15 cm of soil is not really commercially viable, with deciduous trees requiring greater depths than conifers (Thompson, 1975; pers.comm.). Observations have shown that relatively undisturbed bedrock, even though it may contain a system of deep fissures and joints, is only penetrated by short thin roots contributing little to increased stability and that, in well drained

soils, the depth of freely rootable material gives a good idea of the windthrow hazard of soils (Pyatt et al., 1969).

As regards nutrient status, much depends upon species. The majority of common conifers grow best on acid soils, with a pH (water determined) of between 4.5 and 5.5. If the pH is outside this range and especially if the soil is neutral or alkaline (pH 6.5 - 7.5) or greater, many species will grow badly. Broadleaved trees tolerate soils with a more alkaline reaction and will grow best with pH values of up to 7.0 and for poplar (Populus spp.) a pH of over 5.5 is essential (Edlin, 1964). Scots pine, Corsican pine and Japanese and European larch (Larix leptolepis; Larix decidua) will tolerate shallow limestone soils, but other conifers will heel over after about 20 to 30 years because of the calcareous nature of the soil and shallow depth to the calcareous rock (Thompson, 1975; pers.comm.).

Coulter (1974) outlines work on certain parameters as they affect tree growth. Låg (1961) in Norway has shown that the growth of larch and spruce (Picea spp.) is most influenced by depth to bedrock. Wilde and Iyer (1962) in the United States have shown that the poor growth of forests can be associated with small amounts of silt and clay in the soil, a deficiency of some major or minor element, or shallow rooting due to impermeable horizons, waterlogging or compacted surfaces which induce run-off. The multiple regression analysis of Ralston and Barnes (1955) on 12 variables at 200 locations of Slash pine (Pinus sp.) indicates that depth to mottling and depth to the accumulation of fine textured material are the most important soil properties associated with growth. The growth of Lodgepole pine (Pinus contorta) is, according to Duffy (1963) correlated with slope and depth to lime and pH of the B2 horizon. Eck and Whiteside (1963) propose that the growth of Scots pine is adversely affected by the presence of fine calcium carbonate and an underlying compact till. In Britain, Osmond et al. (1949) found that the poor growth of fruit trees correlated with shallow rooting depth, waterlogging, lime (inducing chlorosis) and a sandy texture (inducing drought).

3.4.2.4. Water

Trees cannot thrive if the ground is waterlogged. Although roots will stand temporary submersion they cannot remain alive if water lies for long periods (Edlin, 1964). Thompson (1975; pers. comm.) suggests that three days waterlogging may adversely alter a crop yield. For most trees, therefore, but particularly for conifers with their shallow rooting systems, flooding is detrimental to commercial production.

The cultivation of flood tolerant species, such as poplar, alder (Alnus spp.) and willow (Salix spp.), may be undertaken on sites prone to flooding but, except in certain areas, the Somerset levels for example, these trees are of little economic significance.

3.4.3. Nature Conservation

The importance of natural resource attributes to the undertaking of nature conservation, management and planning is all bound up with the concept of "habitat", which may be defined as "the location (with its attendant physical and biological characteristics) in which a living thing exists" (McVean and Lockie, 1969). The conservation of habitat is essential for the protection of fauna and it is habitat overall that forms the basis

for most nature conservation capability analyses for planning purposes. Goldsmith (1975) succinctly puts the case as follows: "the problem that concerns the naturalist and ecologist is to identify the exact number, extent and spacing of various habitats for the survival of each species of plant, animal and fungus. The problem of society is to decide how many such species are required, their abundance and how they should be distributed and the problem for the planner is to interpret the wishes of society and to ensure that their requirements are accommodated in competition with other demands on land".

The different types of habitat for species conservation cannot, of course, be discussed here but are outlined further in the development of a nature conservation capability analysis in Chapter 6 beginning on Page 187.

Finally, when planning formal wildlife areas; zoos, safari parks, sporting areas etc., similar considerations concerning visitor provision will apply as those outlined for recreation; to be discussed in Section 3.4.6.

3.4.4. Housing and Industrial Development and Road Construction

Natural resource attributes affect building construction in many ways, but since the properties to be considered when undertaking capability analysis are, in essence, similar to both housing and industrial development and, in purely pedological terms, also to road construction, they will be discussed together in this section.

The few studies on physical thresholds for building construction that are available identify certain parameters of prime importance. These include: slope, depth to bedrock, depth to water table, soil drainage, soil bearing capacity, stoniness, erodibility and quality of topsoil (Fabos and Caswell, 1977).

3.4.4.1. Slope

The principal influence of slope on housing and industrial development lies in the fact that the steeper the slope the more difficult construction becomes. The provision of access roads becomes a problem, as does an increasing erosion potential, thus raising costs. Even social costs increase, in terms of an inferior living environment caused by steep slopes, requiring a greater "expenditure" to overcome the problems of living in such a location. Fabos and Caswell (1977)*, in the U.S.A., indicate added development costs of \$1,300 for slopes of between 4.7° - 8.7° but no added costs below 4.7°. Slope form and aspect also add to costs, either through increasing the problems of construction in areas of complex landform configuration, or affecting climate to the detriment of construction and environmental living standards.

Housing development is significantly affected by the angle of slope, slope form and aspect, although a building may be constructed in virtually any situation with the aid of modern building methods and materials. Certain physical thresholds do apply, however, allied to both economic and social thresholds. As a general rule a maximum slope of 8.1° - 9.5° is taken as the threshold for large-scale residential development (Keeble, 1964; Williams, 1972) although opinions vary slightly around these figures.

* The references to development costs of Fabos and Caswell (1977) in Section 3.4.4 refer to the construction of an average of two "single-family wood-framed houses with basements" per acre.

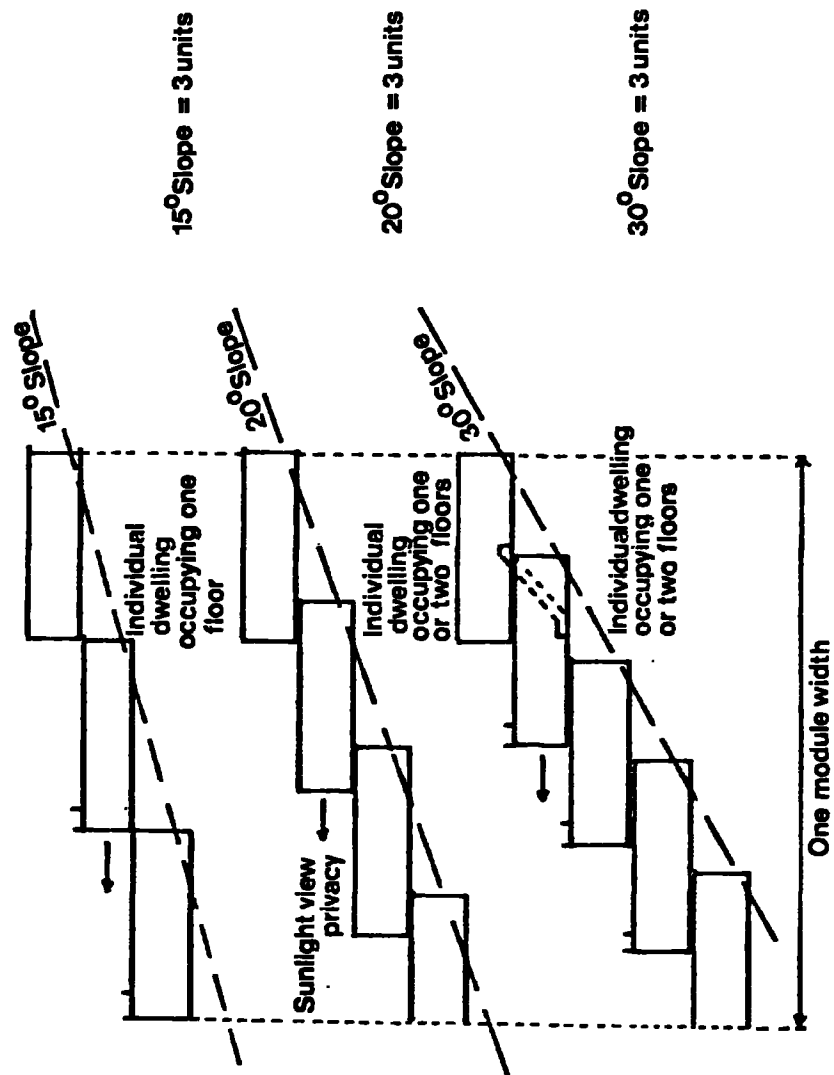
Brown and Crofts (1973) indicate a slope of 2.9° as the "maximum desirable gradient....for extensive development of housing" yet a threshold of 5.7° for "urban development"; presumably to indicate small-scale housing development on individual sites. Holmes (1968), on the other hand, indicates a maximum slope of 10° for general house building and a slope of 2.9° for house building "without special provisions". For specialised developments, such as houses for the elderly or the disabled, flat areas will be necessary.

Apart from the engineering problems of laying foundations in steeply sloping areas, slopes in excess of $8.1-9.5^{\circ}$ also provide social and design problems. There is difficulty in the siting of buildings; problems of road safety in wet conditions and the difficulty of pushing prams and carrying shopping baskets. Steeply sloping surfaces may result in surface-water run-off, particularly during summer storms when peak sewer flows sometimes occur, necessitating an increased sewer size and increased costs. Williams (1972) states that the extra cost of foul and surface-water sewers on a slope of 8.1° compared to an almost flat site is negligible for a small residential development, but is more significant for a large area of steeply sloping land.

If, however, threshold costs are not to be considered, slopes of up to about 30° may be utilised, as they are in many areas already. Pollit (1974), for example, in a review of the problems of the sloping site from an architectural point of view, indicates that by using the "stepped housing" concept, the steeper the slope the higher is the density possible, maintaining both scale and privacy as shown in Figure 3.4.

Aspect is also a significant factor in good housing layout and design. Williams (1972) states that the surface of buildings at ground level is not effectively warmed until the sun reaches an elevation above the horizon of greater than 5° . Therefore a north-facing slope (north-east - north-west) of more than 5° must exclude some effective sunlight from buildings particularly during winter. Although mid-winter sunlight has only a limited heating effect, the psychological effects and improvement in daylighting in buildings located on southerly-facing slopes, is substantial. North-facing slopes will also receive the full effects of cold north winds, will have a greater liability to freezing pipes, and the ground and roads will be more affected by ice and snow. On the other hand, a south-facing slope of greater than about 2.9° effectively increases the angle of inclination of the sun to the ground and thus its warming effect. In mid-winter the sun moves through a 90° arc from south-east to south-west and has a maximum elevation of 15° (Williams, 1972). Thus, a south-east to south-west facing slope will receive the maximum duration of mid-winter sun and will be warmed the quickest. These areas will be the brightest and healthiest, will have shorter frost and ice periods and will be protected from the cold north winds. The visual environment will also be better and this will be helped by smaller areas of permanent winter shadow around buildings. Unlike flat areas, south-facing slopes do not collect cold air. In regards to both direct costs and indirect social costs, these areas are the cheapest to use in requiring the least maintenance.

Fig 3.4 Stepped Housing (after Pollit, 1974)



Weddle (1973), in an analysis of slopes on the Flintshire coast, delineates aspects on slopes steeper than 2.9° of NNW-ENE as being the least advantageous for development in that part of Wales, followed by slopes facing WNW-NNW and ENE-ESE.

Industrial development is similarly influenced by slope. The most suitable land for large-scale industrial development is flat; allowing for both the construction of large buildings and ease of access. Holmes (1968) considers that a slope of 1.1° is the maximum desirable for large-scale industrial buildings and 1.9° the maximum for commercial and small industrial buildings. Brown and Crofts (1973), on the other hand, consider slopes of less than 1.4° , which over short distances "appear to be flat or almost flat" to be appropriate for the construction of major airports and railways and the optimum for large-scale industry, with a slope of 2.9° as the maximum for extensive development of industrial plant. Williams (1972), although agreeing with the latter figure, considers that land of this slope is not suitable for the development of all types of industry, but is about the maximum permissible for a large site. He suggests that a slope of 5° is the maximum for "individual factory sites". This would appear to be rather steep for most industries.

Ease of vehicular access also plays a significant role in the location of industry. A road with a slope in excess of 2.9° is about the maximum advisable because of the weight to power ratio of fully laden lorries and the possibility of de-icing requirements in winter if a road exceeds this angle. It is possible to build an access road in any alignment across land with an angle of slope of between 2.9° and 1.1° without any major increase in costs compared to flat land. However, level sites are naturally more desirable and flat land allows the largest buildings, any type of use or layout and the greatest flexibility in planning.

Aspect is not as important for industry as it is for housing and is only of significance as it affects ice and snow on access roads.

The effect of slope on transportation has been indicated in previous sections as having an influence on both the type of vehicles used and the direct costs involved in construction.

Long steep hills have a considerable effect on vehicle speeds; especially those of commercial vehicles and since restrictive sight distances are usually associated with steep uphill gradients the speed of the traffic is often controlled by the speed of slower commercial vehicles - thus, as a result, not only will the operating costs of the vehicles involved be increased but the capacity of the road may have to be reduced in order to maintain the required level of service (O'Flaherty, 1967).

Steep gradients also tend to increase the likelihood of accidents, as on uphill grades faster vehicles are tempted to overtake where normally they would not. On downhill grades speeds tend to increase and, as a result, the ability of a road user to stop or take other emergency action may be curtailed especially in inclement weather. Angles of slope of up to about 3.8° have relatively little effect on the speed of a motor car but the speeds of commercial vehicles are considerably reduced when long slopes above 1.1° are involved. An angle of 2.3° is regarded as a desirable maximum on major highways (M.O.T., 1968). In some cases, when uphill sections are less than about 183 m, slopes of 2.9° to 3.3° may be used and a relaxation may be applied to slip roads (O'Flaherty, 1967).

O'Flaherty argues that the maximum gradient is not in itself a complete design control, as it is also necessary to consider the length of the slope. If the uphill climb is extremely long "a crawler lane" may be required.

Road drainage is an integral part of highway design and, therefore, must be effective, not only to clear the road of surface water but also to prevent it from seeping into the road foundations(M.O.T. 1968). A maximum longitudinal fall of 0.2° is suitable and special attention is required at changes from superelevation to normal camber to ensure longitudinal fall.

3.4.4.2. Climate

People are continually demanding better environmental standards and as the higher the altitude the worse is the climate, the less is the demand for housing development. The greater the altitude the greater is the exposure to wind, rainfall, frost and snow, and ridge tops are particularly unsuitable and unattractive for housing development. This is especially true in Co. Durham, as such a position is often associated with a lack of tree growth to provide shelter and landscaping; both generally considered as essential to good housing layout. This exposure is particularly severe if ridge tops are not located sufficiently near high enough ground to provide adequate shelter. High altitudes are also affected by the increased incidence of low cloud coverage which, if persistent, is inimical to pleasant living conditions.

The incidence of fog and frost, as previously mentioned, is greatly affected by topography. Air immediately above ground level becomes colder from mid to late afternoon and this cold air drains down to flat valley bottoms and flat, low-lying, coastal areas. In spring and autumn the temperature change is relatively large and water vapour condenses to form mist and fog. Areas of cold damp air are harmful to health and to buildings and cold and wet conditions retard vegetative growth, and poor visibility interrupts road communications, causing accidents.

As far as industry is concerned, climatic factors will have little effect on individual industrial development location in purely physical terms unless process requirements warrant a particular climatic range. They might, however, determine the regional location of a concern purely by entrepreneurial preference. Local climatic conditions affect road provision in terms of the greater costs involved in construction and maintenance with an increase in adverse conditions; in particular frost, snow and fog. They will, have a considerable influence on the choice of route of a particular road, but will have little effect on whether the overall concept of a highway between A and B should be undertaken or not; for example, the M62 over the Pennines.

3.4.4.3. Soil

It is not intended to discuss in this section the engineering properties of soils that are analysed when undertaking housing, industrial or road construction, these being beyond the scope of the thesis. Rather, this section will indicate certain pedological features which give an indication as to the suitability or not of land for development, with special reference being placed upon those factors already mentioned as being significant on Page 46.

A shallow soil depth to bedrock, especially if the rock is very hard, may necessitate the excavation and blasting of material before development can proceed. In addition, to being costly, such measures cause unwanted construction side-effects in the form of air and noise pollution. Hunter, Tipps and Coover (1966) state that at San Antonio in Texas, past experience has shown that the design and performance of buried pipelines has left much to be desired and that a number of soil properties are known to affect the cost of installation and length of service, amongst which is soil depth to hard rock. If the depth to rock is shallow, the costs of excavation are directly affected, whilst hard rock fragments or gravel in the profile and backfill may damage protective pipe coatings. Fabos and Caswell (1977), in developing a suitability technique during the Metland study for the building of "single family wood-frame houses constructed with basements and developed at an average density of two dwelling units per acre," indicate a depth to bedrock of between 0-61 cm as being "least suitable"; between 61-152 cm as being "moderately suitable" and above 152 cm as being the "most suitable" for development. They also indicate that, as a result of a shallow depth to rock affecting excavation and trenching, blasting and grading requirements, the following additional costs can be added to the initial costs of development: at 61 cm \$20,000; between 61-152 cm \$5,000 and at 152+ cm \$200 decreasing. Montgomery and Edminster, in outlining soil limitations for buildings in recreational areas (chalets, lodges, etc.) in 1966 suggest that the depth to hard bedrock for their "none" to "slight" limitations categories should also be 152+ cm but for the "moderate" category depth should be between 91-152 cm and for the "severe" class a figure of less than 91 cm is indicated.

Thornburn (1966) proposes that soil surveys provide enough information on the depth to shallow rock to make valid preliminary estimates of the cost of rock excavation. Shallow depth to rock is significant in all development projects, as the cost of rock excavation is usually three or four times that of earth excavation and for roads the cost of alignment over shallow rock could be 50-100% greater than that where only earth excavation is required.

The drainage properties of soils are extremely important to areas undergoing any type of development (Witwer, 1966), in terms of the actual capacity of soils to retain water and of the depth of soil to the water table; both factors which may be linked in practice.

A high water table will directly affect the construction of foundations, basements, the provision of trenches and excavation in general and is particularly significant to the provision of pipes for utilities. Retaining walls and the general landscaping and "environment" of areas surrounding buildings are also detrimentally affected by high water tables.

Poor soil drainage in general, not necessarily allied to a high water table, as well as adversely affecting development in the ways indicated in the previous paragraph, will also cause problems with grading, slope stability and run-off and erosion control and the effects of lateral seeping and freezing of soil groundwater will soon be felt.

Such adverse effects may be overcome by the use of pumps or other drainage or construction measures, but costs increase substantially with their use. Fabos and Caswell (1977) propose the following additional costs involved in housing development:

Table 3.5

<u>Depth to Water Table</u>	<u>Estimated Added Development Costs</u>	
0-91 cm	\$ 5,000	
91-152 cm	1,400	51
152+ cm	0	

DrainageEstimated Added Development Costs

Poorly to very poorly drained	\$ 5,000
Moderately well drained with hardpan	1,400
Otherwise	0

The same authors also suggest the following classes of suitability for the same parameters:

Table 3.6

	Most Suitable	Suitable	Moderately Suitable	Marginally Suitable	Least Suitable
Depth to Water Table	152 cm	91-152 cm		30-91 cm	0-30 cm
Drainage	Well to moderately well drained. No hardpan	Excessively drained	Mod. well drained with hardpan	poorly drained	very poorly drained

Different soil types modify the amount of solar radiation absorbed by the ground. Differences in moisture content, an important factor in the heat absorbtivity and conductivity of the soil, are particularly important, especially in the case of open non-built-up areas. Dry soils having a high percolation rate exacerbate "climatic stress" by warming quickly and cooling quickly. Wet soils, on the other hand, with a low percolation rate, in combination with low-lying areas, have a higher potential for radiation, fog occurrence. Moist soils are more likely to modify potential extremes in surface temperature, especially diurnal fluctuations (Fabos and Caswell, 1977).

It has already been noted that the provision of pipes for utilities is affected by bad drainage. Corrosion can be a serious problem and may be predicted from the presence of excess soil moisture, low electrical resistance and differences in drainage or soil permeability, any of which can cause differential aeration along a buried metal pipe; hence inducing corrosion. Corcoran, Jarvis, Mackney and Stevens (1977) consider that resistivity, redox potential, pH value, sulphide and sulphate content and moisture are the most important soil properties affecting the corrosion of metal.

Speirs (1976) reports that on the extensive Stirling Soil Series in Perthshire, which is formed on marine silts and clays with buried peat beds, areas of very intense subsoil activity occur locally within the soil. At depths of just over one metre, pH values of 3.4 have been recorded. Sulphate levels can also exceed 1.0% and these conditions are very harmful to normal cements. Resistant materials, such as high alumina cements must be used for pipes and structures and it is now standard practice on this series for the subsoil to be treated before using concrete.

Foul drainage facilities in general are especially problematical in locations not served by public sewer facilities and where on-site sewage disposal schemes have to be used. Although all large-scale housing developments in Great Britain have to be connected to mains drainage, on-site septic tank disposal is often necessary for single sites. Such means of disposal is invariably a necessity in many overseas countries and is widespread in the United States where the density of development does not necessarily warrant the expense involved in the provision of public sewers.

Witwer (1966) has produced a five group capability system of soil limitations for on-site sewage disposal as influenced by soil drainage. Parameters affecting this classification include permeability, porosity, seasonal and permanent high water tables, slope, hillside seepage, soil creep, erosion, surface run-off, hardpan layers, depth of soil to bedrock and others.

The bearing capacity of soils to withstand housing development from a pedological viewpoint has been quantified to a limited extent by Fabos and Caswell (1977) as indicated on Table 3.7 and also put in economic terms; plastic and non-plastic silts and clays, peat and muck adding \$1,500 to development costs. Also the shrink-swell properties of soils preclude the use of rigid pipe construction materials.

Table 3.7

	Most Suitable	Suitable	Moderately Suitable	Marginally Suitable	Least Suitable
Bearing Capacity	Clean Gravels & Sands	Silty & clayey gravels	Silty & clayey sands	Non-plastic silts and clays	Plastic & organic silts & clays; peat; muck

Alluvial soils, formed from sediments deposited by flood waters located on level or near-level areas along streams, do not form desirable development areas. Whilst the construction of housing and industry in those areas is not an engineering impossibility, development is generally unwise "due to cost and design factors that must be considered in overcoming periodic inundation, high water tables, unstable soil conditions and other problems of varying complexity" (Witwer, 1966).

Stony soils significantly affect development. Difficulties are involved with excavation, trenching and grading as well as with the ultimate landscaping of a site. Fabos and Caswell (1977) propose that stonefree soils are the "most suitable" for housing development; few stones are "suitable"; very stony are "moderately suitable" and extremely stony soils are the "least suitable".

Although not considered in this country as being significant as a developmental parameter, the erodibility of a soil is certainly significant overseas and may be significant in certain parts of Britain although, apart from in areas of dune sands, no work has been done on this. Likewise, published information for suitability ratings is very scarce. Fabos and Caswell (1977) indicate the following categories where erodibility affects grading, slope stability, erosion control measures, retaining walls, and general damage to the environment of a dwelling:

Table 3.8

	Most Suitable	Suitable	Moderately Suitable	Marginally Suitable	Least Suitable
Erodibility	0-5 cm topsoil removed	5-15 cm topsoil removed			15 cm topsoil removed

Finally, the absence of a good quality topsoil for landscaping purposes will necessitate additional expense if it requires bringing in to the site from far afield. To a degree, however, the type of landscaping can be moulded to the soil at the site, especially for the landscaping of commercial buildings, although choice of species for any scheme will be restricted on "poor" soils.

If full services (water, sewers etc.,) are provided and the soil is suitable for residential development then the soil is usually suitable for business and industry. Exceptions to this arise from excessive slope and the inability of the soil to support heavy weights. Even in this instance, after the planning factors are looked at and considered suitable, the decision to develop will invariably be one of economics (involving threshold costs). The cost of pilings, floating foundations or other corrective measures that may be required to combat soils with low bearing strength, may be justifiable if the economic pressure is sufficiently great. (Thomas, 1966).

Thornburn (1966) outlines systematically the use of "agricultural" (pedological) soil surveys in the planning and construction of highways and states that even without complete engineering test data soil surveys are useful in detailed location planning. For example, one use is to determine the location of organic soils and other soils of low bearing capacity.

The significance of the measures so far discussed to physical constructional development lies not only in the initial costs to the developer in overcoming natural constraints. The eventual owner of a building may himself bear considerable expense due to the exigencies of repeated water damage, erosion, frost heave, cracked foundations or other consequences of poor site selection which necessitate post-construction site improvements.

Slope, climate and pedological factors, however, are not the only factors to be considered in the choice of a particular site for construction purposes.

3.4.4.4 Vegetation

The development of housing and industry and road construction are influenced by the vegetation existing at a potential site in similar ways.

The physical presence of woodland may offer both advantages and disadvantages. Trees may impose considerable limitations, both in the costs of clearance and the loss of amenity, landscape and wildlife. Likewise, the routing of roads may be significantly affected by woodland on amenity, landscape or wildlife grounds, but the costs of clearance generally does not have much influence on major projects.

On the other hand, the presence of trees may provide desirable landscaping for housing and screening for industrial buildings and roads. Trees also provide shelterbelts in areas of harsh and exposed climate, having a significant effect in reducing wind speed and its associated wind chill factor. For example, a forest can reduce wind speed by up to 50% after a distance of 61 m, and in some instances up to 93% after a distance of 122 m (Geiger, 1965).

The amount of solar radiation received by the ground is also modified by vegetative cover. Tall, dense forests with a height greater than 12 m and a crown density greater than 80% provide ideal moderating influences on adverse climatic effects. Solar radiation receipts are absorbed and reflected at the top of the crown to reduce potential high summer temperatures, thereby increasing comfort and reducing the cooling costs of development. Short, thin forest stands with a height between 6-12 m and crown density between 20-80 % provide similar effects, but to a lesser degree. Open spaces,

however, such as golf courses, playing fields and crop and pasture lands have little moderating effects on winds or temperature (Fabos and Caswell, 1977).

3.4.4.5 Fauna

In the past, fauna has rarely affected these land uses unless a Site of Special Scientific Interest has been involved or if local authorities have adopted conservation procedures as part of policy. Recently the effects of wildlife on industry in the form of damage to industrial processes have been reported, as has the danger to aircraft through birdlife near airport runways. Likewise, the danger to motorists through large mammals straying onto roads has been a cause of concern; for example, deer in the New Forest. Certain enlightened transportation planners have taken the activities of wildlife into consideration in the planning of routeways and in extreme cases have provided road underpasses on traditional animal routes when a new road has been built.

Certain developments, such as the construction of lagoons, and well vegetated or flooded quarries may, on the other hand, provide new and important habitats for wildlife.

3.4.4.6 Water

Flooding causes loss and damage to life and property and anti-flood measures on a large scale are very costly. In addition, it is not possible to eliminate the possibility of exceptional floods, and the engineering difficulties of regulating a flow or providing protective measures in one place, without causing problems elsewhere where urban development may already be present, are great. Areas of known or possible floodland are, therefore, highly negative to housing development.

Areas liable to flood may be used for certain ancillary requirements of industry. For example, for occasional storage facilities, marshalling areas or overflow car or lorry parks. However, for main buildings and plant, these areas limit development, as they do in housing.

It is largely the cost effectiveness in terms of the flat land site versus the frequency of flooding that has to be taken into account. For major highway routes, floodland has a high negative rating owing to the costs of maintenance involved and danger to life, but minor and access roads may be constructed if an economic or social need can be established.

3.4.5 Recreation

3.4.5.1 Slope

Slope, in the form of either angle, form or aspect, may have a positive or negative effect upon recreational land use depending upon the nature of the recreation activity. Areas of steep slope, in being unsuitable for other forms of use and very often being of high scenic value, may be highly regarded for recreation for both informal pursuits such as walking, or certain formal activities such as skiing.

However, the majority of organised formal sports require areas of comparatively flat land. Gooch (1963) states that the maximum lateral slope for playing fields is 1.4° , the recommended angle for winter games areas is 0.9° - 0.7° and the maximum desirable cross-fall for cricket squares is 0.6° . The British Standards Institution (1969) suggest that for general pitches an absolutely horizontal surface is not necessary and may lead to serious drainage difficulties. A uniform fall of 0.7° , is perhaps ideal but slopes of up to 1.1° need not be adjusted provided that they are even. In hilly or rocky districts even steeper angles might be inevitable, but a "reasonable standard of play without undue fatigue" is not possible on slopes of greater than 1.4° .

The planning of informal recreation activities may require the construction of buildings, roads and car parks, camping and picnic areas, paths and trails; all of which will have different threshold limits for their provision. Montgomery and Edminster (1966) propose the following thresholds:-

Table 3.9

	<u>Degree of Limitation</u>		
	<u>None to Slight</u>	<u>Moderate</u>	<u>Severe</u>
	<u>Slope Threshold</u>	<u>Slope Threshold</u>	<u>Slope Threshold</u>
Camp Areas	0 - 4.7°	4.7° - 8.7°	$> 8.7^{\circ}$
Recreational Buildings	0 - 4.7°	4.7° - 8.7°	$> 8.7^{\circ}$
Play Areas	0 - 1.1°	1.1° - 4.7°	$> 4.7^{\circ}$
Paths & Trails	0 - 8.7°	8.7° - 14.0°	$> 14.0^{\circ}$
Picnic Areas	0 - 4.7°	4.7° - 8.7°	$> 8.7^{\circ}$

For example, sanitary facilities involving septic tank filter fields or sewage lagoons will be severely affected by steeply sloping land (Bender, 1961; Witwer, 1966). Bayfield(1973) has shown how on unmanaged footpaths on An Lurg and Ben MacDhui near Cairngorm in Inverness-shire, width increased with the steepness of the path surface as well as the wetness and roughness. Steady increases in width were recorded with increasing angle of slope up to the maximum of about 15° . Slope angle has a significant role in footpath planning if excess costs through increased maintenance are to be avoided.

Aspect will also be of some significance when planning countryside recreation facilities, as southwards-facing slopes will tend to be the most sheltered and desirable from a psychological and sociological standpoint.

3.4.5.2 Climate

Macro-climatic conditions have overall influence upon the type of recreational activity envisaged as far as policy is concerned, and micro-climatic conditions influence the location of recreational buildings and complexes for both formal activities and development for informal pursuits. For example, a recreational sports complex will be affected by exposure to wind, fog and ice in particular and the location of countryside recreational buildings, roads, camp and picnic sites will be heavily influenced by exposure to the elements. The problem of aspect has already been noted.

3.4.5.3 Soil

Although most types of soil are used for some type of recreational activity, most have certain limitations depending upon the nature of the activity in question. Arguably it is the susceptibility of a soil to erosion that is the most significant to development, but virtually no information is available on the threshold levels of people/soil type or characteristics in order that capability classifications can be produced, other than in areas of dune sand.

Soil erosion initiated by the activities of both man and animals is the result of climate, topography and vegetation as well as the nature of the soil. The processes of erosion operate continuously, but the rates of erosion may be retarded or accelerated by either changes in the power of the agencies of erosion or by a change in the degree of protection afforded to the soil by its vegetative cover and/or its structure (Leopold, Wolman and Miller, 1964). These changes are caused principally by trampling and once having started, allow the agencies of erosion, notably wind and water, to increase in severity.

Wind erosion affects a limited range of soils, principally of a peaty or fine sandy nature which dry out rapidly. Water action, however, remains the major agent of erosion on most soil types (Speight, 1973). Thus, unprotected soils with high organic or sand contents, particularly in the topsoil, are unsuitable for play areas, camp sites, trails and other recreational areas that have a heavy foot traffic.

The disappearance of the soil litter layers by mechanical disturbance and subsequent erosion is one of the processes which normally occurs in the initial stages of path formation on any soil (Speight, 1973). Burden (1970) states that on a newly opened nature trail in Surrey, it was found that in the first week of use, with the passage of 8,000 people, the volume of woodland leaf litter on the trail had decreased by 50%. Speight observes that the breakup of soil horizons below the litter layers by the effect of trampling alone appears to be rare and on any soil other than those of a peaty nature, compaction of these horizons occurs instead. This having occurred and the "stability" of the soil having been upset, the agents of erosion finally cut through the layers below. Thus, in recreational areas where wind and water action is slight, it is soil compaction and not erosion as such that is the principal effect of human pressure.

It has already been indicated that soils with a high organic matter content and/or sand content are undesirable for recreational use, as they are unstable when dry and prone to wind and water erosion. On the other hand, soils high in clay become sticky when wet and do not dry out quickly after rain and are susceptible to increased surface run-off and thereby erosion.

Thus, Montgomery and Edminster (1966) propose that soils with a sandy loam or loam surface texture, together with other favourable characteristics such as good drainage, are the most desirable for recreational use that involves heavy trampling.

Soils that remain wet all year, even if not flooded, have severe limitations for most forms of activity. Those that are wet for only a part of the year or have a fluctuating water table are not as affected to such an extent. Vehicles become easily bogged down in wet clayey soils as well as sandy ones and wet soils also pose problems for the establishment of a grass cover, as indeed do dry sandy soils.

The ability of a soil to support a load is important for the establishment of recreational buildings and roads and the same factors apply as for housing and road developments.

Soil depth affects many activities. Locations where the bedrock is near the surface cannot be levelled for camp sites and playgrounds without undue cost and it is difficult to construct metalled roads and trails on these soils. Problems also occur in establishing vegetation on shallow soils with impervious layers or rock, thus making poor locations for playing fields and other intensive uses (Montgomery and Edminster, 1966). However, the opposite may also apply. If no construction is required in the form of metalled surfaces, the bare rock may form a tolerable surface for car parking which can easily be exposed if near to the surface. In addition, paths and trails may be allowed to form "naturally" by the trampling and erosive forces quickly exposing the rock. In limestone areas especially, the scars produced may be perfectly acceptable and maintenance costs will be slight, although when well worn, rock can be dangerous when wet.

Stony or rocky soils may have moderate to severe limitations for camp sites and play areas and well worn gravels and stones form a dangerous surface for paths if the land is steeply sloping.

As well as these direct soil factors of texture, drainage, depth, stone content etc., the ability of a soil to support a vegetative cover is essential for soil conservation factors and for shade and other amenity considerations.

The above discussion has focussed on the problems associated with recreational development in predominantly informal countryside situations. Much attention, however, has been paid in recent years to the ability of a soil to support more formal pursuits, such as cricket and football and other sport and leisure activities.

Casson, Hartnup and Jarvis (1973), in outlining the suitability of soils for golf courses and playing fields, take soil drainage, texture, permeability, stone content and slope as the main parameters for study. Jarvis (1976) discusses the properties to be analysed when determining the suitability of unimproved land for winter playing fields. Retained water capacity, bearing strength, soil moisture and infiltration rate are important qualities for this purpose. These are influenced by texture, wetness, consistency and organic matter content. Slope angle and surface stoniness are other features directly affecting such use. Ideal sites are near level, well drained, have rapid permeability, are free of rock outcrop or stones on the surface and are not slippery when they are wet.

3.4.5.4 Vegetation

In planning a recreational area, the type of vegetative cover will have a significant effect on capability. From an aesthetic point of view, vegetation can provide attractive environments for a specific development whilst from an ecological standpoint intensive projects should not be located in sensitive areas; for example, caravan sites near fragile sand dune environments. On the other hand, when recreational management is considered, certain vegetative complexes, coniferous woodland, for example, are capable of accommodating a great deal of recreational activity and associated facilities without unduly affecting either the landscape or the ecological balance.

Little work has been done on the immediate effects of recreational activities on vegetation in the form of bruising, breaking, cutting and picking, with most of the relevant information, as Speight suggests, coming from casual observations. Quantitative threshold levels for capability analyses, to enable the siting of developments with a minimum of ecological disturbance, are very scarce.

Damage to vegetation may be deliberate, as in the clearing of ground to provide camping or other countryside facilities; e.g. in the U.S.A. where tree cover thinning is carried out to alter ground conditions (Wagar, 1965; Jemison, 1967) and the felling of ageing trees to protect campers from injury as in the New Forest (Speight, 1973). Alternatively, damage may be coincidental, and Speight proposes that nearly all such damage is caused by trampling and is recorded for "sand-dune systems, grassland, heathland, and woodland and mountain areas". Bayfield (1971) in a field trampling trial on Cairngorm found that *Sphagnum* showed signs of saturation at about 80 tramples and *Trichophorum* at 240 tramples. Different species, therefore, react differently to pressure, both in effective damage and ability to recover. For example, the experiments of Bayfield above suggest that *Trichophorum* and S50 Timothy (*Phleum pratense*) appear to be much less seriously affected by trampling than *Sphagnum*, lichen or *Calluna*.

Speight (1973) lists the ground flora species that are resistant to trampling and states that perennial species that are woody and have an erect growth, including "dwarf shrubs" such as *Calluna* and tree saplings are particularly vulnerable. Plant picking and collecting also has a detrimental effect.

Throughout all the above discussion on how vegetation may affect land capability for the land uses under consideration, rare species have not been mentioned. In recent years, more attention has been focussed on the depletion of our native flora and, in any development, due consideration must be paid to rarities and these could form significant parameters in capability analyses. As mentioned on Page 42, in a considerable number of cases a form of statutory protection is afforded by the designation of Sites of Special Scientific Interest under Section 23 of the National Parks and Access to the Countryside Act, 1949.

3.4.5.5 Fauna

Recreational planning is affected by fauna in several ways. Either directly, where certain types of wildlife are inimical to certain leisure activities, (danger or nuisance value such as wild cattle, mosquitoes etc., for camp site location) or indirectly, whereby the actual recreational pursuit will disturb animal species.

Recreation affects animal species both directly by habitat modification and sporting activity and indirectly through disturbance. In some instances the mere presence of people may be sufficient to cause disturbance as has been observed in red deer (*Cervus elephas*) in open moorland (Nicholson, 1970) and many sea bird species. Much depends upon the species, however, and there is evidence that the breeding success of the red grouse (*Lagopus lagopus*) and ptarmigan (*Lagopus mutus*) on slopes is unaffected by people using the cable cars or walking through the area during the summer (Watson, Bayfield and Moyes, 1970). Speight (1973) suggests that animals of open habitats appear to be the most susceptible and that there are indications that the effects of disturbance depend more on the frequency of human pressure than on the number of people present at one time.

It is up to the recreational planner to decide exactly what pressure from recreation is "acceptable" on social as well as ecological grounds. Much depends upon the recreational land use being considered, for example, the presence of fauna may be the purpose of the recreational activity and species conservation a pre-requisite. As a result, recreational ventures may provide positive encouragement for fauna conservation.

3.4.5.6 Water

Water, in the form of rivers, lakes and streams, form a very important recreational resource for sailing, angling, swimming or landscaping. River banks and lakesides are important areas for recreational activity. For such informal countryside activities, flooding is of little significance.

For formal activity areas such as pitches for football, cricket etc., floodland, although perhaps used because of a lack of more suitable land elsewhere, will be a negative factor in capability.

The provision of countryside recreation facilities, such as camp sites, picnic areas, play areas and sanitary and other buildings, will require flood-free areas, as normally will car parks and access roads. The author therefore, cannot agree with Arnold (1975) that such areas are acceptable for such recreational development, as accidents can and do occur where rivers rise very rapidly along their courses.

3.5 Summary

The above discussion, after an initial consideration of the principal natural resource attributes of Stewart (1968) and the concept of thresholds, has outlined the effect of certain important parameters on selected land uses which will be met in later chapters. Although there is a great deal of qualitative information on threshold parameter levels for most land uses, quantitative data is not as freely available and much research has still to be done. In addition, certain parameters do not lend themselves directly to numerical assessments and it is inevitable, therefore, that some parametric evaluations will contain qualitative information.

PART 2

Chapters : 4 and 5

CHAPTER 4 - LOCATION OF STUDY AREA AND PROCEDURES ADOPTED IN
THE COLLECTION OF DATA FOR LAND EVALUATION ANALYSIS IN
SUCCEEDING CHAPTERS

4.1 Introduction

The aims of the study of land evaluation procedures in the Mid-Wear Lowlands have been outlined in the Introduction to the thesis.

This chapter discusses the location of the study area and the reasons for its choice, together with the methodology of data collection that forms the basis of the various analyses undertaken in the succeeding chapters.

4.2 Location of the Study Area

4.2.1 Introduction

In order to place the research on a realistic planning basis from the outset, W. Lanning, the then Countryside Officer of Durham County Council's Planning Department, was consulted as to the best location for a detailed study of land evaluation methods within the County. As a result of these discussions, the potential growth area bounded by Durham City to the south, Houghton-le-Spring to the north, Hetton-le-Hole to the east and Bearpark to the west was chosen for potential investigation (See Figures 4.1 to 4.3). Rather than study on a broad scale all the 77 sq.km. that make up this area, the majority of which is normally referred to as the Mid-Wear Lowlands, it was decided to take an east to west transect across the area to enable a more in depth analysis to be undertaken. The transect would, therefore, form the location for research.

4.2.2 Regional Location of The Transect Study Area

The region within which the transect study area is located is defined by Beaumont (1967) as "Eastern Durham" which he divides into three topographical regions (Figures 4.1 and 4.2). These are:

The Wear Lowlands
The Magnesian Limestone Escarpment and Plateau
The Tees Lowlands

4.2.2.1 The Wear Lowlands

The lowlands of the River Wear form a north to south corridor of constructional topography predominantly composed of thick glacial sands and clays. The maximum length is about 39 km and maximum width about 13km. Widespread depositional surfaces are a feature of the region at elevations of between 85 to 107m O.D. south of Durham City and at heights of between 43 and 61m O.D. to the north of the city around Chester-le-Street.

It is into these surfaces that the River Wear and its tributaries have cut a series of gorge-like channels, with floodplain development where less resistant material outcrops. Apart from these steep valley sides, gentle slopes predominate.

The Wear Lowlands itself, may be divided into three areas, broadly defined as the Upper Wear Lowlands from where the Wear emerges from the Pennine foothills north of Bishop Auckland to the beginning of the gorge sections at Durham City; the Middle Wear Lowlands between Durham City and Lambton and the Lower Wear Lowlands from where the river abruptly turns eastwards at Lambton Park to the estuary at Sunderland.

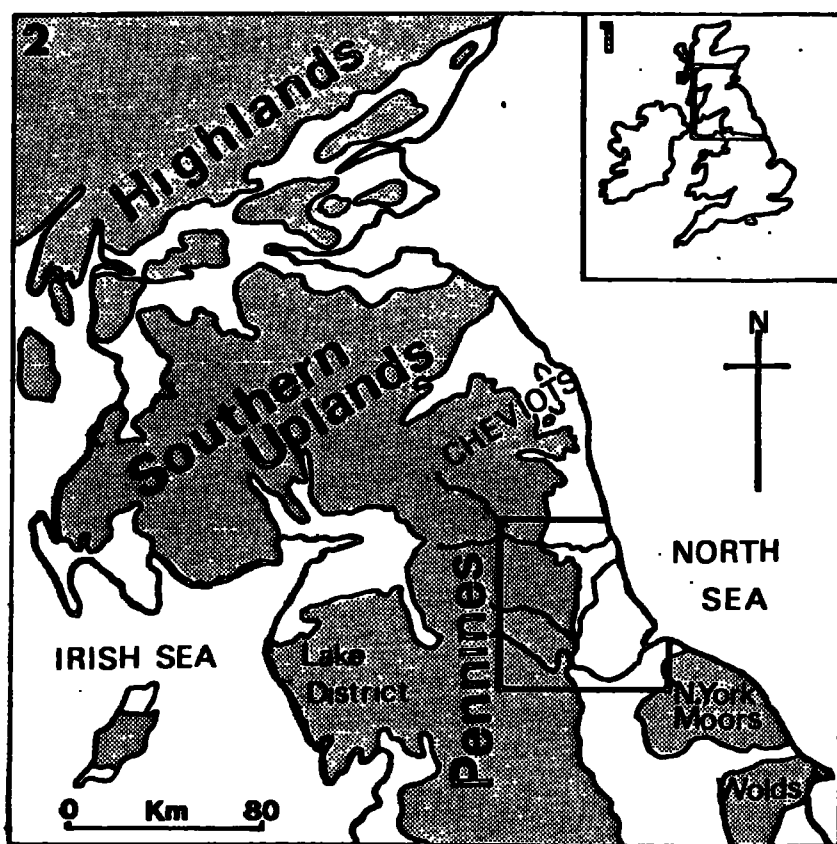


Fig.4.1

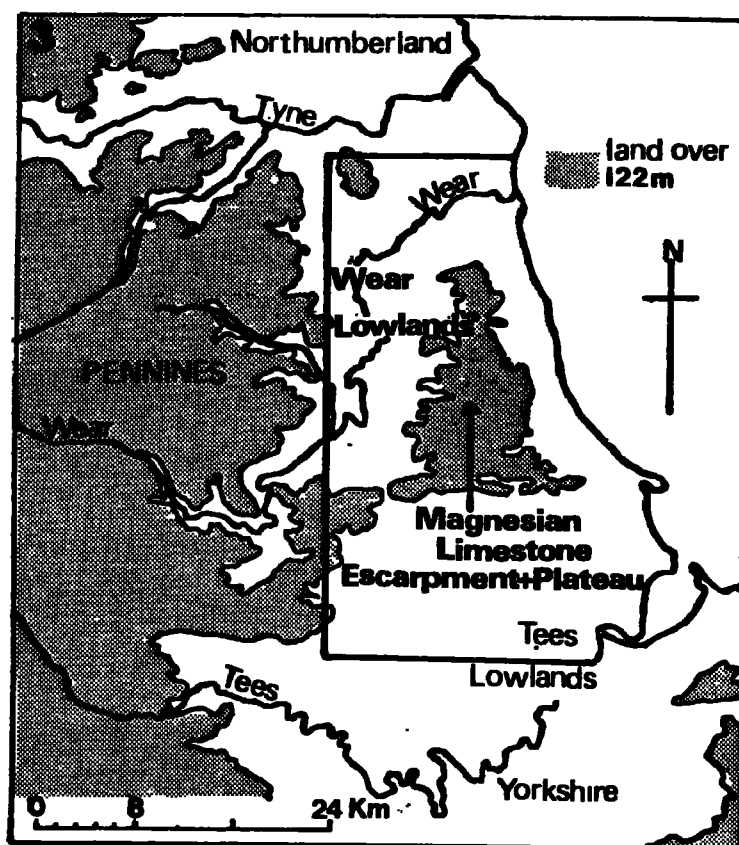


Fig.4.2

4.2.2.2. The Magnesian Limestone Escarpment and Plateau

The Permian Magnesian Limestone Escarpment rises abruptly from beneath thick superficial deposits to mark, according to Beaumont, the eastern boundary of the Wear Lowlands. It forms a west-facing feature cut in the solid limestone which stands about 61m above the area to the west, reaching a maximum altitude of 192m in the Cassop Colliery area. Despite fluvial erosion, which causes its rather dissected form, "the escarpment presents a remarkably unbroken feature throughout its length, and is breached completely in only three places", the most definitive of these being the glacial meltwater channel at Ferryhill (Beaumont, 1967).

The plateau of the Magnesian Limestone itself, which dips to the east, forms a triangle of land reaching to the sea. There is in general a marked accordance in height of the higher points of between 122 to 137m O.D. The fall of the plateau eastwards is quite gentle, but near to the coast a sudden drop to the coastal plain is evident east of a series of reef knoll features.

4.2.2.3 The Tees Lowlands

South of the Magnesian Limestone Plateau, the land drops in altitude into the thick drift covered Tees Lowlands.

The transect study area is situated within two of Beaumont's topographical regions; the middle section of the Wear Lowlands and the Magnesian Limestone Escarpment and Plateau (Figure 4.3).

There is some conflict, however, between Beaumont's definition of the eastern border of the Wear Lowlands using topographical divisions and that of Stevens (pers. comm., 1969) and Alexander (pers. comm., 1977) based on drainage. Whilst the former defines the Wear Lowlands as ending at the Magnesian Limestone, the latter two researchers propose that, because the location of the main watershed between the east bank tributaries of the River Wear and the dip slope streams of the Magnesian Limestone Plateau is some 1 to 1.5 km east of the line of the escarpment, the Wear Lowlands should be defined to this watershed, thus taking in an area of Magnesian Limestone.

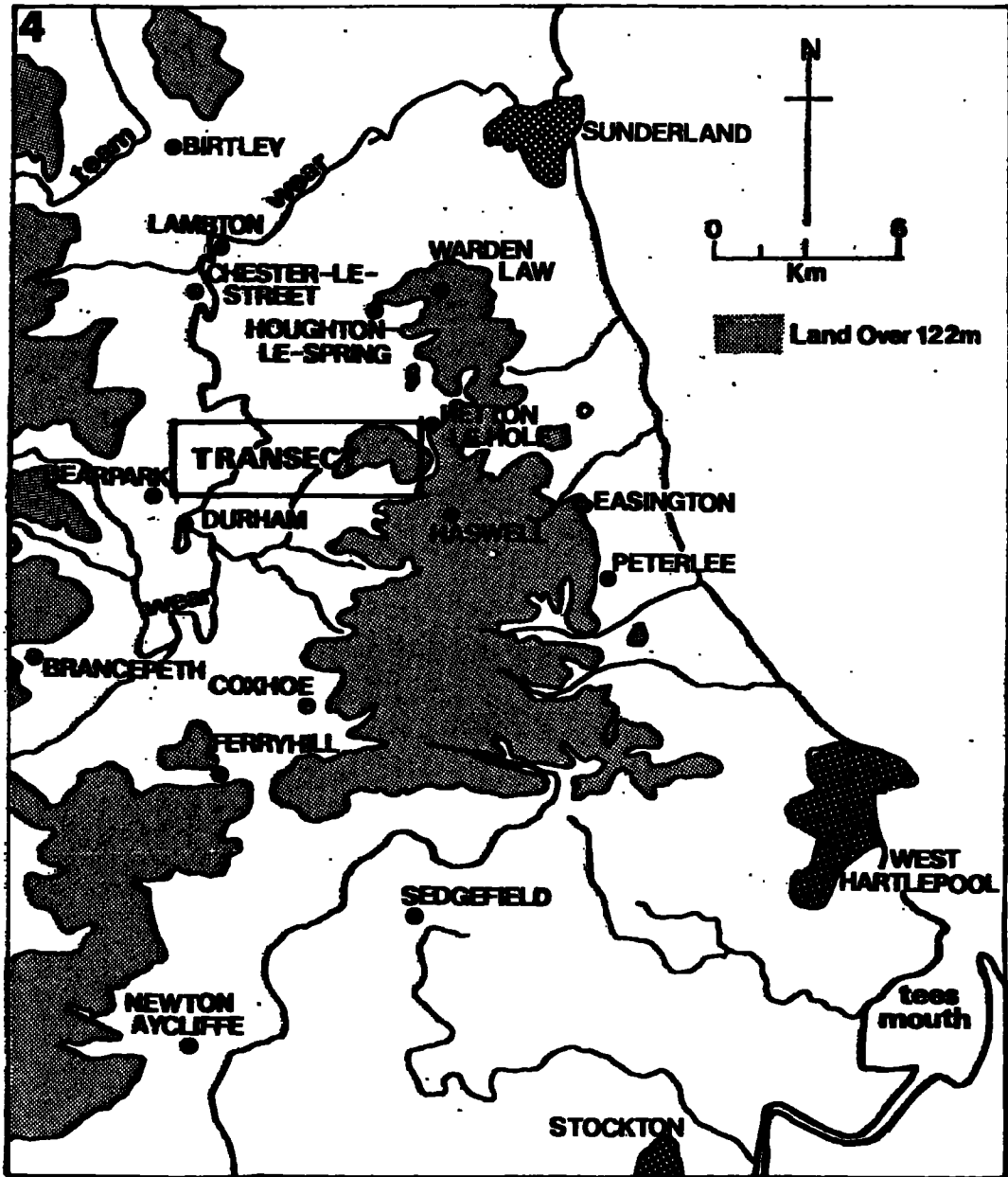
It is suggested by the author that, whilst Stevens and Alexander's definitions are more strictly correct and are, therefore, used in the title of this thesis, Beaumont's definition is more easily recognisable in land use terms because of the differences in underlying geology, and is used throughout the remainder of this work.

4.2.3 Definition of Transect Study Area

Because of the irregular distribution of village and hamlet development throughout the area selected for the location of the transect (outlined on Page 61), generated predominantly by past coal working, it was found impossible to construct a belt transect of any width across the whole area without running into much urban development. In addition, it was decided that a limit had to be placed on the amount of sampling in the field that could be realistically undertaken, particularly if differences in capability resulting from variations in soil type, topography, drainage and the underlying solid and drift geology were to be pinpointed.

After initial field survey and aerial photograph interpretation using a 1 km and then a 500m grid placed over the photographs to assist in interpretation, a transect bounded by Haswell to the east, Framwellgate Moor to the west, West Rainton to the north and Belmont to the south was selected,

Fig. 4.3



which encompassed a wide range of physiographic types. Thus the length of 8 km and width of 2.5 km would enable detailed research to be undertaken on point sample lines without meeting any significant settlements (Figure 4.4).

4.3 Survey Procedure

4.3.1 Point Sample Selection

Within the transect, the method to be used to generate the position of the sample points had to be chosen with care. At the outset, a random sample method was discarded as potentially giving too much weight or bias to a particular area, and attention was focussed on a systematic aligned (checkerboard) sample (King, 1969), with a perfectly even spread of points. Such a method was employed by Rudeforth and Bradley (1972)* in their study of soil type and land classification in west and central Pembrokeshire using a 1 km sample spread, but the inability to keep to even a remotely stable grid because of urban and other developments made the procedure unrealistic. Furthermore, such a selection procedure suggests that all parts of the study area do not have an equal chance of inclusion in the sample as it is fixed, and if there are periodicities in the data being collected, the regularly spaced points would hit the same point in a cycle time and time again and give a biased view of the phenomena under study (King, 1969, after Berry 1962). It was, therefore, ruled out.

To overcome some of the disadvantages of the above, a systematic random sampling procedure, as outlined by Theakstone and Harrison (1970), was investigated. A sample point is taken in each grid square, the co-ordinates of the point being generated randomly using random number tables. This method was finally chosen for the transect.

An advantage of this procedure is that an important assumption underlying many statistical techniques is satisfied, namely that the sample observations are independent and have equal probabilities of being chosen. There is one disadvantage in that the method does not always ensure an adequate areal coverage (King, 1969), but in the transect an examination of the sample pattern, and comparisons with soil type, geology, topography and physiography, did not lead the author to believe that this had happened and thus a more sophisticated procedure, such as a stratified systematic unaligned sample (Berry, 1962), would not be necessary. The final sample problem was at what spacing the grid should be constructed. Naturally, the closer the grid the more complete would be the coverage of the transect, but as the analysis was to be for strategic planning purposes, it was considered that a 1 km grid would be too broad to pick up subtle variations within the area, whilst a 100m grid would be too detailed and produce too many points for what should essentially be a rapid survey. A 500m grid was finally shown as falling between these two extremes and serving the purpose of the research.

This grid was overlain on the 6" O.S. maps in the position used in the initial aerial photograph interpretation phase, and the points on the ground selected by random numbers. If a point so derived was found to be built upon or otherwise incapable of access, it was "re-generated" by referring once again to the random numbers table.

Eighty squares resulted from the 500m grid but because nine represented land under urban use almost in their entirety, these were excluded from the analysis and a final seventy one points were sampled (Figure 4.5).

* This research was being undertaken at the same time as that of the author, but without his knowledge.

Fig.4.4 Transect Reference Points

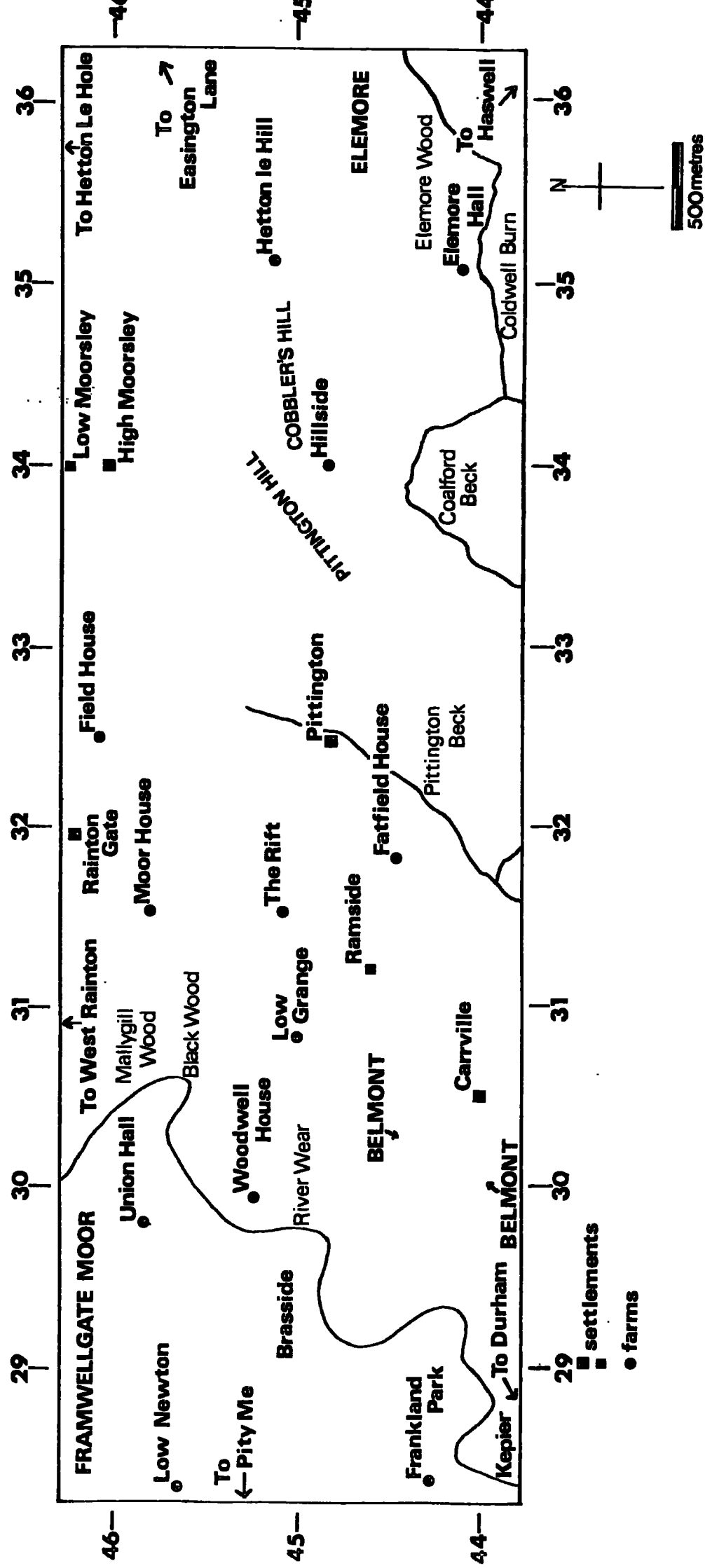
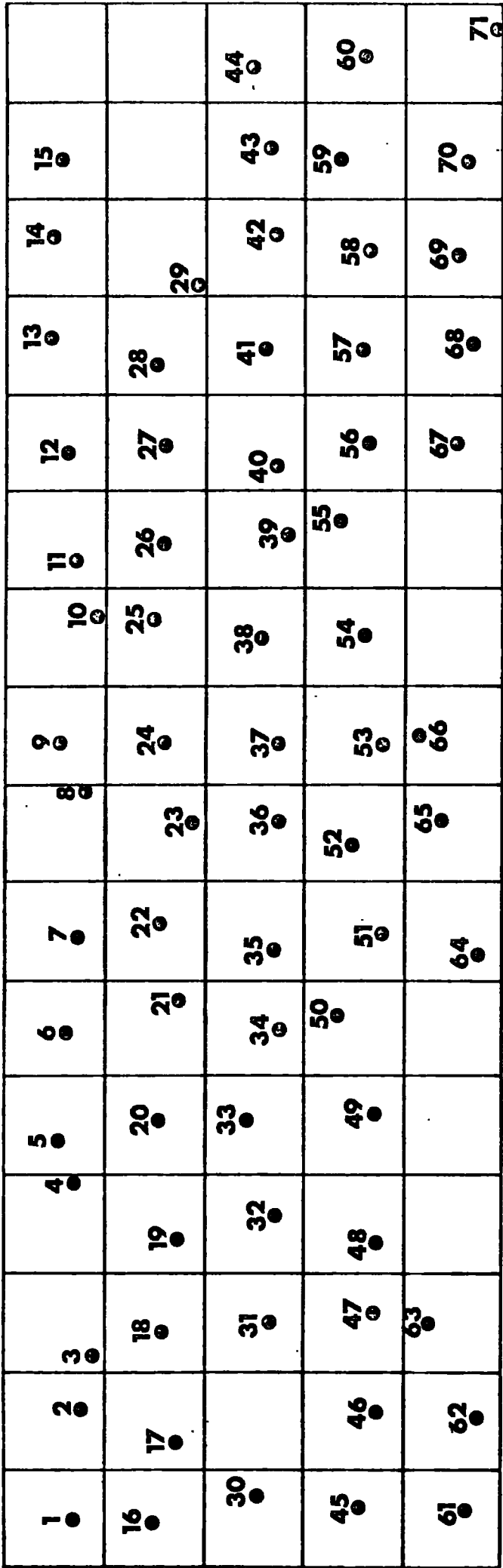


Fig4.5 Transect Sites



4.3.2 Site Sample Methodology

Three criteria governed the overall sample methodology at the seventy one sites. Firstly, the analyses to be subsequently undertaken would be predominantly quantitative. Secondly, it would be preferable if only one visit was made to a site, for reasons of speed in the data collection phase and "public relations". Sampling both of site and soil profile factors would, therefore, have to be regular in all respects. Thirdly, those attributes and parameters measured should be pertinent to the assessment of land capability of the selected land uses of agriculture, forestry, nature conservation, housing, industry and recreation developments, as outlined in the Introduction and extensively discussed in Chapter 3.

At each of the sites, the following site and soil profile data were collected. The survey took place during early 1971.

4.3.2.1 Site Parameters

- 1. Angle of slope
- 2. Form of slope
- 3. Aspect
- 4. Altitude
- 5. Canopy of vegetation
- 6. Drainage
- 7. Exposure
- 8. Land Use and Vegetation

The methods used for data collection and presentation of results in the following chapters are outlined below.

1. Angle of slope

The angle of slope is that pertaining to the soil profile site as measured by clinometer in degrees.

The slope classes used are derived from those suggested by Bibby and Mackney (1969) and Hodgson et al. (1974). The former define "gently sloping" land as 0 to 3°, whilst the latter classify such a slope as 2 to 3°, but include a lower category of "level" at 0 to 1°, the degree of slope being rounded off to the nearest degree.

A level category has much merit and is, therefore, incorporated in the categories that are proposed below. In addition it is suggested that the "precipitous" category should be superseded at 45° by the term "vertical face". The latter three categories do not occur at the transect sites.

<u>Slope in degrees</u>	<u>Category</u>
0 - 1	Level
1 - 3	Gently sloping
3 - 7	Moderately sloping
7 - 11	Strongly sloping
11 - 15	Moderately steeply sloping
15 - 25	Steeply sloping
25 - 35	Very steeply sloping
35 - 45	Precipitous
45+	'Vertical' face

2. Form of slope

Slope form within 100m of the soil profile site is defined using the categories of the Soil Survey Field Handbook (1960) as follows:

Convex
Concave
Regular
Plane
Terraced

3. Aspect

Aspect at the soil profile site is measured in degrees from north.

4. Altitude

The height above sea level (Ordnance Datum), obtained from Ordnance Survey maps in feet is presented in metres, with decimal points rounded to the nearest whole metre.

5. Canopy of vegetation

The canopy of the vegetation at the soil profile site and within a 25m radius around the site, is defined on a scale of 0 - 10 (absence of canopy to no sky visible) as outlined by the Soil Survey Field Handbook (1960).

6. Site drainage

The drainage of the soil profile site is determined according to the categories of the Soil Survey Field Handbook (1960) as follows:-

Shedding
Normal
Receiving

7. Site exposure

The exposure of the site at the soil profile location is measured using the TOPEX system of analysis of Pyatt, Harrison and Ford (1969). This assessment of relative topographic exposure is made for a particular locality by measuring the angle of inclination of the horizon (skyline) at the eight major points of the compass and adding the eight angles to give a Topex value. The lower the figure (the nearer it approaches zero), the higher is the exposure of the site relative to nearby localities, although the value is not linear. Pyatt et al. propose the following zonal scheme to take account of this non-linearity:-

<u>Topex value</u>	<u>Exposure zone</u>
0 - 10	Severely exposed
11 - 30	Very exposed
31 - 60	Moderately exposed
61 - 100	Moderately sheltered
101 - 150+	Very sheltered

8. Land use and vegetation

The land use and vegetation is defined within a 25m radius of the soil profile site.

4.3.2.1 Soil Parameters

At all the sites a sample pit was dug to a depth of 60cm or bedrock, whichever was the shallower, to enable samples to be taken and detailed profile descriptions to be made. If the structureless parent material, in the form of a slightly pedogenetically altered BC or a "raw" C horizon, was not found before the 60cm depth was reached, the pit was augered to a maximum depth of 90 cm to see whether these horizons were present or not to this depth. Likewise, the depth to bedrock, if not present above 60cm, was determined by probing to a maximum of 100cm.

The 60cm limit for sampling was chosen as being a depth capable of rapid soil sampling; a factor of considerable importance, as it was hoped that the methods devised would enable a strategic survey to be undertaken over a wider area than that of the transect by future researchers.

The quantitative nature of the analyses presented in Chapters 7 to 11 required that soil samples be taken on a regular basis from each profile. They were, therefore, taken from the "mineral" topsoil ("mineral" as defined by Hodgson, 1974; "topsoil" as defined by Rudeforth and Bradley, 1972, as the layer between 0 and 25 cm) at 5cm and from the "subsoil" (defined by Rudeforth and Bradley, 1972, as the layer between 25 and 50 cm) at 30cm and 40cm.

Regular sampling between 5cm and 30cm was not undertaken as the predominant arable land use of most of the profiles results in this layer being continually re-worked. However, by sampling at the 30cm as well as the 5cm depth, the bottom as well as the top of the zone of most nutrient content and, therefore, of the most vigorous root development, as generally defined by the Agricultural Advisory Council (1970), was analysed. The 40cm depth for sampling allowed a sample to be taken in the subsoil from a depth well below the plough layer of all the sites and below that of major plant nutrient enrichment, as defined above.

Each of these depths, 5cm, 30cm and 40cm, coincided, of course, with a soil horizon. To enable soil profile descriptions to be written, samples of soil were also taken from the remaining horizons to a depth of 60cm.

All samples were subjected to laboratory analysis as required for the various analyses and both the site and soil profile data were recorded on computer cards.

The soil parameters may be divided into those derived by field observation and those derived by laboratory analysis.

i) Soil Parameters (Field Observation)

1. Drainage
2. Depth to in situ rock
3. Horizons
4. Structure
5. Permeability
6. Roots - quantity; size and nature
7. Stones
8. Fauna - type and amount
9. Field moisture
10. Colour
11. Mottles - type; size; colour and abundance

1. Soil drainage classes

In the Soil Survey's former Field Handbook (Soil Survey Staff, 1960) soil drainage classes are based upon soil morphology using the terms excessively, freely, imperfectly, poorly and very poorly drained.

The new soil classification (Avery, 1973) requires a careful investigation of all morphological features, including those of colour, particle size and structure, formerly used to assess the drainage classes of the soil. "Drainage classes are, therefore, now replaced by soil moisture régime classes (wetness classes and dryness subclasses) which are not assessed by studies of soil morphology but are defined broadly in terms of the periodicity of water states in the rooting zone". (Hodgson et al. 1974).

As the transect site survey and analysis was undertaken during 1971, the author was not able to attempt to fit a moisture regime classification into this study and, as a result, drainage classes based upon morphology were used. However, in order to bring the drainage analysis more "up to date", whilst recognising that there is no simple relationship between the soil moisture régime and the morphological expression of gleying etc., and that the method has its shortcomings, the drainage classes used by Lea, (1975) are slightly altered to take into account the old terms of free and excessive drainages, to give the following classification:-

Well drained

Soils are rarely saturated in any horizon within the top 90cm except during or just after heavy rain. Profiles are usually unmottled throughout and subsurface horizons, if present, are brownish, reddish or yellowish in colour.

The class is subdivided into excessive and freely drained. The former class is found in coarse textured soils with small available water capacity, and which are only saturated during and just after heavy rain. Surplus water is removed rapidly and the water table is well below the solum (Robson and George, 1971). Freely drained soils fit into the remaining morphological characteristics of the well drained class.

Moderately well drained

In this category a part of the soil profile within 90cm is saturated for short periods after heavy rain, but no horizon above 60cm is saturated for more than one month. Colours typical of the well drained class are in evidence when developed on similar materials but may be slightly lower in chroma, especially on ped faces. Faint to distinct ochraceous or grey mottling can occur below 60cm.

Imperfectly drained

Imperfectly drained profiles are saturated for several months in the year at less than 60cm, but rarely at less than 30cm during the growing season. Colours of subsurface horizons are frequently lower in chroma and/or yellowish in hue than well drained soils on similar materials, and B horizons may have distinct or prominent mottling and/or greyish ped faces. Usually there is little or no gleying to 30cm depth.

Poorly drained

The soil is saturated for at least half the year at less than 60cm, but the upper 30cm is not saturated for most of the growing season. Strong gleying is normally in evidence. The A horizon is usually darker and/or greyer in colour than in well drained soils in similar materials, and a

horizon with matrix colours of low chroma, or with much ochreous and greyish mottling is in evidence immediately below.

2. Depth to in situ rock

This is measured in cm to a maximum depth of 100cm.

3. Soil horizons

The horizon notation of the Soil Survey (Hodgson, 1974) is used.

4. Structure

The structural categories of the Soil Survey Field Handbook (1960) are used.

5. Permeability

Relative permeability classes are defined using the method of Wischmeier, Johnson and Cross (1971) and deduced from routine profile descriptions without laboratory determinations of percolation rates. These classes are based on the general permeability classification guides of U.S.D.A. Soil Survey Manual (1951) and are as follows:

Very slow
Slow
Slow to moderate
Moderate
Moderate to rapid
Rapid

6. Roots

The quantity, size and nature of roots are determined using the categories of the Soil Survey Field Handbook (1960).

7. Stones

The quantity, size and shape of stones are defined using the categories of the Soil Survey Field Handbook (1960).

8. Soil Fauna

The type and amount of soil fauna, particularly worms, are noted.

9. Field Moisture

The following categories of the Soil Survey Field Handbook (1960) are used to define field moisture:-

Dry
Slightly moist
Moist (damp)
Very moist
Wet
Waterlogged

10. Colour

The colour of the freshly broken moist soil is noted using Munsell Soil Color Charts.

11. Mottles

The contrast, abundance and size of soil mottles are determined using the Soil Survey Field Handbook (1960) categories, and the colour is diagnosed from Munsell Soil Color Charts.

ii) Soil Parameters (Laboratory Analysis)

1. Soil reaction (pH)
2. Exchangeable cations of magnesium, calcium, sodium, potassium, hydrogen and percentage base saturation.
3. Percentage moisture.
4. Percentage loss on ignition.
5. Percentage organic carbon and percentage organic matter.
6. Particle size analysis (International and U.S.D.A. classes).
7. Percentage calcium carbonate (selected sites only).

All the samples for analysis were air dried first of all and then passed through a 2mm sieve, thus excluding stone content.

1. Soil reaction (pH)

Schofield and Taylor (1955) propose that soil pH is better determined following equilibration with 0.01M CaCl_2 solution rather than with water. With calcium chloride pH is more reproducible and corresponds more closely to the effective pH of the solution in immediate contact with the soil particles (Russell, 1961).

For the author's study, the pH of 1:2.5 soil suspensions using both water and 0.01M CaCl_2 solutions, was determined on an E.I.L. pH meter with glass electrodes.

Davies (1971) proposes an interpretation of the pH of the soil using calcium chloride in line with those used by the Soil Survey of England and Wales for determination with water. This is as follows:-

<u>Description</u>	<u>Water</u>	<u>Calcium chloride</u>
Strongly acid	<4.5	<4.0
Moderately acid	4.5-5.5	4.0-5.0
Slightly acid	5.5-6.5	5.0-6.0
Neutral	6.5-7.5	6.0-7.0
Alkaline	>7.5	>7.0

Throughout the research in the transect, unless stated, soil reaction refers to the determination in CaCl_2 using Davies's categories.

2. Exchangeable Cations and Percentage Base Saturation

Whilst it is recognised that the long term effects of fertilizer treatment and cultivations make percentage base saturation figures less valuable in discussing soil type, it was nevertheless considered essential to establish the exchangeable cations and base status, as it is the characteristics of the soils pertaining at present to land capability, rather than 'natural' soils, that are being considered.

The exchangeable metallic cations (exchangeable bases) of calcium, magnesium, potassium and sodium were extracted by leaching with 250ml 1N ammonium acetate at pH7. The amount of exchangeable calcium and magnesium was measured by atomic absorption spectrophotometer and the amount of potassium and sodium by flame photometer. Exchangeable hydrogen was determined by titration of the ammonium acetate leachate back to pH7 using

0.2N ammonium hydroxide. The results presented are expressed in milli - equivalents per 100g of soil.

The sum of the exchangeable metallic cations and exchangeable hydrogen gives the cation exchange capacity, and the percentage saturation shows the proportion of the exchange capacity satisfied by metallic cations.

Lea (1975) proposes the following classification scheme for discussing cation and base status data:-

Table 4.1

Exchangeable Cations

(Range in me/100g)

<u>Rating</u>	<u>Calcium</u>	<u>Magnesium</u>	<u>Potassium</u>	<u>Sodium</u>
Very Large	> 20	> 6	> 1.2	> 2
Large	10-20	3-6	0.8-1.2	0.7-2
Moderate	5-10	1-3	0.5-0.8	0.3-0.7
Small	2-5	0.3-1	0.3-0.5	0.1-0.3
Very Small	< 2	< 0.3	< 0.3	< 0.1

Table 4.2

<u>Rating</u>	<u>Cation Exchange Capacity (me/100g)</u>	<u>Total Exchangeable Cations (me/100g)</u>	<u>Percentage Base Saturation</u>
Very Large	> 40	> 25	80-100
Large	25-40	15-25	60-80
Moderate	12-25	7-15	40-60
Small	6-12	3-7	20-40
Very Small	< 12	< 3	0-20

However, rather than use the terms "large" and "small" to signify the amount of me/100g, the author suggests that "high" and "low" are more suitable and are, therefore, used throughout.

3. Percentage moisture

Moisture content was established by firstly oven drying the soil sample at a constant temperature of 105°C for at least twenty four hours or until the weight of the soil sample remained constant. The percentage moisture in the oven dried soil was then calculated as a percentage of the air dry soil.

4. Loss on ignition

Although the loss on ignition is often used as an approximation of the organic matter content of soil, some mineral matter is also combustible at temperatures of less than 800°C. Despite the fact that this method was undertaken, because of this problem the analysis of organic carbon content (described below) was used instead in the study to calculate amounts of organic matter.

The loss on ignition was determined by firing a soil sample in a muffle furnace at a temperature of 800°C for 30 minutes and expressing this loss as a percentage of the weight of oven dry soil.

5. Percentage organic carbon and percentage organic matter

The organic carbon content was defined by "wet oxidation" according to the method of Walkley and Black (1934). The result depends upon the oxidation of organic matter by an excess of potassium dichromate and concentrated sulphuric acid. The excess is then titrated with standardised ferrous sulphate, using diphenylamine as indicator.

Assuming that soil organic matter contains 58% carbon, an estimate of organic matter can be obtained by using the correction factor of 1.724.

The organic carbon levels to % clay for the determination of mineral, humose and organic materials (Avery, 1973) are shown in Figure 4.6 supplied by T. R. E. Thompson of the Soil Survey.

6. Particle-size analysis

The method used for particle-size analysis (mechanical analysis) is a modification by the Soil Survey of Scotland of the technique devised by Bouyoucos (1962). Hydrometer determination is preceded by dispersion with sodium hydroxide.

The principal particle-size classification used is that of the International Society of Soil Science (Figure 4.7) with groupings as follows:-

Clay	<0.002mm
Silt	0.002 - 0.02mm
Sand	0.02 - 2.00mm

A major factor in deciding to use this system in preference to others was the fact that it fits exceptionally well into determination by the Bouyoucos method (Millar, Turk and Foth, 1965) and time taken for analysis and laboratory organisation also required that this method be used.

Certain sections of the study refer to the system used by the United States Department of Agriculture (Figure 4.8), which groups particle-size as follows:-

Clay	<0.002mm
Silt	0.002 - 0.05mm
Sand	0.05 - 2.00mm

For a number of samples the proportion of very fine sand (0.05-0.10mm) was calculated using B.S. sieves.

Although previously used by the Soil Survey of England and Wales, the U.S.D.A. system has now been superseded by one based upon the particle size grades of the British Standards Institution and the Massachusetts Institute of Technology.

In determining soil type using the new Soil Survey classification (Avery, 1973) which is based on the B.S./M.I.T. classes, due attention has had to be paid to the differences involved in particle-size between the various classification systems. Of particular significance are the differences in silt and sand content classes (0.002 - 0.06mm and 0.06-2.00mm respectively under the B.S./M.I.T. system). Fortunately, when the U.S.D.A. and B.S./M.I.T. particle classes are compared, sand contents do not rise high enough under the former in the transect sites to cause diagnostic problems using Avery's soil classification. This, together with the fact that silt is not a diagnostic property above soil series level, and that Avery's main diagnostic textural class (clay) remains the same for both systems (< 0.002mm) resulted in no problems being encountered in the definition of soil type.

7. Percentage calcium carbonate

The technique used to calculate calcium carbonate amount measures carbonate content on the basis of the amount of carbon dioxide released by dilute hydrochloric acid. Titration is undertaken with standardised N/1 sodium hydroxide using brom-thymol indicator.

Fig.4.6 Organic Carbon Levels for Humose Materials(afterThompson)

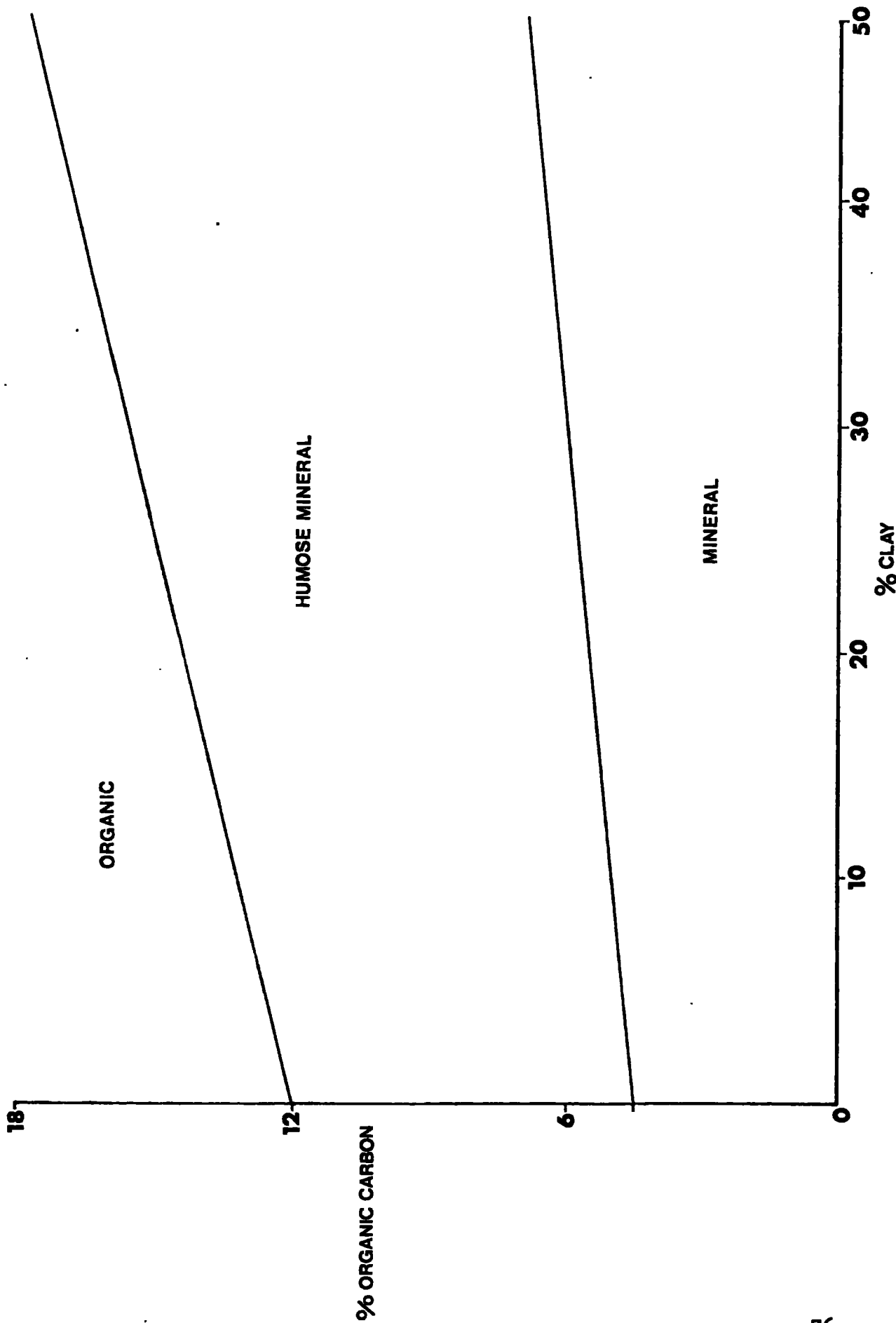


**Fig.4.7 Particle-size
Classes**
(INTERNATIONAL SCALE)

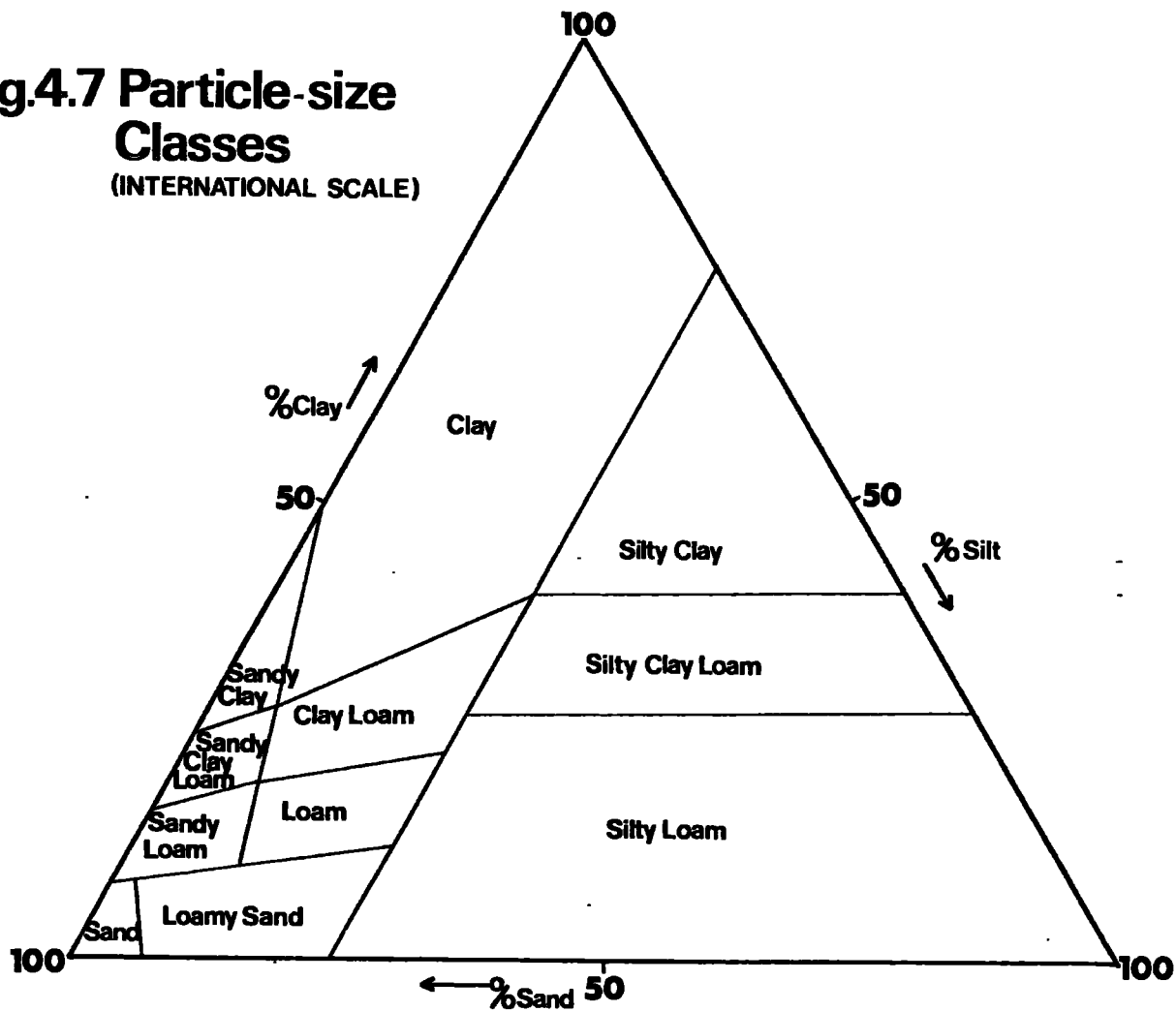
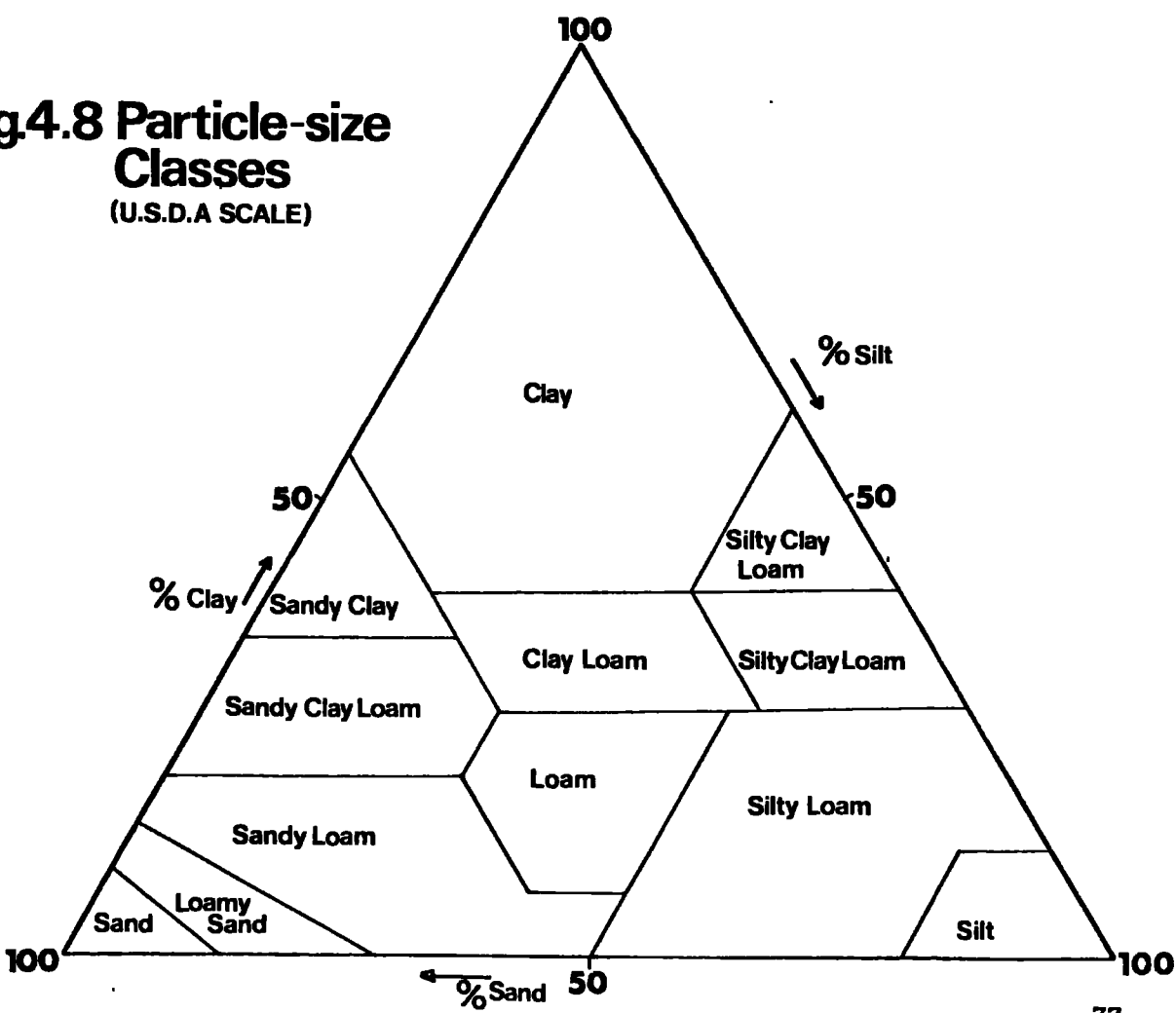


**Fig.4.8 Particle-size
Classes**
(U.S.D.A SCALE)



4.3.2.3. Soil Classification System

The soil classification system used is that of Avery (1973). This has been developed over the past ten years and designed to meet the need for an improved system of soil survey using specific soil properties to define class limits, as in schemes developed for similar purposes in the U.S.A. and the Netherlands. Classes in higher categories are differentiated primarily by the composition of soil material within specified depths and by the presence or absence of "diagnostic horizons" which generally reflect the degree or kind of alteration of original material (Clayden, 1974).

The system is split up into three hierarchies. Major groups and groups at the highest end of the scale reflect the continuity of British Soil classification, in that five of the ten major groups correspond closely with those defined by Clarke (1940). There are forty three groups and these subdivide into ninety nine subgroups.

All of Avery's definitions are accepted in the author's work, apart from the depth to gleying. He suggests that 40cm is the threshold depth to gleying in distinguishing the hydric raw soil and surface and ground-water gley major groups. Lea (1975), however, in the Caersws study in Powys, used 35cm to be the threshold. These limits are essentially arbitrary and reflect experience rather than a quantifiable basis.

It is not the purpose of the author to make comments as to the merits of one depth as opposed to another - 5cm is not a substantial difference and would be accounted for by differences in cultivation method or compaction at different times of the year. However, a criticism, if criticism is the correct word, which could be levied at Avery's system is the implied rigidity of the horizon depths when dealing with agricultural soils. The effects of cultivation, in transferring soil from one part of a field to another, are well known, a result being the progressive thinning of the topsoil and subsequent obliteration of horizons. It is thus possible that one day a particular profile will be above the stated threshold whilst the next day it will not, and sheet erosion can have a similar effect in stripping soil.

There is no provision in Avery's paper, however, for such a situation. Lea (1976, pers. comm.) suggests that these soil depths should not mask the fact that phases or intergrades between soil types do exist. Within a soil series mapping unit, profiles which show definite characteristics of soils within the threshold depths, but do not show the required depth because of cultivation or some other action, would be included in the unit. In describing these "truncated" profiles it is also perfectly proper to include them within the same soil group as those soils exhibiting the correct threshold depth, providing that they are near such profiles and show the same remaining morphological characteristics.

This problem of depth criteria occurs in the transect survey area in the staynogleyic brown earth subgroup (see Pages II4-II8) and appears to be especially significant when undertaking a point sample analysis.

At sites showing such depth variations, Lea's advice was taken, it being considered wrong to assign a soil to the cambic stagnogley subgroup for example, when in fact the soil is a "truncated" or intermediate phase of the stagnogleyic brown earth subgroup.

Seven sites in the transect show depths to gleying of less than 40cm whilst a) showing a truncated profile with, in five of the profiles, an Ap horizon lying directly on a BCg, and in two, a narrow Bw horizon intervening b) showing morphological characteristics of the stognogleyic brown earth subgroup other than the depth c) profiles sampled elsewhere in the same fields, in close proximity to these sites, showed a clear stognogleyic 78

brown earth profile, visually similar to them in essential respects, apart from the occurrence of a deeper Bw horizon.

When Lea's threshold depth to gleying of 35cm is considered, the number of profiles which do not meet the depth criterion drops to four, all having no Bw present, the Ap lying directly on a BCg.

)

CHAPTER 5 - LAND EVALUATION - A THEMATIC APPROACH

This chapter discusses the simplest form of approach to land evaluation; that of describing one attribute at a time, with no attempt being made at integration to form composite units.

5.1 Physiographic Units

As outlined in Chapter 4, the transect covers part of two of the topographical divisions of Eastern Durham defined by Beaumont (1967). These are the Wear Lowlands and the Magnesian Limestone Escarpment and Plateau. Such broad divisions are too large to enable a detailed assessment and comparison to be made of the variations that exist between resource attributes and land capability in the transect, and thus seven smaller Physiographic Units are defined. These are shown in Figure 5.1 and are described below.

Unit 1 Lowlands West of the River Wear

This area corresponds closely to the 58 m O.D. surface remnant as mapped by Maling (1955). The altitude varies from about 56 to 84 m O.D. and slopes, for the most part, are very shallow. Laminated clays and fluvio-glacial sand and gravel form the predominant drift deposits and overlie Middle Coal Measures sandstone, shale, siltstone and coal. (Plate 5.1).

Unit 2 Upper Slopes of the River Wear Gorge East and West of the River

Although it could be argued that the upper slopes of the Wear Gorge to the east and west of the river are separate physiographic units in their own right, because only two sample sites are located in the west and only three in the east, the two areas are combined to form one Physiographic Unit.

To the east of the river the upper slopes of the gorge correspond, in part, to the 58 m O.D. surface remnant mapped by Maling (1955). Altitude varies from about 31 to 58 m O.D., and the area is characterised by the presence of steep-sided stream sections of the tributaries of the River Wear (Plate 5.2). The superficial deposit is mainly Upper Wear Clay, with Middle Coal Measures strata forming the underlying solid geology. At about the 53 m O.D. contour to the west of the Wear, the topography drops sharply for about 15 m before the precipitous slopes of the gorge are met. Here the superficial and solid geology is the same as the eastern sector.

Unit 3 River Wear Gorge and Floodplain

The River Wear Gorge, cut in carboniferous sandstone, forms a distinct feature running N.E. - S.W. across the transect. The sandstones are exposed in many places producing precipitous slopes. At the bottom of the gorge the channel of the river is flanked by terrace development and patches of alluvium (Plate 5.3). In the extreme south-west the gorge opens out near Kepier and the solid rock is not exposed; the valley sides being smoother and the slopes not as steep.

Fig 5.1 Physiographic Units

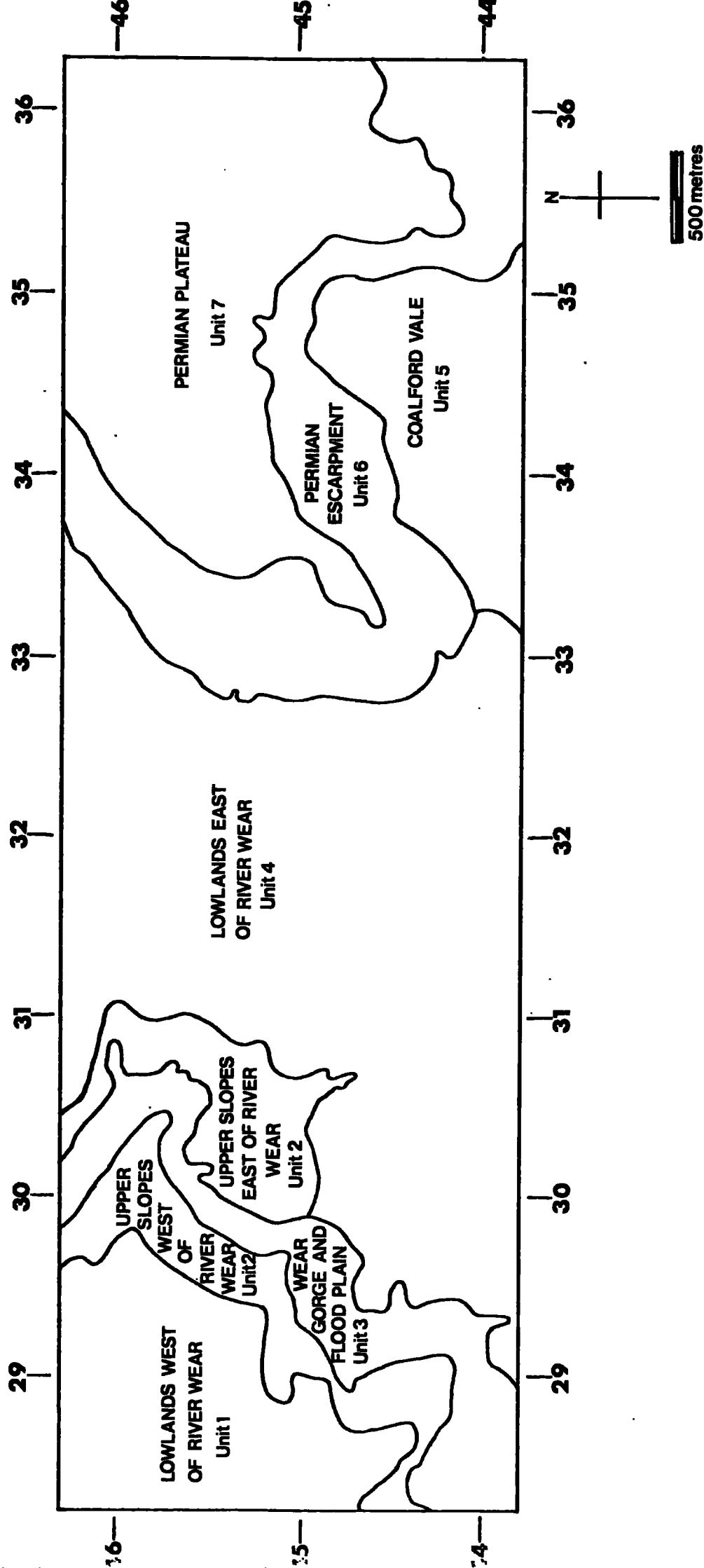




Plate 5.I Unit I. Lowlands West of the River Wear.



Plate 5.2 Unit 2. Steep-sided stream
section falling to the River Wear.



Plate 5.3 Unit 3. River Wear Gorge

Unit 4 Lowlands East of the River Wear

East of the River Wear, the Wear Lowlands extend for some 2.5 km eastwards to the Permian Escarpment of Unit 6 (Plate 5.4). The altitude varies between 30 and 91 m O.D. and, in general, slopes are gentle to moderate. The area at the foot of the escarpment is drained to the south by Pittington Beck which enters the Wear via Sherburnhouse and Old Durham Becks at Old Durham. The superficial deposits of the unit are predominantly Upper Wear Clay and Lower Till, with patches of fluvio-glacial sand and gravel also occurring. Middle and Upper Coal Measures deposits form the solid geology and near Pittington Coal Measures sandstone outcrops at the surface.

Unit 5 Coalford Vale

Near South Hetton, Coldwell Burn follows the line of a glacial meltwater channel to emerge from the Magnesian Limestone at Elemore Hall. Here the stream meets Coalford Beck and flows across a shallow valley between the south-easterly spur of Pittington Hill and Littleton/Dog Kennel Bank, before dropping to the Wear Lowlands proper. This shallow valley will be referred to as "Coalford Vale". The altitude varies between 91 and 114 m O.D. and glacial till overlies Coal Measures strata (Plate 5.5).

Unit 6 Permian Escarpment

The Magnesian Limestone outcrop forms a definitive, predominantly west-facing feature overlooking the Wear Lowlands. Immediately underlying the limestone, the Marl Slate and Basal Sands of the Permian succession also outcrop spasmodically at the surface. The Lower Till of the Permian Plateau, although spasmodic, is in evidence on the higher slopes. Extending and originating from the Permian hard rock outcrop at about 107 m O.D., and dropping to about 91 m O.D., are extensive head and colluvial deposits which cause the slope to decrease lower down and which contaminate the drift of the Wear Lowlands overlying carboniferous strata at the base of the scarp. Mixing of the two tills also probably occurs.

The total feature of the escarpment is taken, for the purpose of this study, as the basal break of slope from the Wear Lowlands, up to the crest of the escarpment, which is defined at a definite break of slope in evidence along the limestone outcrop at heights varying between 129 and 153 m O.D. in the transect. In practice, the escarpment may be split into two sections; the middle and upper slopes developed on Permian strata, with very steep to steep slopes and occasional surface rock outcrop with spasmodic head and till cover, and the lower concave footslopes of moderately sloping land composed of contaminated till, head and colluvium over Upper Carboniferous strata.

The whole feature lies within the "sphere of influence" of the Permian and is referred to as the "Permian Escarpment" (Plate 5.6); physiographically a rather more specific definition than Beaumont's "Magnesian Limestone Escarpment".



Plate 5.4 Unit 4. Lowlands East of the River Wear
viewed from the Permian Escarpment (Unit 6).



Plate 5.5 Unit 5. Coalford Vale

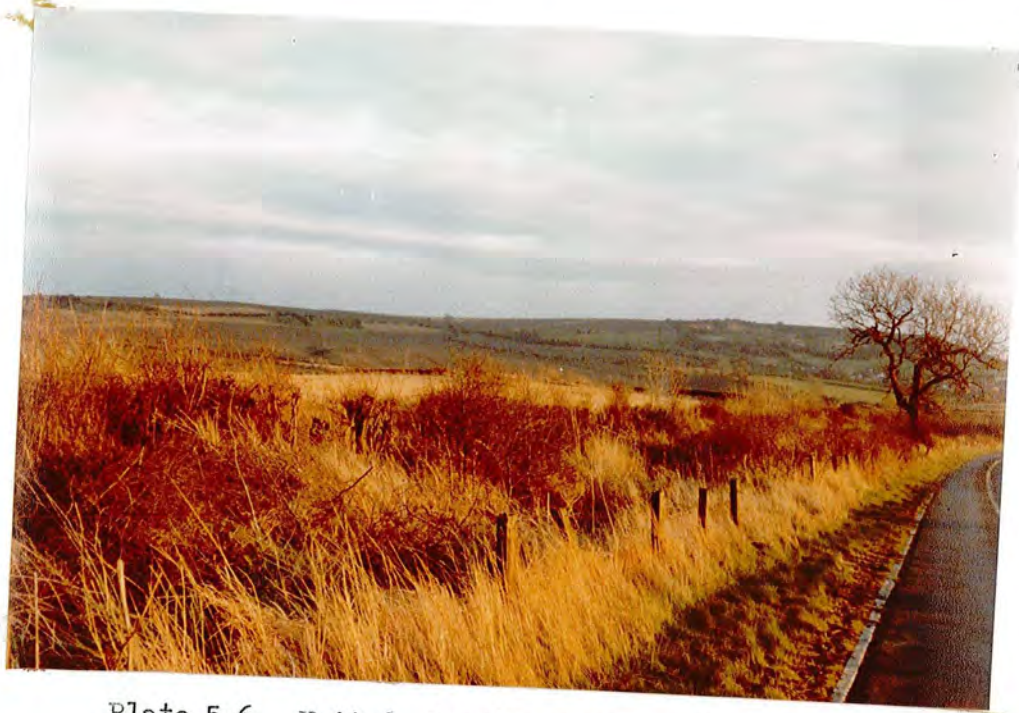


Plate 5.6 Unit 6. Permian Escarpment rising from the Lowlands East of the River Wear (Unit 4)



Plate 5.7 Unit 6. Disused quarry in Magnesian Limestone at Pittington. Note extensive fissures.

The escarpment is breached by a meltwater channel between Elemore and South Hetton and there is a small embayment caused by spring sapping at the Keel Well at Pittington. The Magnesian Limestone has been extensively quarried at Pittington and High Moorsley (Plate 5.7) and the Basal Sands are exploited locally at Elemore..

Unit 7 Permian (Magnesian Limestone) Plateau

The Permian Plateau composed of Magnesian Limestone, rises to a maximum height of 163 m O.D. in the transect at the summit of Pittington Hill, which forms a marked spur jutting out into the Wear Lowlands. Gentle to moderate slopes predominate on the Plateau, and the Lower Till of the Permian Plateau forms a drift deposit over almost the entire surface. Because the limestone is extensively fissured (see Plate 5.7), the drainage on the plateau in this area is almost entirely subterranean and cave development, although not common, is in evidence at Elemore and Pittington. The limestone is the best developed aquifer in the County and has been utilised for water supplies in Sunderland and Hartlepool for over a century (Cairney and Storey, 1970). The unit is identical with the Magnesian Limestone Plateau of Beaumont (1967). See Plate 5.8.

The number of sites sampled in each Physiographic Unit is as follows:

		<u>Sites Sampled</u>
Unit 1	Lowlands West of the River Wear	8
Unit 2	Upper Slopes of the River Wear Gorge	
	East and West of the River	5
Unit 3	River Wear Gorge and Floodplain	6
Unit 4	Lowlands East of the River Wear	22
Unit 5	Coalford Vale	6
Unit 6	Permian Escarpment	12
Unit 7	Permian (Magnesian Limestone) Plateau	12
		—
	TOTAL	71

5.2 Drainage

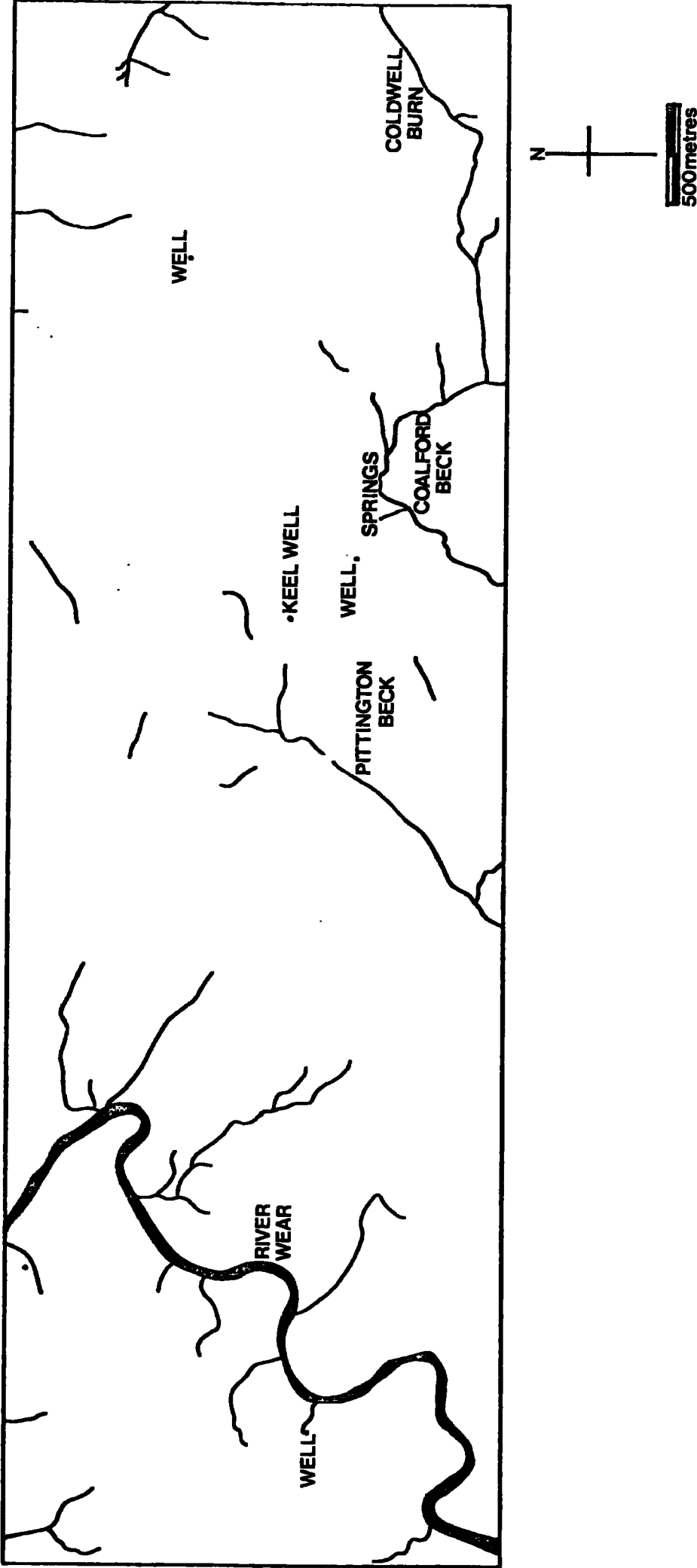
The transect is situated within the largest drainage unit of Eastern Durham, that of the Permian foothills and Wear Lowlands, which is drained northwards by the River Wear to its mouth at Sunderland (Beaumont, 1967).

A particular feature of the drainage pattern of the transect is the location of the main watershed between the east-bank tributaries of the River Wear and the dip-slope streams of the Permian Plateau (Unit 7). This does not coincide with the crest of the Permian Escarpment (Unit 6), but has been displaced by the headward erosion of the tributaries of the Wear to a position 1.5 to 5 km east of the line of the escarpment at about 137 to 152 m O.D. The Permian Plateau is virtually free of surface water, but because of the Magnesian Limestone, the area acts as an important aquifer (Figure 5.2).



Plate 5.8 Unit 7. Permian (Magnesian Limestone) Plateau

Fig.5.2 Drainage



Coalford Vale (Unit 5), on the other hand, is drained by Coalford Beck, which is fed by Coldwell Burn, flowing from the Permian Plateau via the glacial meltwater channel which breaches the escarpment, as mentioned on Page 89. Coalford Beck eventually flows into Pittington Beck, which forms the major River Wear tributary of the transect. This latter stream joins Sherburnhouse Beck outside the study area, which in turn flows into the River Wear at a point south of Durham City.

Apart from Pittington Beck, the Lowlands West and East of the River Wear (Units 1 and 4) are characterised by extensive areas of low relief across which little surface water drains; the heavy till retaining moisture, and wells sunk into it give very small yields (Kirby, 1968). Several short tributary streams flow into the Wear from these Physiographic Units in steep-sided sections; most crossing Unit 2 in the process.

5.3 Geology

Geological details are taken predominantly from Beaumont (1967) and Johnson (1970).

The rocks which outcrop in the transect study area are of Upper Carboniferous and Permian age. Apart from a few igneous intrusions within the Coal Measures, the stratigraphic succession has been little disturbed by any major igneous or orogenic activity. The strata dip gently to the east and south-east (Beaumont, 1967). Figure 5.3 shows the regional geology and Figure 5.4 that of the transect.

5.3.1. Carboniferous Strata

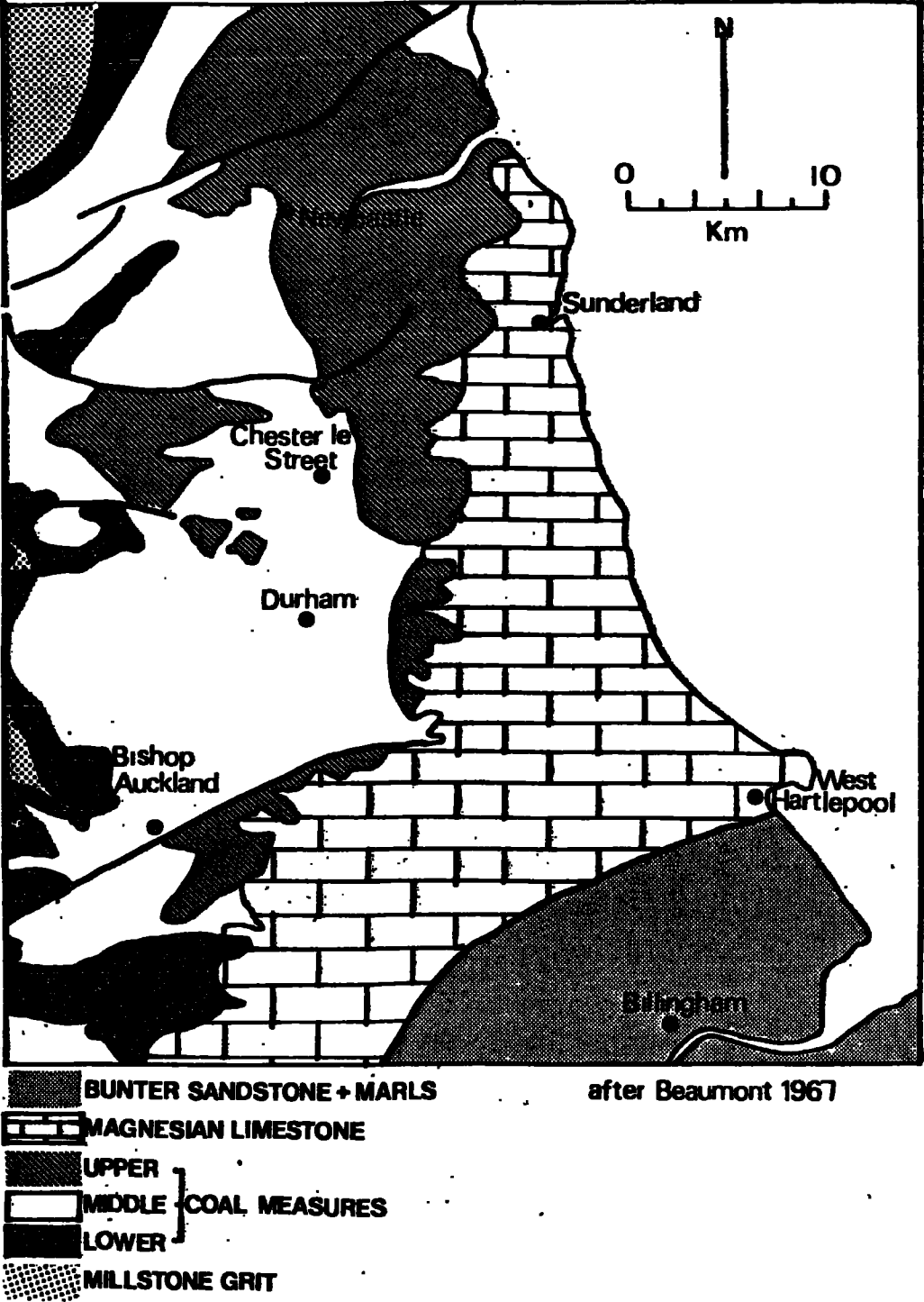
The rocks of the Carboniferous form the oldest strata in Eastern Durham and outcrop in the north and west of the Wear Lowlands forming a part of the Northumberland and Durham coalfield. Of the three divisions of the Coal Measures succession, of which the proven thickness in Co. Durham is some 610 m., the Upper and Middle divisions are represented in the transect in Physiographic Units 1 to 5. The top is erosional and is overlain unconformably by the Permian in the east and south of the County.

The Coal Measures vary considerably in rock type, owing to the cyclical sedimentation conditions under which they were laid down, with a generalised stratal sequence of shale-siltstone-sandstone-seatearth and coal, in ascending order. Within the Durham Coal Measures, sandstones predominate near to the base and thick coal seams are characteristic of much of the middle of the sequence and predominate near the top.

Coal Measures shales and mudstones are mainly dark grey in colour, passing upwards into paler coloured siltstones. The sandstones are mainly cross-bedded fine to medium grained rocks composed of quartz with a wide assemblage of accessory minerals (Johnson, 1970). The coal deposits of the Durham Coalfield are almost entirely bituminous, although cannel is found locally at the top of certain seams.

The Middle or Productive Coal Measures occupy most of the area of Carboniferous strata in the transect, as well as in Eastern Durham as a whole, and include between fifteen and twenty important coal seams. The characteristic cyclothem of sandstones, shales and mudstones occurs, with a marked tendency for the arenaceous component to increase upwards in the series.

Fig5.3 Regional Geology



The Upper Coal Measures forms the solid strata immediately west of the Permian outcrop. Sandstones predominate, with individual beds of more than 15 m in thickness separated by sub-ordinate argillaceous zones of sandy shale and fireclay. The upper part of the sequence marks a notable lithological change, being predominantly argillaceous and the sandstones, where present in this upper part, are always thin.

Exposures of Coal Measures deposits in the transect are confined to the Wear Gorge of Unit 3, where the Middle series sandstone forms significant features, and a local exposure of Upper Coal Measures sandstone at Pitlington in a quarry section in Unit 4.

The nature of the coal measures deposits, however, has a marked influence on the soils developed in the area both directly, where drift is thin or non-existent, and indirectly through the mixture of glacial till with these deposits.

5.3.2. Permian Strata

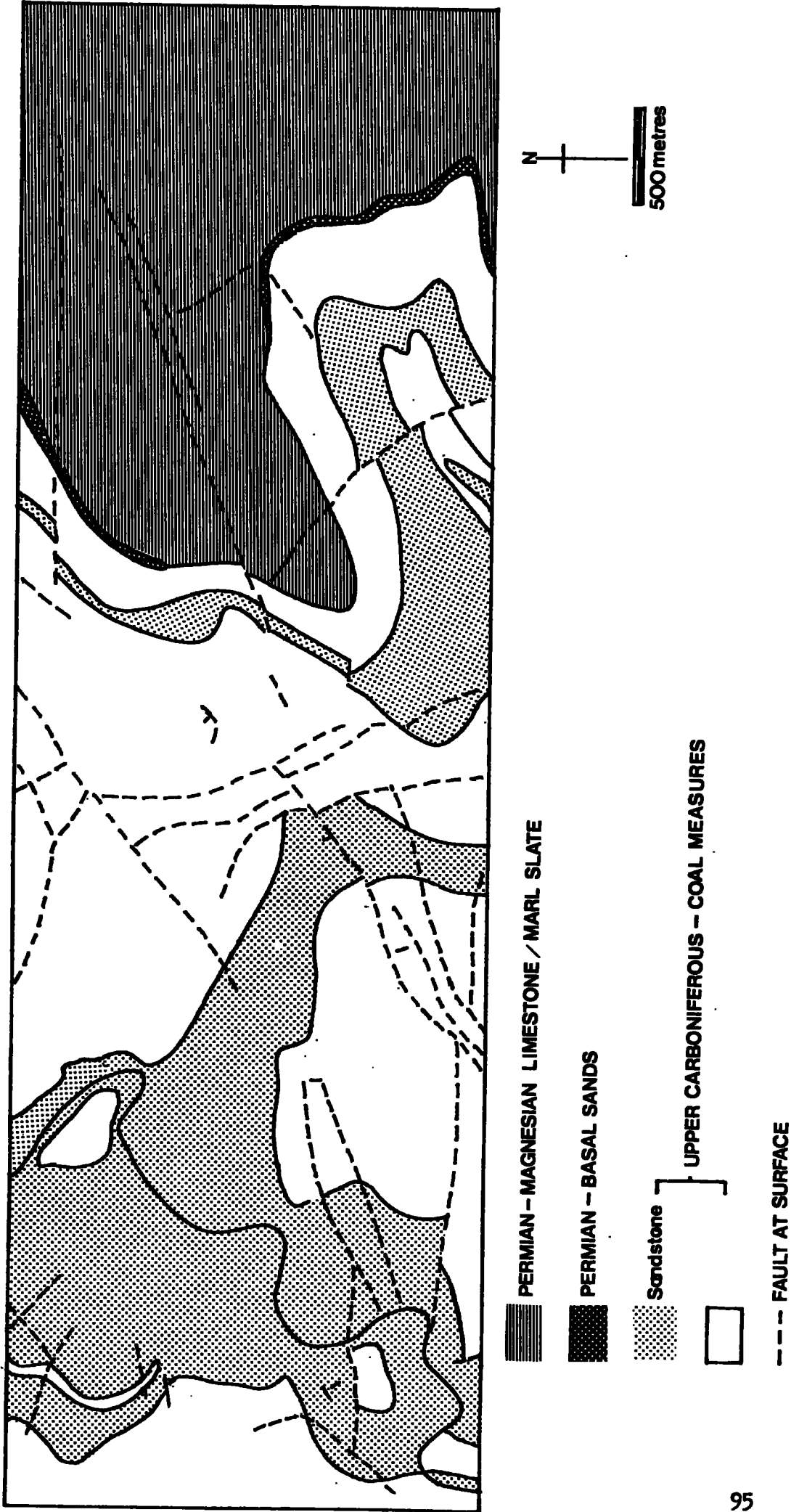
Just as the carboniferous succession has a significant influence on soil type within the transect, so has the Permian strata of Physiographic Units 6 and 7. Within Eastern Durham as a whole, the Permian deposits were deposited unconformably upon the eroded Carboniferous and show wide areal and lithological variation, varying from sand to slate, limestone, gypsum and anhydrite. In the transect, however, only three elements of the lower orders of the succession occur, namely:

Lower Magnesian Limestone
Marl Slate
Basal Sands
..... Unconformity

The poorly cemented sandstones of the Basal or "Yellow" sands form the basal Permian deposit in the study area and in northern Durham as a whole. Of aeolian origin, the deposit is well sorted, comprising frosted, well-rounded "millet seed" sand grains in the coarser fraction and is also characterised by large-scale cross-bedding typical of wind deposition. The basal sands outcrop locally towards the base of the escarpment at Elemore and have a significant effect upon soil texture along the scarp.

The transgression of the Zechstein Sea ended the continental phase of the Permian and a prolonged period of marine conditions began. After the transgression most of east Durham lay on the marginal shelf of the sea and the deposits laid down show evidence of cyclical sedimentation. The first cycle begins with a bituminous silty carbonate the marl slate which outcrops on the Permian Escarpment, particularly at High Moorsley. It is finely laminated and grey coloured, but on exposure weathers to a yellow or brown colour. The average thickness over the whole of the deposit is about 0.6 m (Johnson, 1970). Sulphides of copper, lead and zinc, together with iron pyrite, are present in the Marl Slate in concentrations over 100 times greater than the normal geochemical background values. It is possible that these heavy metals may have toxic effects on the environment and so affect land use, but because of the deposits' very limited outcrop this is unlikely in the transect. There are no published results on the likelihood of toxicity, however.

Fig. 5.4 Geology < solid - SIMPLIFIED >



The Lower Magnesian Limestone forms the major outcrop both on the Permian Escarpment and on the plateau (Units 6 and 7). The rock is up to 76 m thick and is a relatively fine-grained dolomitic limestone of a grey-buff colour (see Plate 5.7). The rock outcrops in a belt 1.5 - 3 km wide along the western edge of the plateau and is well exposed in a number of quarries in the area as outlined.

Owing to the extensive drift cover of the plateau, the Magnesian Limestone has little direct effect on soils as a parent material, having local importance only on the escarpment where the drift thins. It has, on the other hand, a substantial indirect effect through its incorporation with glacial drift.

5.4 Glacial Deposits

The following discussion is taken from the two major works on the subject by Maling (1955) and Beaumont (1967) who summarised the work of previous researchers; notably Smith and Francis (1967); Woolacott (1921) and Trechmann (1915, 1919).

A greater part of the area of Eastern Durham is covered by glacial drift which, in places reaches a thickness of more than 91 m. The drift is thickest in the lowland areas and is often absent in areas above 152 m on the Permian Escarpment. In the Wear Lowlands, as in the coastal area of the County and the Tees Lowlands, a composite sequence of deposits is found; whilst on the Permian Plateau only a single till sheet with associated gravels is present.

5.4.1. Stratigraphy of the Wear Lowlands

Succession (after Francis, 1962)

Upper Stony Clay (Upper Wear Clay)	0-4.6 m
Middle Sands and Gravels and Laminated Clays	0-76.2 m
Lower Till	0-30.5 m

5.4.1.1. Lower Till

Though mantling much of the Coal Measures strata of the Wear Lowlands, the Lower Till is rarely exposed, since in turn, it is covered by more recent deposits. The Till has a grey brown clay matrix, with many local carboniferous rocks, and erratics derived from the Lake District and Southern Uplands. It contains no Magnesian Limestone and appears to be continuous with the Lower Till of the Permian Plateau and the coastal area. It is a persistent deposit averaging about 8 m in thickness in borehole records and is absent only from the sides of the deeper buried valleys. Exposures may be seen near Finchale in the Wear Gorge and in quarries near Chester-le-Street.

5.4.1.2. Middle Sands, Gravels and Laminated Clays

These deposits form a very complex sequence which reaches a total thickness of more than 76 m at Low Newton. The fine laminated clays appear to be the most frequent drift overlying the Lower Till. These deposits have been, and still are, extensively used for brick making, particularly around Birtley, and at Brasside and Low Newton in the transect.

The sands and gravels vary significantly. Some gravels show very poor sorting, which Francis (1962) argues is indicative of ice contact conditions, but generally the origin is obscure since they contain material derived from both the Lower Till and the Magnesian Limestone. Elsewhere the sands and gravels are well sorted reaching thicknesses of more than 12 m in sections along the A167. These deposits appear to be the result of deposition under very rapidly changing and complex environmental conditions.

5.4.1.3. Upper Stony Clays (Upper Wear Clay)

These clays form extremely extensive surface deposits and are mostly less than 2.4 m in thickness and contain variable amounts of stones. Rock types of other than Coal Measures origin are rare and the drift shows considerable lateral variation; with local concentrations of angular sandstone in a clay matrix. In other areas large and small abraded fragments of coal and little else are found in the clay. Beaumont considers this to be a deposit of entirely local origin. Within the Wear Lowlands in general, and Physiographic Units 1-5 of the transect, any of these variations can outcrop at the surface.

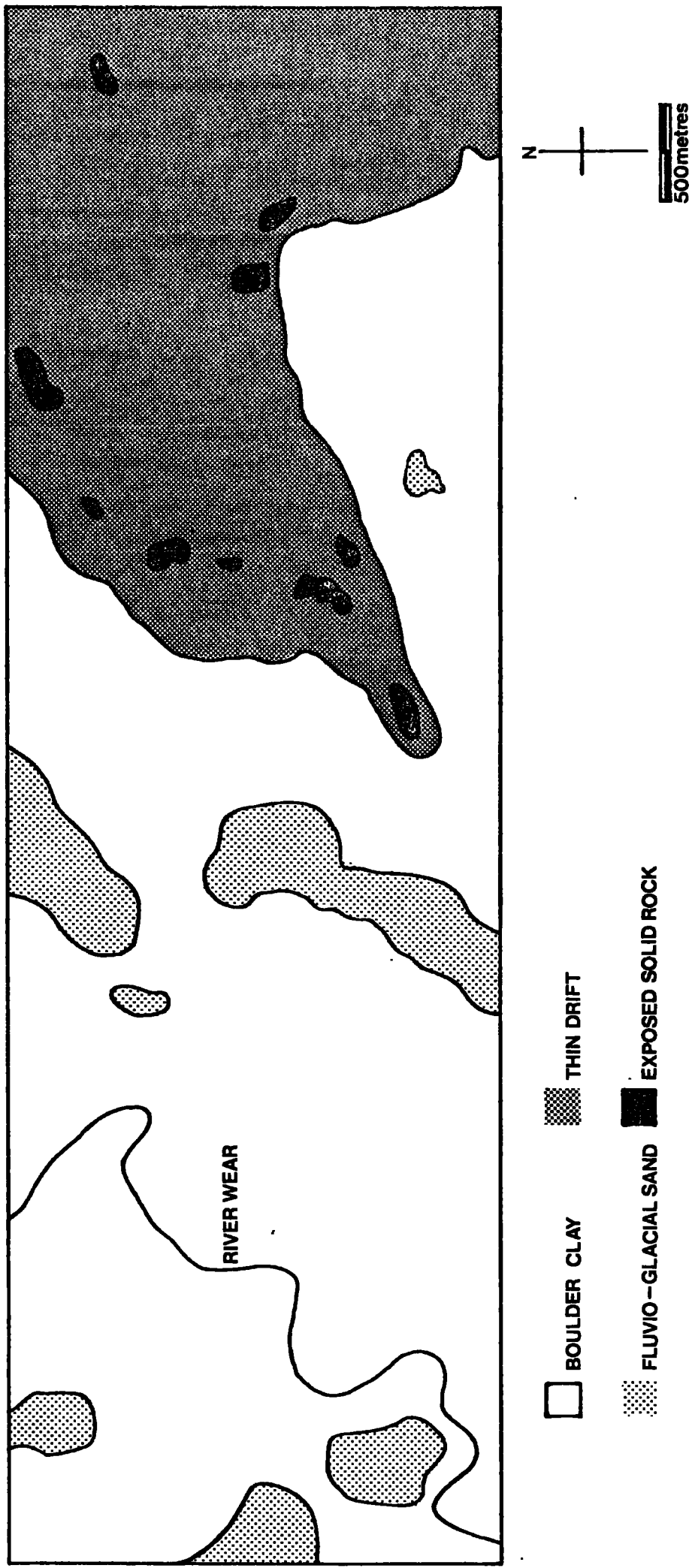
Maling (1955) has produced the only map of surface drift (other than that of the Geological Survey). He maps the deposits as "boulder clay", "thin drift" and "fluvio-glacial sand" (Figure 5.5). "Boulder Clay" and "thin drift" appear to be synonymous with the Lower Till, Laminated Clay and Upper Stony Clay areas as differentiated by Francis, the term "thin drift" being used by Maling for areas with superficial clay deposits of less than 3 m in thickness appearing as drift-free areas on the Geological Survey Maps.

5.4.2. Stratigraphy of the Permian (Magnesian Limestone) Plateau

Succession after Beaumont (1967)

Stony and Stoneless Clays	0-7.3 m Not found in transect
Laminated Clays	0-30.5 m Not found in transect
Gravels and Sand	0-45.7 m
Lower Till	0-30.5 m

Fig5.5 Glacial Deposits (after Maling 1955)



5.4.2.1 Lower Till

The Lower Till is laterally equivalent to the Lower Till of both the Wear Lowlands and the coastal area and is the only deposit which is continuous in outcrop over large areas of the plateau. The till shows rapid variations in thickness, reaching a maximum of 3.7 m, and towards the escarpment it thins and becomes discontinuous. The clay is yellowish brown or brown in colour and is characterised by the presence of Carboniferous rocks of varying lithology (coal, sandstone and limestone) together with Lake District Borrowdale Volcanic Series material and Southern Uplands greywackes. Even where no drift currently overlies the limestone, its former presence is indicated by coal fragments found within soil profiles.

5.4.2.2. Sands and Gravels

The overlying sands and gravels vary in both composition and degree of sorting. Some of these, as at Grindon, Warden Law and Battar Law, outside the transect to the east, are extremely thick, being more than 30.5 m deep in places.

Several of the deposits, such as those to the south of Eppleton Colliery appear to be associated with meltwater channels, whilst others seem to bear no apparent relationship with any landform feature.

5.4.3. Deposition of the Drift

The complex depositional conditions under which the drift deposits of the area were laid down are extensively set out by Beaumont (1967). He considers that all the deposits in the Wear Lowlands are the products of a single ice sheet (the Lower Till) with the basin-like nature of the area being important when considering the succession.

It is likely that the higher ground of the Magnesian Limestone and the Pennine Foothills emerged first from the ice, leaving a mass of stagnant ice in the Wear Lowlands. The initial basal melting of this ice sheet would lead to the deposition of the Lower Till. However, before the final release of the basal material could take place from the ice, large quantities of meltwater from the higher ground to the east and west would probably have poured into the Lowlands, and much of this would have penetrated beneath the ice mass.

Rapid melting of the basal layers of the ice, with extensive water movement, partial water sorting of released deposits and floating ice occurred and complex environments ensued. In these complex conditions, the deposits of the Wear Lowlands are considered to have been laid down; the laminated clays as lake sediments or deposited material beneath floating ice; the sands as kames or marginal deposits; the stony clays as portions of basal till deposited from grounding ice and subjected, in parts, to water action, or perhaps, as underwater flowage deposits.

On the Magnesian Limestone the Lower Till, as in the Wear Lowlands, appears to be the sub-glacial till of a terrestrially-based ice sheet.

These variable conditions of drift deposition are reflected both in the complex types of deposits and in their irregular spatial distribution. As a result, the soils which have developed from these **parent** materials are also complex in character and distribution.

5.5 Climate

There is no direct information on the climatic conditions of the transect area as such, but both Smith (1970) and Wong (1973) give general information on the conditions experienced within the region as a whole, and give particular reference to the observations of the Durham University observatory at Durham City which is located just outside the southerly margin of the transect.

5.5.1 Temperature

Two temperature thresholds may be considered to be significant from the agricultural point of view; 6°C is generally accepted as the threshold temperature for the onset of growth in most plants and 0°C is critical for the survival of some plant species or during certain periods in their life cycle. Taking the threshold of mean monthly temperature of 6.1°C and applying it to the figure derived from the Durham University Observatory (102 m O.D.), the normal growing season lasts from about the beginning of April until mid-November in Lowland Durham (about 229 days). At 500 m this period is reduced to 5½ months. A comparison of the mean monthly soil temperatures for the Durham Observatory and Moor House in Teesdale (556 m O.D.) give an indication of this (Table 5.1 after Smith, 1970).

Table 5.1 Mean Monthly Soil Temperatures at 30 cm Depth 1963-68 (°C)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Durham	2.5	2.8	4.5	7.1	10.6	14.2	15.2	15.3	13.8	11.0	7.0	3.9	9.0
Moor House	1.3	1.3	1.8	3.6	6.6	10.3	11.4	11.5	10.0	7.8	4.5	2.4	6.0

The final air frost of the winter may be expected at Durham about the 10th May with the frost free period lasting until 5th October (Manley, 1941). Ground frost is much more frequent, and is only reliably absent during July, with January and February having the highest incidence.

Owing to the cumulative effect of the northerly latitude and the coolness of the North Sea, relatively low mean annual temperatures are found in the area (Figure 5.6). A steady upward trend in mean temperature has occurred, however, from 8.2°C to 8.9°C between 1880 and 1950. Although mean temperatures have decreased since 1950, the values still remain rather above the long-period average. The annual mean temperature has varied from 6.7°C in 1879 to 9.9°C in 1949, whilst the daily extremes have ranged from 31.7°C on 16th July, 1876 to -18.3°C on the 8th February, 1895. The maximum average monthly temperature occurs in July (15°C) and the minimum in January (4.7°C) and in any one year maximum temperature may occur anytime from May to September, with an absolute minimum possible right through the winter from October to April.

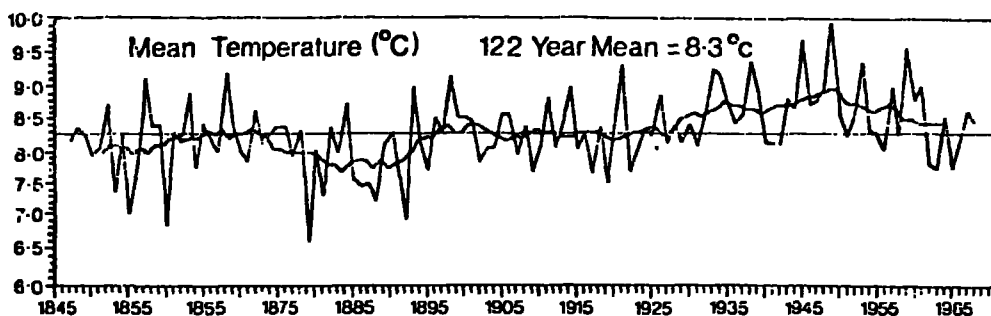
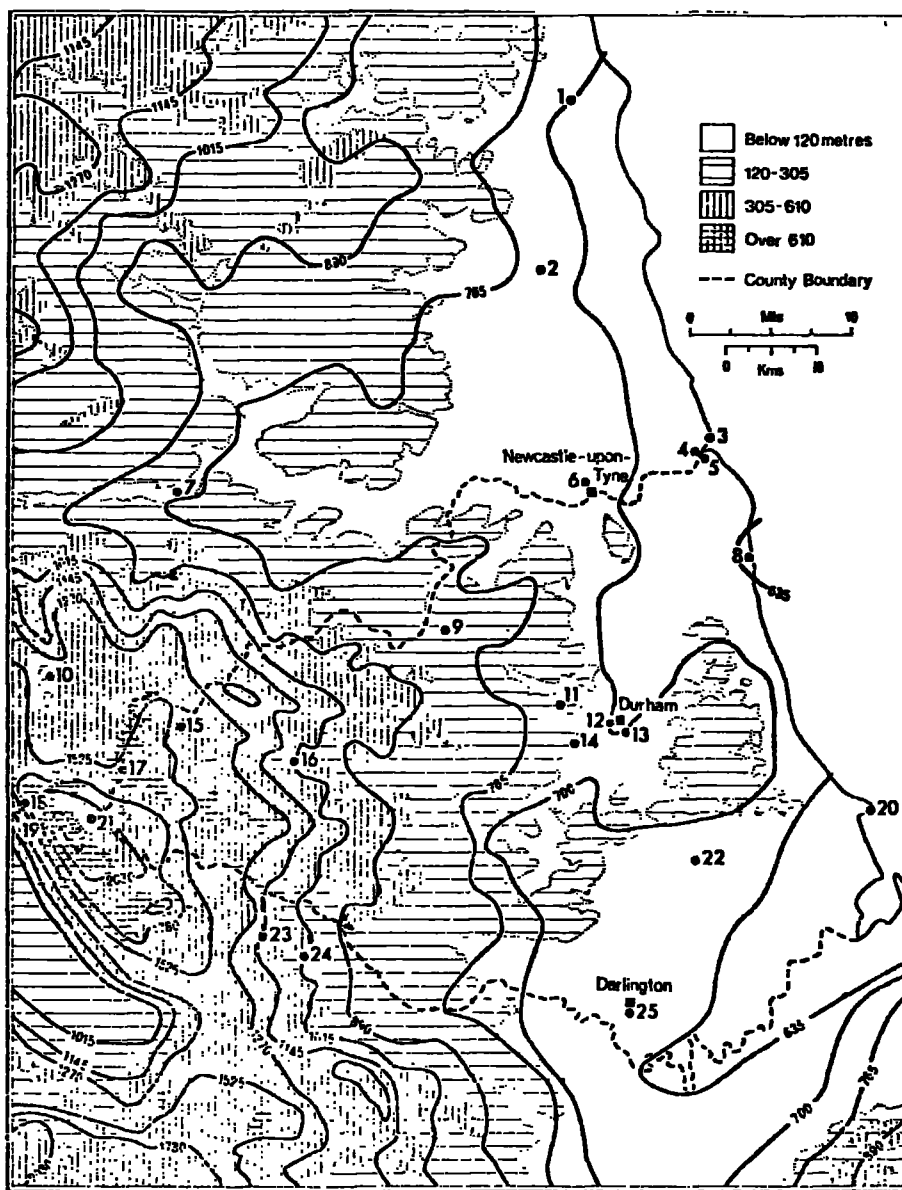


Figure 5.6 Long-Period Mean Temperature, With 10-Year Moving Averages from Durham University Observatory. Annual Temperatures (°C), 1847-1968. (after Smith, 1970)



MEAN ANNUAL PRECIPITATION, 1916-50

Isohyets rounded to nearest 5 mm.

Place names referred to in text: 1. Acklington, 2. Cockle Park (Morperth), 3. Tynemouth, 4. North Shields, 5. South Shields, 6. Newcastle, 7. Haydon Bridge, 8. Sunderland, 9. Consett, 10. Alton, 11. Ushaw, 12. Durham Observatory, 13. Houghall, 14. Brandon, 15. Lanehead, 16. Eastgate, 17. Burnhope Seat, 18. Cross Fell, 19. Great Dun Fell, 20. Hartlepool, 21. Moor House, 22. Sedgfield, 23. Selset Reservoir, 24. Hury Reservoir, 25. Darlington.

Figure 5.7 Mean Annual Precipitation, 1916-50 (after Smith, 1970)



5.5.2 Precipitation

A rain shadow effect is apparent in Co. Durham because of the Pennine Uplands, and, as a result, the mean annual precipitation declines steadily towards the east coast. The 700 mm isohyet for mean annual precipitation between 1916 and 1950 crosses the lowlands of the transect and takes in most of the Permian Escarpment and Plateau in a "balloon shaped" extension in an otherwise remarkably straight line running from north of Newcastle-upon-Tyne to just west of Darlington (Figure 5.7).

The fluctuations of the yearly totals since 1886 at the University Observatory at Durham are shown in Figure 5.8; and such variations can be very large with the extremes being 886 mm in 1930 and 440 mm in 1959. The mean monthly rainfall totals show February to be the driest month with a steady increase during the following three months. Rainfall rises again in July to reach a maximum in August. From September to January the monthly rainfall tends to fluctuate in amount.

Duration of rainfall is commonly expressed as the number of wet days or rain days; the former being identified as days with 1 mm of rain or more, and the latter as days with more than 0.2 mm of rain. The average number of rain days is about 175 at the observatory but may be slightly higher on the Permian Plateau at a higher altitude.

Since most of the rainfall is basically cyclonic in origin, there is usually a fairly direct relationship between monthly rainfall value and the number of rain days. This is less true when high individual monthly totals are considered, as these often reflect heavy falls on particular days, and the large daily falls are not confined to the high total rainfall areas. Smith suggests that the more intense falls occur over the lowlands and that there is some evidence for convectional rainfall taking place over the flatter lowland in the east. Seventeen individual storms with rainfall amounts of 25 mm or more, lasting for not more than two hours, occurred between the years 1865 and 1960, and ten of these took place during July or August, with none recorded during October to May. The heaviest daily falls tended to occur between May and October between 1916 and 1950. Despite the occurrence of intense storms, hail and thunder activity is low.

The regular precipitation generally precludes the possibility of prolonged drought, especially in the west of the County, but rainfall deficiencies are expected in June or September especially, or during settled weather in spring. However, when the rainfall deficiency persists, spanning the period of maximum evaporation need, as happened during 1959 and 1976, exceptional drought conditions prevail.

At the University Observatory, snowfall is mainly restricted to the period from the beginning of November until early May, with the most falling between December and March.

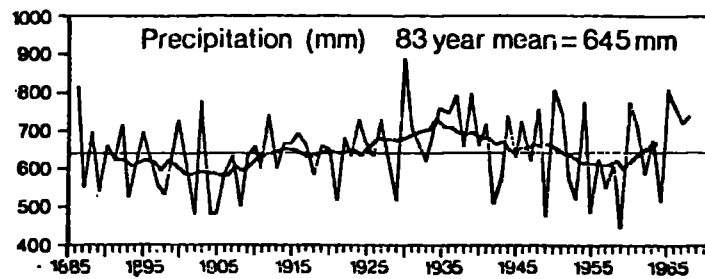


Figure 5.8 Long-Period Precipitation Amounts,
With 10-year Moving Averages from Durham
University Observatory. Annual Precipitation (mm),
1886-1968 (after Smith, 1970)

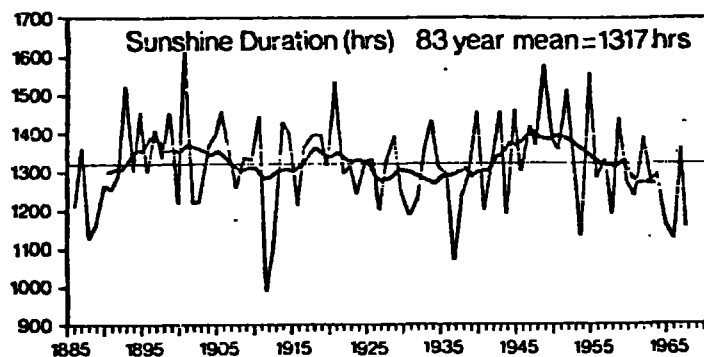


Figure 5.9 Long-Period Sunshine Duration Amounts,
With 10-year Moving Averages from Durham University
Observatory. Annual Sunshine Duration in Hours,
1886-1968 (after Smith, 1970)

The number of mornings with snow lying can reflect the severity of the winter climate rather than the incidence of snowfall. This measurement also has a rather different distribution over North east England, for whilst in the lowlands and along the coast the number of days with snowfall usually exceeds the period with snow lying, the reverse applies on the Pennine Hills, due to the lower mean temperatures and the greater initial accumulations of snow occurring there. Thus, the duration of snow-cover (in days), normally increases inland from the coast according to its depth. At Durham the figure is 17 (102 m O.D.) compared to 21 at Ushaw (181 m O.D.), 40 at Alston (303 m O.D.) and 55 at Moor House (556 m O.D.).

5.5.3 Sunshine, Cloud and Atmospheric Quality

Smith (1970) suggests that the duration of bright sunshine is perhaps the most reliable single index of the pleasantness of regional climate in Britain. According to Watson (1949), despite the presence of sea fret, most of the region is less cloudy than at comparable places west of the Pennines. Smith, however, argues that Co. Durham is unfortunate in falling within the only stretch of the east coast between the Humber and the Tweed that experiences less sunshine than comparable latitudes on the west coast. This is attributed almost entirely to the sea "fret" or "haar" from the North Sea, which is one of the most distinctive features of the Durham climate in spring and early summer. In town planning terms this phenomenon should be considered as a highly relevant factor, particularly when considering the potential of areas of residential development. This appears not to have been the case in the past and the siting of Peterlee New Town in the particularly susceptible coastal area testifies to this. It is, however, a "fact of life" in the region as a whole and even the lowland valleys of Teesdale and Weardale permit deep incursions to take place and Manley (1935) estimated a frequency of five to ten days a year for a well developed advance.

As a result of the above in particular, the mean annual sunshine at the Durham Observatory is about twenty hours more than on the coast. For individual years, the total has varied from 1606 hours in 1901 to 982 hours in 1912, (the latter being attributed to the volcanic eruption of Mount Katmai in Alaska) (Figure 5.9).

Apart from low cloud on the higher hills and the haar there is little fog recorded over the area as a whole, largely due to the prevailing breeziness, the absence of very large urban areas and the generally isolated nature of large-scale industrial pollution (Smith, 1970). This is not to underestimate air pollution; although there has been a noticeable decline during the 1960's.

A particular feature in the past has been the incidence of polluted haze and haar from the Teesside industrial complexes carried by coasterly winds across Lowland Durham, but improvements in pollution control measures associated with the chemical plants have done much to reduce incidence (Eggleton and Atkins, 1972).

5.5.4 Wind

Whilst Durham County as a whole remains generally sheltered from the prevailing westerly circulation as a result of the location in the lee of the Pennines, the hills and coast are noticeably windy. 60% of all winds blow from the south-west quadrant, but it appears that north and north-east winds have recently become more frequent throughout the year, with an overall decrease in direct easterlies and westerlies.

Gale-force winds are less common than on the west coast and are usually restricted to about five days a year (Meteorological Office, 1952), although there is a high incidence of northerly gales in Spring, and in January, 1968 a gust of 142 km/h was recorded.

Over lowland Durham, local winds are usually associated with sea breeze effects. Confined to the summer months, they are more vigorous along the coast, but occasionally penetrate inland for some miles via the lower Wear and Tees Valleys.

5.6 Soils

This section discusses the characteristics of the soil profiles sampled within the transect in the context of the general distribution of soil type within the transect as a whole. All the site descriptions and analytical results are outlined in Appendices 1 and 2 and, as discussed in Chapter 4, the new Soil Survey Classification scheme of Avery (1973) is used.

5.6.1 Summary of Transect Soil Types

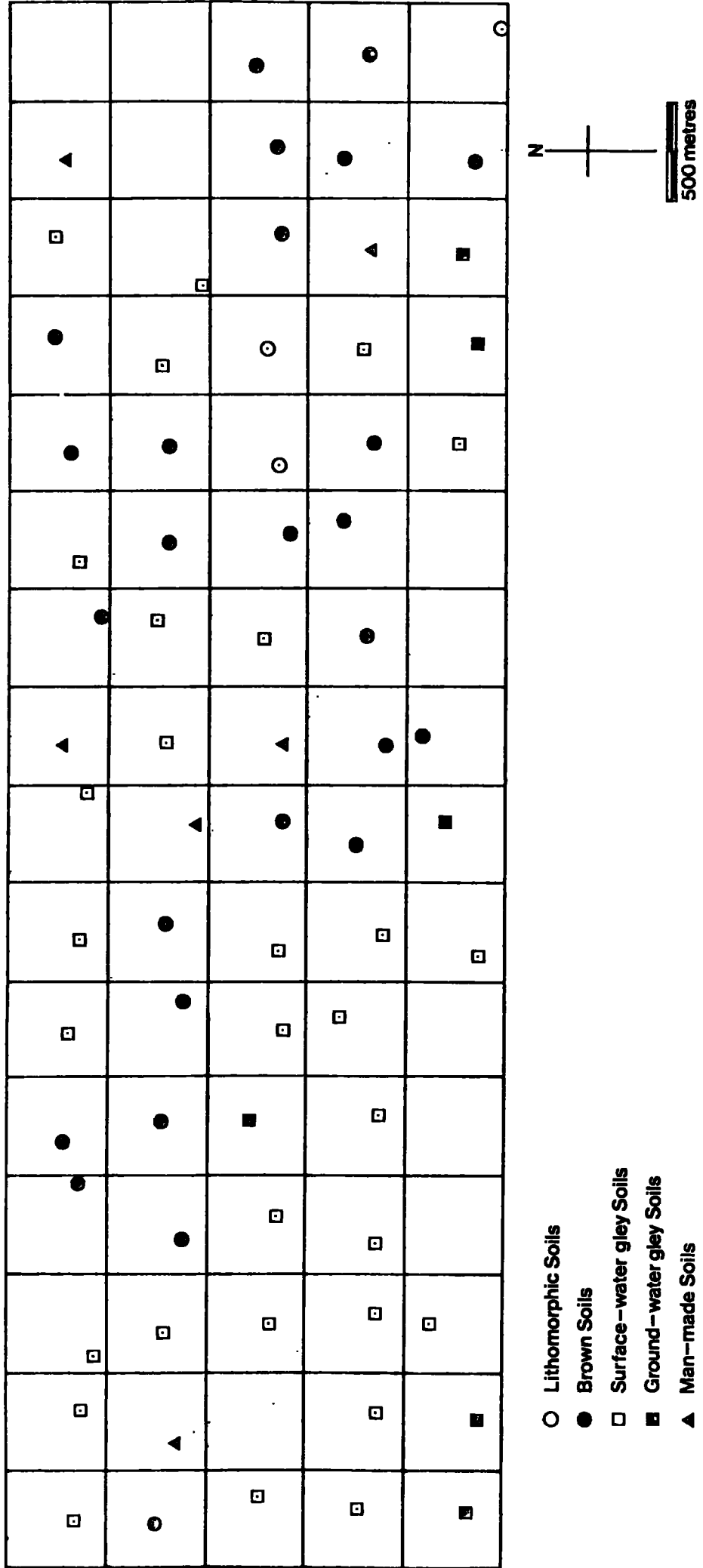
The following major groups are recognised as being present among the seventy one transect sites:

Table 5.2 Soil Major Groups of the Transect Sites.

<u>Major Group No.</u>	<u>Major Group</u>	<u>No. of Sites</u>	<u>% of Total Sites</u>
3	Lithomorphic (A/C) soils	3	4.2
5	Brown soils	26	36.6
7	Surface-water gley soils	30	42.2
8	Ground-water gley soils	6	8.4
9	Man-made soils	6	8.4
		<u>71</u>	<u>100.0</u>

Terrestrial raw soils, hydric raw soils, pelosols and peat (organic soils) are not in evidence in the area, but, although not sampled, the podzolic major group occurs in the western part of the transect where it is spatially associated with brown soils and surface-water gleys. A drawback to point sampling is this problem of not accounting for a specific soil type.

Fig5.10 Distribution of Major Soil Groups



Surface-water gley soils, which form the largest grouping, and ground-water gley soils, account together for over one half of sites (50.7%). These divisions do not, however, indicate the extent of drainage impedence in the area, as stagnogleyic and gleyic categories occur in the brown soils major group, as well as there being gleyed profiles in the man-made grouping.

The widespread occurrence and depth of the drift cover is reflected in the fact that only 4.2% of sites are of the lithomorph-
phic grouping.

Figure 5.10 and Table 5.3 show the distribution of the major groups within the transect and the number of points occupied by each.

Table 5.3 Distribution of Soil Major Groups Within the Transect

	Physiographic Units						
	1	2	3	4	5	6	7
	%	%	%	%	%	%	%
Lithomorphic (A/C) Soils						25.0	
Brown soils	12.5	20.0	50.0	27.3	16.7	50.0	66.7
Surface-water gley soils	75.0	60.0	16.7	54.5	33.3	25.0	25.0
Ground-water gley soils		20.0	33.3	4.5	33.3		
Man-made soils	12.5			13.6	16.7		8.3

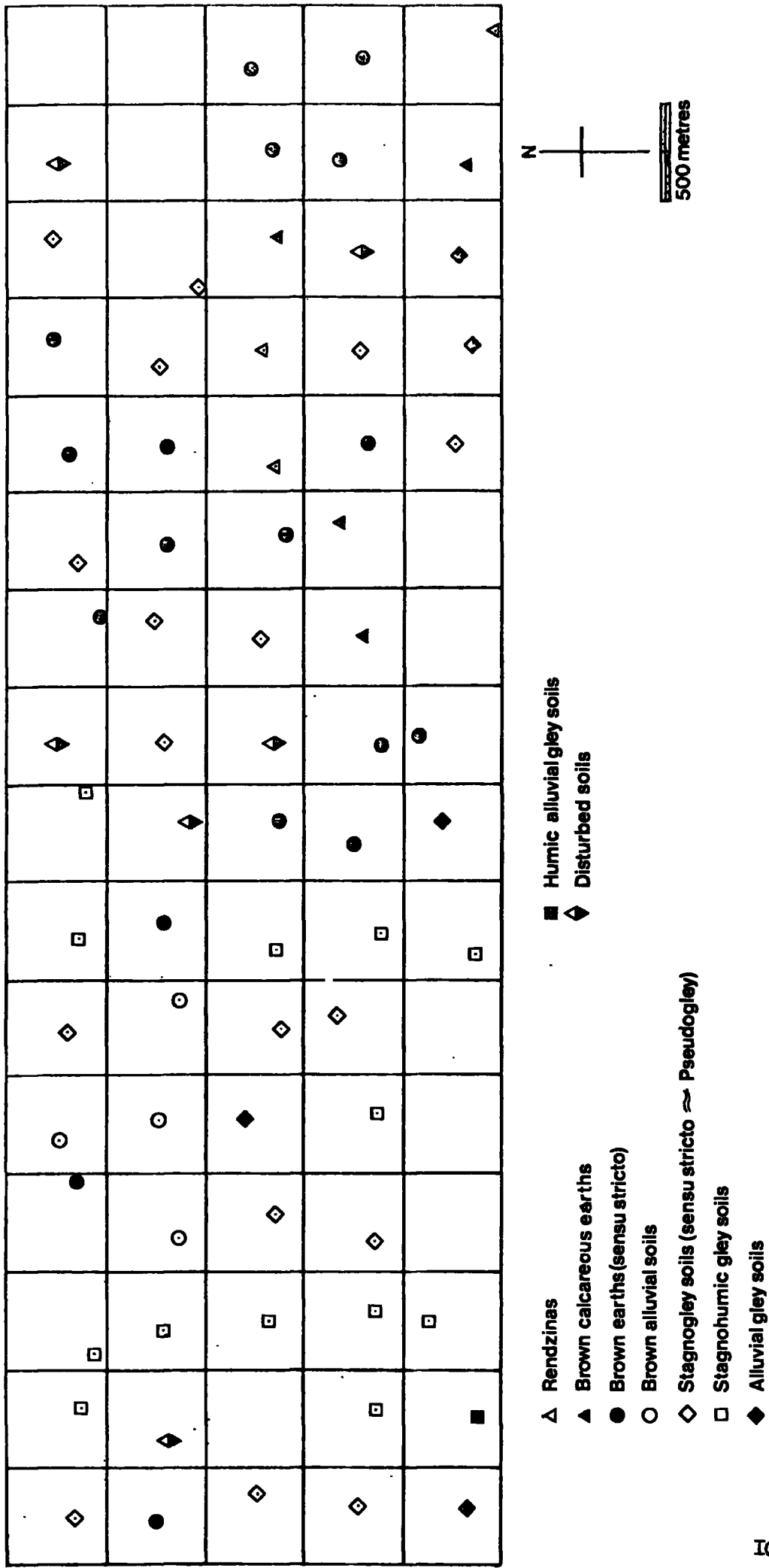
Lithomorphic soils are confined to where the Magnesian Limestone is drift free towards the crest of the Permian Escarpment (Unit 6). Brown soils, on the other hand, are distributed about the transect in every Physiographic Unit, but are more prominent to the middle and east; whilst ground-water gleys are confined to the major river and stream valleys and man-made soils are located sporadically in the lowlands.

The major soil groups are divided into soil groups of which nine are recognised as being present in the transect sites. Table 5.4 shows their numbers overall in the transect and Figure 5.11 their spatial distribution.

Table 5.4 Soil Groups of the Transect Sites

<u>Group No.</u>	<u>Group</u>	<u>No. of Sites</u>	<u>% of Total Sites</u>
3.4	Rendzinas	3	4.2
5.1	Brown calcareous earths	4	5.6
5.4	Brown earths (sensu stricto)	18	25.4
5.6	Brown alluvial soils	4	5.6
7.1	Stagnogley soils (sensu stricto ≈ pseudogley)	17	23.9
7.2	Stagnohumic gley soils	13	18.3
8.1	Alluvial gley soils	5	7.0
8.5	Humic alluvial gley soils	1	1.4
9.2	Disturbed soils	6	8.4
		<u>71</u>	<u>100.0</u>

Fig5.11 Distribution of Soil Groups



The nine soil groups are further sub-divided into ten subgroups, the distribution of these being shown in Figure 5.12 and percentage occurrence in Table 5.5. The six disturbed soil profiles are not sub-divided to subgroup level.

Table 5.5 Soil Subgroups of the Transect Sites

<u>Subgroup No.</u>	<u>Subgroup</u>	<u>No. of Sites</u>	<u>% of Total Sites</u>
3.43	Brown (non-humic) rendzina	3	4.2
5.11	Typical brown calcareous earth	4	5.6
5.41	Typical brown earth	2	2.8
5.42	Stagnogleyic brown earth	16	22.5
5.61	Typical brown alluvial soil	2	2.8
5.62	Gleyic brown alluvial soil	2	2.8
7.13	Cambic stagnogley soil	17	23.9
7.21	Cambic stagnohumic gley soil	13	18.3
8.11	Typical (non-calcareous) alluvial gley soil	5	7.0
8.51	Typical (non-calcareous) humic alluvial gley soil	1	1.4
		65	91.3

5.6.2. Detailed Discussion of Transect Soil Types

This section, which discusses the characteristics of the transect soil types in some detail, concentrates on the soil subgroup level in the context of their associated groups and major groups.

5.6.2.1 Major Group 3 - Lithomorphic (A/C) soils

These soils have a distinct or humic A horizon overlying a C horizon or bedrock at 40 cm or less, and have no diagnostic B (i.e. extending to more than 10 cm below an Ap or to more than 30 cm) or a gleyed horizon within that depth (Clayden, 1974).

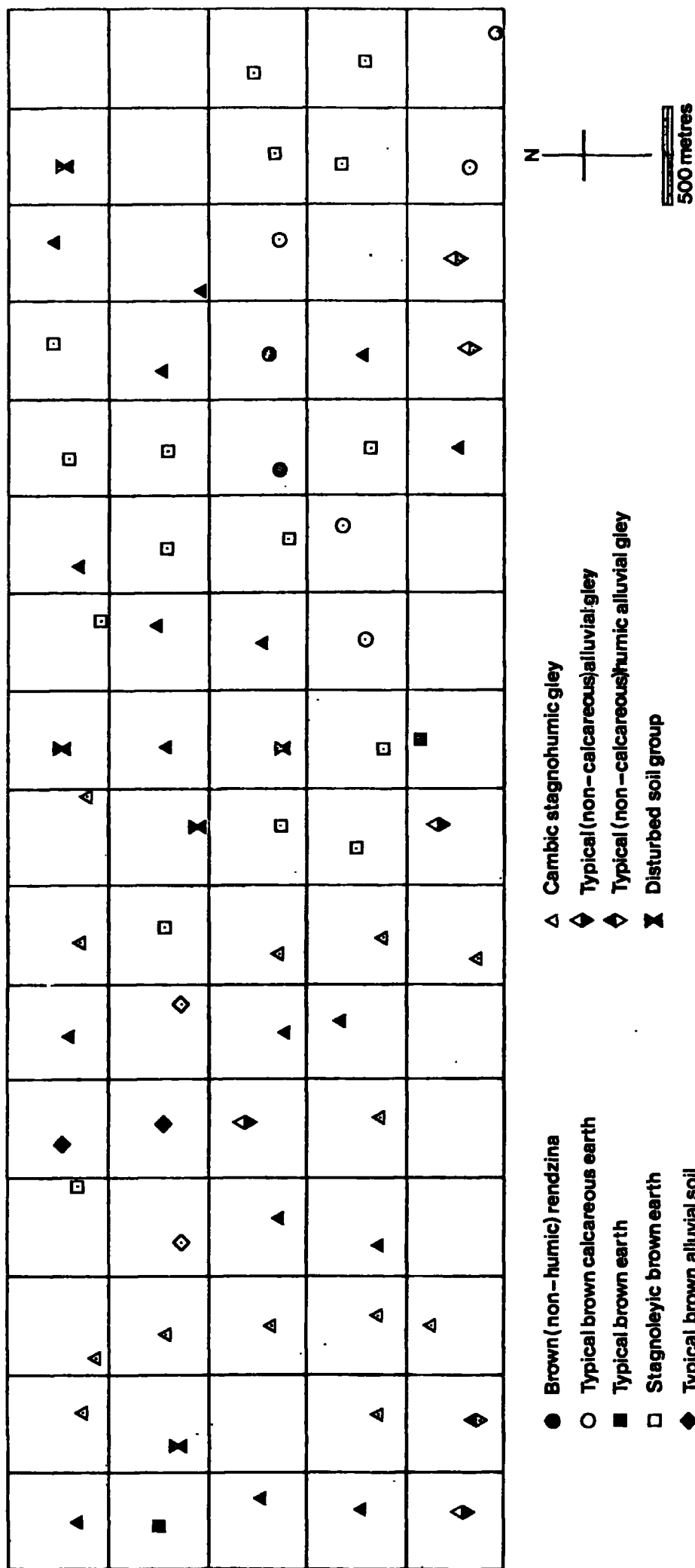
Group 3.4. Rendzinas

Developed over the extremely calcareous non-alluvial C horizons of fragmentary Magnesian Limestone, rendzinas are the only group of the lithomorphic soils encountered in the transect and are represented by the brown subgroup.

Subgroup 3.4.3 Brown (non-humic) rendzina

On account of the extensive drift cover over the limestone, soils of this subgroup are very restricted in their distribution, being confined to parts of the upper and middle slopes of the Permian Escarpment (Unit 6) that are drift free. Where drift is in evidence on the escarpment brown soils are in evidence. The inclusion of drift-derived material in the rendzina profiles is evidenced by rare volcanic rock and coal fragments in the topsoils and coarse rounded quartz grains (Frisby, 1961). Site 40

Fig5.I2 Distribution of Soil Subgroups



(described on Page 439) is representative of the subgroup.

The three rendzina profiles sampled, range in altitude from 136 to 154 m O.D. and lie on moderate to steeply sloping land of convex form. Site drainage is shedding and profile drainage well drained (excessive), but on less convex slopes free drainage is found. Soil textures vary from loam, as at Site 71, to clay loam as at Site 40 and 41 (U.S.D.A. particle size classes); these being somewhat heavier than the loam, silt loam and fine sandy loam textures (U.S.D.A. determination) reported by Crompton and Matthews (1970) on the Magnesian Limestone to the north and east of Leeds.

When subjected to arable cultivation, as at Sites 40 and 41, large quantities of rock are brought to the surface by ploughing and hence the profiles are very calcareous throughout, with calcium carbonate rising to 24.0% in the Ap horizon of Site 41. In a similar horizon nearby under matted grasses and scrub, where less disturbance had taken place, leaching had reduced calcium carbonate to 15.5%

Soil structures are moderately weak to moderately developed, with granular, crumb or subangular blocky peds, the latter being present in the cultivated profiles. Where the profile has not been ploughed (for example, Site 71), a narrow weakly structured loamy Bw horizon lies under a darker coloured, weak, humose loam Ah. Similar soils with non-diagnostic Bw horizons appear in the Leeds district (Crompton and Matthews 1970). On the cultivated sites of the transect, a firm clay loam or silty clay loam Ap lies directly on the C horizon or has a mixed Ap/C horizon intervening.

Over the transect in general, these soils are predominantly under arable cultivation (barley and wheat), particularly near Pittington. A silty clay to clay loam texture, coupled with an ability of crops to extract some water from the rock below (Hartnup and Jarvis, 1973), does not make them as drought prone as might be expected. During very dry periods, however, the presence of solid rock affects available soil moisture, the depth to limestone showing up in the grass as a "scorching pattern", particularly where the rock is less than 30 cm from the surface. Such a phenomenon is also described for rendzina soils in eastern Clwyd by Thompson (1975). In normal years their drainage status, together with good texture and high nutrient content (in general a high to very high base saturation) and alkaline reaction, make them highly productive. The exchangeable cation content depends upon the amount of humus and not the clay content (Frisby, 1961) and generally decreases with depth.

As in the Leeds area, the evidence of exposures in Durham confirms the view of Palmer (1966) that periglacial frost action has shattered the limestone to a depth of a metre or so, so aiding root penetration.

Apart from the shallowness of the profiles inducing excessive drainage, the principal management problem is of the presence of abundant limestone fragments and shallow depth to bedrock causing damage to agricultural equipment.

All the sites of the transect are diagnostically non-humic; Site 71 (described on Page 470) not being placed in this category, despite humose textures, because of an inadequate depth (11cm) of the Ah horizon. The 9 cm thick Bw horizon of the profile is just less than the thickness required for it to be diagnostic of a brown calcareous earth.

5.6.2.2. Major Group 5 Brown soils

According to Avery (1973), the brown soils major group contains those soils, excluding pelosols, with a weathered argillic or paleoargillic B and no diagnostic gleyed horizon at 40 cm or less. (See Chapter 4, Page 78).

Group 5.1 Brown calcareous earths

The brown calcareous earths of the transect are represented by:

Subgroup 5.1.1 Typical brown calcareous earth

These are defined as non-alluvial soils with a loamy or clayey texture without an argillic horizon.

Accounting for 5.6% of all sites, this subgroup is situated on the gently to moderately steeply sloping land of the Magnesian Limestone part of the Permian Escarpment (Unit 6), particularly around Pittington Hill and Elemore. Altitudes vary between 116 m O.D. and 130 m. O.D. where sampled. Although profiles are formed in situ on the limestone, alluvial activity results in the inclusion of drift from the Lower Till of the Plateau, evidenced by the presence of coal, sandstone, shale and Borrowdale Volcanic Series material in the soil. Despite the inclusion of these contaminants, (also found in the Aberford Series in Yorkshire (Crompton and Matthews, 1970)), it was decided to define these soils as brown calcareous, as actively weathering limestone was found at the base of the profile, there was little coarse sand in evidence and the soils complied with Avery's diagnostic requirements.

All the sites were under mixed woodland or permanent grass when surveyed. This was due in particular, to their location on sloping land or, in the case of Site 70, to a restricted site in a small stream valley. Site 42 (described on Page 441) is representative of the soil.

The profiles are typified by a stony Ah horizon, up to 22 cm thick, of very dark grey, very friable to friable, humose or mineral loam, silty loam or silty clay loam texture, with a medium granular or medium subangular blocky structure. Soil reaction is neutral or alkaline and base saturation moderate

to very high. Below this horizon, and containing increasing stone content, is a moderately structured, very dark greyish brown to dark yellowish brown, friable to firm Bw horizon of clay loam to silty clay loam texture. This overlies a brashy C horizon of fragmented Magnesian Limestone. Alkalinity and base saturation increases in the Bw and C horizons, the latter reaching over 80%.

Where slope permits in the transect, these soils provide good arable land, with their high nutrient content, free, but not excessive drainage, friable consistency and good working properties. Stone content, and in some cases shallowness, can give problems for ploughing, and potash deficiency, common to most limestone soils may affect fertility.

Group 5.4 Brown earths (sensu stricto)

The brown earth group, as defined by Avery (1973), is composed of non-alluvial, non-calcareous soils with loamy or clayey horizons, but without an argillic horizon. This group is very common in the transect, accounting for 36.6% of the sites, and five subgroups are recognised.

Subgroup 5.4.1 Typical brown earth

This subgroup is not common in the transect, being represented by two sites developed on different parent materials.

1). Typical brown earth developed on Carboniferous sandstone

Site 66 (described on Page 465) is situated on a localised Carboniferous sandstone outcrop at Pittington in Unit 4. This outcrop has been quarried over a significant area and as a consequence the soils are often disturbed. Where disturbance has not taken place the following characteristics are typical for flat to gently sloping sites around the 91 m contour. A well drained (free), dark grey humose sandy loam or loam Ah horizon, with weak crumb structure and common angular sandstone fragments, overlies a Bw horizon of sandy loam or loam texture with increasing clay and sandstone content with depth. Below is a BC horizon of weakly structured brown loamy sand or loam with much fragmented sandstone, or a C horizon of fragmented sandstone with iron staining. At Site 66 a transitional AB horizon is present. An increase in the sodium and potassium cations, and low % base saturation down the profile is indicative of leaching.

Appreciable amounts of drift are absent, although it is thought that some drift material may be incorporated in the soils owing to the presence of coal traces in the profile sampled. The soils are generally shallow and ploughing is difficult but sites are so restricted in the transect that woodland is the major land use. Similar soils have been mapped as the Kirkby Overblow Series by Crompton and Matthews (1970) in Yorkshire.

ii). Typical brown earth developed on Middle Sands and Gravels

The second type of parent material found to be associated with the typical brown earth subgroup is the Middle Sands and Gravel deposits, which are located spasmodically in the Lowlands East of the River Wear (Unit 4) and more extensively to the west of the Wear towards Framwellgate and Pity Me in Unit 1.

Although not mapped by Maling (1955) as being an area of "fluvio glacial sand" (see Figure 5.5; Page 98), the location of Site 16 (described on Page 415) is on such parent material. Soils of the podzolic major group are located nearby to this site, and it can be hypothesised that these typical brown earths are developed in association with podzolic soils over a significant area of the western part of the transect.

Although Site 16 displays a colour in the B horizons of 10YR4/4, rather dull for a Bs horizon typical of the brown podzolic soil group, in order to place the site into the appropriate category, the amount of pyrophosphate extractable Fe + Al in relation to the clay content was determined (Hodgson et al., 1974). The test proved that the percentage Fe + Al compared with clay content was insufficient to meet the criterion for a podzolic Bs horizon and the site was placed in the typical brown earth category.

An Ap horizon of moderately developed subangular blocky structure overlies deep Bw horizons of a sandier nature before altered parent material is found of a sandy loam texture.

Sodium and potassium cations increase in the B_{2w} horizon, after a decrease in the B_{1w} from the Ap, indicative of leaching down the profile; potassium reaching very high amounts in the lower horizons. Clay content also increases in the B_{2w}. Base saturation is generally low which, coupled with the moderately to slightly acid pH, make these soils somewhat "hungry".

Subgroup 5.4.2 Stagnogleyic brown earth

This important subgroup, accounting for 22.5% of all sites sampled, is developed on the Lower Till of the Permian Plateau, predominantly on the plateau itself (Unit 7), and locally on the escarpment (Unit 6). It is also associated with colluvium contaminated drift of the footslopes of the escarpment and the drift of the Wear Lowlands, mainly east of the river in Physiographic Unit 4.

The soils are characterised by drainage impedance at depth, caused by a relatively impermeable subsurface horizon or substratum. They are thus distinguished from the typical brown earth subgroup by grey and mottled colours at depth and as such can be regarded as soils transitional to the stagnogley soil group (Lea, 1975).

The following descriptions are based on the parent materials encountered in the transect.

i). Stagnogleyic brown earth developed on the Lower Till of the Permian Plateau

Predominantly found in Physiographic Unit 7 on the plateau, but also occasionally towards the top of the escarpment in Unit 6, these soils account for over one half of the subgroup. As the result of a combination of land use and topographical factors, slight horizon variations occur. The most common horizon sequence is of an Ap, or less frequently an Ah horizon, of very dark grey to very dark brown, occasionally humose, loam or clay loam, moderately structured and with variable amounts of very small to small stones of sandstone, shale, coal, limestone and igneous and metamorphic material. Below the plough layer is a well structured Bw horizon of dark yellowish brown clay loam with variable stone content (as Ap). This overlies a moderately structured or massive reddish brown to dark yellowish brown BCg horizon of pedogenetically altered parent material, with prominent rusty and grey mottles which decrease in the C(g) at considerable depth. Site 43 is representative of this type and is described on Page 442.

Near to the edge of the plateau (and occasionally a distance away) a combination of ploughing and topography has resulted in soil movement stripping off topsoil. As a result of continued cultivation, the Bw horizons have become totally incorporated into the Ap horizon. These soils meet the criteria proposed in the previous Chapter for "truncated soils" in the stagnogleyic brown earth subgroup (see Chapter 4, Page 78). At Sites 12, 26 and 27, a moderate to moderately weakly structured dark grey to very dark greyish brown Ap of clay loam texture, overlies a BCg horizon similar to that described above. Site 27 is representative of this type and is described on Page 426.

Away from the edge of the plateau at Sites 44 and 59 shallower Bw horizons remain, with BCg horizons being met at 35 cm. Taking Avery's 40 cm threshold depth, these two sites would be included as being "truncated", whilst taking the 35 cm of Lea (1975) they would be included as normal examples of the subgroup.

Both the above variants of the stagnogleyic brown earth subgroup have imperfectly drained horizons, but locally a moderately well drained variant occurs, as at Site 13 (described on Page 412) where soil creep and cultivation practice produces at the bottom of a slope, deep Ap and Bw horizons, which overlie a sandier till which has distinct ochreous and grey mottling below 60 cm. This better drained variant has slightly browner coloured horizons than those of the imperfectly drained soil, being very dark greyish brown in the Ap and becoming dark brown in the Bw horizon. Likewise, the texture of the

topsoil may be a loam (sometimes humose) rather than clay loam and the structure also weaker. The result of this "lighter" nature and better drainage is increased leaching, with a moderately acid pH of 4.3 recorded at Site 39 in the Ap, which increases to a slightly acid 5.5 at depth. Very low to low base saturation is also in evidence. To counteract this acidity frequent liming may be necessary.

Soil reaction in the imperfectly drained soils is higher than in the better drained variant, with a neutral reaction in the Ap increasing with depth. An alkaline reaction in the Ap is occasionally found (for example, Site 12), and is thought to be the result of over-zealous liming.

The reasonable nutrient status of these soils is a reflection of the neutral to alkaline nature of the drift over the Magnesian Limestone (Beaumont, 1967) and the level to moderately sloping land, which reaches a maximum of 5° at Site 12. Arable cultivation is, therefore, most in evidence. The climatic exposure at the top of the plateau can restrict crop choice and barley is the most common crop. Winter wheat is only grown where shelter permits, or on the more clement south-western facing slopes.

ii). Stagnogleyic brown earth developed on colluvium contaminated drift of the Permian Escarpment (Unit 6)

These soils are not widespread and are confined to the lowest part of the footslope of the escarpment, where calcareous colluvium, derived from the Magnesian Limestone, Marl Slate and Basal Sands, has moved down-slope to contaminate the drift of the Wear Lowlands. This movement down slope is evidenced by the presence of Magnesian Limestone fragments incorporated in the Lower Till of the Wear Lowlands, normally free of this material. Upper carboniferous rocks rest beneath.

Only Site 10 (described on Page 409) exhibits such development; a proportion which probably reflects this soils occurrence over the whole area.

A dark brown humose silty loam Ap horizon, with moderately weak structure and slight stone content, which includes Magnesian Limestone fragments as well as the siltstone, sandstone, coal and igneous and metamorphic pebbles characterising the drift, overlies a friable loamy Bw horizon of slightly better structure. Below this is the BCg of altered parent material of a reddish brown colour. Profile drainage is imperfect. The calcareous nature of the colluvium and, possibly, subsurface lateral seepage from the deposits upslope, results in the soil having an alkaline reaction throughout.

The good nutrient status, moderate slope and fine texture make them high quality arable soils.

iii). Stagnogleyic brown earth developed on the till of the Wear Lowlands (Lower Till and Upper Wear Clay)

Apart from Site 4, located immediately above the western slope of the Wear Gorge in Unit 2, all the stagnogleyic brown earths of the lowland sites are situated east of the river in Unit 4. As in similar soils developed on the Permian Plateau outlined in i) above, there are three horizons sequences, the result of agricultural practice and topography; but unlike the plateau soils, examples are found in the transect on steeper slopes, ranging from gently to strongly sloping.

The most frequently encountered horizon sequence is one of a dark grey to greyish brown Ap or Ah of well structured loam, silty loam or clay loam, overlying a Bw horizon of browner colour and moderate to strongly structured clay loam or silty loam. This merges into a mottled reddish brown to yellowish brown silty clay loam to clay loam BCg. The mottles decrease in the C(g) below, at depths in excess of 90 cm. Profile drainage is imperfect and stone content is variable, depending on the content of the drift. Site 22 is representative of this and is described on Page 421.

A truncated horizon sequence of Ap, BCg was found near to Pittington, where a moderately weakly structured very dark greyish brown loamy Ap horizon directly overlay the BCg. In Site 52 (described on Page 451) the yellowish brown altered parent material is typical. However, in Site 53 the prominently mottled BCg is much sandier, and it is considered that the drift has been contaminated by Coal Measures sandstone material.

As on the limestone, a moderately well drained deeper variant to the imperfectly drained soils occurs at the base of cultivated slopes, where the drift is sandier and soil creep, through ploughing, has deepened the profile.

Site 4 (described on Page 403) is the only representative of this variant. It has a friable, moderately weak structured loamy Ap horizon, overlying a clay loam Bw horizon of lighter colour and of moderately developed medium subangular blocky structure. The sandier drift has distinct mottles below 60 cm. The lighter nature of this soil with its better drainage and increased leaching, results in a more acid soil reaction, which ranges from a slightly acid 5.1 in the Ap to a moderately acid reaction (between 4.4 and 4.7) in the Bw horizons.

In the imperfectly drained soils, pH is predominantly neutral to alkaline, with the highest values being in the BCg, rising to 7.6 at Site 56. In general, the stagnogleyic brown earths in the Wear Lowlands have a low to moderate base saturation which decreases with depth and a very variable cation exchange capacity. This low to moderate base status for a relatively high pH, in the lower horizons in particular, may be accounted for by a dominance of kaolinite in the clay fraction of the drift.

Nevertheless, these soils, compared with the poorly drained gleys, which characterise the Wear Lowlands, are generally under arable cultivation owing to their better drainage, higher soil reaction and more workable qualities.

Group 5.6 Brown alluvial soils

Brown alluvial soils are defined by Avery (1973), as being non-calcareous soils developed in recent alluvium, and are distinguished from otherwise similar soils because "the resultant classes usually characterise natural soil landscape units of practical significance". The group coincides with brown warp soils (Mackney and Burnham, 1964) and has gleyic and typic subgroups, both of which are found in the transect. The B horizons are weakly defined and the typic subgroup has no mottling above 70 cm. The sites are liable to flooding.

Subgroup 5.6.1. Typical brown alluvial soil

These well drained soils are found on the level sandy alluvial flats and low terraces of the River Wear Gorge and Floodplain (Unit 3), occurring particularly on the inside of meander bends. Site 5 is representative of this subgroup and is described on Page 404.

The alluvium gives an almost stoneless dark greyish brown coloured soil, whose texture varies from very friable humose loamy sand in the Ah and top Bw horizons, with weak to moderately weak granular structure, to sandy loam in the lower Bw, which grades to a single grain dark brown sand in the parent material at about 46 cm. At certain sites a transitional AB horizon is present, as at Site 20, described on Page 419.

Throughout this soil subgroup profiles are slightly to moderately acid. Base saturation generally decreases with depth, indicative of the absence of extensive leaching of bases and is very low to moderate in amount. At Site 20, however, there is an increase in the base status of the B_w horizon, with a drop in status below this horizon as well as a lower status in the AB above. This is indicative of illuviation. Moderate amounts of sodium increase with depth, whereas the other metallic cations generally decrease.

Because of the restricted nature of the sites and their liability to flooding, cultivation is not practiced on these soils. Cattle are grazed at some sites (Site 20), but the predominant land use is of amenity woodland. Cattle may cause some compaction, resulting in faint rusty mottles in root channels in the Ah horizon.

Subgroup 5.6.2. Gleyic brown alluvial soil

This subgroup has distinct mottling above 70 cm, but without the gleyed horizon in the upper 40 cm required by the ground-water gley major group (Avery, 1973).

The subgroup occurs on alluvium containing appreciably less sand than the typical brown alluvial soil. It is common in the Wear Gorge and also along tributary streams flowing across the till sheets of the Wear Lowlands.

In the Wear Gorge these soils are developed on level alluvial flats similar to the typical brown alluvial soil sites. A representative profile (Site 19, described on Page 418), has a mor humus overlying a moderately weakly developed, very dark brown, Ah horizon of humose loamy sand texture. Below this are loamy Bw horizons of similar structure, and at greater depth, a friable, loamy Cg horizon of dark yellowish brown colour, with distinct rusty and grey mottles. Sand content of the parent material reaches nearly 70%. Stones are rare, as are worms, the latter indicative of an acid (or wet) environment.

Base saturation remains very low throughout the profile and the reaction strongly acid. At less demanding locations, the nutrient status is similar to the typical brown alluvial soil. In the profile sampled (Site 19) exchangeable magnesium exceeds exchangeable calcium in all but the B₂w horizon. Profile drainage is imperfect.

As indicated, the restricted drainage and tendency to flooding at these sites results in predominantly amenity woodland land use with occasional grazing sites.

The streams flowing to the River Wear across the till of the Wear Lowlands cut through predominantly silty and clayey material and in certain restricted areas, especially where stream velocities are reduced, small alluvial flats have developed with loam, clay loam or silty clay loam textures. Here, unlike the Wear Gorge locations, stone content is relatively high, again reflecting the nature of the immediate surrounding drift. Soils developed on these deposits may be imperfectly drained or moderately well drained, as in Site 21 (described on Page 420) according to depth to gleying. Better drainage is the result of agricultural practice and topographical factors. Although % base saturation is low, soil reaction was found to be neutral to alkaline in Site 21; the former decreasing down the profile whilst the latter increased. Despite being subjected to periodic flooding, agricultural production is not affected.

5.6.2.3. Major Group 7 Surface-water gley soils

These soils are defined by Avery (1973) as non-alluvial with distinct, humose or peaty topsoil, non-calcareous Eg and/or Bg or Btg horizons, and no G or relatively pervious Cg horizon affected by free groundwater. Waterlogging within profiles results from slowly permeable horizons, giving a diagnostic gleyed horizon within 40 cm of the surface. This major group is equivalent to the seasonal ground-water soils of Robinson (1934).

The gley horizons have dominantly greyish and or ochreous colours and unless artificially drained, are normally wet for significant periods. Although the soil is classified as a surface-water gley, the subsurface, which should usually be grey, may be greyish brown to brown, indicating the effects of artificial drainage. Wetness in these horizons is often present in too great a quantity to account for the colour present (for example Sites 34 and 57), suggesting that subsidence is a significant factor at these sites in modifying the drainage. Generally speaking, the soils are "heavy" and "cold", particularly to the west of the transect.

They are developed on all the varying tills of the area, and are described on the basis of differing parent material, separated at group level according to the presence or absence of a humic topsoil.

Group 7.1 Stagnogley soils (sensu stricto $\approx$ Pseudogley)

These are surface-water gley soils without a diagnostic humose Ah and/or Ahg horizon and, in the transect, are represented by the cambic subgroup which is typically of fine or medium textured material, without a subsurface horizon of clay accumulation.

Subgroup 7.1.3 Cambic stagnogley soil

The cambic subgroup is found throughout the transect, but is best developed from Ramside westwards and, as in Wales (Clayden, 1974), is widespread on till derived from Coal Measures sediments.

i). Cambic stagnogley soil developed on the Lower Till of the Permian Plateau (Unit 7).

Stagnogley soils developed on the neutral to alkaline till of the plateau are not widespread, the principal soil with impeded drainage being the stagnogleyic brown earths described in Section 5.6.2.2. In some restricted areas of the plateau, where topographic factors, agricultural practice, subsidence or heavier parent material results in waterlogging of the subsoil in winter, poor profile drainage is in evidence and stagnogleys develop. This can occur even on moderately sloping land, as between High Moorsley and Hetton-le-Hill.

A representative horizon sequence (Site 29, described on Page 428) is of a dark grey, loam or clay loam Ap, Ap(g) or Ah(g) horizon, over an olive brown to yellowish brown clay loam or clay Bg with ochreous mottles. Below is a clay or clay loam BCg horizon, typical of stagnogley soils, of olive brown to yellowish brown colour, mottled rusty and grey and extending to a considerable depth (>90 cm) before merging into a C(g) with decreasing mottles.

The poor drainage of these soils confines roots to within 23-30 cm of the top of the altered parent material, whereas, in the better drained areas, roots may grow through 2 m of the Lower Till into the Magnesian Limestone below (Beaumont, 1967). Beaumont states that the depth of gleying in the parent material

shows considerable variation owing to varied environmental conditions, but one of the characteristics of the Lower Till of the Magnesian Limestone is that gleying is a widespread phenomenon throughout the profile and is not just confined to joint spaces.

The neutral to alkaline reaction of the till parent material (values below 8.0 are common in the top 1 to 1.5 m according to Beaumont, 1967) is maintained throughout the soil profile and % base saturation normally increases downwards. Exchangeable calcium is variable with depth and, as would be expected, exchangeable magnesium increases from moderate to high, or remains moderate, down the profile.

Despite the poor drainage, reasonable nutrient status, coupled with the moderate topography, results in arable cultivation being practised at most sites, although Site 14 was under permanent grass when surveyed. Climatic exposure may be a problem.

ii). Cambic stagnogley soil developed on contaminated drift of the Permian Escarpment (Unit 6)

At the top of the footslopes of the escarpment, on Upper Carboniferous strata just below the junction with the Permian, stagnogley soils have developed on till mapped by Maling (1955) as "thin drift", but which is either the Lower Till of the Wear Lowlands or a mixture of the Plateau and Lowland Till. The presence of Magnesian Limestone fragments in the soil profiles indicates that either movement of such debris has occurred downslope to contaminate the lowland till as head deposits, or that this drift has been mixed with the till of the plateau which contains Magnesian Limestone, both processes may also have occurred. Further contamination occurs where head in the form of Marl Slate and Colluvium derived from the Basal Sands has been incorporated in the profile, thereby giving the soil a slightly coarser texture.

The increase in Basal Sands content results in higher sand levels, as at Site 25 (described on Page 424) which becomes sandier with depth until an impervious BCg of sandy clay loam texture is met. In the profiles sampled, a very dark grey to dark yellowish brown Ah or Ap horizon (which may be slightly gleyed) with moderately developed blocky or granular structure, overlies mottled Bg horizons of dark brown to yellowish brown colour and distinct to prominently mottled BCg horizons. Where the content of sand is less, clay loam or clay textures dominate. Site 25, located on the escarpment below High Moorsley, has an alkaline reaction, probably derived from lateral seepage of calcium carbonate enriched water from the limestone at higher levels, as well as from the nature of the

parent material. Site 11 (described on Page 410) situated further down the slope, has a neutral reaction, and Site 38 (described on Page 437) at Pittington is moderately to slightly acidic, more akin to that found in the Wear Lowlands. Likewise, base saturation varies, decreasing from high proportions at Site 25 to low to moderate amounts at the other sites. It is suggested that these variations reflect the very complex parent material relationships in this marginal zone, where not only differing strata, but also separate till sheets meet and where colluvial and head deposits are intermixed with the drift; with still further complications resulting from lateral and vertical seepage of lime enriched waters.

This complex of soils has no true "representative" profile, but the type occupying most of the area is that of Site 11 at High Moorsley.

iii). Cambic stagnogley soil developed on the drift deposits of the Wear Lowlands

The complex succession of drift deposits found in Physiographic Units 1, 2, 4 and 5 provide varying parent materials for the stagnogleys of the area. They will be discussed separately.

a). Upper Wear Clay and Lower Till.

The cambic stagnogley soils developed on these parent materials account for 14.2% of all the sites sampled and, because of their similarity, will be discussed under one heading. The soils are developed on level to moderately sloping land of Units 1, 2, 4 and 5 at elevations between 58 and 107 m O.D.

The Ah, or more typically Ap horizon, is often gleyed to form an Ahg, Ah(g), Apg or Ap(g), with faint, or more rarely, distinct, fine rusty mottles, a very dark grey to very dark greyish brown colour and moderately developed subangular blocky structure. Texture is loam, silty loam, silty clay loam or clay loam, which is sometimes humose when associated with night soiling or woodland sites, but horizons are not deep enough to give a diagnostic humic horizon (night soiling is discussed in Section 5.7.4. on Page 136 - 37).

A lighter coloured Bg horizon frequently follows, with fine to prominent rusty and grey mottles and silty loam, silty clay loam, silty clay, clay or clay loam texture. Several Bg horizons might be in evidence before the weathered parent material (BCg) is reached. In its unweathered form, the Upper Wear Clay, considered the prominent parent material, is dark brown in colour, but the top 60 cm to 1.5 m, of altered profile is often "bright yellow and orange" in colour due to the

oxidation of iron minerals (Beaumont, 1967). In effect, the dark brown C(g) horizon is rarely met within 100 cm of the surface. The extreme variability of the deposit (Beaumont states that in terms of textural conditions it exhibits considerable variety with rapid changes taking place over short distances), results in the BCg horizon varying from a clay to silty clay, silty clay loam or sandy clay loam. However, as the outcrop of the deposit is characterised by a very close association with laminated clay and Coal Measures material, silty textures predominate. Site 50 (described on Page 449) is representative of the soil and Site 30 (described on Page 429) shows its sandier form.

The stone content of the Upper Wear Clay and, therefore, of the soil profile, is also extremely variable, ranging from slightly to extremely stony. Sandstone is the prevailing lithology of the stones, reaching 68.2% (Beaumont, 1967), which, together with the absence of far-travelled material, suggests a Coal Measures origin of the deposit.

Because of the absence of igneous or metamorphic material within the soil profiles, it is tentatively suggested that all but one profile is developed from Upper Wear Clay. However, Site 24 (described on Page 423) contains small stones of metamorphic material which would indicate Lower Till parent material.

Horizon development and general chemical and organic contents in the Lower Till soils are similar to the Upper Wear Clay profiles but sand content is slightly higher throughout the profile, although a clay loam texture is maintained. The sand content is in keeping with that found by Beaumont for the drift itself. As with the Upper Wear Clay, the unweathered form of the Lower Till, which is a dark grey to brown colour, changes colour to show extensive yellow and brown mottles.

The depth of root penetration into the Lower Till has been indicated when discussing the cambic stagnogleys of the plateau, and that of the Upper Wear Clay is similar. Beaumont states that much depends upon topography; the well drained profiles, such as those where stagnogleyic brown earths have developed, may have root penetration to depths of 1.2 to 1.5 m, but in the poorly drained stagnogleys they rarely reach depths greater than 45 cm.

The soil reaction of the cambic stagnogleys developed on both tills varies from moderately acid to neutral throughout (increasing with depth), but where the sites are under woodland the pH may be strongly acid, as at Site 6.

Only one of the transect sites is located west of the Wear (Site 45) the remainder situated particularly around the Belmont area. The poor drainage, texture, acidity and low to moderate base status results in these soils principally being down to woodland and grass, with some arable cultivation. The gentle topography is a factor in their favour, however, and they lack the climatic exposure of the "limestone" stagnogleys.

b). Laminated Clay

The laminated clay deposits most frequently occur at altitudes between 55 and 67 m O.D; the height of the second important glacial platform, the 58 m surface, which was recognised and described by Anderson (1939) and Maling (1955). The grey (10 YR 5/1) clay, which is suggested by Maling to be of either lacustrine or under-melt origin, is "cold" and "heavy" and produces poor to very poorly drained soils on the level to moderately sloping land around Low Newton and Brasside. The stagnohumic subgroup is more common, as a result of night soiling activity.

Only one site of the cambic stagnogley subgroup (Site 1, described on Page 400, was encountered on laminated clay. An Apg horizon of dark greyish brown (almost humose) silty loam overlies a Bg of dark brown silty clay loam, with an increasingly strong prismatic or subangular blocky structure. The BCg, of massive greyish brown silty clay, follows at 33 cm.

The pH of the soil is neutral throughout the profile and base saturation is moderate to very high. Land use is predominantly arable.

Subgroup 7.2.1. Cambic stagnohumic gley soil

Stagnohumic gleys have a humic or peaty topsoil, developed as a result of the accumulation of organic residues over a slowly permeable mineral soil. They normally occur in regions of high rainfall, the high organic content of the topsoils (>4.5%) being uncommon in agricultural soils, without some anthropogenic influence (Thompson, 1976; pers. comm.).

The subgroup is found only in the Wear Lowlands in the transect, where it forms a common grouping. It is suggested that the nature of these soils in this area is the result of the practice of "night soiling" i.e. the dumping of urban waste on agricultural fields (described in Section 5.7.4. on Page 137). The accumulation of debris and organic matter from human waste to levels diagnostic of the stagnohumic subgroup, produces in some profiles a lighter-textured topsoil, and the degree of gleying is extremely variable, from none in evidence to (g) or g. Both field drainage systems and subsidence have also modified the drainage of these soils. Only Site 31 (see Page 430) is considered not to have developed in this way.

It is the differing parent materials found within the Wear Lowlands that effects the ultimate nature of these soils and, as in previous sections, the subgroup will be described on a parent material basis.

1). Upper Wear Clay and Lower Till

Cambic stagnohumic gley soils developed on these parent materials account for 14.2% of all the sites in the transect. They are mainly found on level to gently sloping areas, although moderate to strongly sloping sites do occur (for example, Sites 46 and 47). Altitudes vary from 38 to 95 mm O.D. and site drainage is normal or receiving and profile drainage poor.

A typical horizon sequence, as found at Site 63 (described on Page 462), is one of an Ap, Ap(g), Apg, or, more rarely, Ahg or Ah(g) of very dark grey or dark or very dark greyish brown humose silty loam, silty clay loam, or clay loam with a moderately developed angular blocky or subangular blocky structure. Organic carbon content varies from 6.4 to 7.9%, and the surface is frequently littered with debris in the form of fragments of clay pipes, china and glass.

Beneath the A horizon lie Bg horizons, dark brown to dark yellowish brown in colour, with distinct rusty mottling and loam, silty loam, clay loam, silty clay or clay, texture, which is occasionally humose. The BCg, of silty clay loam, silty clay or clay, has prominent ochreous and grey mottles and is met at a variety of depths.

The stone content, varies, in accordance with the variability of the drift, from very rare stones to very stony or extremely stony, as in the lower horizons of Site 18, which proved impossible to penetrate after 30 cm.

The pE is moderately acid to neutral, as encountered with the cambic stagnogleys, but Sites 8 and 51 were found to be alkaline which, although not characteristic, may be accounted for by over-zealous liming.

Base saturation in the topsoil varies from low to moderate and occasionally high and, as found with the non-humic stagnogleys, is variable down the profile, but may reach high or very high amounts in the BCg.

The friable humose nature of the topsoil makes these soils more attractive to arable cultivation than the non-humic subgroup and, apart from Sites 31 and 49, all were under arable cultivation at the time of survey.

Site 31 (described on Page 430), developed on the Upper Wear Clay of the upper slopes of the Wear Gorge (Unit 2), is a more organic variant, the amount of which cannot be put down to night soiling activity but to the nature of the predominant vegetation. The mixed woodland, coarse grasses and bracken have produced a diagnostic O horizon, which overlies silty clay loam and clay loam horizons. The pH is strongly acidic throughout the profile.

ii). Laminated Clay

The stagnohumic gleys developed on laminated clay are located on level sites in the Brasside area at Framwellgate Moor.

At Site 3 (described on Page 402) an Ap(g) of dark grey to very dark grey humose silty loam or clay loam, with faint ochreous mottles and moderately developed subangular blocky structure, overlies a Bg horizon of dark grey humose silty clay loam. Site 2 (described on Page 401) as a result of cultivation, does not have a B horizon, the Apg/ Bg lying directly over the greyish brown BCg. In both examples, the massive BCg is strongly mottled and a very intractable silty clay or clay. The C(g) horizon comprises a massive grey silty clay.

Both sites are slightly stony in the topsoil, increasing in content with depth and the stones are small and largely consist of coal fragments.

Organic carbon in the topsoil varies from 6.4 to 7.6%, indicating the presence of night soiling on these flat, accessible areas; debris is also in evidence.

Soil reaction is neutral in the topsoil but becomes increasingly acid with depth. Similarly base saturation decreases sharply with depth.

The sites are not inherently fertile, requiring the use of inorganic fertilizers, and the intractable nature of the parent material makes these soils "cold". However, the organic content of the A horizon and amount of human interference has produced A horizons that are not as gleyed as would occur naturally and this, coupled with the flat nature of the area, makes arable the primary land use. Compaction, due to structural instability, can be a problem. Oats is the principal cereal crop.

iii). Middle Sands and Gravels

Although not mapped as being an area of fluvio-glacial sand and gravel by Maling (1955), Site 35 (described on Page 434) shows a very sandy texture throughout, and it is considered that this profile is developed on such a parent material. The most usual soil developed on the sands and gravels is of a typical brown earth, but where an impedance occurs, particularly in receiving situations, gleyed horizons develop. This impedance may be the result of subsidence, fragipan lower down the profile or till below the sands, but the nature of such a restriction was not confirmed at this site. The humose nature of the Ap horizon is again probably the result of anthropogenic influence as the presence of debris testifies.

Below the humose loamy Ap horizon the Bg is of strongly mottled clay loam. The increase in clay content in this horizon, with a decrease in the horizons below, suggests some argillic development, but the amount of clay difference between the horizon and the Ap is less than specified for a diagnostic argillic horizon; the necessary chromic or ferrichromic characteristics also being absent. However, the presence of cutans indicates active translocation of clay. Below the Bg, strongly mottled BCg horizons of sandy loam are deep and structureless, but the amount of sand in the profile is not great enough to be diagnostic of a sandy stagnohumic gley. Under the U.S.D.A. textural definitions, the BCg horizons are sandy loam, and since percentage sand is less in the M.I.T./B.S. system, these soils cannot be termed sandy.

The pH is neutral throughout the profile with a slight increase in the BCg. Base saturation is low in all but the BC_{1g} horizon, suggesting the leaching of bases from the surface horizons.

This type of soil appears to be uncommon in the transect and is probably the result of very local, soil moisture conditions.

5.6.2.4. Major Group 8. Ground-water gley soils

This major group is composed of gley soils with a relatively pervious substrata affected by fluctuating groundwater, and has alluvial, or much less frequently, non-alluvial groups. They have distinct, humose or peaty topsoils and a diagnostic gleyed horizon at less than 40 cm from the surface (Avery, 1973). The groundwater rises and falls relatively freely through the Cg horizon.

Group 8.1 Alluvial gley soils

Alluvial gley soils occur principally on silty or clayey, or occasionally sandy, alluvium, recently deposited by the River Wear and its major tributary streams.

Subgroup 8.1.1 Typical (non-calcareous) alluvial gley soil

In this subgroup, which is the only one of Group 8.1 found in the transect, gleying is most intense in the structureless Cg horizon above which, in the zone of the fluctuating water table, the profile is distinctly mottled and well structured. These soils are particularly associated with the River Wear near Kepier, where the floodplain opens out from the gorge, and along Coalford Beck at Elemore, where it flows from the Magnesian Limestone onto the Lowlands.

Slopes are gentle to moderate on the floodplains, but where the streams have cut deep sections, steeply sloping land is found, as at Site 33. Altitude varies from 27 to 105 m O.D.

A typical horizon sequence is one of an Ah, Ah(g) or Ahg, of very dark grey to very dark greyish brown humose clay loam, silty clay loam or clay, with faint rusty mottles when gleyed, and a fine subangular, angular blocky or granular structure.

Stone content is variable, but is usually only slightly stony or has very rare stones. Below this horizon, clay, silty clay or, rarely, clay loam B(g) or Bg horizons of dark brown to dark greyish brown colour and prismatic or subangular blocky structure, overlie BCg horizons of weathered parent material, or, more typically, Cg horizons of clay loam, clay or silty clay. Both of these types are heavily mottled and become greyer with depth. Clay may reach nearly 75% in the parent material, as at Site 68, (described on Page 467) which has a typical profile.

Soil reaction varies from moderately acid to neutral in the Ah horizon, decreasing with depth at Sites 33 and 69, but increasing at Sites 68 and 61.

Base saturation is low or moderate in the topsoil and varies down the profile, although Site 69 (described on Page 468) recorded a very high percentage.

The poor drainage and liability to flooding, together with seasonal waterlogging on level sites, restricts land use to permanent pasture.

A sandy variant, developed on sandy alluvium, is found in the transect along Pittington Beck. A very dark grey humose loam Ah(g) overlies a Bg of very dark greyish brown humose loam, with more distinct mottles than the topsoil, below which is a distinctly mottled BCg of loamy sand. The slightly acid topsoil increases to neutral in the subsoil and base saturation is low throughout the profile (Site 65 is described on Page 464).

Group 8.5 Humic-alluvial gley soils

The soils of this group have a humose or peaty topsoil and are developed on loamy or clayey alluvium (Avery, 1973). They are not widespread in the transect, with only one subgroup being represented.

Subgroup 8.5.1 Typical (non-calcareous) humic alluvial gley soil

Only one site of this subgroup is represented in the transect, situated on a terrace-like feature below the sandstone bluff in the River Wear Gorge before it opens out at Kepier. The soils are similar in characteristics to the non-humic typic subgroup, but contain diagnostic amounts of organic matter in the topsoil, which is greater than 15 cm in thickness.

As in the case of many alluvial deposits (Lea, 1975), Site 62, (described on Page 461) has a variation in lithology; the clay increasing with depth to 35 cm; whilst below this decreasing, in marked contrast to an increase in sand content.

An Ah horizon of moderately structured humose silty loam overlies a slightly mottled B(g) of humose silty clay loam. This grades to a humose loam on reaching the Cg, which has distinct reddish brown and grey mottles. Coal, sandstone and shale of medium size in the topsoil decrease to coal traces only in the parent material.

The pH is slightly acid throughout the profile and base saturation is moderate, but the latter decreases with clay content between the A and B horizon and decreases in the C.

5.6.2.5. Major Group 9. Man-made soils

This major group includes soils with a thick man-made A horizon (not found in the transect) or disturbed soils, (including material recognisably derived from pedogenic horizons), more than 40 cm thick (Avery, 1973). Examples of such soils encountered in the transect are confined to the Lowlands East of the River Wear (Unit 4), an area near Coalford Beck in Unit 2, at Coalford Vale (Unit 5) and on the Permian Plateau near Hetton in Unit 7.

Group 9.2 Disturbed soils

This group consists of "artificially" disturbed or transported material, which also includes recognisable fragments of pedogenic horizons, without a discernible natural order, occurring below an Ah or Ap horizon. Deeply worked ground and soil replaced after mineral extraction is included. There is no subgroup recognised and, as a result, such soils may take very different forms within the overall characteristics summarised above.

In the transect a selection of such soils is found as follows:-

Site 58 developed on sand extraction pit infill over sands.
Site 37 developed on contaminated alluvium?
Site 23 developed on disused railway deposits over Upper Wear Clay.
Site 9 developed at a disturbed old orchard over Upper Wear Clay.
Site 17 developed at a derelict brickworks over Laminated Clay.
Site 15 developed at a derelict colliery over Lower Till.

Human disturbance is also attested by the presence of humose topsoils in those sites under cultivation and the inclusion of brick and other contaminants in the subsoil.

The soils lying on sandy material are freely drained, whilst those on the clayey drift are poorly drained. Soil reaction varies markedly from site to site; from moderately acidic as at Site 9, to alkaline, as in the subsoil of Site 23. Base saturation generally is very low.

Depending upon land ownership, these soils are down to a variety of land uses; scrub, conifer plantation, orchard, and arable sites all being encountered within the transect.

5.7 Land Use Response to the Physical Environment

The land uses pertaining to the area may be seen as a response to the physical characteristics described in Sections 5.1 to 5.6. In this context, underground mining is taken as a land use, as it is manifested at the surface both by buildings and spoil and by subsidence.

This section outlines the present uses within an historical context, with special reference being given to two effects of past and present land use practices that have special significance to land use potential; these are night soiling and underground mining subsidence.

5.7.1 Regional Land Use

The principal land use encountered in Eastern Durham is that of agriculture, punctuated by centres of major urban development, and scattered hamlets and villages associated primarily with past and present coal mining activity. The lowland area is mainly under grass, with dairying and stock rearing being the main enterprises. In the areas of shallow mining during the last century and earlier, as the coal industry developed in what was essentially a sparsely populated area, the only way to attract labour from the land to the mines was to offer land in the form of smallholdings as an inducement; a situation which has given rise to the present problem of small farms (Warwick Percy, 1970).

On the northern part of the Permian outcrop there are two principal systems of farming; dairying and arable. The average size of the dairy herds here is greater than for the county as a whole, but units still range from the very small to the very large. The arable farms are concentrated mainly on the eastern dip slope of the Permian escarpment and produce wheat, barley and potatoes. Despite the poor weather during the late 1960's when margins declined, the corn acreage has continued to increase.

On the Permian to the east and south of Durham City, mixed farming is practised, with medium-sized dairy herds being located on the mainly grass farms of the "heavier soils" of the plateau, whilst on the lighter soils mixed farms of potatoes, barley and wheat together with sheep and/or dairying predominate.

Forestry is spasmodic throughout the region and the Wear Lowlands, when viewed from the Permian Plateau, present a windswept treeless landscape (Plate 5.4 on Page 86). Patches of coniferous and deciduous trees have been planted on the Permian outcrop, in particular, but are not widespread. National Coal Board plantings managed under dedication agreements with the Forestry Commission are typical and account for some 1,012 hectares in the County as a whole.

5.7.2. Transect Land Use

The land uses encountered in the 8 x 2.5 km of the transect tend to reflect types found in the region as a whole, being one of scattered hamlets and villages of a predominantly coal mining origin set in an agricultural economy of small to medium-sized holdings (Plate 5.9). Surrounding the transect are the urban centres of Durham City, Hetton-le-Hole, Houghton-le-Spring and Chester-le-Street.



Plate 5.9 Unit 4. Pittington village (left middle - distance) set among a broad agricultural landscape.

Tables 5.2 and 5.3 show the land use types encountered when the 80 point sample sites were first surveyed in 1971, together with proportions after the subtraction of the built up locations. Figure 5.13 shows the land use in spatial terms.

Table 5.2 Transect Point Sample Land Use - 1971

Land Use	No. of Sites	% (80 sites)	% (71 sites)
Arable	37	46.2	52.1
Grass Ley	3	3.7	4.2
Permanent Grass	16	20.0	22.5
Woodland-	12	15.0	16.9
Deciduous	7	8.7	9.9
Coniferous	2	2.5	2.8
Mixed	3	3.7	4.2
Scrub	3	3.7	4.2
Built-up; non-agricultural or woodland use	9	11.2	-

Of the eighty sites, nine were built up accounting for 11.2%, but the vast majority (69.9%) were under arable or grass, with the former use being found at nearly one half of the sites. Woodland accounted for 15% of sites, with deciduous trees, for amenity use, having the greatest proportions. National Coal Board plantations are found in the Elemore area (Plate 5.10).

Table 5.3 Transect Point Sample Land Use by Physiographic Unit - 1971.

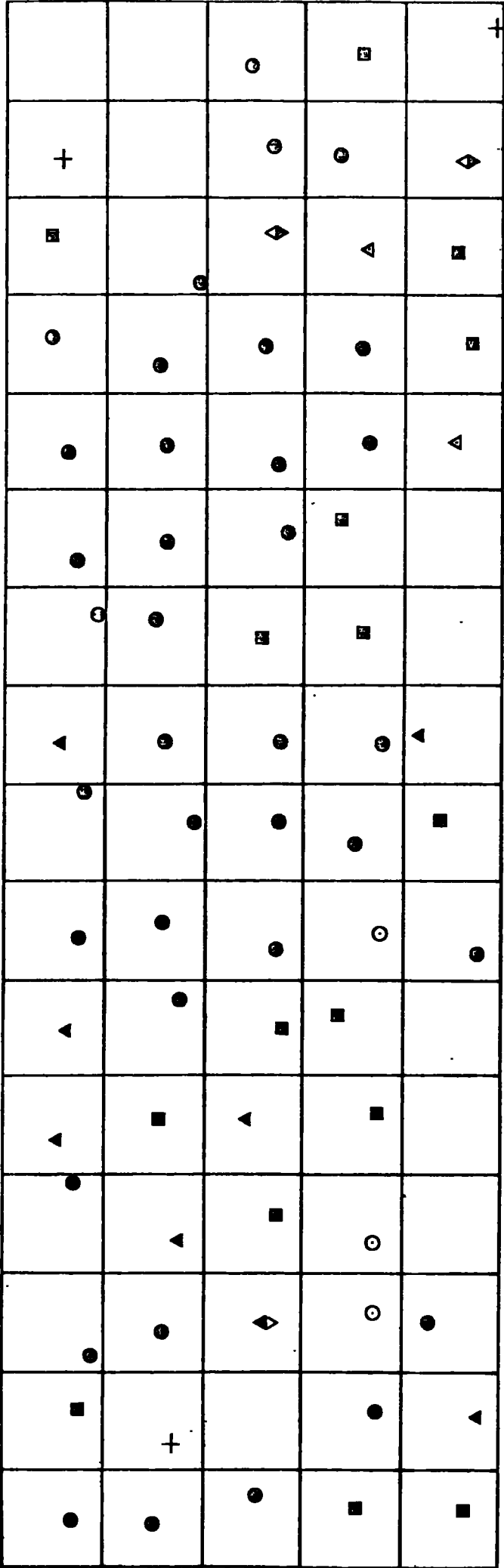
	<u>Physiographic Units</u>						
	1 %	2 %	3 %	4 %	5 %	6 %	7 %
Arable	62.5	40.0		59.1	33.3	41.7	83.3
Grass Ley				13.6			
Permanent grass	25.0	20.0	33.3	18.2	33.3	33.3	8.3
Woodland-		40.0	66.7	9.1	33.3	16.7	
Deciduous		40.0	50.0	9.1			
Coniferous					33.3		
Mixed			16.7			16.7	
Scrub	12.5					8.3	8.3

Arable accounts for the greatest majority of the seventy one sites in four out of the seven Physiographic Units (1,4,6,7) and is equal in proportion with woodland and plantation in two others (2,5). Only in the Wear Gorge and Floodplain (Unit 3) was arable cultivation not encountered, with two-thirds of the sites devoted to woodland. Permanent grassland is represented throughout the units reaching one-third of sites in Units 3, 5 and 6.

5.7.3 Underground Mining and Subsidence

County Durham is the oldest coalmining area in the country, which has meant that, with the very rapid exploitation during the 19th Century, it has been the first coalfield to exhaust its more workable seams,

Fig 5.13 Land Use



- Arable
- Grass Ley
- Permanent Grass
- ▲ Deciduous Woodland
- △ Coniferous Woodland
- ◈ Mixed Woodland
- + Scrub





Plate 5.10 N.C.B. mixed woodland on the Permian Escarpment
(Unit 6) at Elemore.

having passed its peak production in the 1880's (Reid, 1970). The mining industry has continued to decline with only twenty one of the 127 pits operating in 1947 still functional.

Although only one working colliery is located in the transect, namely that at Elemore which is linked to Hawthorn, Eppleton and Murton collieries to the north and east. Most of the area, in both the Wear Lowlands and Permian outcrop sections, has been worked underground in the past. As in most of the Durham coalfield, the problem of widespread subsidence remains as a permanent record of past and present mining activity (Warwick Percy, 1970).

Subsidence affects the land capability for both agriculture, building and road construction. The stresses imposed by a structure at foundation level are dissipated with depth and in thick uniform deposits, site investigation boreholes often finish at depths equivalent to about one and a half to twice the width of the proposed structure where stresses are negligible. In mining areas, however, the situation is entirely different; an example being that at a vertical subsidence of about 0.98 m (80% of the coal seam thickness), tilts of 12.7 cm in 30.5 m, extensional strains of up to 12.7 cm per 30.5 m and compressional strains of 15.2 cm per 30.5 m are typical for the new town of Peterlee (Attewell and Taylor, 1970). Orchard (1954) shows that the value of maximum subsidence for a given section of extraction may be basically related to the width and depth of working. If the voids left by extraction are untreated the maximum possible subsidence is between 84% and 90% of the extracted thickness but if the voids are solidly stowed then subsidence is reduced.

The nature of the subsidence depends much upon the type of underground working, its extent and depth. The oldest type of coal workings were simple shafts called "bell-pits", about 1.2 m in diameter with a depth rarely exceeding 12.2 m. Coal was extracted from the immediate vicinity of the shaft until it became unstable and the pit was abandoned and another dug nearby. Due to the depth of superficial deposits these are rare in this area of County Durham. The two systems commonly encountered are the "room and pillar" and "long wall" systems. The former consists principally of roadways usually driven approximately at right angles to each other via pillars left to support the overlying strata, so sterilizing a large tonnage of unexploited coal. Records for 1835 indicate that pillar sizes reached 18.3 x 5.5 m. Long wall techniques, on the other hand, generally a feature of modern mining are developed from an initial drive within the seam, and with the advance of the face, supports are withdrawn allowing the collapse of the roof behind the current working face.

The long wall techniques produce surface subsidence which decelerates rapidly and usually reaches equilibrium about one year after extraction. Subsidence is more "reliable" using this technique than the room and pillar. The extraction of shortwall pillars during the retreat phase simulates the longwall surface condition, but it can never be assumed that all pillars have been removed. Ancient workings of this room and pillar type at shallow depth of less than about 30.5 m produce the most difficult subsidence problems during development.

Attwell and Taylor (1970) state that compaction at both seam level, and to a certain extent, of the overlying measures, is of increasing importance as structures get higher, hence greatly increasing ground loadings, the bearing capacity required being in the order of "0.2 ton/ft² per storey".

The collapse of the roof span in room and pillar workings results in an upward migration of the room void, and the mechanical arching effect ceases when an overlying bed possesses a sufficiently high tensile strength and competency to stop further migration, or when the formation of the arch is complete. In exceptional cases, the latter may be at ground level giving rise to "crown holes". Instability may also be induced by heaving of the seatearth floor of coalseams, which sometimes completely infill the rooms; this being especially marked in the Harvey seam, a principal reason being the presence of expandable montmorillonite as an interlayer component of the micaceous fraction of the rocks' clay minerals. Due to the close spacing of joints (cleat) of certain coals, spalling of the pillar edge may cause stress redistribution, so causing pillars to fall progressively, and the equilibrium may be further disturbed by workings at lower seams. At the surface, collapse underground is manifested by poorly drained uncultivable hollows, affecting soil morphology and drainage, as already indicated in Section 5.6. The phenomenon is widespread in the transect.

Shafts were sunk through the Magnesian Limestone for the first time in 1821 at Hetton, heralding an intensive development of the coal industry; forty such shafts being eventually sunk. These mining operations beneath the brittle, variably bedded limestone which has a well-developed latticed jointing system of regional trend (Moseley and Ahmed, 1967), produce a spectacular form of subsidence in the opening of deep fissures extending to considerable depths from the surface. Shadbolt and Mabe (1970) observe that troughs of mining subsidence have shown orthodox deformation in some cases, whilst others have shown "misbehaviour" in varying degree according to the incidence and extent of joint opening.

These joints usually exist before the effects of mining are felt, from chemical weathering, glaciation and periglaciation, but the humping of mining subsidence profiles with attendant tensile strain may activate the fractured zones. The large tension gashes which may open up "overnight" are known locally in Durham as "pit-falls". They have been recorded also in the Castleford area of Yorkshire by Hartnup and Jarvis (1973) and in Nottinghamshire by Shadbolt and Mabe, and in these areas they are known as "gulls". Alignment is roughly parallel to the outcrop with the oldest gashes closest to outcrop and the newest ones lying "to the deep" of the outcrop (Attewell and Taylor, 1970). They occur particularly when driving a face.

The fissures are not always apparent at the surface, even when strained by subsidence, and the removal of superficial deposits may reveal variable joint development, but in the transect, at High Moorsley in particular, pit-falls are a common occurrence and specimens examined by the author extended for over 15 m in length, were of indeterminate depth and several metres wide. These gashes are particularly important when considering building development and are a particular handicap to agriculture. It was reported to the author that a tractor had met one such fissure and had keeled over. The only way to deal with them is to chock the gap with rubbish and fill again with soil; they thus have a significant effect on all aspects of land capability.

5.7.4. Night Soiling

The practice of night soiling has been widespread throughout the region, with the numerous colliery villages and larger urban centres of the area providing a ready supply of sewage and domestic refuse. Lasting for

over a century, the practice has significantly affected the soils of the transect, usually by increasing the depth of topsoil. A more localised practice was the application of cinders and ash to the soil. The combined affect of these processes has produced a topsoil with a coarser and more permeable texture, more organic matter and greater nutrient status than that found under "natural" conditions. Soils of this nature are reported to occur in the Castleford area of Yorkshire by Hartnup and Jarvis (1973), where the Arrow Series has an Ap horizon with an organic carbon content of up to 5.7%.

The amount of night soil and refuse dumping depended upon the individuals concerned in its application, but throughout the transect the activity is indicated by high amounts of organic matter found in the top horizons of a significant number of profiles and by the presence of quantities of debris in the form of old clay pipe stems, bottles, china and glass fragments found on the surface of most of the ploughed agricultural sites.

There appears to be a difference in the intensity or type of application of material between the Wear Lowland sites and those on the Permian outcrop. Non-calcareous cultivated topsoil horizons, with an organic carbon to % clay ratio high enough to enable a humose classification according to Avery (1973), are found almost entirely in the lowlands. Despite the fact that such topsoils of the Permian have quantities of surface debris, with one or two exceptions, horizons do not have sufficient organic matter to be diagnostically humose.

On the other hand, diagnostic humic topsoils are only found in the Wear Lowlands (e.g. cambic stagnohumic gley soils), combining a high organic content with a greater topsoil depth. It is suggested, therefore, that possibly because of the easier access from the major centres of population to the flatter Wear Lowlands than to the more far off and steeper Permian Escarpment and Plateau, the practice of night soiling was more prevalent in the former area.

5.8 Conclusions

The thematic approach has produced detailed arguments of the main physical attributes of the transect upon which to base quantitative land use potential analyses. All of Stewart's (1968) natural resource attributes have been considered, although not in the same categories or order of climate, landform, soil, vegetation, fauna and water as suggested by him. This change has been necessary because of having to define landform with "Physiographic Units", first of all, and the importance of geology to the transect land use. In addition, because of the predominantly intensive agricultural use of the area, vegetation is accounted for by considering land use. An assessment of the fauna has not been necessary for subsequent analyses, as habitat will form the key factor, implied in the various thematic discussions, notably drainage, soils and land use.

In direct land capability terms, however, this type of analysis does not tell us much. Subjective appraisals may be made of the effects of each attribute on land use, but that is all. Clearly, in order to quantitatively analyse land capability, a different approach is required; that involving the parameters of natural resource attributes - the parametric approach.

PART 3

Chapter : 6

CHAPTER 6 - LAND EVALUATION - A PARAMETRIC APPROACH

6.1 Introduction

Chapter 1 has discussed the concept and application of the parametric approach to land evaluation and Chapter 3 has outlined parameter thresholds. The point sample methodology and physical characteristics of the transect have been discussed in Chapters 4 and 5. This chapter takes the data collected on the point sample basis and, using capability thresholds, produces parametric land capability classifications for the following land uses:

- Agriculture
- Forestry
- Nature Conservation
- Housing Development
- Industrial Development
- Recreational Development.

A transportation capability analysis is not attempted as it is considered that, to undertake a meaningful classification, engineering data, particularly in the form of soil mechanics (for example, California bearing ratio; liquid limit; plasticity index etc.,) are required.

6.2 Land Capability Classification for Agriculture

6.2.1 Introduction

The capability classification devised is based on the system developed for Great Britain by Bibby and Mackney (1969) who, in turn, based this upon the system of the Soil Conservation Service of the United States Department of Agriculture (Klingebiel and Montgomery, 1961).

The Bibby and Mackney is a national system of classification, the gradings being capable of application on a British Isles basis. Although it could be argued that in undertaking a capability classification for an area it is towards local needs that we should be looking (i.e. what is the best land locally ?) and so plan accordingly, in practice, this cannot form the basis for analysis. If a planning permission for a development is refused on agricultural capability grounds, the applicant has the right of appeal to the Secretary of State. In deciding whether the appeal is to be upheld or dismissed the Minister will have to consider many factors, but one of overriding importance will be the conservation of agricultural land in national rather than local terms. A local planning authority cannot, therefore, base its argument solely on local land capability as far as agriculture is concerned - it would not stand up to council cross-examination. Thus the system used in the transect is national rather than local.

6.2.2 Explanations and Assumptions

The following explanations and assumptions are derived, in large part, from the Bibby and Mackney system. They are modified where necessary, so as to apply to the point sample nature of the study.

1. The classification is primarily for agricultural purposes.
2. Land is assessed on its capability under a moderately high level of management and not necessarily on its present use.
3. The capability classification may be changed by major reclamation projects (for example, pump schemes) which permanently alter the previous limitations in use. Minor changes, for example, mole drainage liable to regress in time, will not change the classification.
4. Within capability classes, soils may differ in management and fertilizer requirements and detailed cropping, and are only grouped because they have similar degrees of limitations affecting adaptability. The classification, however, is not necessarily a grouping of sites according to the most profitable use to be made of the land.
5. Within specific subclasses are sites which suffer from the same degree and kind of limitation, but which may differ in management requirements.
6. The system is based not on chemical but on physical limitations, for, in general, these are more permanent and difficult to rectify; severely limiting chemical properties are however recognised as a soil limitation.
7. Distance to markets, types of roads and farm structure do not influence the grading, although these factors will affect decisions about land use.
8. The interpretations try to express current knowledge, and as new experience is acquired new interpretations will be necessary.
9. The system is not a capability classification for specific crops or use. Interpretations for such purposes may require different groupings.

6.2.3 Capability Classes

Seven capability classes are recognised; the same as those of Bibby and Mackney.

Class 1. Land with very minor or no physical limitations to use.

A wide range of crops can be grown and yields are good with moderate inputs of fertilizer.

Class 2. Land with minor limitations that reduce the choice of crops and interfere with cultivations.

A wide range of crops can be grown, though some root crops and winter harvested crops may not be ideal choices because of difficulties in harvesting.

Class 3. Land with moderate limitations that restrict the choice of crops and /or demand careful management.

The limitations affect the timing of cultivations and range of crops, which are restricted mainly to grass, cereal and forage crops. Whilst good yields are possible, limitations are more difficult to overcome.

Class 4. Land with moderately severe limitations that restrict the choice of crops and/or require very careful management.

Climatic disadvantages combine with other limitations to restrict the choice and yield of crops and increase risks. The main crop is grass, with cereals and forage crops as possible alternatives where the increased hazards can be expected.

Class 5. Land with severe limitations that restrict its use to pasture, forestry and recreation.

High rainfall, exposure and a restricted growing season and/or other restrictions prohibit arable cropping, although mechanised pasture improvements are feasible. The land has a wide range of capability for forestry and recreation.

Class 6. Land with very severe limitations that restrict use to rough grazing, forestry and recreation.

The land has limitations which are sufficiently severe to prevent the use of machinery for pasture improvement.

Class 7. Land with extremely severe limitations that cannot be rectified.

Exposed situations, protracted snow cover and a short growing season preclude forestry, though a poor type of rough grazing may be available for a few months.

6.2.4 Capability subclass

Five capability subclasses, based upon the kind of limitations affecting land use, are recognised:

- w wetness limitations.
- s soil limitations (shallowness; stoniness; texture and structure; inherent fertility).
- g angle of slope and soil pattern limitations.
- e liability to erosion.
- c climatic limitations.

"Angle of slope", rather than "gradient" as used by Bibby and Mackney, is preferred, as gradient normally indicates a slope associated with road or rail transport. The suffix "g" is maintained, however.

Because of the nature of the point sample method, a further subclass of site restrictions (b) is added by the author in order to give a more "pragmatic" assessment to the actual potential of undertaking a specific land use at a site. "No site limitation" is defined as a) having a sample site situated in an open field enabling arable cultivation to be practised using conventional mechanical methods (i.e. a tractor may conveniently turn around at the end of a row) or, b) having a sample site situated in an area of land use, other than an open field or built up area, of sufficient size to enable agricultural cultivation to take place. Sites with a limitation are classified as Class 6 or 7.

The following criteria apply to the subclass notation:

- i) Only two subclass symbols are used in the maps of capability in this thesis to indicate different types of limitations affecting class; but all are used in text descriptions.

- ii) The symbol of the dominant limitation takes priority.
- iii) Where several limitations are of equal weight the following order is suggested b w s g c e
- iv) A subclass symbol is shown where the limitation it represents has been a factor in determining class.

6.2.5 Threshold Guidelines for the Recognition of Capability Classes.

On account of the interpretative nature of the classificatory method, Bibby and Mackney offer the following guidelines for the recognition of classes "to maintain uniformity". These have been modified, where necessary, to incorporate the maximum rooting depths of Rudeforth and Bradley (1972).

Class 1.

Angle of slope	:	Not above 7°, but usually below 3°.
Climate	:	Group I. Usually below 152 m.
Wetness	:	Not a limitation; soils usually well or moderately well drained, with some imperfectly drained in areas of low rainfall (< 760 mm).
Soil	:	Usually loams, sandy or silt loams, or humose variants deeper than 76 cm or peat; stoneless or slightly stony.
Erosion	:	Risk is very slight.

Class 2.

Angle of slope	:	Not above 7°.
Climate	:	Group I. Usually below 229 m.
Wetness	:	Usually moderately well or imperfectly drained.
Soil	:	Usually having a rooting depth > 51 cm; stoneless or slightly stony; clays in wet areas and coarse sands or loamy coarse sands in areas with low summer rainfall excluded.
Erosion	:	Wind erosion possible in some eastern areas; otherwise risks slight.

Class 3.

Angle of slope	:	Not above 11°.
Climate	:	Groups I and II Usually below 381 m. Land over 122 m with more than 1020 mm annual rainfall (1140 mm in Western Britain) not better than Class 3.
Wetness	:	Usually imperfectly or poorly drained where an effective drainage scheme has been, or could be, installed. There will be a continuing wetness limitation even after drainage.

- Soil : Rooting depth usually > 25 cm; textures range from stoneless to stony and sandy to clayey. Well drained coarse sandy soils in areas with soil moisture deficits seven years in ten not graded above Class 3.
- Erosion : Risk should be slight.
- Class 4.
- Angle of Slope : Not above 15°.
- Climate : All climatic groups, as defined by Bibby and Mackney. Land with more than 1270 mm annual rainfall usually not better than Class 4.
- Wetness : Poorly drained soils, with or without peat, requiring a comprehensive drainage scheme, but where piecemeal drainage has, or could, effect improvements. Land may be subject to occasional damaging floods (1 in 5 years).
- Soil : Sufficiently deep to allow ploughing; rooting depth < 26 cm; very stony and with a wide range of texture.
- Erosion : Slight to moderate erosion on sandy soils.
- Class 5.
- Angle of Slope : Not over 25° but usually between 15 and 20°.
- Climate : Usually below 533 m. Land over 183 m with more than 1270 mm annual rainfall not better than Class 5.
- Wetness : Very poor or poorly drained land where drainage can be improved to maintain grassland. Subject to floods possible (1 year in 3).
- Soil : Rooting depth < 16 cm; Only rock and boulder strewn soils which prevent mechanized improvement are excluded from this class; extremely stony (50-75%).
- Erosion : Moderate to severe.
- Class 6.
- Angle of Slope : Over 25°.
- Climate : Usually below 610 m. Land over 305 m with more than 1520 mm annual rainfall not better than Class 6.
- Wetness : Very poorly drained and not improvable by small schemes.
- Soil : Extremely stony (> 75%), rocky or boulder strewn land, with enough vegetation to maintain grazing.
- Erosion : Severe erosion.

Class 7.

- Angle of Slope : Over 25°.
- Climate : Over 610 m (533 m in Western and Central Highlands).
- Wetness : Very poorly drained.
- Soil : Extremely stony, rocky or boulder strewn soils, bare rock, scree or beach sands and gravels.

6.2.6 Transect Land Capability Analysis for Agriculture.

On account of the hierarchical structure of the capability classification and the parametric approach to the study, the final classification will be built up from an initial consideration of the subclass limitations.

6.2.6.1 Wetness Limitations (subclass w)

Imperfect or poor drainage regimes are registered at 74.6% of the sample sites and their distribution is shown in Figure 6.1 and in Table 6.1.

Table 6.1 Distribution of Sites with Wetness Limitations by Physiographic Unit(% Sites)

Physiographic Unit	Imperfect Profile Drainage	Poor Profile Drainage	Flooding Risk
1	0.0	87.5	0.0
2	0.0	80.0	25.0
3	16.7	50.0	83.3
4	18.2	63.6	0.0
5	16.7	66.7	33.3
6	16.7	25.0	8.3
7	50.0	33.3	0.0
Total Units	19.7	54.9	12.7

The greatest proportion of poorly drained sites are located in Physiographic Units 1 to 5 in the Wear Lowlands itself, with Unit 1 to the west of the Wear having 87.5% of its sites so affected. The Permian Plateau (Unit 7) contains the greatest percentage of imperfectly drained locations.

The River Wear Gorge and Floodplain (Unit 3) and Coalfield Vale exhibit the greatest flooding risk.

6.2.6.2 Soil Limitations (subclass s)

i). Shallowness

Where root depth restriction is a limitation in the site profiles it is the result of the proximity of bedrock to the surface and not the result of compact drift, plough layer or other factors (Figure 6.2). Most of the sites so affected are, therefore, found on the Magnesian Limestone of Unit 7 where they account for 58.3% of the total. Site 66 with a depth of 70 cm located at the localised outcrop of Coal Measures sandstone near Pitlington in the eastern lowlands is the only exception.

Fig6.1 Sites with Wetness Limitations - Agriculture(subclass w)

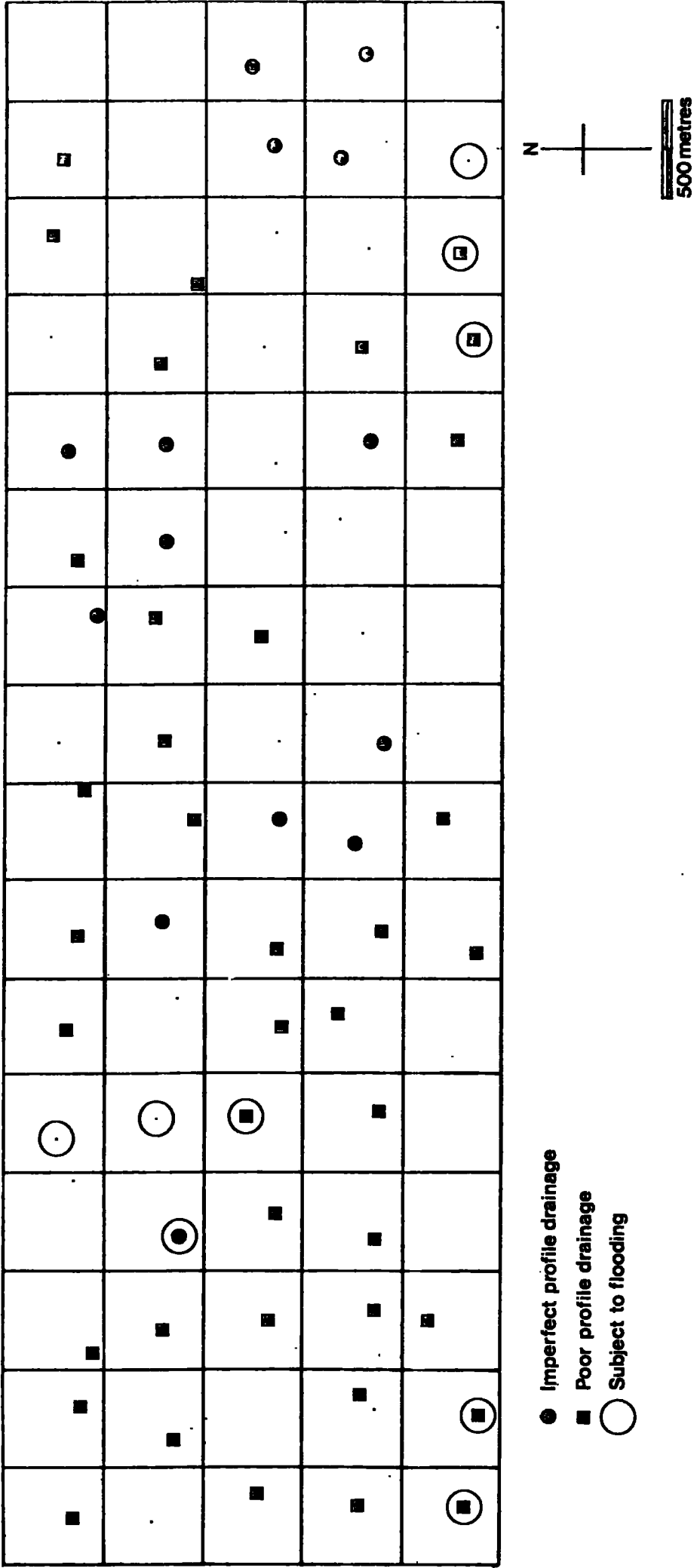
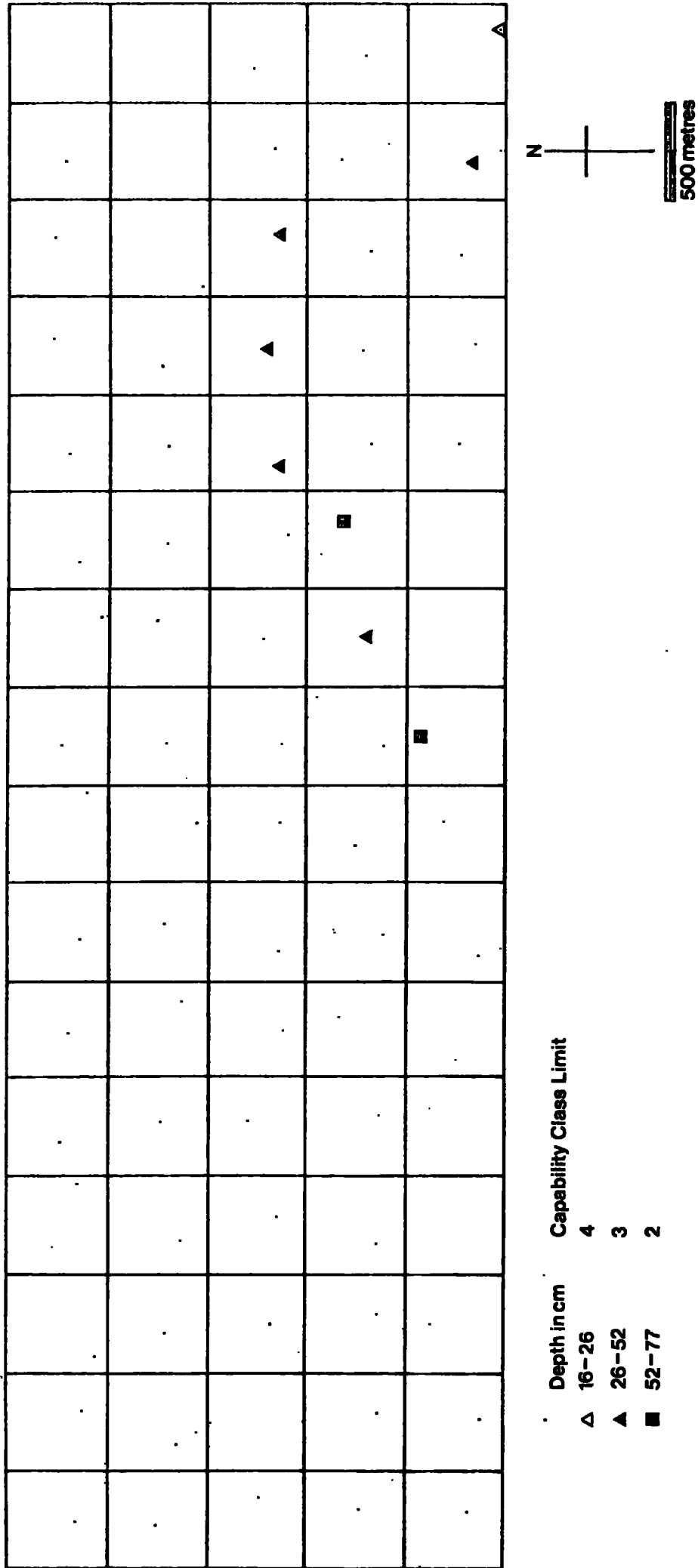


Fig6.2 Sites with Soil Depth to In Situ Rock Limitations-Agriculture (subclass s)



ii). Stoniness

A stony profile, defined by the Soil Survey as having between 5 and 20% stones, is the lowest threshold percentage affecting capability; stony profiles not being classified better than Class 3. Within the transect it is the stone content to a depth of 30 cm that is taken as the threshold depth, as this is at or near the maximum plough depth at all of the transect profiles under cultivation.

Table 6.2 Distribution of Sites with Soil Stoniness Limitations by Physiographic Unit (% Sites)

Physiographic Unit	No Limitations	Limitations			
	Stoneless or slightly stony	Stony	Very Stony	Extremely Stony	Sites with Limitations
1	75.0	0.0	25.0	0.0	22.2
2	100.0	0.0	0.0	0.0	0.0
3	100.0	0.0	0.0	0.0	0.0
4	59.1	13.6	27.3	0.0	40.9
5	100.0	0.0	0.0	0.0	0.0
6	33.3	41.7	0.0	25.0	66.7
7	66.7	33.3	0.0	0.0	33.3
Total Units	40.0	15.5	11.3	4.2	31.0

The most stony sites affecting agricultural capability are located on the Permian Escarpment (Unit 6), with a majority of sites being affected (66.7%). Because of the covering of drift, the Permian Plateau (Unit 7) has only small areas with stone limitations. The variable stone content of the drifts of Unit 4 in the centre of the lowlands is reflected in 40.9% of its sites being influenced by a stony or very stony topsoil. (Figure 6.3; Table 6.2).

iii). Soil Texture and Structure

The textural limitations of the mineral soil (as defined by Hodgson, 1974) are defined using the texture measured at a depth of 5 cm in the topsoil and at 40 cm in the subsoil. In addition, the overall textural class of each soil horizon is also taken into account.

Loams, sandy loams and silt loams do not affect the capability class allocation. The spatial distribution of sites showing textural and structural limitations to agriculture is shown in Figures 6.4 and 6.5 and Table 6.3.

The sites with textural limitations account for 60.5% of sites, with clay loams forming the predominant class.

Fig6.3 Sites with Soil Stoniness Limitations in Topsoil - Agriculture (subclass s)

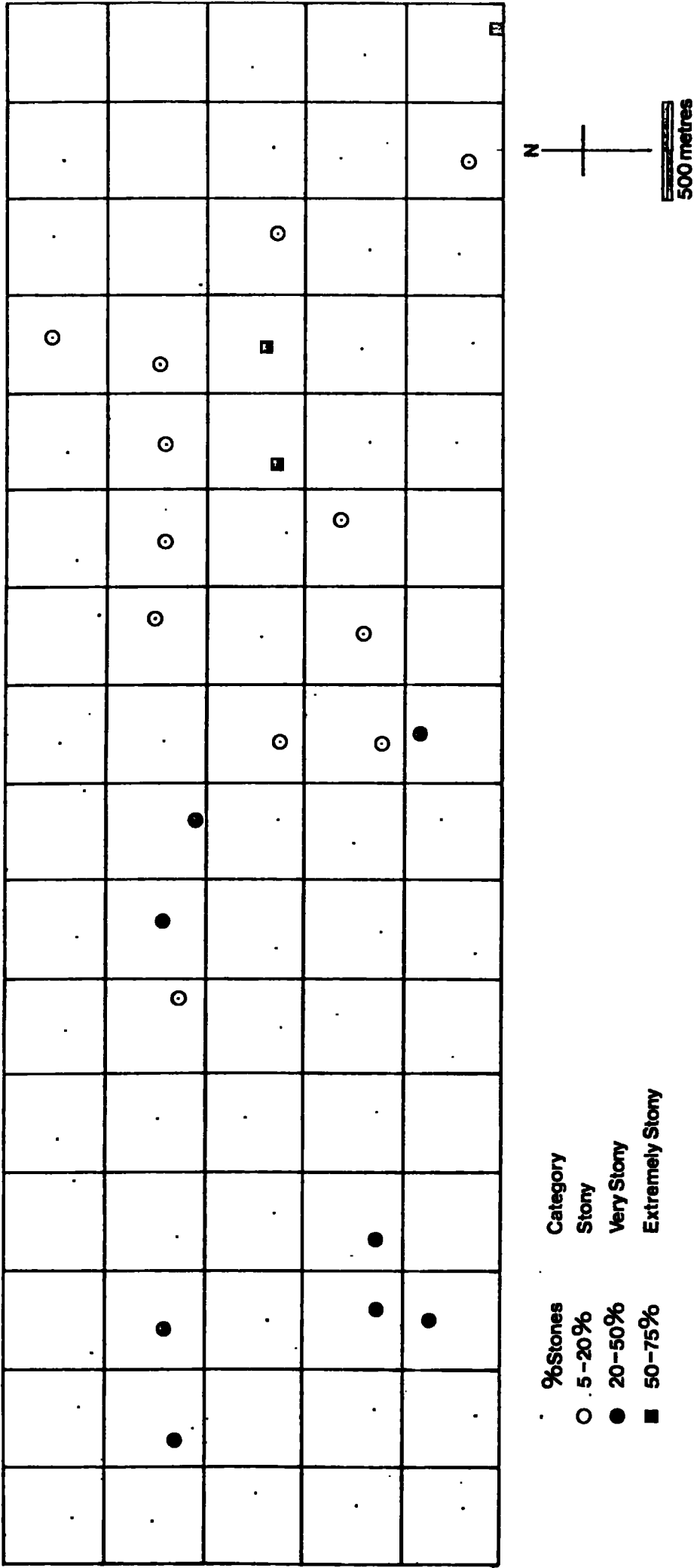


Fig6.4 Sites with Soil Texture and Structure Limitations in Topsoil(5cm)-Agriculture (subclass s)

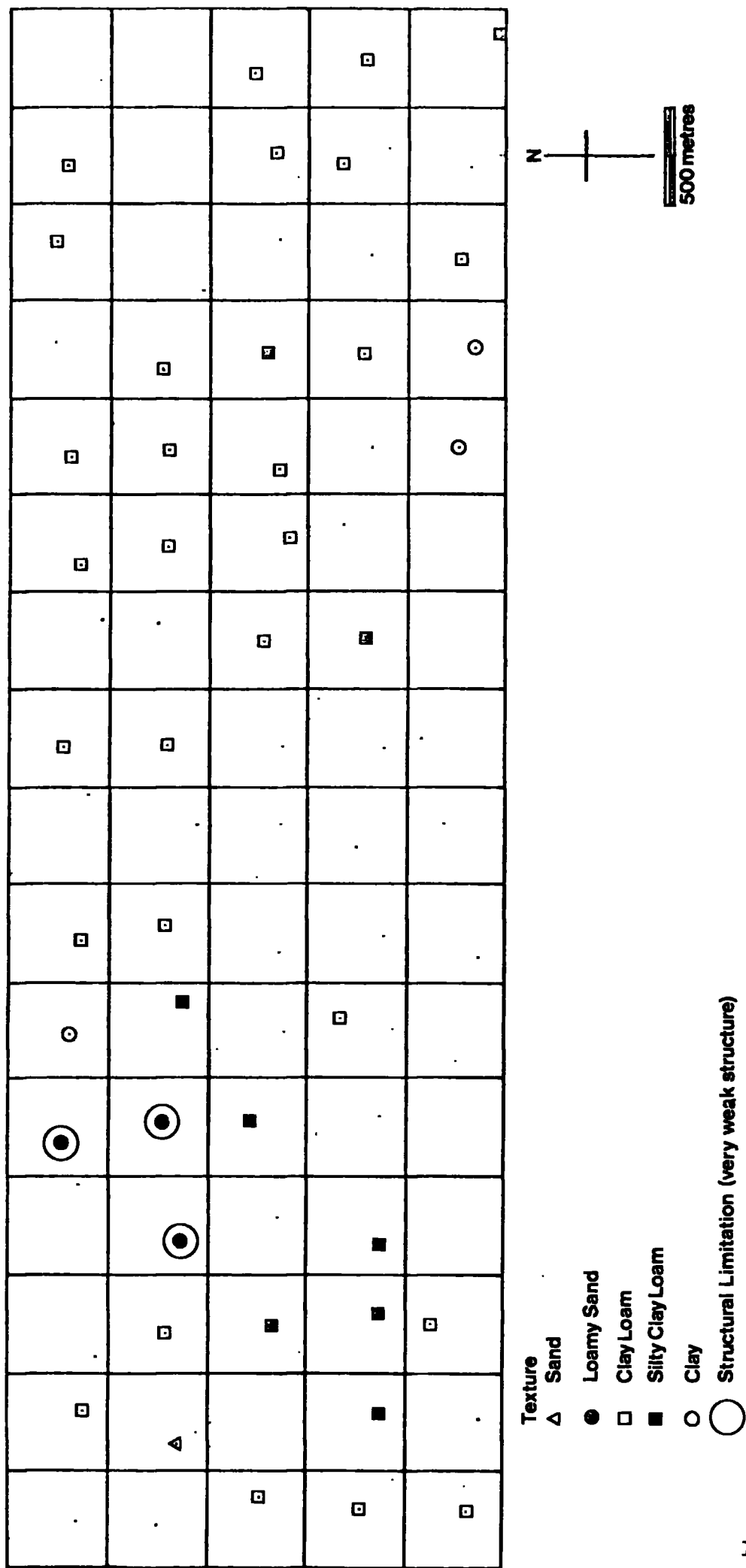


Fig6.5 Sites with Soil Texture and Structure Limitations in Subsoil (40cm) Agriculture (subclass s)

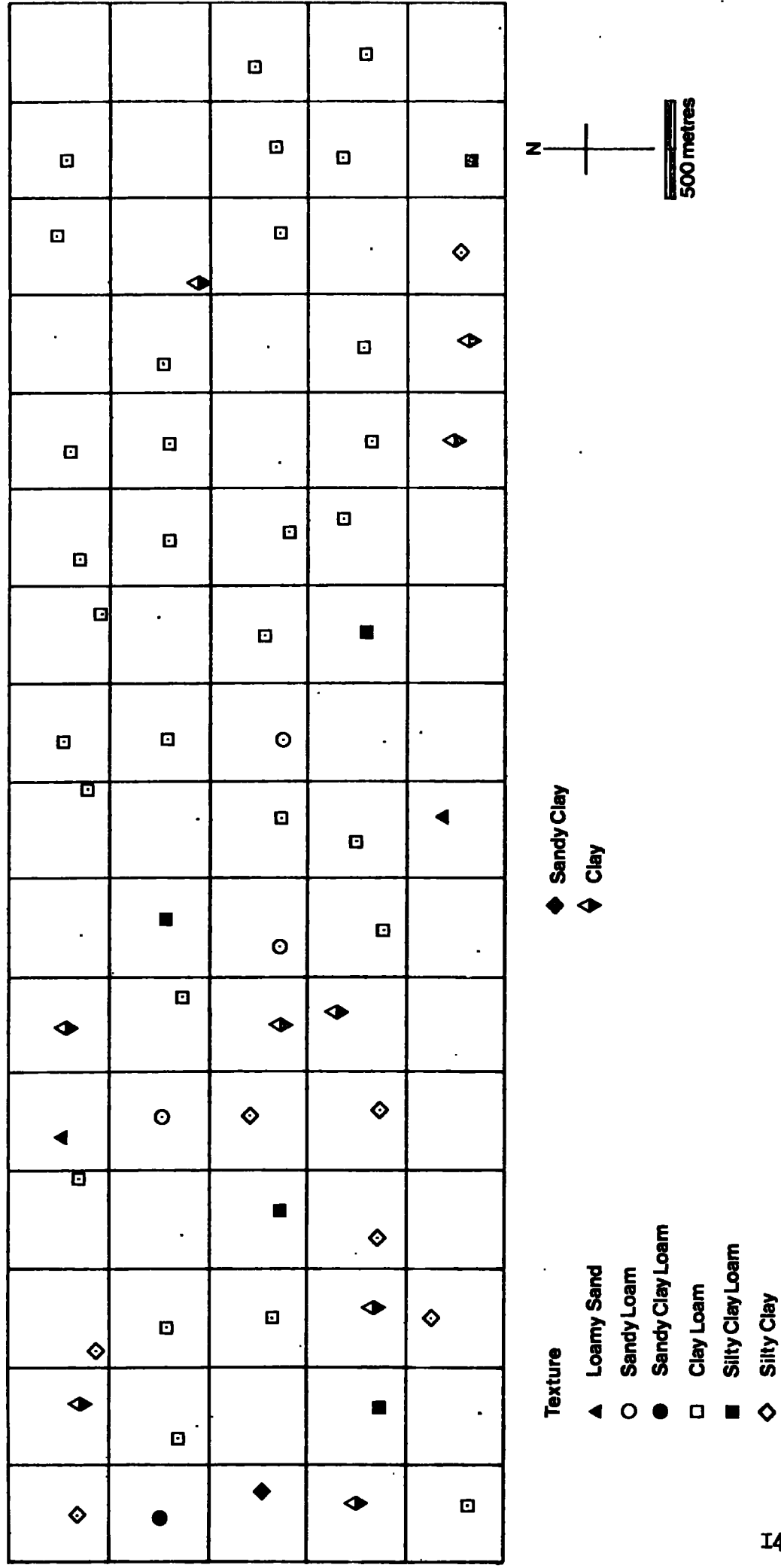


Table 6.5 Distribution of Sites with Soil Textural Limitations by Physiographic Unit (% Sites)

Physiographic Unit	No Limitations	Limitations					Sites with Limitations
	Loam , Sandy Loam , Silt Loam	Sand	Loamy Sand	Clay Loam	Silty Clay Loam	Clay	
1	37.5	12.5	0.0	50.0	0.0	0.0	62.5
2	40.0	0.0	0.0	0.0	40.0	20.0	60.0
3	16.7	0.0	50.0	16.7	16.7	0.0	83.4
4	59.1	0.0	0.0	27.3	13.6	0.0	40.9
5	33.3	0.0	0.0	33.3	0.0	33.3	66.9
6	41.7	0.0	0.0	33.3	25.0	0.0	58.3
7	16.7	0.0	0.0	83.3	0.0	0.0	83.3
Total Units	39.4	1.4	4.2	38.0	12.7	4.2	60.5

Only the lowlands of Unit 4 have more than 50% of representative sites with no textural limitations. The Wear Gorge and Floodplain (Unit 3) and the Permian Plateau (Unit 7) have the highest proportion of sites with topsoil limitations (> 83% each), with clay loam textures being the most common in four of the seven Physiographic Units.

Sites with a structural limitation, in this case a weak structure coupled with a fine sandy texture, are restricted to three sites in the Wear Gorge (5, 19, 20).

iv). Soil Fertility (Nutrient Status)

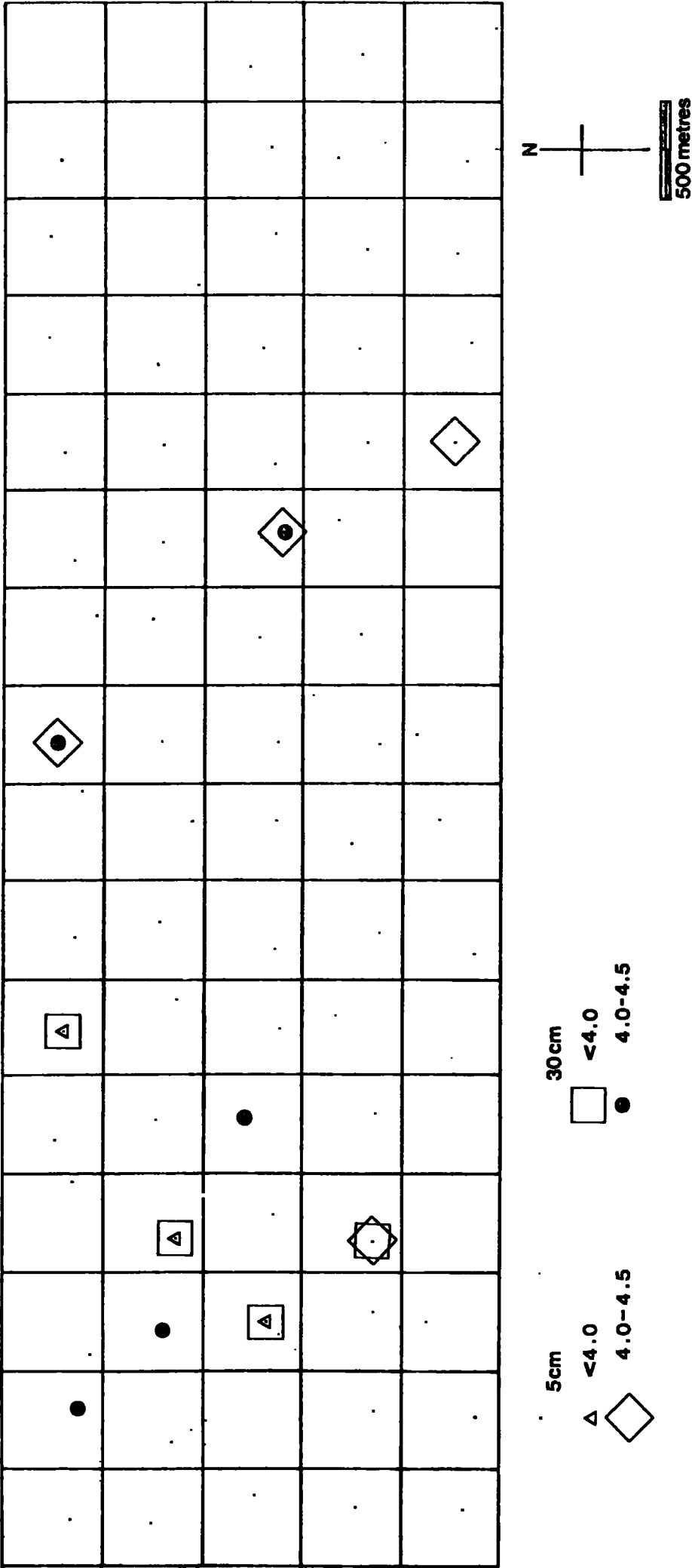
Natural "low fertility" may be difficult to correct by management, and is taken into account by Bibby and Mackney in this subclass. For the purpose of the transect analysis, pH is taken as an indicator of soil fertility; low nutrient status being a perennial problem for the farmer. Soils with a moderate to strong acidity (below 4.5) require considerable management input to improve them to such a level as to be capable of supporting arable crops.

A value below 4.5 at either of the two sample depths in the transect (5 cm and 30 cm) is taken as a limitation and the distribution is shown in Figure 6.6 and Table 6.4.

Table 6.4 Distribution of Sites with Soil Fertility (Nutrient Status) Limitations By Physiographic Unit (% Sites)

Physiographic Unit	5 cm depth		30 cm depth	
	No Limitations	Limitations	No Limitations	Limitations
1	100.0	0.0	75.0	25.0
2	80.0	20.0	60.0	40.0
3	66.7	33.3	66.7	33.3
4	90.9	9.1	90.9	9.1
5	83.3	16.7	100.0	0.0
6	100.0	0.0	100.0	0.0
7	91.7	8.3	91.7	8.3
Total Units	90.1	9.9	87.3	12.7

Fig6.6 Sites with Soil Acidity Limitations in Topsoil and/or Subsoil (5cm and 30cm)
Agriculture (subclass s)



The River Wear Gorge and Floodplain (Unit 3) has the highest proportion of sites with limitations in the topsoil (33.3%), with the remaining Physiographic Units all having 75% or more of their sites with no fertility limitations. At depth, the areas to the west of the Wear Gorge have the greatest proportion of sites with limitations.

6.2.6.3 Angle of Slope and Soil Pattern Limitations (subclass g)

Figure 6.7 and Table 6.5 show the distribution of threshold slope values according to the Bibby and Mackney classification. No sites are above the steeply sloping class and 60.5% are within the gently sloping category of 3° ; this threshold being the limit for Class 1 land. 87.4% of sites are at, or below, the maximum slope for Class 1 land, of 7° .

Table 6.5 Distribution of Sites with Angle of Slope Limitations by Physiographic Unit (% Sites)

Physiographic Unit	No Limitations			Limitations			Sites with Limitations	Sites with Limitations
	$\leq 3^{\circ}$	$\leq 7^{\circ}$	3- 7°	7- 11°	11- 15°	15- 20°	$> 3^{\circ}$	$> 7^{\circ}$
1	75.0	100.0	25.0	0.0	0.0	0.0	25.0	0.0
2	40.0	60.0	20.0	20.0	0.0	20.0	60.0	40.0
3	50.0	83.3	33.3	16.7	0.0	0.0	50.0	16.7
4	81.8	100.0	18.2	0.0	0.0	0.0	18.2	0.0
5	66.7	83.4	16.7	16.7	0.0	0.0	33.4	16.7
6	33.3	58.3	25.0	25.0	8.3	8.3	66.6	41.6
7	50.0	100.0	50.0	0.0	0.0	0.0	0.0	0.0
Total Units	60.5	87.4	26.8	8.5	1.4	2.8	39.5	12.7

The Permian Escarpment (Unit 7) has the greatest proportion of sites with slopes exceeding 7° (41.6%), whilst the Permian Plateau (Unit 7) and Units 1 and 4 in the lowlands have no sites with slopes of over 7° .

The soil pattern limitation which results from soil types of widely differing capability occurring in "intricate small scale patterns" was noted if located in the area surrounding the soil profile pit. Only Sites 21 and 58 are so affected.

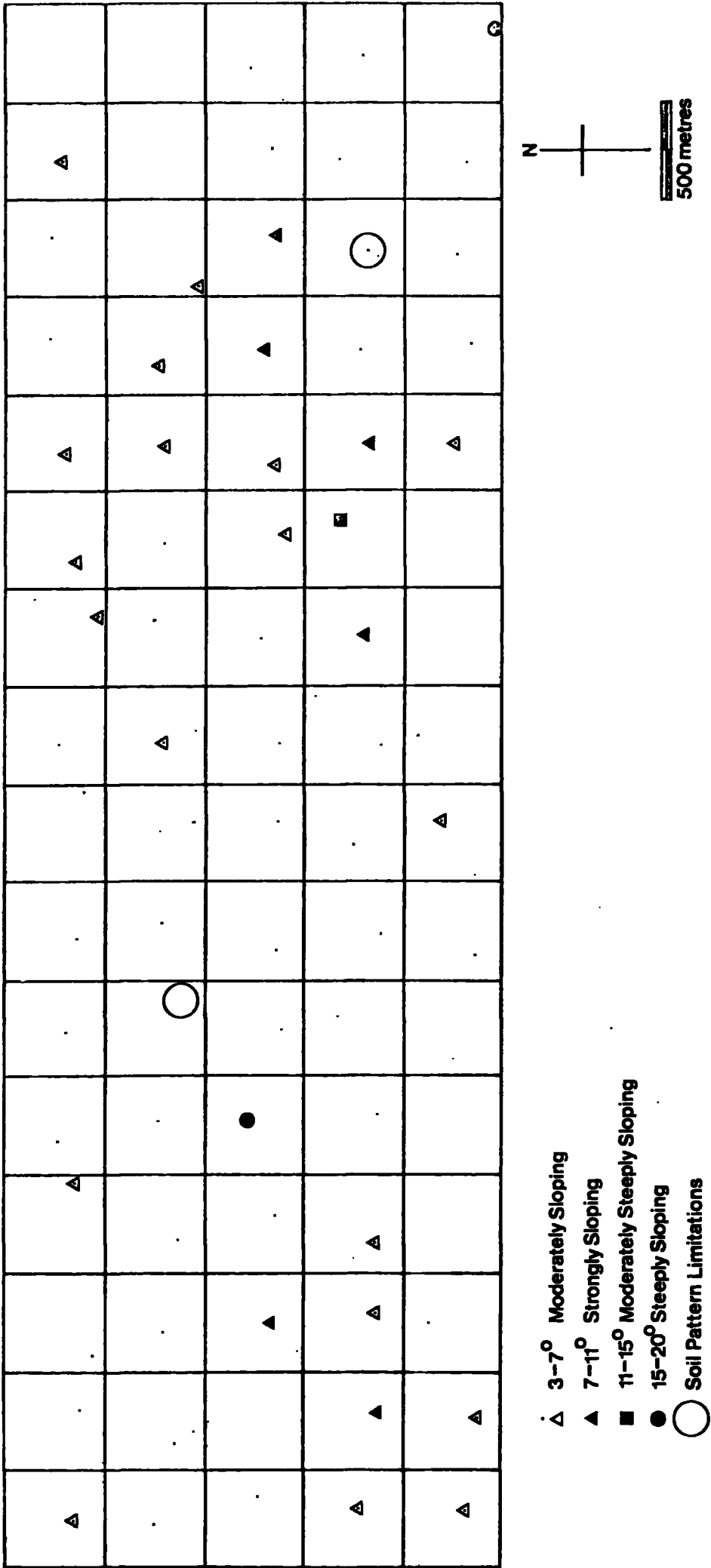
6.2.6.4 Soil Erosion Risk Limitation (subclass e)

There is no recognised quantitative analysis of soil erosion risk related to capability class applicable to Great Britain, and the Soil Survey base their assessments on subjective lines. Bibby and Mackney use vague terms such as "slight" or "low" risk. Clearly, such a situation is far from satisfactory.

In order to give a more quantitative base to the prediction of erosion potential in the transect, two methods were employed by the author; the Universal Soil-Loss Equation and the assessment, based on soil texture, of Morgan (1974). The detailed workings of these analyses are presented in Appendix 3 beginning on Page 490.

Even so, there are no physical threshold values of acceptable soil loss published on which to base an agricultural capability system, and much work has still to be done on this point. In the final analysis, the assessment of erosion risk has had to be undertaken on "subjective" lines, but has had as its basis the quantitative data of the two approaches outlined above.

Fig6.7 Sites with Angle of Slope and Soil Pattern Limitations-Agriculture (subclass g)



The presence of an erosion risk is considered to limit "the soils to Classes 4 to 7 and the distribution in the transect is shown in Figure 6.8 and Table 6.6.

Table 6.6 Distribution of Sites with Soil Erosion Limitations by Physiographic Unit (% Sites)

Physiographic Unit	Erosion Risk
1	0.0
2	40.0
3	16.7
4	0.0
5	16.7
6	41.7
7	16.7
Total Units	15.5

15.5% of all sites have an erosion risk, but Physiographic Units 2 and 6, associated with the River Wear, ^{and Fargate Loop} have considerably higher proportions, at 40.0% and 41.7% respectively.

These areas have steeper slopes and soil textures which are particularly affected by run-off (clay content between 10 and 25%). The Lowlands West and East of the Wear (Units 1 and 4), however, have no sites with an erosion risk.

6.2.6.5 Climatic Limitations (subclass c)

Bibby and Mackney (1969) outline a method for the determination of macroclimatic groupings which places emphasis on establishing an inventory rather than a classification of climate as is usually understood.

Water balance and temperature during the period April to September are used to delineate these macroclimatic groupings as follows:

$R - PT$ and $\bar{T}(x)$ where

R = average rainfall (mm)

PT = average potential transpiration (mm)

$\bar{T}(x)$ = long term average of mean daily maximum temperature.

Three climatic groups are defined:

Group I

$R - PT < 100 \text{ mm}$ and $\bar{T}(x) > 15^{\circ}\text{C}$

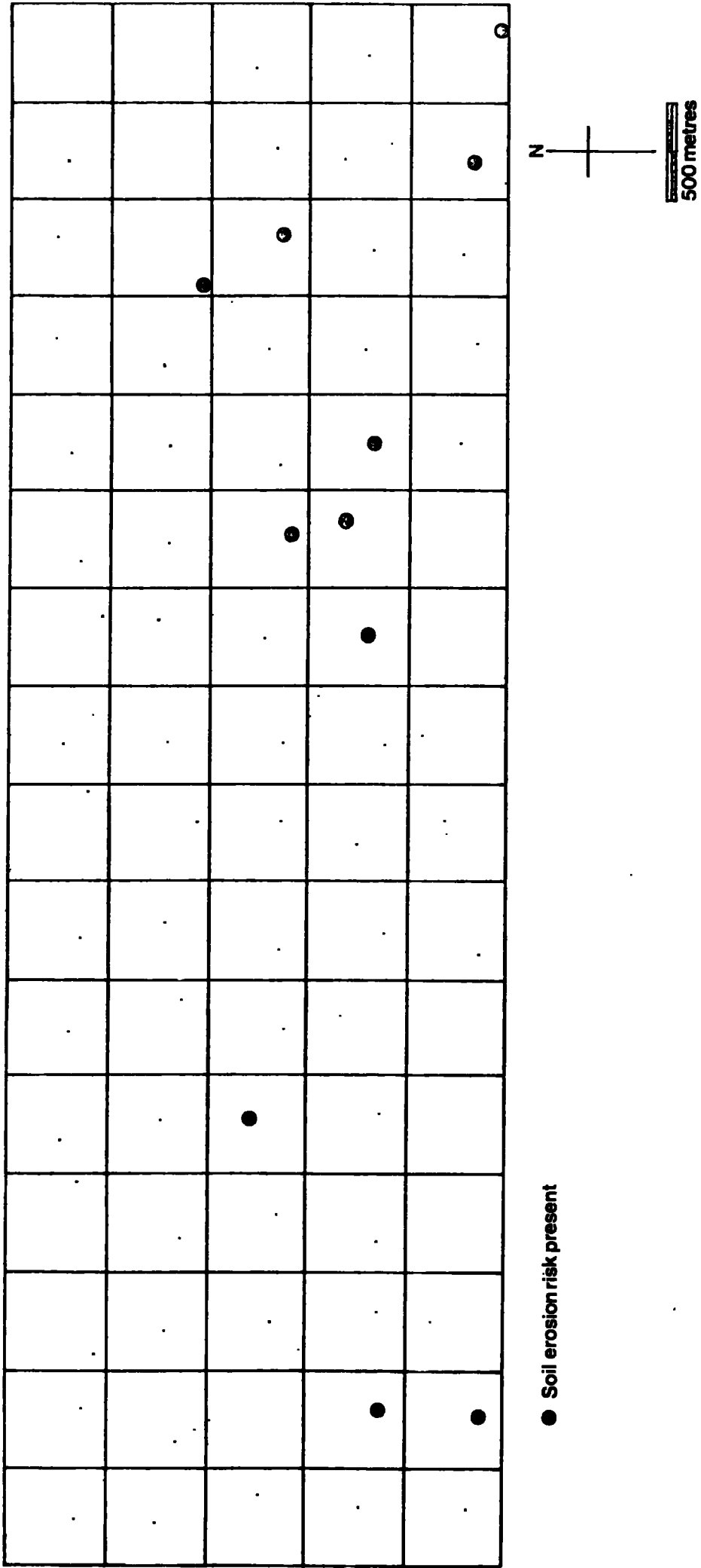
Here there are no, or only slight, climatic limitations imposed on crop growth.

Group II

$R - PT < 300 \text{ mm}$ and $\bar{T}(x) > 14^{\circ}\text{C}$ but excluding Group I

These areas suffer from a moderately unfavourable climate which restricts the choice of crops.

Fig6.8 Sites with Soil Erosion Risk Limitation-Agriculture(subclass e)



Group III

$$R - PT > 300 \text{ mm or } \bar{T}(x) < 14^{\circ}\text{C}$$

These areas have a moderately severe to extremely severe climate which restricts further the range of crops.

The following climatic inventory data (Meteorological Office, 1969) group Durham City at 102 m O.D. firmly in Group I.

R	=	340.4 mm
PT	=	407.7 mm
R-PT	=	-67.3
$\bar{T}(x)$	=	16.7

Within the climatic class three microclimatic parameters are defined, the first by Bibby and Mackney and the second and third are added to the system by the author.

1. Altitude

The threshold for Class 1 land is 152 m and that for Class 2 is 229 m. Three sites (26, 27, 39) on the Permian Plateau (Unit 7) are at or above 152 m (Figure 6.9). No site is situated above 160 m.

2. Site Exposure

No quantitative analysis of site exposure is suggested by Bibby and Mackney, but Rudeforth and Bradley (1972) delineate a "no severe exposure" requirement, with a Topex value of greater than 10 (the severely exposed category) as being the threshold for Class I in locations outside eastern Britain.

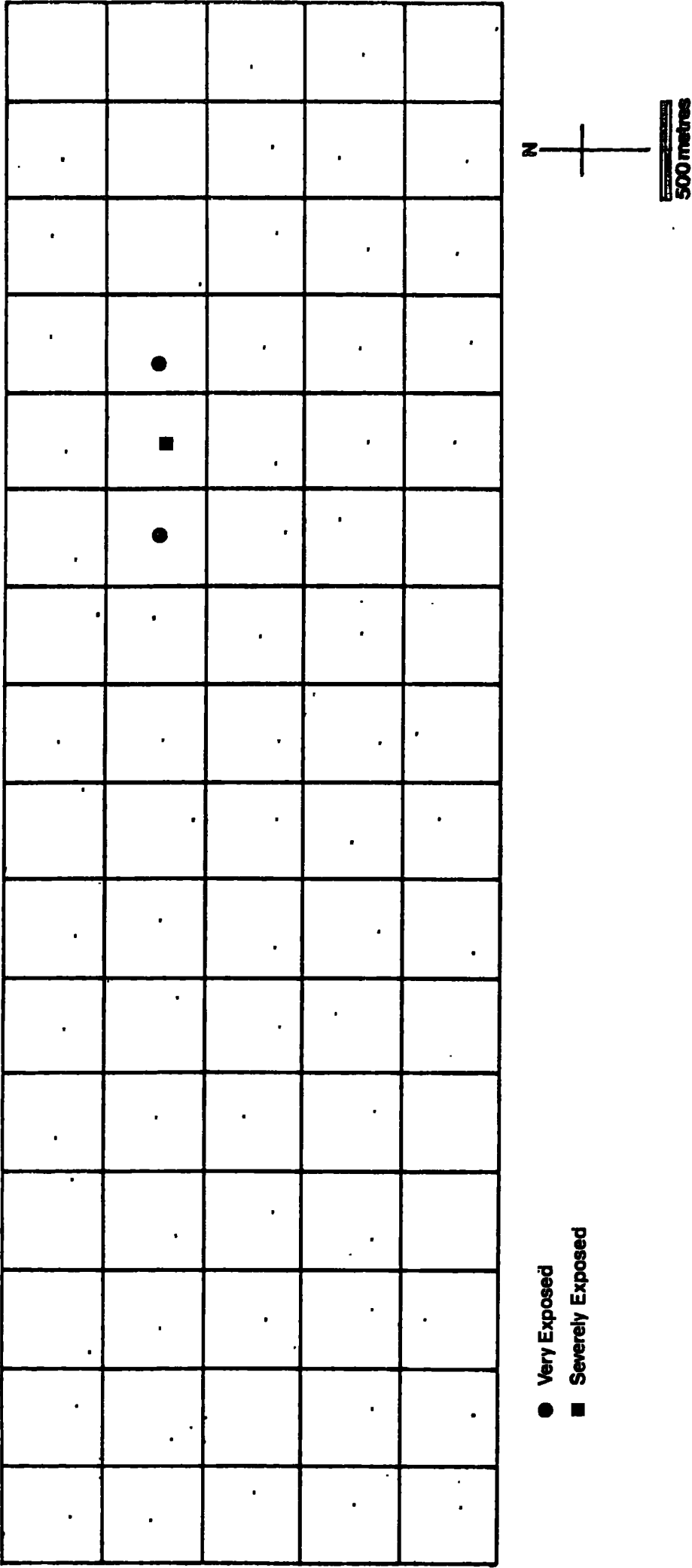
As the transect is located in east Britain, with a "harsher" climate than that experienced by Rudeforth and Bradley in west and central Pembrokeshire, it is suggested that the second category of "very exposed" with values between 11 and 30 be used as a threshold for Class 1 in the area. Further research requires to be done on this topic.

Only two sites (26,28) are in the Topex category of "very exposed". whilst Site 27, is the only one to occur in the "severely exposed" category (Figure 6.10). All are located at the top of the Permian Plateau (Unit 7).

3. Aspect

The relationship of angle of slope and aspect to the equivalent extension of the growing season, and thereby the equivalent decrease in height above M.S.L., is discussed by Smith (1969). As altitude is the parameter chosen by Bibby and Mackney to summarise temperature effects in their classification, by "adjusting" the actual altitude by the equivalent decrease in height above M.S.L. according to site slope and aspect, the meso-climatic guideline of altitude can be worked out taking into account the effects of south-facing slopes.

Fig 6.10 Sites with Exposure Limitations-Agriculture (subclass c)



In the transect, only three sites, 26, 27 and 39 are above 152 m O.D. and none of these are south-facing (SE-SW). There is, therefore, no equivalent extension of the growing season and no equivalent decrease in height and subsequent alteration of Class limits on these grounds for the sites.

6.2.6.6 Site Restriction Limitation (subclass b)

Sites with site restrictions, as shown in Figure 6.11, are situated entirely within the River Wear Gorge and Floodplain (Unit 3) and its associated tributaries. These locations prohibit agricultural use almost entirely and as a result are restricted to classes 6 and 7.

6.2.7 Discussion of Agricultural Land Capability Classification

This section discusses the capability classes assigned to the sites and makes a comparison of the author's system with that of A.D.A.S. (1971).

6.2.7.1 Land Capability Classes

The classificatory groupings assigned to each of the seventy one sites are shown in Figure 6.12 and Tables 6.7 and 6.8. See Plates 6.1 and 6.2.

Classes 3 and 4 account for 80.2% of the sites, with Class 4 being slightly more numerous. Classes 5 and 6 reach nearly one fifth (18.4%), but the Class 2 requirements are satisfied by only one site.

The Physiographic Units to the centre and east of the transect (Units 4 and 7) have the greatest proportions of Class 3 land.

Table 6.7 Land Capability Classes for Agriculture by Physiographic Unit (% sites)

Physiographic Unit	Suitable for Cultivation			Not Suitable For Cultivation		
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
1	0.0	12.5	25.0	50.0	12.5	0.0
2	0.0	0.0	40.0	40.0	0.0	20.0
3	0.0	0.0	0.0	0.0	50.0	50.0
4	0.0	0.0	63.6	36.4	0.0	0.0
5	0.0	0.0	16.7	83.3	0.0	0.0
6	0.0	0.0	25.0	33.3	33.3	8.3
7	0.0	0.0	50.0	50.0	0.0	0.0
Total Units	0.0	1.4	39.4	40.8	11.3	7.0

In the other areas, apart from the Permian Plateau and slopes above the Wear (Unit 2), Class 4 is in greater proportion than Class 3. The Wear Gorge and Floodplain (Unit 3) is the only area which has a greater proportion of non-cultivable sites, with all being of Classes 5 and 6. All other areas have over one half of their sites suitable for cultivation, with only the Permian Escarpment (Unit 7) having under 60% (58.3%), the remainder being 75% or over.

6.2.7.2 Dominant Subclass

Figure 6.13 and Table 6.9 show the number of sites with the specified dominant limitation. Over the total area the wetness limitation (w) dominates, with over one half of sites (54.9%). Within these thirty nine sites, imperfect or poor profile drainage is

Fig.6.II Sites with Site Restrictions ‹subclass b›

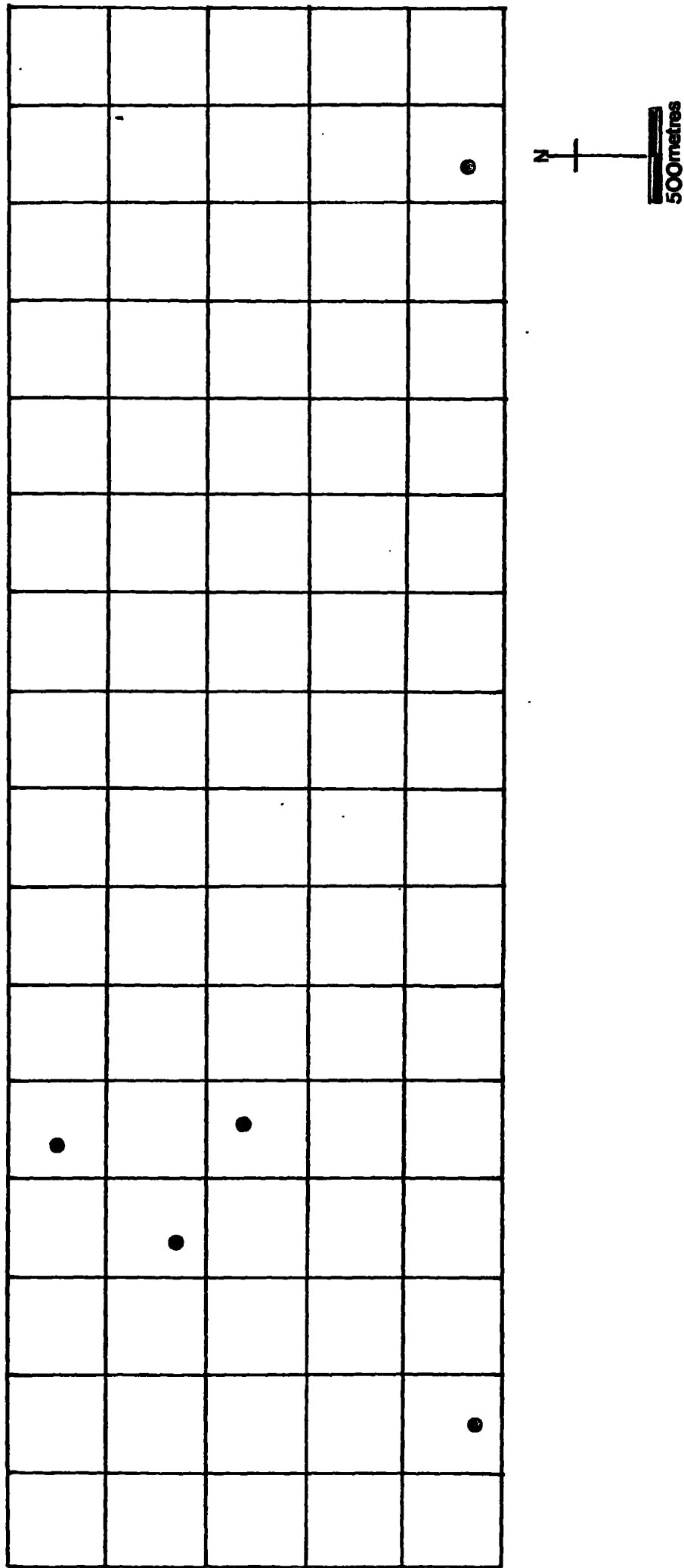


Table 6.8 Land Capability Classes for Agriculture

Site	Capability Class	Site	Capability Class
1	3 ws	37	3 s
2	4 ws	38	4 ws
3	3 ws	39	4 sce
4	3 s	40	4 s
5	6 bws	41	4 sg
6	4 sw	42	5 esg
7	3 ws	43	3 ws
8	3 ws	44	3 ws
9	3 s	45	4 ws
10	3 ws	46	4 wsge
11	4 ws	47	4 sw
12	3 ws	48	4 sw
13	3 s	49	3 ws
14	4 ws	50	4 ws
15	4 ws	51	3 ws
16	2 s	52	3 ws
17	5 ws	53	3 ws
18	4 sw	54	5 esg
19	6 bws	55	5 egs
20	5 ws	56	4 ewg
21	3 sg	57	4 ws
22	4 sw	58	3 g
23	4 sw	59	3 ws
24	4 ws	60	3 ws
25	3 ws	61	5 ws
26	4 cws	62	6 bwe
27	4 cws	63	4 sw
28	4 wcs	64	3 w
29	3 ws	65	3 w
30	4 ws	66	4 s
31	5 swg	67	4 sw
32	3 ws	68	4 ws
33	6 bwgse	69	4 ws
34	3 ws	70	6 bwse
35	3 w	71	5 gse
36	3 ws		

Fig6.12 Land Capability Classes for Agriculture

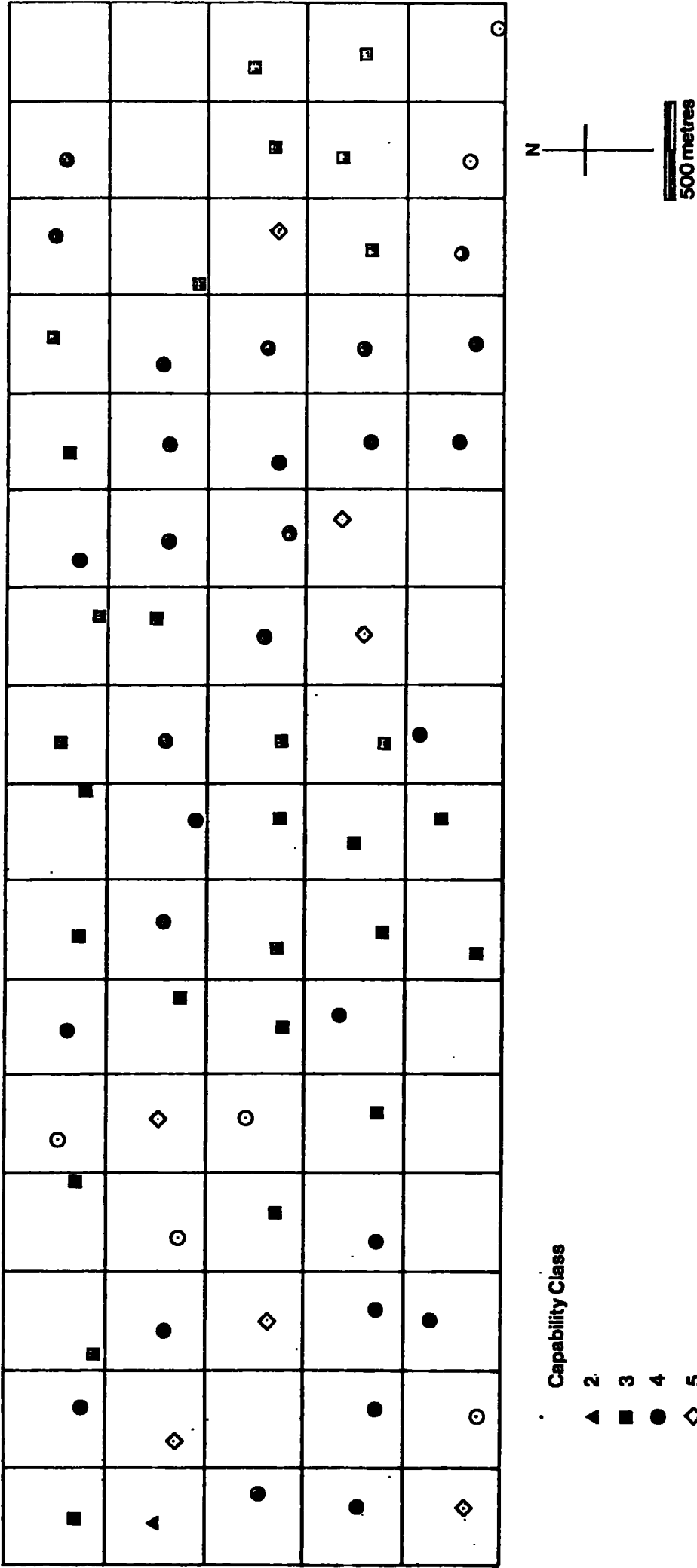




Plate 6.1 Class 3ws land for agriculture in the foreground, on stagnogleyic brown earth soils of Unit 4, contrasts with 5esg slopes of Pittington Hill, of predominantly brown calcareous and rendzina soils, in the distance.



Plate 6.2 Poorly drained cambic stagnogley land of Class 4ws at Site II near the base of the Permian Escarpment (Unit 6) at High Moorsley.

Table 6.9 Dominant Subclass by Capability Class (Number of Sites)

Class	subclass					
	b	w	s	g	c	e
2			1			
3		22	5	1		
4		14	12		2	1
5		3	1	1		3
6	5					
Total Sites	5	39	19	2	2	4
% Total Sites	7.0	54.9	26.8	2.8	2.8	5.6

the limiting parameter at thirty five, the remaining four being affected predominantly by a flooding risk. This is mainly a reflection of the nature of the underlying parent material producing surface-water gleys and stagnogleyic brown earths. Wetness acts as a major limiting factor at Class 3 level (78.6% of Class 3 sites), whereas, of the total sites of Class 4, under one half (48.3%) have wetness as the dominant subclass.

Soil factors (s) comprise over one quarter (26.8%) of the dominant limitation factors, being especially associated with Class 4, accounting for 41.4% of that class.

The remaining parameters total only 18.2% of the sites overall, with site limitations (b) in the river and stream valleys being the most important.

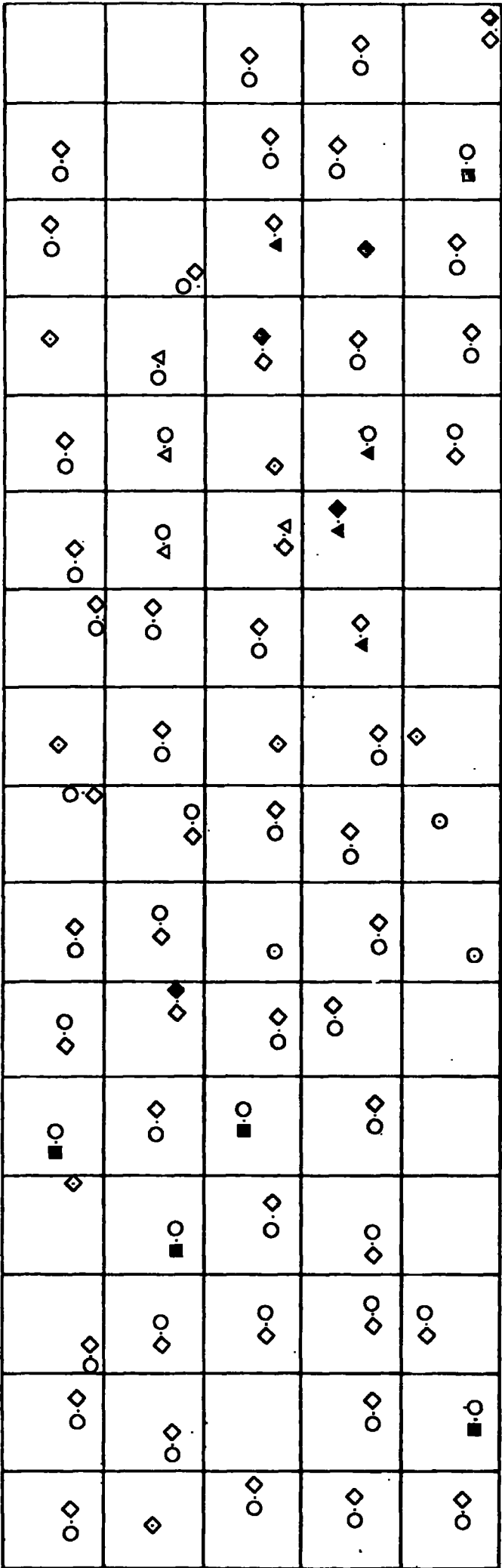
In no Physiographic Unit does the wetness subclass fall below 25% of sites, (Table 6.10), and it rises to 75% of sites west of the River Wear in Unit 1. The Lowlands East of the Wear (Unit 4) and the Permian Plateau (Unit 7) show the next highest proportions. The wetness parameter assigns sites to Classes 3 and 4 in the main, but the number of sites of 3 w class in Unit 4 is interesting. In this unit the combination of effective drainage schemes, installed or capable of improvement, and the practice of night soiling improving the texture and thereby drainage, results in many poorly drained profiles being of Class 3 w rather than Class 4 w. Where Class 4 w occurs the soil texture is more clayey and drainage even less effective; but it could be improved with a comprehensive scheme.

This observation also applies to other units, but in Unit 5 at Elemore several flooding sites are classified as 4 w, and in the Wear Gorge (Unit 3) certain sites with a flooding risk are of Class 5 w standard.

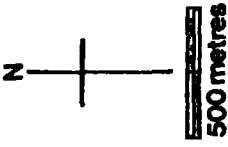
On the Permian Plateau (Unit 7) and Escarpment (Unit 6) in particular, but also in the lowlands, the presence of imperfect drainage assigns sites to Class 3 w and is associated with the stagnogleyic brown earth soils.

Next in importance overall is the soil limitation subclass, and this is dominant in 41.4% of the Class 4 sites. It is most significant in Unit 4 in the centre of the transect.

Fig6.13 Land Capability Subclasses for Agriculture



- b
- w
- ◇ s
- ◆ g
- △ c
- ▲ e



Within the subclass the breakdown is as follows:-

**Table 6.11 Soil Limitations Dominant Subclass (s) by Capability Class
(number of sites)**

Class	Shallowness	Stoniness	Texture	Fertility (nutrient status)
2			1	
3		3	1	
4		8		5
5				
% Total Sites	0.0	57.9	10.5	31.6

Despite the fact that the rendzina profiles have shallow depths to rock (≤ 30 cm), and as such, according to Rudeforth and Bradley's depth thresholds, should be assigned to Class 3, the presence of extremely stony horizons close to the surface in places assigns them to Class 4 rather than Class 3. Stoniness accounts for 57.9% of sites affected by soil limitations, with very stony and extremely stony profiles placing 80% of stone affected soils in Class 4. This reflects the stoniness of the rendzina profiles of the Magnesian Limestone, as indicated, and the high stone contents of some of the drifts of the Wear Lowlands, especially the Upper Wear Clay.

Plant nutrient limitations, in the form of very low pH, are the second most important of the soil factors. Sites so affected are represented from east to west in the transect; from Site 39 on the Permian Plateau (Unit 7), with a moderately well drained profile, to poorly drained sites under woodland at and above the Wear Gorge of Unit 3.

Textural problems are only locally the dominant factor, but influence other parameters, such as wetness, at a majority of sites. A dominant structural limitation is not represented.

The remaining four subclasses (b,g,c,e), apart from one site with slope limitations (g) in Unit 5, are all representative of Class 4 land or worse. All five sites of Class 6b are associated with site restrictions in the River Wear Gorge and its tributaries.

Sites with a dominant erosion risk (e), slope(s) or climatic (c) limitation are located in the east of the transect in Units 5, 6 and 7.

6.2.7.3 Combinations of Subclasses

Table 6.12 shows that Class 3 does not have more than two subclass limitations whereas Classes 4, 5 and 6 frequently have more than two limitations and Class 6 has three or over.

Nineteen combinations of subclasses are recognised, but the ws subclass accounts for nearly one half of the sites, and together with the sw subclass, takes up 59.2% of all sites. 3 ws is the dominant class combination followed by 4 ws.

Table 6.12 Combinations of Subclasses by Capability Class (number of sites)

Class	w	s	g	ws	sw	sg	bws	bwe	wcs	swg	sce	gse	cws	ewg	esg	egs	bwse	wsgse	bwgse
2		1																	
3	3	4	1	19		1													
4		2		12	8	1			1		1		2	1			1		
5				3						1		1			2	1			
6							2	1									1		1
Total Sites	3	7	1	34	8	2	2	1	1	1	1	1	2	1	2	1	1	1	1
% Total Sites	4.2	9.9	1.4	47.9	11.3	2.8	2.8	1.4	1.4	1.4	1.4	1.4	2.8	1.4	2.8	1.4	1.4	1.4	1.4

Table 6.13 Soil Type, Capability Class and Dominant Subclass (% Sites)

	b						w						s						R						c						e						
	Class						Class						Class						Class						Class						Class						
	2	3	4	5	6		2	3	4	5	6		2	3	4	5	6		2	3	4	5	6		2	3	4	5	6		2	3	4	5	6		
Brown (non-humic Rendzina																	66.7																				
Typical Brown calcareous earth					25.0																																75.0
Typical brown earth																	66.7																				
Stagnogleyic brown earth							56.2						12.5	12.5																						6.2	
Typical brown alluvial soil					50.0						50.0																										
Gleyic brown alluvial soil					50.0								50.0																								
Cambic stagnogley							29.4	52.9					17.6																								
Cambic stagnohumic gley							53.8	15.4					23.1	7.7																							
Typical (non-calc) alluvial gley					20.0		20.0	40.0	20.0																												
Typical (non-calc) humic-alluvial gley					100.0																																
Disturbed Soil Group							16.7	16.7					33.3	16.7																						16.7	

6.2.7.4 Capability Class and Soil Type

Only one site, a typical brown earth, is classified as Class 2, but it is to those sites with a Class 3 grouping that an indication of soil suitability is to be sought. Both the stagnogleyic brown earth profiles and cambic stagnohumic gley soils have over 50% of their sites classified as Class 3. (68.7 and 53.8% respectively), both having soil drainage as the dominant subclass. The cambic stagnogley soils, with less workable topsoils than the humose subgroup, are principally of Class 4 (70.5%), and also have drainage as the dominant subclass. Table 6.13. shows this distribution.

The lowest classificatory groups are assigned to the alluvial soil groups, which are significantly affected by flooding risk, and the typical brown calcareous earth sites of the escarpment which have an erosion risk sufficient to warrant their placement in Class 5.

6.2.7.5 Land Use and Capability Class.

The land use, as recorded at the time of sampling, is tabulated in Table 6.14 to assess how this corresponds to land capability. Arable is dominant on Class 2 and 3 sites, with some arable on Class 4 sites. No arable was recorded on sites classed as 5 or 6.

The proportion of sites under permanent grass in each class, as well as those under grass ley, increase in the lower classes, as does woodland and scrub.

Table 6.14 Percentage of Sites in Each Land Capability Class According to Land Use

Land Use	Land Capability Class				
	2	3	4	5	6
Arable	100.0	71.4	55.2	0.0	0.0
Grass ley	0.0	3.6	6.9	0.0	0.0
Permanent grass	0.0	17.9	24.1	50.0	0.0
Woodland	0.0	7.1	10.3	25.0	100.0
Scrub	0.0	0.0	3.4	25.0	0.0

Woodland accounts for 100% of the Class 6 sites, being located in the River Wear Gorge and tributaries.

The percentage of permanent grass, woodland and scrub sites associated with Class 3 (25.0%) and Class 4 (37.8%) land indicates that more land could be used for arable crops if required.

Generally, however, the current land use corresponds well with land capability.

6.2.7.6 Comparison with the A.D.A.S. Agricultural Land Capability System

It is interesting to compare the above classification with that of the Agricultural and Development Advisory Service of the Ministry of Agriculture, Fisheries and Food (1971), which grades agricultural land in the transect as Class 3 or 4, with areas of "other land primarily in non-agricultural use" and "land primarily in urban use".

The A.D.A.S. system grades land into five grades; from Grade 1 with very minor or no physical limitations to agricultural use, to Grade 5 with very severe limitations, due to adverse soil, relief or climate or a combination of these (Ministry of Agriculture - A.L.S. 1966 and 1968). The Bibby and Mackney classification, however, as used by the author as a basis for classification, grades land into Class 1 with very minor or no physical limitations to land use, to Class 7 with extremely severe limitations that cannot be rectified.

It would appear that Grade 3 of A.D.A.S., with "moderate limitations" restricting cropping within the grade, is similar to Classes 3 of Bibby and Mackney, with "moderate limitations" that also restricts the choice of crops. Likewise, the A.D.A.S. Grade 4 land, of "severe limitations" with a high proportion of grass with "occasional fields of oats, barley or forage crops", is similar to Class 4 of Bibby and Mackney, with "moderately severe limitations that restricts the choice of crops". Grade 5 of A.D.A.S., of land with "very severe limitations" is equivalent, in general to the Classes 5, 6 and possibly 7 in some cases, of Bibby and Mackney.

It is thought, however, that Grade 3 of A.D.A.S., would probably be classified as Class 4 or 2 in the other system at the "diffuse" ends of the scale, and the wide ranging category of Grade 3 has suffered criticism as a result. Dennis (1976) comments that the need for a review of Grade 3 is well recognised by the Ministry, and a Working Party has already reported on a method of sub-division (into 3a, b and c) and pilot surveys are in operation (as at February, 1976). In addition, Grade 4 of A.D.A.S. at the extreme end of the scale would probably be classified as Class 5 by Bibby and Mackney; both having "severe limitations".

These discrepancies are well shown when the A.D.A.S. system and that used by the author are compared on a point sample basis for the seventy one sites (Table 6.15).

Table 6.15 Comparison of Agricultural Capability Systems - A.D.A.S. (1971) and Brown (1971 Survey)

		A.D.A.S. (1971)	Brown (1971). (after Bibby and Mackney, 1969).
		% Sites	% Sites
Grade or Class	2	0.0	1.4
	3	71.8	39.4
	4	0.0	40.8
	5	0.0	11.3
	6	Not applicable	7.0
Land Primarily in non-agricultural use.		28.2	21.1

Under the A.D.A.S. system, Grade 3 land amounts to nearly twice as much as that found by the author, and no Grade 4 sites are classified. If, however, Classes 2, 3 and 4 are totalled, the sum of 81.6% of the sites is still nearly 10% (9.8%) higher than the total A.D.A.S. Grade 3. This gap appears to lie predominantly in the amount of land primarily in non-agricultural use recognised by the Ministry, which is 7.1% higher than that found by the author. An inspection of the A.D.A.S. map shows that these sites are accounted for almost entirely by sites on the Permian Escarpment

and Plateau (Units 6 and 7) between Hillside Farm at Pittington and High Moorsley where a large area of agricultural land, mostly of Class 4, is graded as not being in agricultural use. As these soils have been under agriculture for generations, evidenced by the amount of refuse (clay pipes etc.,) found, this mistake cannot be explained. The remainder of sites not classified as in agricultural use by A.D.A.S., but under a capability class of the author, are accounted for by woodland or scrub land use. Of the fifty one sites classified as Grade 3 by A.D.A.S., the following class groupings are found using the author's system:

Class 2	-	2.0
Class 3	-	52.9
Class 4	-	37.3
Class 5	-	7.8

The A.D.A.S. system, in assigning all the agricultural site to Grade 3, is thus giving a false optimistic impression of agricultural capability in the area, and it is suggested that the system is somewhat limited compared with that of Bibby and Mackney. It is interesting to note that the Soil Science Departments of A.D.A.S. at Newcastle-upon-Tyne is co-operating with the Soil Survey in classifying land according to the latter system (Le Grice, 1975).

It is also interesting to note that the A.D.A.S. system is becoming increasingly incapable of standing up to legal cross examination when faced with a detailed parametric analysis, as indicated by Aitken (1977).

6.2.8 Conclusions

A modification of the Bibby and Mackney land capability system has been developed for the study transect and applied to the area. The point sample method indicates that Classes 3 and 4 are the most commonly encountered with inherent problems for a wide variety of agricultural practice. The method has been compared with that of the Ministry of Agriculture's (A.D.A.S.) agricultural capability system pinpointing deficiencies in the Ministry's approach.

6.3 Land Capability Classification for Forestry

6.3.1 Aims and Problems of a Capability Analysis

The aim of a land capability system for forestry may be seen at two levels. Firstly, at a detailed level for the forest manager, it must provide an objective prediction of growth on different site types for the most commonly planted species and to relate this prediction to a series of management activities or inputs designed to achieve it (Toleman, 1974). Secondly, at a less detailed level, it must provide the local or national government planner with an overall means of land assessment as part of a particular stage in the planning process; detailed species capability assessments are too detailed at an overall planning level and too time consuming. The development and application of forestry capability systems is fraught with difficulties. Toleman (1974) states five problems which have commonly been experienced when attempts have been made to evolve general site capability systems for the U.K.

- 1). The site factors directly influencing production of the major commercial species are not well understood. He notes that while the autecology of Corsican pine, Sitka spruce and the commercial minor species of Western hemlock, Grand fir, Lawson cypress and Western red cedar have been studied on limited areas of Britain (Fourt et al., 1971; Malcolm, 1971; Aldous and Low, 1972), similar studies for the remaining commercial species (for example Scots pine) are lacking, and thus only a general classification can be attempted on an assessment of composite site features.

Further, the relative importance of site factors in the growth of commercial species is not well understood and it is likely that the ranking of importance of factors would change according to climatic regions. The relative importance will also change according to the age of the crop. It is not until final rotation that the combination of these will have revealed their effect on production; for example, the correlation of growth and stability with soil texture compaction, permeability and gleying may not be evident in early crop life on peaty gleys over clay.

- 2). The effects of changing alterable site limitations are also difficult to quantify. Drainage, cultivation and the application of fertilizer gradually ameliorate site conditions over time; but over what time period? Such an alteration of limitations affects the difference between a site being regarded as economically viable or not. For example, oligotrophic blanket and hill peat are only viable if adequately drained and fertilized.
- 3). The third difficulty is that tree growth has a greater effect on the site itself than have other crops. Transpiration and interception will improve the moisture status of a poorly drained soil while the crop will insulate the ground from extreme temperature variations. Thus, site factors investigated before a tree crop is planted may differ from those found on the same location under a mature crop.
- 4). Fourthly, the introduction and extensive use of non-indigenous species has only increased the extent of unknown relationships between species, yield and site factors, which are naturally wide at the outset due to Britain's climatic, physiographic and lithological variation. Of the eight major coniferous species, few have been grown to full rotation on a range of sites and with a range of cultivation treatments.
- 5). Finally, much early work on site classification was based on vegetative description and although the natural vegetation of the site, as modified by anthropogenic factors, does reflect site limitations, only empirical correlations can be made when making decisions on the selection of species for planting (Anderson, 1950).

Such problems as listed above for the U.K. seem not to be experienced elsewhere. For example, in the Canadian Land Capability Classification for forestry productivity (McCormack, 1970), virgin forest provides an invaluable source of information on species performance under different conditions. Furthermore only native species are used in commercial forestry, hence removing another variable from the system. Consequently the Canadian system has developed rapidly and extremely successfully.

The agricultural capability classes 5 and 6 of the Soil Survey of Great Britain are stated as being suitable for forestry (classes 1 to 4 being ruled out because of their agricultural value), but it is felt that because of the site factors adopted and the value judgements involved for forestry, in what is a classification for agriculture, the approach is unsatisfactory.

However, commercial forestry classifications have been undertaken on occasion with reported successful results in Britain. For example, Hewitt (1976) describes how the Matthews Wrightson Land Group use such surveys as an aid to forest and hill farm management. Thematic and parametric maps were made of soils, vegetation, topography and exposure (Topex survey) and synthesised on a land potential basis for use as an aid to forest location and farm viability.

6.3.2 The Development of a Land Capability Classification for Forestry

Because of the above difficulties, it was decided to develop a national rather than a local system for forestry potential, capable of use in the transect, that would be of use to the planner rather than to the forest manager, in that an "overall", rather than a detailed approach, would be taken. The commercial content would be considered and, therefore, the system would be for general conifer production rather than amenity plantings of deciduous species.

6.3.2.1 Parameters

The attributes and parameters most significant to successful tree growth have already been discussed in Chapter 3, Section 3.4.2. Certain of these may be considered as being susceptible to "modification" by man; others are entirely out of man's control and by their nature "unmodifiable". For example, conifers will grow on a wide variety of drainage/texture regimes, and draining land before planting is a common occurrence. A very shallow depth to in situ limestone, however, will automatically rule out a crop, being a condition virtually impossible to rectify.

In addition to these factors, there is invariably an economic threshold which renders theoretically modifiable parameters, unmodifiable in practice. For example, soil pH may be of such a nature that it can be altered with little cost; hence "modifiable", but it also may be of such a status that little improvement can take place to make a site economically viable without undue cost; hence "unmodifiable" in this case.

The selected parameters in these two broad categories are as follows:

Modifiable Parameters

1. Soil profile drainage coupled with soil texture.
2. Observed surface water.
3. Soil pH.

Unmodifiable parameters

4. Depth to in situ rock
5. Liability to flooding
6. Site exposure to wind
7. Aspect
8. Angle of slope
9. Altitude

1. Soil profile drainage coupled with soil texture

The detrimental effects of the combination of poor profile drainage coupled with a clay texture to tree growth as outlined by Toleman (1974), are assessed by the determination of the drainage class and the soil texture at both 5 and 40 cm. To qualify as a limitation, the soil profile must have a combination of poor drainage and have one or both of the depths with a clay or silty clay texture.

2. Observed surface-water

The occurrence of free water lying on the soil surface is noted by observation to determine permeability status, and if positive during winter conditions is taken as a site limitation. It is recognised that this may be variable and should be investigated in association with profile and site drainages, textural and structural characteristics of the soil profile and gleyed horizons.

3. Soil pH

Soil reaction, although variable, is critical to tree growth, and the limits stated by Edlin (1964), with the following alterations, are used. As it is considered that the pH determined in 0.01 M Ca Cl₂ solution is more reproducible and corresponds more closely to the effective pH of the solution in immediate contact with the soil particles (Davies, 1971 after Russell, 1961), this method is used, and Edlin's thresholds converted to the reaction under the saline solution. Consequently, the pH of the topsoil at 5cm and the subsoil at 30cm is considered in the analysis as follows:-

- a). If the reaction is below 4.0 (strongly acid) for both depths, or if one depth is below 4.0 and the other in between 4.0 and 6.0, or if the pH is greater than 6.0 and below 7.0 for one of the sample depths, with the other between 4.0 and 6.0, the parameter is considered modifiable.
- b). If, however, the pH value is greater than 6.0 (that is neutral or above) for both depths the parameter is considered unmodifiable for the purpose of the classification, in that considerable management may be required to bring the value down to an optimum 4.0 - 5.0 (moderately acid) for coniferous growth of good quality.
- c). If one depth is greater than 6.0 and the other between 5.0 and 6.0 or if one depth is above 7.0 the limitation is considered unmodifiable, and in the seemingly unlikely event of one depth being below 4.0 and the other above 6.0 the unmodifiable limit applies.

Between 4.0 and 6.0 no pH limitation is considered to be in effect, although between 5.0 and 6.0 desirability decreases on a gradational threshold.

4. Depth to in situ rock

The undesirable effects of shallow soils, especially if the in situ rock is calcareous, are considered by taking a soil depth to in situ rock of equal to, or less than, 45 cm as being the threshold for adequate conifer growth, and the unmodifiable parametric limit (Thompson, pers. comm., 1975).

5. Liability to flooding

Any degree of liability to flooding of a site is taken as an unmodifiable factor.

6. Site exposure to wind

It is generally accepted that wind speeds increase with altitude, both at the ground surface as well as in the free atmosphere. The effects of topographic shelter has, however, proved difficult to quantify and although subjective methods of exposure assessment have been shown to be valid in some cases obvious disadvantages accrue (Pyatt, Harrison and Ford, 1969).

In order to give an objective analysis of relative exposure the method as devised by Pyatt et.al. (1969) of assessing the relative topographic exposure (Topex method) is used at the transect sites.

Pyatt et.al. do not suggest in their paper the effects of the various categories on tree growth, but using their analysis of windthrow hazard, which combines rooting conditions and exposure zones, it seems that "very exposed" and "severely exposed" sites have a moderate to high windthrow hazard. These two categories are, therefore, used in the analysis.

7. Aspect

The effect of aspect on tree growth has not been quantified but the parameter, according to Pyatt et.al. (1965), has, in suitable circumstances, a "readily observable" effect on the soil moisture regime, and by implication on tree growth. However, in the absence of concrete quantifiable evidence this factor cannot be included in the analysis.

8. Other Parameters

The angle of slope threshold, as defined by Toleman (1974), is 35° , but is not operable in the transect as slope does not rise at the sample sites above 17.2° . Likewise, altitude does not rise above 160 m, and as such will not affect tree growth.

6.3.2.2 Classification System

i). Classes

Three broad classes are recognised:

Class 1 suitable - defined as having no limitations either modifiable or unmodifiable

Class 2 Conditionally Suitable - defined as having one or more modifiable limitation.

Class 3 Unsuitable - defined as having one or more unmodifiable limitation.

6.3.2.3 Subclass Notation

Five subclasses are noted:

- w to denote drainage/texture, or surface-water limitations.
- a to denote pH limitations.
- d to denote soil depth to in situ rock limitations.
- f to denote liability to flooding.
- c to denote site exposure to wind.

The dominant subclass and unmodifiable parameters take priority. If several subclasses are of equal weight the following priority is suggested:

d f c a w

6.3.3 Transect Land Capability Analysis for Forestry

The land capability system outlined above was applied to the transect sites and the results are presented below.

6.3.3.1 Discussion of Parameters

Those sites with poor profile drainage coupled with clay or silty clay textures are shown in Figure 6.14, and are predominantly found on the more intractable drift to the west of the Wear, i.e. in a belt running NE - SW from West Rainton to Belmont, and in the shallow valley of the Coldwell Burn and Coalford Beck streams at Elemore.

The observed surface-water parameter is not widespread (Figure 6.14) and is particularly associated with the laminated clays to the west and the alluvial flats of Coldwell Burn to the east.

The soil pH limitation is, however, significant in its unmodifiable state, being particularly effective in the centre and east of the transect (Figure 6.15).

All the sites with a depth to in situ rock of 45 cm or less are located on the Permian Escarpment (Unit 6) and are either brown rendzina or brown calcareous earth soils. Those areas with a liability to flood are the same as those encountered in the agricultural classification and are shown in Figure 6.1 on Page I44.

The final parameter to be considered in the transect is site exposure, and the only sites with a very or severely exposed Topex rating are located on the Permian Plateau (Unit 7) at High Moorsley, as shown in Figure 6.9.

6.3.3.2. Land Capability Classes

The overall land capability classes for forestry are shown in Tables 6.16, 6.17 and Figure 6.16. See plates 6.3 and 6.4.

Fig6.14 Sites with Soil Drainage and Texture Limitations-Forestry (subclass w)

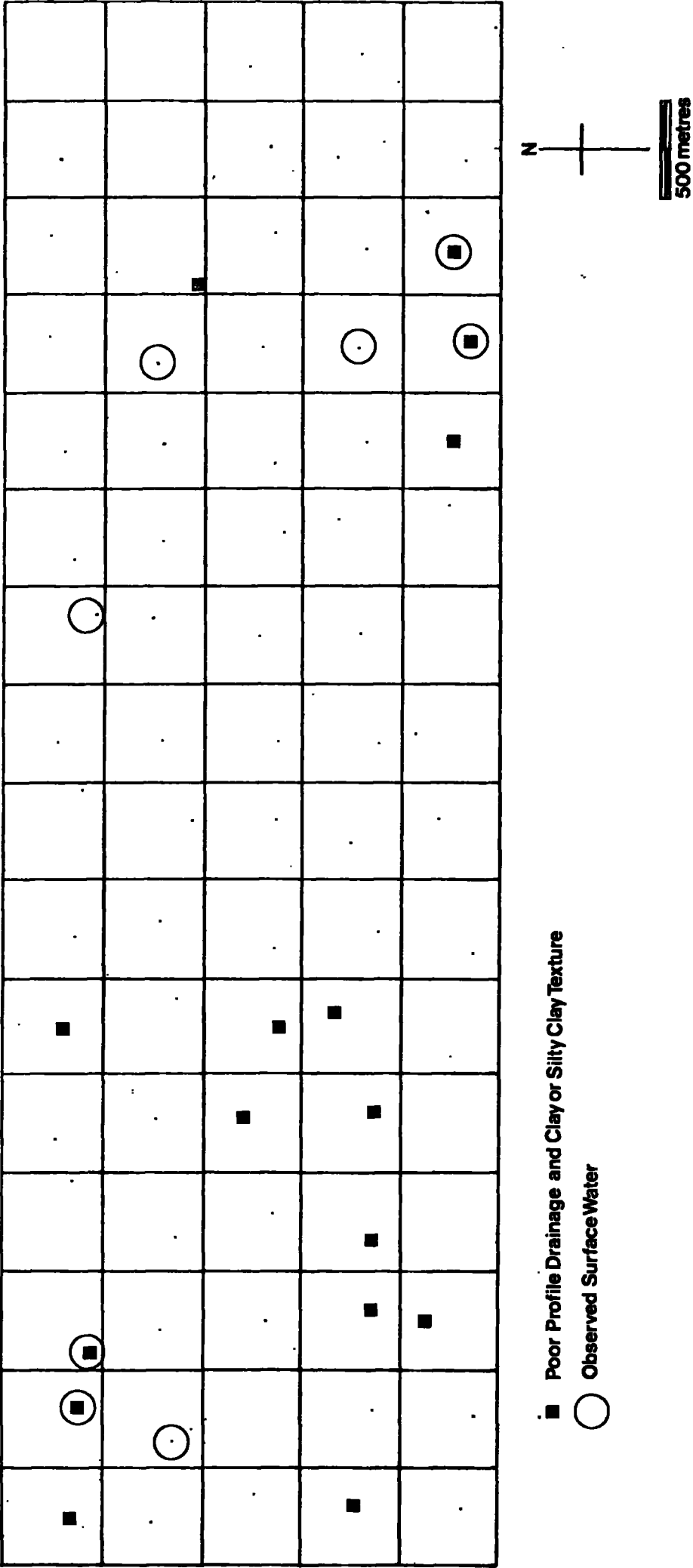


Fig 6.15 Sites with pH Limitations-Forestry(subclass a)

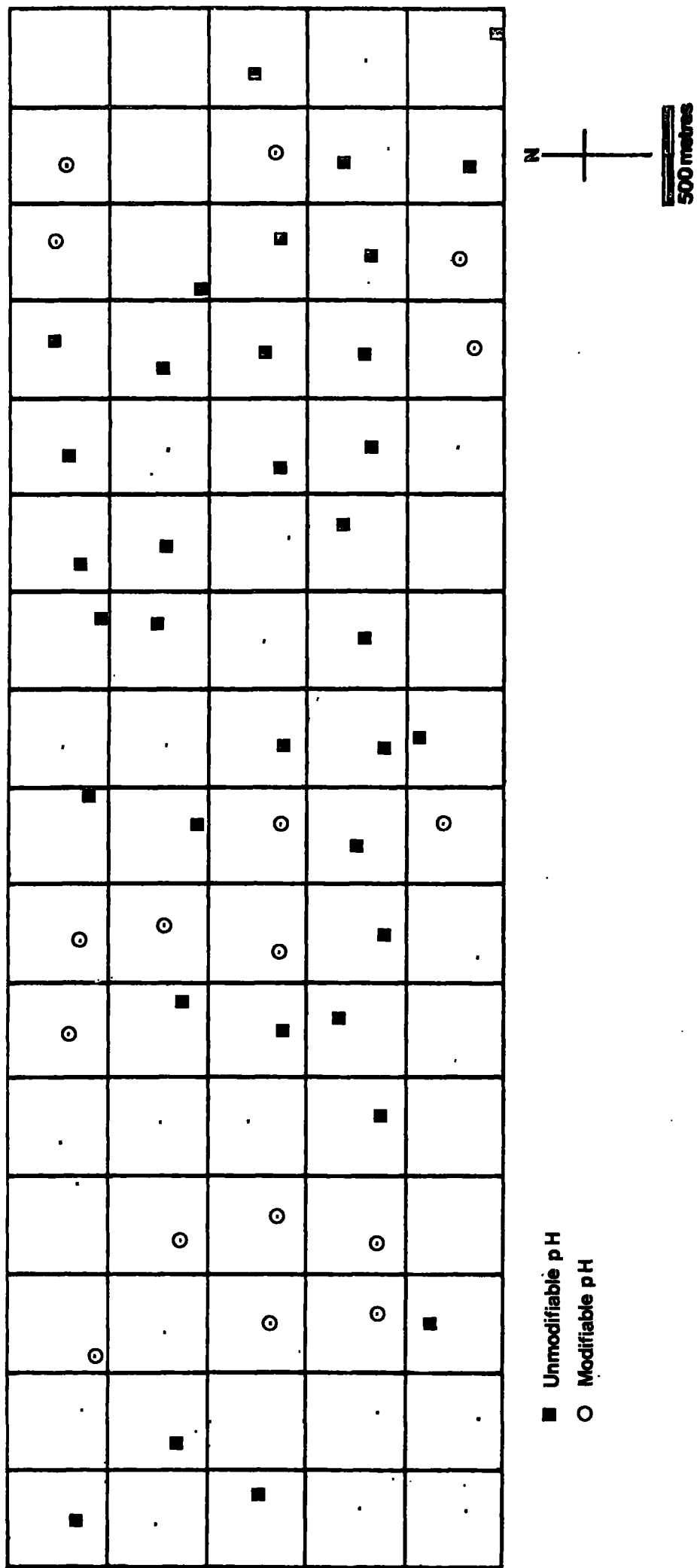


Table 6.16 Land Capability Classes for Forestry

Site	Capability Class	Site	Capability Class
1	3 aw	37	3 a
2	2 w	38	1
3	2 aw	39	1
4	1	40	3 da
5	3f	41	3 da
6	2 aw	42	3 da
7	2 a	43	2 a
8	3 a	44	3 a
9	1	45	2 w
10	3 aw	46	1
11	3 a	47	2 aw
12	3 a	48	2 aw
13	3 a	49	3 aw
14	2 a	50	2 w
15	2 a	51	3 a
16	1	52	3 a
17	3 aw	53	3 a
18	1	54	3 a
19	3 fa	55	3 a
20	3 f	56	3 a
21	3 a	57	3 aw
22	2 a	58	3 a
23	3 a	59	3 a
24	1	60	1
25	3 a	61	3 f
26	3 ca	62	3 f
27	3 c	63	3 aw
28	3 caw	64	1
29	3 aw	65	2 a
30	3 a	66	3 a
31	2 a	67	2 w
32	2 a	68	3 faw
33	3 fw	69	3 faw
34	3 aw	70	3 dfa
35	3 a	71	3 da
36	2 a		

Fig6.16 Land Capability Classes for Forestry

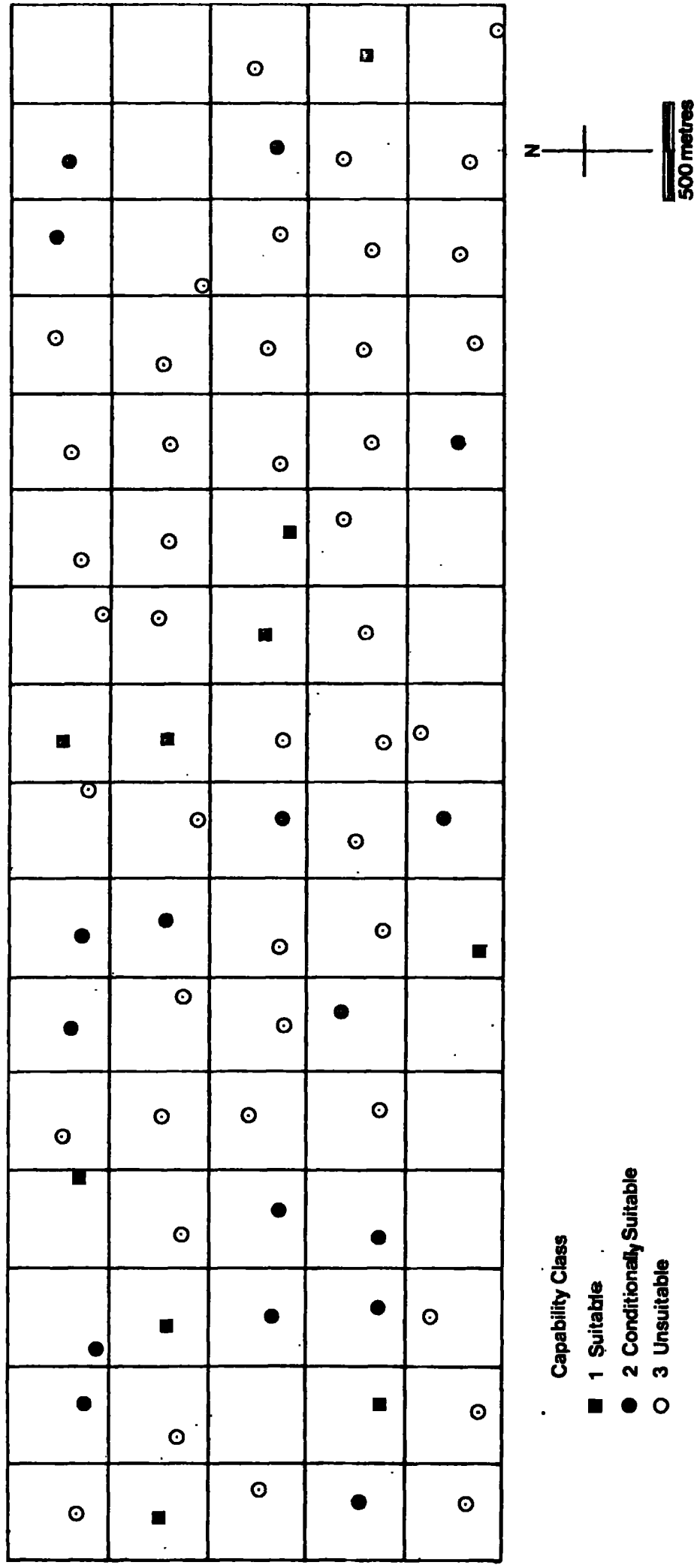




Plate 6.3 Typical brown earth soils on well drained land at Framwellgate Moor form Class I sites for forestry (near Site I6 in Unit I).



Plate 6.4 Class 2aw land for forestry near Carrville (Unit 4); cambic stagnohumic gley soils showing pH and drainage/texture limitations.

Table 6.17 Land Capability Classes for Forestry by Physiographic Unit (% Sites)

Physiographic Unit	Suitable Class 1	Conditionally Suitable Class 2	Unsuitable Class 3	Class 1 + 2
1	25.0	37.5	37.5	62.5
2	40.0	40.0	20.0	80.0
3	0.0	16.7	83.3	16.7
4	13.6	31.8	54.5	45.4
5	0.0	16.7	83.3	16.7
6	16.7	0.0	83.3	16.7
7	8.3	25.0	66.7	33.3
Total Units	14.1	23.9	62.0	38.0

Classes 1 and 2, (suitable and conditionally suitable), account for 38.0% of all sites, with 14.1% having no limitations.

Physiographic Units 1 and 2 have the greatest proportions of Class 1 and 2 land, whereas the Wear Gorge and Floodplain (Unit 3) and the Permian Escarpment (Unit 6) have the least potential and the greatest percentages of Class 3 sites..

6.3.3.3 Dominant Subclass

Figure 6.17 and Table 6.18 show the dominant subclasses associated with each capability class.

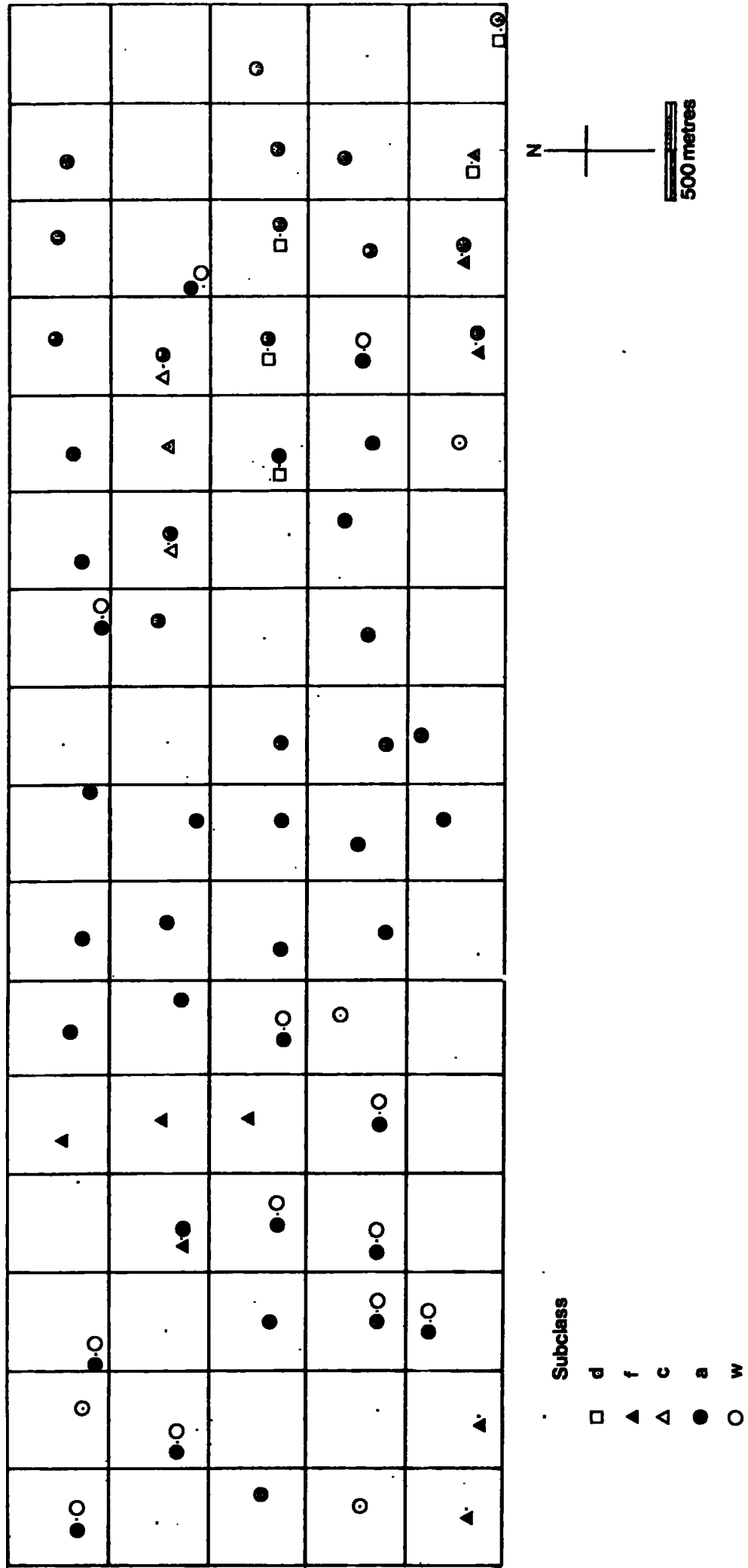
Table 6.18 - Dominant Subclass by Capability Class (number of Sites)

Class	None	Subclass				
		d	f	c	a	w
1	10					
2					13	4
3		5	8	3	28	
Total Sites	10	5	8	3	41	4
% Total Sites	14.1	7.0	11.3	4.2	57.7	5.6

Soil reaction (a), predominantly in terms of alkalinity, is the dominant limitation at 57.7% of sites. Of the forty one sites so affected, 68.3% have a limitation of sufficient degree to warrant a Class 3 grading.

At least 40.0% of sites in all units, other than in the Wear Gorge and Floodplain have a soil reaction limitation, rising to 81.8% of sites in the agricultural lowlands East of the Wear (Unit 4) (Table 6.19). It is the main determining parameter for Class 3 in all areas except the Wear Gorge and Floodplain, where flooding (f) accounts for 83.3% of Class 3 limitations, and the Permian Escarpment, where shallow soil depth (d) is found at 40% of unsuitable sites.

Fig6.17 Land Capability Subclasses for Forestry



The next most frequent overall limitation is the liability to flood at 11.3% of sites, ensuring an automatic Class 3 grading. Shallow soil depth follows, with wetness/texture (w) and site exposure (c) following in that order. Wetness limitations of one kind or another account for over one sixth of all sites, at 16.9%.

6.3.3.4 Combinations of Subclasses

Twelve combinations of subclasses are recognised, but the soil reaction subclass (a) accounts for nearly 40% of all sites and 63.6% of all Class 3 sites. Next in importance is soil reaction coupled with a drainage/textured limitation (aw) which accounts for 23.5% and 18.2% of Class 2 and 3 respectively. The remaining subclass combinations do not rise above 7.0% of all sites (Table 6.20).

Table 6.20 Combinations of Subclasses by Capability Class (number of Sites)

Class	None	f	c	a	w	da	fa	ca	aw	dfa	fw	faw	caw
1	10												
2				9	4				4				
3		5	1	19		4	1	1	8	1	1	2	1
Total Sites	10	5	1	28	4	4	1	1	12	1	1	2	1
% Total Sites	14.1	7.0	1.4	39.4	5.6	5.6	1.4	1.4	16.9	1.4	1.4	2.8	1.4

6.3.3.5. Capability Class and Soil Type

Table 6.21 Soil Type, Capability Class and Dominant Subclass (% Sites)

	None	d		f		c		a		w	
	Class	Class		Class		Class		Class		Class	
	1	2	3	2	3	2	3	2	3	2	3
Brown (non-humic) rendzina			100.0								
Typical brown calcareous earth			50.0						50.0		
Typical brown earth	50.0								50.0		
Stagnogleyic brown earth	18.7					12.5		18.7	50.0		
Typical brown alluvial soil					100.0						
Gleyic brown alluvial Soil					50.0				50.0		
Cambic stagnogley	11.8					5.9		23.5	41.2	17.6	
Cambic stagnohumic gley	23.1							30.8	38.4	7.7	
Typical (non-calc) humic alluvial gley					80.0			20.0			
Typical (non-calc) humic alluvial gley					100.0						
Disturbed soil group	16.7							16.7	66.6		

As far as Class 1 sites are concerned, apart from the one typical brown earth profile, the stagnogleyic brown earths and cambic stagnohumic gley soils are the most suitable soils for forestry in the transect (Table 6.21). When Classes 1 and 2 are considered together, however, the stagnohumic gleys have the most proportion of their sites in these two classes at 61.6%, whereas the cambic stagnogley soils have 52.9% and the stagnogleyic brown earths only 37.4%. 50% of the stagnogleyic brown earths are in fact of Class 3, with soil reaction rather than drainage as the dominant limitation. Of the thirty surface-water gley profiles, 56.7% are of Class 1 or 2 with soil reaction or drainage/texture being the dominant limitations.

The least suitable sites for forestry, all graded as Class 3, are the rendzina and brown calcareous earth profiles, affected, predominantly, by soil depth limitations. Only one alluvial profile is rated above Class 3, the dominant limitation being a liability to flooding at these near watercourse locations.

6.3.4 Conclusions

The land capability classification system for forestry has proved difficult to formulate owing to the lack of quantitative thresholds for tree growth and performance. Hence it was decided to adopt the "modifiable/unmodifiable" parametric assessment rather than attempt to define specific thresholds for each of the three capability classes. This has produced a distribution indicating that forestry production is suitable for specific well defined locations among areas unsuitable for worthwhile production. Detailed quantitative analysis may, therefore, be undertaken in these areas.

6.4 Land Capability Classification for Nature Conservation

6.4.1 Approaches to Classification

The factors which distinguish areas of existing nature conservation value will depend on resource attributes which include vegetation, geology soils, topography, climate, water and the past and present land use. Tubbs and Blackwood, (1971) suggest such areas will be characterised by the dominance of three broad categories of vegetation which are directly related to land use; namely:

1. The complex of habitats comprising agricultural land.
2. Plantation woodland.
3. "Unsown" vegetation.

They also suggest that, in assigning classes to these habitat types, "Unsown" vegetation, (which includes non-plantation woodland) will be of Class 1 or 2 significance; plantation woodland will be Class 2 or 3 and agricultural land will be of Classes 2 to 5 depending upon the associations of features that make up this land use. An alternative habitat approach is favoured by Helliwell (1969), in which he proposes a method for the rapid survey of the conservation value of large areas based on the diversity of habitat types; ranking these in order of biological richness rather than only considering the quality of individual plant communities. The gradings that he assigns to each "reflects the consensus of opinion among a number of conservation staff (of the Nature Conservancy) as to the relative weighting to be given to different habitat types". Coppock and Duffield (1975), in using a simplified system based on Helliwell's basic work, rank the following grades

of habitat in order of ascending ecological significance:

- Grade 1 - urban areas
- " 2 - improved agricultural land
- " 3 - moorland or coniferous woodland
- " 4 - broad-leaved woodland, marsh, bog, dunes or water
- " 5 - combinations of 1-4 above

Capability classifications such as those outlined above, based on the analysis of habitat quality, are emerging as the standard evaluation procedures for wildlife areas.

6.4.2 The Development of a Land Capability Classification for Nature Conservation

When considering the approach to be taken for the determination of land capability for nature conservation in the transect, it became apparent that both Helliwell's and Tubbs and Blackwoods' systems suffer from certain defects. Helliwell's system appears to permanently place agricultural land, with its many facets of ecological importance, in a low grade. The importance of agricultural land to wildlife has been much discussed in recent years at the various conferences convened to discuss the likelihood of reconciling agricultural and conservation interests; for example, at Silsoe in 1970 and Dinas in 1972, and the Nature Conservancy Council have recently published a booklet on the subject (N.C.C. 1977). The Tubbs and Blackwood system, on the other hand, allows the investigation of agricultural land to vary according to its inherent features but, unlike the Helliwell system, does not give the significance of water to wildlife enough weight. Both methods have advantages and form the basis for the point sample system devised which, because it is based on general habitat, is capable of application throughout the country.

6.4.2.1 Sample Methodology

Since both Helliwell's and Tubbs and Blackwoods' system are for grid square mapping, their methods have had to be modified to allow for the point sample design of the author's project which incorporates a built-in factor (as outlined in Chapter 4 on Page 65) to allow for the randomly selected points to be re-located in the event of them occurring on banks, in hedgerows, water bodies etc. As these features are of considerable importance in determining habitat diversity, a sampling strategy was devised whereby the area within a 25 m radius of the soil pit was used as a basis for investigating the ecological capability of a site.

6.4.2.2 Classification System

Five capability classes are recognised; the first two take into account the importance of "semi-natural" vegetation, woodland and water features. The third considers plantation woodland and moorland, and Classes 4 and 5 are purely devoted to agricultural land. However, agricultural land can, in certain circumstances, be of great significance to wildlife; way above the Class 4 or 5 definition and to take this into account the following method has been devised.

The determination of the non-agricultural elements of Class 1 to 3 land is relatively straightforward, but agricultural land is more difficult to analyse since it involves a consideration of field pattern, nature of field boundaries, cropping practice etc.

Tubbs and Blackwood (1971) assume that the relative value of agricultural land will depend upon the "extent of habitat diversity and that this will be reflected in the presence and amount of a number of definable features". These features are

grouped and evaluated by them for each zone according to a subjective method of scoring; defined as follows, and applied to Classes 2 to 5 of their system outlined on Page 187:-

- Features
- a) Permanent grassland.

b) Hedgerows and hedgerow timber.

c) Boundary banks, roadside cuttings and banks, roadside verges.

d) Park timber and orchards, other than those in commercial production.

e) Ponds, ditches, streams, and other watercourses.

f) Fragments of other unsown vegetation (including woodland)

Each feature, or group of features, is then assigned a score:-

<u>Score</u>	<u>Feature</u>
0	= None or virtually none present.
1	= Present (not a conspicuous feature of zone).
2	= Numerous (a conspicuous feature of zone).
3	= Abundant.

The capability classes for agricultural land are then determined as follows:-

<u>Class</u>	<u>Score</u>
2	15-18
3	11-14
4	6-10
5	0- 5

As the Tubbs and Blackwood scoring system was developed for a grid square sample, using a presence/abundance scoring system for features in a zone, it requires a minimum of five abundant features in any one zone to warrant a Class 2 classification. This is too high for a point sample analysis. In addition, on such a basis, size, as well as abundance of a particular feature, is a desirable feature to include in an evaluatory system.

To overcome these problems, a new scoring system has had to be devised which takes three abundant features in each 25 m radius about the sample pit as the minimum for Class 2. To take the size of a feature into account a subjective judgement of "small" - "medium" - "large" has had to be used, with a minimum of three large-sized features in each 25 m radius about the sample pit as a minimum for Class 2. Thus, the scoring is as follows, and is applied to Classes 2 to 5.

<u>Score</u>	<u>Feature</u>
0	= None or virtually none present.
1	= Present, but small in size.
2	= Numerous or medium in size.
3	= Abundant or large in size.

<u>Class</u>	<u>Score</u>
2	9+
3	6-9
4	3-6
5	0-3

A final problem in capability classification for wildlife is land falling into the category of derelict or disturbed. The nature and cause of such areas are so completely interrelated that it is extremely difficult to apply anything other than a purely subjective analysis of their wildlife quality, which may be considerable. Such land is, therefore, graded in Classes 2 to 5 according to such a subjective judgement.

The final classification scheme for the system as a whole is as follows:

- Class 1 "Unsown" or semi-natural vegetation; deciduous woodland; marsh or bog; rivers or lakes or other important water features.
- Class 2 "Unsown" or semi-natural vegetation; mixed woodland; marsh or bog; ponds, ditches and streams; agricultural land scoring 9+.
- Class 3 Coniferous plantation woodland or moorland; agricultural land scoring 6-9.
- Class 4 Agricultural land scoring 3-9.
- Class 5 Agricultural land scoring 0-3.

6.4.3 Transect Land Capability Classification for Nature Conservation

The results of the capability system applied to the transect sites are discussed in this section. The classes are shown in Figure 6.18 and Table 6.22. See Plates 6.5 and 6.6.

Table 6.22 Land Capability Classes for Nature Conservation by Physiographic Unit (% Sites)

Physiographic Unit	Class 1	Class 2	Class 3	Class 4	Class 5
1	0.0	12.5	0.0	50.0	37.5
2	20.0	20.0	0.0	60.0	0.0
3	50.0	50.0	0.0	0.0	0.0
4	4.5	0.0	18.2	31.8	45.5
5	0.0	0.0	50.0	33.3	16.7
6	0.0	25.0	16.7	25.0	33.3
7	0.0	0.0	16.7	0.0	83.3
Total Units	7.0	11.3	15.5	26.8	39.4

The fact that 80.3% of all the sites were under agricultural production when surveyed is reflected in the capability classes assigned. Just under two thirds are graded as Class 4 or worse, with only 18.3% graded as Class 2 or better. Class 5 (the poorest for wildlife) alone accounts for 39.4%.

Fig6.18 Land Capability Classes for Nature Conservation

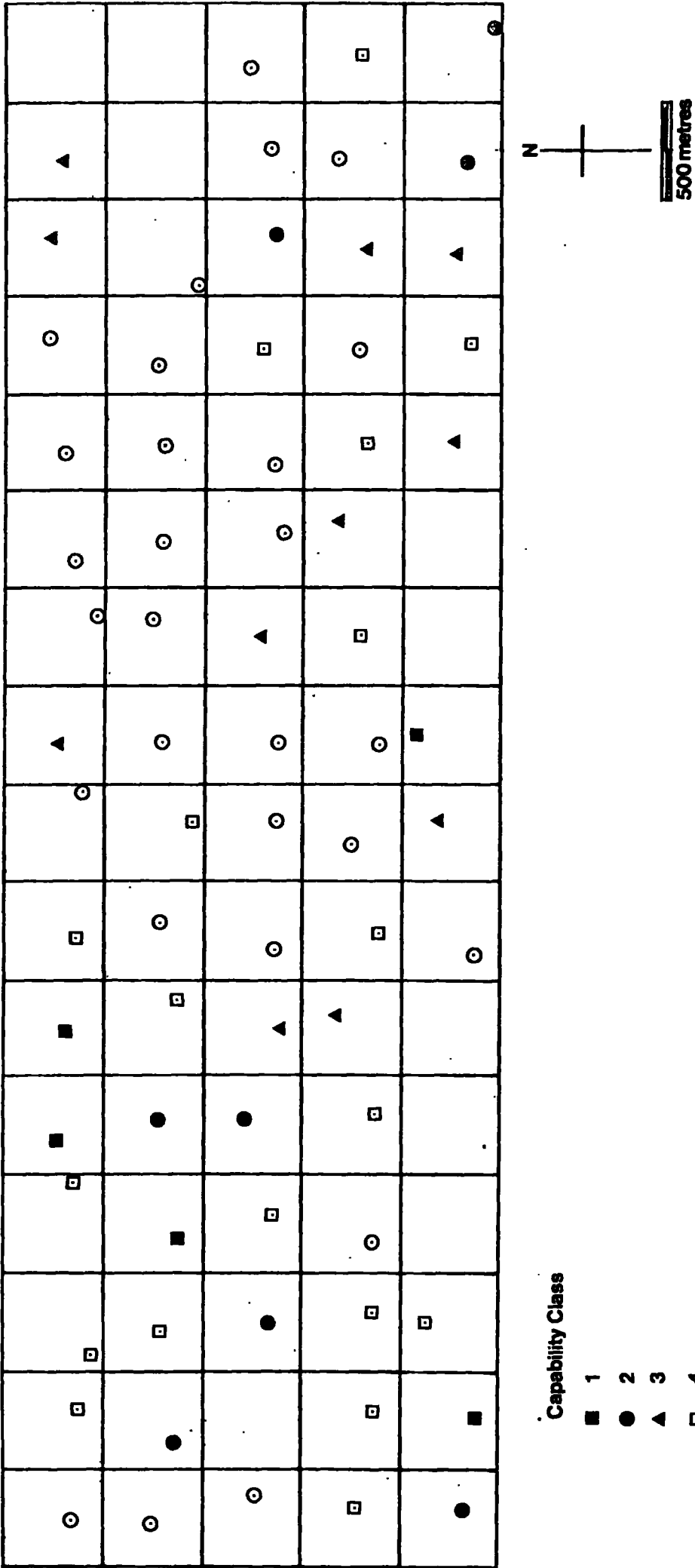




Plate 6.5 Class I site for nature conservation in the River Wear Gorge and Floodplain (Unit 3). Note presence of deciduous woodland, water and luxuriant vegetation in combination to give the high score.



Plate 6.6 Agricultural sites such as this, with a combination of permanent grass, hedges and hedgerow trees can form valuable wildlife habitats. This example, of Class 3 standard, is in Unit 4 near Ramside.

Six Physiographic Units have Classes 4 and 5 of greater or equal proportion than Classes 1 + 2 + 3 with the Lowlands West of the Wear (Unit 1) and the Permian Plateau (Unit 7) having the greatest proportions; 88.8% and 83.3% respectively, with the sites on the plateau all being in the lowest class.

The most significant area for nature conservation is the Wear Gorge and Floodplain (Unit 3), where the presence of deciduous woodland, scrub and luxuriant vegetation, coupled with the river itself, give a high score. The sites in this area allocated to Class 1 are all associated with deciduous woodland, with the two under agriculture (20 and 61 under permanent grass) located next to the river, scoring enough on the agricultural point system to be graded as Class 2. The other Class 2 site (31) is in the Gorge itself and is associated with mixed woodland.

The slopes immediately above the river (Unit 2) score well also, with 40% of the sites being classified as Class 1 and 2, whereas the Lowlands East of the River Wear (Unit 4), with a predominantly mixed agricultural land use, have only one site grading better than Class 3 and nearly one half (45.5%) in the lowest grade.

Towards the limestone in Coalford Vale (Unit 5), the wildlife significance is proportionally greater than in the lowlands outlined above; a reflection of the presence of the streams flowing through the area and a permanent grass land use.

The Permian Escarpment (Unit 6) grades consistently through Classes 2 to 5, reflecting the variable land use of the zone, whereas the Permian Plateau, which is devoted predominantly to arable agricultural use is of least significance. One quarter of the sites on the escarpment are of Class 2, being mainly associated with mixed woodland (Sites 42,70) or scrub, with some coniferous woodland (Site 71).

As the agricultural locations assume so great an importance it is worthwhile looking at them in a little more detail.

Table 6.23 Land Capability Classes of the Agricultural Sites

<u>Capability Class</u>	<u>% Agricultural Sites</u>
2	3.5
3	14.0
4	33.3
5	49.1

As can be seen from Table 6.23, 82.4% of the sites are graded in the bottom two classes, with 14.0% in Class 3. The Class 2 sites of the Wear Gorge and Floodplain account for only 3.5% of the total.

The most significant agricultural features, from a wildlife standpoint, are listed in Table 6.24. This shows that hedgerows and permanent grass are of primary importance in the transect.

Table 6.24 Agricultural Features

<u>Agricultural Feature</u>	<u>% Agricultural Sites</u>
Hedges and hedgerow trees	24.6
Permanent grass	24.6
Trees	21.1
Boundary banks	10.5
Ponds	1.8
Streams	1.8
Roadside verges	1.8
Other "unsown" vegetation	1.8

6.4.4 Conclusions

The advantages of the Tubbs and Blackwood and Helliwell capability methods have been embodied in a parametric point sample capability system, with particular emphasis being placed on the importance of agriculture to nature conservation.

The system, which is capable of interpretation from aerial photographs, allows large areas to be covered very rapidly and appears to give significant weighting to the vagaries of the various land uses. Research, however, needs to be done on the method of scoring the features in a particular zone and into the development of a less subjectively based system. In addition, because of the point sample basis, small areas of interest, (water or woodland for example) may be overlooked, and an increase in survey radius about the sample pit would alleviate this problem to a certain extent.

When the system is applied in the transect, the predominant agricultural land use is reflected in the dominance of low capability classes, but, unlike other systems, the accumulative significance of agriculture to nature conservation is not ignored. Areas of high nature conservation interest do occur, however, in well defined areas, and are especially associated with water bodies.

6.5 Land Capability Classification for Housing Development

6.5.1 Introduction and Problems of a Housing Capability Analysis

No definitive attempt at land classification for residential development has been undertaken in Britain, but in the United States the recent work of Fabos and Caswell (1977) has produced a classification for housing of a specific nature in the New England - North Atlantic region as outlined in Chapter 3 on Page 51. However, the problems involved in classifying land for residential development are similar in both countries, and as is stated by the American researchers "it should be noted that as yet the direct and indirect costs involved in overcoming natural physical constraints to development are not well defined. In this area particularly, much more work is needed if planner - designers are to properly assess the characteristics which in practice contribute to and detract from physical development suitability".

Fabos and Caswell list eight physical parameters of significance to the construction of "single-family wood-framed houses constructed with basements and developed at an average density of two dwelling units per acre." These are "slope, depth to bedrock, depth to water table, soil drainage, soil bearing capacity, stoniness, erodibility and quality of topsoil". The significance of these characteristics, it is stated, lies not only in the initial financial costs to the developer, and eventually to the home-buyer in overcoming natural constraints, but in the fact that the eventual home-owner may bear considerable expense himself due to the exigencies of repeated water drainage, frost-heave, and other problems of poor site selection which necessitate post-construction site improvements.

Unlike the agriculture, forestry and nature conservation classifications which have been considered on national lines for the reasons stated, a meaningful housing capability classification cannot be looked at on a national basis. Each local district authority is a housing authority, and as such has a statutory duty to see that its inhabitants are housed on the "best" sites within its area; a duty shared by the strategic County authorities. In addition, private developers, will be guided by market forces within certain defined areas of demand which will vary from area to area. The capability classification for application in the transect which follows is, as a result, a local rather than a national scheme.

6.5.2 The Development of a Land Capability Classification for Housing Development

6.5.2.1 Problems of Scale

Before a classification scheme for housing can be attempted, the scale and type of such development must be defined. The most frequently encountered and important form of housing is the public or private estate, with dwellings at a density of about twenty two to the hectare. For the purpose of strategic planning single house sites can be ignored.

Whilst it is obviously essential for a detailed site survey to be made for any area chosen for housing, at a strategic planning level, which aims merely to identify broad areas suitable for development, the information required to make such a decision is less demanding; The parameters chosen for the system are, therefore, selected with this in mind and are presented in the next section.

6.5.2.2. Parameters

The threshold values for housing development have been discussed in detail in Chapter 3, Section 3.4.4.

Angle of slope increases social and economic costs and difficulty of construction. Likewise, the depth to in situ rock affects construction to a great extent, although threshold levels tend to come from "rule of thumb" experience.

The costs associated with the variables of depth to water table and soil drainage tend, in practice, to be overlapping ones (Fabos and Caswell, 1977). Although both are included in their analysis at the outset, only the higher cost parameter, according to site, is included in the ultimate classification. Water table figures are better indicators of drainage problems than soil drainage information, but as detailed depth to water table data are not available for the transect, and the agricultural nature of most of the sites precluded experiments to be made, only soil drainage assessments can be used for the classification.

Although the bearing capacity of a soil is a desirable parameter at detailed survey level, at a strategic level the time-consuming nature of such an engineering analysis makes it undesirable to include in the transect system. The stoniness of a soil, however, is easily determined and affects excavations and trenches, grading and landscaping. On the other hand, there is no information in this country on the problems associated with the erodibility of a soil. Certain thresholds are available for the United States but are of little use in Gt. Britain where there are entirely different rainfall/erosion regimes. Much research is needed on this point and, regretfully, erosion has had to be left out of the analysis. The quality of the topsoil, however, is included, although it will have no affect on whether an estate will be built or not; just altering the gradings.

Apart from the above physical, soil and slope characteristics, certain climatic and site location factors are included in the scheme. A consideration of the problems and advantages of aspect and site exposure is vital for the choice of a good location, despite the fact that in lowland areas in particular, where the competition for land is intense, they tend to be ignored.

The liability of a site to flood or subside is of fundamental importance to capability analysis and together with the inclusion of a site limitations factor, similar to that included in the agricultural analysis of Section 6.1, it completes the list of parameters.

1. Angle of slope

A threshold slope of 8.1° as outlined for general housing development (Williams, 1972), is used.

2. Depth to in situ rock

The two threshold depths of 61 and 153 cm, as defined by Fabos and Caswell (1977), are included in the classification. As the depth to bedrock was only determined in the transect to 100 cm, and as the depth of the drift cover is in excess of 1.5 m over most of the area, a depth to in situ rock is assumed to exceed 153 cm, if not encountered before 100 cm.

3. Soil drainage

The soil drainage classes of the Soil Survey (1960) are used to determine the overall status of the soil profile.

4. Soil stoniness

The stoniness of the soil profile to 60 cm is used to indicate the problems associated with this parameter.

5. Topsoil quality

There is no quantitative definition of a "good quality" topsoil as there are different types of landscaping and garden plants to cater for most conditions.

However a good garden "loam" with a not too acid or alkaline pH is probably as good an indicator as any. For the classification, a loamy topsoil (loam, sandy loam, silt loam) with a neutral pH will determine a "good" quality topsoil as opposed to one of "poor" quality, and will be included in the Class 1 definition. It is considered that this parameter, with its various combinations of characteristics defining quality, is not of sufficient importance to affect housing development, other than for Class 1 land. Topsoil can always be brought into a site at reasonable cost, depending on delivery distance.

6. Aspect

Combination of the aspect/slope classes, as utilised by Weddle (1973) and Williams (1972), are used to achieve the benefits inherent in both systems. ESE - WNW slopes, in receiving the most benefit from sunlight, and all aspects with slopes of less than or equal to 2.9° will not limit development. WNW - NNW or ENE - ESE aspects with slopes of greater than 2.9 are considered as less desirable, and NNW - ENE aspects of over 2.9 even more so.

7. Site exposure

The effects of site exposure to the elements on housing development are measured by using the Topex classes as outlined for the forestry capability classification in Section 6.2. This is an objective assessment of exposure rating and is the only one available at present. Exposures of "moderately sheltered" and upwards will affect class.

8. Liability to flooding

The liability of land to flood has long been a basic factor of concern to planners in their investigations of land unsuitable for housing. Any degree of threat is considered a negative characteristic.

9. Liability to subsidence

The effects of mining subsidence on housing development are often catastrophic. The types of subsidence risk to be encountered in the transect area have been discussed in Chapter 5, Section 5.7. Because most of the area has been underworked by coal mining activity in the past, it could be argued that no part is free from the potential effects of subsidence. However, the most "spectacular" and damaging subsidence is that experienced on the Magnesian Limestone and, as this is a local classification, the effects of subsidence in the rest of the transect, which are very difficult to quantify anyway, are not considered.

10. Site limitations

The inclusion of a site limitations variable, in common with that included in the agricultural classification, is to take account of the point sample nature of the analysis. A point might lie in an area so restricted by physical landform characteristics, for example, in the River Wear Gorge, that development as envisaged is just not possible on this factor alone.

6.5.2.3 Classification System

Four broad classes are defined:

- Class 1 Suitable - having no limitations to residential development as defined.
- Class 2 Conditionally Suitable 1 - having some limitations to development which with certain modifications will become suitable for use (but not ideal).
- Class 3 Conditionally Suitable 2 - having more limitations to use than Class 2, but which with additional measures will become moderately suitable for use, though not offering as "pleasing" an environment as Class 2.
- Class 4 Unsuitable - being unsuitable for housing development of the type under analysis.

6.5.2.4 Class Thresholds

Class 1

- Angle of slope : 0 - 8.1°
- Depth to insitu rock : 153 cm +
- Soil drainage : Well to moderately well drained.
- Soil stoniness : Stoneless to very rare stones.
- Topsoil quality : Good (loamy topsoil with neutral pH).
- Aspect : ESE - WNW, or all other slopes less than or equal to 2.9°.
- Site exposure : Topex zone of very sheltered to moderately sheltered.
- Liability to flooding: None.
- Liability to sub-
sidence : None (within limits of transect as defined in 6.5.2.3.).
- Site limitations : None.

Class 2

- Angle of slope : 0 - 8.1°
- Depth to in situ rock: 153 cm +
- Soil drainage : Imperfectly drained.
- Soil stoniness : Slightly stony.
- Topsoil quality : Poor.
- Aspect : WNW - NNW or ENE - ESE
- Site exposure : Topex zone of moderately sheltered.
- Liability to flooding: None.
- Liability to sub-
sidence : None (within limits of transect as defined in 6.5.2.3.).
- Site limitations : None.

Class 3

Angle of slope	: 0 - 8.1°.
Depth to in situ rock	: 61 cm - 153 cm.
Soil drainage	: Poorly drained.
Soil stoniness	: Stony to very stony.
Topsoil quality	: Poor.
Aspect	: NNW - ENE slopes of between 2.9° - 5.0°.
Site exposure	: Topex zone of moderately exposed.
Liability to flooding	: None.
Liability to subsidence	: None (within limits of transect as defined in 6.5.2.3).
Site limitations	: None.

Class 4

Angle of slope	: Greater than 8.1°.
Depth to in situ rock	: 0 - 61 cm.
Soil drainage	: Very poorly drained.
Soil stoniness	: Extremely stony to stones or rock dominant.
Topsoil quality	: Poor.
Aspect	: NNW - ENE slopes of greater than 5.0°.
Site exposure	: Topex zone of very exposed to extremely exposed.
Liability to flooding	: Present.
Liability to subsidence	: Present.
Site limitations	: Present.

6.5.2.5 Subclass Notation

Eight subclasses are recognised:

- g to denote angle of slope limitations.
- d to denote depth to in situ rock limitations.
- w to denote soil drainage limitations.
- s to denote soil stoniness and topsoil limitations.
- c to denote aspect and site exposure limitations.
- f to denote a liability to flooding.
- m to denote a liability to mining subsidence.
- b to denote site limitations.

The dominant subclass takes priority, but if the subclasses are of equal weight the following priority is suggested:

b m f g d w c s

6.5.3 Transect Land Capability Analysis for Housing Development.

The results of applying the capability classification devised to the transect sites are presented in this section.

6.5.3.1 Discussion of Parameters

The seven sites with an angle of slope limitation are shown in Figure 6.19 and are distributed about the transect in Physiographic Units 1, 2, 5 and 6. Seven sites also, show depths to bedrock of up to 61 cm, the threshold for Class 4, and are located entirely on the Magnesian Limestone in Unit 6. One site (66) shows a depth of between 61 and 153 cm, the Class 3 threshold. Figure 6.20 shows the distribution of these sites.

As the soil drainage thresholds used for housing are the same as those used for the agricultural classification, the distribution of sites with such limitations is shown in Figure 6.1 on Page 144. Those with soil stoniness limitations are indicated on Figure 6.21 which shows a slight increase in stone content eastwards.

Over a third (39.4%) of sites have good quality topsoils (Figure 6.22) with the centre of the transect in Physiographic Unit 4 having the major conglomeration with an adequate texture and pH.

Figure 6.23 shows the aspect and exposure limitations, which cover just over one half (52.1%) of all sites in some form or another, with the Permian Escarpment and Plateau (Units 6, 7) and Lowlands West of the River Wear (Unit 1) being particularly affected.

Sites subjected to flooding are the same as for the agricultural classification in Figure 6.1 on Page 144, and those with a serious subsidence risk are all located on the Magnesian Limestone (as indicated on Page 197) and are shown in Figure 6.24. Site limitations (subclass b) are the same as those for agriculture, defined in Section 6.2.6.6. on Page 159.

6.5.3.2 Land Capability Classes

The capability classes are shown in Figure 6.25 and Tables 6.25 and 6.26. See Plates 6.7 and 6.8.

Table 6.25 Land Capability Classes for Housing by Physiographic Unit (% Sites)

	Suitable	Conditionally Suitable		Unsuitable	
Physiographic Unit	Class 1	Class 2	Class 3	Class 4	Class 1 + 2 + 3
1	0.0	0.0	100.0	0.0	100.0
2	0.0	0.0	60.0	40.0	60.0
3	0.0	0.0	0.0	100.0	0.0
4	0.0	4.5	95.5	0.0	100.0
5	16.7	0.0	33.3	50.0	50.0
6	0.0	0.0	33.3	66.7	33.3
7	0.0	0.0	0.0	100.0	0.0
Total Units	1.4	1.4	52.1	45.1	54.9

Fig6.19 Sites with Angle of Slope Limitation-Housing (subclass g)

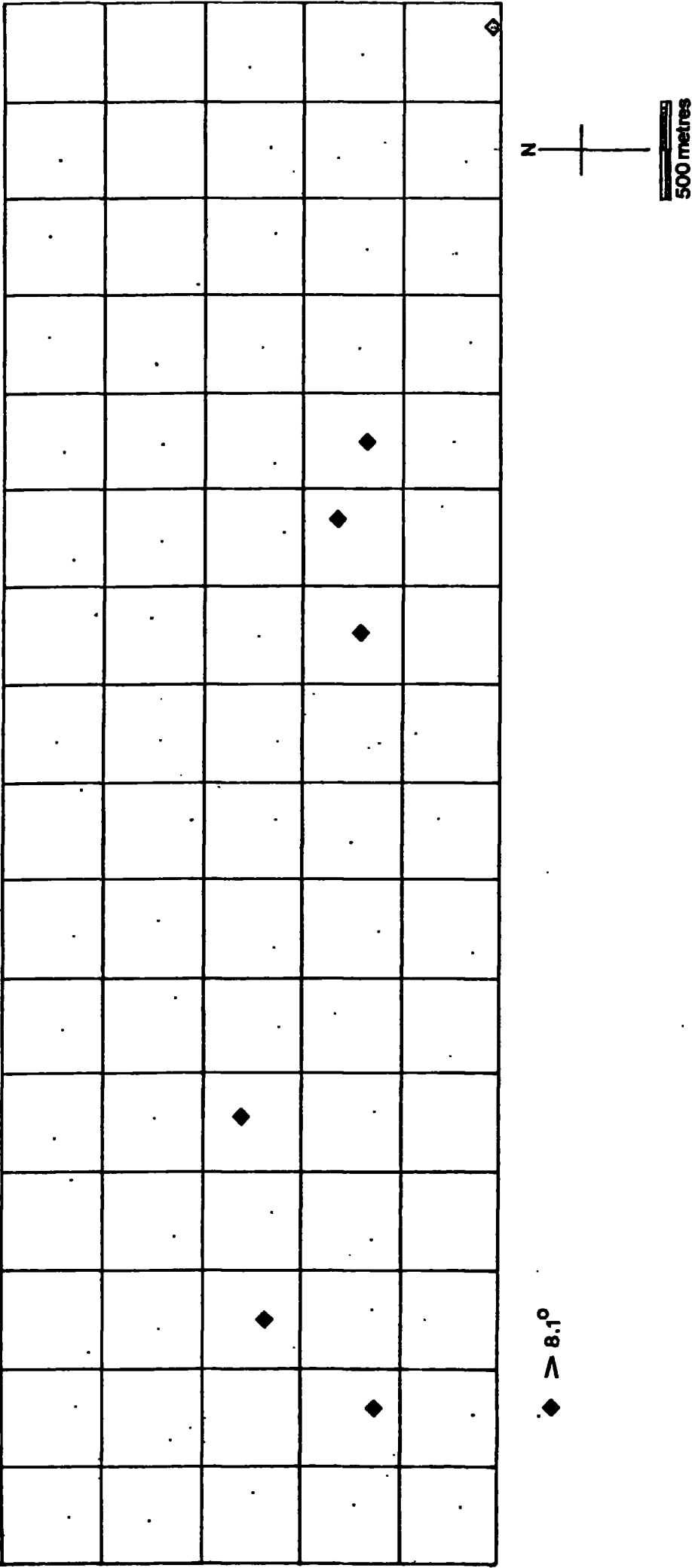


Fig6.20 Sites with Depth to in situ Rock Limitations (subclass d)

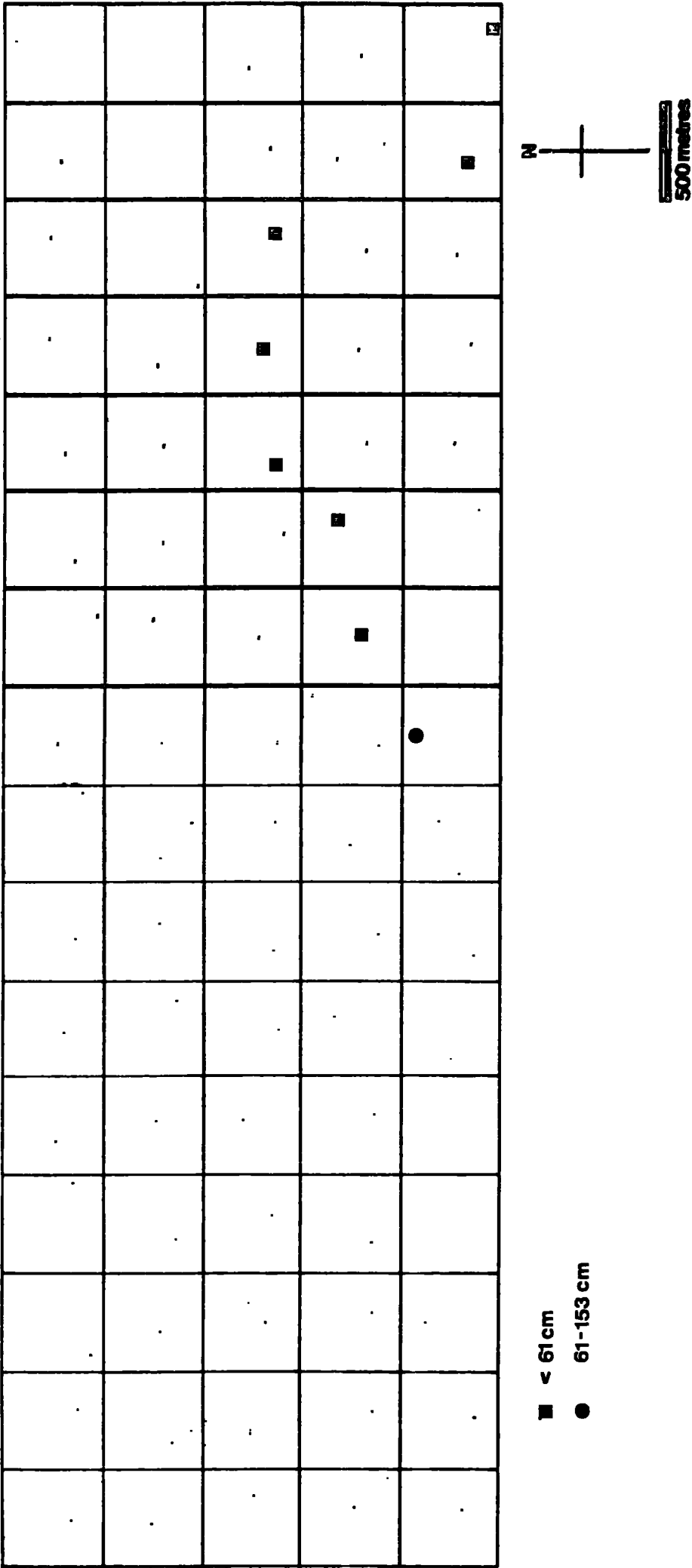


Fig 6.21 Sites with Soil Stoniness Limitations - Housing <subclass s>

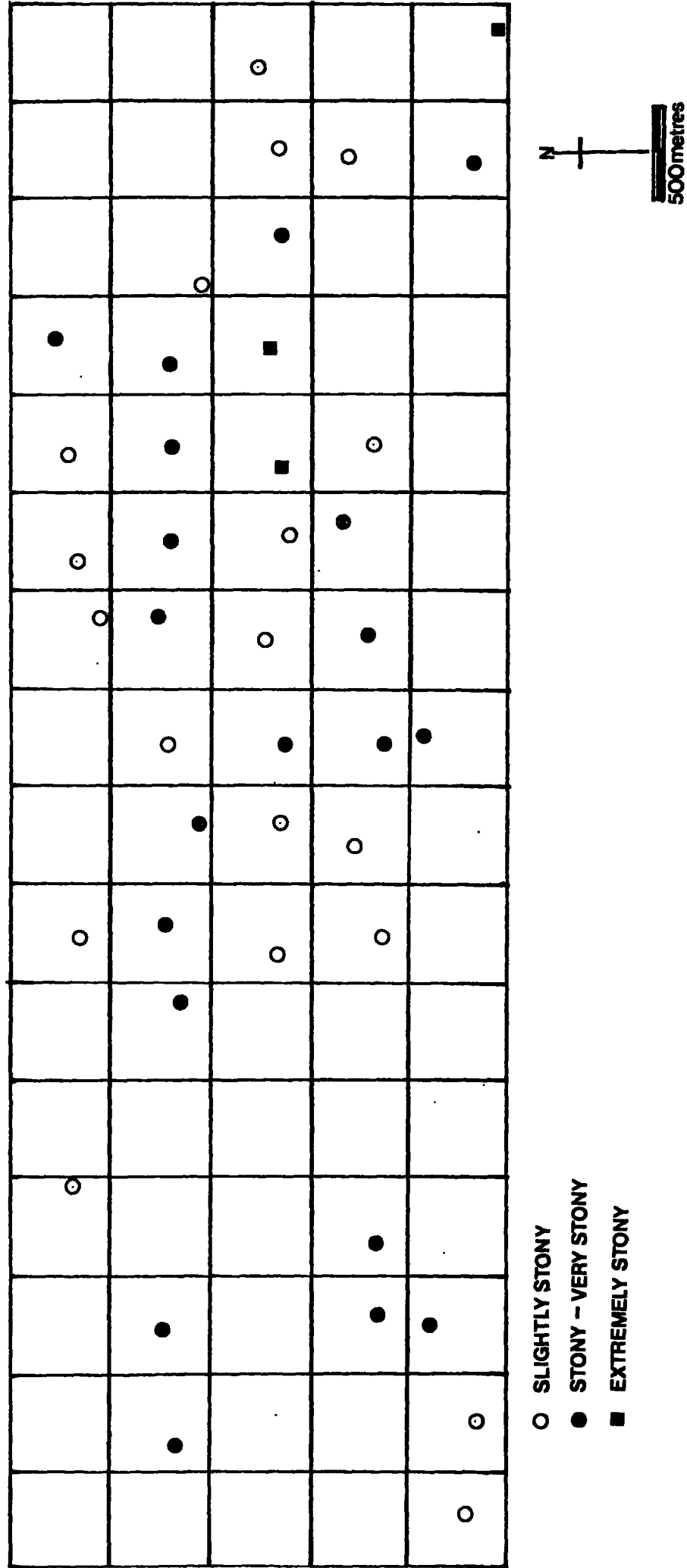


Fig6.22 Sites with Topsoil Quality Limitations-Housing (subclass s)

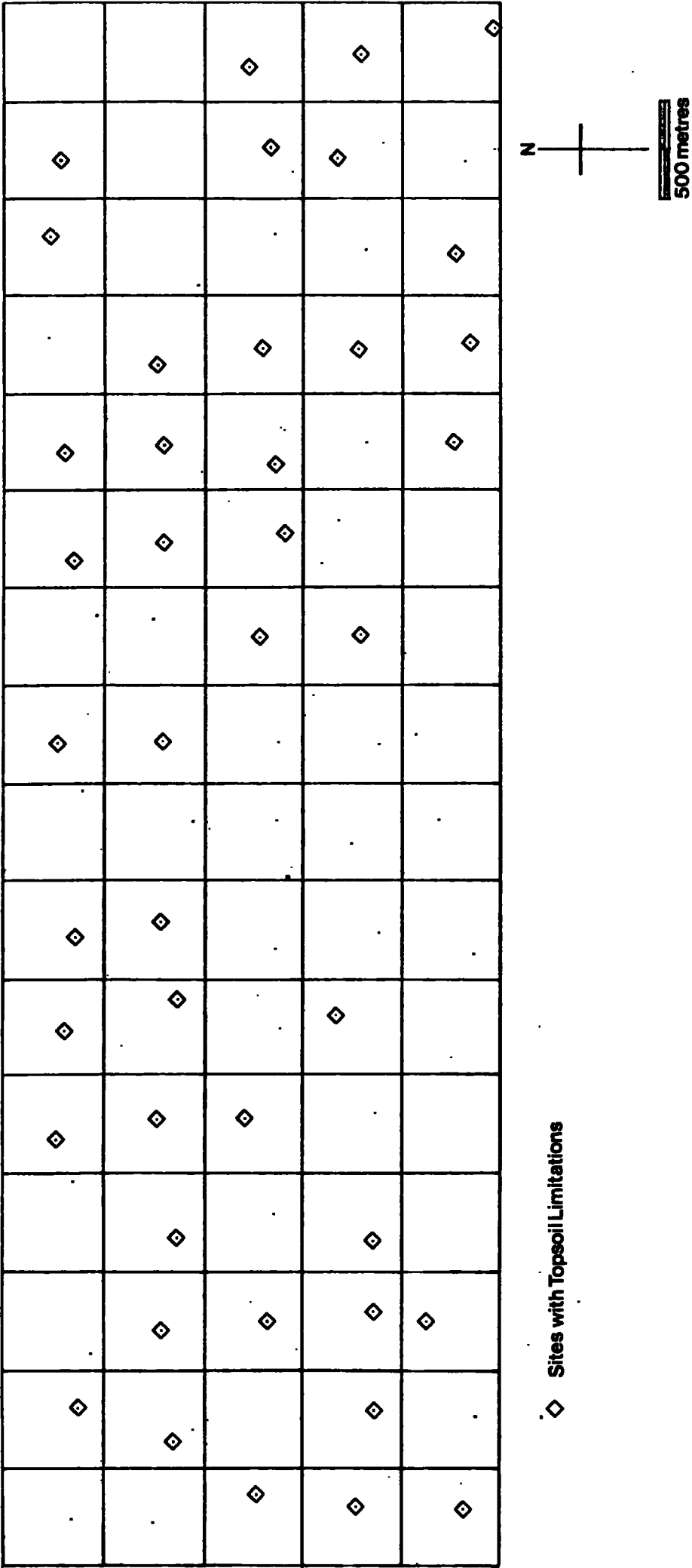


Fig6.23 Sites with Aspect and Exposure Limitations - Housing (subclass c)

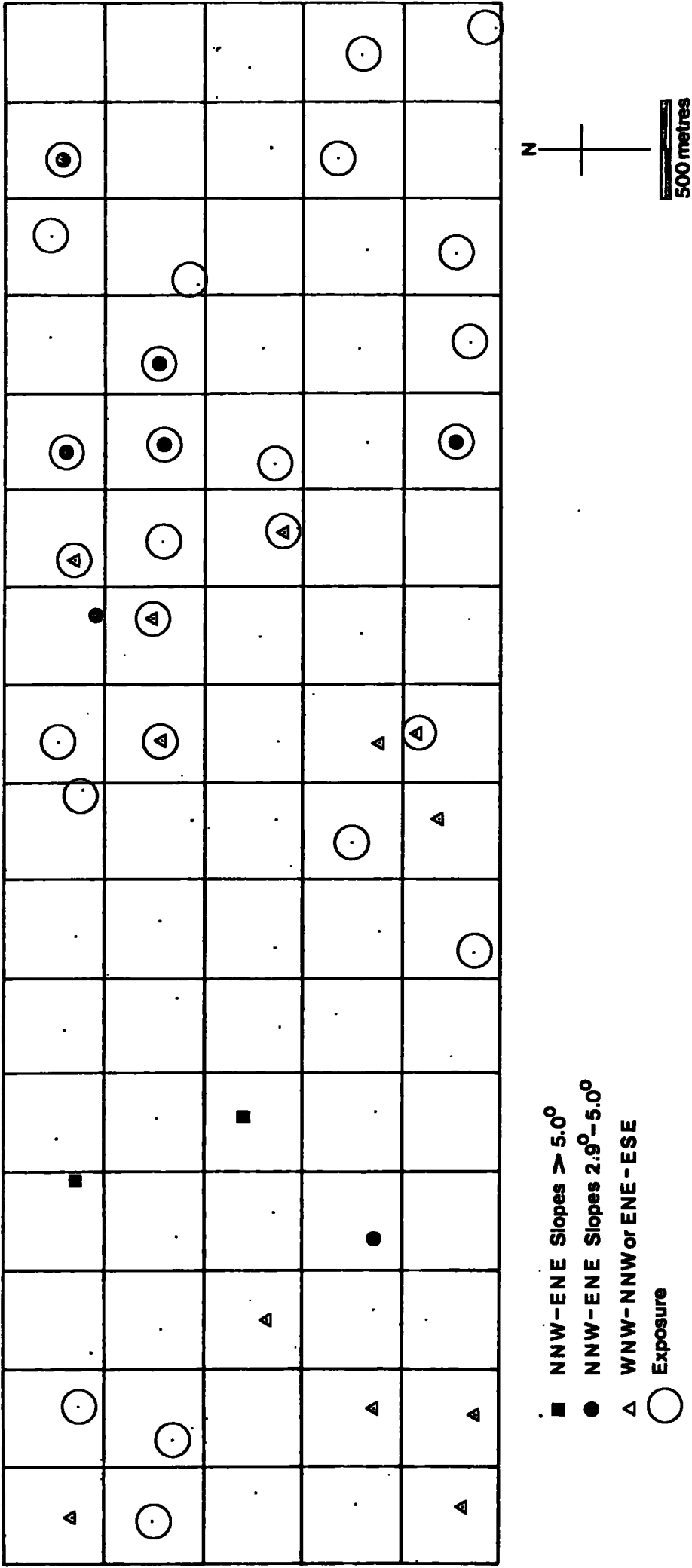


Fig6.24 Sites with Liability to Mining Subsidence Limitation-Housing (subclass m)

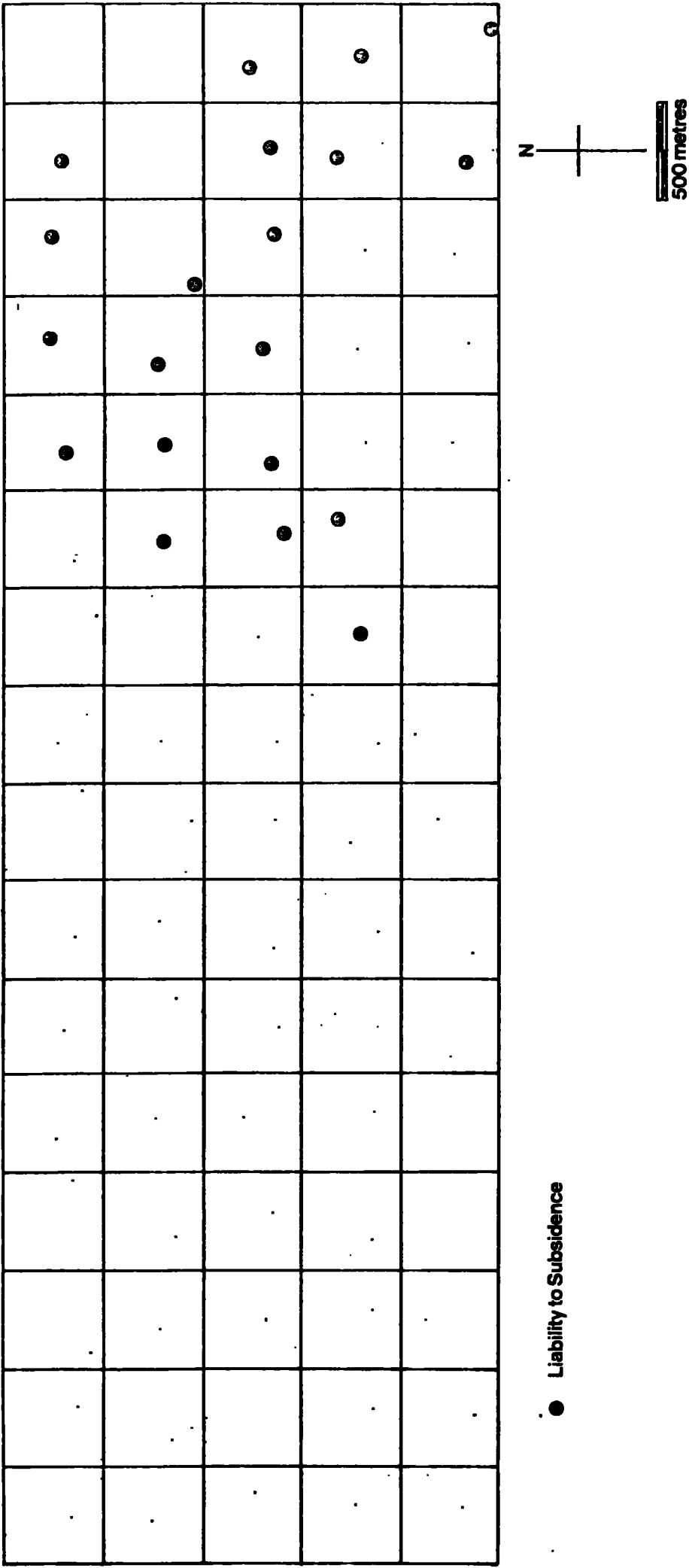


Table 6.26 Land Capability Classes for Housing

Site	Capability Class	Site	Capability Class
1	3 wc	37	3 s
2	3 wcs	38	3 ws
3	3 w	39	4 mcs
4	4 cs	40	4 mds
5	4 bfs	41	4 mds
6	3 ws	42	4 mds
7	3 ws	43	4 mws
8	3 wc	44	4 mws
9	3 cs	45	3 ws
10	3 cws	46	4 gwcs
11	3 wcs	47	3 ws
12	4 mcws	48	3 wcs
13	4 ms	49	3 w
14	4 mwcs	50	3 ws
15	4 mwcs	51	3 ws
16	3 c	52	3 cws
17	3 wcs	53	3 swc
18	3 ws	54	4 mds
19	4 bfws	55	4 mgds
20	4 bfs	56	4 gwr
21	3 s	57	3 ws
22	3 sw	58	1
23	3 ws	59	4 mcws
24	3 wcs	60	4 mcws
25	3 wcs	61	4 fwcs
26	4 mcws	62	4 bfwcs
27	4 mcws	63	3 ws
28	4 mcws	64	3 wc
29	4 mwcs	65	3 wc
30	3 ws	66	3 dcs
31	4 gwcs	67	3 wcs
32	3 w	68	4 fwcs
33	4 bfgwcb	69	4 fwcs
34	3 w	70	4 bmfd
35	3 ws	71	4 mgdcs
36	2 ws		

Fig6.25 Land Capability Classes for Housing Development

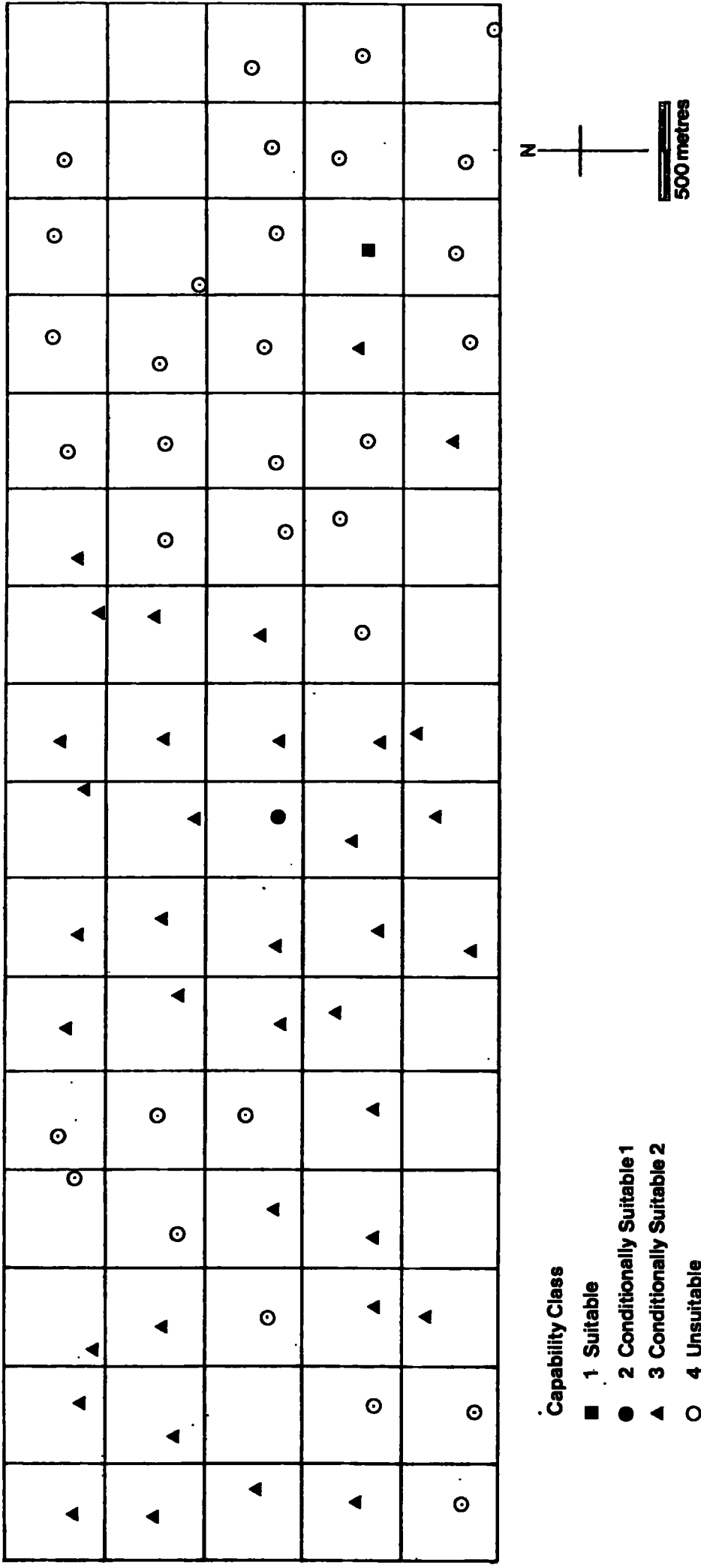




Plate 6.7 Class 3ws land for housing, with poor drainage and stoniness limitations, near Site 7 at Moorhouse (Unit 4)



Plate 6.8 Although flat, the effects of mining subsidence and exposure relegate this area near Hetton le Hill on the Permian Plateau (Unit 7) to Class 4mc for housing.

Only one site (58 in Unit 5) is classified as suitable (Class 1) for housing, and similarly, only one (Site 36 in Unit 4) is placed in Class 2. With 53.5% in Classes 2 or 3, just over one half of sites are considered as conditionally suitable. The remaining 45.1% are of Class 4 - unsuitable for development.

The Lowlands West and East of the River Wear (Units 1 and 4) are the most suitable areas overall, a pattern which reflects the actual location of housing in the transect.

6.5.3.3 Dominant Subclass

Figure 6.26 and Table 6.27 show the dominant subclasses for each capability class.

Table 6.27 Dominant Subclass by Capability Class (number of sites)

Class	None	Subclass							
		b	m	f	g	d	w	c	s
1	1								
2							1		
3						1	28	4	4
4		6	19	3	3			1	
Total Sites	1	6	19	3	3	1	29	5	4
% Total Sites	1.4	8.5	26.8	4.2	4.2	1.4	40.8	7.0	5.6

Soil drainage (w) is the major subclass limitation at 40.8% of sites, and, as poor profile drainage is the predominant status for this category, the majority so affected are placed in Class 3.

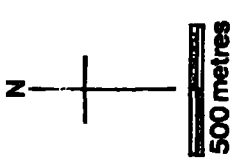
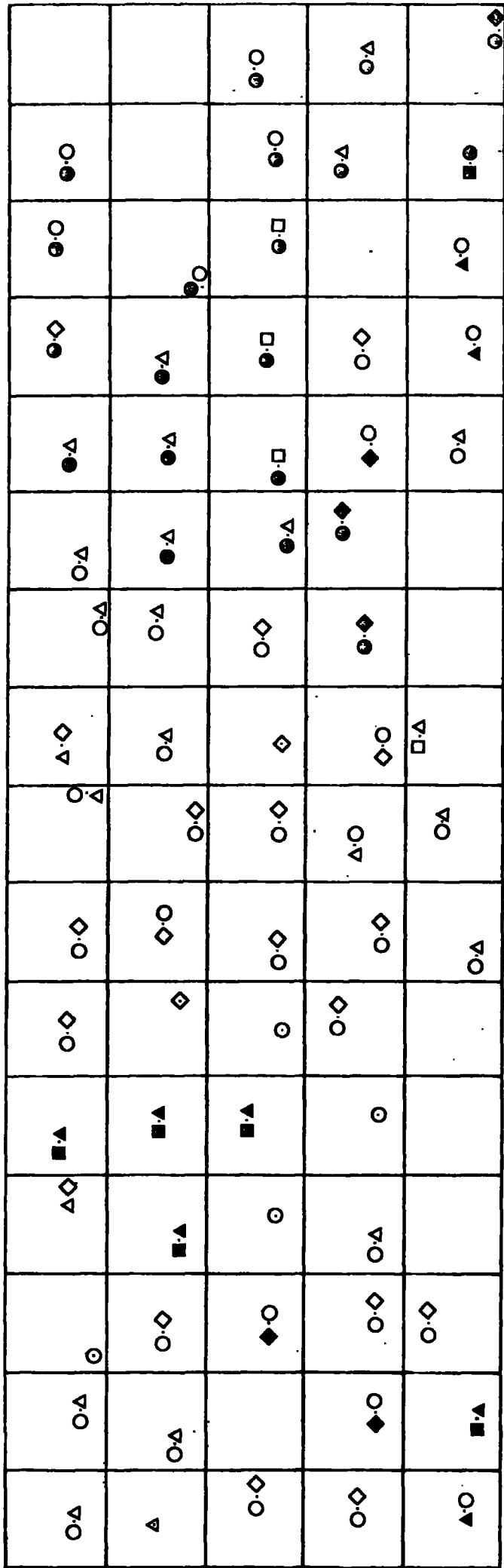
The second dominant subclass is liability to mining subsidence (m) at just over a quarter of sites (26.8%), automatically assigning them to Class 4. The remaining subclasses do not rise in importance above 8.5%.

Table 6.28 shows the dominant subclasses among the Physiographic Units, and indicates that Units 1, 2 and 4 have soil drainage as the dominant limitation. On the Permian Escarpment (Unit 6) and Plateau (Unit 7) subsidence is the dominant variable, whilst in the Wear Gorge and Floodplain (Unit 3) site limitations (b) are the most significant. Soil stoniness and topsoil limitations (s) are only found in the Lowlands East of the River Wear (Unit 4).

6.5.3.4 Combinations of Subclasses

Although twenty seven combinations of subclasses are recognised (Table 6.29), two combinations with soil drainage, ws and wcs, account for 31.0% of all sites. Over half (52.1%) the total are affected by climatic factors somewhere in the classifications with site exposure (mostly moderate) being the most significant, particularly on the Permian outcrop. The lowlands East of the River Wear (Unit 4) are the most sheltered, but overall the transect presents an exposed and windswept appearance.

Fig6.26 Land Capability Subclasses for Housing Development



Subclass

- b
- m
- ▲ f
- ◆ g
- d
- w
- Δ c
- ◇ s

Table 6.29 Combinations of Subclasses (number of sites)

Class	w	c	s	ms	vs	wc	cs	sv	bfr	mds	mvs	mcs	gvs	dcs	wcs	cvs	avc	bavs	mgds	mavs	fvcs	gvcs	bmfds	bfvcs	mgdcs	bfgvcs	None
1																										1	
2					1																						
3	4	1	2		13	4	1	1						1	7	2	1										
4				1			1		1	4	2	1	1					1	1	3	6	3	2	1	1	1	
Total Sites	4	1	2	1	14	4	2	1	2	4	2	1	1	1	7	2	1	1	1	3	6	3	2	1	1	1	
Σ Total Sites	5.6	1.4	2.8	1.4	19.7	5.6	2.8	1.4	2.8	5.6	2.8	1.4	1.4	1.4	9.9	2.8	1.4	1.4	1.4	4.2	8.5	4.2	2.8	1.4	1.4	1.4	

6.5.3.5 Capability Class and Soil Type

As shown in Table 6.30, the disturbed soil group, typical brown earth, cambic stagnohumic gley and cambic stagnogley soils are the most suitable for housing development, although wetness limitations assign the vast majority to Class 3. The stagnogleyic brown earth subgroup is affected by mining subsidence to a considerable extent, as these soils are located to a notable degree on the Magnesian Limestone. The least suitable soils for housing are the rendzina, brown calcareous and alluvial subgroups.

6.5.4 Conclusions

The capability analysis for housing development proposed, although suffering from the lack of quantitative threshold levels, appears to give a realistic assessment of potential.

By using fundamental soil and environmental information as a basis, considerable time is saved at the strategic planning level by the omission of the time consuming analysis involved in assessing engineering properties of the sites. This more detailed investigation work can be carried out once the possible housing locations have been identified.

The approach adopted permits a rapid assessment of overall potential for housing development in the transect area. A further advantage of the scheme is that it allows attention to be focussed on the areas of higher class without the initial value judgements on desirability or not of specific locations entering the decision making process.

6.6 Land Capability Classification for Industrial Development

6.6.1 Introduction and Problems of An Industrial Capability Analysis

There appears to be no capability classification system devised for industrial use. The METLAND study of Fabos and Caswell (1977) assumes that if all areas for residential development are identified, then among these a sufficient number of sites for industrial use can also be found. In addition, the wide range of building materials available and the differing types and scale of industrial developments make the selection of parameters for a capability analysis difficult.

In line with the housing analysis, a local rather than a national system is used, for similar reasons. For the best use of resources it is desirable that people work relatively near to their work and that locally suitable sites be found for industrial development.

6.6.2 The Development of a Land Capability Classification for Industry

6.6.2.1 Problems of Scale

Prior to the development of a classification system the nature and scale of industrial activity has to be defined and certain assumptions made. For the author's system these are as follows:

- i) No specific building type will be considered.
- ii) No engineering variables will be included.

- iii) to allow for a strategic industrial classification, not taking specific types into consideration (chemical processing for example), the system will be devised for general "large-scale" and "small-scale" development, with the significant variable between the two being angle of slope.

Having defined the desirability or not of industrial development, on a physical basis, it will be up to a future detailed investigation to see whether a particular site is suitable for a particular industry. This approach to planning industrial development, with locations being allotted without an actual type of industry being considered, is the general method of planning practice and is unavoidable.

6.6.2.2 Parameters

Within the constraints and assumptions noted above, and given the fact that site quality demands for industry are equal to, or in certain cases, greater than for housing, it is proposed to use a number of the same parameters and thresholds for industrial land classification that are used for housing in Section 6.5.2.2. These are:

- Depth to in situ rock
- Soil drainage
- Liability to flooding
- Liability to subsidence
- Site limitations

The exception to this list is angle of slope which has different thresholds for industrial development at both the large-scale and small-scale level, as outlined in Chapter 3 on Page 49.

Soil stoniness and topsoil quality limitations are not included, as the significance of these parameters to the greater capital investment associated with industrial development, as opposed to housing development, is not considered to warrant their inclusion. Likewise, the climatic factors considered in the housing classification are not as important to industrial development, particularly since it is very likely that, because of the competition for land, it is to sites with less amenable climatic conditions that industry in an area is directed.

6.6.2.3 Classification System

Four broad classes define capability:

- Class 1 Suitable - having no limitations to industrial development.
- Class 2 Conditionally Suitable 1 - having some limitations which with certain investment in modifications, will become suitable for use.
- Class 3 Conditionally Suitable 2 - having further limitations to use than Class 2 but which with additional measures, will become moderately suitable for use.
- Class 4 Unsuitable - Being unsuitable for industrial development of the kinds envisaged.

6.6.2.4 Class Thresholds

Class 1

Angle of slope : Small-scale = $0 - 2.9^{\circ}$; large-scale = $0 - 1.4^{\circ}$.
Depth to in situ rock : 153 cm+
Soil drainage : Well to moderately well drained.
Liability to flooding : None
Liability to subsidence : None (within limits of transect as defined in 6.5.2.3)
Site limitations : None

Class 2

Angle of slope : Small-scale = $0 - 2.9^{\circ}$; Large-scale = $0 - 1.4^{\circ}$
Depth to in situ rock : 153 cm+
Soil drainage : Imperfectly drained.
Liability to flooding : None
Liability to subsidence : None (within limits of transect as defined in 6.5.2.3).
Soil limitations : None.

Class 3

Angle of slope : Small-scale = $0 - 2.9^{\circ}$; Large-scale = $0 - 1.4^{\circ}$.
Depth to in situ rock : 61 cm - 153 cm.
Soil drainage : Poorly drained.
Liability to flooding : None
Liability to subsidence : None (within limits of transect as defined in 6.5.2.3).
Site limitations : None.

Class 4

Angle of slope : Small-scale = greater than 2.9° ; Large-scale = greater than 1.4° .
Depth to in situ rock : 0 - 61 cm.
Soil drainage : Very poorly drained.
Liability to flooding : Present.
Liability to subsidence : Present.
Site limitations : Present.

6.6.2.5 Subclass Notation

Six subclasses are recognised:

- g to denote angle of slope limitations.
- d to denote depth to in situ rock limitations.
- w to denote soil drainage limitations.
- f to denote liability to flooding.
- m to denote liability to mining subsidence.
- b to denote site limitations.

The dominant subclass takes priority but if the subclasses are of equal weight the following priority is suggested:

b m f g d w

6.6.3 Transect Land Capability Analysis for Industrial Development

This section outlines the results of applying the above classification to the transect sites.

6.6.3.1 Discussion of Parameters

Depth to bedrock, soil drainage, liability to flooding, liability to subsidence and site limitations affect the same sites as for the housing classification in Section 6.5.3.1. The angle of slope limitation, however, is very different, and is shown in Figure 6.27. There is a slight decrease in slope limitation in the western part of the transect.

6.6.3.2 Land Capability Classes

Figures 6.28 and 6.29 and Tables 6.31, 6.32 and 6.33 show the capability classes of the transect sites. See Plates 6.9 and 6.10.

Nearly two-thirds of sites are unsuitable for small-scale industry and over three-quarters are not suitable for large-scale development. Only 7.0% and 4.2% respectively are of Class 1 whilst Class 2 is not represented.

Table 6.31 Land Capability Classes for Small-Scale Industry by Physiographic Unit (% sites)

Physiographic Unit	Suitable	Conditionally Suitable		Unsuitable	Classes 1 + 2 + 3
	Class 1	Class 2	Class 3	Class 4	
1	12.5	0.0	62.5	25.0	75.5
2	0.0	0.0	40.0	50.0	40.0
3	0.0	0.0	0.0	100.0	0.0
4	13.6	0.0	63.6	22.7	77.2
5	16.7	0.0	16.7	66.7	33.4
6	0.0	0.0	8.3	91.7	8.3
7	0.0	0.0	0.0	100.0	0.0
Total Units	7.0	0.0	32.4	60.6	39.4

Fig6.27 Sites with Angle of Slope Limitations-Industry(subclass g)

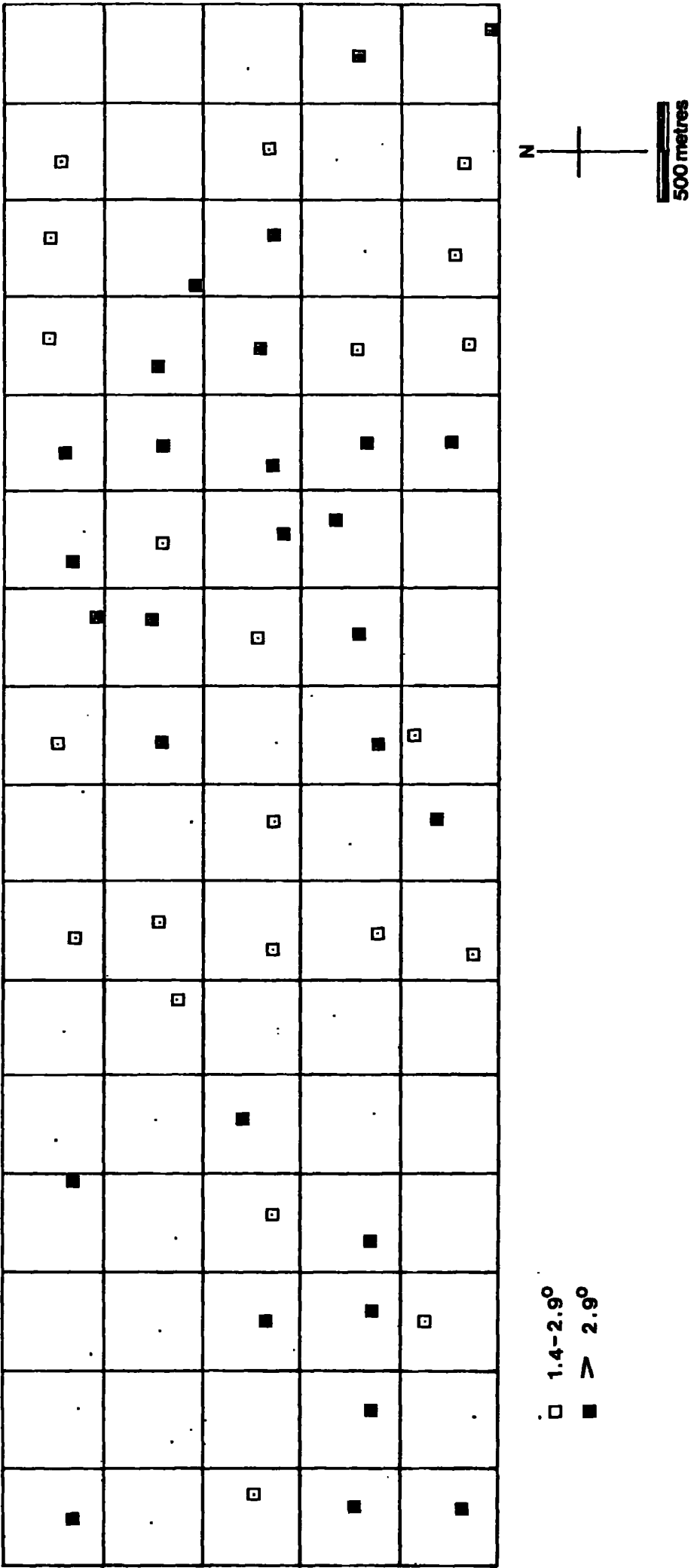


Table 6.33 Land Capability Classes for Industry

Site	Small Scale	Large Scale	Site	Small Scale	Large Scale
1	4 gw	4 gw	37	1	1
2	3 w	3 w	38	3 w	4 gw
3	3 w	3 w	39	4 mg	4 mg
4	4 g	4 g	40	4 mdg	4 mdg
5	4 bf	4 bf	41	4 mdg	4 mdg
6	3 w	3 w	42	4 mdg	4 mdg
7	3 w	4 gw	43	4 mw	4 mgw
8	3 w	3 w	44	4 mw	4 mw
9	1	4 g	45	4 gw	4 gw
10	4 gw	4 gw	46	4 gw	4 gw
11	4 gw	4 gw	47	4 gw	4 gw
12	4 sgw	4 sgw	48	4 gw	4 gw
13	4 s	4 sg	49	3 w	3 w
14	4 sgw	4 sgw	50	3 w	3 w
15	4 sgw	4 sgw	51	3 w	4 gw
16	1	1	52	3 w	3 w
17	3 w	3 w	53	4 gw	4 gw
18	3 w	3 w	54	4 mdg	4 mdg
19	4 bfw	4 bfw	55	4 mdg	4 mdg
20	4 bf	4 bf	56	4 gw	4 gw
21	1	4 g	57	3 w	4 gw
22	3 w	4 gw	58	1	1
23	3 w	3 w	59	4 mw	4 mw
24	4 gw	4 gw	60	4 mgw	4 mgw
25	4 gw	4 gw	61	4 fgw	4 fgw
26	4 mw	4 mwg	62	4 bfw	4 bfw
27	4 mwg	4 mwg	63	3 w	4 gw
28	4 mwg	4 mwg	64	3 w	4 gw
29	4 mwg	4 mwg	65	4 gw	4 gw
30	3 w	4 gw	66	3 d	4 gd
31	4 gw	4 gw	67	4 gw	4 gw
32	3 w	4 gw	68	4 fw	4 fgw
33	4 bfgw	4 bfgw	69	4 fw	4 fgw
34	3 w	3 w	70	4 bmfd	4 bmfdg
35	3 w	4 gw	71	4 mdg	4 mdg
36	3 w	4 gw			

Fig6.28 Land Capability Classes for Small-scale Industrial Development

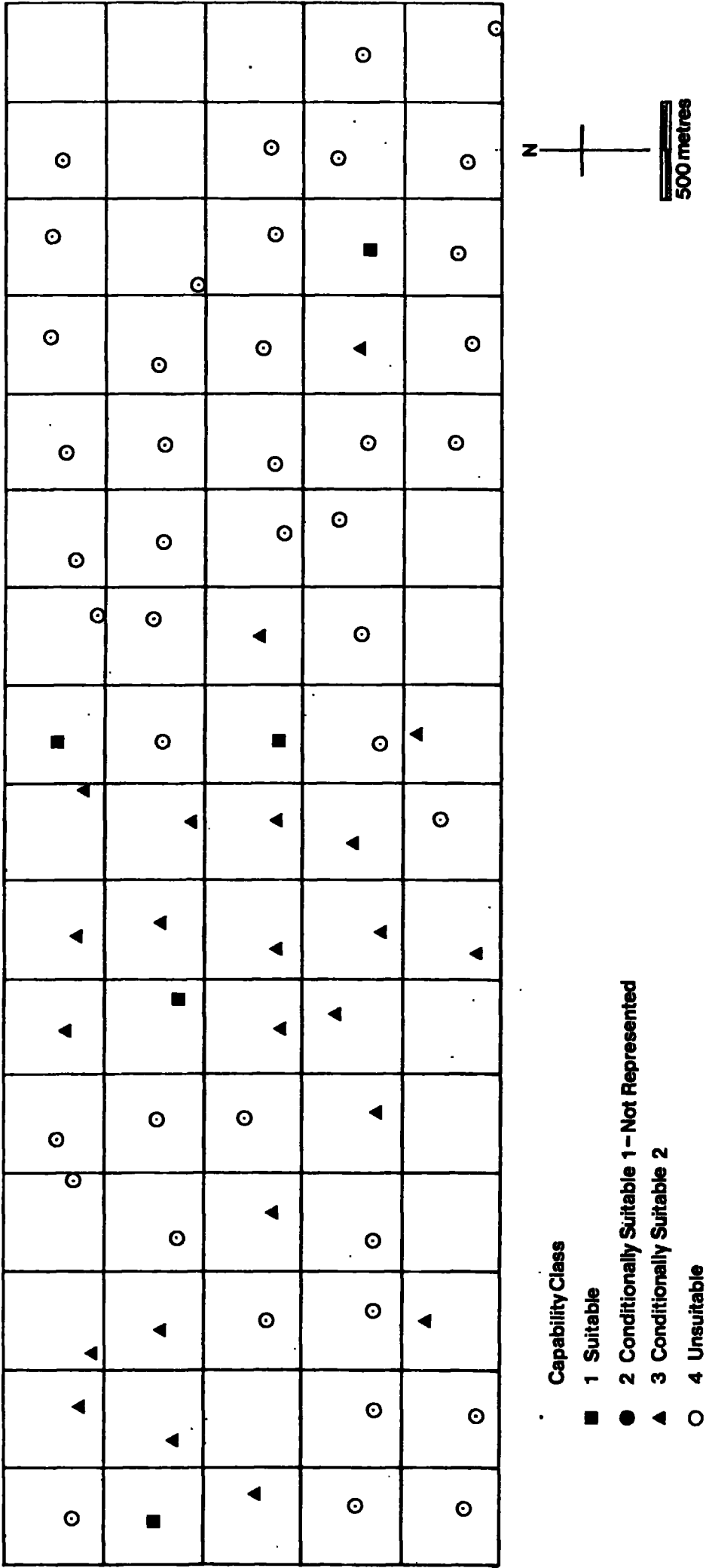


Fig6.29 Land Capability Classes for Large-scale Industrial Development

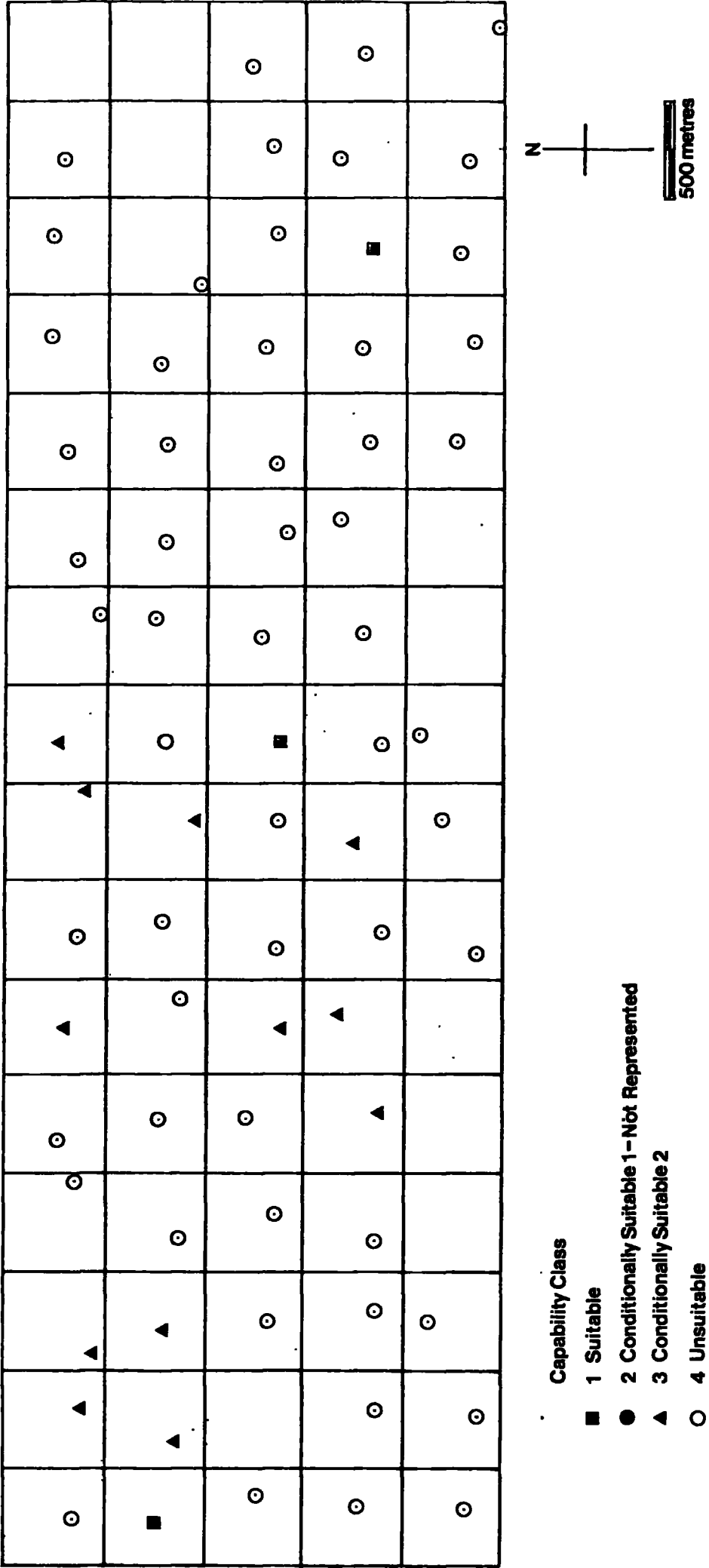




Plate 6.9 Poorly drained cambic stagnohumic gley soils, developed on laminated clay at Site 3 near Brasside (Unit I), result in Class 3w status for small and large-scale industry.



Plate 6.10 Although Class 3w for small-scale industry, this location, near Site 36 in Unit 4, is 4gw for large-scale industry.

Table 6.33 Land Capability Classes for Large-Scale Industry by Physiographic Unit (% Sites)

Physiographic Unit	Suitable	Conditionally Suitable		Unsuitable	Classes 1 + 2 + 3 %
	Class 1 %	Class 2 %	Class 3 %	Class 4 %	
1	12.5	0.0	50.0	37.5	62.5
2	0.0	0.0	20.0	80.0	20.0
3	0.0	0.0	0.0	100.0	0.0
4	4.5	0.0	31.8	63.6	36.3
5	16.7	0.0	0.0	83.3	16.7
6	0.0	0.0	0.0	100.0	0.0
7	0.0	0.0	0.0	100.0	0.0
Total Units	4.2	0.0	15.5	80.3	19.7

The Lowlands West and East of the River Wear (Units 1 and 4) are the most favoured areas, having around three-quarters of their sites in Classes 1 to 3 at the small-scale level. For large-scale industry the proportions west of the Wear in Unit 1 for these classes do not drop as much as those of Unit 4 to the east; the two areas having 62.5 and 36.3% respectively.

6.6.3.3 Dominant Subclass

Figures 6.30 and 6.31 and Table 6.34 show the dominant subclasses for each capability class.

At small-scale industry level, the drainage subclass (w) has the greatest proportions, all being of Class 3. This is followed by subsidence (m) and slope (g); both account for over 20% of the limitations. The remainder are all below 10%, with site limitations (b) being the most significant.

For large-scale industry there is a large increase in the slope component, predominantly at the expense of the wetness parameter which is of third importance after subsidence.

Table 6.35 shows the dominant subclass among the Physiographic Units.

Soil drainage is the most significant parameter in the Lowlands both East and West of the Wear for small-scale industry. The Wear Gorge and Floodplain (Unit 3) is dominated by site limitations, whilst slope is the most important in Coalford Vale (Unit 5). Subsidence problems dominate on the Permian outcrop.

For large-scale industry, drainage is still the most important subclass limitation west of the Wear where there are large areas of level sites. Slope assumes greatest significance in Unit 2 above the Wear, as it does in the Lowlands East of the Wear and in Coalford Vale.

Subclass														
Class	None		b		m		f		g		d		w	
	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale
1	5	3												
2														
3											1		22	11
4			6	6	19	19	3	3	15	29				
Total Sites	5	3	6	6	19	19	3	3	15	29	1		22	11
% Total Sites	7.0	4.2	8.5	8.5	26.8	26.8	4.2	4.2	21.1	40.8	1.4	0.0	31.0	15.5

6.6.3.4 Combinations of Subclasses

Table 6.36 Combinations of Subclasses by Capability Class (Number of Sites)

a) Small-Scale Industry

Class	None	s	g	d	w	bf	mg	mw	fw	gw	bfgw	mgw	mdg	fgw	bmfd	bfgw
1	5															
2		7														
3				1	22											
4		1	1			2	1	4	2	14	2	7	6	1	1	1
Total	5	1	1	1	22	2	1	4	2	14	2	7	6	1	1	1
% Total Sites	7.0	1.4	1.4	1.4	31.0	2.8	1.4	5.6	2.8	19.7	2.8	9.9	8.5	1.4	1.4	1.4

b) Large-Scale Industry

Class	None	g	w	bf	mg	mw	gd	gw	bfgw	mgw	mdg	fgw	bfgw	bmfdg
1	3													
2														
3			11											
4		3		2	2	2	1	25	2	9	6	3	1	1
Total	3	3	11	2	2	2	1	25	2	9	6	3	1	1
% Total Sites	4.2	4.2	15.5	2.8	2.8	2.8	1.4	35.2	2.8	12.7	8.5	4.2	1.4	1.4

Subclasses w and gw account for just over one half (50.7%) of sites for both small-scale and large-scale industry. Subclass mgw, at 9.9% and 12.7% for each scale respectively, is also significant. The remaining combinations are of limited significance (Table 6.36).

6.6.3.5 Capability Class and Soil Type

From Table 6.37, it is evident that the disturbed soil group provides the best soils for industry, with one half being of Class 1 for small-scale and one third for large-scale. Class 3 also accounts for one third of the grouping at both scales of development. Apart from one typical brown earth, and one gleyic brown alluvial site of Class 1, the surface-water gley soils form, where slope permits, conditionally suitable sites of Class 3. The cambic stagnohumic subgroup is proportionally more suitable, with over three-quarters of its sites (76.9%), of Class 3 for small scale and 38.5% of Class 3 for large-scale industry. The stagnogleyic brown earth subgroup also has a number of Class 3 sites, but these soils are significantly affected by mining subsidence and slope limitations.

6.6.4 Conclusions

The land capability classification system proposed for industrial development, in concentrating on site and soil information, without the inclusion of engineering data or the consideration of specific types of industry, enables a rapid survey and analysis of potential to take place. This is especially the case when investigated in association with the housing capability system of Section 6.5, as a significant number of parameters are held in common.

Likewise, it is submitted that the division of development into large-scale and small-scale based on slope thresholds, produces, in planning terms, a more meaningful classification than would occur if "industry" was merely considered as one general land use.

6.7 Land Capability Classification for Recreational Development

6.7.1 Choice of Activity

The final land use to be considered is that of recreational development. Recreation comes in many forms and degrees of intensity, both formal and informal in character, and unlike the previous land uses considered a specific type has had to be chosen in order to develop a meaningful classification.

The choice depended on two factors. Firstly, the type of recreation had to be of particular interest to planning in general and of common concern throughout the country - it had to be in demand. Secondly, it had to be of significance to the area of the transect, which is generally undeveloped but surrounded by areas of extensive urban development.

The intensive use of land for camp sites and picnic areas fits both of these requirements. The demand for informal countryside activities is expanding rapidly throughout the country and the location of the Mid-Wear Lowlands makes them an obvious leisure resource.

The nature of the land use, in that peoples basic location requirements are unlikely to differ much throughout the country, makes the following classification a national rather than a local scheme.

6.7.2 The Development of a Land Capability Classification for Camp Sites and Picnic Areas

6.7.2.1 Parameters

The parameter thresholds of significance to recreation have been discussed in Chapter 3, Section 3.4.5.

Angle of slope affects the choice of camp sites and picnic areas, both through the problems of undertaking such activities on sloping land and through the increased costs of construction for access roads. Although buildings for recreation are not considered in this analysis, slope will significantly affect their location, and in the case of the provision of toilet blocks a slope may be essential for the septic tank location.

The drainage status of a soil, which is influenced by particle size distribution is very important, and an ideal site will have a well drained profile with rapid permeability; wet and muddy conditions are totally incompatible with a camp or picnic site. The topsoil texture and organic content of the surface layer, which will influence not only drainage but erosion potential, are especially significant. Likewise, the stone content of the soil will determine the possibility of the pitching of tents and affect the provision of paths.

A soils erosive properties are highly significant to recreation, but there exists at present, no threshold figures for soil loss on which to superimpose a classification system. Much research has to be done on erosion before it can be included to effect in a capability system. As a result, the parameter, is regrettably not included in the analysis.

A good camp site location will have an equable microclimate, and both aspect and site exposure will be of importance to potential. The latter is more significant and an exposed situation will be out of the question for development. Locations subject to flooding or the site limitations parameter, as used in the agriculture, housing and industrial classifications, will be ruled out; the type of recreation under consideration requiring an unrestricted site.

1. Angle of Slope

Threshold slopes of 4.7° and 8.7° , as suggested by Montgomery and Edminster (1966), are used.

2. Soil Drainage

The soil drainage classes of the Soil Survey (1960) determine the overall status of the profile.

3. Soil permeability status

The method of determining soil permeability status, as used for the Universal Soil Loss Equation, discussed in Appendix 3 on Page 490, is used.

4. Soil Texture

The threshold for soil texture are developed from those suggested by Montgomery and Edminster (1966).

5. Presence of Organic Horizon

No work has been done on acceptable threshold thicknesses of organic horizons (F, H, O) for the capability of recreational activity, and research needs to be done to meet this gap in the literature. Rather than ignore this parameter, it was decided to use two thicknesses found to be significant by the author for parking and picnic facilities as a result of qualitative observation and preliminary survey of soil erosion/organic horizons in the Moel Famau County Park in North Wales. These threshold thicknesses are 5 cm for limiting development and 10 cm for prohibiting it.

6. Soil Stoniness

The stoniness of the topsoil at 5 cm is used to indicate the problems associated with this parameter and the thresholds are based on those of Montgomery and Edminster (1966).

7. Aspect

A north-facing slope (NW-NE) with an angle of between 1 and 5° is taken to limit development, and above 5° to exclude development. 5° is the slope threshold that significantly affects the warming of the earth's surface as indicated in Chapter 3 on Page 47 .

8. Site Exposure

The Topex zones, as used in the forestry and housing classifications (Sections 6.2 and 6.5), indicate degrees of exposure for the recreation analysis.

9. Liability to flooding

Any degree of the liability of a site to flood is seen to prohibit development.

10. Site Limitations

Site limitations, which restrict site development to an unrealistically small area will prohibit use.

6.7.2.2 Classification System

Three broad classes are recognised, on lines similar to those suggested by Jarvis (1976); as follows:

Class 1 Suitable with no limitations to development.

Class 2 Suitable but with moderate limitations to development.

Class 3 Unsuitable with severe limitations to development.

6.7.2.3 Class Thresholds

Class 1

Angle of slope : 0 - 4.7°.

Soil drainage : Well to moderately drained.

Soil permeability status: Very rapid to moderate.

Soil texture : Sandy loam, loam, loamy sand with well developed B horizon.

Organic horizon : 0 - 5 cm.

Soil stoniness : Stoneless to slightly stony.

Aspect : North-facing (NW-NE) slope absent.

Site exposure : Topex zone of very sheltered to moderately sheltered.

Liability to flooding : None.

Site limitations : None.

Class 2

Angle of slope : $4.7^{\circ} - 8.7^{\circ}$.
Soil drainage : Imperfectly drained.
Soil permeability status: Moderately slow.
Soil texture : Loamy sand, silty loam, clay loam, sandy clay loam, silty clay loam.
Organic horizon : 5-10 cm
Soil stoniness : Stony.
Aspect : North-facing (NW-NE) with slope of $1 - 5^{\circ}$.
Site exposure : Topex zone of moderately exposed.
Liability to flooding : None.
Site limitations : None.

Class 3

Angle of slope : Greater than 8.7° .
Soil drainage : Poorly to very poorly drained.
Soil permeability status: Slow to very slow.
Soil texture : Sandy clay, silty clay, clay, sand.
Organic horizon : Greater than 10 cm.
Soil stoniness : Very stony to rock dominant.
Aspect : North facing (NW-NE) with slopes of over 5° .
Site exposure : Topex zone of very exposed to extremely exposed.
Liability to flooding : Present.
Site limitations : Present.

6.7.2.4 Subclass Notation

Six subclasses are recognised:

g to denote angle of slope limitations.
w to denote soil drainage and permeability limitations.
s to denote soil texture, soil stoniness and organic horizon limitations.
c to denote aspect and site exposure limitations.
f to denote liability to flooding.
b to denote site limitations.

The dominant subclass takes priority, but if the subclasses are of equal weight the following priority is suggested:

b f g w s c

6.7.3 Transect Land Capability Analysis for Camp site and Picnic Areas.

The capability scheme applied to the transect sites is outlined in this section.

6.7.3.1 Discussion of Parameters

The slope limitation is shown in Figure 6.32. Limiting thresholds are located about the River Wear Gorge and Floodplain in Physiographic Units 2 and 3 and on the Permian Escarpment (Unit 6). Soil drainage classes are shown in Figure 6.1 on Page 144 and their distribution about the transect is discussed on Page 143. Figure 6.33 shows that 73.2% of the sites sampled have permeability limitations to this type of recreational development. Three quarters of those so affected have a slow to very slow permeability status, with a majority located in the eastern half of the transect. Only five sites (6, 17, 19, 31 and 67) have organic horizon limitations and, apart from Site 67 in Unit 5, all are situated to the west in Units 1, 2 and 3. Soil texture has been extensively discussed in Chapter 5 Section 5.9, and the textural limitations to camp sites and picnic areas are shown in Figure 6.34. The Class 2 category of loamy sand, silty loam, clay loam, sandy clay loam and silty clay loam accounts for 73.2% of the sites, with only four profile topsoils relegated to the Class 3 threshold level. The distribution of the soil stoniness thresholds are the same as for the agricultural classification and are discussed in Section 6.1 on Page 146.

Figure 6.35 shows the aspect limitation distribution, which reduces 15.5% of all sites to Class 2 level but only two to Class 3 level. The site exposure limitation is shown in Figure 6.21 of the housing classification, and the flooding and site limitations distribution are the same as for the previous classifications.

6.7.3.2 Land Capability Classes

Figure 6.36 and Tables 6.38 and 6.39 show the capability classes for the transect sites. See Plates 6.11 and 6.12.

Table 6.38 Land Capability Classes for Camp Sites and Picnic Areas by Physiographic Unit (% sites)

Physiographic Unit	Suitable	Suitable	Unsuitable	Suitable
	Class 1	Class 2	Class 3	Classes 1 + 2
1	0.0	12.5	87.5	12.5
2	0.0	20.0	80.0	20.0
3	0.0	0.0	100.0	0.0
4	0.0	27.3	72.7	27.3
5	16.7	16.7	66.7	33.4
6	0.0	33.3	66.7	33.3
7	0.0	50.0	50.0	50.0
Total Units	1.4	26.8	71.8	28.2

Only one site in the transect is rated as Class 1 (Site 58); even including Class 2 sites only just over a quarter (28.2%) are suitable for development.

There is a trend for suitability to increase from west to east across the transect, with the Permian Plateau (Unit 7) having the greatest proportion of suitable sites.

Fig 6.32 Sites with Angle of Slope Limitations for Recreation Camp Sites and Picnic Areas (subclassg)

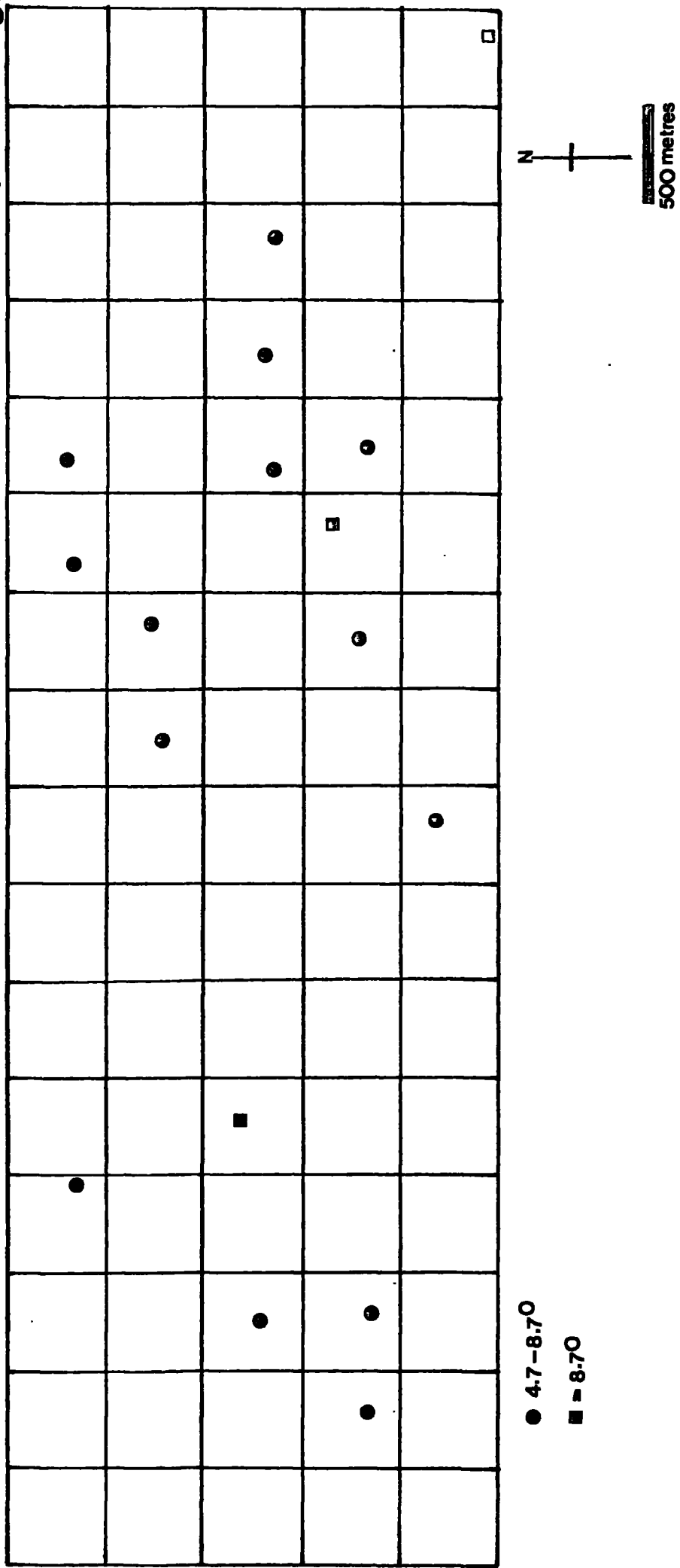


Fig6.33 Sites with Soil Permeability Limitation for Recreation-Camp Sites & Picnic Areas (subclass w)

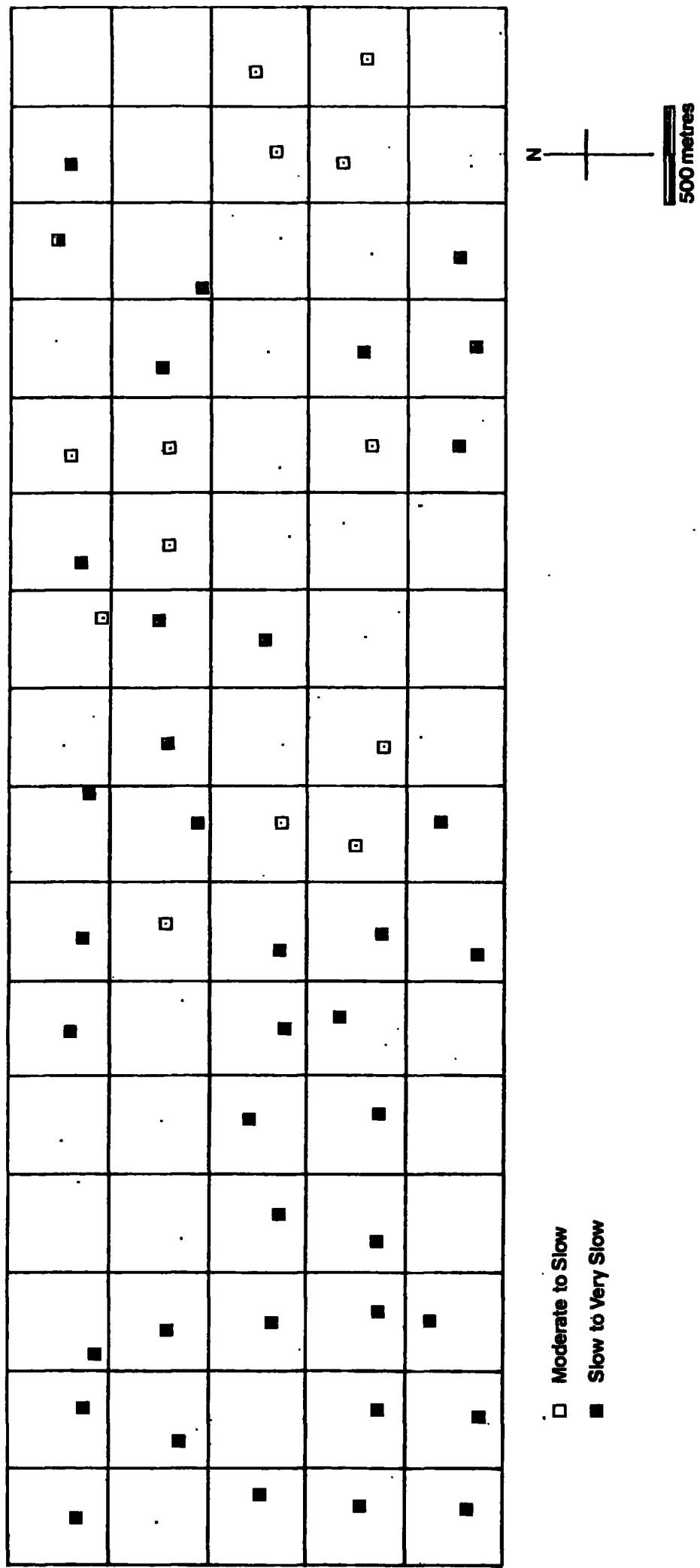


Fig6.34 Sites with Soil Texture Limitations for Recreation–Camp Sites & Picnic Areas
(subclass s)

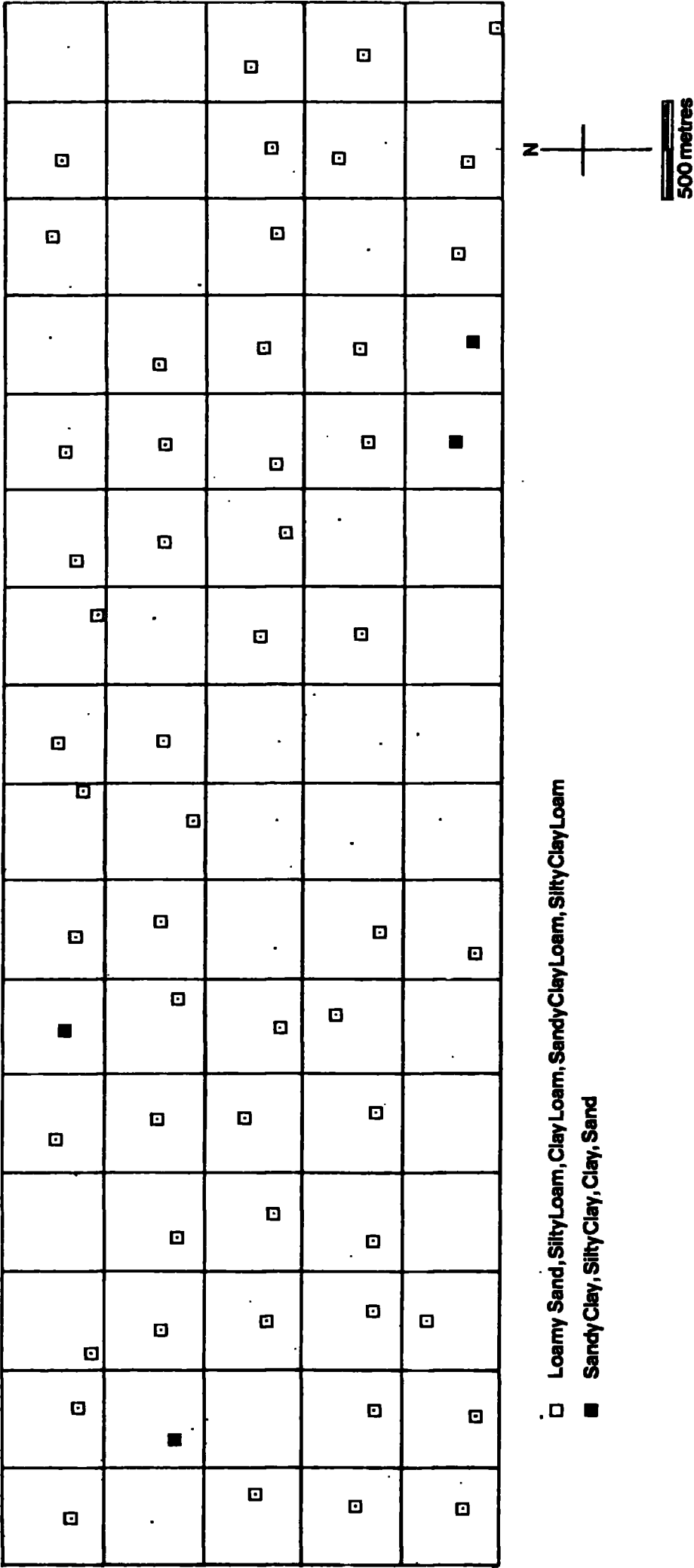


**Fig6.35 Sites with Aspect Limitations for Recreation-Camp Sites& Picnic Areas
(subclass c)**

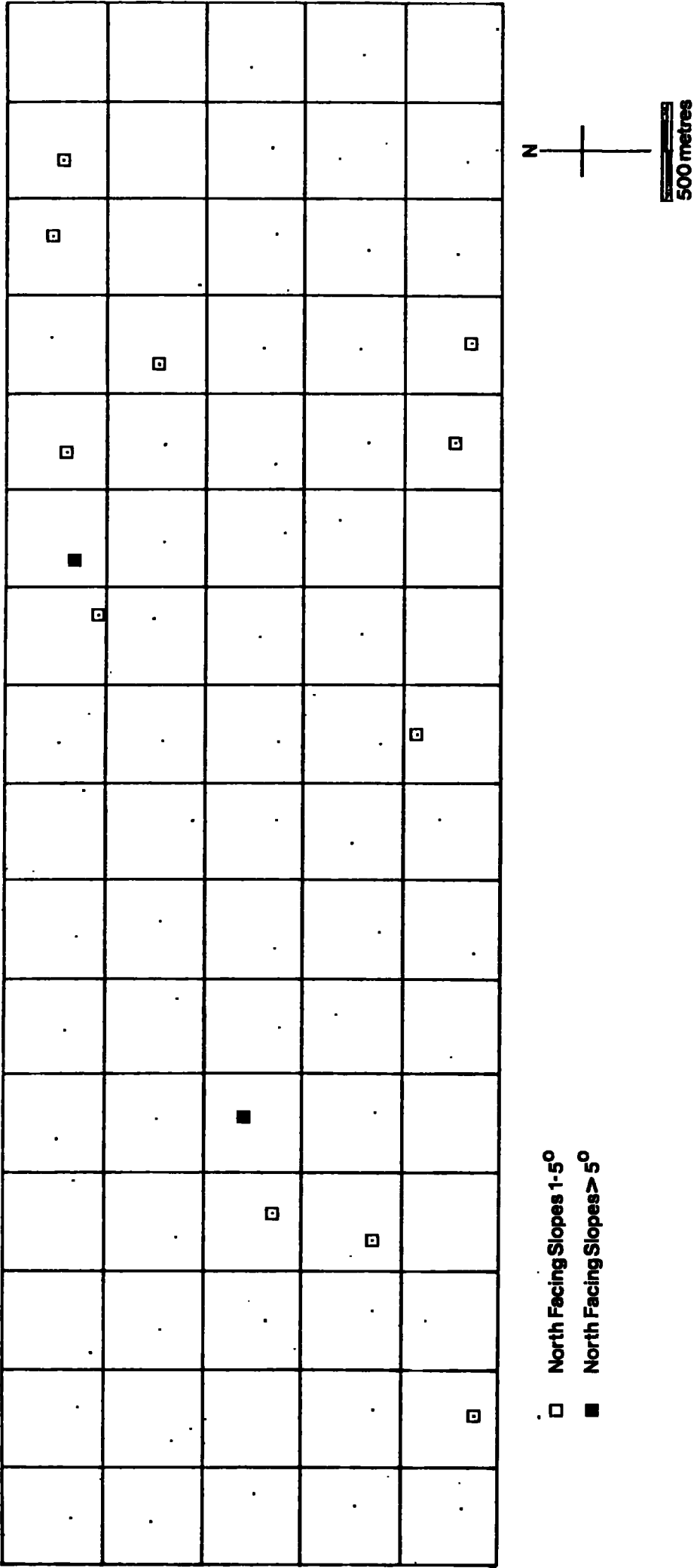


Table 6.39 Land Capability Classes for Camp Sites and Picnic Areas

Site	Capability Class	Site	Capability Class
1	3 ws	37	2 s
2	3 wsc	38	3 ws
3	3 ws	39	2 wsc
4	2 g	40	3 sgc
5	3 lf	41	3 sg
6	3 ws	42	2 gs
7	3 ws	43	2 ws
8	3 wsc	44	2 ws
9	2 c	45	3 ws
10	2 wsc	46	3 wgs
11	3 wgs	47	3 wsg
12	2 gwsc	48	3 fwsc
13	2 s	49	3 ws
14	3 wsc	50	3 ws
15	3 wsc	51	3 ws
16	2 c	52	2 wc
17	3 wsc	53	2 ws
18	3 ws	54	2 gs
19	3 lfs	55	3 gs
20	3 lf	56	2 gws
21	2 s	57	3 ws
22	3 sw	58	1
23	3 ws	59	2 wsc
24	3 wgs	60	2 wsc
25	3 wgs	61	3 fws
26	3 cws	62	3 lfwsc
27	3 cws	63	3 ws
28	3 wcs	64	3 wsc
29	3 wc	65	3 wgs
30	3 ws	66	3 sc
31	3 wsg	67	3 wsc
32	3 wsc	68	3 wsc
33	3 lfwsc	69	3 fwsc
34	3 ws	70	3 lfs
35	3 w	71	3 gsc
36	2 w		

Fig6.36 Land Capability Classes for Recreation-Camp Sites and Picnic Areas

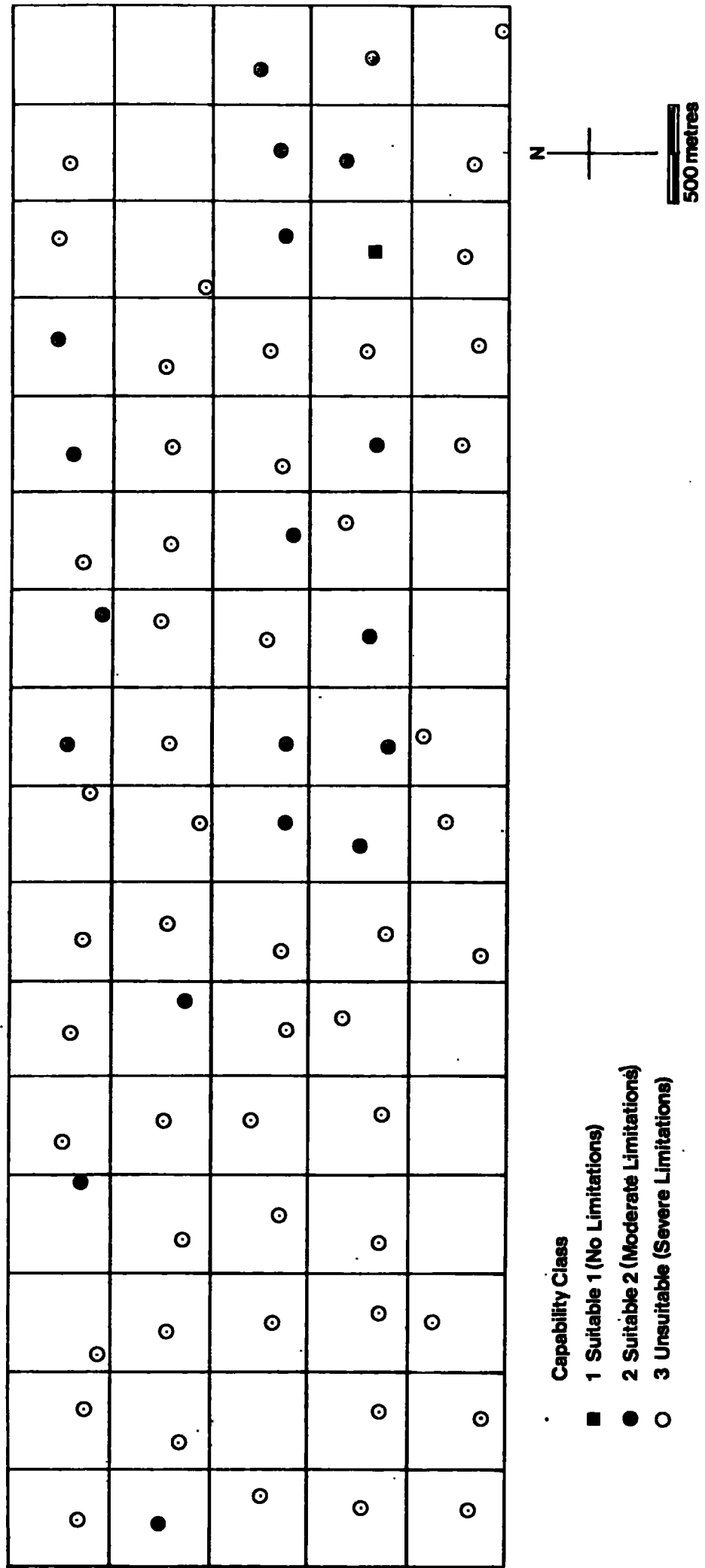




Plate 6.II The effects of angle of slope and a stony profile relegate the location in the foreground (Site 54) at Pittington in Unit 6, on brown calcareous earths, to Class 2gs for camp sites and picnic areas. This passes to Class 3gs further upslope.



Plate 6.I2 Soil drainage, exposure, soil texture and stoniness limitations restricts the use of this land, typical of the Permian Plateau (Unit 7) near Hetton le Hill, to Class 3wcs for camp sites and picnic areas.

6.7.3.3 Dominant Subclass

Figure 6.37 and Table 6.40 show the dominant subclasses encountered.

Table 6.40 Dominant subclass by Capability Class (Number of Sites)

Class	None	Subclass					
		b	f	g	w	s	c
1	1						
2				5	9	3	2
3		6	3	2	34	4	2
Total Sites	1	6	3	7	43	7	4
% Total Sites	1.4	8.5	4.2	9.9	60.6	9.9	5.6

Soil drainage and permeability limitations (w) are by far the dominant subclass and together are especially indicative of Class 3 status. No other subclass rises above 10% of sites; slope (g) and soil limitations (s) each account for 9.9%.

Table 6.41 shows the dominant subclass among the Physiographic Units.

Apart from Unit 3, where the site limitation subclass (b) is the most important, the remaining areas have a dominant drainage and/or permeability limitation, sufficiently severe to downgrade most sites to Class 3. Slope and soil limitations are the next most significant, especially in the centre and east.

6.7.3.4 Combinations of Subclasses

Two combinations of subclasses account for 43.7% of sites, ws and wsc at 25.4 and 18.3% respectively. 77.4% of these groupings are of Class 3 status. The figures indicate poor drainage/permeability, indifferent soil conditions (texture and stoniness in particular) and inclement micro-climate (predominantly exposure) of the transect as far as the provision of camp sites and picnic areas is concerned. No other subclass combination accounts for above 4.2% of all sites (Table 6.42).

6.7.3.5 Capability and Soil Type

Table 6.43 indicates that the stagnogleyic brown earths, with 81.1% of their sites at Class 2 level, and the disturbed soil group, with one half of their sites of Class 1 or 2, are the best soils for camp sites and picnic areas in the transect. These are followed by the typical brown calcareous earths and the limited number of typical brown earth and gleyic brown alluvial soils, with one half of their sites each in Class 2.

The poorest soils are the cambic stagnohumic and cambic stagnogley profiles, strongly affected by the soil drainage/permeability subclass w.

Fig6.37 Land Capability Subclasses for Recreation - Camp Sites and Picnic Areas

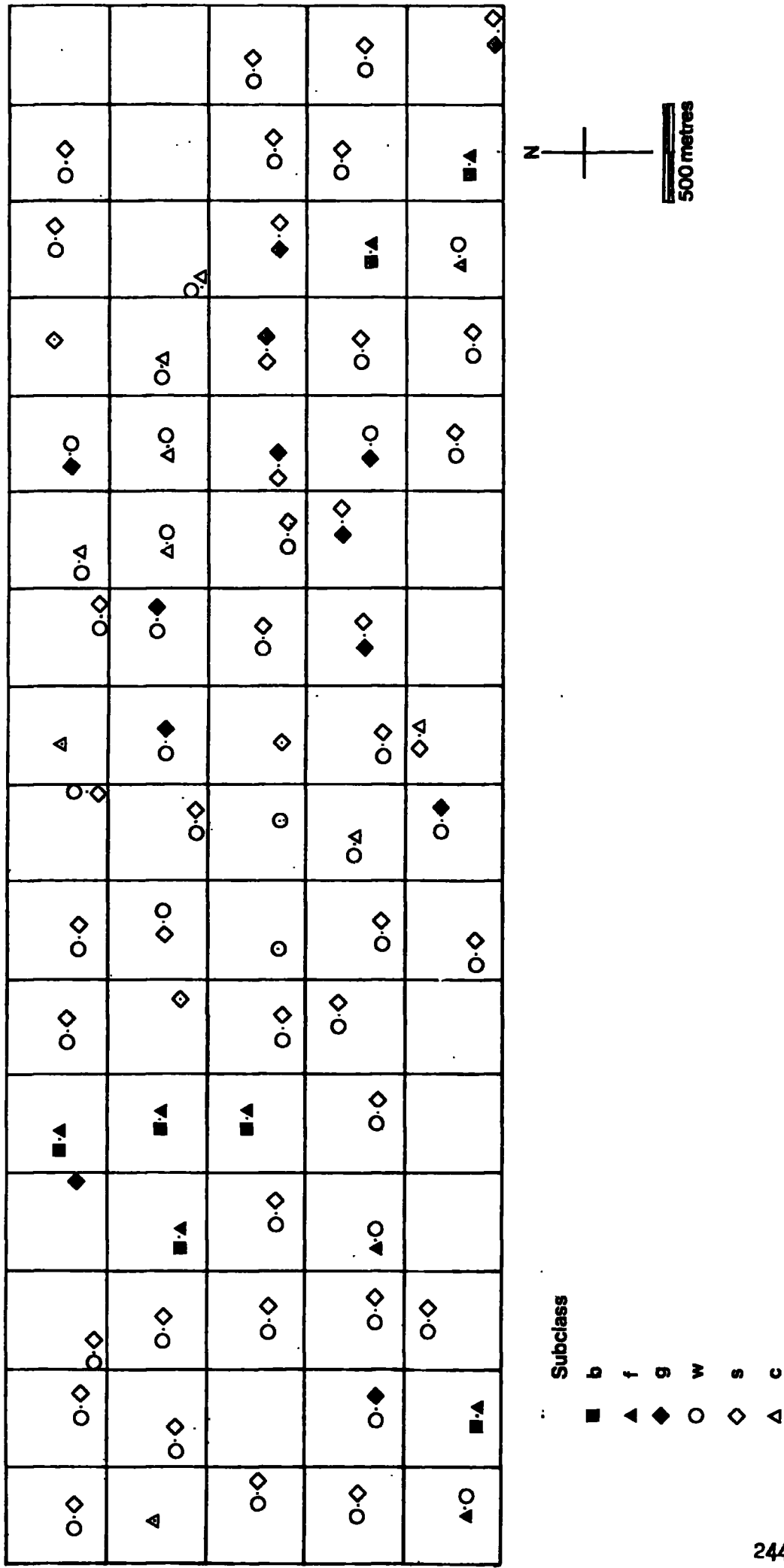


Table 6.41 Dominant Subclass Among the Physiographic Units By Capability Class (Number of Sites)

Class/Unit	None							b							f							g							h							i							j							k							l							m							n							o							p							q							r							s							t							u							v							w							x							y							z							aa							ab							ac							ad							ae							af							ag							ah							ai							aj							ak							al							am							an							ao							ap							aq							ar							as							at							au							av							aw							ax							ay							az							ba							bb							bc							bd							be							bf							bg							bh							bi							bj							bk							bl							bm							bn							bo							bp							bq							br							bs							bt							bu							bv							bw							bx							by							bz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn							co							cp							cq							cr							cs							ct							cu							cv							cw							cx							cy							cz							ca							cb							cc							cd							ce							cf							cg							ch							ci							cj							ck							cl							cm							cn			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Table 6.42 Combinations of Subclasses by Capability Class (Number of Sites)

Class	None	g	w	s	c	lf	gs	ws	wc	sg	sw	sc	lfs	fws	gvs	gac	wgs	wsg	wsc	vcs	sgc	cvs	lfsv	fvs	gvac	wgvac	lfgvac	lfgvsc
1	1																											
2		1	1	3	2		2	3	1						1				4									
3						2	1	15	1	1	1	1	1	1		1		1	2	9	1	1	2	1	2	1	1	1
Total Sites	1	1	2	3	2	2	3	18	2	1	1	1	1	1	1	1	1	2	13	1	1	2	1	2	1	3	1	1
2 Total Sites	1.4	1.4	2.8	4.2	2.8	2.8	4.2	25.4	2.8	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.8	18.3	1.4	1.4	2.8	1.4	2.8	1.4	4.2	1.4	1.4

Table 6.43 Soil Type, Capability Class and Dominant Subclass (% Sites)

	None			b			f			g			w			s			c		
	Class			Class			Class			Class			Class			Class			Class		
	1	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
Brown (non-humic) Rendzina										33.3							66.7				
Typical Brown Calcareous Earth			25.0							50.0	25.0							50.0	50.0		
Typical Brown Earth																					
Stagnogleyic Brown Earth								18.7				56.2				6.2	6.2				12.5
Typical Brown Alluvial Soil																					
Gleyic Brown Alluvial Soil			100.0														50.0				
Cambic Stagnogley							5.9								94.1						
Cambic stagnohumic gley															100.0						
Typical (non-calc) Alluvial Gley			20.0				40.0								40.0						
Typical (non-calc) humic Alluvial Gley			100.0																		
Disturbed Soil Group	16.7														50.0	16.7	16.7		16.7		

6.7.4 Conclusions

The analysis indicates that the transect is a poor area for this type of recreational development, with only a small number of individual sites having some potential. In common with the other land uses, attention can now be focussed on these better classed areas to aid future development at a detailed level.

6.8 Conclusions to Chapter 6

This chapter has discussed in detail the development of point sample parametric land capability classification systems for six different types of land use that would have to be analysed in the strategic planning of an area. A great deal more information on land use capability has been gleaned by using this approach than was possible using the thematic basis of study.

Over the transect the 500 metre grid has allowed patterns of land capability classes to be extracted that are capable of interpretation, with the inherent parameters of each Physiographic Unit producing their own specific capability distributions. This level of sampling would appear successful for a strategic analysis.

Finally, Table 6.44 shows a synthesis of the capability classes for each land use at each site. Very noticeable is the extremely small number of sites graded as Class 1, and this indicates that certain specific areas are worthy of further detailed investigation.

Table 6.44 Land Capability Classes for the Selected Land Uses.

Site	Agriculture	Forestry	Nature Conservation	Housing	Industry	Recreation	Site	Agriculture	Forestry	Nature Conservation	Housing	Industry	Recreation
1	3	3	5	3	4	4	37	3	3	5	3	1	1
2	4	2	4	3	3	3	38	4	1	3	3	3	4
3	3	2	4	3	3	3	39	4	1	5	4	4	4
4	3	1	4	4	4	4	40	4	3	5	4	4	4
5	6	3	1	4	4	4	41	4	3	4	4	4	4
6	4	2	1	3	3	3	42	5	3	2	4	4	4
7	3	2	4	3	3	4	43	3	2	5	4	4	4
8	3	3	5	3	3	3	44	3	3	5	4	4	4
9	3	1	3	3	1	4	45	4	2	4	3	4	4
10	3	3	5	3	4	4	46	4	1	4	4	4	4
11	4	3	5	3	4	4	47	4	2	4	3	4	4
12	3	3	5	4	4	4	48	4	2	5	3	4	4
13	3	3	5	4	4	4	49	3	3	4	3	3	3
14	4	2	3	4	4	4	50	4	2	3	3	3	3
15	4	2	3	4	4	4	51	3	3	4	3	3	4
16	2	1	5	3	1	1	52	3	3	5	3	3	3
17	5	3	2	3	3	3	53	3	3	5	3	3	4
18	4	1	4	3	3	3	54	5	3	4	4	4	4
19	6	3	1	4	4	4	55	5	3	3	4	4	4
20	5	3	2	4	4	4	56	4	3	4	4	4	4
21	3	3	4	3	1	4	57	4	3	5	3	4	4
22	4	2	5	3	3	4	58	3	3	3	1	1	1
23	4	3	4	3	3	3	59	3	3	5	4	4	4
24	4	1	5	3	4	4	60	3	1	4	4	4	4
25	3	3	5	3	4	4	61	5	3	2	4	4	4
26	4	3	5	4	4	4	62	6	3	1	4	4	4
27	4	3	5	4	4	4	63	4	3	4	3	4	4
28	4	3	5	4	4	4	64	3	1	5	3	4	4
29	3	3	5	4	4	4	65	3	2	3	3	4	4
30	4	3	5	3	3	4	66	4	3	1	3	4	4
31	5	2	2	4	4	4	67	4	2	3	3	4	4
32	3	2	4	3	3	4	68	4	3	4	4	4	4
33	6	3	2	4	4	4	69	4	3	3	4	4	4
34	3	3	3	3	3	3	70	6	3	2	4	4	4
35	3	3	5	3	3	4	71	5	3	2	4	4	4
36	3	2	5	2	3	4							

PART 4

Chapters : 7, 8, 9, 10 and 11

CHAPTER 7 - LAND EVALUATION - AN INTRODUCTION TO A

NUMERICAL COMPOSITE PARAMETRIC APPROACH

Chapter 6 outlined a parametric point sample approach to land capability classification based upon selected parameters and their threshold values pertaining to certain types of development. A classification or grade of potential was allotted to each land use. Chapters 8, 9, 10 and 11 are devoted to an analysis of the relationships between parameters and sites using statistical methods without this initial land use requirement.

7.1 Introduction

In Chapter 1, Section 1.3.3, it was stated that a composite approach to land evaluation does not determine grades for a physiographic unit. It is up to a researcher investigating the feasibility of a particular land use to use this inventory to analyse capability as required. The approach has been expressed in the past by procedures such as "land system and facet" analysis, notably in the United States, Australia and in Great Britain. These methods involve quasi-quantitative assessments of a particular land type, with much emphasis being placed upon the use of aerial photographic interpretation. However, a degree of subjectivity is involved, as experienced by the author using a facet approach in the Clwydian Hills of Eastern Clwyd (Brown, Ratcliffe and Hawkes, 1978).

A parametric approach, on the other hand, is based on specific measured properties, and within the analysis there is no room for subjectivity, as discussed in Chapter 1, Section 1.3.4.

Clearly, both these approaches have advantages and a system which combines the flexibility in land use terms for inventory purposes of composite boundaries with the quantitative nature of a parametric analysis would appear to hold a key to the advancement of the land evaluation discipline.

Methods of data storage which seek to combine the advantages of both approaches have been attempted by the Canadian Army using "small composite parametric units" where "punched cards are made out for each envelope showing the parameters used to define it. These cards can then be scanned by the computer to find units which have any specified attribute or combinations of attributes." A map of an area with the required attributes may then be printed (Mitchell, 1973 after Parry et al. 1968).

No attempt has been made, however, at combining the approaches using a point sample survey, and it was thus decided to attempt to undertake research into the feasibility of achieving this, taking the transect sites as the spatial base.

7.2 An Approach to a Composite Parametric Point Sample Land Evaluation Method for the Transect Sites

The concept of relationships between sets of objects and between sets of events is a part of everyday experience (Cole and King, 1968) and both the social and physical sciences have evolved and applied rigorous techniques for testing for correlation with the help of statistical methods based upon probability. Although relationships have been a part of geography for a long time, it is only during the past decade or so that the more advanced mathematical and statistical methods have become a part of geographical research.

Land evaluation is concerned in essence with discerning areas or points of "likeness"; in analysing relationships between attributes and sites or areas; in ordering and classifying land according to certain criteria and in simplifying a seemingly incomprehensible number of factors into an easily recognisable whole capable of interpretation. Despite one or two notable exceptions, particularly the work of the U.S. Army and others on terrain analysis, which has tended to be on a particularly academic sphere, it is surprising that statistical techniques, which lend themselves to the analysis of relationships have not been used more widely in land evaluation research.

In the transect, for any parameter measured at the seventy one sites, a spatial distribution map could be drawn. The uses to which these maps could be put would be limited, however, especially for the land resource planner investigating the potential of an area for multi-land use purposes.

A more meaningful scheme would be to place one map on top of another and "by eye" sieve out clusters of sites showing similar characteristics. However, in order to produce an inventory that would allow many land uses to be considered, similar to the boundaries produced by a composite approach mentioned above, a great many site and soil parameters would have to be measured. To sieve out these clusters manually would not be a viable proposition; but would be possible using statistical techniques.

In not being based on genetic lines, such a "numerical composite parametric" method does not embody the elements of prediction inherent in land systems of facet analysis, nor are the boundaries or clusters produced hierarchical in the composite unit sense.

In order to achieve the reduction in inventory maps quoted above, three quantitative methods are tested in the following four chapters. It is in no way professed that the analyses undertaken are complete in their development as quantitative assessments, and thus these chapters should be seen as a statement of research to date.

Chapter 8 discusses the application of two cluster analysis techniques to produce an information inventory for the transect sites, whilst Chapter 9 and 10 outline in detail the results of principal components analysis as a means of reducing the number of parameters pertinent to a resource assessment prior to site clustering, which is presented in Chapter 11.

7.3 Data Selected

Having defined the general statistical approach, the type of data to be included had to be selected with care, as the clusters produced are determined by the data. Being for strategic planning purposes, the clusters of sites had to be capable of interpretation in broad multi-land use terms. A significant number of site and soil parameters would, therefore, be required. In addition, in order to facilitate the use of statistical methods, it was desirable that certain criteria should be met; namely :-

- i) the data should remain the same for all the different types of analysis outlined above. Comparison would then be possible.
- ii) The number of parameters selected should not be too great. In undertaking a principal component analysis, the limited amount of extra information gained in using a large data set is often offset, to a considerable degree, by an increase in interpretation and multicollinearity difficulties (Traill; pers. comm. 1974).

Thirty variables were finally chosen and are shown in Table 7.1. These characteristics are called "variables" for the analyses rather than "parameters" on account of the fact that certain of the parameters, site drainage for example, have had to be included as separate types; in this case - shedding, normal and receiving - which are not parameters, as such, in their own right.

The variables devoted to site characteristics take into account the essential elements of location, i.e. angle of slope, altitude, aspect and site drainage, with a reflection of land use being embodied in the canopy of the vegetation. Site drainage is included in the analyses as three separate dichotomous variables- shedding, normal and receiving, as 1 or 0, according to presence or absence respectively.

The first of the soil profile characteristics, that of profile drainage is also included as four dichotomous variables, namely one of:- well drained (excessive), well drained (free), imperfect or poor drainage. A moderately well drained status is included in the well drained (free) category, as it was considered that the difference between the two, and the very limited number of moderately well drained profiles, did not warrant the inclusion of another dichotomous variable. Within the text, the terms "excessive" and "free" are frequently used without "well drained" purely for means of brevity.

Table 7.1 Site and Soil Variables

SITE VARIABLES

1. Angle of slope
2. Altitude
3. Aspect
4. Canopy of the vegetation.
5. Drainage - i) Shedding
 ii) Normal
 iii) Receiving

SOIL PROFILE VARIABLES

1. Drainage - i) Well drained (excessive)
 ii) Well drained (free)
 iii) Imperfect
 iv) Poor
2. Depth to in situ rock
3. Texture of soil at 5 cm i) % sand
 ii) % silt
 iii) % clay
4. Texture of soil at 40 cm i) % sand
 ii) % silt
 iii) % clay
5. % carbon of soil at 5 cm
6. % carbon of soil at 30 cm
7. % moisture of soil at 5 cm
8. % moisture of soil at 30 cm
9. pH of soil at 5 cm

10. pH of soil at 30 cm
11. % base saturation of soil at 5 cm
12. % base saturation of soil at 30 cm
13. Thickness of organic horizons (F and/or H and O)
14. Thickness of top mineral horizon
15. Depth to the BC or C horizon (excluding organic horizons)
16. % stones in top mineral horizon

The dichotomous variables of site and profile drainages, coded as 0 - 1, although causing no problems of calculation, do not meet with the distribution of the "deviations" being a customary normal distribution with constant variance. A consequence of this is that the method of statistical fitting does not give the "best fit" in the usual sense, although the fitted relationship does have one desirable property in that it is "unbiased" in the statistical sense of the word (Settle, 1973).

Therefore, where variables are not normally distributed samples of a given population, confidence levels are no longer strictly valid; however, they can be used as approximations, the degree of approximation depending on the amount of deviation from normality (Mather, 1969). Furthermore, Traill (pers. comm. 1974) suggests that six or seven dichotomous variables is about the maximum suitable for a principal axes solution.

The second of the soil profile variables, that of depth to in situ rock, proved to be highly significant to land capability using the parametric evaluations of Chapter 6, but as presence of rock was only determined if at 100 cm or above, a figure of 100 had to be set in the data matrix for rock situated in excess of this depth.

The importance of soil texture to land use, both in the topsoil at 5 cm and below the zone of ploughing disturbance at 40 cm, is noted by particle-size. In common with the major paper on principal component analysis using soil data of Norris (1971), all three major fractions are included.

Percentage carbon and moisture content in the topsoil at 5 cm and subsoil at 30 cm reflects the organic/moisture status of the zone of most significance to plant growth, as indicated in Chapter 4 on Page 70, whilst the pH and % base saturation at these depths measure nutrient status.

A measurement of the thickness of the organic horizons and the top mineral horizon, and the depth to the BC or C horizon are factors of significance to land use and are prime indications of the "character" of the soil profile. The term "top mineral horizon" is used rather than "A horizon" as a certain number of profiles fall into the disturbed soil group and do not necessarily have A horizons present.

Percentage stones in the top mineral horizon completes the list of variables. As stone content was determined in the field, the mid-point of the scale of stone percentages of the Soil Survey Handbook (1960) was set for each site.

Thus, the data matrix used in the following chapters involves the thirty variables outlined above, at the seventy one transect sites; giving 2130 separate items of data.

CHAPTER 8 - THE APPLICATION OF CLUSTER ANALYSIS TO LAND EVALUATION PROCEDURE

8.1 Introduction

This chapter outlines two techniques of clustering applied to the transect sites as a means of resource inventory assessment, both methods giving equal weight to all variables when allocating a site to a group or "cluster". As Armen (1972) states, this factor is one of the six axioms of Adansonian classification (Adanson, 1763), as outlined by Sokal and Sneath (1963). Another axiom is that the affinity between two entities is to be regarded as a function of the similarity of the characteristics by which these entities are being compared. In order to satisfy both of these axioms the following method was used in the transect and the results of each part are discussed in succeeding sections.

- i). the determination of the affinity between each site.
- ii). the grouping or "clustering" of sites.
- iii). the analysis of the interrelationships between groups.

8.2. Site Affinity Determination

One of the most frequently employed coefficients of similarity in numerical taxonomy is the Pearson product-moment correlation coefficient, calculated between pairs of "operational taxonomic units" (OTU's), which are defined by Sneath and Sokal (1973) as "the lowest ranking taxa employed in a given study; "i.e. individuals, species, sites etc. As long ago as 1936, Stephenson used this method in psychometric work, but it was first applied to numerical taxonomy by Michener and Sokal in 1957 and Sokal and Michener in 1958. Since then it has been employed in many disciplines, and in 1967 Moore and Russell applied the technique to soil classification.

In statistical theory, Sneath and Sokal point out that the Pearson product-moment correlation coefficient estimates a parameter ρ of the bivariate normal frequency distribution, but in numerical taxonomic data such a distribution is "unlikely in view of the heterogeneity of the column vectors". The characters (rows of the data matrix) are not independent of each other and, therefore, significance tests of the correlation coefficients cannot be based on the usual assumptions. In addition, if different characters are measured in widely differing scales, the validity of the correlation coefficient will be impaired even further. Sneath and Sokal propose that, to by-pass this problem, the long advocated procedure of psychometricians, that the rows of the data matrix should be standardised (equivalent to standardization of characters over all OTU's) is desirable. In such cases, the mean of the column vectors frequently approaches 0 and permits a representation of inter-OTU relations by a relatively simple geometrical model, as Rohlf and Sokal (1965) point out. Thus, the angles between the vectors bearing the OTU's at their tips are measures of the similarity between the OTU's. The smaller the angles the greater the similarity between the OTU's. In those instances in which the vectors carrying the OTU's are of unit length and the column means are zero, the cosine of the angle between any two vectors is an exact measure of the correlation coefficient. Standardisation of the characters will approximately normalise the column vectors of the OTU's and correlation coefficients based on such data will, therefore, approximate the cosines of the angles of a geometrical model in A - space for these OTU's.

The Pearson product-moment correlation coefficients and standardisation procedure of Sneath and Sokal (1973) as outlined above, were calculated for the transect sites and the resultant coefficient matrix is shown schematically in Figure 8.1. As Armen (1972) indicates, the computation of correlation or, in the case of the data matrix under consideration, more correctly, "similarity coefficients", between all the possible combinations of the selected seventy one sites into pairs, may be likened to a search for similar patterns of variation over the total thirty characteristics. If each site's characteristics were plotted as a line waving above or below the level datum represented by the average of the sites as a whole, then the coefficient may be said to express the degree of wave concordance between two sites.

8.3. Definition of the Term "Cluster"

There has been much controversy over the years as to what constitutes a cluster and there is no universal agreement on a definition. It is probably true that no single definition is sufficient (Everitt, 1974). Many proposed definitions contain statements such as "a cluster is a set of entities which are alike and entities from different clusters are not alike". Others indicate that entities within a cluster are more similar to each other than entities from other clusters. Wallace and Boulton (1968) suggest that a cluster is a subset of entities which may usefully be treated as equivalent in some discussion. Gengrelli (1963), on the other hand, defines a cluster as an aggregate of points in a test space, such that the distance between any two points in the cluster is less than the distance between any point in the cluster and any point not in it.

However, perhaps the most pragmatic estimate criterion for evaluating the meaning of terms such as "cluster" or "similarity" is suggested by Bonner (1964), as being purely the value judgement of the user. Everitt indeed proposes that "if using the terms produces an answer of value to the investigator, that is all that is required".

For the transect analysis, two methods of producing clusters of sites from the initial similarity matrix were employed. The first is a simple highest affinity pair by pair analysis and the second is a more detailed hierarchical clustering procedure. The details and analysis of each, together with natural resource inventories produced from the groupings, are discussed in Sections 8.4 and 8.5 which follow.

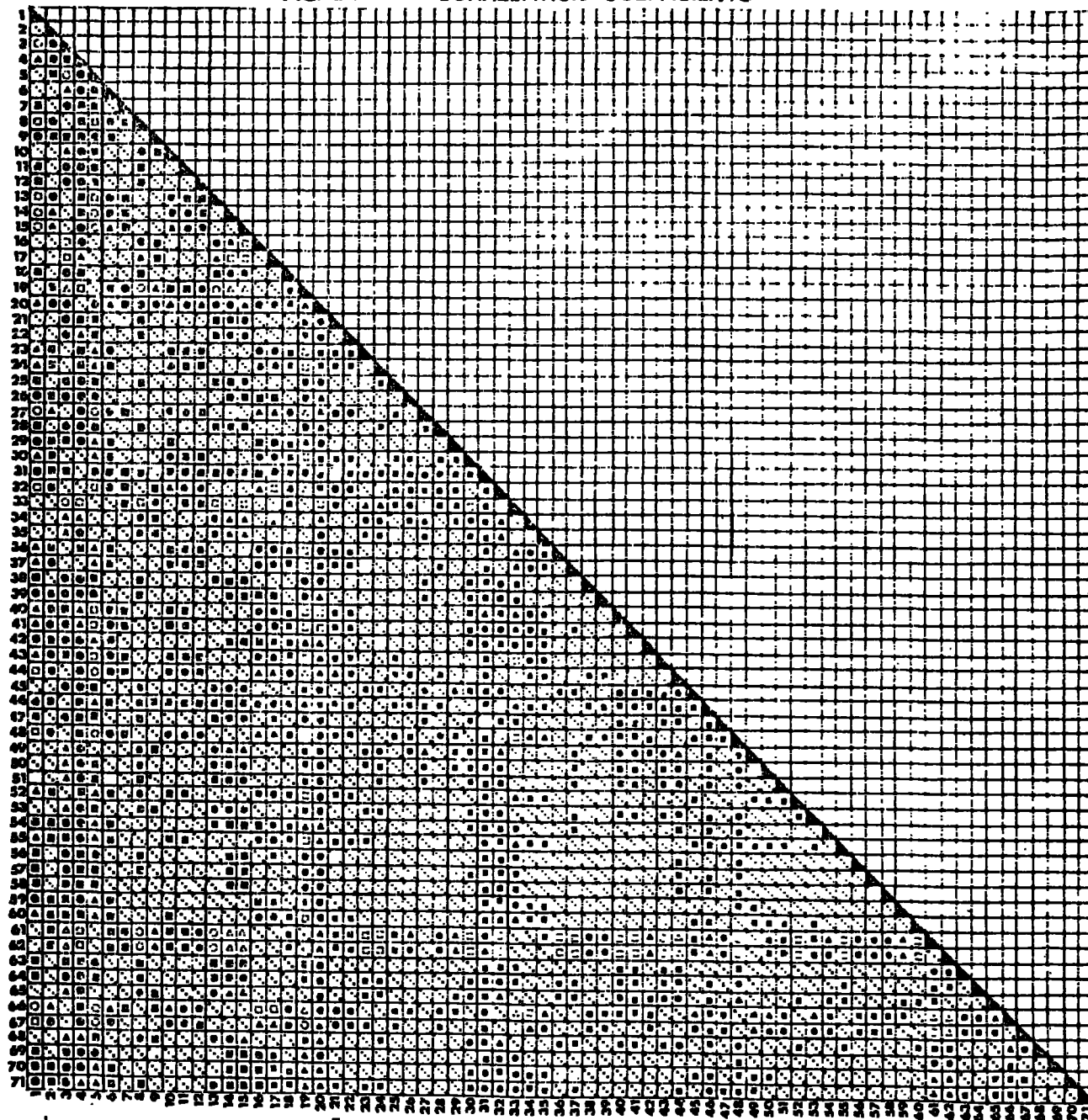
8.4 The Clustering of Transect Sites on the Basis of Highest Affinity

8.4.1 Clustering Procedure

Each site was paired with another on the basis of the highest affinity of each, as suggested by Cole and King (1968) and Armen (1972). The lowest affinity is 0.900 and the highest 0.999.

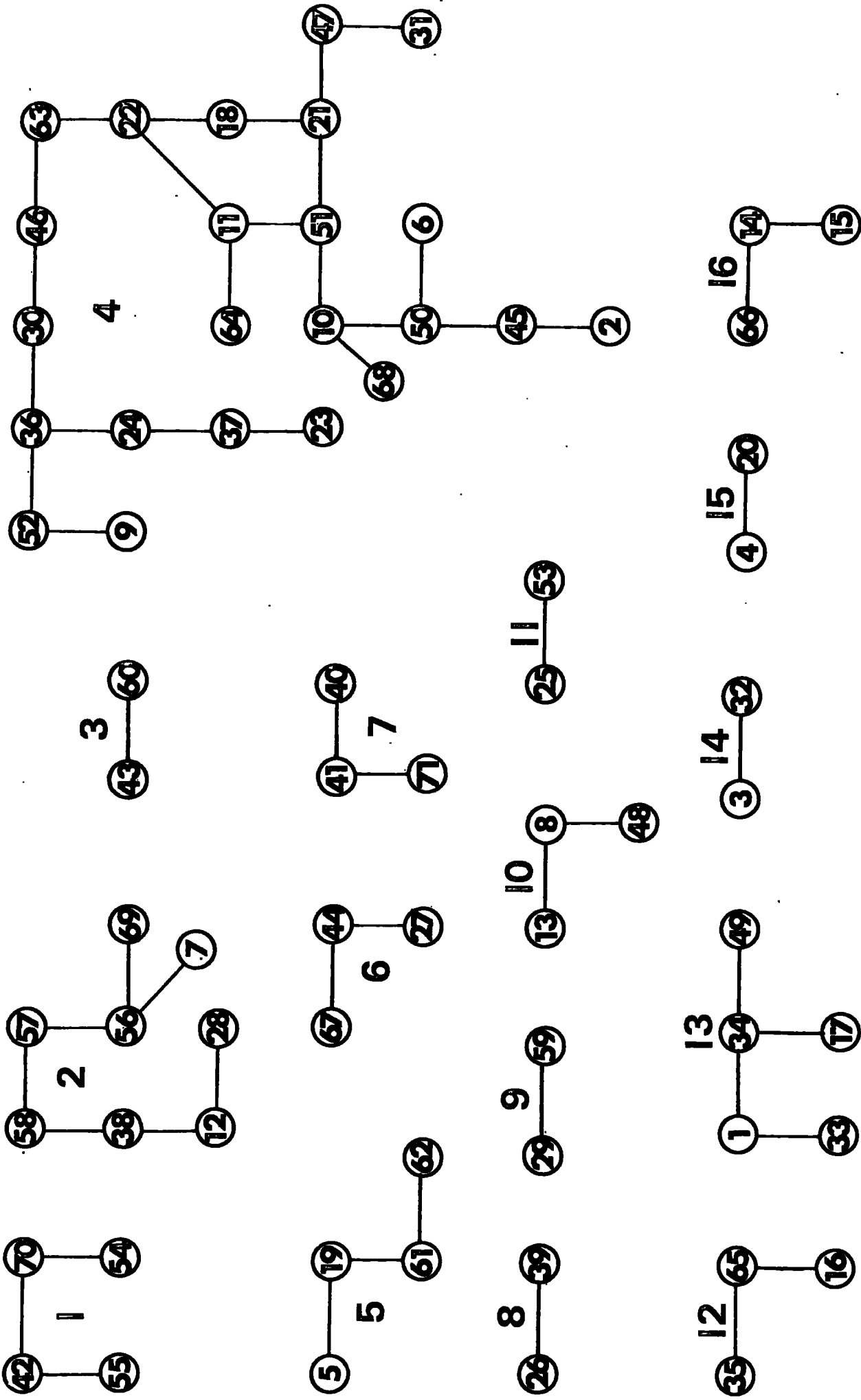
From these initial pairs, clusters of sites were delineated by observation at the highest level to form enclosed groups. Sixteen such clusters emerge as shown in Figure 8.2. A site at the focus of radial links may be considered as the archetype of a particular group; for example, Sites 19, 34 and 57, whilst a position at the end of a chain of links indicates a highly individual or unique site, for example, 2, 9 and 28.

FIG. 8.1 SITE CORRELATION COEFFICIENTS



Δ .3-.4
 $\circ$.4-.5
 $\square$.5-.6
 ∇ .6-.7
 $\bullet$.7-.8
 $\blacksquare$.8-.9
 $:$.9-1.0

Fig.8.2 HIGHEST AFFINITY CLUSTERS



The description of each cluster (Figure 8.2) is presented in Section 8.4.2 in short note "modal" profile form; i.e. a profile is constructed which has the general properties of the sites in the cluster. Special reference is made to the topsoil, sampled for this analysis at the 5 cm depth, and the subsoil, sampled at 30 and 40 cm according to characteristic (see Chapter 7, Page 253). Topsoil and subsoil, as described in the text, refer to these depths. Although not included in the cluster analysis calculation, depths outside these points and certain other site and soil characteristics are also included, to make a more complete inventory. The order in which the sites are discussed has no significance.

8.4.2. Description of Clusters Showing Main Soil and Site Characteristics and Short Outline of Land Potential

Cluster 1

Sites : 42,54,55,70
Location: : Permian, Escarpment (Unit 6).

Main Site Characteristics

Angle of Slope : Apart from Site 70 all are strongly to moderately steeply sloping.
Altitude : 116 - 130 m O.D.
Land Use : Mixed woodland or permanent grass.
Aspect : SSE - WSW.

Main Soil Characteristics

Soil Type : Typical brown calcareous earth.
Texture : Loam, silty loam or silty clay loam (humose or mineral) in the topsoil, with clay loam or silty clay loam (humose or mineral) in the subsoil. Stony topsoil; content increasing with depth.
Structure : Moderately developed, fine to medium granular or medium subangular blocky at the surface, passing to fine to medium subangular blocky in lower horizons.
Depth : Depth to in situ rock varies between 44-55 cm.
pH : Neutral to alkaline (6.6 - 7.3) in the topsoil, increasing to alkaline in the subsoil (7.0 - 7.5). More alkaline with depth.
Base Status : Base saturation is moderate to high in the topsoil and increases with depth to reach very high values in the C horizon.
Drainage : Well drained (free) at shedding sites.
Land Potential : Excessive slope restricts agricultural practice to permanent pasture where it provides good grass, or to forestry. Coniferous production is limited owing to the soil reaction and shallow depth to rock. These sites are not suitable for building development but are useful for recreation. Subsidence is a problem. Good nature conservation potential.

Cluster 2

- Sites : 7,12,28,38,56,57,58,69
- Location : Apart from Site 7 at MoorHouse, all are located in the eastern part of the transect, particularly associated with Coalfield Vale (Unit 5). Two sub-clusters may be distinguished; the first of Sites 12,28,38 and 58 being slightly better drained than the second of Sites 7,56,57 and 69. The latter are well drained (free) and imperfectly drained profiles as against a preponderance of poorly drained in the former group. Site 58, although appearing to play an archetypal role, is a well drained disturbed soil which has possibly suffered drainage problems before disturbance. This site, however, does appear to play a "watershed" role between the two sub-clusters.

Main Site Characteristics

- Angle of Slope : Level to moderately sloping, apart from Site 56 which is strongly sloping.
- Altitude : 79-142 m O.D.
- Land Use : Predominantly under arable or permanent grass.
- Aspect : SSW-NNW.

Main Soil Characteristics

- Soil Type : Stagnogleyic brown earth; cambic stognogley, cambic stagnohumic gley or disturbed soil.
- Texture : Predominantly clay loam, but also loam or silty loam (humose or mineral) in the topsoil, with loam, clay loam or occasionally silty clay in the subsoil. Very rare stones to slightly stony, with Site 28 being stony.
- Structure : Moderately weak to moderately developed, medium to coarse sub_angular or angular blocky in the surface horizon, passing to moderate to moderately strongly developed, medium or coarse subangular blocky in lower horizons. Becomes massive.
- Depth : Depth to in situ rock in excess of 100 cm. Roots generally penetrate into heavier drift subsoil layers without difficulty, although, in some profiles, root penetration may be restricted by wetness, as at Site 57 below 47 cm and Site 69 below about 40 cm.
- pH : The topsoil is pedominantly neutral (6.1 - 6.8), although some sites show a slightly or moderately acid horizon and one is alkaline. In the subsoil reactions vary from slightly acid to alkaline, but generally are neutral.
- Base Status : Base saturation is generally low or moderate throughout the profile but occasionally increases with depth.
- Drainage : Apart from Site 58, all are imperfect or poor. Profiles may be wet during winter owing to the receiving nature of some sites.

Land Potential : Although providing reasonable arable land, acidity and base status problems may be encountered and poor drainage may adversely affect a crop. Providing drainage problems can be solved, coniferous forestry may be advantageous if the reaction is carefully considered. Poor drainage is similarly a problem for building and recreational developments.

Cluster 3

Sites : 43,60.
Location : Permian Escarpment and Plateau (Units 6 and 7) located 620 m apart.

Main Site Characteristics

Angle of Slope : Gently sloping.
Altitude : 126 and 137 m O.D.
Land Use : Arable and permanent grass.
Aspect : ESE - SE.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth.
Texture : Clay loam in the topsoil and subsoil. Very rare stones to slightly stony.
Structure : Moderately developed subangular blocky in the surface horizon passing to moderately developed coarse or medium subangular blocky in lower horizons. Becomes massive.
Depth : Depth to in situ rock in excess of 100 cm. No roots visible in the BCg horizons at 40 cm and below.
pH : Slightly acid to neutral topsoil passing to slightly acid to moderately acid subsoil.
Base Status : Base saturation is low (<42%) in all horizons.
Drainage : Imperfect.
Land Potential : Acidity and base status problems may restrict arable production even though the rock in situ is limestone; the full effect of the overlying till being felt. The sites appear reasonably good for forestry. Subsidence restricts building construction but there is good recreational potential.

Cluster 4

Sites : 2,6,9,10,11,18,21,22,23,24,30,31,36,37,45,46,47,50,51,52, 63,64,68.
Location : 56.5% of the sites are located in the centre of the transect in Unit 4, with 21.7% west of the River Wear in Units 1 and 2. Sites 10 and 1 are situated in Unit 6, although off the Magnesian Limestone.

Main Site Characteristics

- Angle of Slope : Gently to moderately sloping predominates (mean = 3.0°).
Altitude : 38-103 m O.D. (mean = 75.0m).
Land Use : Mainly arable or grass ley (69.6%) with some permanent grass. Mixed farming accounts for 91.3% of the sites, the remainder being under woodland.
Aspect : ENE-NNW.

Main Soil Characteristics

- Soil Type : Surface - water gley soil accounts for 60.8% of sites, divided equally between cambic stagnogley and cambic stagnohumic gley. The remaining profiles are stagnogleyic brown earth (17.4%), gleyed soil on alluvium (typical (non-calcareous) alluvial gley and gleyed brown alluvial soil) and disturbed soil.
The disturbed soils (Sites 9,23,37) are situated at the end of the cluster links.
- Texture : Topsoil texture falls into two broad groups; humose or mineral loams or silty loams (34.8% of all sites) and humose or mineral clay loam, silty clay loam or clays (65.2% of all sites). Subsoil texture is heavier, the majority of profiles being clay loam, silty clay loam or sandy clay loam. The remainder of profiles are silty clay or clay, or loam and silty loam. Very rare stones to very stony but very rare to slightly stony predominates at 69.6% of sites.
- Structure : Moderately weak to moderately developed, granular or subangular to angular blocky in the surface horizon, passing to granular, subangular blocky or prismatic in lower horizons. Becomes massive, or occasionally single grain.
- Depth : Depth to in situ rock exceeds 100 cm. Root penetration is restricted by wetness and/or the intractable nature of the drift parent material at certain sites; in particular those associated with the laminated clays west of the River Wear. In general, a clay loam or silty clay loam subsoil does not appear to unduly affect rooting, whereas a clay subsoil does. The stagnogleyic brown earth profiles are less affected by this phenomenon than the surface or ground-water gleys.
- pH : Mainly slightly acid (34.8%) or neutral (30.4%) topsoil, although 17.4% of sites are moderately or strongly acid. Only 13.0% are alkaline. In the subsoil there are less sites with an acid reaction (47.8%) but over one quarter have a moderately or strongly acid pH.
- Base Status : Base saturation is below 50% at the majority of profiles, being commonly around 30-40%. It falls below 10% at some sites.

- Drainage : Predominantly poorly drained, with some imperfect or occasionally, moderately well drained or well drained (free) conditions associated with disturbed soils.
- Land Potential : Soil reaction and base saturation problems affect agricultural potential at most sites, making liming at regular intervals a necessity. Poor drainage may also be detrimental. Acidity makes coniferous forestry worthwhile on adequately drained sites or where drainage improvements can be effected. Weak structure and high silt content may lead to capping and the formation of hard clods at some sites in the western part of the transect. The gentle slopes of Units 1 and 4 allow building development to take place, although adequate drainage may prove a defect, but one that is capable of being overcome. Recreational development for both passive and active pursuits is possible where slope and drainage permit.

Cluster 5

- Sites : 5,19,61,62.
- Location : River Wear Gorge and Floodplain (Unit 3). There appear to be two sub-clusters recognisable. Sites 5 and 19 are both brown alluvial soils developed on river sand, located in close proximity at Mallygill. Sites 61 and 62, on the other hand, are both ground-water gleys developed on heavier alluvium at Kepier.

Main Site Characteristics

- Angle of Slope : Level (Sites 5,19) or moderately sloping (Sites 61,62).
- Altitude : 27-30 m O.D.
- Land Use : Deciduous woodland or permanent grass.
- Aspect : NW-WSW.

Main Soil Characteristics

- Soil Type : Typical and gleyic brown alluvial soil, typical (non-calcareous) alluvial gley or typical (non-calcareous) humic alluvial gley.
- Texture : Loamy sand, silty loam or clay loam (humose or mineral) in the topsoil, passing to loamy sand, loam or clay loam in the lower horizons and parent material. Very rare stones to slightly stony.
- Structure : Weakly to moderately developed, granular or subangular blocky structure in the surface horizon, passing to weak to moderately strongly developed, granular, subangular blocky or prismatic in the lower horizons. These lie above massive or single grain alluvial parent material.
- Depth : There are few restrictions on root penetration particularly those profiles developed on river sand. The ground-water gley profiles may show wetness limitations to roots in winter.

pH : Strongly to slightly acid (3.4 - 5.6) in the topsoil, increasing slightly, to strongly to slightly acid (3.8 - 5.9) in the subsoil.

Base Status : Base saturation does not rise above a moderate 57% and falls to as low as 5.54% in the Ah horizon of Site 19.

Drainage : Well drained (free) or imperfect or poor, according to sub-cluster, on normal or receiving sites.

Land Potential : All sites are subject to flooding and most have physical site restrictions in being located in the Wear Gorge and Floodplain. The soils are acidic with low base status. Agricultural potential is low, although livestock may be grazed, especially where the gorge opens out at Kepier. Commercial forestry is restricted because of the flooding risk, and building construction is not possible, also because of this factor and site restrictions. The sites are particularly suitable for amenity woodland and recreational use of an informal nature and nature conservation potential is very high.

Cluster 6

Sites : 27,44,67.

Location : Coalford Vale (Unit 5) and Permian Plateau (Unit 7).

Main Site Characteristics

Angle of Slope : Level or moderately sloping (Mean = 2.6°).

Altitude : 109 - 160 m O.D. (Mean = 132.0 m).

Land Use : Arable or coniferous woodland.

Aspect : NE-ESE.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth or cambic stagnogley.

Texture : Clay loam or clay in the topsoil and subsoil (occasionally humose). Very rare stones to stony.

Structure : Moderately developed medium to coarse subangular blocky surface, passing to moderately developed medium subangular blocky lower horizons. Becomes massive.

Depth : Depth to rock in situ in excess of 100 cm. Root penetration is affected; particularly if the subsoil is clay.

pH : Moderately acid to neutral in the topsoil and subsoil.

Base Status : Base saturation does not rise above a moderate 53% and is commonly below 37%.

Drainage : Imperfect or poor.

Land Potential : Acidity and base status problems restrict good arable production. The requirements of commercial forestry are better met, although windthrow hazard on the Permian Plateau is a restriction. Building and recreational potential is low.

Cluster 7

Sites : 40,41,71.
Location : Permian Escarpment (Unit 7) on the Magnesian Limestone.

Main Site Characteristics

Angle of Slope : Moderately to steeply sloping.
Altitude : 128-145 m O.D.
Land Use : Arable or scrub.
Aspect : SSE-W.

Main Soil Characteristics

Soil Type : Brown (non-humic) rendzina.
Texture : Loam, clay loam or silty clay loam (humose or mineral) in the topsoil, which overlies the brecciated Magnesian Limestone of the C horizon. Topsoil may be slightly to extremely stony, depending on whether ploughing has brought rock to the surface.
Structure: Moderate to weakly developed crumb or subangular blocky.
Depth : Depth to in situ rock varies from 25-30 cm, with the C horizon met at 19-21 cm. As with most rendzinas, root development is restricted by rock, but the friable nature of the limestone allows root penetration to an extent.
pH : Alkaline (7.1 - 7.4); increasing in intensity with depth.
Base Status : Base saturation is high to very high, but profiles may be inherently deficient in potash, a situation corrected by the application of potash fertilizer or manure.
Drainage : Well drained (excessive) on shedding sites. Because of the fragmented nature of the underlying rock, allowing roots to penetrate to water stored in the rock, crops rarely suffer badly from drought, although scorching may occur in dry periods.
Land Potential : Despite the shallowness of the soil, where slope permits, these sites are well adapted to arable crops, particularly cereals. Cultivation may be difficult because of the shallow depth to the C horizon resulting in damaged implements. The sites are less suitable for grass which may suffer damage in dry periods. Alkalinity and shallow depth preclude coniferous forestry and depth also affects deciduous trees. Subsidence, slope and shallow depth precludes building development but, being located on the limestone, the sites provide good informal recreation areas. Because of the alkaline soil reaction and inherent characteristics of the limestone, these areas are important botanically and can form valuable havens for all types of wildlife.

Cluster 8

Sites : 26,39.
Location : Permian Plateau (Unit 7); located 450 m apart on the spur of Pittington Hill.

Main Site Characteristics

Angle of slope : Gently to moderately sloping.
Altitude : 152 and 155 m O.D.
Land Use : Arable.
Aspect : NW.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth.
Texture : Clay loam in the topsoil and subsoil. Slightly stony to stony.
Structure : Moderately developed medium subangular blocky plough horizon overlies moderately developed medium to coarse subangular blocky lower horizons if present. Massive below.
Depth : Depth to in situ rock in excess of 100 cm. No rooting restrictions.
pH : Site 26 is neutral to alkaline in the topsoil and subsoil whilst Site 39 is moderately acid.
Base Status : Base saturation does not rise above 35%.
Drainage : Moderately well or imperfectly drained.
Land Potential : Acidity and base status problems require attention, but otherwise, apart from exposure, there are few restrictions on arable or forestry use. Subsidence affects building construction, but recreational development of an informal nature is possible.

Cluster 9

Sites : 29,59.
Location : Permian Plateau (Unit 7) at Hetton-le-Hole.

Main Site Characteristics

Angle of Slope : Level or moderately sloping.
Altitude : 137 m O.D.
Land Use : Arable.
Aspect : SSW.

Main Soil Characteristics

Soil Type : Cambic stagnogley or stagnogleyic brown earth.
Texture : Loam or clay loam in the topsoil, overlying clay loam or clay in the subsoil. Slightly stony.

Structure : Moderately developed, medium granular or subangular blocky Ap horizon, overlies moderately developed medium subangular blocky lower horizons. Becomes massive.

Depth : Depth to in situ rock in excess of 100 cm. Apparent rooting restrictions occur where clayey drift results in wetness.

pH : Neutral to alkaline in the topsoil and subsoil.

Base Status : High base saturation.

Drainage : Poor or imperfect. May be wet during winter.

Land Potential : Generally good for arable if wetness in spring does not persist, but too alkaline for coniferous forestry. Unsuitable for building construction owing to subsidence, but good for informal recreation if the drainage is improved.

Cluster 10

Sites : 8,13,48.

Location : Lowlands East of the River Wear (Unit 4) and Permian Plateau (Unit 7).

Main Site Characteristics

Angle of Slope : Level to moderately sloping.

Altitude : 64-119 m O.D.

Land Use : Arable or grass ley.

Aspect : NNE-ENE.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth, cambic stagnogley or cambic stagnohumic gley.

Texture : Loam, silty loam or silty clay loam (humose or mineral) in the topsoil, above a loam, clay loam or silty clay subsoil. Very rare stones to very stony.

Structure : Moderate to moderately weakly developed, granular, angular or subangular blocky in the surface horizon, passing to moderately developed, angular or subangular blocky in lower horizons. Becomes massive.

Depth : Depth to in situ rock in excess of 100 cm. Deep B horizons facilitate root penetration.

pH : Moderately acid to neutral in the topsoil, widening in range to strongly acid to alkaline in the subsoil.

Base Status : Base saturation is low, not rising above 35%.

Drainage : Moderately well, imperfect or poor drainage.

Land Potential : These sites form tolerable arable land, where acidity and low base status can be combatted, but stones can be a problem. Regular liming necessary. Deep solum allows good rooting. Potential is moderately good for forestry and also building development if located off the limestone. Formal and informal recreational potential is moderately high.

Cluster 11

Sites : 25,53.
Location : Lowlands East of the River Wear (Unit 4) near Pittington.

Main Site Characteristics

Angle of Slope : Level to gently sloping.

Altitude : 87 and 106 m O.D.

Land Use : Arable.

Aspect : WNW.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth and cambic stagnogley.

Texture : Loam (humose or mineral) in the topsoil and subsoil.
Stony.

Structure : Moderately developed medium subangular blocky; becoming massive at depth.

Depth : Depth to rock in situ in excess of 100 cm. Sandier texture facilitates root penetration.

pH : Neutral to alkaline in the topsoil and subsoil.

Base Status : Base saturation is moderate to very high.

Drainage : Imperfect or poor depending on normal or receiving nature of site.

Land Potential : Good for arable despite wetness at surface as there is good texture and structure. Soil reaction too alkaline for coniferous forestry. Suitable for recreation if the drainage is improved.

Cluster 12

Sites : 16,35,65.

Location : Lowlands, West and East of the River Wear (Units 1 and 4).

Main Site Characteristics

Angle of slope : Level to moderately sloping.

Altitude : 61-78 m O.D.

Land Use : Arable or permanent grass.

Aspect : WNW.

Main Soil Characteristics

Soil Type : Typical brown earth, cambic stagnohumic gley or typical (non-calcareous) alluvial gley.

Texture : Loam topsoil (humose or mineral) overlies a sandy loam, loamy sand or sandy clay loam subsoil. Very rare stones to slightly stony.

Structure : Moderately weak to moderately developed subangular blocky in the surface horizon, passing to moderately weak to moderately developed, subangular or angular blocky in lower horizons. Predominantly massive below.

Depth : Depth to rock in situ in excess of 100 cm.

pH : Slightly acid to neutral topsoil, becoming moderately acid to neutral in the subsoil.

Base Status : Base saturation is commonly below 40% but does not rise above 46%.

Drainage : Well drained (free) or poor depending on site.

Land Potential : Despite gleyed profiles at two of the sites, agricultural production is not restricted by drainage factors, the sandy horizons aiding root development. Coniferous forestry potential is high. Building and formal recreational developments are restricted by poor drainage and/or slope.

Cluster 13

Sites : 1,17,33,34,49.

Location : Lowlands West and East of the River Wear (Units 1 and 4) and Upper Slopes East of the River Wear (Unit 2).

Main Site Characteristics

Angle of Slope : Level to moderately sloping, apart from Site 33 which is steeply sloping.

Altitude : 46-69 m O.D.

Land Use : Arable, permanent grass, scrub or deciduous woodland.

Aspect : N-WNW.

Main Soil Characteristics

Soil Type : Cambic stagnogley, cambic stagnohumic gley, typical (non-calcareous) alluvial gley or disturbed soil.

Texture : Silty loam or silty clay loam (predominantly humose) in the topsoil, over clay or silty clay in the subsoil and drift below. Stones are very rare, apart from Site 17, which is very stony.

Structure : Moderately weak to moderately developed, granular or subangular blocky at the surface, passing to moderately developed, medium subangular or prismatic lower horizons. Becomes massive.

Depth : Depth to in situ rock in excess of 100 cm. Heavy textured drift affects root penetration and drainage from 28-71+ cm.

pH : Moderately acid to neutral in the topsoil and subsoil, apart from Site 17 which is alkaline in the subsoil.

Base Status : Base saturation is variable from very low to high.

Drainage : Poor.

Land Potential : Acidity and poor drainage affect agriculture and the "heavy" texture make soils difficult to cultivate. The sites are better suited to grass than arable. Improved drainage is also required for forestry, building and recreation but the gentle slopes (apart from Site 33) assist these land uses.

Cluster 14

Sites : 3,32.
Location : Lowlands West of the River Wear (Unit 1) and Upper Slopes East of the River Wear (Unit 2).

Main Site Characteristics

Angle of Slope : Level to gently sloping.
Altitude : 55 and 58 m O.D.
Land Use : Arable or permanent grass.
Aspect : NNE.

Main Soil Characteristics

Soil Type : Cambic stagnohumic gley and cambic stagnogley.
Texture : Humose silty loam topsoil overlies a silty clay loam to silty clay subsoil. Very rare stones.
Structure : Moderately developed, granular or subangular blocky in the surface horizon, passing to moderately developed coarse angular blocky in lower horizons. Becomes massive.
Depth : Depth to rock in situ in excess of 100 cm. Rare roots after 28-34 cm indicates the impermeability of the drift.
pH : Moderately acid to neutral in the topsoil and subsoil. Becomes more acid in Site 3 with depth.
Base Status : Base saturation is variable, from low to high.
Drainage : Poor drainage, with a possibility of ponding on soil surface during winter periods due to slow percolation of water.
Land Potential : The sites are not particularly suited to arable crops, although oats were grown at Site 3 when surveyed. The high silt content may lead to capping and the formation of hard clods. Acidity is a restriction. Forestry may be adequate with drainage improvements and the level to gentle slopes facilitate building and recreational development, but drainage again is a problem.

Cluster 15 :

Sites : 4,20.
Location : Upper slopes West of the River Wear (Unit 2) and River Wear Gorge and Floodplain (Unit 3).

Main Site Characteristics

Angle of Slope : Level or moderately sloping. Both sites are situated at the base of long regular slopes where the angle levels off.
Altitude : 30 and 37 m O.D.
Land Use : Arable or permanent grass.
Aspect : NE.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth or typical brown alluvial soil.
Texture : Loam or loamy sand in the topsoil passes to clay loam or sandy loam in the subsoil. Horizons are sandy with typically over 62% sand. Very rare stones to slightly stony.
Structure : Moderately weak to moderately developed, granular or subangular blocky surface overlies very weak to moderately developed, fine to medium subangular blocky lower horizons. Massive or single grain at depth.
Depth : Depth to in situ rock in excess of 100 cm.
pH : Slightly acid topsoil overlies a slightly to moderately acid subsoil.
Base Status : Base saturation is very small to moderate, not rising above 42.5%.
Drainage : Well or moderately well drained.
Land Potential : Physical site restrictions, flooding risk, acidity, low base status and poor structure affect agriculture, forestry and building development according to site. Recreational potential is restricted to amenity woodland, paths and trails. Nature conservation potential is high.

Cluster 16

Sites : 14,15,66.
Location : Lowlands East of the River Wear (Unit 4) and Permian Plateau (Unit 7).

Main Site Characteristics

Angle of Slope : Level to moderately sloping.
Altitude : 91-118 m O.D.
Land Use : Permanent grass, scrub or deciduous woodland.
Aspect : NNE.

Main Soil Characteristics

Soil Type : Typical brown earth, cambic stagnogley or disturbed soil.
Texture : Sandy loam or clay loam topsoil overlies a loam or clay loam subsoil. Very rare stones or very stony.
Structure : Moderately developed, crumb or subangular blocky; becoming massive where drift present.
Depth : Depth to rock in situ in excess of 100 cm at Sites 14 and 15 where drift near the surface, but at 70 cm at Site 66. Root penetration is restricted.
pH : Slightly acid topsoil passes to a neutral or alkaline subsoil.
Base Status : Base saturation is small (< 35.4%).

- Drainage : Well drained (free) at Site 66; poorly drained at Sites 14 and 15.
- Land Potential : Wetness is a limitation to arable production at Sites 14 and 15, and drift or rock in situ near to the surface at all sites poses rooting problems. Forestry, building and recreational development is possible, but stoniness is a restriction at Site 66.

8.4.3. Conclusions

The analysis of site affinity by means of pair by pair highest affinity clustering, has produced recognisable groupings that are definable in both pedological and general non-classificatory land capability terms. The method proves not only useful in highlighting the complex relationships between sites, but enables problems concerning the management and land use potential of the sites to be analysed by means of an inspection of the clusters produced.

As this analysis is not a typical parametric capability classification for a specific land use, undertaken to define specific capability gradings, but is, in many ways, more akin to a composite information inventory evaluation, capability is inferred for most land uses for each cluster of sites. As indicated in Chapter 7 on Page 250, to an extent, the advantages of both the parametric and composite approaches are encapsulated in one method - a quantitative approach allowing multi-land use site inventory assessment.

The method has, however, considerable drawbacks in that, as the sites are clustered on a highest affinity basis, the number of groupings is large and in some cases clusters only refer to two sites.

The next section, in attempting to reduce the number of clusters to a manageable number, outlines a more analytical approach to the problem of site grouping by using a method of numerical cluster analysis. The application of a linkage algorithm, to cluster sites from the initial similarity matrix, introduces the concept of a hierarchy of sites.

8.5 The Clustering of Transect Sites by Linkage Analysis

8.5.1 Clustering Procedure

The linkage program used to cluster the transect sites from the initial similarity matrix, described on Page 255 and shown in Figure 8.1, is the one developed by Palmer (1974). The procedure is a type of grouping algorithm, through hierarchal classification by reciprocal pair analysis with no inbuilt contiguity constraint. The methodology is extensively described in Palmer's work on the population characteristics of North East England, but is essentially based upon the concept of the proximity between points distributed in multi-dimensional space being a measure of the overall similarity between the areas concerned (Palmer, 1975; pers.comm.). It is similar to the linkage analysis outlined by Baxter (1976).

The results of the computation appear as a table of "distances of link", or "linkage coefficients", between various sites, which may be efficiently represented as a dendrogram or linkage tree. This indicates which observational units join a cluster at each level of the process; the linkage coefficients providing a measure of the distance separation of the observational unit about to join a cluster and the centroid of the cluster. These increase in value for each level of the dendrogram.

The dendrogram for the seventy one sites is shown in Figure 8.3. For the total number of sites there are seventy levels of the linkage process before the entire collection constitutes only one cluster. Thus, at a linkage coefficient of zero there is complete detail, with seventy one separate cases; at a coefficient of 1.0 this is reduced to four clusters and at 1.5 only two clusters are represented.

Perhaps the greatest problem involved in all clustering techniques, on anything other than a highest affinity basis, is the difficulty of deciding the number of clusters present in the data, and as Everitt (1974) points out, this is not surprising considering the difficulty inherent in defining the term "cluster" in the first place. Clearly, in the case of clustering the transect sites to produce a quantitative multi-land use site inventory system, the number of clusters extracted and thus described, will affect both the nature and interpretation of such a system and it is here that such clustering techniques can be criticised. To an extent, the number of clusters recognised is dependent on the amount of detail required by the investigator, and this implies that a somewhat arbitrary decision has to be made.

Most hierarchical techniques, including that of Palmer (1974), embody no clear indication of the number of groups to extract, but there are several methods by which they can be defined. For those techniques which seek to optimise some clustering criterion, in this case the linkage coefficients, it is generally suggested that a plot of the criterion value against the number of groups will indicate the number to consider, by showing a sharp increase (or decrease, if the criterion is being minimised) at the correct number of groups. This has been suggested by several authors, for example Friedman and Rubin (1967) and Baxter (1976), but it must be noted that this has been found unsatisfactory by others, for example Thorndike (1953).

Everitt (1974), however, proposes that, in cases where some indication of the correct number is required, it is generally suggested that an examination of the dendrogram for large changes between fusions is useful. The clustering procedure adopted for the transect sites embodies both an analysis of the plot of criterion value against the number of groups and an examination of the dendrogram, within an overall subjective consideration of the number of groups to extract.

As stated in the conclusion to the highest affinity analysis (Section 8.4.3. on Page 271), sixteen clusters is too large a number for convenient interpretation in site inventory terms. The number of clusters, therefore, should be below this figure and, purely on a subjective basis, a figure of about ten would seem appropriate.

An analysis of the plot of linkage coefficients against the number of groups, as shown in Figure 8.4. shows several sharp increases, but especially at levels of about 0.1, 0.14, 0.18, 0.24, 0.45, 0.54 and 0.7. The overall inspection of the dendrogram (Fig.8.3) results in noticeable clusters of sites at a level of between about 0.5 and 0.65, and on a detailed examination at the level of 0.54, as determined on the graph, a figure of eight clusters is extracted. At the next level above, at 0.7, five clusters are extracted, with two disproportionately large clusters taking up fifty four sites between them. At the level below 0.54, at 0.45, twelve clusters are extracted, but four of these involve only one site each. In order to bring these four, statistically, into an appropriate cluster, multiple discriminant analysis, as indicated by Mather (1969) and Knox (1974), could be used. It was considered that this time-consuming process would be of little benefit to the transect site analysis, when at a value of 0.54 a seemingly useful number of clusters is extracted without any uncategorised site problems. The eight clusters at this level were, therefore, chosen for consideration.

FIG. 8.3 SITE DENDROGRAM (Palmer, 1974)

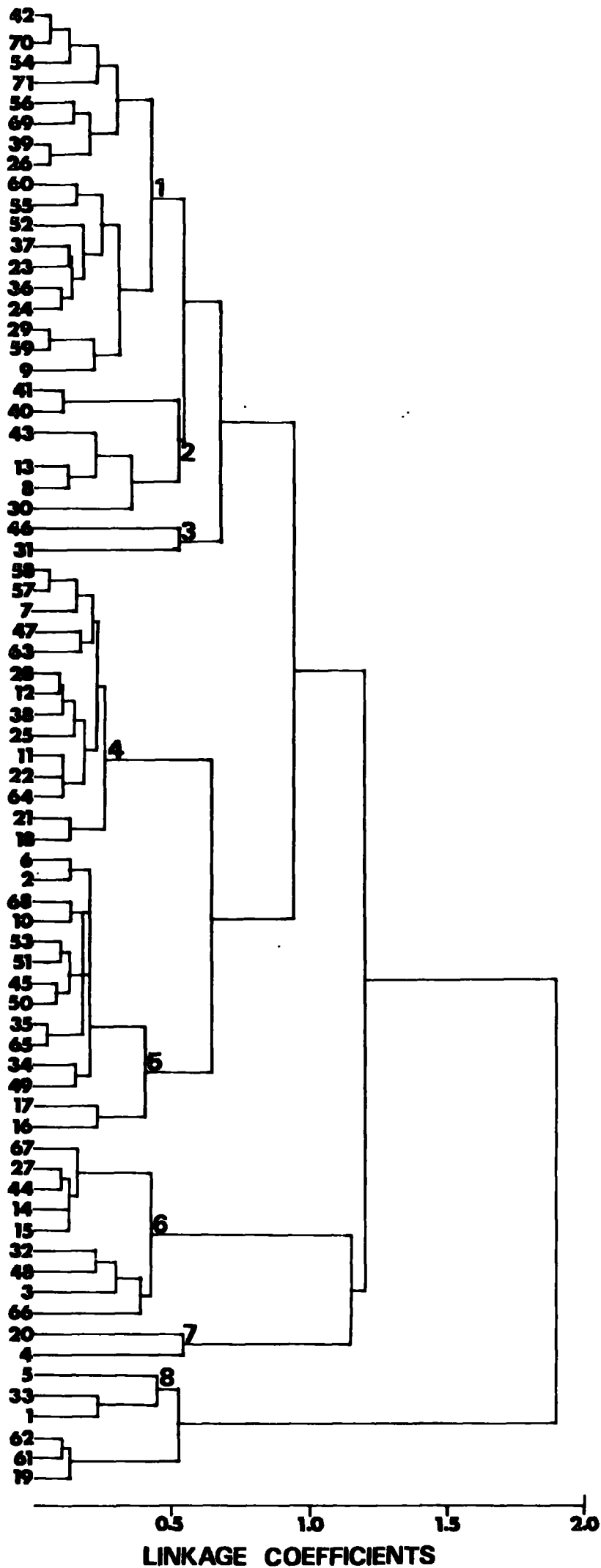
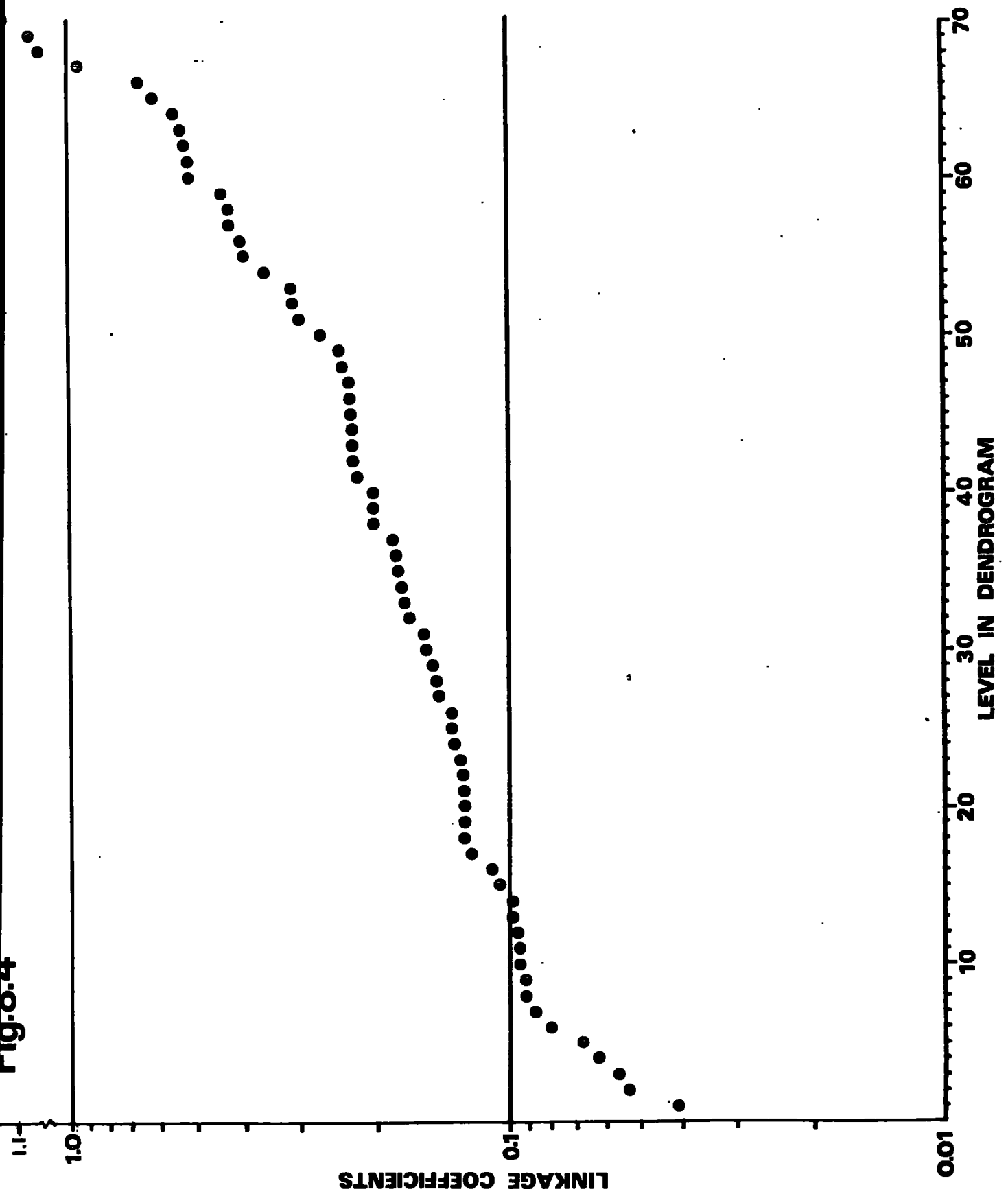


Fig. 8.4



The results of the clustering are described below in Section 8.5.2. following the same format as Section 8.4.2.

8.5.2. Description of Clusters Showing Main Soil and Site Characteristics and Short Outline of Land Potential

The number of each cluster is shown on the site dendrogram of Figure 8.3.

Cluster 1

Sites : 42,70,54,71,56,69,39,26,60,55,52,37,23,36,24,29,59,9.

Location	Physiographic Unit	No. of Sites	% of Sites in Cluster
	4	6	33.3
	5	2	11.1
	6	6	33.3
	7	4	22.2

All the sites are located in the eastern half of the transect, with over half (55.5%) situated on the Magnesian Limestone of the Permian Escarpment and Plateau (Units 6,7). The remaining sites are located just off the escarpment in the Lowlands East of the River Wear (Unit 4) and Coalfield Vale (Unit 5).

Main Site Characteristics

Angle of Slope : Level to steeply sloping, but sites have a moderately sloping mean of 4.8° .

Altitude : 79-155 m O.D.

Land Use - : Arable, permanent grass, mixed or deciduous woodland.

Aspect : E-NW.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth (38.9%), typical brown calcareous earth (22.2%), disturbed soil (16.7%), cambic stagnogley (11.1%), brown rendzina (5.6%) or typical (non-calcareous) alluvial gley (5.6%).

Texture : Loam, silty loam, silty clay loam or clay loam in the topsoil, passing to clay loam or occasionally loam, sandy loam, silty clay loam, silty clay or clay in the subsoil. Stone content variable; from slightly stony to very stony; occasionally very rare stones.

Structure : Moderately to moderately weakly developed, medium crumb, granular, subangular or angular blocky surface horizon, over moderately to moderately weakly developed medium to fine subangular blocky lower horizons. Becomes massive where drift is parent material.

- Depth** : Five profiles have depth to in situ rock of less than 100 cm (42,70,55,54,71). Few root restrictions, apart from the shallow depth of Site 71.
- pH** : 72.2% of sites have neutral or alkaline topsoils; of the remainder only two fall below a pH of 5.0 (Sites 9, 39). In the subsoil the same proportion of sites have neutral or alkaline pH, but the percentage of alkaline profiles rises from 38.8% to 55.6%.
- Base Status** : Base saturation is variable, from very low to very high, but often "hovers" around the moderate category.
- Drainage** : Well drained (free; occasionally excessive) or imperfect. Very occasionally poor where site drainage is receiving.
- Land Potential** : Although steep slope may be a limiting factor at certain locations, the sites are generally good for agriculture, with amenable soil and site characteristics. The effects of the Magnesian Limestone will affect forestry at certain sites and the high pH status will also adversely affect coniferous production at sites off the limestone.
- Subsidence is a problem for building development on the limestone, but off the Permian outcrop, reasonable drainage at most sites makes such development a worthwhile proposition. Nature conservation potential is generally high, as is informal recreation where slope permits.

Cluster 2

- Sites** : 41, 40, 43, 13, 8, 30.
- Location** : As in Cluster 1, this is a grouping of the eastern part of the transect with over half located on the Permian Escarpment and Plateau (Units 6 and 7). Also represented are the Lowlands West and East of the River Wear (Units land 4).

Main Site Characteristics

- Angle of Slope** : Level to gently sloping predominates, but occasionally moderately or strongly sloping.
- Altitude** : 67-137 m O.D.
- Land Use** : Arable.
- Aspect** : ENE-SSE.

Main Soil Characteristics

- Soil Type** : Brown rendzina, stagnogleyic brown earth, cambic stagnogley or cambic stagnohumic gley.
- Texture** : Loam, silty loam, silty clay loam or clay loam in the Ap horizon, passing to loam, clay loam, silty clay loam or rarely sandy clay in the subsoil. Stone content variable.
- Structure** : Moderately, or occasionally, moderately weakly developed medium crumb or medium subangular blocky in the surface horizon, passing to moderately developed medium subangular blocky in lower horizons. Becomes massive where drift is parent material.

Depth: : Apart from the rendzina sites (40,41) depth to in situ rock exceeds 100 cm.

pH : All the topsoils and subsoils are neutral or alkaline, apart from Site 43 which has a slightly acid subsoil.

Base Status : Base saturation varies from low to very high, but has a bias towards moderate to high levels.

Drainage : Well drained (excessive), moderately well drained, imperfect or poor.

Land Potential : Despite variable drainage regimes, good soil and site characteristics make these sites amenable to agriculture. Alkalinity and/or shallow depth factors inhibit forestry. Subsidence affects building development on the limestone at a majority of sites. Where slope permits, recreation potential is high.

Cluster 3

Sites : 31,46.

Location : Upper slopes West of the River Wear (Unit 2) and the River Wear Gorge and Floodplain (Unit 3).

Main Site Characteristics

Angle of Slope : Strongly sloping.

Altitude : 38 and 49 m O.D.

Land Use : Arable or mixed woodland.

Aspect : E.

Main Soil Characteristics

Soil Type : Cambic stagnohumic gley.

Texture : Humose loam or humose silty clay loam topsoil, passing to clay loam or silty clay loam in the subsoil. Very rare stones.

Structure : Very weakly developed fine crumb to moderately developed coarse subangular blocky, according the organic content, at the surface, passing to moderately developed prismatic in lower horizons. Becomes massive.

Depth : Depth to in situ rock in excess of 100 cm. Firm texture may restrict rooting in the subsoil.

pH : Strongly to moderately acid topsoil and subsoil.

Base Status : Base saturation does not rise above low levels in the mineral topsoil, but increases to moderate to high with depth.

Drainage : Poorly drained.

Land Potential : Poor nutrient status and site location restricts use to forestry, amenity woodland, indifferent agriculture or nature conservation.

Cluster 4

Sites : 58,57,7,47,63,28,12,38,25,11,22,64,21,18.

Location	<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
	1	1	7.1
	4	6	42.9
	5	2	14.3
	6	3	21.4
	7	2	14.3

One half of the sites are located to the east in Physiographic Units 5,6 and 7, but the most important single area is Unit 4.

Main Site Characteristics

Angle of Slope : Level to moderately sloping.

Altitude : 55-142 m O.D.

Land Use : Arable and grass ley predominates (85.7%). Also permanent grass and coniferous woodland (Site 58).

Aspect : SSE-N.

Main Soil Characteristics

Soil Type : Cambic stagnogley or cambic stagnohumic gley (71.4%); stagnogleyic brown earth (14.3%); gleyic brown alluvial soil or disturbed (14.3%).

Texture : Loam, silty loam, silty clay loam or clay loam in the topsoil, passing to loam, silty loam, silty clay loam, clay loam or silty clay in the subsoil. Stone content variable.

Structure — : Moderately developed, medium or coarse subangular or angular blocky throughout. Occasionally medium crumb at the surface. Massive predominates at depth.

Depth : Depth to in situ rock in excess of 100 cm. Root restrictions in massive parent material.

pH : Slightly acid to alkaline in the topsoil, apart from the moderately acid Site 38. Subsoil is moderately acid to alkaline apart from the strongly acid Site 18.

Base Status : Base saturation varies from low to very high, but is generally low to moderate in content.

Drainage : Poor drainage predominates. Occasionally imperfect, moderately well drained or well drained (free).

Land Potential : Despite the poor drainage of most of the sites, agriculture or forestry potential is reasonable. Root restrictions may be in evidence, however. There is little restriction on building development, apart from profile drainage. Formal and informal recreational development potential is high if drainage measures take place.

Cluster 5

Sites : 6,2,68,10,53,51,45,50,35,65,34,49,17,16.

Location	Physiographic Unit	No. of Sites	% of Sites in Cluster
	1	4	28.6
	2	1	7.1
	4	7	50.0
	5	1	7.1
	6	1	7.1

The number of sites associated with the Permian outcrop drops substantially in this cluster and those in the Lowlands West of the River Wear (Unit 1) increase to over 25%.

Main Site Characteristics

Angle of Slope: Only one site, the moderately sloping Site 65, rises above the gently sloping category.

Altitude : 52-99 m O.D.

Land Use : Permanent grass (50%) or arable. Occasionally grass ley, deciduous woodland or scrub.

Aspect : SSW-NNW.

Main Soil Characteristics

Soil Type : Predominantly cambic stagnogley or cambic stagnohumic gley. Also typical (non-calcareous) alluvial gley or occasionally disturbed soil or typical brown earth.

Texture : Loam, silty loam, clay loam or clay in the topsoil, overlying loam, silty loam, clay loam, clay or sandy clay subsoil. Stone content is variable.

Structure : Moderately, or occasionally moderately weakly developed, fine or medium granular or fine to coarse subangular blocky surface horizon. Moderately weakly to moderately strongly developed medium to coarse subangular blocky lower horizons. Predominantly massive with depth.

Depths : Depth to in situ rock in excess of 100 cm. Intractable drift restricts rooting where present.

pH : Slightly acid to alkaline horizons predominate, but occasionally moderately or strongly acid.

Base Status : Low to moderate at most sites, but occasionally high or very high, apart from Site 6 which is very low throughout the profile.

Drainage : All sites are poorly drained, apart from Site 57 which is well drained (free).

Land Potential : Poor drainage restricts agricultural use to permanent grass at a number of sites. Forestry potential is fairly good, as is building and recreational development on these shallow sloping sites if drainage can be improved.

Cluster 6

Sites : 67,27,44,14,15,32,48,3,66.

Location	Physiographic Unit	No. of Sites	% of Sites in Cluster
	1	1	11.1
	2	1	11.1
	4	2	22.2
	5	1	11.1
	7	4	44.4

The sites are widely distributed about the transect, but the majority are in the eastern half.

Main Site Characteristics

Angle of Slope : Level to moderately sloping.

Altitude : 55-160 m O.D.

Land Use : Arable, grass ley, woodland, permanent grass or scrub.

Aspect : NNE-ESE.

Main Soil Characteristics

Soil Type : Cambic stagnogley, cambic stagnohumic gley, or stagnogleyic brown earth account for 77.7% of sites, with one disturbed and one typical brown earth.

Texture : Clay-loam or occasionally loam, silty loam or clay in the topsoil, passing to clay loam, silty clay loam or sometimes loam, silty loam or silty clay in the subsoil. Stone content is variable.

Structure : Moderately to moderately strongly developed, crumb, granular or more commonly, medium or coarse subangular or angular blocky surface horizon (apart from Site 66 which is moderately weakly developed). Moderately to moderately strongly developed, coarse angular or subangular blocky or occasionally prismatic in lower horizons. Predominantly massive at depth.

Depth : Depth to bedrock in excess of 100 cm, apart from Site 66 at 70 cm. Parent material may restrict full rooting potential.

pH : Topsoils and subsoils are strongly acid to neutral, apart from Site 66 which has an alkaline subsoil.

Base Status : Base saturation is predominantly low and sometimes very low.

Drainage : Poorly or imperfectly drained, apart from Site 66 which is well drained (free).

Land Potential : As in the last cluster, drainage may restrict agriculture, but nutrient status is also poor. Forestry potential is reasonable and building development is possible on all but those sites on the Permian Plateau (Unit 7). Where drainage can be improved and slope permits, recreational development of an informal nature is feasible.

Cluster 7

Sites : 20,4.
Location : Upper Slopes West of the River Wear (Unit 2) and River Wear Gorge and Floodplain (Unit 3).

Main Site Characteristics

Angle of Slope : Level to moderately sloping.
Altitude : 30 and 37 m O.D.
Land Use : Arable or permanent grass.
Aspect : NE and ENE.

Main Soil Characteristics

Soil Type : Typical brown alluvial soil or stagnogleyic brown earth.
Texture : Loam or loamy sand in the topsoil, passing to clay loam or loamy sand and sand in the subsoil. Very rare stones to slightly stony.
Structure : Moderately weakly to moderately developed, granular or subangular blocky structure at the surface, passing to subangular blocky lower horizons. Becomes massive or single grain with depth.
Depth : Depth to bedrock in excess of 100 cm.
pH : Slightly acid topsoil, passing to moderately acid or slightly acid subsoil.
Base Status : Base saturation is low to moderate in the topsoil, decreasing to very low in the subsoil.
Drainage : Well drained (free) or moderately well drained.
Land Potential : Location restricts the use of these sites to agriculture, amenity woodland or nature conservation.

Cluster 8

Sites : 5,33,1,62,61,19.
Location : Four of the six sites are situated in the River Wear Gorge and Floodplain (Unit 3), with one in Unit 2 above the gorge and another in the Lowlands to the West of the Wear in Unit 1.

Main Site Characteristics

Angle of Slope : Level to moderately sloping, apart from Site 33 which is steeply sloping.
Altitude : 27-49 m O.D.
Land Use : Deciduous woodland predominates; also arable and permanent grass.
Aspect : WSW-N.

Main Soil Characteristics

Soil Type	: Typical brown alluvial soil, gleyic brown alluvial soil, typical (non-calcareous) humic alluvial and alluvial gley account for all but Site 1, which is a cambic stagnogley.
Texture	: Loamy sand, silty loam, clay loam or silty clay in the topsoil, overlying loam, loamy sand, clay loam or silty clay in the subsoil.
Structure	: Moderately or moderately weakly developed, medium granular or subangular blocky in the surface horizon. Moderately developed granular, subangular blocky or prismatic in lower horizons. Becomes single grain or massive.
Depth	: Bedrock in excess of 100 cm.
pH	: Strongly acid to neutral topsoils and subsoils.
Base Status	: Base saturation is predominantly low to moderate, but at Site 19 status is very low, whilst at Site 5 a high level is reached.
Drainage	: Well drained (free) to poorly drained.
Land Potential	: The uses to which the sites can be put, apart from Site 56, are severely restricted because of location. Flooding risks are high. Very important habitats for wildlife and significant for recreation in the form of amenity woodland, paths and trails.

8.5.3 Conclusions

The reduction in the number of clusters from sixteen to eight produced by this analysis, gives a more manageable assessment of site resources and potential than that resulting from the highest affinity analysis of Section 8.4. It has proved possible to recognise certain characteristics that make each cluster capable of interpretation in general land potential terms.

Because of this reduction, there is an increase overall in sites per cluster, but at this level of linkage (0.54) certain anomalies occur. This is especially true with the brown calcareous and rendzina profiles in Clusters 1, 2 and 3, which are grouped together with other soil types. If the linkage level had been set lower, all but one of these calcareous profiles (Site 55) would have formed clusters in their own right.

The clustering of sites across the dendrogram shows a steady movement from east to west across the transect, with the greatest dissimilarity occurring between Site 42 on the Permian Escarpment (Unit 6) and Site 5 in the Wear Gorge (Unit 3) at a linkage of 1.890.

8.6 Conclusions to Chapter

The use of cluster analysis to construct a natural resource inventory of the seventy one transect sites that is capable of interpretation in general land potential terms has met, it is submitted, with a modicum of success. Both the techniques used to link the initial similarity coefficients between sites have produced clusters that show overall features in common - each shows a trend - and each cluster is capable of land potential interpretation.

Problems have emerged, however. Firstly there is the correct number of site groupings to extract, and it has been suggested that this is essentially a matter of arbitrary choice. Apart from the difficulty of the recognisability of site and soil characteristics when a small number of clusters is used, too small a number increases the problems of interpretation for the user of the system. Likewise, too large a number of groups may mask crucial interrelationships between sites, but as a general rule, it is felt that too large a number is preferable to too small. The problem of the level of linkage and the type of sites clustered has been referred to in Section 8.5.3. on Page 283 and, because of the nature of the clustering system, this will remain a drawback.

The second difficulty is the location of certain sites in clusters whose trend characteristics appear to bear little relation to their own inherent properties. Apart from the level of linkage, as mentioned above, this is basically a result of the essential variability of soil parameters coupled with the inclusion of site factors in the same system, so producing confusing results. For example, Site 66 in Cluster 6 of the linkage analysis on Page 280. It is possible that such a phenomenon could be avoided by using a different choice of parameters in the calculation, or by clustering sites on significant characteristics, rather than on all the characteristics with equal weight being placed on each.

The third problem is one of clustering; different clustering techniques producing slightly different patterns of site linkage within clusters. An example of this is the fact that Sites 56 and 69 are situated in Cluster 2 of the highest affinity analysis (Page 259) in association with Sites 7, 12, 28, 38, 57, and 58, yet are linked in Cluster 1. of Palmer's linkage method (Page 275) to totally different sites. Generally speaking, however, when the two types of analysis are compared, associations of sites remain remarkably constant.

Despite the above disadvantages to the method, it is now possible for a land resource planner or other researcher, to interrogate either of the two types of data bank to obtain information about the sites and their general capability. If necessary, he may then "home in" on a specific site or area for detailed planning purposes. Being of a quantitative nature, the system lends itself to the use of computer methods for interrogation, including the use of visual display unit and other means of graphical display and manipulation of the data bank.

Mention has been made of the possibility of grouping sites according to characteristics that show more importance than others in the physical "make up" of the sites. The next chapter begins an investigation into clustering on this basis.

CHAPTER 9 - THE APPLICATION OF PRINCIPAL COMPONENT ANALYSIS TO LAND EVALUATION PROCEDURE - PART 1

9.1 Introduction

The last chapter has outlined a clustering technique by which equal weight is placed on all the variables when allocating a site to a group. It can be argued, however, that certain variables are of greater importance than others when producing such groupings; perhaps angle of slope is more important than either soil texture or nutrient status; or is it vice versa? The inclusion, on an equal footing, of variables of little significance may substantially affect an analysis and produce unclear results. As indicated in Chapter 8, to an extent, this appears to have occurred when using cluster analysis from the raw data. A subsequent natural resource inventory based on these groupings may thus be confusing and difficult to interpret. In order to attempt to overcome these problems, the following procedure was adopted and applied to the thirty variables and seventy one sites of the transect.

Firstly, Principal Component Analysis (PCA) was used to enable these important characteristics to be extracted from the data, which is large and unmanageable, and to classify them in spatial terms to form information inventories of each. Cluster analysis then followed, to link sites on the basis of a synthesis of these characteristics, and finally, a resource inventory, on lines similar to that presented in the last chapter, was constructed.

There are implicit assumptions made in many systems of soil classification, that the variations that occur between differing soils can be explained by the variation of a relatively few soil properties. This results from the observation that soil properties are not independently variable, but that change in one is likely to be associated with a change in others (Norris, 1971). There are many different properties to choose from, and invariably single parameters, or amalgams of parameters manifested in single parameters, have been chosen as a basis; as for example, the Soil Survey of England and Wales approach, which is dependent upon hydrological conditions and parent material. Inevitably, therefore, work has been undertaken in the past into the use of PCA to reduce the complexity of dealing with these large numbers of different soil properties in soil grouping and classification (notably by Burrough, 1969; Webster and Wong, 1969; Cuanalo and Webster, 1970 and Norris, 1968, 1971), but, to the author's knowledge, the technique has not been applied to land evaluation research before.

A description of the 'mechanics' of PCA and the results of the first stage of the analysis in the transect, which concerns the reduction in the number of variables as described above, are presented in the succeeding sections of this chapter.

9.2. The Analysis

Principal Component Analysis (PCA) and its near neighbour Principal Factor Analysis (PFA) are multivariate statistical techniques for analysing the intercorrelations within a set of variables by determining whether the variance in the original set of variables can be accounted for adequately by a smaller number of basic categories, or "hypothetical variables", called "components" (or "factors", according to the type of analysis undertaken). The purpose of the method is to explain observed relationships among numerous variables in terms of these simpler relationships; i.e. the components (or factors), which may be considered as underlying influences which, in further measurement, can be substituted for the more numerous original variables, and which largely account for the correlations among the latter.

The progression of the analysis may be briefly summarised as follows. At the outset n independent variables (using PCA not necessarily random variables) are selected, and thus, for each survey site there are n variables. In the case of the transect analysis, the same thirty variables were selected as used in the cluster analyses (see Chapter 7, Page 252-3). Each site may be represented by a single point in n - dimensional space (similar to identifying a point on a two - dimensional graph). The difference between two of these points, and therefore between sites, "may be assessed in terms of a straight line joining them, which in itself may be defined in terms of the angles it makes with each of the n axes and the magnitude of the movement in each of the n directions." These measures "reflect the variations between the two sites, and if it were possible to construct an n - dimensional "envelope" around all the points, this could be conceived as representing the total amount of variation between all the different sites" (Traill, 1974).

The concept of "structure" is central to the analysis. If the points described above are homogeneously spread throughout space, there will be no such structure; it being defined as the measure of associations and disassociations among the n variables selected. If, however, two variables are related, a clustering of points around a line occurs; if three variables are related the clustering occurs around a plane. Thus, for each component in the structure, there is a clustering of points in $k - 1$ dimensions, where k is the number of independent variables that are related to the component.

The original axes of the space relate to the n independent variables of the data set, and each axis is defined entirely in terms of one of these. However, if the axes are rotated then two things occur. Each axis becomes defined in terms of a linear combination of all n independent variables and the rotation can be made in such a way as to allow account to be taken of the clusters and to ensure that the linear combinations are uncorrelated. These linear combinations are the components. Initially each component contains all the original independent variables, although most will be of little importance in the determination of the component value and only a few will be highly related. The component will be named in terms of those variables with which it is highly correlated.

Certain variables may show far less importance in the component structure than others, and the measure of this structural importance is termed the "communality". It is advisable to delete from the analysis those variables which show low communalities.

The delineation of a threshold communality value, below which deletion takes place is of importance, as it will determine relationships between the other variables and so affect the structure itself. The approach adopted by (Traill 1974) in the Clwyd landscape study was to keep as many variables in the analysis as possible within certain bounds, as he considered that the landscape is made up of the interaction of many variables. A communality threshold of 0.3 was used. For a more rigorous analysis he suggests a figure of 0.5 and this figure was used for the transect analysis. It must be remembered, however, that the deletion of any variable will result in the extraction of some measure of the structure.

Harman (1967) makes a distinction between PCA and PFA and this distinction has become generally established. In the former, the diagonals of the correlation matrix are unities; the total variance of the hyperdimensional cluster of points is explained by the vectors obtained. For an $n \times n$ correlation matrix, n principal components can be extracted (unless there are fewer $k < n$, independent dimensions; i.e. the rank r of the matrix is less than n).

These components will (within rounding error) reproduce the original correlation matrix. In PFA the diagonals are reduced by their "uniqueness" to the communalities. PCA is characterised by faithful representation of distances between the major groups or clusters but is notorious for falsifying distances between close neighbours (Rohlf, 1968).

The delineation of the numbers of components or factors to be extracted and retained is fundamental, and choice depends much upon the type of analysis being undertaken. For the purpose of the transect study the criterion of unity in the diagonal was selected to ensure that all the original variance was used, thus making it a principal component solution. This method was used in preference to a true factor solution as no hypothesis need to be made about the original variables (they need not even be random variables) and it is the recommended method when the generation of hypothesis from a data set is required (Armstrong, 1967). A true factor analysis would be more applicable when the pure investigation of factor structure is required, as in the reduction of variables prior to multiple regression, where there may be no idea of the structure and associations among the variables. PCA has been the most popular method used when dealing with soil data.

In the absence of prior knowledge of the number of common components in the correlation matrix, the safest course to adopt in determining the number of components to extract is to use Guttman's lower bound theorem (1954), which demonstrates that eigenvalues with roots of less than 1.0 are statistically insignificant; i.e. that one can use this to set an upper bound on the number to extract. This figure was selected for the analysis.

Each component extracted represents a grouping of a set of input variables resulting from the relationships existing between the variables, and the analysis can be likened to a sieve process, where the n variables represent the mesh of the sieve. Instead of the problem of dealing with these n variables independently, by superimposing n maps, PCA collapses these variables into the number of components which are capable of explanation. The measure of association between each variable and each component is called the "component loading". In order to explain the configuration of variables in such a way that each component is represented by only a few variables (i.e. it loads or correlates with the smallest number of variables); to give a "cleaner" solution, a Varimax rotation (Kaiser, 1958) may be performed on the loadings. This was undertaken.

The final feature of the component analysis as such is the calculation of "component scores"; the measure of association between each component and each site.

The approach considered above, as used in the transect, where suites of variables within sites are correlated over the sites, is called an R - mode technique. Where sites are correlated over the variables the term is Q - mode.

The computer program used to perform the analysis was from the IBM Statistical Subroutine Package (S.S.P.).

9.3 Transect Principal Component Analysis Discussion

9.3.1 Elementary Statistics

The calculation of elementary statistics (mean ($\bar{x}$) standard deviation (s) standard error ($\sigma_{\bar{x}}$), maximum, minimum and range) and the coefficient of variation (V) provides a useful guide to the degree of variation of the individual measurements of each of the thirty variables as well as of the absolute value of the variables.

The standard deviation (the measure of the scatter about the mean) may be closely related to the mean in many instances, the two values increasing together (Cole and King, 1968). The range of variability of the data does play a significant part in the way one variable correlates with another. When the range of variability is small, the variable tends towards a constant and will not correlate with others so highly. The standard deviation may be useful in considering the value of the correlations. However, when comparing one variable with another, the problems of the standard deviation, in taking the peaks of the data too much into consideration, and the fact that the differences of variation between data types makes comparison difficult (the standard deviation is expressed in the same units as measured), make the need for another statistic expressing variation necessary. A far more meaningful relative measure of variation for the purpose under consideration is the coefficient of variation (V) :

$$V = \frac{s}{\bar{x}}$$

The elementary statistics are shown in Table 9.1, in order of increasing variability. The dichotomous variables are included, although not normal in the statistical sense with constant variance (see Chapter 7, Page 253).

Going down the table of coefficients of variation certain interesting points emerge. There is less variation in the topsoil variables than those at depth, % base saturation being an exception, possibly due to liming effects at certain profiles. The most constant variable is pH at 5 cm with a mean of 6.0. Even in the calcareous profiles, the maximum pH does not rise above the 7.5 of Site 12. Although Site 19, located on river sand of the River Wear gorge, drops to a strongly acid 3.4, samples at 5 cm "hover" predominantly around the mean, the effects of years of intensive cultivation of the agricultural profiles having a levelling effect on the figures. At depth, the pH is also constant, with a mean of 6.1, slightly less acidic than at 5 cm. The highest value is at Site 17 with 7.6. The lowest is the strongly acid B_{lg} horizon of Site 31 at 3.7.

The constancy of depth-to rock is spurious, as it was necessary to enter the data set at 100 cm for the profiles where the determination of actual depth was not possible. Although it is considered that the figures reflect depth variability to an extent, for the purpose of this analysis, the variation as measured by V may be too low. The texture of the topsoil at 5 cm, with coefficients of variation ranging between 0.226 and 0.347, is fairly stable, particularly % sand. This stability is greater at depth where the effects of parent material are felt to a greater extent, against the cultivated and more weathered top horizons. The means of the top horizons at 5 cm are 52.48 for % sand; 22.50 for % silt and 25.02 for % clay; a clay loam on the International scale.

At 40 cm the least variable fraction is silt, but sand is only 0.002 more variable. The means at this depth are 48.79 for % sand; 19.15 for % silt and 32.07 for % clay; again a clay loam on the International scale.

% stones in the top mineral horizon, on the other hand, shows a high coefficient of variation at 1.589. A mean of 9.1% is recorded with a maximum of 62.5% at the Magnesian Limestone brown rendzina of Site 41.

Table 9.1 Elementary Statistics

<u>Variable</u>	$\bar{x}$	s	σ_x	max.	min.	range	V
pH - 5 cm	6.03	1.02	0.12	7.50	3.39	4.26	0.169
pH - 30 cm	6.13	1.14	0.18	7.61	0.0	7.61	0.186
Depth to in situ rock	93.79	18.23	2.16	100.00	25.0	75.00	0.194
% sand - 5 cm	52.48	11.84	1.41	86.78	28.04	58.74	0.226
% silt - 5 cm	22.50	6.68	0.79	38.84	5.70	33.14	0.297
% carbon - 5 cm	6.34	2.09	0.25	15.53	2.57	12.96	0.330
% clay - 5 cm	25.02	8.27	0.98	51.29	7.04	44.25	0.331
% moisture - 5 cm	2.45	0.85	0.10	5.58	1.41	4.17	0.347
% silt - 40 cm	19.15	7.90	0.94	36.60	0.0	36.60	0.375
% sand - 40 cm	48.79	19.86	2.36	86.35	0.0	86.35	0.377
Altitude	89.34	34.98	4.15	160.02	27.43	132.59	0.392
Depth to BC or C horizon	43.97	17.69	2.10	84.00	14.00	70.00	0.402
% clay - 40 cm	32.07	14.04	1.66	71.91	0.0	71.91	0.411
Normal site drainage	0.84	0.36	0.04	1.00	0.0	1.00	0.431
Thickness of top mineral horizon	19.89	8.58	1.02	34.00	4.00	30.00	0.431
% carbon - 30 cm	3.73	1.79	0.22	7.98	0.0	7.98	0.480
% base saturation - 5 cm	41.64	20.65	2.45	100.00	3.25	96.75	0.496
% moisture - 30 cm	2.03	1.04	0.13	7.27	0.0	7.27	0.512
Aspect ^o	195.52	104.59	12.41	357.00	15.00	342.00	0.535
% base saturation - 30 cm	40.22	23.97	2.84	100.00	0.0	100.00	0.559
Angle of slope ^o	3.52	3.40	0.40	17.25	0.10	17.15	0.965
Poor profile drainage	0.49	0.50	0.06	1.00	0.0	1.00	1.022
% stones in top mineral horizon	9.15	14.54	1.72	62.50	0.50	62.00	1.589
Imperfect profile drainage	0.25	0.44	0.05	1.00	0.0	1.00	1.724
Free profile drainage	0.21	0.41	0.05	1.00	0.0	1.00	1.948
Thickness of organic horizons	1.11	2.35	0.28	11.00	0.0	11.00	2.114
Canopy	0.66	1.90	0.22	9.00	0.0	9.00	2.866
Receiving site drainage	0.10	0.30	0.04	1.00	0.0	1.00	3.030
Shedding site drainage	0.06	0.23	0.03	1.00	0.0	1.00	4.143
Excessive profile drainage	0.04	0.20	0.02	1.00	0.0	1.00	4.833

Both % carbon and % moisture at 5 cm are far less variable than at 30 cm, where the effects of differences in cultivation and land use and a fluctuating water table become more important. The practice of liming also affects the soil moisture regime in breaking up clay soils, as does the ploughing itself. Overall there is more carbon and soil moisture is greater in the 5 cm layer than at 30 cm; means ranging from 6.34% at 5 cm to 3.72% at 30 cm for carbon, and 2.45% and 2.03% respectively for % moisture. Sites, of course, vary and the greatest % moisture is in fact recorded at 30 cm, associated with a wet cambic stagnogley with standing water at 50 cm (Site 57).

Both the thickness of the top mineral horizon and the depth to the parent material are constant, the former less so than the latter. This is to be expected as some profile topsoils are cultivated and some are not. The effects of cultivation are reflected in the mean thickness of the overall horizons being 19.89 cm, whilst the mean thickness of the Ap horizons is 25.49 cm. The thickness of the organic soil horizons, however, show a high variability (2.114), and such horizons are found at nearly 41% of all sites in some form or other, with a maximum thickness of 11 cm recorded at Sites 6 and 31.

The nutrient status of the soils, measured as the % base saturation, is more variable, as indeed might be expected in a mixture of intensely cultivated pasture, woodland and scrub profiles. Base saturation at 5 cm is less variable than at 30 cm. As texture, % carbon and % moisture are less variable in the topsoil, and since base enrichment is directly affected by clay and organic content and indirectly by moisture, % base saturation will reflect this trend. Base enrichment is slightly higher overall at 5 cm.

The least variable of the site parameters which, in general, are far more variable than the profile parameters, is altitude. Heights above sea level vary from between 27 m O.D. at Site 61 to 160 m O.D. on the limestone above Pittington at Site 27. In general, altitudes are fairly constant ($V = 0.392$).

Both aspect and angle of slope show variation. The mean aspect is nearly south west (195.5°), but in general aspects are less variable than slope. Slopes range from nearly level (0.1° at Sites 2 and 3) to a maximum of 17.2° at Site 33, a steep stream side. A moderately sloping mean of 3.5° is recorded and, overall, slopes are slight to moderate.

Vegetative canopies of any description are not common, hence the high variation. The Mid - Wear Lowlands are not well vegetated and this is reflected in the transect, only eleven sites having a canopy. The highest is 9 on the Soil Survey scale at Site 62.

Apart from normal site drainage, which is found at 80.28% (57) of the sites, and has a coefficient of variation of 0.431, the dichotomous variables of site and profile drainage are highly variable, reflecting the variations between the soil types themselves. Being an analysis on a presence/absence basis the most variable are parameters related to the fewest sites; i.e. shedding and excessive drainage ($V = 4.143$ and 4.833 respectively). Likewise, receiving site drainage, found at only seven locations, is highly variable, whereas poor, imperfect and free profile drainages are more common.

9.3.2 Correlation Matrix

The presence of sets of variables existing together is identified first of all by examining the bivariate correlation matrix (Pearson product-moment). For some reason many factor analytic studies ignore this step entirely in

discussion, only considering loadings and scores. To do so is a mistake, and the analysis as a result is made more difficult to interpret. If there are high correlations in the matrix there is evidence of a spatial linkage between the variables and the data can be seen to have an underlying structure (Traill, 1974. pers.comm.). Figure 9.1 shows the correlation matrix of 450 unique indices of correlation. The lowest acceptable statistically significant limit at 95% probability, for thirty variables with two degrees of freedom in accordance with Student's "t" test, is 0.361 ($p = 0.05$). Above 0.463, the significance limit for 99% ($p = 0.01$), the association is particularly strong.

The significant correlations with the angle of slope variable; i.e. shedding site drainage (0.542), normal profile drainage (-0.434), depth to in situ rock (-0.472) and excessive profile drainage (0.387) reflect the physiography of the area, with the influence of the Magnesian Limestone being particularly felt. The greater the slope, the greater the effects of shedding site drainage, a shallower soil and a move away from normal profile drainage are shown; the shallow calcareous soils being found, in general, on the steeper slopes.

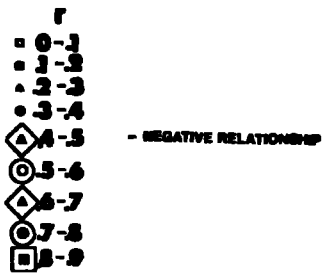
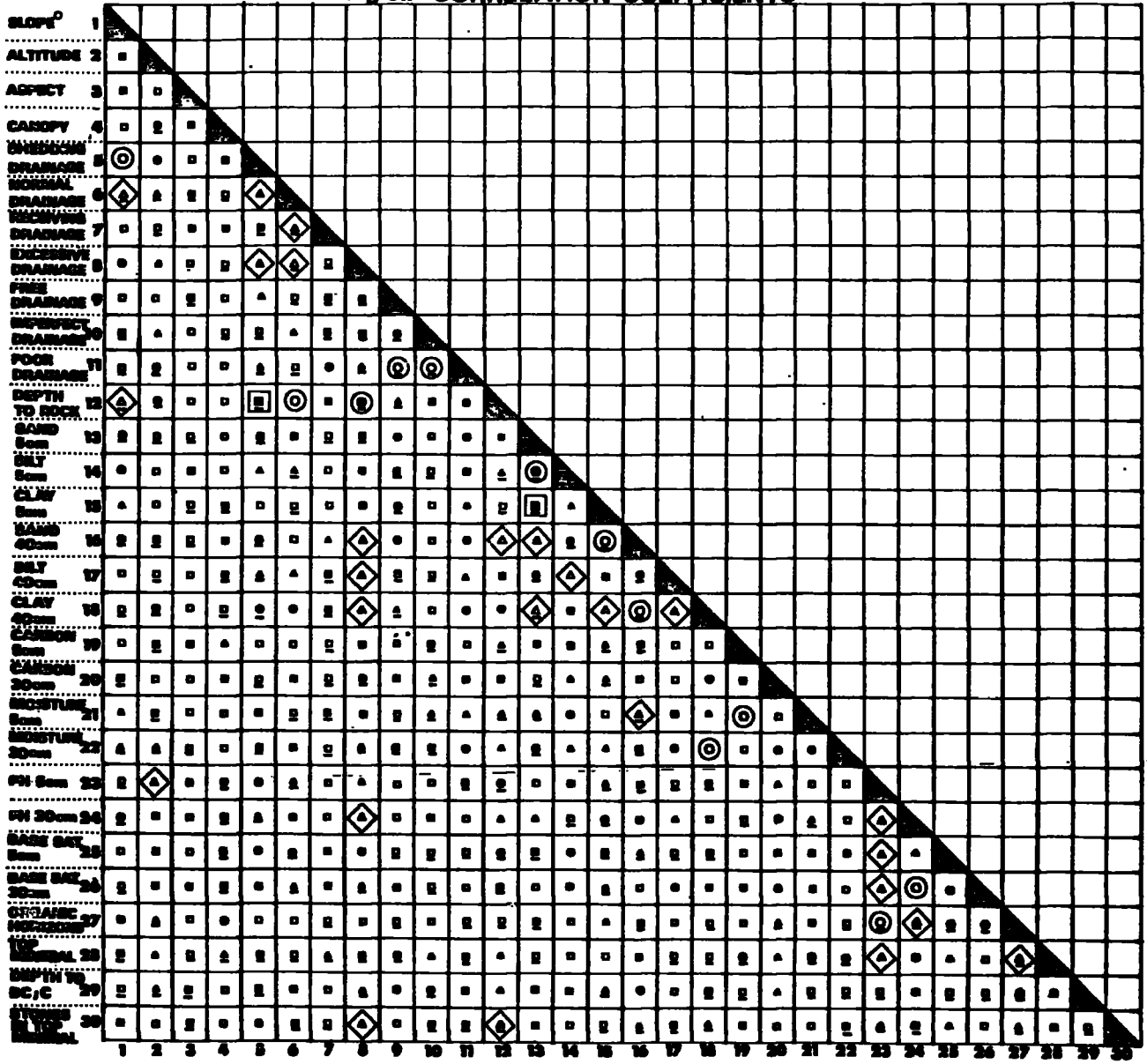
The shedding nature of the drainage of the sites also increases with altitude (0.372) and as the altitude increases, so the depth to rock decreases, showing the effects of the limestone (-0.381). The pH of the topsoil increases with altitude (0.406), the soils of the lower, wetter sites being more impoverished as a result of cultivation and the influence of the deposits of river and glacial sand, found at the lower altitudes, which show a lower pH. At higher altitudes the soils have a greater inbuilt pH because of the limestone.

No significant relationships are found with the aspect variable. This is reflected in the fact that the same soil type is found at different aspects; for example, brown calcareous earths are situated on either side of Pittington Hill. The slight to moderate angles of slope will also tend to modify the influence of aspect.

Correlation coefficients are considerably higher for the vegetation canopy variable than for aspect, but do not show significant relationships. Although not significant at the 95% level or above, two variables reflect the fact that greater canopies occur in the valleys of the River Wear and its tributaries. A coefficient of 0.302 for altitude suggests that, as altitude increases, canopy decreases, and -0.356 for pH at 5 cm indicates that as the pH decreases the canopy increases, the sandy soils of the Wear Gorge showing low pH, as do the gleys of some of the tributary streamlets.

Apart from the increasing occurrence of shedding drainage with slope and altitude, which reflects the location of calcareous soils on the higher slopes and crests of the Magnesian Limestone, the occurrence of a high negative correlation between shedding site drainage and normal site drainage (-0.642) is interesting, as the two occur in close proximity on the same Magnesian Limestone slopes, the normal drainage being found associated with brown calcareous profiles. As expected, there is a high positive correlation (0.691) between shedding and excessive drainage regimes and a high negative correlation with depth to rock (-0.889), reflecting the influence of the rendzina profiles. Shedding drainage is not associated with a sandy subsoil (-0.384 with % sand at 40 cm), as it is confined to the rendzinas with in situ rock predominant at this depth. % base saturation at 5 cm increases with the occurrence of shedding drainage, suggesting a good inherent base status of the limestone soils, and stones in the top mineral horizon also shows a significant positive correlation (0.379).

Fig.9.I CORRELATION COEFFICIENTS



The occurrence of normal site drainage shows a negative relationship with angle of slope. The majority of normally drained sites, other than those of a calcareous nature, are located on gentle to moderate slopes distributed across the whole of the transect from east to west and associated with stagnogleyic brown earths. There is a high negative correlation (-0.699) between normal drainage and receiving sites, as expected.

Receiving site drainage is not highly correlated with any other variable than normal site drainage. There is a weak correlation with poorly drained profiles, the unexpected low value resulting from the large number of poorly drained soils (particularly found on the heavy clays of the Brasside area) being associated with normal drainage.

Freely drained soils are not common and are associated with the calcareous soils of the limestone plateau, the alluvial profiles of the Wear valley and the brown earths around Pity Me.

There is a significant negative correlation between the occurrence of freely drained profiles and poor profile drainage (-0.510), as expected, and a positive relationship with % sand at 5 cm (0.374), but a less positive one (0.326) with % sand at 40 cm, the clay content increasing with depth at a large number of sites. Likewise there is a significant negative relationship with % clay at 5 cm (-0.385), but less so with % clay at 40 cm (-0.249). There is a significant positive correlation between free drainage and depth to the BC or C horizon, the freely drained profiles being of considerable depth compared to the stagnogleyic brown earths and other gleyed profiles.

Negatively correlated with imperfect and freely drained profiles, but not significantly correlated with excessively drained profiles, the poorly drained sites show a significant positive relationship with % moisture at 30 cm. This is also indicated by the slight, but not significant relationship, between poor drainage and depth to rock (0.338), reflecting, rather more, the deeper profiles of the poorly drained soils than the freely drained calcareous soils. Also not significant, but indicative of the situation, is a negative correlation with altitude (-0.313), the majority of the poorly drained soils being off the Magnesian Plateau, despite the nature of the drift, and a positive non-significant correlation with % clay at 40 cm (0.325).

Excessive profile drainage, being confined to the rendzinas of the limestone, correlates positively with angle of slope (0.387), shedding drainage (0.691) and % stones in the top mineral horizon (0.476) but negatively with depth to rock (-0.759).

Depth to in situ rock decreases with increasing angle of slope, increasing altitude, the presence of shedding site drainage, excessive profile drainage and increasing base status at 5 cm. As with the excessive drainage variable described above, the effect of the poorly drained gleys on normal or receiving sites, low degree of slope, low altitude and low base status is contrasted, to an extent, with the excessively and freely drained high base calcareous profiles of the shedding and normally drained sites of the limestone. The strengths of the correlations do not indicate, however, that the two "ends of the scale" of depth to rock are the gley and calcareous soils, and because of sampling finishing at a 100 cm depth no hypothesis is made.

% Sand in the topsoil at 5 cm increases with the presence of free profile drainage, and with % sand at 40 cm, the profiles with sandy topsoils tending to be sandy at depth (0.629). The non-significant correlations of sand at 5 cm with % moisture at both depths (-0.258 and -0.308 for 5 and 30 cm respectively) are possibly the result of the effects of cultivation residues left in the soil.

% silt at 5 cm shows a negative correlation with % sand at both the depths sampled and a positive relationship with % silt at 40 cm.

% clay at 5 cm correlates negatively with the presence of free profile drainage (-0.385) and % sand at 5 and 40 cm.

The negative correlations of % sand at both sample depths with % clay are higher than with % silt.

At 40 cm, apart from the relationships mentioned above, % sand correlates positively with depth to the BC or C horizon (0.370), the sandier soils being often deeper and exhibiting several B horizons. There is a negative correlation with % moisture at 30 cm, as might be expected at depth.

Silt content at 40 cm increases with clay content (0.683) and also with % base saturation at 30 cm, a functional relationship with the cation exchange capacity being indicated. Likewise, there is a positive correlation with % moisture at 30 cm, also a functional relationship reflecting the organic content. Indeed the slight non-significant correlation with % carbon at 30 cm (0.346) reflects this.

% clay at 40 cm also correlates highly with % moisture at 30 cm; clay soils retaining the moisture.

Despite the presence of a significant number of cultivated cambic stagnohumic gley soils, % carbon at 5 cm decreases with an increasing thickness of the top mineral horizon (-0.387) and increases with % moisture at 5 cm (0.575). The former relationship reflects the presence of less humose deep Ap horizons, whilst the horizons with very high organic content are generally fairly thin and under uncultivated grassland or woodland which have many fibrous roots. The latter relationship reflects the hypothesis that the organic content of the upper horizon affects moisture rather than % silt or clay content, which show coefficients of 0.338 and 0.096 with % moisture at 5 cm respectively.

At a depth of 30 cm, % carbon increases with the pH content (0.397) and with increasing % moisture (0.392), but at this depth, with decreasing organic content, silt and clay contents appear to be the main determinants in holding moisture, having higher coefficients of correlation with % moisture (0.394 and 0.585 respectively).

Decreasing significantly with % sand at 40 cm and increasing significantly with % carbon at 5 cm as outlined above, % moisture at 5 cm correlates negatively with the thickness of the top mineral horizon (-0.393), again a reflection of the slightly higher organic contents of the soils under pasture compared with the cultivated profiles.

The positive relationship of % moisture with the occurrence of poor profile drainage is greater at 30 cm than at 5 cm (0.384 and 0.253 respectively) and the positive, significant correlations with % silt and clay (0.394 and 0.585 respectively) confirm this.

Unlike the value at 30 cm, the pH at 5 cm correlates significantly with altitude (0.406); this being a reflection of the high pH of the topsoils at the higher altitudes, as opposed to the lower status of the sandier soils of lower altitudes, and in particular of the River Wear area. The pH in the topsoil also increases with the thickness of the top mineral horizon, the thinner Ah horizons of the grassland profiles and the river valleys being of an acid nature, compared with the deeper Ap horizons of the cultivated profiles.

The pH at 30 cm correlates negatively with the occurrence of excessive profile drainage (-0.480) and positively with the pH at 5 cm (0.403) and % base saturation at 30 cm (0.578). At this depth pH increases slightly with % carbon, possibly due to greater residues of crops being left in more fertile soils, which generally show a higher pH content. The variable decreases, as does % silt at 5 cm, with increasing thickness of the organic horizons (-0.436 and -0.600 respectively). Profiles with thicker litter/organic layers are more acid and generally down to woodland, as in the Wear Gorge and immediately surrounding land at Brasside.

The % base saturation at 5 cm increases slightly with the presence of shedding site drainage, which occurs on the rendzina sites. Likewise, there is an appreciably significant increase with the pH at 5 cm (0.610), but a decrease with increasing depth to rock (-0.363) and organic horizons, both indicative of a decreasing nutrient status of the deeper non-calcareous soils.

At 30 cm, % base saturation increases with % silt (0.394), and the pH at both the sample depths.

The thickness of the top mineral horizon correlates significantly with the pH at 5 cm (0.411), indicating the better nutrient status of the cultivated soils compared with the uncultivated soils which show thinner A or AB horizons; for example the Wear Gorge profiles. The variable also exhibits a negative correlation with % carbon and % moisture at 5 cm; those profiles which show organic horizons having thinner uncultivated A horizons.

The depth to the BC or C horizon increases with free profile drainage. The acidic soils of the River Wear and the lower lying areas show such horizons at considerable depth.

As indicated above, the thickness of the organic horizons decreases significantly with the increasing thickness of the top mineral horizon and the increasing pH of the soil at 30 cm.

Apart from certain sites, both on and off the limestone, % stones in the top mineral horizon is not important and likely to be of little value in the analysis. The variable increases with the presence of shedding site drainage, excessive profile drainage and decreases with increasing depth to rock.

This detailed discussion provides a substantial basis for the interpretation and analysis of the further stages of the Principal Component Analysis.

9.3.3. Principal Component Analysis - Run 1

9.3.3.1. Variance Explained

Having calculated the product - moment correlation matrix the program then calculates the main part of the analysis, that pertaining to the components themselves, using all thirty variables. There were three computer runs.

As explained, Guttman's lower bound theorem (1954) was adopted, the eigenvalues with roots of less than 1.0 being considered statistically insignificant. Using thirty variables there may be considered to be a variation totalling thirty units. If there is zero correlation between all these variables, each of the thirty figures of twenty nine dimensions fitting the cluster of observations will be roughly the same size, and each eigenvector, as the figures are called, will be roughly the same size. However, if all the variables are entirely correlated, then the first eigenvector will absorb all the variation and will have an eigenvalue of 100.0, the remaining twenty nine each being zero.

As expected in the transect analysis, there is neither complete inter-correlation, nor zero correlation. Intercorrelation is moderate, as the table of eigenvalues shows (Table 9.2).

Table 9.2 Run 1 Eigenvalues and % Variance Explained

<u>Eigenvalues</u>	<u>% Variance Explained</u>	<u>Cumulative % Variance Explained</u>
5.123	17.077	17.077
4.442	14.807	31.884
3.736	12.453	44.337
2.682	8.940	53.277
2.257	7.523	60.800
1.646	5.487	66.287
1.632	5.440	71.727
1.198	3.993	75.720
0.994	3.313	79.033
0.853	2.843	81.876
0.783	2.610	84.486
0.743	2.477	86.963
0.582	1.940	88.903
0.549	1.830	90.733
0.475	1.583	92.316
0.415	1.383	93.699
0.322	1.073	94.772
0.276	0.920	95.692
0.274	0.913	96.605
0.243	0.810	97.415
0.189	0.630	98.045
0.165	0.550	98.595
0.150	0.500	99.095
0.121	0.403	99.498
0.095	0.317	99.815
0.055	0.183	99.998
0.000	0.000	99.998
0.000	0.000	99.998
-0.000	0.000	99.998
-0.000	0.000	99.998

5.123 out of the thirty units of variation accumulate on the first and highest eigenvector, another 4.442 units on the next and so on. The second column of Table 9.2 shows these values expressed as percentages of the total variation, and the third column the cumulative totals.

For the first component, 17.077% of the total variance is explained; for the second 14.807%; for the third 12.453%; for the fourth 8.940% and so on. Therefore, four out of thirty "directions" (Cole and King, 1968) account for over one half (53.277%) of the variation. Taking Guttman's (1954) lower bound of 1.0, the first eight eigenvalues are above this and, between them, account for over three quarters (75.720%) of the variation.

The component values are related to the degree of intercorrelation of the variables. Where the correlation coefficients are low, as in the majority of the data under consideration, the percentage variances are smaller and the values more equal on each successive component. The variances found in the transect analysis compare favourably with those found using soil data by Courtney (1973), in a taxonomic study of the Sherborne Soil Series in the southern Cotswolds, and this is discussed in the final component section of this chapter on Page 305.

Thus, the greater the homogeneity among the parameters of an area, the less the components can hope to expose by way of variation. The coefficients of variation appear to support this hypothesis in the transect.

If intercorrelations are weak, no particular variable can give a good characterization of the area concerned and, at this stage of the analysis, the variances indicate that a series of variables rather than a specific one or two will appear as significant. The fact that only 8.137% is the difference between the percentage variance explained for the first and fourth component supports this view.

9.3.3.2. Component Loadings

The individual components are related to the character of the variables, and the loadings on the different variables give information concerning the part the variables play in accounting for the variation within the transect.

Table 9.3 shows how each variable loads on the components extracted. The loadings on each variable are closely related to the correlation coefficients; when correlations are high, the loadings are high, and the closer a variable lies to the component axis the higher will be its loadings (Cole and King, 1968). The more important a variable is on a component, the higher will be its value in either a positive or negative direction. When several variables all have high loadings they will be close to the component axis and will themselves be highly correlated.

On the first run the eight components produced the following variable loadings of importance and associated loadings of lesser significance but worthy of consideration in the understanding of the components.

Component 1

Shedding site drainage (0.91617); depth to in situ rock (-0.91253); excessive profile drainage (0.70750). Also of higher value when compared with other variables in the component are, normal site drainage (-0.66461), angle of slope (0.65666) and altitude (0.42407).

Table 9.3 Component Loadings of the Three Computer Runs

	C1	C2	C3	C4	C5	C6	C7	C8	Run
Angle of slope	0.65666	-0.24946	-0.23653	0.01615	0.14628	0.02488	-0.05159	-0.13346	1
	0.65060	-0.26311	0.20834	-0.01317	0.13265	-0.06499	0.11155	-0.06358	2
	0.65316	-0.20280	-0.21293	-0.02718	-0.13940	-0.07743	0.08220	0.16038	3
Altitude	0.42407	0.00752	0.33727	0.36716	-0.16370	-0.16757	0.23814	0.03552	1
	0.42401	0.00034	-0.36153	-0.35134	-0.17162	0.23139	-0.05631	0.14588	2
	0.43673	0.01961	0.35481	-0.34591	0.13537	0.24570	-0.14309	-0.07475	3
Aspect	0.04487	0.02102	0.02800	-0.13202	0.13917	-0.23001	0.20038	-0.58907	1
	0.04325	0.00831	-0.03721	0.11151	0.12525	0.18874	0.59452	0.20094	2
	-	-	-	-	-	-	-	-	3
Canopy	-0.06175	0.17297	-0.35473	-0.28710	0.06231	0.21240	-0.22346	-0.48182	1
	-0.05396	0.16379	0.42125	0.22871	0.07821	-0.20563	0.52276	-0.13980	2
	-0.08980	0.29023	-0.46745	0.30199	-0.14818	-0.00628	0.04429	0.46467	3
Shedding Drainage	0.91617	-0.01934	0.14778	-0.09442	-0.02987	0.00940	0.05195	0.05924	1
	0.91806	-0.02129	-0.13252	0.09502	-0.02907	0.05316	-0.05684	0.00484	2
	0.92186	0.00703	0.13242	0.08482	0.02647	0.00425	0.01297	-0.02156	3
Normal drainage	-0.66451	-0.04962	-0.14054	-0.08030	-0.64473	0.03980	-0.05168	0.13530	1
	-0.66760	-0.03748	0.13376	0.09444	-0.64404	-0.05373	-0.14802	-0.04338	2
	-0.65570	-0.09220	-0.11181	0.05148	0.68366	-0.03109	0.05994	-0.06611	3
Receiving drainage	0.00728	0.08242	0.04444	0.19227	0.86430	-0.06039	0.01857	-0.23080	1
	0.00952	0.06849	-0.04989	-0.21118	0.86266	0.02010	0.24507	0.05176	2
	-0.00947	0.11306	0.02150	-0.14593	-0.91164	0.03637	-0.08986	0.10589	3
Excessive drainage	0.70750	-0.00928	0.19269	-0.14633	-0.00938	0.54368	0.27949	-0.04018	1
	0.71166	-0.01286	-0.18862	0.16237	-0.01605	0.26727	-0.03286	-0.53201	2
	0.71582	0.02374	0.19374	0.16032	0.00337	0.20945	0.55318	-0.03447	3
Free drainage	0.32370	0.47181	-0.14526	-0.00746	-0.23623	-0.32358	-0.48105	0.28758	1
	0.32463	0.48086	0.16462	-0.00682	-0.22532	-0.46398	-0.29122	0.32774	2
	0.30043	0.42050	-0.13135	-0.05650	0.31214	-0.56059	-0.30240	-0.20780	3
Imperfect drainage	-0.19339	-0.00397	0.03176	0.43065	-0.53923	0.00339	0.39953	-0.44085	1
	-0.19542	-0.02576	-0.05416	-0.44008	-0.55031	0.38817	0.42259	-0.02012	2
	-0.19168	0.10713	-0.00322	-0.35774	0.40440	0.67794	-0.07493	0.33147	3
Poor drainage	-0.38069	-0.37805	0.01344	-0.30974	0.66587	0.04249	-0.06733	0.13262	1
	-0.38136	-0.36503	-0.01139	0.32315	0.66927	-0.06646	-0.11671	-0.03603	2
	-0.36653	-0.44612	0.03209	0.29289	-0.60810	-0.21646	0.08952	-0.10488	3
Depth to in situ rock	-0.91253	-0.00321	-0.17075	0.20915	0.10261	-0.07313	-0.04605	-0.02879	1
	-0.91691	-0.00415	0.14038	-0.20561	0.09841	-0.05011	0.01769	0.04070	2
	-0.91803	-0.04592	-0.13408	-0.20602	-0.08512	-0.03413	-0.04079	-0.02073	3

Table 9.3 (cont.)

		C1	C2	C3	C4	C5	C6	C7	C8	Run
% sand	5cm	-0.23279	0.89315	0.06035	-0.10054	-0.11742	-0.11795	0.04280	0.14969	1
		-0.22520	0.90238	-0.04162	0.08126	-0.10416	0.05570	-0.12600	0.11412	2
		-0.25059	0.80733	0.05825	0.10333	0.13235	-0.03622	-0.11468	-0.39525	3
% silt	5cm	0.28596	-0.62409	0.17356	-0.10256	0.04850	-0.00592	-0.37956	-0.46149	1
		0.28373	-0.62687	-0.18213	0.11751	0.03494	-0.39729	0.43816	0.01167	2
		0.27780	-0.45242	0.13836	0.13376	-0.09323	-0.15342	-0.08884	0.72465	3
% clay	5cm	0.10213	-0.77414	-0.22660	0.22659	0.12006	0.17349	0.24535	0.15862	1
		0.09308	-0.78510	0.20671	-0.21106	0.12062	0.24123	-0.17368	-0.17266	2
		0.13421	-0.79002	-0.19515	-0.25579	-0.11388	0.17577	0.23581	-0.01974	3
% sand	40cm	-0.35648	0.74198	-0.06897	0.27863	0.16433	-0.05430	-0.30025	-0.12447	1
		-0.35199	0.73617	0.04919	-0.29372	0.15816	-0.30091	0.11741	0.01788	2
		-0.40252	0.75574	-0.05535	-0.24765	-0.16527	-0.23449	-0.08164	0.02005	3
% silt	40cm	-0.20426	-0.60822	-0.03446	-0.09141	-0.20205	-0.55325	-0.19142	-0.05646	1
		-0.21167	-0.60082	0.06225	0.08114	-0.18878	-0.17777	0.05849	0.59041	2
		-0.18309	-0.60032	-0.07524	0.05396	0.18920	-0.09811	-0.58958	0.20402	3
% clay	40cm	-0.36738	-0.70389	-0.15176	-0.14108	-0.10811	-0.37431	0.14300	0.15221	1
		-0.37544	-0.69473	0.15876	0.14585	-0.09742	0.15340	-0.15351	0.38913	2
		-0.32529	-0.77393	-0.14993	0.09832	0.12500	0.09542	-0.32849	-0.09375	3
% carbon	5cm	0.03926	0.11061	0.10790	-0.81080	-0.05863	-0.03720	0.03253	-0.18568	1
		0.04643	0.13001	-0.06666	0.80132	-0.05550	0.03635	0.21739	0.06361	2
		0.04441	0.12446	0.04716	0.83390	0.04142	0.06185	-0.09235	0.08532	3
% carbon	30cm	-0.14246	-0.15156	0.37086	-0.11054	-0.03471	-0.27695	-0.59444	-0.05774	1
		-0.13789	-0.13375	-0.33467	0.11395	-0.02409	-0.58429	0.06145	0.33103	2
		-0.15186	-0.10248	0.33207	0.08981	0.05623	-0.48999	-0.36661	0.29673	3
% moisture	5cm	0.14685	-0.31476	-0.04104	-0.73040	0.01257	0.02556	-0.02158	-0.04985	1
		0.14550	-0.29666	0.02570	0.75748	-0.00130	-0.03717	0.04027	-0.05873	2
		0.15938	-0.31008	-0.02738	0.74318	0.02322	-0.06544	0.06980	0.09436	3
% moisture	30cm	-0.33323	-0.54853	0.17351	-0.32503	0.02661	-0.12351	-0.15592	0.21116	1
		-0.33408	-0.52430	-0.18353	0.36387	0.02602	-0.15898	-0.22687	0.12368	2
		-0.30762	-0.59046	0.20364	0.30753	0.03737	-0.21748	-0.08578	-0.01335	3
pH	5cm	0.26013	0.07215	0.82979	-0.01077	-0.05101	-0.18358	0.04407	-0.07146	1
		0.26645	0.08508	-0.84601	0.04813	-0.06488	0.02888	0.05821	0.16967	2
		0.26967	0.09880	0.83937	0.05221	0.05026	0.05393	-0.18083	0.03778	3
pH	30cm	-0.30718	0.19514	0.48202	0.09863	-0.03699	-0.58213	-0.11324	-0.06019	1
		-0.30359	0.20610	-0.45722	-0.10762	-0.02723	-0.09960	0.07293	0.60787	2
		-0.30728	0.18771	0.43922	-0.07930	0.00534	-0.02210	-0.65047	0.00691	3
% base sat.	5cm	0.29020	-0.09194	0.68430	-0.09543	0.11409	-0.00856	-0.04478	-0.12010	1
		0.29610	-0.08107	-0.70044	0.13275	0.09946	-0.06213	0.10641	-0.00103	2
		0.29326	-0.02620	0.68395	0.14962	-0.12601	0.00739	-0.03571	0.19421	3

Table 9.3 (cont.)

	C1	C2	C3	C4	C5	C6	C7	C8	Run
% base sat.									
30cm	0.11278	0.02893	0.35206	-0.08129	0.13449	-0.80681	-0.01324	-0.07949	1
	0.11462	0.03750	-0.31356	0.05751	0.14891	0.00824	0.10154	0.83704	2
	0.12510	0.00605	0.29024	0.08288	-0.17158	0.01983	-0.84939	-0.04216	3
Organic									
horizons	0.12772	-0.12953	-0.77072	-0.09424	-0.08264	0.13946	0.02003	-0.20689	1
thickness	0.12130	-0.14743	0.76311	0.06538	-0.08527	0.01962	0.20004	-0.16063	2
	0.11802	-0.09103	-0.77810	0.07843	0.05899	0.07250	0.15273	0.17706	3
Top mineral	-0.22505	-0.07703	0.58051	0.61416	0.07741	0.07704	-0.09525	-0.06792	1
horizon	-0.22501	-0.08289	-0.60721	-0.58608	0.06843	-0.10947	0.04809	-0.07797	2
thickness	-0.23264	-0.01992	0.60101	-0.58014	-0.09734	-0.00063	0.04208	0.18433	3
Depth to	-6.12876	0.14543	-0.06751	0.06912	0.06968	0.03131	-0.80782	0.10357	1
BC or C	-0.13278	0.15299	0.06037	-0.05921	0.06705	-0.81293	-0.11948	-0.03935	2
	-0.17185	0.16739	-0.03215	-0.11147	0.02022	-0.80374	0.02636	0.17680	3
% stones									
top mineral	0.31655	0.05871	0.40818	-0.15977	-0.09538	0.34164	-0.01878	0.21898	1
horizon	-	-	-	-	-	-	-	-	2
	-	-	-	-	-	-	-	-	3

Component 2

% sand - 5 cm (0.89315); % clay - 5 cm (-0.77414); % sand - 40 cm (0.74198); % clay - 40 cm (-0.70389). Also, % silt - 5 cm (-0.62409); % silt - 40 cm (-0.60822); % moisture - 30 cm (-0.54853) and free profile drainage (0.47181).

Component 3

pH-5 cm (0.82978); thickness of organic horizons (-0.77072). Also, % base saturation - 5 cm (0.68430) and thickness of the top mineral horizon (0.58051).

Component 4

% carbon - 5 cm (-0.81080); % moisture - 5 cm (-0.73040). Also, thickness of the top mineral horizon (0.61416).

Component 5

Receiving site drainage (0.86430). Also, poor profile drainage (0.66587), normal site drainage (-0.64473) and imperfect profile drainage (-0.53923).

Component 6

% base saturation - 30 cm (-0.80681). Also pH - 30 cm (-0.58213); % silt 40 cm (-0.55325) and excessive profile drainage (0.54368).

Component 7

Depth to the BC or C horizon (-0.80782). Also, % carbon - 30 cm (-0.59444) and free profile drainage (-0.48105).

Component 8

No really important variables are extracted, but worthy of consideration are, aspect (-0.58907); canopy of vegetation (-0.48182); % silt - 5 cm (-0.46149) and imperfect profile drainage (-0.44085).

9.3.3.3. Communalities

The table of original and final communalities for the three computer runs (Table 9.4) indicates the amount of variance for each variable, accounted for by all the common components together and is a measure of the 'structure' of the analysis. The communality of a variable is, therefore, a measure of the most that it has in common with other variables, and it was decided, as stated earlier, to extract from the analysis those variables with a communality of less than 0.5, on the assumption that they would be more likely to be significantly associated, either with other variables not included in the analysis, or "uniquely" correlated; i.e. with no other variable.

Two variables fitted these criteria; aspect at 0.48010 and % stones in the top mineral horizon at 0.46992. The micro-topography of the sites made it unlikely that aspect would be of importance in the transect. Slope angles are not great overall, and the parametric analysis of Chapter 6 shows relatively few sites to be affected by aspect thresholds.

Table 9.4

Original and Final Communalities for the Three
PCA Computer Runs

	Run 1		Run 2		Run 3	
	Original	Final	Original	Final	Original	Final
Angle of Slope	0.59215	0.59213	0.57441	0.57439	0.57176	0.57174
Altitude	0.54131	0.54129	0.54139	0.54138	0.54144	0.54142
Aspect	0.48012	0.48010	0.46092	0.46090	-	-
Canopy of						
Vegetation	0.57310	0.57308	0.60073	0.60071	0.64191	0.64189
Shedding Site						
Drainage	0.87770	0.87768	0.87682	0.87680	0.87597	0.87595
Normal Site						
Drainage	0.90850	0.90847	0.91541	0.91538	0.92994	0.92991
Receiving Site						
Drainage	0.85009	0.85007	0.85922	0.85919	0.88634	0.88632
Excessive						
Profile	0.93463	0.93460	0.92439	0.92436	0.92729	0.92726
Drainage						
Free Profile						
Drainage	0.82319	0.82316	0.82206	0.82203	0.83387	0.83384
Imperfect						
Profile	0.86866	0.86863	0.86799	0.86796	0.91487	0.91484
Drainage						
Poor Profile						
Drainage	0.85130	0.85127	0.85053	0.85050	0.85587	0.85584
Depth to in situ						
Rock	0.92447	0.92445	0.91691	0.91688	0.91630	0.91628
% sand - 5 cm	0.91624	0.91622	0.91622	0.91619	0.91689	0.91686
% silt - 5 cm	0.87136	0.87133	0.87165	0.87162	0.88417	0.88414
% clay - 5 cm	0.84232	0.84229	0.84507	0.84504	0.84544	0.84551
% sand - 40 cm	0.89563	0.89560	0.88422	0.88419	0.88696	0.88693
% silt - 40 cm	0.80796	0.80793	0.83552	0.83549	0.83716	0.83713
% clay 40 cm	0.86880	0.86877	0.87811	0.87808	0.87839	0.87836
% carbon - 5 cm	0.72318	0.72317	0.72134	0.72133	0.73644	0.73642
% carbon - 30 cm	0.62764	0.62762	0.61724	0.61722	0.61762	0.61760
% moisture - 5cm	0.65958	0.65956	0.69008	0.69006	0.69324	0.69322
% moisture -30cm	0.63256	0.63254	0.64533	0.64531	0.63557	0.63555
pH - 5 cm	0.80491	0.80489	0.83352	0.83350	0.82933	0.82931
pH - 30 cm	0.73123	0.73120	0.74079	0.74076	0.76255	0.75253
% base satura-						
tion 5 cm	0.59959	0.59957	0.62758	0.62756	0.63181	0.63179
% base satura-						
tion 30 cm	0.81966	0.81963	0.84939	0.84937	0.85989	0.85987
Thickness of						
Organic						
Horizons	0.70548	0.70546	0.69655	0.69654	0.69724	0.69722
Thickness of						
top mineral						
horizon	0.79640	0.79638	0.79478	0.79476	0.79754	0.79751
Depth to BC						
or C horizon	0.71622	0.71620	0.72938	0.72936	0.74940	0.74937
% stones in						
top mineral						
horizon	0.46993	0.46992	-	-	-	-

% stones in the top mineral horizon is more difficult to understand, but proportions of stones, other than in the calcareous soils, appear to bear little relationship either to soil type or to the character of the sites as a whole. The drifts of the area differ markedly in stone content among themselves.

Rather than extract both variables at once, the one with the lowest communality, % stones, was extracted first, to see what effect this would have on the other variables and on the component loadings. Changes indicate associations within the variables, i.e. the structure itself, and by doing this it is possible to see if the structure becomes more "stable" and whether relationships between other variables and between variables and components change.

9.3.4. Principal Component Analysis - Run 2

9.3.4.1. Variance Explained

The twenty nine remaining variables were re-run, and the eigenvalues and % variance explained are tabulated on Table 9.5.

With the extraction of % stones there is an increase in variance in seven out of the eight components showing eigenvalues above 1.0. It is not the increase that is of interest, as with twenty nine variables compared with thirty an increase will occur (one variable will exhibit 100% of the variance), but the distribution of the increase about the components. Increases in variance occur in Components 1 to 6 and 8. The greatest increases are in Component 3, associated with the thickness and chemical nature of the top horizons, and Component 2 associated with texture, particularly at 5 cm. The importance of these components increases in comparison with Component 1 which still refers to good site and profile drainage, depth to rock and angle of slope.

It is to be expected that the variance of the stones in the top mineral horizon would be "transferred" more to the second and third components which are associated with the top soil, and this is what has occurred.

9.3.4.2. Component Loadings

Table 9.3 on Pages 297-9 shows the component loadings.

Component 1

The loadings of shedding site drainage (0.91806), depth to in situ rock (-0.91691), excessive profile drainage (0.71166) and normal site drainage (-0.66760) all increase in importance, either positively or negatively, whereas those of angle of slope and altitude decrease to 0.65060 and 0.42401 respectively. This increase in the drainage and depth parameters possibly reflects an increase in importance of the parent material to the analysis.

Component 2

Considerable changes occur to the component loadings after the deletion of % stones. The loadings of % sand, silt and clay at 5 cm all increase; sand in a positive direction to 0.90238 and silt and clay in a negative direction to -0.62687 and -0.78510 respectively. The textural variables at 40 cm all decrease; % sand to 0.73617, % silt to -0.60082 and % clay to -0.69476; % moisture at 30 cm also decreases in loading to -0.52430, which is

Table 9.5 Run 2 Eigenvalues and % Variance Explained

<u>Eigenvalues</u>	<u>% Variance Explained</u>	<u>Cumulative % Variance Explained</u>
4.977	17.162	17.162
4.395	15.155	32.317
3.730	12.862	45.179
2.682	9.248	54.427
2.245	7.741	62.168
1.634	5.634	67.802
1.534	5.290	73.092
1.192	4.110	77.202
0.878	3.028	80.230
0.805	2.776	83.006
0.762	2.628	85.634
0.620	2.138	87.772
0.551	1.900	89.672
0.523	1.803	91.475
0.458	1.579	93.054
0.353	1.217	94.271
0.303	1.045	95.316
0.275	0.948	96.264
0.255	0.879	97.143
0.215	0.741	97.884
0.187	0.645	98.529
0.152	0.524	99.053
0.122	0.421	99.474
0.097	0.334	99.808
0.055	0.190	99.998
0.000	0.000	99.998
0.000	0.000	99.998
-0.000	0.000	99.998
-0.000	0.000	99.998

consistent with the decrease in the textural importance of the subsoil and the fact that % sand at 40 cm does not decrease as much as % silt and clay (the more sand, invariably the less moisture in a profile). Allied to the increase in the sand variable is the increase of the free profile drainage variable to 0.48086 (the more sand the freer the drainage).

In this run, the texture of the soil at 5 cm, and particularly of % sand, increases in importance at the expense of the subsoil at 40 cm.

Component 3

Significant changes occur, in that the signs of all the variables change from positive to negative and vice versa. Thus, the signs of the pH at 5 cm (-0.84601), % base saturation at 5 cm (-0.70044) and the thickness of the top mineral horizon (-0.60721) all change from positive to negative, whilst the thickness of the organic horizons (0.76311) changes from negative to positive. The loadings on all but the latter increase, there being an increase in the importance of the chemical nature of the top horizon over horizon thickness.

Component 4

Changes of sign occur in the variables, and % carbon at 5 cm decreases to 0.75748. The loading of the thickness of the top mineral horizon drops to -0.58608.

Component 5

Receiving site drainage (0.86266), poor profile drainage (0.66927) and imperfect profile drainage (-0.55031) all increase their loadings, whereas normal site drainage decreases to -0.64404.

At this point interesting changes in the hierarchy of components appear. Component 6 of Run 1 associated with chemical variables of the subsoil at 30 cm becomes Component 8; Component 7 of Run 1, associated predominantly with soil depth to the BC or C horizon, becomes Component 6 and Component 8 of Run 1 becomes Component 7.

Changes such as these do not indicate moves towards stability, the aspect variable possibly still having a detrimental effect.

Component 6

This component now becomes associated with depth to the BC or C horizon with an increased loading (-0.81293) and, rather less so, with decreased loadings of % carbon at 30 cm (-0.58429) and free profile drainage (-0.46398).

Component 7

Low loadings characterise this component as they did Component 8 of Run 1. This not a good sign for a satisfactory analysis, as it has been argued that there should be at least one variable with a loading of >0.7071 for a complete result and a correct number of components (Trail, 1974. pers. comm.). However, some small changes do occur from Run 1. Aspect and canopy of vegetation change sign to positive and increase in loading to 0.59252 and 0.52276 respectively. Imperfect profile drainage and % silt at 5 cm change to a positive sign, but decrease in loading to 0.43816 and 0.42259 respectively.

Component 8

Signs change from those associated with the variables in Component 6 of Run 1. % base saturation at 30 cm (0.83704), pH at 30 cm (0.60787) and % silt at 40 cm (0.59041) change to positive with increased loadings, and excessive site drainage changes to negative with a decreased loading (-0.53201). This is an increase in the chemical status variables, as also found in Component 3, but refers to the subsoil rather than the topsoil.

With the extraction from the analysis of % stones in the top mineral horizon, significant changes happen. The first five Components become clearer, with increased loadings on certain variables and decreases on others. The last three components, however, show instability, with Component 7, with its low loadings, being particularly unsatisfactory.

9.3.4.3. Communalities

The table of original and final communalities (Table 9.4) shows that aspect decreases in communality from Run 1 at 0.48010 to 0.46040. The amount of variance of this variable accounted for by all the common components together decreases, and as a result, its significance in the analysis decreases also.

9.3.5. Principal Component Analysis - Run 3

9.3.5.1. Variance Explained

Although in Run 2, with the extraction of % stones, aspect decreased in importance in the component structure, no other variable fell below the cut-off point of 0.5. Aspect alone was, therefore, deleted from the data for the third computer run, leaving a total of twenty eight variables.

Eight vectors exhibit eigenvalues of 1.0 or over (Table 9.6), and the communalities of all twenty eight variables are over 0.5 (Table 9.4).

The % variance of all eight components increases, with the first showing the greatest increase, followed by the second, seventh and third. The % variance of the first four components increases from 53.277% using thirty variables to 56.278% using twenty eight. The eight components account, in total, for nearly 80% of the variance (79.092%), compared with 75.720% for Run 1.

The % variance figures for the first four components are remarkably similar to those determined by Courtney (1973) in a PCA analysis of the Sherborne Soil Series in the southern Cotswolds, where using fifteen soil variables, of slightly different character to those of the author, % variances of 17.73, 14.26, 11.59 and 8.62 were determined. Again in the Cotswolds, Norris (1971) using thirty six soil variables, computed 46% of the variance on the first two components, as against 33.442% by the author and 31.99% by Courtney.

Table 9.6 Run 3 Eigenvalues and % Variance Explained

<u>Eigenvalues</u>	<u>% Variance explained</u>	<u>Cumulative % Variance Explained</u>
4.969	17.746	17.746
4.395	15.696	33.442
3.717	13.275	46.717
2.677	9.561	56.278
2.239	7.996	64.274
1.604	5.729	70.003
1.363	4.868	74.871
1.182	4.221	79.092
0.849	3.032	82.124
0.788	2.814	84.938
0.631	2.254	87.192
0.560	2.000	89.192
0.523	1.868	91.060
0.458	1.636	92.696
0.353	1.261	93.957
0.306	1.093	95.050
0.279	0.996	96.046
0.260	0.929	96.975
0.220	0.786	97.761
0.193	0.689	98.450
0.156	0.557	99.007
0.123	0.439	99.446
0.098	0.350	99.796
0.058	0.207	100.003
0.000	0.000	100.003
0.000	0.000	100.003
-0.000	0.000	100.003
-0.000	0.000	100.003

Such resemblances between the results lead one to believe that the indifferent variance figures result from the loose nature of the relationships within soil itself and between soil and site characteristics. Thus, although certain variables will be of more importance than others in the "make up" of sites, they will not be relatively few in number.

Because the first few components account for only a moderate amount of the total variance in all the studies, the variables are largely uncorrelated. This is confirmed by inspecting the correlation matrix of the author (Figure 9.1) which contains few high correlations, other than the textural variates. Distribution of component values is rather extended in the several component dimensions; the structure of values in component space "being more nearly hyperspherical than in other similar studies using the same technique" (Cuanalo and Webster, 1970 and Norris, 1971).

Courtney, in ascribing the above statement in parenthesis to his work in the Cotswolds, states that "this is probably partly because the population is more homogeneous, consisting of samples from within one mapping unit. In the other works mentioned, the samples were from many mapping units. However, the sites of the Mid-Wear transect were taken from a varied selection of soil mapping units and yet achieved this hyperspherical nature with weakish correlations.

9.3.5.2. Component Loadings

Table 9.3 on Pages 297-9 shows the component loadings.

Component 1

All of the variables which loaded highly in Run 2 increase in value, with a decrease in the normal drainage variable and an increase in the associated slope angle and altitude variables. The final variables of importance are:

Shedding site drainage	0.92186
Depth in situ to rock	-0.91803
Excessive profile drainage	0.71582

and Normal site drainage	-0.65570
Angle of slope	0.65316
Altitude	0.43673

The two variables of shedding site drainage and depth to rock load vary highly compared with the others, the latter in an inverse direction. Both exhibit over 84% (84.98 and 84.28%) of their variation on this component and are, therefore, highly significant (The variable variation is calculated as the square of the component loading x 100).

Excessive profile drainage has 51.24% of its variance accounted for by Component 1, but normal profile drainage has a lower loading. This fits into an emerging pattern of normal drainage decreasing with an increase in shedding site and excessive drainage régimes, whilst increasing with a greater depth to rock.

Angle of slope has 42.66% of its variance on this component. Steepness generally increases with the presence of shedding and excessive drainages and a decrease in depth to rock and normal drainage. Although not loading highly (19.07% variance), increasing altitude is consistent with the other variables.

The component is very much one of site and profile drainage status, but the highly loaded depth to rock does not make it entirely a drainage component and the associated angle of slope and altitude confirm this interpretation.

Component 2

% sand at 5 cm is still the most important variable but drops in loading, although 65.18% of its variance is on this component. The negative loading of % clay at 5 cm increases to 62.41% of its variance, but % silt at this depth declines to a loading of -0.45242. % clay at 40 cm increases negatively to exhibit 59.9% of its variance and % sand increases to 57.11%. % clay at 40 cm is more important in a negative direction than % sand, unlike Runs 1 and 2, where % sand is more significant. % moisture at 30 cm increases inversely, to show 34.86% of its variance, as does the presence of poor profile drainage to -0.44612 in line with the % clay variable. The occurrence of free profile drainage drops in loading to 0.42050, corresponding to a drop in the loading of % sand at 5 cm, The final variables of importance are as follows:

% Sand at 5 cm	0.80733
% Clay at 5 cm	-0.79002
% Clay at 40 cm	-0.77394
% Sand at 40 cm	0.75574

and % Silt at 40 cm	-0.60032
% Moisture at 30 cm	-0.59046

The parameters associated with this component are textural, and especially associated with the 5 cm depth, where % sand and clay are the most important. % clay and sand, at the 40 cm depth, in that order, also figure highly.

Component 3

The signs change from Run 2 as they did from Run 1. Although loadings drop in the chemical attributes at 5 cm, pH at this depth remains the most important variable, 70.45% of its variance being on this component. The thickness of the organic horizons now has a negative loading and increases to 60.54% of its variance, whereas % base saturation at 5 cm drops to 46.78%, and thickness of the top mineral horizon drops to 36.12%, both exhibiting positive loadings.

Over the transect, the pH at 5 cm increases with a decreasing thickness of the organic horizon, as does base saturation at 5 cm. Overall, the soils associated with the presence of organic horizons are noticeably acidic. Less clear is the relationship between chemical factors and the thickness of the top horizon, the result of cultivation and fertilisers; hence the loading of 0.60101. The final variables of importance are as follows:

pH at 5 cm	0.83937
Thickness of the organic horizons	-0.77810

and % base saturation at 5 cm	0.68395
Thickness of the top mineral horizon	0.60101

To summarise, Component 3 is associated with the nutrient status and thickness of the topsoil, but particularly with the pH at 5 cm and the thickness of the organic horizons.

Component 4

The signs remain the same with no changes occurring as happened between Runs 1 and 2. % carbon at 5 cm increases in importance to exhibit 69.54% of its variance on this component. % moisture decreases slightly to 55.23% of its variance, as does the thickness of the top mineral horizon to show 33.66%. The final variables of importance are as follows:

% Carbon at 5 cm	0.83390
% Moisture at 5 cm	0.74318

and Thickness of the top mineral horizon	-0.58014

This component is clearly associated with the organic content of the soil at 5 cm.

Component 5

A change of emphasis occurs from Run 2, with the signs of the variables changing. The highly loaded drainage variables, of receiving site drainage and poor profile drainage, change to negative loadings. The former increases in importance to show 83.11% of its variance on this component, but the latter decreases to show 36.98%. Normal site drainage increases to exhibit 46.74% of its variance and is the most important variable after receiving drainage, whereas imperfect profile drainage drops to a loading of 0.40440, only 16.35% of its variance. The final variables of importance are as follows:

Receiving site drainage	-0.91164
Normal site drainage	0.68366

and Poor profile drainage	-0.60810

The site drainage parameter has increased in importance at the expense of profile drainage during this run, and as profile drainage is, in part, a function of site drainage this is a good result. Normal site drainage is more clearly associated with imperfect profile drainage in the transect, hence the negative loading of the poor drainage variable, which is associated more clearly with receiving site drainage, and positive loading of imperfect profile drainage.

The component is predominantly one of site drainage status.

Component 6

The depth to the BC or C horizon remains the most important variable, but with a decreased loading from Run 2: 64.6% of its variance is on this component. % carbon at 30 cm decreases its negative loading appreciably to -0.48999, whereas free profile drainage increases its loading in a negative direction to exhibit 31.43% of its variance. The most significant difference from Run 2, however, is the increase in the imperfect profile drainage variable to show 45.96% of its variance.

The situation is that a decreasing depth to the BC or C horizon is matched by an increasing presence of imperfect profile drainage and a concomitant decreasing presence of free profile drainage; hence the appropriate positive or negative loadings. The final variables of importance are as follows:

Depth to the BC or C horizon	-0.80374
Imperfect profile drainage	0.67794

and Free profile drainage	-0.56059

The depth of the solum is by far the most significant variable, but profile drainage is associated to an extent.

As in the case of Run 2, changes occur in the last two components. The loadings of Component 7 change place with Component 8 to give a far more stable and satisfactory result.

Component 7

The loadings increase considerably with the changing of emphasis from Component 8 and the signs of the variables change. There is now, unlike Run 2, a variable with a loading above 0.7071, that of % base saturation at 30 cm, which increases in importance from Run 2 to show 72.15% of its variance. pH at 30 cm increases from Run 2 to exhibit 42.31% of its variance. Of the other variables, % silt at 40 cm decreases to a variance of 34.76%, whilst excessive site drainage increases to 30.6%. The same sign of the loadings of base status and pH are to be expected, as % base saturation decreases with decreasing pH. The final variables of importance are as follows:

% Base saturation at 30 cm	-0.84939
pH at 30 cm	-0.65047

and % Silt at 40 cm	-0.58958
Excessive site drainage	0.55318

The component is associated with the nutrient status of the soil at 30 cm, but in particular with % base saturation.

Component 8

It is not intended to read much into Component 8. Two variables remain with loadings noticeably above the others. % silt at 5 cm increases to over 0.7071, thereby indicating a stability of the analysis using eight components; 52.51% of its variance is accounted for on this component. Canopy decreases in loading to show only 21.59% of its variance. Imperfect profile drainage decreases from Component 7 of Run 2, to reach only 0.33147. The final variables are as follows:

% Silt at 5 cm	0.72465

and Canopy of Vegetation	0.46467

% Silt at 5 cm is the most important variable by far, but as only just over 50% of its variance is accounted for, the component cannot really be characterised by this variable alone. It will, therefore, be considered as "mopping up" the rest of the significant variance remaining, as defined by Guttman (1954).

9.3.5.3. Summary of Run 3

Run 3 shows itself to be far more stable than either Runs 1 or 2. In each component a variable, or certain variables, increase in significance from Run 2, making a clearer interpretation possible. In each Component there is a variable with a loading of 0.7071, and Component 7 is now associated with readily distinguishable variations. Component 8 is now left to "soak up" the remaining significant variance.

Rationalising the above analysis results in the following interpretation of the components, derived from the original thirty variables:

Component

1	Site and profile drainage status, depth to rock and angle of slope.
2	Soil texture (particularly of the soil at 5 cm).
3	pH and % base saturation (nutrient status) of the soil at 5 cm and thickness of the organic horizons.
4	Organic content of the soil at 5 cm.
5	Site drainage.
6	Depth of the solum, to BC or C horizon.
7	Base saturation and pH (nutrient status) of the soil at 30 cm.

These variables are the most diagnostic and significant that can best be used to characterise the area of the transect.

The next chapter discusses the grouping of sites according to each component and the characteristics of each grouping, in resource inventory terms.

10.1 Introduction

In Chapters 7 and 9 it was suggested that a spatial distribution map could be drawn for each of the thirty variables at the seventy one sites, making a total of thirty separate maps (or information inventories) in all.

In order to produce a composite analysis of these variables, for inventory and eventual capability purposes, a researcher would have to place one map on top of another and "by eye" sieve out clusters of sites. Of course this is not possible.

Chapter 9 has discussed in detail the extraction of the loadings for each variable associated with each component and has attempted to interpret the components in overall terms (Section 9.3.5.3. on Page 311). However, in addition to interpretation according to variables, principal component analysis also allows the components extracted to be analysed according to the sites associated with these variables; in this case the sites of the transect. The calculation enabling this spatial analysis to take place is that of component scores, and it is the discussion and interpretation of these as site resource inventories that follows in this chapter.

10.2 Definitions of Component Scores

Component scores are a weighted summation of the original scores on each of the components for a given observation and give a profile score for each observation over the components extracted. Scores can either be positive or negative, as can component loadings, and are thus positively or negatively associated with the variables which characterise the components.

A problem inherent in the diagrammatic representation of component scores is by what means are the agglomerations of sites in this case, or areas in others, to be differentiated. Most social area analysts have used sextiles to group the values (Davies, 1969), but an inspection of the scores in the transect analysis indicated that a more detailed breakdown into octiles seemed to fit the data better. The fact that seventy one sites were being grouped meant that not all the groups would contain the same number of sites. There was, therefore, no alternative but to allot one less site for one of the octiles, and it was decided that the first Octile should be the one; there was no other reason for this but that it was the first.

10.3 Analysis of The Component Scores of The Transect Sites

The analysis produces seven inventories of site and soil data, and these are presented in detail in this section. All the information required to characterise the transect sites according to the parameters initially chosen for analysis is embodied in these inventories.

10.3.1 Component 1 Discussion

Figure 10.1 shows the component scores mapped out spatially on the 500 metre grid; the component being positively associated with shedding site drainage and excessive profile drainage and slope and negatively associated with depth to rock and normal site drainage. The sites which score highest on the component are most associated with these variables, with gradations of association down the octile ranges to the sites of greatest disassociation with these variables in Octile 8. It is important to remember that Component 1 only accounts for 17.162% of the variance explained and that as a result the agglomerations of sites produced may not be too clear. Table 10.1 shows the parameters of most importance to the component as their characteristics differ down the component range.

Fig 10.1 Component 1

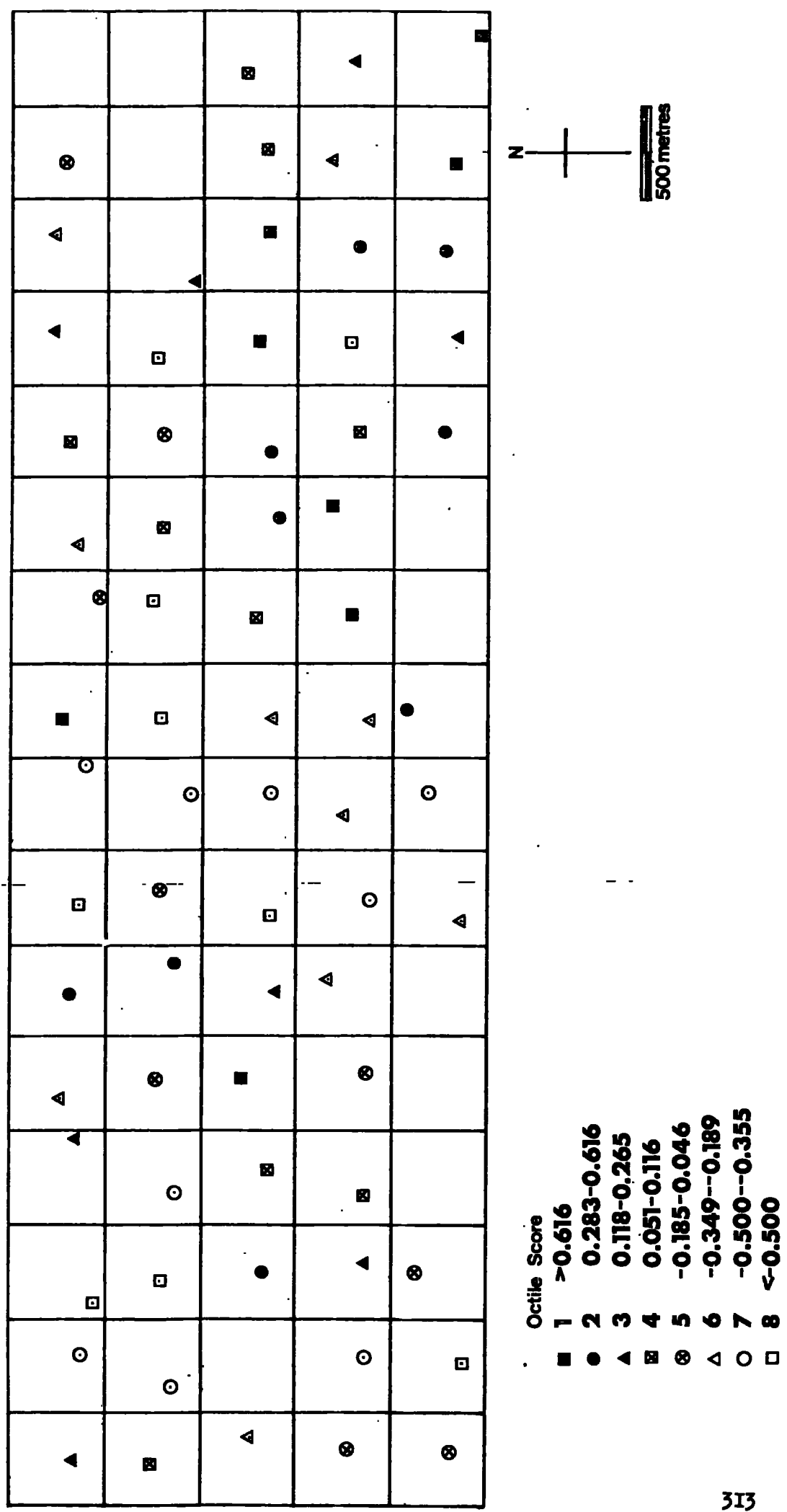


Table 10.1 Component 1

<u>Octile 1</u>					
<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>	<u>Depth to Rock (cm)</u>	<u>Slope °</u>
70	1.742	Shedding	Well drained (free)	44	2.0
54	1.417	Shedding	Well drained (free)	50	8.1
71	1.412	Shedding	Well drained (excessive)	25	16.7
55	1.360	Shedding	Well drained (free)	55	12.8
42	1.137	Shedding	Well drained (free)	45	7.1
33	1.028	Normal	Poor	>100	17.2
41	0.760	Shedding	Well drained (excessive)	30	7.5
9	0.641	Normal	Well drained (free)	>100	2.8
Mean				56.12	9.27
 <u>Octile 2</u>					
39	0.616	Normal	Moderately well drained (free)	>100	4.6
31	0.494	Normal	Poor	>100	8.5
67	0.437	Normal	Poor	>100	3.7
58	0.370	Normal	Well drained (free)	>100	0.9
6	0.368	Normal	Poor	>100	1.4
40	0.347	Shedding	Well drained (excessive)	30	5.0
66	0.347	Normal	Well drained (free)	70	2.0
21	0.304	Normal	Moderately well drained (free)	>100	2.3
69	0.283	Normal	Poor	>100	2.9
Mean				>96.7	3.47
 <u>Octile 3</u>					
13	0.265	Normal	Moderately well drained (free)	>100	1.5
1	0.249	Normal	Poor	>100	3.4
29	0.239	Normal	Poor	>100	3.6
59	0.183	Normal	Imperfect	>100	0.7
4	0.168	Normal	Moderately well drained	>100	6.3
43	0.151	Normal	Imperfect	>100	2.8
60	0.138	Normal	Imperfect	>100	2.9
68	0.131	Normal	Poor	>100	1.5
47	0.118	Normal	Poor	>100	6.3
Mean					3.22

Table 10.1 (Continued)

Octile 4

<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>	<u>Depth to Rock (cm)</u>	<u>Slope^o</u>
34	0.116	Normal	Poor	>100	1.2
38	0.114	Normal	Poor	>100	1.9
12	0.106	Normal	Imperfect	>100	4.8
16	0.106	Normal	Well drained (free)	>100	0.8
56	0.084	Normal	Imperfect	>100	8.4
48	0.073	Normal	Poor	>100	4.2
44	0.063	Normal	Imperfect	>100	0.8
32	0.056	Normal	Poor	>100	2.3
26	0.051	Normal	Imperfect	>100	2.9
Mean					3.03

Octile 5

22	0.046	Normal	Imperfect	>100	2.2
27	0.032	Normal	Imperfect	>100	3.1
10	0.009	Normal	Imperfect	>100	3.5
15	0.005	Normal	Poor	>100	4.5
45	-0.005	Normal	Poor	>100	3.7
63	-0.036	Normal	Poor	>100	2.0
61	-0.045	Normal	Poor	>100	3.2
20	-0.114	Normal	Well drained (free)	>100	0.6
49	-0.185	Normal	Poor	>100	0.6
Mean					2.6

Octile 6

11	-0.189	Normal	Poor	>100	5.9
14	-0.200	Normal	Poor	>100	2.6
5	-0.205	Normal	Well drained (free)	>100	0.6
37	-0.208	Normal	Well drained (free)	>100	0.5
53	-0.267	Normal	Imperfect	>100	2.9
52	-0.284	Normal	Imperfect	>100	1.4
30	-0.340	Normal	Poor	>100	2.3
50	-0.343	Normal	Poor	>100	1.4
64	-0.349	Normal	Poor	>100	2.8
Mean					2.27

Table 10.1 (Continued)

Octile 7

<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>	<u>Depth to Rock (cm)</u>	<u>Slope °</u>
8	-0.355	Normal	Poor	>100	0.6
65	-0.364	Normal	Poor	>100	5.7
51	-0.366	Normal	Poor	>100	2.4
36	-0.401	Normal	Imperfect	>100	1.5
17	-0.401	Normal	Poor	>100	1.0
2	-0.415	Normal	Poor	>100	0.1
23	-0.431	Normal	Poor	>100	0.6
46	-0.476	Receiving	Poor	>100	8.2
19	-0.500	Normal	Imperfect	>100	0.6
Mean					2.3

Octile 8

7	-0.569	Normal	Poor	>100	2.3
3	-0.632	Normal	Poor	>100	0.1
18	-0.636	Receiving	Poor	>100	0.5
28	-0.746	Receiving	Poor	>100	3.1
24	-1.076	Receiving	Poor	>100	7.0
25	-1.175	Receiving	Poor	>100	0.9
62	-1.310	Receiving	Poor	>100	5.0
57	-1.437	Receiving	Poor	>100	1.6
35	-1.506	Receiving	Poor	>100	2.9
Mean					2.6

Octile 1

Octile 1 scores between 1.742 and 0.641. The general characteristics of the sites in this group are as follows:- shedding sites with well drained profiles on strongly to steeply sloping land, generally calcareous throughout with a depth to rock of 50cm or less. All but Site 33 are located on or near the Permian Escarpment (Unit 6) and this is reflected in the mean height of the sites being 97.9m O.D. (range 49-145m). Associated with the shallow rooting depths and steep slopes, land use, at all but two sites, is non-arable.

Inevitably some exceptions to the general pattern occur. The inclusion of Site 33, a cambic stagnogley located in a stream section in Unit 2, appears at first to be highly anomalous. However, the site has a steep slope, suggesting that it is the overwhelming effect of slope (the steepest of all the sites) that places it in this octile.

Octile 2

The second octile includes nine sites, all but four of which were uncultivated when surveyed.

Included within this cluster are a variety of soil types ranging from typical brown earth and brown rendzina to stagnogleyic brown earth, surface and ground-water gley and disturbed soil. The majority have well to moderately well drained profiles and, apart from Site 40, all have normal site drainage.

In general, there is a move towards greater drainage impedance from Octile 1. Likewise, slopes are less steep whilst depth to rock increases.

The sites are distributed widely about the transect, but there is a definable trend towards the eastern half. Sites 66 and 69 are located not very far from the escarpment and two-thirds of the sites are situated on or around the slopes of Pittington Hill. To the west, the remaining three sites (6, 21, 31) are located on or near the slopes above the Wear (Unit 2). The mean altitude is 95.8 m.O.D.

Site 40 provides the only apparently anomalous profile in the octile, being a rendzina with depth to rock of less than 50 cm. At first examination, it would seem more similar to those sites of Octile 1, but it is better suited to cultivation than equivalent rendzinas in Octile 1 on the basis of site factors and the fact that the rock is extremely brecciated, permitting adequate root penetration. Thus, on the basis of land use, it is appropriately allocated to Octile 2.

Octile 3

Octile 3 is more associated with cultivated sites than the previous two, with six of the nine sites being under arable and the remainder devoted to permanent grass or ley. Imperfectly to poorly drained conditions prevail, with two-thirds of the sites being stagnogleyic brown earths and the remainder being surface or ground-water gleys.

All sites have a normal site drainage and all are impeded to varying degrees. This is the first octile with depths to rock being indeterminate, and slopes overall are less steep, Site 59 being in the level category. One site (68) is subject to flooding.

Two-thirds of the grouping are located on or around the Permian outcrop in Physiographic units 5, 6 and 7 (Sites 13, 29, 43, 59, 60, 68), those of the Permian Plateau itself (Unit 7) all being stagnogleyic brown earths or

cambic stagnogleys. The remaining sites are to the west, with the first situated in the Lowlands West of the Wear (Unit 1) appearing in the component (1 and 4).

However, the preponderance of eastern sites is reflected in the mean height of 99.9m O.D. with a range of 37-137m.

Octile 4

As in Octile 3, land use is predominantly arable. Similarly, apart from Site 16, all sites exhibit a profile drainage impediment, are of normal site drainage and have depth to rock in excess of 100cm.

Soil types are stagnogleyic brown earth or cambic stagnogley, with one typical brown earth (Site 16).

The mean slope is slightly less than in previous octiles, but is still in the moderately sloping category.

Most of the sites are again within the eastern sector of the transect with five located on or near the Permian outcrop in Units 5, 6 or 7. Nevertheless, the "core area" has moved further west. The mean altitude decreased to 95.6m O.D., with a range of 58-155m.

Octile 5

The scores of the fifth octile range from -0.185 to 0.046. Eight of the nine sites show poor or imperfect profile drainage. Surface or ground-water gleys and stagnogleyic brown earths predominate, with one disturbed and one brown alluvial soil being represented. A permanent grass land use predominated when surveyed. All nine sites have normal site drainage and a depth to rock in excess of 100cm.

The mean slope continues to decline to the gently sloping category, and the mean altitude drops to 78.3m O.D. with a range of 27-160m. This reflects the distribution of the sites. Six are located in the western part of the transect in Physiographic Units 1, 3 and 4. The remaining three are situated on the Permian Escarpment or Plateau (Units 6 and 7).

Octile 6

All the scores are negatively associated with this octile, indicating that the sites are negatively linked with the variables that characterise the component. Unlike Octile 5, most sites are arable, but like that grouping all shown impeded profiles and normal site drainages.

Although soil types vary considerably, all but two locations show evidence of gleying to some degree. Slope is less steep than in previous octiles and only one site (11), right at the top of the range, is above gently sloping.

The trend towards site location further west continues; although the mean altitude of 81.3m shows a slight increase, the range is narrower at 30-118m. Only two sites are situated on the Permian outcrop, the cambic stagnogleys of 11 and 14. Over half of sites are in the Lowlands East of the Wear, (Unit 4). These are located in two areas; firstly, to the east in a band following the line of the escarpment: from north to south Sites 37, 52, 53; being under arable cultivation. Secondly, an area to the west towards Ramside; the surface-water gleys of Sites 50 and 64.

The final two sites (5 and 30) form "outliers" further to the west in the Wear Gorge and Lowlands West of the river respectively.

Octile 7

The proportion of sites under arable cultivation declines from the 66% of the previous Octile to 44.4%. Soil type is either surface or ground-water gley (particularly cambic stagnohumic gley), stagnogleyic brown earth, gleyic brown alluvial or disturbed soil.

All but one site exhibits normal site drainage, and the first receiving site appears, at the base of the range. Mean slope remains similar to the last octile at gently sloping.

There is a firm move to the west in location; mean altitude dropping to 71.2m O.D. with a range of 30-79m. The sites occur in three areas; the most important being the Lowlands East of the Wear (Unit 4) with five sites (8, 23, 36, 51, 65) situated in a narrow belt running from north to south, some 500 metres wide between Pittington Beck, south west of Pittington village to near Rainton Gate.

The second area in the Wear Gorge (Site 19) and the Lowlands West of the Wear (Unit 1).

Octile 8

The last octile of the component scores between -0.569 and -1.506. Two-thirds of the sites exhibit receiving site drainage and all have poor profile drainage. Arable is the major land use.

As in the last octile, two sites show steeper slopes than the rest resulting in a slightly higher mean, but still remaining in the gently sloping category. The receiving site drainage of Sites 24 and 62 results in their inclusion in this octile despite the steeper slopes.

All the sites are gleyed, and all but one, the typical humic alluvial gley of Site 62, are cambic stagnogley or cambic stagnohumic gleys.

The mean altitude increases to 81.3m O.D. with a range of 30-142m, a reflection of the occurrence of receiving sites on the Permian outcrop and nearby (25, 28, 57). The remaining sites are located between Rainton Gate and Framwellgate Moor.

10.3.2 Conclusion and Summary of Component 1 Scores

10.3.2.1 General Trends

i) The above description of the octile groupings shows specific trends appearing, as the scores go down the component, from positive to negative. The signs of the variables indicate that those octiles with high positive scores will be characterised by good site and profile drainage, a shallow depth to in situ rock and, to an extent, a steeper angle of slope.

ii) As the octiles progress down the component, drainage worsens. After Octile 2 there are no localities with shedding site drainage and in Octiles 3 to 6 all sites have a normal site drainage régime. A receiving site first appears in Octile 7, and in 8 over threequarters have such drainage. There is thus a progression from positively scored shedding drainages to negatively scored receiving drainages, with normal drainage in between.

iii) Likewise, profile drainage changes from the domination of excessive and well drained (free) profiles in Octile 1, through less well drained in Octile 2 to imperfect in Octiles 3 and 4. Poor profile drainage emerges as dominant in Octile 5 and continues to increase in proportion to find its major expression in 8 where all profiles are poorly drained.

iv) The first two octiles include sites where depth to rock could be measured i.e. <100 cm; three quarters of the 8 locations in Octile 1 having such depths. Octile 2 shows profiles deepening with only two of the nine sites being less than 100 cm deep. Octiles 3 to 8, however, all have depths to rock in excess of 100 cm.

v) The patterns of slope changes down the component are more difficult to interpret as would be expected with the lower loading of this variable but the trend is a general decrease as it progresses. This inference is supported by correlating the rank of each site (1-71) with the slope angle of each site by means of the Spearman rank correlation technique. This proves a decrease of $-0.874 \alpha = 0.01$.

vi) There is also a notable decrease in altitude of the sites down the octiles. Again, taking the altitude of each site down the component and correlating these with the rank of each site (1-71) there is a decrease in altitude ($r_s = -0.809 \alpha = 0.01$).

vii) Coinciding with these differences in drainage and site parameters specified above, are changes in soil type down the component (Table 10.2).

Lithomorphic soils only occur in the first two octiles, associated with shallow depths to rock, shedding sites and excessive profile drainage.

There is a trend for the major group of brown soils to decline in importance down the component from maxima in Octiles 1 and 3 to a minimum in the last Octile. At subgroup level, brown calcareous earths occur only in the first Octiles and typical brown earths are absent below Octile 4. Stagnogleyic brown earths decline after a maximum in Octile 3, but the brown alluvial soil group occurs from Octiles 2 to 7 with no apparent trend. Brown soils do not rise above 50% of any Octile after Octile 4.

Surface-water gley soils, increase erratically in importance down the component to reach a maximum in the last octile. The humic subgroup shows a more definite trend, to be most significant in the last two octiles, whereas the mineral subgroup shows little trend reaching greatest proportions in Octiles 4 and 8. Ground-water gleys developed on alluvium, like their brown soil counterpart, do not show any particular distribution, although the humic subgroup is only represented in Octile 8. Likewise, man-made soils (disturbed) are distributed throughout the component.

viii) Associated with the site and profile parameter changes down the component are changes in land use type, resulting from, among other things, the changes in the site/profile parameters (Table 10.3).

Woodland is associated with the better drained soils which have shallow depths to rock and steeper slopes, hence this land use predominates in Octiles 1 and 2. It assumes minor importance in the lower octiles (6, 7, 8) where it is only associated with the steep slopes of the Wear Gorge. Scrub sites occur sporadically throughout the range but do not assume significant proportions.

Table 10.2 Percentage of Sites in Each Soil Type by Ostile - Component 1.

Ostile	Litho-morphic Soils		Brown Soils				Surface-Water gley soils		Ground-Water Gley Soils		Man-Made Soils	
	Brown Rendzina	Brown Calc. Earth	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic Stagnogley humic Gley	Typical Alluvial Gley	Typical Humic Alluvial Gley	Disturbed Soil	
1	25.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	0.0	12.5	12.5
2	11.1	0.0	11.1	11.1	0.0	11.1	22.2	11.1	11.1	0.0	11.1	11.1
3	0.0	0.0	0.0	55.5	0.0	0.0	22.2	11.1	11.1	0.0	0.0	0.0
4	0.0	0.0	11.1	44.4	0.0	0.0	44.4	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	33.3	11.1	0.0	11.1	22.2	11.1	0.0	11.1	11.1
6	0.0	0.0	0.0	22.2	11.1	0.0	33.3	22.2	0.0	0.0	11.1	11.1
7	0.0	0.0	0.0	11.1	0.0	11.1	0.0	44.4	11.1	0.0	22.2	22.2
8	0.0	0.0	0.0	0.0	0.0	0.0	44.4	44.4	0.0	11.1	0.0	0.0

Table 10.3 % Occurrence of Land Use Types by Octile - Component 1

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable and Grass Ley	Agricultural Sites
1	50.0	12.5	25.0	0.0	12.5	12.5	37.5
2	55.6	0.0	11.1	0.0	33.3	33.3	44.4
3	0.0	0.0	22.2	11.1	66.7	77.8	100.0
4	0.0	0.0	33.3	11.1	55.6	66.7	100.0
5	0.0	11.1	44.4	0.0	44.4	44.4	88.9
6	11.1	0.0	22.2	0.0	66.7	66.7	88.9
7	11.1	11.1	22.2	11.1	44.4	55.6	77.8
8	11.1	0.0	0.0	0.0	88.9	88.9	88.9

Permanent grass, as is to be expected, occurs in all octiles reaching highest proportions in Octiles 4 and 5. Arable shows an increase down the octile range despite the progressively indifferent soil and site drainage, but coincides with shallower angle of slope.

Thus, down the octile range of Component 1 there is an increase in the intensity of indifferent site and profile drainage and depth to rock within the 100 cm restriction; a decrease in angle of slope and altitude; an increase in the proportions of gleyed profiles and humic subgroups; a decrease in woodland areas; a slight decrease in grass and an increase in arable.

10.3.2.2 Spatial Variations of the Sites

In addition to the changes in emphasis down the component of the site and profile parameters, there are variations in the spatial distribution of the sites, namely a trend for the gradual movement of emphasis from east to west across the transect. The pattern is shown in Table 10.4.

Table 10.4 % Site Distribution Among the Physiographic Units by Octile - Component 1

Octile	Physiographic Unit								
	W						E		
	1	2	3	4	5	6	7	1+2+3	5+6+7
1	0.0	12.5	0.0	12.5	0.0	75.0	0.0	12.5	75.0
2	0.0	11.1	11.1	22.2	33.3	11.1	11.1	22.2	55.6
3	11.1	11.1	0.0	22.0	11.1	11.1	44.4	22.2	66.7
4	11.1	11.1	0.0	11.1	11.1	11.1	33.3	22.2	55.6
5	11.1	0.0	22.2	33.3	0.0	11.1	22.2	33.3	33.3
6	11.1	0.0	11.1	55.6	0.0	11.1	11.1	22.2	22.2
7	22.2	11.1	11.1	55.6	0.0	0.0	0.0	44.4	0.0
8	22.2	0.0	11.1	33.3	11.1	11.1	11.1	33.3	33.3

The proportion of sites located on the Permian Escarpment and Plateau (Unit 6, 7) drops sharply after Octile 4, and even more after Octile 5 if Coalford Vale (Unit 5) is included. Complimentary to this decrease is a rise in the proportions situated in Units 1, 3 and 4.

Of particular interest in Octile 1 is the absence of any location on the Permian Plateau, all but two sites being on the escarpment. This is the result of the occurrence of excessively drained steeper slopes on the escarpment which is characterised, on its upper slopes by an absence of drift. The plateau, with its cover of Lower Till, is predominantly imperfectly drained and, as a result, is most frequent in the octiles which are associated with this profile drainage; namely 3 and 4. It is only in Octiles 3, 4 and 5 that the plateau has a significant effect on the total proportions of the "eastern" areas of Units 5, 6 and 7.

The Lowlands East of the River Wear (Unit 4) are represented in all components, which reflects their diversity of drainage characteristics, which in turn reflects the diversity of parent material. The rather heavy nature of much of the parent material is indicated by the dominance of Unit 4 in Octiles 6 and 7.

The sites of the Wear Gorge and Floodplain (Unit 3) occur mainly in Octiles 5 to 8 which belies their diversity of site and parent material.

The Upper Slopes of the Wear Gorge (Unit 2) show trends similar to the areas further to the east, only one site being represented after Octile 4. This is probably a reflection of the steeper slopes encountered in this area compared with the lowlands to the east and west and the Wear Gorge itself.

The Lowlands West of the River Wear (Unit 1), predominantly with heavy parent material, poor profile drainage and gentle slopes, are not represented in either of the first two octiles but, as is to be expected, increase in representation from Octiles 3 to 8 which are related to increasing site and profile wetness.

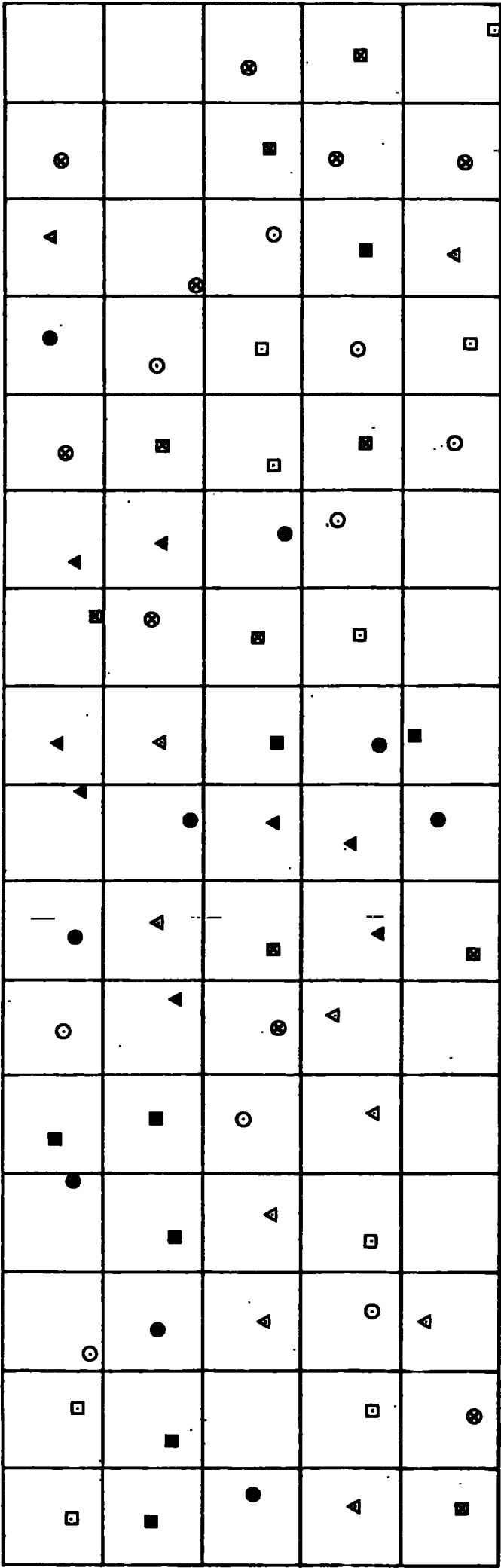
Overall, the analysis of Component 1 indicates that there is a trend for better drained shallow soils with steeper slopes at higher altitudes to be located in the eastern part of the transect, especially associated with the Magnesian Limestone, whilst the poor drained deeper soils on shallower slopes and at a lower altitude are concentrated in the west.

10.3.3 Component 2 Discussion

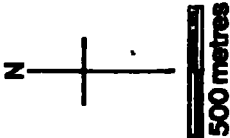
Component 2, which accounts for only slightly less of the variance than the first component, loads heavily on soil texture, and in particular on the positive relationship with % sand at 5 cm and the negative loading of % clay at this depth. Also of importance are % sand and clay at 40 cm. The sites are thus classified predominantly on these textural variables. Silt at 5 cm and 40 cm is slightly less important, but shows negative loadings in association with the decrease in sand and increase in clay.

It is to be expected that sandy profiles will score highest, with clayey and silty soils scoring down the component range (Figure 10.2 and Table 10.5).

Fig10.2 Component 2



- Octile Score
- | | | |
|---|---|---------------|
| ■ | 1 | >1.271 |
| ● | 2 | 0.730-1.271 |
| ▲ | 3 | 0.341-0.716 |
| ⊠ | 4 | 0.064-0.171 |
| ⊙ | 5 | -0.191-0.051 |
| △ | 6 | -0.725--0.230 |
| ○ | 7 | -1.159--0.789 |
| □ | 8 | <-1.159 |



Octile 1

All but one of the eight sites are well drained brown earths, brown alluvial or disturbed soils, with an imperfectly drained gleyic brown alluvial soil being the exception at subgroup level, although classified as a brown alluvial soil at group level. Woodland or scrub is the major land use.

All the sites exhibit high sand contents, but down the octile the texture at 5 cm becomes less sandy, apart from at Site 17 which has a clay loam texture at 40 cm to place it at the base.

The sites are located in four areas; just off the Magnesian Limestone at Elemore (Site 58); near Pitlington Village (Sites 37, 66); in the Wear Gorge at Mallygill (Sites 5, 19, 20) and in the west of the transect at Low Newton and Brasside (Sites 16, 17).

Apart from Site 17, all are associated with sandy parent materials, the mean sand content at 5 cm being 74.63% (61.25 - 86.78%), and at 40 cm slightly lower at 70.24% (66.59 - 86.35%).

Octile 2

All the sites of the second octile are gleyed and vary in type from surface and ground-water gley and stagnogleyic brown earth to disturbed soil. All but one was under arable when surveyed.

Overall, textures are heavier than in the first octile, particularly at the 5 cm depth where increasing clay content is apparent down the range. At 40 cm the situation is not as clear, but there is a perceptible increase in heavier texture at the base of the octile; the first sandy clay in the component appearing at Site 30.

Parent materials are overall less sandy than those of the first Octile, all but Site 65 having the Lower Till or Upper Wear Clay as parent material. Locations vary from east to west across the transect.

Octile 3

As in the previous octile, soil type reflects drainage impedance and all but one profile shows evidence of gleying. Over three quarters of sites are surface-water gleys or stagnogleyic brown earths. The numbers of poorly drained profiles increases, reflecting a move away from the high positive scores associated with high sand content and the brown soils major group. Arable is the major land use. Textures are "heavier" than in the two preceding groupings. There is a preponderance of silty loams and clay loams at 5 cm and all textures at 40 cm are clay loams.

In location, there is a slight emphasis towards the eastern half of the transect and a congregation of sites in the Lowlands East of the Wear (Unit 4) between Rainton Gate and Pitlington (8,9,21,36,51,52); the remainder being on the Permian outcrop.

Lower mean sand contents indicate heavier parent materials - mean sand content at 5 cm is 53.07% and at 40 cm 55.66%, whilst mean clay content increases to 24.75% and 25.4% at these depths respectively.

Octile 4

Five sites are stagnogleyic brown earths and the remainder are surface or ground-water gleys; the later at the base of the range (Site 61).

The trend of increasing clay content at the expense of sand continues and both sample depths are dominated by clay loam textures. Mean clay content increases to 25.0% and 28.8% at 5 and 40 cm respectively and sand content decreases to 52.4 and 48.3%.

The sites are situated throughout the transect with the highest proportion being on the Permian Escarpment or Plateau (Units 6 or 7).

Table 10.5 Component 2

Octile 1

<u>Site</u>	<u>Score</u>	<u>Texture (5cm)</u>	<u>Texture (40cm)</u>
66	2.602	Sandy loam	Loam
20	2.600	Loamy sand	Sandy loam
5	2.586	Loamy sand	Loamy sand
19	1.952	Loamy sand	Loam
58	1.826	Loam	Loam
37	1.638	Loam	Sandy loam
16	1.581	Loam	Sandy clay loam
17	1.454	Sand	Clay loam

Octile 2

65	1.271	Loam	Loamy sand
13	1.226	Loam	Loam
7	1.217	Clay loam	Loam
4	1.119	Loam	Clay loam
18	1.011	Clay loam	Clay loam
53	0.981	Loam	Loam
39	0.950	Clay loam	Clay loam
30	0.826	Clay loam	Sandy clay
23	0.730	Silty loam	Loam

Octile 3

9	0.716	Clay loam	Clay loam
14	0.698	Clay loam	Clay loam
36	0.675	Loam	Clay loam
8	0.595	Silty loam	Clay loam
52	0.539	Loam	Clay loam
51	0.520	Silty loam	Clay loam
11	0.424	Clay loam	Clay loam
26	0.358	Clay loam	Clay loam
21	0.341	Silty clay loam	Clay loam

Octile 4

<u>Site</u>	<u>Score</u>	<u>Texture (5cm)</u>	<u>Texture (40cm)</u>
10	0.171	Silty loam	Clay loam
35	0.157	Loam	Sandy loam
64	0.156	Silty loam	Silty loam
56	0.154	Silty loam	Clay loam
38	0.128	Clay loam	Clay loam
43	0.118	Clay loam	Clay loam
60	0.103	Clay loam	Clay loam
27	0.073	Clay loam	Clay loam
61	0.064	Clay loam	Clay loam

Octile 5

15	0.051	Clay loam	Clay loam
29	0.042	Loam	Clay
12	-0.005	Clay loam	Clay loam
59	-0.022	Clay loam	Clay loam
25	-0.023	Loam	Loam
70	-0.071	Silty loam	Silty clay loam
44	-0.080	Clay loam	Clay loam
62	-0.092	Silty loam	Loam
34	-0.191	Silty loam	Clay

Octile 6

32	-0.230	Silty loam	Silty clay loam
50	-0.277	Clay loam	Clay
45	-0.351	Clay loam	Clay
69	-0.431	Clay loam	Silty clay
22	-0.445	Clay loam	Silty clay loam
49	-0.452	Clay loam	Silty clay
31	-0.587	Silty clay loam	Clay loam
63	-0.590	Clay loam	Silty clay
24	-0.725	Clay loam	Clay loam

Octile 7

<u>Site</u>	<u>Score</u>	<u>Texture (5cm)</u>	<u>Texture (40cm)</u>
57	-0.789	Clay loam	Clay loam
55	-0.812	Loam	Clay loam
47	-0.962	Silty clay loam	Clay
67	-1.054	Clay	Clay
33	-1.104	Silty clay loam	Silty clay
28	-1.157	Clay loam	Clay loam
42	-1.159	Silty loam	Clay loam
6	-1.159	Clay	Clay
3	-1.159	Silty clay	Silty clay

Octile 8

68	-1.254	Clay	Clay
48	-1.307	Silty clay loam	Silty clay
1	-1.308	Silty loam	Silty clay
2	-1.491	Clay loam	Clay
46	-1.898	Silty clay loam	Silty clay loam
54	-2.119	Silty clay loam	Silty clay loam
40	-2.775	Clay loam	N.D.
71	-2.808	Loamy sand	N.D.
-41 -	-3.053 -	Silty clay loam	N.D.

Octile 5

Only Site 70 is not gleyed to some degree, and stagnogleyic brown earth and cambic stagnogleys account for two-thirds of all sites. Arable is the primary land use.

Textures at 5cm are very similar to those of Octile 4, though the sand content continues to decline (mean = 50.13%). At 40cm the sand content decreases to a mean of 46.58% and for the first time clay textures are encountered. This octile is associated primarily with the Permian outcrop.

Octile 6

The sixth octile is the first with all negative scores, and the profiles show, more significantly, the affect of greater clay content and decreasing sand. Cambic stagnogleys or cambic stagnohumic gleys dominate with only one exception, the stagnogleyic brown earth of Site 22. Agricultural land use predominates.

Mean textures are noticeably heavier than in previous octiles with the mean clay content rising to 27.6% at 5cm and 37.4% at 40cm; for the

first time mean sand content falls to less than 50% at both depths, whilst silt appears as a significant fraction at the 40cm depth.

This increase in silt and clay is accompanied by a westward "shift" of the profiles away from the Permian outcrop onto the heavier textured parent materials of the Lowlands East of the Wear (Unit 4) and Coalford Vale (Unit 5).

Octile 7

Two-thirds of the profiles are surface-water gleys, with one ground-water gley and two brown calcareous earths. There is an increase in wooded sites.

Apart from at Site 55, textures are much heavier at 5cm than in previous octiles and the first clay texture appears. Mean sand content declines further to 44.4% at 5cm and to 37.67% at 40cm, whilst % clay increases substantially to 30.99% at 5cm and 40.48% at 40cm.

Locations are widespread across the transect.

Octile 8

The silt content at both the sample depths, and the fact that for three of the sites (40, 71 and 41) the shallowness of the profiles prohibited sampling at 40cm, appears to influence the grouping within this octile, with its varying nature of soil type (from gley to rendzina). The mean silt content at 5cm is 25.1% and at 40cm, for those soils sufficiently deep, is 26.2%. The mean clay content remains high at both depths (30.0% and 50.0% respectively) whilst the mean sand content continues to fall to 44.2% at 5cm and 19.13% at 40cm.

10.3.4 Conclusions and Summary of Component 2 Scores

10.3.4.1 General Trends

Component 2 shows a series of distinct trends down the octile ranges; these are summarised below:-

i) As the component loads highest on % sand (+) and % clay (-), the sites are correlated from positive to negative in the former and from negative to positive in the latter.

At the 5cm depth, Octile 1 is associated with sandy or loamy horizons, textures becoming increasingly more clayey from Octile 2 downwards; the first clay texture being recorded in Octile 7. From Octile 7 to 8, clay content continues to increase and sand to decrease, whilst silt also becomes an important fraction in the latter.

A similar pattern occurs with the textures at 40cm, though clay content increases more sharply; the first clay textured class occurring is Octile 5.

Thus, there is a definite trend down the component - from sandy to clayey to clayey/silty profiles. Spearman rank correlations between the textures and rankings of each site confirm this trend.

	<u>5cm</u>		<u>40cm</u>	
% sand	= -1.0	(significant at 0.01)	-0.976	(Significant at 0.01)
% clay	= 0.904	(significant at 0.01)	1.0	(Significant at 0.01)

Table 10.6 Z Sites in Each Soil Type by Octile - Component 2.

Octile	Litho- morphic Soils	Brown Soils						Surface-Water Gley Soils		Ground-Water Gley Soils		Man-Made Soil
		Brown Cal- careous Earth	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic Stagno- humic Gley	Typical Alluvial Gley	Typical Humic- Alluvial Gley	Disturbed Soil	
1	0.0	0.0	25.0	0.0	25.0	12.5	0.0	0.0	0.0	0.0	37.5	
2	0.0	0.0	0.0	44.4	0.0	0.0	11.1	22.2	11.1	0.0	11.1	
3	0.0	0.0	0.0	33.3	0.0	11.1	22.2	22.2	0.0	0.0	11.1	
4	0.0	0.0	0.0	55.6	0.0	0.0	11.1	22.2	11.1	0.0	0.0	
5	0.0	11.1	0.0	33.3	0.0	0.0	33.3	0.0	0.0	11.1	11.1	
6	0.0	0.0	0.0	11.1	0.0	0.0	44.4	44.4	0.0	0.0	0.0	
7	0.0	22.2	0.0	0.0	0.0	0.0	44.4	22.2	11.1	0.0	0.0	
8	33.3	11.1	0.0	0.0	0.0	0.0	22.2	22.2	11.1	0.0	0.0	

ii) Accompanying the textural changes down the component are complementary changes in soil type at both the major group and subgroup level (Table 10.6).

Brown soils are distributed throughout the component, dominating the first five Octiles. Surface-water gleys occur in Octiles 2 to 8, and are the dominant groups in Octiles 6 to 8. Ground-water gleys and man-made soils have a wide distribution but remain at low frequencies. Lithomorphic soils only occur in Octile 8.

This overall pattern of major groups conceals several important variations at subgroup level. Octile 1 is dominated by freely drained typical brown earths, brown alluvial and disturbed soils, with only 12.5% in the gleyic brown alluvial category. In Octiles 2 to 6 stagnogleyic brown earths are the only brown soils of any consequence present, and in Octile 4 are the dominant subgroup. Cambic stagnogley and cambic stagnohumic gleys increase in importance down the component as the texture becomes finer. Typical alluvial gley and typical humic alluvial gleys are distributed throughout the component, reflecting topographic position rather than the dominance of a particular textured parent material. A final group of soils to note are the brown rendzinas, which, with their silty structure, occur only in Octile 8.

iii) Land use trends are more diffuse and difficult to interpret than those of soil type (Table 10.7). Nevertheless, certain rather weak patterns do emerge. Woodland is particularly associated with Octiles having either high sandy content (1) or heavier clay/silt textures (5 to 7). Permanent grass increases down the component to reach a peak in Octile 6 which is associated with "heavier" texture. There is a slight trend for arable proportions to decline down the component after Octile 1.

Table 10.7 % Occurrence of Land Use Types by Octile - Component 2

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable & grass ley	Agricultural Sites
1	50.0	12.5	12.5	0.0	25.0	25.0	25.0
2	0.0	0.0	11.1	0.0	88.9	88.9	100.0
3	11.1	0.0	11.1	11.1	66.7	77.8	88.9
4	0.0	0.0	33.3	0.0	66.7	66.7	100.0
5	22.2	11.1	11.1	0.0	55.6	55.6	66.7
6	11.1	0.0	55.6	0.0	33.3	33.3	88.9
7	44.4	0.0	11.1	11.1	33.3	44.4	55.6
8	0.0	11.1	33.3	11.1	44.4	55.6	88.9

10.3.4.2 Spatial Variations of the Sites - Component 2

Table 10.8 shows the distribution of the sites in each octile about the Physiographic units.

Table 10.8 % Site Distribution Among the Physiographic Units by Octile - Component 2

Octile	Physiographic Units							1+2+3	5+6+7
	W						E		
	1	2	3	4	5	6	7		
1	25.0	0.0	37.5	25.0	12.5	0.0	0.0	62.5	12.5
2	22.2	11.1	0.0	44.4	0.0	0.0	22.2	33.3	22.5
3	0.0	0.0	0.0	66.7	0.0	11.1	22.2	0.0	33.3
4	0.0	0.0	11.1	22.2	11.1	33.3	22.2	11.1	66.7
5	0.0	0.0	11.1	11.1	0.0	22.2	55.6	11.1	77.8
6	11.1	11.1	11.1	55.6	11.1	0.0	0.0	33.3	11.1
7	11.1	22.2	0.0	11.1	22.2	22.2	11.1	33.3	55.5
8	22.2	11.1	0.0	11.1	11.1	44.4	0.0	33.3	55.5

The contrasting nature of the parent materials found, both in the Lowlands West of the Wear (Unit 1) and the slopes of Unit 2 above the river, of sandy or clayey/silty textures, is well shown in the location of these Units at the top and bottom of the range. Likewise, the distribution of the River Wear Gorge and Floodplain (Unit 3) is similar, in being especially associated with the sandier Octile 1, but, unlike the first two groupings, is represented in Octiles 4 and 5 in the middle of the range. Units 1 to 3 are, therefore, associated with every Octile, apart from number 3, but influence the upper and lower groupings in particular.

The Units to the east of the transect (5, 6 and 7), on the other hand, are more significant in the middle and lower octiles. The association appears to be with clay and silt textures, rather than sand, but this interpretation masks certain factors.—

The Permian outcrop units (6 and 7) differ slightly in their emphasis, there being a trend for those locations on the plateau proper to be higher up the component with the more sandy or sandy/clayey textures, rather than in the lower octiles of clayey/silty textures, as are the majority of the escarpment sites. Coalford Vale (Unit 5) differs in being distributed about the component, but has a recognisable emphasis in the lower octiles.

In between these areas in the Lowlands East of the Wear (Unit 4), there is a slight trend for a higher/middle octile emphasis; towards sandy/clayey textures rather than towards clay/silt.

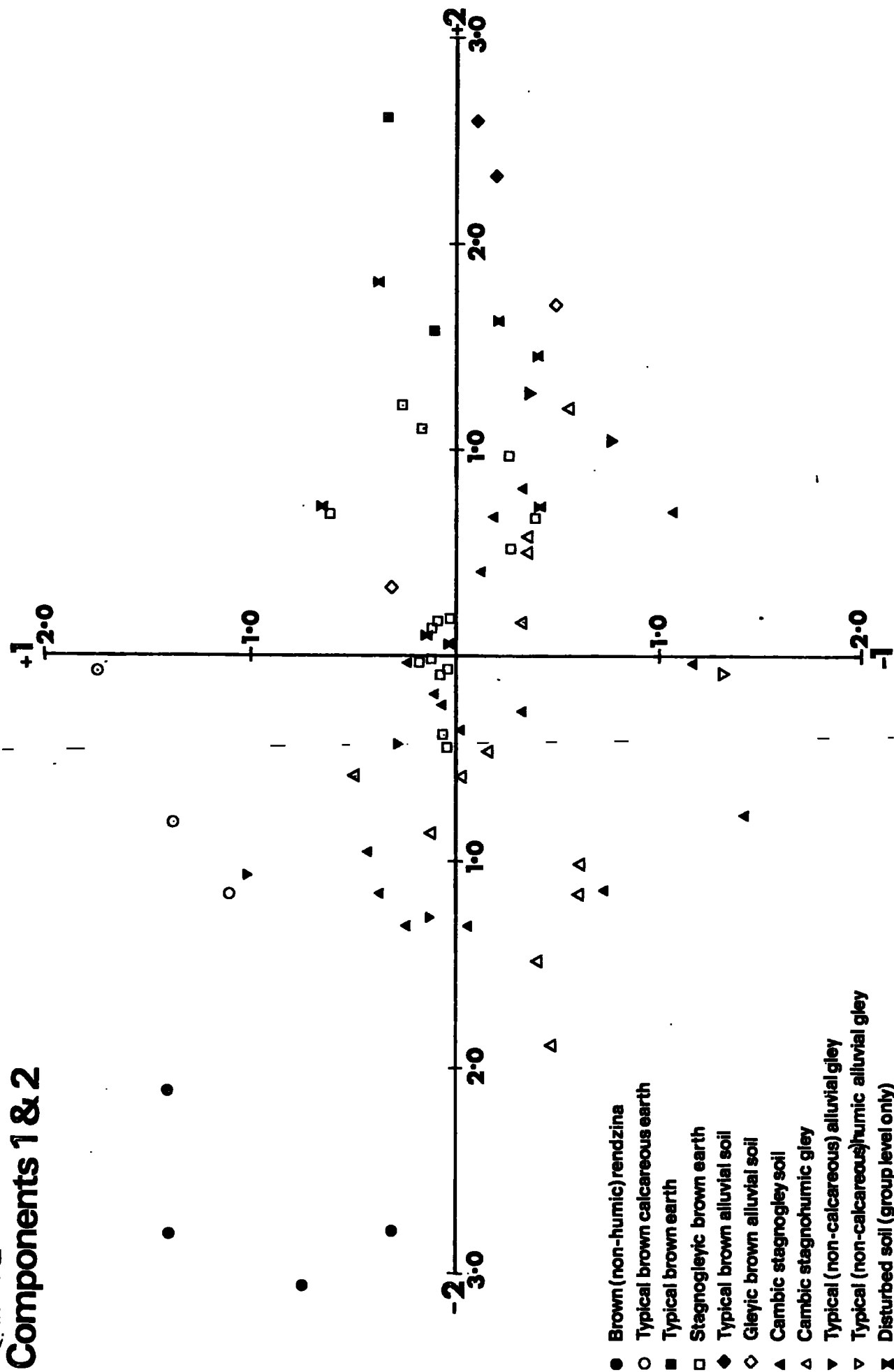
These textural differences are, therefore, the result of parent material variations. Sandy textures are associated predominantly with those soils developed on river or stream deposits or middle sands and gravels, together with sites such as 66 affected by an exposure of Carboniferous sandstone.

Silty textures are particularly associated with profiles developed on drift free Magnesian Limestone of the escarpment in the east and the laminated clays in the west.

10.3.5 Synthesis of Components 1 and 2

Figure 10.3 shows components 1 and 2 diagrammatically represented according to site number and soil subgroup; 33.4% of the variance is accounted for; i.e. one-third of the information about site interrelationships is displayed in this two-dimensional summary of twenty eight dimensional space.

Components 1 & 2



Soil subgroups cluster fairly well; particularly the stagnogleyic brown earths. The rendzina sites are located away from other soil groups on the diagram but the brown calcareous soils are nearer the central axis. The gleyed profiles in general show the most dispersal. The stagnogleyic brown earths form a close group in the centre and the cambic stagnogleys and cambic stagnohumic gley soils show recognisable groups. Although distributed about the axis, the location of the ground-water gley soils is not so well defined, explained by their diverse parent materials which vary from sand to clay and silt. Brown earths and brown alluvial soils also form loose clusters, but the disturbed soil group, although distributed among other subgroups as would be expected from such a potentially diverse group, is situated only on the right hand of the Y axis belying a "certain homogeneity".

Component 3 Discussion

The first two components account for one-third of the variance between them. Although Component 3 explains slightly less, it is still "significant" at 13.3%.

The component is positively associated with the pH value of the 5cm layer and, to a lesser extent, the % base saturation at the same depth. Of greater importance than the latter is the negative association with the thickness of the organic (F and/or H and O) horizons which has a positive loading, but of lesser importance is the thickness of the top mineral horizon.

Figure 10.4 shows the component scores mapped out on the 500 metre grid and Table 10.9 the characteristics in tabular form.

Sites with the highest score may, therefore, be expected to be associated with good nutrient status of the topsoil, have shallow or no organic horizons and thick surface mineral horizons.

Octile 1

The sites of the first octile have a mean soil reaction of pH 6.8, no site falling below 6.0. Base saturation at 5cm averages 73.2%, though varying from 100% at sites 25 and 40 to 42.6% at site 51. Only site 49, at the bottom of the range, has an organic horizon, reflecting the dominant arable land use of these sites. The top mineral horizons exceeds 15cm in thickness and have a mean of 23.6cm. The sites are evenly distributed about the transect.

Table 10.9 Component 3

<u>Site</u>	<u>Score</u>	<u>pH (5cm)</u>	<u>% Base Saturation (5cm)</u>	<u>Thickness of Organic Horizons</u>	<u>Thickness of Top Mineral Horizon</u>
<u>Octile 1</u>					
40	2.075	7.1	100.0	0.0	15.0
23	1.678	6.4	83.83	0.0	25.0
25	1.567	7.4	100.0	0.0	23.0
3	1.479	6.3	64.5	0.0	17.0
51	1.463	7.4	42.62	0.0	33.0
2	1.440	6.0	60.95	0.0	24.0
29	1.339	7.4	60.84	0.0	26.0
49	1.163	6.2	72.62	2.0	26.0
Mean		6.8	73.17	0.3	23.6

<u>Site</u>	<u>Score</u>	<u>pH (5cm)</u>	<u>%Base Saturation (5cm)</u>	<u>Thickness of Organic Horizons</u>	<u>Thickness of Top Mineral Horizon</u>
<u>Octile 2</u>					
41	1.130	7.4	59.09	0.0	21.0
57	0.936	6.4	32.75	0.0	34.0
11	0.930	6.8	37.59	0.0	32.0
37	0.921	7.2	41.71	0.0	33.0
53	0.881	6.7	82.71	0.0	29.0
8	0.804	6.9	34.76	0.0	15.0
12	0.765	7.5	40.81	0.0	35.0
63	0.752	6.5	43.84	0.0	24.0
35	0.669	6.2	38.01	0.0	29.0
Mean		6.8	45.70	0.0	28.0
<u>Octile 3</u>					
64	0.651	5.9	24.08	0.0	23.0
36	0.647	5.9	57.01	0.0	29.0
1	0.595	6.5	57.92	0.0	23.0
59	0.552	6.6	70.22	0.0	27.0
54	0.512	7.3	88.69	1.3	22.0
28	0.469	6.4	31.26	0.0	27.0
56	0.468	6.8	44.11	0.0	30.0
52	0.456	7.0	36.00	0.0	29.0
10	0.390	7.1	37.35	0.0	28.0
Mean		6.6	49.63	0.1	26.4
<u>Octile 4</u>					
27	0.321	5.9	36.72	0.0	33.0
24	0.295	5.2	46.35	0.0	29.0
30	0.216	6.2	56.53	0.0	26.0
68	0.203	5.7	42.69	1.0	10.0
65	0.203	5.6	38.75	2.5	12.0
71	0.173	7.3	61.77	5.0	6.0
45	0.165	5.8	56.39	1.0	18.0
47	0.162	6.2	38.63	0.0	22.0
17	0.162	6.3	15.06	1.0	6.0
Mean		6.0	43.65	1.2	18.0

<u>Site</u>	<u>Score</u>	<u>pH (5cm)</u>	<u>% Base Saturation (5cm)</u>	<u>Thickness of Organic Horizons</u>	<u>Thickness of Top Mineral Horizon</u>
<u>Octile 5</u>					
43	0.152	6.6	32.12	0.0	30.0
21	0.145	6.8	38.78	0.0	26.0
7	0.138	5.1	47.42	0.0	29.0
44	0.122	6.5	33.30	0.0	27.0
14	0.074	5.8	24.42	0.5	17.0
13	0.013	6.2	34.28	0.0	28.0
69	-0.025	6.1	37.54	1.8	9.0
32	-0.046	5.3	59.38	1.0	6.0
26	-0.056	6.5	13.66	0.0	27.0
Mean		6.1	35.66	0.4	22.1
<u>Octile 6</u>					
42	-0.070	7.1	52.88	1.3	15.3
22	-0.115	5.9	34.21	0.0	26.0
70	-0.138	7.1	49.93	0.0	11.0
34	-0.193	6.3	55.57	1.0	9.0
15	-0.301	5.1	21.64	1.9	17.0
18	-0.469	5.0	21.07	0.0	17.0
48	-0.476	4.2	24.67	0.0	20.0
16	-0.484	5.8	37.30	0.0	19.0
58	-0.538	6.8	35.98	1.0	12.7
Mean		5.9	36.92	0.6	16.3

<u>Site</u>	<u>Score</u>	<u>pH(5cm)</u>	<u>%Base Saturation (5cm)</u>	<u>Thickness of Organic Horizons</u>	<u>Thickness of Top Mineral Horizon</u>
<u>Octile 7</u>					
50	-0.548	4.8	18.16	1.0	8.0
46	-0.563	5.2	38.52	0.0	18.0
61	-0.597	5.2	26.79	0.5	16.0
4	-0.601	5.1	38.02	0.0	25.0
55	- 0.633	6.6	38.75	1.3	10.0
20	-0.757	5.8	42.47	1.0	7.0
62	-0.768	5.3	49.65	3.0	18.0
38	-0.869	4.9	37.86	1.5	10.0
5	-0.883	5.6	27.16	1.0	8.0
Mean		5.4	35.26	1.0	13.3

Octile 8

60	-0.910	5.0	20.65	1.0	15.0
39	-1.050	4.3	17.90	0.0	24.0
66	-1.160	5.9	28.80	1.0	9.0
67	-1.541	4.0	8.33	5.2	20.3
33	-1.844	4.9	42.64	3.0	6.0
9	-2.244	4.4	14.26	5.0	7.0
31	-2.881	3.6	3.25	11.0	10.0
19	-3.213	3.4	5.54	10.0	4.0
6	-3.266	3.6	8.28	11.0	13.0
Mean		4.4	16.63	5.2	12.0

Octile 2

All but two sites of the second octile are surface-water gley or stagnogleyic brown earths, the exceptions being a rendzina and a disturbed soil.

The pH, which has a mean of 6.8 (slightly more than the first octile) has a wider range, from 6.2 to 7.5. Base status also has a wide range, from 32.75% to 82.71%, but the overall mean of 45.7% is appreciably less than the first octile.

As all the sites are cultivated, no organic horizons are present. The range of thickness of the top mineral horizon is greater (15-35cm), and the mean thickness of 28cm is higher, than in Octile 1. Because the amount of variance extracted by this horizon is less, it is to be expected that the trends will be more diffuse than the variables which have a higher loading.

The sites are spatially more concentrated than those of Octile 1, all being located east of the Wear, either in the Lowlands East of the Wear (Unit 4), or less commonly, on the Permian Escarpment (Unit 6).

Octile 3

Stagnogleyic brown earth and surface-water gley soils dominate this octile at eight of the nine sites, the exception being a brown calcareous earth.

The mean pH of 6.6 is lower than that of the previous octiles and increasing acidity is also indicated by the fact that the first sites with a pH of below 6.0 appear. Mean base saturation increases slightly over the second octile but remains moderate. The range, however, is slightly wider.

Arable continues to be the main land use, reflected in the absence of organic horizons at eight of the nine sites. The thickness of the top mineral horizon on the other hand, is less, but the mean of 26.4 cm is still deep enough to reflect the effects of cultivation.

Octile 4

Apart from Site 71, all the profiles are gleyed to some degree, either stagnogleyic brown earths, surface or ground-water gleys or disturbed soils.

Although the range of pH has increased to 5.3-7.3, the mean pH decreases to 6.0. Base status declines also to a mean of 43.65% with a range from 15.06-56.53%.

A change in land use towards non-arable is indicated by the increase in sites which have organic horizons. This change is also reflected by the mean thickness of the top mineral horizon decreasing to 18 cm.

The sites are widely distributed about the transect.

Octile 5

In the fifth octile, which scores from -0.056 to 0.152, negative scores appear for the first time in the component. Of the nine sites included, all but one show signs of gleying; two-thirds of these are in the stagnogleyic brown earth or gleyed brown alluvial subgroups.

The mean pH of 6.1 is very similar to that of Octile 4, but the range, from 5.1 to 6.8, is more acidic in nature. The mean base saturation decreases further to 35.66% with a range of 13.66 to 59.38%. Unlike previous octiles, no profile has a high saturation.

An increase in arable land use is indicated by the decrease in the mean thickness of the organic horizons; this land use effect also being carried over to increase the mean thickness of the top mineral horizon.

The spatial distribution of the sites is more compact, over one half being located on the Permian Plateau (Unit 7).

Octile 6

The number of better drained soils increases markedly, four sites being well drained brown or disturbed soils, and the pH values are noticeably more acid, the mean falling below pH 5.0 for the first time (Site 48 falls to pH 4.2).

Base status rises slightly to a mean of 36.92%, although the highest status of 55.57% is less than the highest found in the last octile.

In association with an increase in grassland and scrub vegetation, the mean thickness of the organic horizons increases slightly and, concomitantly, the mean thickness of the top mineral horizon drops sharply.

Spatially, there is a move away from the limestone towards the Lowlands East and West of the Wear.

Octile 7

This grouping includes a wide variety of soils, ranging from brown soils to surface-water gleys.

The mean pH declines further to 5.4. Base saturation, however, does not have as high a range of values as Octile 6, and every site has a value below 50%; the mean status is 35.26% and has a range of 18.16 to 49.65%.

As seven of the nine sites are non-arable, the mean thickness of the organic horizons increase considerably, whilst the thickness of the top mineral horizon decreases.

Over three-quarters of the sites are situated in, or immediately west of the Wear Gorge (Unit 3), the remainder being located on the Permian Escarpment (Sites 38, 55).

Octile 8

Gleyed horizons are present at all but two sites (9 and 66), and the non-arable status of all but one site (39) is reflected in the mean pH of 4.4. Site 39 was confirmed by the farmer as being "troublesome" regarding acidity. At three locations (Sites 6, 19 and 31) situated in or near the Wear Gorge (Unit 3) strongly acid horizons are found.

The mean base status of 16.63% is very low and four profiles, the three at the Wear Gorge (Unit 3) noted above, and Site 67 at Coalford Vale (Unit 5) have base saturations below 10%.

As seven of the sites are under woodland the mean thickness of the organic horizons inevitably increases, whilst the mean thickness of the top mineral horizon decreases.

Other than those situated in the Wear Gorge, the sites are found in the centre and east of the transect.

10.3.7 Conclusions and Summary of Component 3 Scores

10.3.7.1 General Trends

The trends which emerge down the component are significant and readily recognisable.

- i) The positive association of pH at 5cm with the component, results in sites having high pH values in the upper octiles. The Spearman rank correlation coefficient between site ranking and the pH of the topsoil is -0.970 (significant at 0.01) showing a decrease in pH down the component.

The pH goes as follows:-

Table 10.10

<u>Octile</u>	<u>Mean pH (5cm)</u>	
1	Neutral	6.8
2	Neutral	6.8
3	Neutral	6.6
4	Neutral	6.0
5	Neutral	6.1
6	Slightly acid	5.9
7	Slightly acid	5.4
8	Moderately acid	4.4

pH values in the transect topsoils are a reflection of land use (including the use of fertilizers), parent material, physiographic and climatic factors.

The near neutral pH values of the great majority of sites is well shown in Table 10.10 with the first five octiles having a mean pH of 6.0 or above.

- ii) Base status closely follows the pH trend, declining down the component from 73.17% in Octile 1 to 16.63% in Octile 8.

Table 10.11

<u>Octile</u>		<u>% Base saturation (5cm)</u>
1	high	73.17
2	moderate	45.70
3	moderate	49.63
4	moderate	43.65
5	low	35.66
6	low	36.92
7	low	35.26
8	low	16.63

- iii) The lower loading of the organic horizons on the component results in a slightly less clear trend, but overall there is an increase in thickness down the component. This is particularly manifested in the fact that Octile 1 has only one organic horizon represented, whilst Octile 8 has all but one site with such an horizon. These horizons reflect markedly the prevailing land use at the sites.
- iv) The thickness of the top mineral horizon, which is mainly a reflection of land use, also shows a significant trend, although it is not as pronounced as pH or base status. The mean thickness of Octile 8 is approximately one half of that of the first Octile.
- v) Table 10.12 shows that there is a significant association of soil type with position down the component.

Lithomorphic soils are only found in Octiles 1, 2 and 4, whilst the brown soil major group is represented in all Octiles apart from the first, but reaches maxima in 3 and 5. Surface-water gley soils, however, decline in proportion down the component to reach steady one-third proportions after the middle of the range. Ground-water gley soils do not appear until Octile 4, whilst the man-made major group is in evidence throughout.

At subgroup level, the trends are more marked. The brown rendzina subgroup is situated in the first half whilst, apart from Site 54 in Octile 3, the brown calcareous earths are found at the bottom of the component. The rendzina profiles have a higher combination of pH and base status in general than the brown calcareous soils; a fact aided by their location at the crest of the escarpment on more cultivable sites than the latter subgroup, with subsequent effect on land use, organic horizons and thickness of the top mineral layer, and ultimately on their placement in the component.

Of the other brown soils, the typical brown earths and two subgroups of brown alluvial soil (with sandier horizons and greater leaching potential) are found only in the bottom half of the component, whilst the more fertile stagnogleyic brown earths reach a maximum in Octile 2 and perceptibly decline after Octile 5.

The surface-water gleys are also more fertile when considered at major group level, but at subgroup level differences are manifest. The cambic stagnogleys are found in steady proportions throughout the component, but the stagnohumic subgroup are at their greatest proportion in Octiles 1 and 2, reflecting greater fertility and thicker top mineral horizons.

The typical alluvial and humic alluvial gleys, however are only found in the bottom half of the component on less attractive sites for agriculture and lack an inherent fertility build up throughout the topsoil.

- vi) Table 10. 13 shows the pattern of land use changes down the component.

Table 10.12 Z Sites in Each Soil Type by Octile - Component 3

Octile	Litho- morphic Soils	Brown Soils						Surface-Water gley soils		Ground-water gley soils		Man-Made Soils
		Brown Rendzina	Brown Calcareous Earth	Typical Brown Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic Stagnohumic Gley	Typical Alluvial Gley	Typical Humic Alluvial Gley	
1	12.5	0.0	0.0	0.0	0.0	0.0	0.0	25.0	50.0	0.0	0.0	12.5
2	11.1	0.0	0.0	0.0	22.2	0.0	0.0	22.2	33.3	0.0	0.0	11.1
3	0.0	11.1	0.0	0.0	55.6	0.0	0.0	22.2	11.1	0.0	0.0	0.0
4	11.1	0.0	0.0	0.0	11.1	0.0	0.0	33.3	11.1	22.2	0.0	11.1
5	0.0	0.0	0.0	0.0	44.4	0.0	11.1	22.2	11.1	11.1	0.0	0.0
6	0.0	22.2	11.1	11.1	11.1	0.0	0.0	22.2	11.1	0.0	0.0	22.2
7	0.0	11.1	0.0	11.1	11.1	22.2	0.0	22.2	11.1	11.1	11.1	0.0
8	0.0	0.0	11.1	22.2	11.1	0.0	11.1	22.2	11.1	11.1	0.0	11.1

Table 10.13 % Occurrence of Land Use Types by Octile - Component 3

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable and Grass Ley	Agricultural Sites
1	0.0	0.0	25.0	12.5	62.5	75.0	100.0
2	0.0	0.0	0.0	0.0	100.0	100.0	100.0
3	0.0	0.0	11.1	0.0	88.9	88.9	100.0
4	0.0	22.2	33.3	11.1	33.3	44.4	77.8
5	0.0	0.0	33.3	0.0	66.7	66.7	100.0
6	33.3	11.1	11.1	11.1	33.3	44.4	55.6
7	22.2	0.0	55.6	0.0	22.2	22.2	77.8
8	77.8	0.0	11.1	0.0	11.1	11.1	22.2

Unlike the other components so far described, the variables are as much a reflection of land use as is land use a reflection of parameter characteristics; for example, tree growth is demanding on soil nutrients, resulting in low pH and base status levels, yet agricultural soils may be regularly limed and fertilised to counteract crop uptake of nutrients and inherent infertility, so maintaining production. Correlations with land type are, therefore, to be expected.

Tree growth occurs from Octile 6 onwards, reaching a maximum in the least fertile Octile 8. Scrub growth, a reflection of land ownership as well as physical problems, is found in middle and lower octiles.

Permanent grass shows an increase with lower fertility, greater organic horizons and shallower top mineral horizons, although it drops in proportion in the last octile.

Grass ley is widely distributed, but arable production shows a marked decline down the component, with the maxima occurring in the top three octiles and the minima in the last two. This decline is also evident when arable and grass ley are added together.

The combination of all the agricultural land types of permanent grass, ley and arable shows, inevitably, a less of a decline down the component; the arable decrease being complimented by the permanent grass increase. The first three and fifth octiles are, however, all agricultural.

The agricultural sites show greater pH and base status, inherent or otherwise, than do the non-agricultural sites.

10.3.7.2 Spatial Variations of the Sites - Component 3.

Table 10.14 shows the distribution of the sites in each octile about the Physiographic Units.

Table 10.14 % Site Distribution Among the Physiographic Units by Octile - Component 3

Octile	W Physiographic Units E							1+2+3	5+6+7
	1	2	3	4	5	6	7		
1	25.0	0.0	0.0	37.5	0.0	25.0	12.5	25.0	37.5
2	0.0	0.0	0.0	55.5	11.1	22.2	11.1	0.0	44.4
3	11.1	0.0	0.0	33.3	11.1	22.2	22.2	11.1	55.5
4	33.3	0.0	0.0	33.3	11.1	11.1	11.1	33.3	33.3
5	0.0	11.1	0.0	22.2	11.1	0.0	55.5	11.1	66.6
6	22.2	0.0	0.0	33.3	11.1	22.2	11.1	22.2	44.4
7	0.0	22.2	44.4	11.1	0.0	22.2	0.0	66.6	22.2
8	0.0	22.2	22.2	22.2	11.1	0.0	22.2	44.4	33.3

Taken overall, the spatial analysis indicates that pH and base status are generally better in the east than the west of the transect. This distribution is largely to be expected considering the nature and distribution of the soil parent materials.

Not surprisingly, the soils on the Permian Escarpment and Plateau (Units 6 and 7) are located principally in the first five octiles, being associated with limestone or till derived from limestone parent materials. The spread of these sites is explained by the secondary elements of Component 3, namely thickness of the organic and top mineral horizons. As several of the escarpment sites are on steep - moderately steep slopes, cultivation is impossible and hence an organic horizon is present, resulting in a lower component score.

The sites to the west of Units 6 and 7; i.e. those of the Lowlands East and West of the Wear, are scattered throughout the Octiles depending very much on the nature of the parent material. For example, the coarse alluvium of Sites 5, 19 and 20 placing them down the component in Octiles 6 or 7.

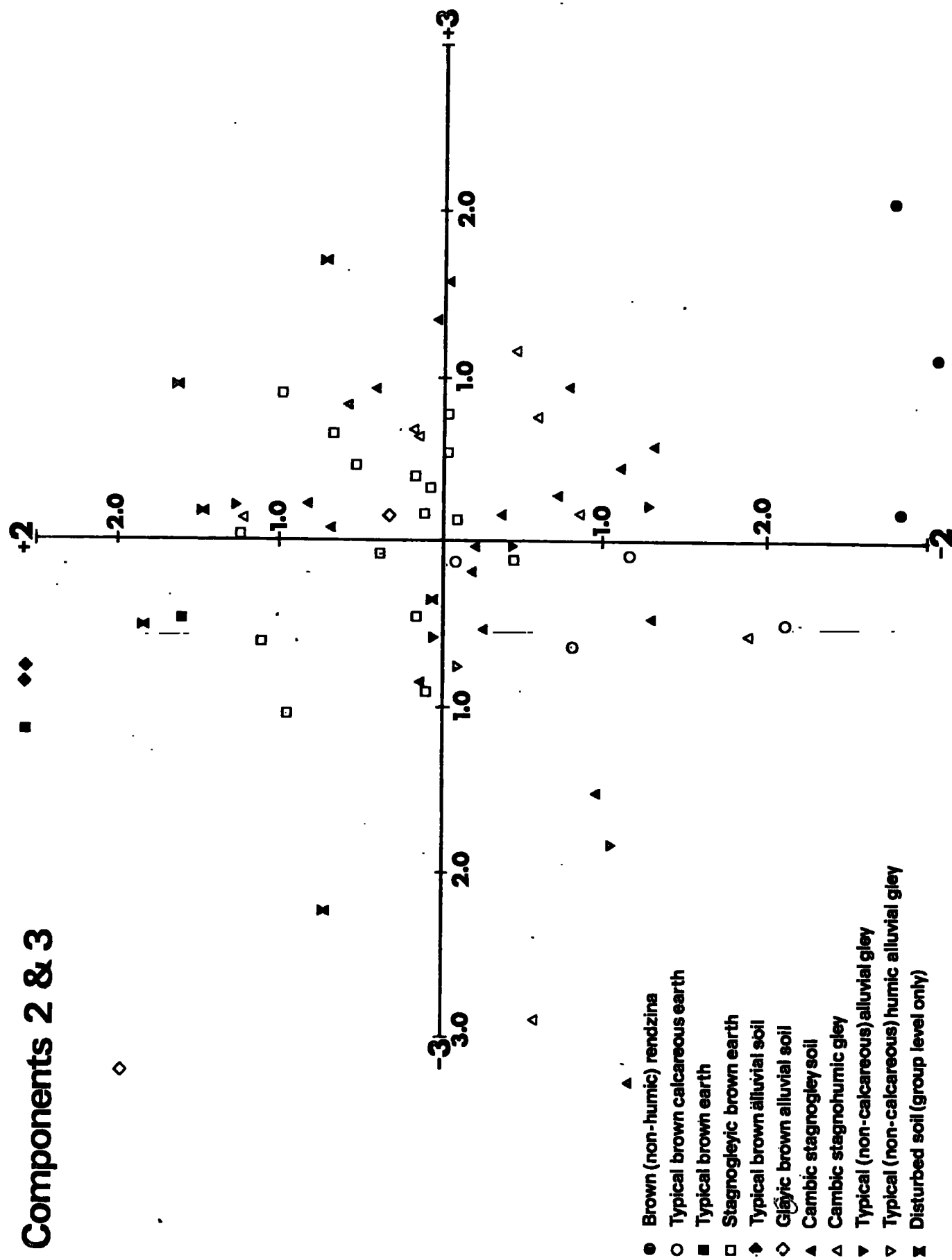
10.3.8 Synthesis of Components 2 and 3.

Figure 10.5 shows Components 2 and 3 displayed in a two-dimensional summary of the twenty-eight dimensional space accounting for 28.97% of the variance or nearly 30% of the information about site interrelationships.

Soil subgroups do not group as well as they did when Components 1 and 2 were compared (Figure 10.3), but there are still some recognisable loose clusters. Rendzina soils are grouped together at the base of the group, whilst the brown calcareous earths are more mixed with other subgroups. The typical brown earths and typical brown alluvial soils are grouped together at the top of the graph whilst stagnogleyic brown earths again dominate the axis.

The surface-water gleys also group loosely together, but the ground-water gleys, with their very different parent materials, do not cluster as clearly.

Components 2 & 3



10.3.9 Component 4 Discussion

The fourth component is associated positively with the organic content of the mineral topsoil at 5 cm in the form of % carbon and to a lesser extent % moisture content. Associated with the parameters to a minor degree is a negative association with the thickness of the top mineral horizon. Figure 10.6 shows the spatial arrangement of the sites and Table 10.15 the parameter characteristics.

Octile 1

The first Octile scores between 1.094 and 3.303. Whilst all the major soil groups are represented, the major influence on the sites is the land use factor; At the time of survey, all were uncultivated and under permanent grass, scrub or woodland. Thus, organic horizons are present and the lack of disturbance by cultivation ensures thin top mineral horizons (mean = 11.5 cm) and a high organic carbon content (mean = 9.67%). Most of the sites are located in or west of the Wear Gorge and Floodplain (Unit 3.).

Octile 2

Surface-water gley soils, particularly cambic stagnohumic gleys, predominate, with rendzina, brown calcareous, brown alluvial and disturbed soils also. The first arable sites of the component appear, the remainder being devoted to mixed woodland or permanent grassland.

As in Octile 1, the sites are distributed from east to west about the transect from Elemore to Frankland, but with a majority in the western half.

The mean of carbon declines to 7.07% and, with the appearance of Ap horizons in the arable sites, the mean thickness of the top mineral horizon increases to nearly 16 cm.

Table 10.15 Component 4

<u>Site</u>	<u>Score</u>	<u>% Carbon (5 cm)</u>	<u>% Moisture (5 cm)</u>	<u>Thickness of the Top Mineral Horizon.</u>
<u>Octile 1</u>				
71	3.303	12.69	5.58	6.0
17	3.149	12.80	2.24	6.0
68	2.094	11.36	4.85	10.0
66	2.027	10.34	3.34	9.0
62	1.604	7.76	2.44	18.0
19	1.309	7.65	2.97	4.0
2	1.151	7.65	3.35	24.0
42	1.094	7.14	3.02	15.3
Mean		9.67	3.47	11.5

Octile 2

<u>Site</u>	<u>Score</u>	<u>% Carbon (5 cm)</u>	<u>% Moisture (5 cm)</u>	<u>Thickness of the Top Mineral Horizon</u>
49	1.085	6.99	4.29	26.0
3	1.039	6.37	3.04	17.0
46	0.963	7.53	2.89	18.0
40	0.948	4.10	1.69	15.0
70	0.924	9.90	3.08	11.0
23	0.809	7.53	3.99	25.0
34	0.802	7.53	3.51	9.0
20	0.771	6.33	1.67	7.0
18	0.755	7.33	2.49	17.0
Mean		7.07	2.96	16.1

Octile 3

69	0.718	7.25	3.43	9.0
65	0.662	7.28	3.41	12.0
41	0.637	5.83	2.34	21.0
54	0.598	7.30	2.60	22.0
25	0.591	4.80	1.83	23.0
35	0.529	6.32	2.26	29.0
32	0.524	7.64	3.11	6.0
15	0.519	5.89	4.72	17.0
55	0.491	3.59	2.37	10.0
Mean		6.21	2.90	16.6

Octile 4

5	0.463	6.82	1.49	8.0
1	0.340	5.74	3.39	23.0
50	0.309	6.06	2.82	8.0
8	0.139	7.88	2.63	15.0
33	0.071	6.48	2.94	6.0
64	0.006	7.49	2.67	23.0
57	-0.020	5.98	2.06	34.0
63	-0.051	6.26	2.37	24.0
58	-0.122	5.77	1.77	12.7
Mean		6.50	2.46	17.1

Octile 5

<u>Site</u>	<u>Score</u>	<u>% Carbon (5 cm)</u>	<u>% Moisture (5 cm)</u>	<u>Thickness of the Top Mineral Horizon</u>
28	-0.132	4.48	1.79	27.0
24	-0.232	4.52	1.79	29.0
37	-0.245	7.25	2.19	33.0
7	-0.274	6.73	1.96	29.0
9	-0.311	5.92	2.71	7.0
61	-0.421	3.83	1.79	16.0
47	-0.432	6.46	3.09	22.0
48	-0.442	6.00	3.09	20.0
21	-0.444	7.14	2.70	26.0
Mean		5.81	2.35	23.2

Octile 6

38	-0.478	6.98	1.95	10.0
4	-0.492	5.11	2.20	25.0
36	-0.503	6.73	1.97	29.0
45	-0.517	5.50	2.11	18.0
16	-0.578	4.15	2.09	19.0
52	-0.632	5.62	1.91	29.0
53	-0.688	5.83	1.50	29.0
14	-0.752	4.84	1.81	17.0
51	-0.763	6.38	1.74	33.0
Mean		5.68	1.92	23.2

Octile 7

29	-0.772	3.88	1.55	26.0
22	-0.804	5.83	1.83	26.0
13	-0.827	6.51	1.77	28.0
10	-0.861	5.81	2.38	28.0
56	-0.862	6.91	2.27	30.0
30	-0.865	4.13	1.88	26.0
60	-0.952	7.37	1.95	15.0
11	-1.021	5.11	1.91	32.0
12	-1.252	5.30	1.90	35.0
Mean		5.65	1.94	27.3

Octile 8

<u>Site</u>	<u>Score</u>	<u>% Carbon (5 cm)</u>	<u>% Moisture (5 cm)</u>	<u>Thickness of the Top Mineral Horizon</u>
44	-1.269	5.15	1.68	27.0
67	-1.281	4.60	1.68	20.3
26	-1.374	5.56	1.94	27.0
31	-1.456	3.65	1.99	10.0
27	-1.562	4.56	1.94	33.0
43	-1.592	4.54	1.56	30.0
39	-1.650	3.66	1.41	24.0
59	-1.650	3.26	1.50	27.0
6	-1.847	2.57	2.13	13.0
Mean		4.17	1.76	23.5

Octile 3

As in Octile 2, soil type varies, but surface and ground-water gleys predominate. At the time of survey, all but one site was under agriculture, thus percentage carbon declines still further to a mean of 6.21% with a range of 7.64 to 3.59.

Percentage moisture likewise declines, whilst the mean thickness of the top mineral horizon increases; a reflection of increasing agricultural use in this grouping. For the first time, areas east of the Wear dominate the distribution.

Octile 4

Over three quarters of the sites are surface or ground-water gleys and over half of these are arable. The inclusion of three locations under woodland (5, 33, 58) causes a slight rise in the mean organic carbon content to 6.5%, but the mean % moisture content continues to decrease and the mean thickness of the top mineral horizon continues to increase. There is a slight reversion in distribution westwards towards the Wear Gorge.

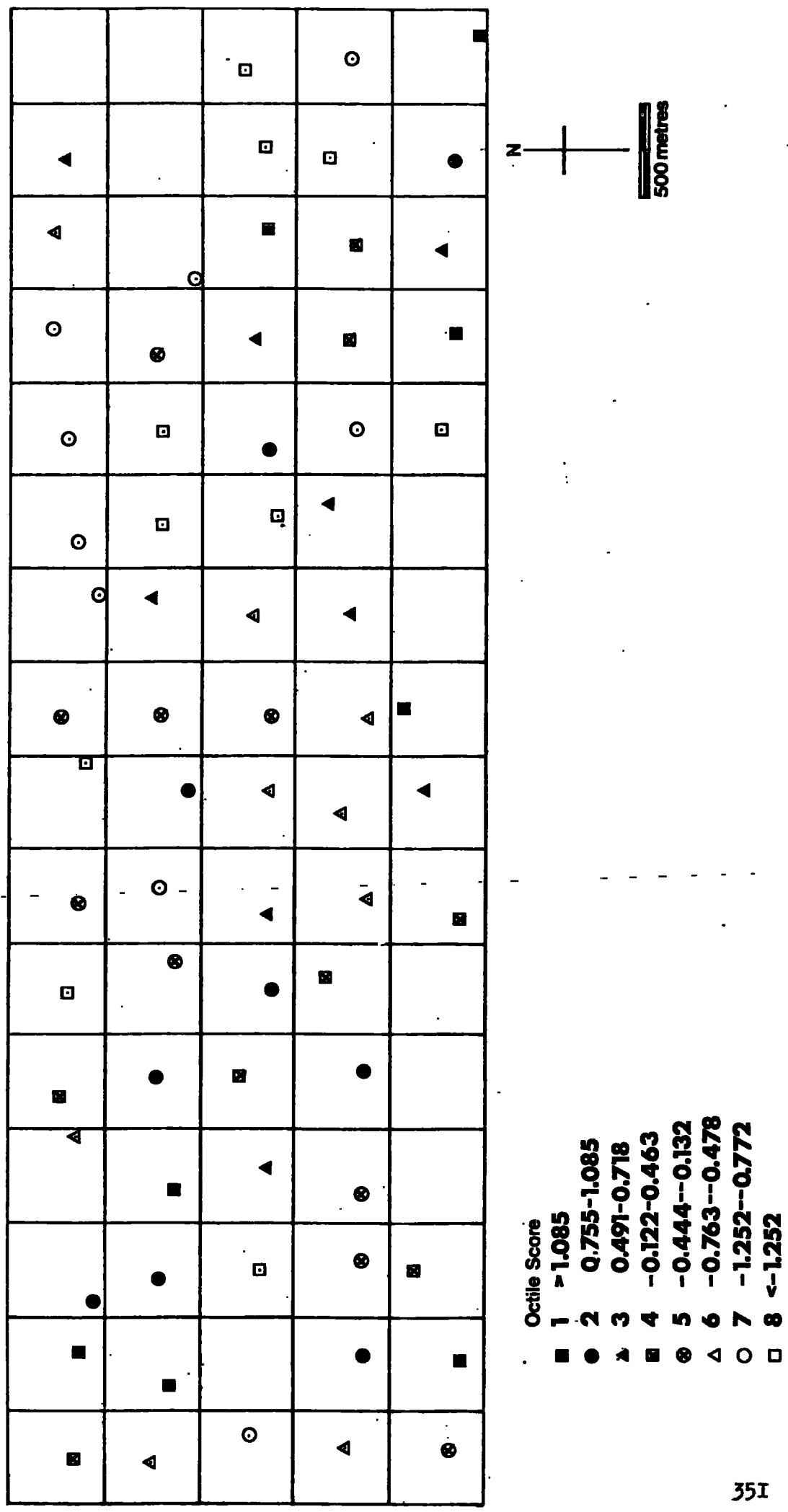
Octile 5

Surface-water gleys represent over half of the profiles, the remainder being alluvial gley, gleyic brown alluvial or disturbed soil.

As in the previous octile, over half the sites were under arable cultivation at the time of survey. Thus the trends of the component continue, with the mean % carbon declining substantially to 5.81; % moisture also declines and the mean thickness of the top mineral horizon increases substantially to over 20 cm.

Seven of the sites are situated in the Lowlands East of the Wear (Unit 4), but the Permian Plateau (Unit 7) and Wear Gorge and Floodplain (Unit 3) are also represented.

Fig10.6 Component 4



Octile 6

The proportion of surface-water gleys decreases in this octile to less than half, whilst the number of stagnogleyic brown earths increases. The proportion of land under arable rises to two thirds of the total with the remaining sites being down to ley or permanent grass.

The component trend of decreasing carbon and moisture content continues; the mean of the latter dropping to below 2% for the first time. The mean thickness of the top mineral horizon remains the same as the previous octile.

Apart from Sites 14 and 38 on the Permian outcrop, the trend is for a location in the centre and western parts of the transect.

Octile 7

The soils are either stagnogleyic brown earth or cambic stagnogley and all but one (Site 60) are arable.

Although the moisture content rises very slightly, the general trend of the component continues, with a slight fall in the mean carbon content and the continuing increase in the mean thickness of the top mineral horizon.

Site 60 appears to owe its inclusion in this grouping to low % moisture content, despite a moderate/high carbon content and shallower top mineral horizon.

Seven of the nine sites are located on the Permian Escarpment or Plateau (Units 6 and 7).

Octile 8

The profiles are predominately stagnogleyic brown earths, the remainder being surface-water gleys. Although arable land use dominates, three are under woodland.

Mean carbon and moisture contents decrease substantially as would be expected in the last octile but the mean thickness of the top mineral horizon decreases. This latter trend is accounted for by the presence of the three sites under woodland.

The sites are located either to the east of the transect, and in particular on the Permian Plateau associated with arable cultivation; or on the Upper Slopes of the Wear Gorge (Unit 2) associated with woodland sites.

10.3.10 Conclusions and Summary of Component 4 Scores

10.3.10.1 General Trends

- i) The positive association of % carbon in the topsoil and % moisture at the same depth results in the highest values being located in the upper octiles and a gradation down the component to show the lowest values in the last octile. This relationship may be shown statistically by ranking the sites down the component and correlating the carbon and moisture contents by Spearman rank.

% carbon = -0.976 (significant at 0.01)
% moisture = -0.976 (significant at 0.01)

The declining content of organic carbon and moisture is almost entirely a reflection of land use.

- ii). The lower loading of the thickness of the top mineral horizon results in a slightly less clear trend down the component, but overall there is an increase in thickness down the component associated with an increase in arable profiles and stagnogleyic brown earths. The mean of the first octile is less than one half that of the last octile.
- iii). There is a marked association of soil type with position down the component (Table 10.16).

The lithomorphic major group is confined to the first three octiles whilst the brown soils are distributed throughout the range but do not rise above 50% of sites in the last three octiles. The surface-water gleys, on the other hand decrease after the sixth octile after reaching a maximum in Octile 4. The ground-water gley soils and man-made soils are not represented after Octile 5.

These trends are explained by an analysis at subgroup level. The intense microbial activity found in limestone soils, coupled with a grassland, woodland or scrub land use (without deep H or O horizons) for some sites and the shallow nature of such soils, results in all the brown rendzina and brown calcareous earths being associated with high organic contents and shallow depths of the top mineral horizon, and, therefore, a location in the top three octiles only.

Less microbial activity in the more acidic environments of the typical brown earth and brown alluvial soils (apart from certain sites), and an increasing agricultural use, results in a position a little further down the component than the calcareous profiles. Finally the stagnogleyic brown earths, with their dominantly arable cultivation régimes, show lower organic contents and deeper top mineral horizons, reaching maxima in the last two octiles.

The cambic stagnogley subgroup is constant down the range after Octile 1. Although these soils have been affected by night soiling activity, it has been insufficient to raise organic contents to diagnostic propositions of a humic subgroup. The stagnohumic subgroup which has higher organic levels shows a gradual decline down the component after reaching a maximum in the second octile. The occurrence of old permanent grassland in these subgroups has also aided organic build up.

The disturbed soils are also more associated with higher organic levels and are not represented after Octile 5.

- iv). The trends in land use are shown in Table 10.17.

The patterns produced are as expected, as the variable values of carbon, moisture and thickness of the top mineral horizon are as much a reflection of land use, as is land use a reflection of the inherent parameter characteristics.

Table 10.16 % Sites in Each Soil Type by Octile - Component 4

Octile	Litho-morphic Soils				Brown Soils				Surface-water gley soils		Ground-water gley soils		Man-Made Soils	
	Brown Rendzina	Calcareous Earth	Brown Earth	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic Stagnohumic gley	Typical Alluvial Gley	Typical Humic Alluvial Gley	Disturbed Soil		
1	12.5	12.5	12.5	12.5	0.0	0.0	12.5	0.0	12.5	12.5	12.5	12.5	12.5	
2	11.1	11.1	11.1	0.0	0.0	11.1	0.0	11.1	44.4	0.0	0.0	11.1	11.1	
3	11.1	22.2	22.2	0.0	0.0	0.0	0.0	22.2	11.1	22.2	0.0	11.1	11.1	
4	0.0	0.0	0.0	0.0	0.0	11.1	0.0	33.3	33.3	11.1	0.0	11.1	11.1	
5	0.0	0.0	0.0	0.0	0.0	0.0	11.1	33.3	22.2	11.1	0.0	22.2	22.2	
6	0.0	0.0	0.0	11.1	44.4	0.0	0.0	33.3	11.1	0.0	0.0	0.0	0.0	
7	0.0	0.0	0.0	0.0	66.7	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	
8	0.0	0.0	0.0	0.0	66.7	0.0	0.0	22.2	11.1	0.0	0.0	0.0	0.0	

Table 10.17 % Occurrence of Land Use Types By Octile - Component 4

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable and Grass Ley	Agricultural Sites
1	50.0	25.0	25.0	0.0	0.0	0.0	25.0
2	11.1	0.0	33.3	0.0	55.6	55.6	88.9
3	0.0	11.1	55.6	0.0	33.3	33.3	88.9
4	33.3	0.0	11.1	0.0	55.6	55.6	66.7
5	11.1	0.0	11.1	22.2	55.6	77.8	88.9
6	0.0	0.0	33.3	11.1	55.6	66.7	100.0
7	0.0	0.0	11.1	0.0	88.9	88.9	100.0
8	33.3	0.0	0.0	0.0	66.7	66.7	66.7

Wooded sites decrease from a maximum in the first octile, with subsidiary peaks in Octiles 4 and 8. They occur most frequently in the first five octiles as is to be expected with more organic build up under such conditions. The secondary "peak" in Octile 8 is associated with woodland on acid soils (Sites 6 and 31) which results in thicker organic horizons. However, as soil faunal activity is limited under these conditions of soil formation, there is little mixing of the O and A horizons; hence the organic carbon content of the 5 cm sampling depth in the top mineral horizon is relatively low

Scrub profiles, remaining undisturbed for a number of years, also show high organic contents in the topsoil and shallower top mineral horizons, as do the sites under permanent grass which reach a maximum proportion in Octile 3, although showing a general decline down the component.

Grass ley and arable locations, on the other hand, show greater proportions after Octile 4, with the latter most important in Octiles 7 and 8. The arable sites of Octiles 1 to 4 are predominantly accounted for by the cambic stagnohumic gleys which have higher organic levels.

10.3.10.2. Spatial Variations of the Sites - Component 4

Table 10.18 shows the distribution of the sites in each octile about the Physiographic Units.

Table 10.18 % Site Distribution Among the Physiographic Units by Octile - Component 4

Octile	W Physiographic Units							E	
	1	2	3	4	5	6	7	1+2+3	5+6+7
1	25.0	0.0	25.0	12.5	12.5	12.5	12.5	50.0	37.5
2	22.2	11.1	11.1	33.3	0.0	22.2	0.0	44.4	22.2
3	0.0	11.1	0.0	22.2	11.1	44.4	11.1	11.1	66.7
4	11.1	11.1	11.1	44.4	22.2	0.0	0.0	33.3	22.2
5	0.0	0.0	11.1	77.8	0.0	0.0	11.1	11.1	11.1
6	22.2	11.1	0.0	44.4	0.0	11.1	11.1	33.3	22.2
7	11.1	0.0	0.0	11.1	0.0	44.4	33.3	11.1	77.8
8	0.0	11.1	11.1	0.0	11.1	0.0	66.7	22.2	77.8

The patterns are not easy to interpret. Despite all the calcareous soils falling in Octiles 1 to 4, sites in the western half of the transect are more important in the first four octiles than those of the eastern half, indicating greater organic contents and shallower topsoils overall.

There is a slight decrease in proportions down the component in Units 1 to 3 around and west of the River Wear and a corresponding increase in Units 4 to 7 near to and on the Permian Escarpment and Plateau (Units 6 and 7). This high proportion of eastern sites located in Octiles 7 and 8 is accounted for by the prevalence of stagnogleyic brown earths under arable cultivation in these Units.

10.3.11 Component 5 Discussion

The fifth component is predominantly associated with site drainage. The most important variable is receiving site drainage with a negative loading but normal site drainage and poor profile drainage also score highly. Figure 10.7, shows the location of the sites throughout the component and Table 10.19 the component scores.

Octile 1

The scores range between 1.302 and 1.719 representing sites with normal site and mainly free profile drainage. Soil types vary from stagnogleyic brown earths to disturbed soils. Arable is the principal land use and locations to the east of the transect dominate.

Octile 2

Normal site and imperfect profile drainages are most represented in this octile and stagnogleyic brown earth is the main soil type.

Only Sites 19 and 20, the alluvial soils of the Wear Gorge, were not under arable cultivation when surveyed, and the Lowlands East of the Wear (Unit 4) is the only Physiographic Unit not represented.

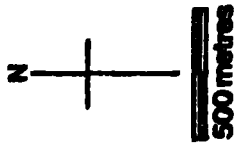
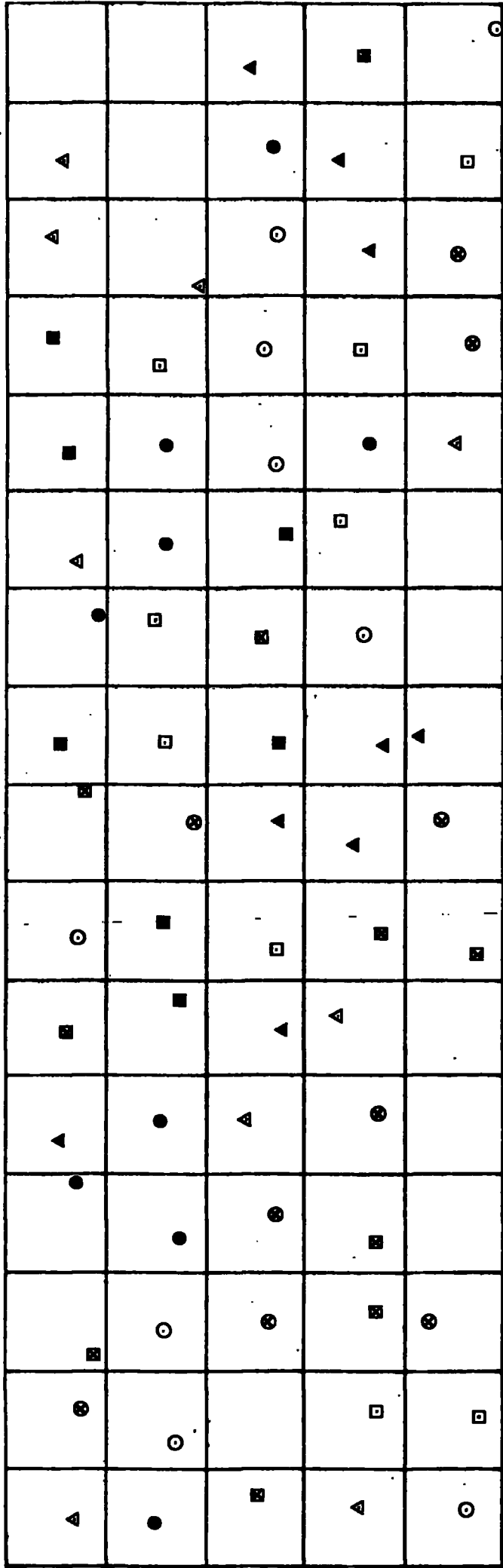
Octile 3

In common with Octiles 1 and 2, all sites have normal site drainage with, predominantly, imperfect profile drainage. The first poorly drained profile of the component appears at the base of the octile. Although arable cultivation is the most important land use, woodland is represented at one third of the locations. Stagnogleyic brown earths with imperfect drainage account for over half of the sites and the first surface-water gley (Site 34) appears. There is a movement away from the eastern part of the transect; only two sites (44,59) being located on the Permian Plateau (Unit 7).

Octile 4

Whilst all sites have normal site drainage, poor profile drainage becomes important for the first time. The soils are either cambic stagnogley or cambic stagnohumic gley, the latter not occurring till the fifth site down the range. All the locations under grass ley in the transect are included in this octile but the remaining sites have a variety of land uses.

Fig10.7 Component 5



Octile	Score
■	1 >1.292
●	2 1.206-1.292
▲	3 0.929-1.191
◼	4 0.391-0.899
⊗	5 0.172-0.380
△	6 -0.009-0.156
○	7 -1.804--0.077
□	8 <-1.804

Table 10.19 Component 5

<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>
<u>Octile 1</u>			
21	1.719	Normal	Moderately well drained (free)
9	1.602	Normal	Well drained (free)
13	1.539	Normal	Moderately well drained (free)
37	1.493	Normal	Well drained (free)
60	1.380	Normal	Imperfect
22	1.332	Normal	Imperfect
39	1.322	Normal	Moderately well drained (free)
12	1.302	Normal	Imperfect
Greatest Proportion		Normal	Well drained and moderately well drained (free)
<u>Octile 2</u>			
56	1.292	Normal	Imperfect
20	1.278	Normal	Well drained (free)
4	1.254	Normal	Well drained (free)
26	1.243	Normal	Imperfect
27	1.237	Normal	Imperfect
10	1.235	Normal	Imperfect
19	1.211	Normal	Imperfect
43	1.208	Normal	Imperfect
16	1.206	Normal	Well drained (free)
Greatest Proportion		Normal	Imperfect.
<u>Octile 3</u>			
44	1.191	Normal	Imperfect
58	1.168	Normal	Well drained (free)
36	1.163	Normal	Imperfect
66	1.143	Normal	Well drained (free)
5	1.075	Normal	Well drained (free)
52	1.069	Normal	Imperfect
59	1.052	Normal	Imperfect
53	0.937	Normal	Imperfect
34	0.929	Normal	Poor
Greatest Proportion		Normal	Imperfect

Octile 5

<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>
31	0.380	Normal	Poor
32	0.368	Normal	Poor
49	0.346	Normal	Poor
2	0.265	Normal	Poor
65	0.220	Normal	Poor
69	0.199	Normal	Poor
68	0.191	Normal	Poor
23	0.185	Normal	Poor
63	0.172	Normal	Poor
Greatest Proportion		Normal	Poor

Octile 6

11	0.156	Normal	Poor
50	0.156	Normal	Poor
45	0.150	Normal	Poor
15	0.115	Normal	Poor
33	0.107	Normal	Poor
1	0.087	Normal	Poor
29	0.082	Normal	Poor
67	0.073	Normal	Poor
14	-0.009	Normal	Poor
Greatest Proportion		Normal	Poor

Octile 7

7	-0.077	Normal	Poor
18	-0.139	Normal	Poor
61	-0.250	Normal	Poor
17	-0.362	Normal	Poor
54	-1.291	Shedding	Well drained (free)
71	-1.498	Shedding	Well drained (excessive)
41	-1.565	Shedding	Well drained (excessive)
42	-1.621	Shedding	Well drained (free)
40	-1.804	Shedding	Well drained (excessive)
Greatest Proportion		Shedding	Poor and well drained (excessive)

Octile 8

<u>Site</u>	<u>Score</u>	<u>Site Drainage</u>	<u>Profile Drainage</u>
55	-1.817	Shedding	Well drained (free)
70	-1.841	Shedding	Well drained (free)
57	-4.386	receiving	Poor
24	-4.549	receiving	Poor
28	-4.665	receiving	Poor
46	-4.712	receiving	Poor
62	-4.764	receiving	Poor
35	-4.789	receiving	Poor
25	-4.798	receiving	Poor
Greatest Proportion		receiving	Well drained (free) and poor.

Octile 5

The trend for normal site and poor profile drainages continues, and all but one site (a disturbed soil - Site 23) are either surface or ground-water gley soils.

Two thirds of the locations are devoted to permanent grass, whilst only two are arable. All Physiographic Units are represented apart from the Permian outcrop.

Octile 6

Octile 6 scores range from -0.009 to 0.156 and, as in the last octile, all the sites have normal site and poor profile drainage, all the profiles show evidence of gleying and over three-quarters are cambic stagnogleys. The sites are distributed throughout the transect and are under a variety of land uses.

Octile 7

The mechanics of the PCA calculation have resulted in sites with shedding site drainage occurring near the base of the component a distance away from normal site drainage. This is quite consistent with the nature of a one dimensional tabular representation, where normal site drainage loads higher at 0.68366 than shedding site drainage at 0.02647. If shedding site drainage had loaded higher, a gradation from shedding to normal to receiving site drainage would have been represented.

As a result, there are two distinct groups of sites with a difference in score between the two of 0.929. This line between -0.362 and -1.291 marks the difference between the normal/poorly drained gleyed sites numbered 7 to 61 (scores -0.077 to -0.362) and the shedding/free or excessively drained brown calcareous earth or brown rendzina soils of Sites 54 to 40 (scores -1.291 to -1.804).

One third of the sites in this octile are arable, but the two groups described above differ markedly in their distribution. The first group of normal/poorly drained sites are located mainly west of the River Wear in Unit 1 or in the Wear Gorge (Unit 3), whilst the second group, representing the shedding/freely drained locations, are situated on the Permian Escarpment (Unit 6).

Octile 8

The anomaly encountered in the previous octile of very different site drainage/profile drainage groups appearing in the same octile, also occurs in this octile. This is a problem encountered when data is divided into octiles or any such arbitrary subdivision. Sites 55 and 70 belong more to the bottom half of Octile 7 in both score, site and profile characteristics as well as soil type.

The remainder of the locations all exhibit receiving site and poor profile drainage; all are surface-water gleys, apart from the humic alluvial gley of Site 62, and arable cultivation is encountered at all but that site.

10.3.12 Conclusions and Summary of Component 5 Scores

10.3.12.1 General Trends

- i) The high negative loadings of receiving site drainage and poor profile drainage, and the high positive association with normal site drainage results in normal site drainage and free profile drainage grading to normal site drainage and imperfect profile drainage and then to poor profile drainage. After this, and for the reasons expressed in the Octile 7 discussion, soils on shedding sites with free or excessive profile drainage occur, to be followed at the base of the component by receiving sites with poor profile drainages. By locating the shedding/free or excessive sites in Octile 7, this program indicates that they are nearer to the normal/free sites of the first octile in characteristics than are the receiving/poor sites of Octile 8. (Table 10.20).

Table 10.20

<u>Octile</u>	<u>Greatest Proportion of Drainage Type</u>	
	<u>Site</u>	<u>Profile</u>
<u>1</u>	normal	Well drained and moderately-well drained (free)
2	normal	imperfect
3	normal	imperfect
4	normal	poor
5	normal	poor
6	normal	poor
7	normal or shedding	poor and well drained (excessive)
8	shedding or receiving	well drained (free) and poor

- ii) Table 10.21 shows the relationship between soil type and the Octiles.

The brown soil major group (apart from calcareous profiles) with well drained (free), moderately well drained (free) and imperfect profile drainages and normal site drainage, are found only in the top three octiles, whilst both the brown calcareous earth subgroups and the brown rendzinas of the lithomorphic major group; having freely drained profiles and shedding site drainage, are restricted to Octiles 7 and 8 (see foregoing discussion for Octile 7).

The surface-water major group is represented after the second octile; the mineral subgroup, reaching a peak further down the octile than the humic subgroup. This further indicates that the higher organic content of the latter is more of a land use phenomenon than of a physiographic nature.

The ground-water soils, however, are only found in the bottom half of the component indicating more intense gleying and poorer drainage.

- iii) Table 10.22 shows that there are few, if any, distinct trends in land use type.

Table 10.21 % Sites in Each Soil Type by Octile - Component 5

Litho- morphic Soils	Brown Soils						Surface-Water gley soils	Ground-water gley soils	Man-Made Soils	
	Brown Calcareous Earth	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic Stagno- humic Gley	Typical Alluvial Gley	Typical Humic Alluvial Gley	Disturbed Soils
Octile Rendzina										
1	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	25.0
2	0.0	0.0	11.1	11.1	11.1	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	11.1	11.1	0.0	11.1	0.0	0.0	0.0	11.1
4	0.0	0.0	0.0	0.0	0.0	44.4	55.6	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	11.1	44.4	33.3	0.0	11.1
6	0.0	0.0	0.0	0.0	0.0	77.8		11.1	0.0	11.1
7	33.3	22.2	0.0	0.0	0.0	0.0	22.2	11.1	0.0	11.1
8	0.0	22.2	0.0	0.0	0.0	44.4	22.2	0.0	11.1	0.0

Table 10.22 % Occurrence of Land Use Types - Component 5

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable & Grass ley	Agricultural Sites
1	12.5	0.0	12.5	0.0	75.0	75.0	87.5
2	11.1	0.0	11.1	0.0	77.8	77.8	88.9
3	33.3	0.0	11.1	0.0	55.6	55.6	66.7
4	11.1	0.0	11.1	33.3	44.4	77.8	88.9
5	11.1	0.0	66.7	0.0	22.2	22.2	88.9
6	22.2	11.1	33.3	0.0	33.3	33.3	66.7
7	11.1	22.2	22.2	0.0	44.4	44.4	66.7
8	22.2	0.0	11.1	0.0	66.7	66.7	77.8

Wooded sites are found under all drainage regimes, but proportions are highest in Octile 3 on normal/freely drained sites. Likewise, permanent grass is represented in all groups but the normal/poor drainage of Octile 5 provides the greatest percentage.

Grass leys are restricted to Octile 4, whilst arable land use is lowest on sites with normal site and poor profile drainage in Octile 5 or 6.

10.3.12.2 Spatial Variations of the Sites - Component 5

Table 10.23 shows the Physiographic Unit breakdown of the Octiles.

Table 10.23 % Site Distribution Among the Physiographic Units by Octile Component 5

Octile	W Physiographic Units E							1+2+3	5+6+7
	1	2	3	4	5	6	7		
1	0.0	0.0	0.0	50.0	0.0	12.5	37.5	37.5	50.0
2	11.1	11.1	22.2	0.0	11.1	11.1	33.3	44.4	55.6
3	0.0	0.0	11.1	55.6	11.1	0.0	22.2	11.1	33.3
4	22.2	11.1	0.0	55.6	0.0	11.1	0.0	33.3	11.1
5	11.1	11.1	11.1	44.4	22.2	0.0	0.0	33.3	22.2
6	22.2	11.1	0.0	11.1	11.1	11.1	33.3	33.3	55.6
7	22.2	0.0	11.1	11.1	0.0	55.6	0.0	33.3	55.6
8	0.0	11.1	11.1	22.2	11.1	33.3	11.1	22.2	55.6

This succeeds in showing the importance of the lower octiles for the Permian Escarpment (Unit 6); but Octiles 1 and 2, are significant for the Permian Plateau (Unit 7) reflecting local impeded drainage in this area. The lowlands east of the River Wear (Unit 4) are of most significance in Octiles 1 to 5, again reflecting impeded drainage, but also occasionally, better drained soils located on suitable sites.

10.3.13 Component 6 Discussion

Soil depth to the BC or C horizon (solum thickness) is the most significant variable and has a negative loading. Complimentary to this, is a positive loading for imperfect profile drainage and a negative loading for free profile drainage. Figure 10.8 and Table 10.24 show the component distribution.

Octile 1

Three quarters of the sites of Octile 1 are stagnogleyic brown earths of the Permian Plateau (Unit 7) and Lowlands East of the River Wear (Unit 4). All the profiles have a thin solum (mean depth to BC or C = 30.5 cm), and all but one have imperfect drainage, the exception being at Site 17 which has poor drainage and is extremely shallow, hence its placement in the component. Arable predominates.

Octile 2

The number of stagnogleyic brown earths falls to two thirds and the proportion of arable sites to just over half with increasing depth to the BC or C horizon (mean = 32.8 cm) and poorer drainage. The first surface-water gley appears (Site 6) at the base of the range, and there is a movement to locations further to the west, although the Permian Escarpment and Plateau (Units 6 and 7) continue to have the greatest proportion of sites.

Octile 3

The inclusion of three excessively drained shallow brown rendzinas in this octile causes a slight decrease in the mean depth to the BC or C (28.5 cm). Despite this, the trend to increasingly poor profile drainage continues, with surface-water gleys (cambic stagnogleys) representing just over 50% of the sites. Eastern locations again predominate, although the first site west of the Wear appears at this level. Arable land use falls slightly in proportion.

Octile 4

Mean solum thickness increases once again in the fourth octile to 30.6 cm and poor profile drainage is now common to all the profiles. Surface-water gleys occupy over three-quarters of the sites, and the first cambic stagnohumic gley soils of the component appear. The remainder are typical (non-calcareous alluvial gleys).

There is a shift in emphasis to locations to the west, particularly to west of the River Wear, and arable land use regains importance.

Octile 5

There is a significant increase of over 15 cm in the mean depth to the BC or C (mean = 45.3 cm) and poor profile drainage dominates. The first well drained (free) profile appears half way down the range.

Over three-quarters of sites are surface-water gleys, and the "centre of gravity" of the locations is moving westwards away from the Permian Escarpment (Unit 6).

Fig 10.8 Component 6

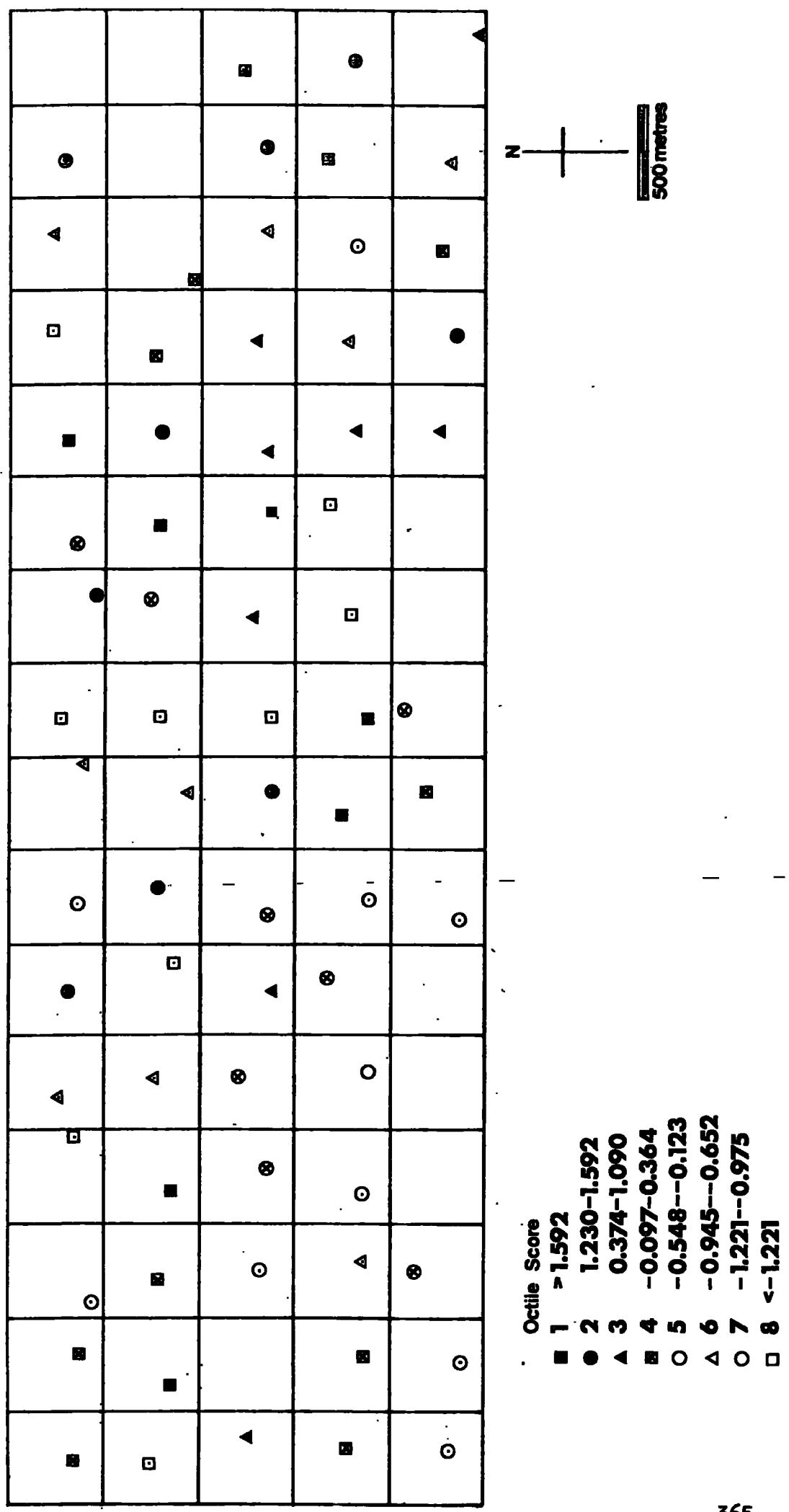


Table 10.24. Component 6

<u>Site</u>	<u>Score</u>	<u>Depth to BC or C Horizon (cm)</u>	<u>Profile Drainage</u>
<u>Octile 1</u>			
26	1.919	27	imperfect
53	1.863	29	imperfect
12	1.816	35	imperfect
59	1.774	35	imperfect
44	1.709	35	imperfect
52	1.657	29	poor
17	1.592	14	poor
19	1.589	40	imperfect
Mean/greatest proportion		30.5	imperfect
<u>Octile 2</u>			
43	1.592	40	imperfect
60	1.589	41	imperfect
27	1.570	33	imperfect
22	1.428	40	imperfect
10	1.333	40	imperfect
68	1.311	20	poor
36	1.303	40	imperfect
6	1.246	24	poor
15	1.230	17	poor
Mean/greatest proportion		32.8	imperfect
<u>Octile 3</u>			
71	1.090	20	Well drained (excessive)
67	0.948	23	poor
34	0.879	28	poor
30	0.865	26	poor
40	0.791	20	Well drained (excessive)
38	0.567	30	poor
14	0.458	31	poor
56	0.435	58	imperfect
41	0.374	21	Well drained (excessive)
Mean/greatest proportion		28.5	poor

Octile 4

<u>Site</u>	<u>Score</u>	<u>Depth to BC or C Horizon (cm)</u>	<u>Profile Drainage</u>
2	0.364	24	poor
65	0.334	30	poor
18	0.333	30	poor
46	0.220	24	poor
1	0.173	33	poor
45	0.083	32	poor
29	-0.050	34	poor
69	-0.064	25	poor
28	-0.097	43	poor
Mean/greatest proportion		30.6	poor

Octile 5

35	-0.123	37	poor
25	-0.157	38	poor
63	-0.162	33	poor
50	-0.251	36	poor
33	-0.258	40	poor
66	-0.303	55	Well drained (free)
11	-0.317	42	poor
7	-0.439	65	poor
32	-0.548	62	poor
Mean/greatest proportion		45.3	poor

Octile 6

20	-0.652	47	Well drained (free)
8	-0.686	69	poor
70	-0.700	39	Well drained (free)
39	-0.751	65	Moderately well drained (free)
57	-0.759	47	poor
5	-0.827	46	Well drained (free)
42	-0.830	45	Well drained (free)
47	-0.941	71	poor
23	-0.945	70	poor
Mean/greatest proportion		55.4	Well drained and moderately well drained (free)

<u>Site</u>	<u>Score</u>	<u>Depth to BC or C Horizon (cm)</u>	<u>Profile Drainage</u>
<u>Octile 7</u>			
31	-0.975	70	poor
62	-0.977	39	poor
58	-0.992	65	Well drained (free)
61	-1.021	41	poor
49	-1.024	71	poor
48	-1.061	71	poor
3	-1.108	34	poor
51	-1.164	66	poor
64	-1.221	43	poor
Mean/greatest proportion		55.6	poor
<u>Octile 8</u>			
24	-1.365	53	poor
9	-1.567	75	Well drained (free)
55	-1.570	50	Well drained (free)
54	-1.576	45	Well drained (free)
13	-1.591	75	Moderately well drained (free)
4	-1.791	61	Moderately well drained (free)
16	-1.798	84	Well drained (free)
21	-1.880	70	Moderately well drained (free)
37	-1.893	61	Well drained (free)
Mean/greatest proportion		63.8	Well drained and moderately well drained (free).

Octile 6

The proportion of well or moderately well drained profiles increases in this octile as does the depth to the BC or C (mean = 55.4 cm). Gleyed profiles predominate, but brown soils are increasing in number and associated with the distribution of sites, tending towards the eastern sector of the transect. Arable declines in importance.

Octile 7

In the penultimate octile, mean depth to the BC or C increases slightly to 55.6 cm. Poorly drained profiles are found at all but Site 58, which is included in this grouping because of solum depth. Surface and ground-water gleys predominate. A location towards the middle and west of the transect dominates and arable land use declines further.

Octile 8

The last octile has the greatest mean depth to the BC or C horizon at 64 cm, befitting the high negative loading of the parameter, and all but one site have well or moderately well drained profiles. Reflecting this trend, brown earths dominate with an 'easterly' distribution returning. Arable increases in importance.

10.3.14 Conclusion and Summary of Component 6 scores

10.3.14.1 General Trends

- i) the negative association of depth to the BC or C horizon with the component results in shallower solums at the top of the component and deeper solums at the base (Table 10.25). The nearness of the drift or Magnesian Limestone to the surface, the two principal parent materials, appears to be very variable but in further sections certain trends will be discussed.

Table 10.25

<u>Octile</u>	<u>Mean Depth to BC or C Horizon</u>
1	30.5
2	32.8
3	28.5
4	30.6
5	45.3
6	55.4
7	55.6
8	63.8
Total Mean	42.8

- ii) Profile drainage also alters down the component, from exhibiting imperfect drainage at the top to free drainage at the bottom, in line with the loadings of these variables.

In conclusion, there is an overall trend for a shallow depth to the BC or C horizon to be associated with imperfectly drained soils; for well (free) and moderately well drained profiles to be linked with the thickest solums; and for poorly and well drained (excessive) soils to be in the middle; the latter drainage type being associated with shallow profiles on shedding sites as against shallow soils on receiving sites.

Table 10.26 % Sites in Each Soil Type by Octile - Component 6

Octile	Litho- morphic Soils		Brown Soils				Surface-water gley soils			Ground-water gley soils	Man-Made Soils	
	Brown Rendzina	Brown Calcareous	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluvial Soil	Gleyic Brown Alluvial Soil	Cambic Stagnogley	Cambic stagno- humic gley	Typical Alluvial gley	Typical humic alluvial gley	Disturbed Soil	
1	0.0	0.0	0.0	75.0	0.0	12.5	0.0	0.0	0.0	0.0	12.5	
2	0.0	0.0	0.0	66.7	0.0	0.0	11.1	0.0	11.1	0.0	11.1	
3	33.3	0.0	0.0	11.1	0.0	0.0	55.6	0.0	0.0	0.0	0.0	
4	0.0	0.0	0.0	0.0	0.0	0.0	33.3	44.4	22.2	0.0	0.0	
5	0.0	0.0	11.1	0.0	0.0	0.0	44.4	33.3	11.1	0.0	0.0	
6	0.0	22.2	0.0	11.1	22.2	0.0	11.1	22.2	0.0	0.0	11.1	
7	0.0	0.0	0.0	0.0	0.0	0.0	11.1	55.6	11.1	11.1	11.1	
8	0.0	22.2	11.1	22.2	0.0	11.1	11.1	0.0	0.0	0.0	22.2	

- (iii) Table 10.26 shows the relationship between soil type and the octiles of the component.

Lithomorphic brown rendzina profiles only occur in Octile 3, whereas the brown soil major group, as a whole, is either represented at the top or bottom half of the range, but not in Octile 4. The stagnogleyic brown earth subgroup, associated with shallower depths to the BC or C horizon, particularly on the Permian Plateau, and imperfect drainage, is most significant in the top two octiles. Typical brown earth and brown alluvial soils occur in the bottom half of the component in Octiles 5, 6 and 8.

The mineral and humic subgroups of the surface-water gley major group show different trends. The former is most important between Octiles 3 and 5, whilst the latter, with greater depths to the BC or C horizon, resulting from the practice of night soiling, is most important between Octiles 4 and 7.

Both the ground-water gley and man-made major group have wide ranges. The former group is more frequent in Octiles 4 to 7 whilst the latter group is represented at the extremes of the component.

- (iv) Variations down the component according to land use are not as discernible as those of soil type (Table 10.27).

Table 10.27

% Occurrence of Land Use Types by Octile - Component 6

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable & Grass Ley	Agricultural Sites
1	12.5	12.5	0.0	0.0	75.0	75.0	75.0
2	11.1	11.1	22.2	0.0	55.6	55.6	77.8
3	22.2	0.0	33.3	0.0	44.4	44.4	77.8
4	0.0	0.0	44.4	0.0	55.6	55.6	100.0
5	22.2	0.0	22.2	0.0	55.6	55.6	77.8
6	33.3	0.0	11.1	11.1	44.4	55.6	66.7
7	33.3	0.0	22.2	22.2	22.2	44.4	66.7
8	11.1	0.0	22.2	0.0	66.7	66.7	88.9

Arable is the only land use type to be represented in every octile, with peaks in Octiles 1 and 8, showing an interesting relationship between shallow soils with imperfect drainage and deep soils with a highly variable profile drainage. Permanent grass sites are fairly evenly distributed throughout the component after Octile 1, whilst woodland is absent only from Octile 4, associated with shallow soils and poor profile drainage.

10.3.14.2 Spatial Variations of the Sites - Component 6

Table 10.28 shows the distribution of the sites in each octile about the Physiographic Units.

**Table 10.28 % Sites Distribution Among the Physiographic Units by Octile
- Component 6**

Octile	Physiographic Units							1+2+3	5+6+7
	W						E		
	1	2	3	4	5	6	7		
1	12.5	0.0	12.5	25.0	0.0	0.0	50.0	25.0	50.0
2	0.0	11.1	0.0	22.2	11.1	22.2	33.3	11.1	66.7
3	11.1	0.0	0.0	11.1	22.2	44.4	11.1	11.1	77.8
4	44.4	11.1	0.0	11.1	11.1	0.0	22.2	55.6	33.3
5	0.0	22.2	0.0	55.6	0.0	22.2	0.0	22.2	22.2
6	0.0	0.0	22.2	33.3	11.1	22.2	11.1	22.2	44.4
7	11.1	11.1	11.1	55.6	0.0	11.1	0.0	33.3	11.1
8	11.1	11.1	0.0	44.4	0.0	22.2	11.1	22.2	33.3

The distribution is shown to be complex. This is particularly so for the Units (1 and 2) west and near the Wear, reflecting the complex pattern of soil parent materials found in that area.

The alluvial soils of the Wear Gorge (Unit 3), show a bias towards deeper profiles, but drainage is variable. On the other hand, the Units east of the Wear show a more stable pattern.

In Unit 4, there are increasing proportions in the lower octiles (particularly Octiles 5 and 7), associated in particular with the Upper Wear Clay, Lower Till of the Wear Lowlands and Middle Sands and Gravels. In Unit 5 adjacent to, and in Units 6 and 7, actually on the Permian, the distribution becomes even more clearly defined.

Coalford Vale (Unit 5), on Upper Wear Clay, is associated with the middle of the octile range of "moderate" depth but poor drainage.

The sites of the Permian Escarpment (Unit 6), however, are found in all octiles, apart from the first and fourth, reflecting the shallow rendzinas, deeper brown calcareous profiles of the limestone parent material and stagnogleyic brown earths of the Lower Till and colluvial material.

The plateau sites, however, developed predominantly on the Lower Till of the Magnesian Limestone, are found in greater proportion in the first four octiles and decrease overall down the range. This is a reflection of the prevalence of imperfectly drained stagnogleyic brown earths, which have shallow/moderate depths to a BCg horizon on the plateau, contrasting, in particular, with poorly drained gleys of areas to the west which exhibit thicker solums and well drained brown earth and brown alluvial soils.

10.3.15 Component 7 Discussion

Component 7 is primarily associated with soil nutrient status properties at the 30 cm depth, unlike Component 3 which was associated with these properties at the 5 cm depth. Component 7 has a negative association with % base saturation, being more important than pH. Also of some importance is the negative loading of % silt at 40 cm. The distribution of the sites and the variable scores are shown in Figure 10.9 and Table 10.29.

Fig10.9 Component 7

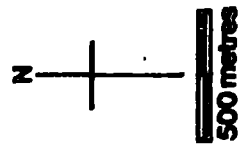
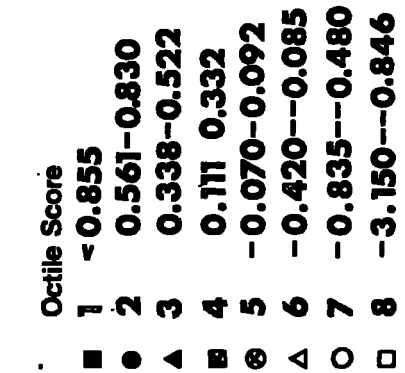
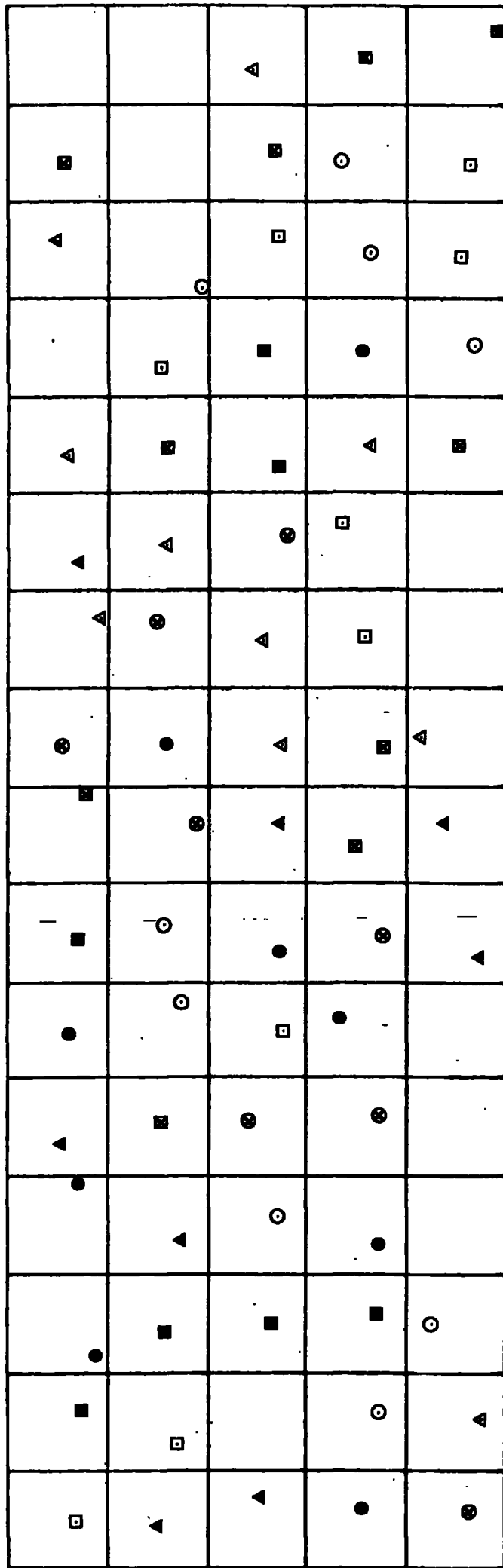


Table 10.29 Component 7

<u>Site</u>	<u>Score</u>	<u>% Base Saturation (30cm)</u>	<u>pH (30cm)</u>	<u>% Silt (40cm)</u>
<u>Octile 1</u>				
41	3.182	-	-	-
71	2.810	-	-	-
40	1.757	25.22	7.5	-
2	1.041	21.90	4.3	18.36
47	0.935	17.23	4.6	24.83
18	0.913	21.67	4.4	13.10
31	0.895	2.67	3.7	24.26
7	0.855	29.47	6.2	14.62
Mean		19.69	5.1	19.03
<u>Octile 2</u>				
48	0.830	16.27	3.9	26.62
4	0.760	14.57	4.7	11.30
24	0.686	31.53	5.7	15.29
45	0.661	21.74	5.4	17.07
6	0.656	8.37	3.7	19.45
57	0.642	32.95	6.4	10.19
35	0.620	39.97	6.7	4.49
50	0.572	27.09	5.4	12.56
3	0.561	20.41	4.9	25.96
Mean		23.65	5.2	15.88
<u>Octile 3</u>				
65	0.552	26.42	6.8	12.01
14	0.530	28.42	6.8	10.04
30	0.507	48.40	6.4	6.59
19	0.495	10.60	3.8	13.55
11	0.491	37.63	6.8	16.58
64	0.481	19.97	5.5	27.13
16	0.452	45.36	4.8	8.61
5	0.409	17.28	5.9	7.17
36	0.338	30.77	6.4	14.88
Mean		29.43	5.9	12.95

<u>Site</u>	<u>Score</u>	<u>% Base Saturation (30cm)</u>	<u>pH (30cm)</u>	<u>% Silt (40cm)</u>
<u>Octile 4</u>				
15	0.332	24.39	6.6	18.67
20	0.318	36.10	5.2	7.42
8	0.276	29.14	7.7	18.06
60	0.251	23.80	4.7	19.51
53	0.186	46.38	6.8	16.27
27	0.173	36.72	5.9	16.85
67	0.147	22.94	4.9	22.34
52	0.114	25.86	7.3	19.14
43	0.111	42.07	5.3	20.04
Mean		31.94	6.0	17.59
<u>Octile 5</u>				
9	0.092	12.04	4.4	17.41
51	0.086	42.66	7.4	20.77
61	0.071	55.39	5.6	24.32
39	0.036	26.81	4.4	13.41
25	0.019	65.64	7.2	11.07
13	0.013	30.42	6.1	16.77
49	-0.038	36.74	6.7	27.98
33	-0.061	9.92	4.2	31.02
23	-0.070	73.32	7.1	16.75
Mean		39.22	5.9	19.94
<u>Octile 6</u>				
37	-0.085	41.75	7.3	7.07
38	-0.129	31.85	5.4	19.47
56	-0.153	37.45	7.4	20.94
26	-0.154	35.45	7.0	20.29
10	-0.288	37.81	7.3	21.22
62	-0.331	56.73	5.2	12.43
12	-0.366	40.86	7.5	21.43
66	-0.405	28.21	7.2	13.08
44	-0.420	52.63	6.5	23.16
Mean		40.30	6.7	17.68

<u>Site</u>	<u>Score</u>	<u>% Base Saturation (30cm)</u>	<u>pH (30cm)</u>	<u>% Silt (40cm)</u>
<u>Octile 7</u>				
32	-0.480	46.91	6.9	30.51
59	-0.485	64.8	6.8	19.93
68	-0.514	48.54	6.6	22.1
21	-0.522	38.59	7.3	20.38
22	-0.540	36.42	6.8	35.55
63	-0.596	60.76	6.6	25.42
58	-0.653	55.77	6.7	12.50
29	-0.800	59.51	7.5	23.23
46	-0.835	70.27	5.1	26.22
Mean		53.51	6.7	23.98

<u>Octile 8</u>				
28	-0.846	78.52	6.6	18.36
69	-0.896	84.91	5.8	27.95
34	-0.962	67.88	7.0	17.66
1	-1.038	86.38	6.3	34.70
17	-1.324	77.54	7.6	22.09
55	-2.698	88.54	7.0	20.99
42	-2.906	100.0	7.2	23.49
70	-3.070	100.0	7.2	36.60
54	-3.150	91.53	7.5	33.20
Mean		86.14	6.9	26.12

Octile 1

The brown rendzina soils of Sites 40, 41 and 71 were of insufficient depth to permit the full range of sampling; Sites 41 and 71 could not be sampled at 30cm, whilst Site 40 could not be sampled at 40cm. The result is that the brown rendzina soils occur at the top of the component. The remaining sites in Octile 1 are all cambic stagnohumic gleys, under grass, arable or woodland.

Mean base saturation is very low, no site rising above 30%, whilst pH is slightly acid overall, but has a range varying from strongly acid to alkaline.

Locations are either to the west of the transect in the case of the gley soils, to the east in the case of the rendzinas.

Octile 2

The second Octile has a higher overall base status than the first Octile although with a mean of 23.65%, it is still in the low category. Mean pH also increases slightly, but is still in the slightly acid range. % silt decreases. All sites are surface-water gleys apart from the stagnogleyic brown earth of Site 4 and arable is the main land use.

Octile 3

The trend of nutrient status increase down the component continues; the first base status of over 45% appears at Sites 16 and 30 in the Lowlands West of the Wear (Unit 1), and the mean pH rises to 5.9 but remains in the slightly acid category.

Surface-water gleys are the major grouping but alluvial soils (brown alluvial and alluvial gley) brown earth and stagnogleyic brown earths form the remainder, giving a slightly western bias to the distribution. Arable is the principal land use.

Octile 4

Base saturation increases to a mean of over 30% for the first time in the component but is still in the low category. pH also increases to a neutral mean and the first alkaline sites (apart from Site 71 in Octile 1) appear. % silt also increases substantially.

Having first appeared in the last Octile, the numbers of stagnogleyic brown earths increases to over half of the sites. Accompanying this is a trend for locations to the centre and east of the transect. Arable continues to be the dominant land use.

Octile 5

The fourth Octile has a mean base status just below the moderate threshold of 40% but four of the sites satisfy this criterion. pH, on the other hand, drops back to being slightly acid, but silt content continues to increase.

There is a mixture of soil types represented in this Octile, ranging from stagnogleyic brown earths to surface and ground-water gleys and disturbed soils; consequently the land use is equally mixed. As in the last Octile sites are located more to the centre and east.

Octile 6

Mean base saturation rises to the moderate category for the first time and no profile falls below 28%. pH also rises well into the neutral range and three-quarters of the sites show an alkaline reaction. Silt content falls slightly.

Stagnogleyic brown earths predominate under arable land use and the trend towards a more easterly distribution continues.

Octile 7

The inclusion for the first time of two sites with a high base saturation increases the mean base saturation to over 50% but still remains in the moderate range. Mean pH remains similar to that of Octile 6 but only one site is below 6.0. Silt content rises once again to a mean of 23.98%.

Surface water gleys are the most important soil grouping, but alluvial soils (typical alluvial gley and gleyic brown alluvial), stagnogleyic brown earth and disturbed are in evidence. Arable continues as the principal land use, but there is a shift in location back towards the western sector.

Octile 8

With all the profiles having a high or very high % base saturation, Octile 8 has the highest mean at 86.14%, placing it in the very high category. Mean pH, although increasing slightly, remains neutral at just below the alkaline threshold of 7.0. % silt also increases to a mean of over 25%, reaching over 30% at three sites.

There are two very distinct groupings of soil subgroups in this Octile. Sites 28 to 17 are cambic stagnogley, typical (non-calc) alluvial gley or disturbed with high or very high base saturation (mean 79.05%) and slightly acid to alkaline pH (mean = 6.67). Sites 55 to 54, on the other hand are all brown calcareous earths with very high base saturation (mean = 95.02%) and alkaline reaction (mean = 7.25).

10.3.16 Conclusions and Summary of Component 7 Scores

10.3.16.1 General Trends

Whilst both pH and base saturation increase down the component there is not a perfect correlation between the two (see tables 10.36 and 10.37 below). This is to be expected since every soil does not have the same pH value for a given base saturation, since the exchangeable hydrogen does not ionize with equal ease from the different clay minerals and organic colloids (Millar et al. 1965). The drift parent materials of the majority of the soils in eastern Durham have illite as the dominant clay mineral with kaolinite the principal subsidiary clay mineral, although the latter does occasionally appear to be dominant (Beaumont, 1967).

Thus, it is possible that differences in kaolinite content inherent in the parent material is an important factor involved in the variations in base saturation levels for a given pH. This will be particularly so at depth in the profile, where the effects of cultivation and the use of inorganic fertilizers have little impact on the soil; i.e. at the 30cm depth encountered in this component.

- i) Base saturation increases down the component as follows:

Table 10.30

<u>Octile</u>	<u>Mean base saturation category</u>	
		%
1	Very low	19.69
2	Low	23.65
3	Low	29.43
4	Low	31.94
5	Low	39.22
6	Moderate	40.30
7	Moderate	53.51
8	Very High	86.14

Compared with the topsoil (Table 10.11 on Page 341) the mean figures of the subsoil show lower figures in the middle octiles but higher figures at the end of the range in the highest status octile.

- ii) pH similarly increases down the component as follows:-

Table 10.31

<u>Octile</u>	<u>Mean pH category</u>	
1	Slightly acid	5.1
2	Slightly acid	5.2
3	Slightly acid	5.9
4	Neutral	6.0
5	Slightly acid	5.9
6	Neutral	6.7
7	Neutral	6.7
8	Neutral	6.9

The categories are similar to those found in the topsoil (Table 10.10 on Page 341), but acidic means are represented in a greater number of octiles and slightly acid is the lowest reaction.

- iii) % silt also increases, albeit erratically, down the component.

- iv) The distribution of soil subgroups amongst the octiles is shown in Table 10.32.

The reason for the association of brown rendzinas entirely with the first octile have been explained in the discussion of Octile 1 on Page 377.

The brown soil major group is most common in Octiles 4 and 6 and is not represented in Octile 1, whereas surface-water gley soils reach maxima in the first two Octiles. Ground-water gleys are most significant in the second half of the component as are disturbed soils.

Table 10.32 % Sites in Each Soil Type By Octile - Component 7

	Litho- morphic Soils	Brown Soils					Surface Water Gley Soils		Ground water Gley Soils		Man Made Soils
		Brown Calcareous Earth	Typical Brown Earth	Stagnogleyic Brown Earth	Typical Brown Alluv- ial Soil	Gleyic Brown Alluv- ial Soil	Cambic Stagnogley	Cambic Stagnohumic Gley	Typical Alluvial Gley	Typical humic Alluvial Gley	
Octile	Brown Rendzina										Disturbed Soil
1	37.5	0.0	0.0	0.0	0.0	0.0	0.0	62.5	0.0	0.0	0.0
2	0.0	0.0	0.0	11.1	0.0	0.0	77.8	11.1	0.0	0.0	0.0
3	0.0	0.0	11.1	11.1	11.1	11.1	33.3	11.1	11.1	0.0	0.0
4	0.0	0.0	0.0	55.5	11.1	0.0	11.1	11.1	0.0	0.0	11.1
5	0.0	0.0	0.0	22.2	0.0	0.0	11.1	22.2	22.2	0.0	22.2
6	0.0	0.0	11.1	55.6	0.0	0.0	11.1	0.0	0.0	11.1	11.1
7	0.0	0.0	0.0	22.2	0.0	11.1	22.2	22.2	11.1	0.0	11.1
8	0.0	44.4	0.0	0.0	0.0	0.0	33.3	0.0	11.1	0.0	11.1

At the subgroup level the brown calcareous earths, with high base status, pH and silt content, are all allocated to the last octile. The stagnogleyic brown earths show most proportions in octiles associated with small/moderate base saturation and neutral pH, whilst the cambic stagnogley subgroup, on the other hand, is most significant in the small base status and slightly acid reaction Octile 2, and the cambic stagnohumic soils are most important in the first octile.

The agricultural status of the surface water gleys is reflected in the octile breakdown of Component 3. At the 5 cm depth, they are included in those octiles associated with good base saturation and pH contents, whereas at the 30 cm depth, the inherent "lack of fertility of these soils, particularly of the humic subgroup, is shown in the bias towards octiles having lower nutrient levels.

v) Table 10.33 shows the pattern of land use changes down the component.

Table 10.33 % Occurrence of Land Use Types By Octile - Component 7

Octile	Woodland	Scrub	Permanent Grass	Grass Ley	Arable	Arable & Grass Ley	Agricultural Sites
1	12.5	12.5	12.5	12.5	50.0	62.5	75.0
2	11.1	0.0	22.2	11.1	55.6	66.7	88.9
3	22.2	0.0	22.2	0.0	55.6	55.6	77.8
4	11.1	11.1	22.2	0.0	55.6	55.6	77.8
5	22.2	0.0	22.2	11.1	44.4	55.6	77.8
6	22.2	0.0	11.1	0.0	66.7	66.7	77.8
7	11.1	0.0	22.2	0.0	66.7	66.7	88.9
8	22.2	11.1	44.4	0.0	22.2	22.2	66.7

It is to be expected that, in an area which has been subjected to intensive agriculture or woodland use for many years, the characteristics of the subsoil will show less importance overall (hence its position in the penultimate component compared with the topsoil in component 3) and less importance and correlation with land use, than the topsoil. This appears to be the case when this component is compared with Component 3 (Table 10.13 on Page 344) which shows land use variations to be more pronounced.

Table 10.33 shows wooded sites to be found throughout the component range with just a slight bias towards greater proportions on those octiles associated with higher base status, pH and silt levels.

Permanent grass is found in all octiles in fairly constant proportions. Arable, on the other hand, is most significant in Octiles 6 and 7, but overall there appears to be little pattern and this is even more pronounced when arable, grass ley and total agricultural sites are analysed together.

10.3.16.2 Spatial Variations of the Sites - Component 7

Table 10.34 shows the trend of sites in each octile among the Physiographic Units.

Table 10.34 % Site Distribution Among the Physiographic Units By Octile-Component 7

	W Physiographic Units E								
Octile	1	2	3	4	5	6	7	1+2+3	5+6+7
1	25.0	0.0	12.5	25.0	0.0	37.5	0.0	37.5	37.5
2	22.2	22.2	0.0	44.4	11.1	0.0	0.0	44.4	11.1
3	22.2	0.0	22.2	33.3	0.0	11.1	11.1	44.4	22.2
4	0.0	0.0	11.1	33.3	11.1	11.1	33.3	11.1	55.6
5	0.0	11.1	11.1	44.4	0.0	11.1	22.2	22.2	33.3
6	0.0	0.0	11.1	22.2	11.1	22.2	33.3	11.1	66.7
7	0.0	22.2	0.0	33.3	22.2	0.0	22.2	22.2	44.4
8	22.2	0.0	0.0	11.1	11.1	44.4	11.1	22.2	66.7

In line with Component 3 (Table 10.14 on Page 345), the sites in the eastern sector show higher base status and pH when compared with locations to the west. An exact similarity in trend between the two components is, however, unlikely as the topsoil in Component 3 shows the effects of agricultural practice and, perhaps more importantly, the subsidiary parameters in the two components differ.

The sites of the Wear Gorge and Floodplain (Unit 3), particularly those which show sandy parent materials, are more widely distributed about this component than they are in Component 3, where they are allocated to poorer quality octiles only. This could reflect a redistribution of nutrients within the soils by leaching.

The brown calcareous earths of the Permian Escarpment (Unit 6), however, show the effects of limestone parent material more at depth than in the topsoil and are located in the highest status profile in Component 7 as against throughout the range in Component 3.

The sites of the Permian plateau (Unit 7), as a whole, are more significant in Octiles 4 to 7, which show overall mean % base status of between 31.94 and 53.51 and mean pH of 6.07 - 6.72 for all sites, this is in contrast to those of the till in the Lowlands East of the Wear (Unit 4) which are more important between Octiles 2 and 5 which have mean % base saturation of 23.65 to 39.22 and mean pH of 5.24 to 5.93. Likewise, west of the River Wear, Octiles 1 to 3 are more significant.

These results demonstrate that the effects of parent material, manifested in the poorer pH levels of the Upper Wear Clay of the Lowlands compared with those of the Lower Till of the Permian Plateau, show up more in the subsoil where land use factors are less felt. A similar situation is also found when the Lower Till and the mixed deposits west of the Wear are compared.

These variations show, therefore, that the sites of the Permian outcrop have greater inherent subsoil "fertility" in terms of base saturation and pH than those in the Lowlands and that right across the transect there is a decrease in nutrient status from east to west.

Silt content is also shown to decline slightly from east to west.

10.3.17 Component 8

As has already been indicated in Chapter 9 this last component is not capable of clear definition and is considered as having a "mopping up" effect on variance. A detailed spatial assessment is, therefore, not included.

10.4 Conclusions

The factor scores for each component have been mapped out in spatial terms and described in detail, to provide seven information inventories of the characteristics extracted by the component loadings which were discussed in Chapter 9.

Certain problems have emerged in the interpretation of these inventories. There is the difficulty of the number of groups to extract. Breaking up the data into octiles appears to be fine enough to produce tolerable groupings, but, in one or two cases, sites would seem better suited to groups other than those to which they are allocated. It is unlikely, however, that using some other clustering technique, standard deviations for example, would have achieved better results. Of more importance than the grouping procedure in the allocation of sites to groups having seemingly different characteristics, is the amount of variance extracted, which is only moderate in amount. This is a reflection of the inherent variability of soil and site data and will be outlined further in Chapters 11 and 12.

To an extent these seven inventories can be interrogated by a researcher into the land potential of the area. He will now be able to look directly at the "essential characteristics" of the transect, for example site drainage and slope in Component 1, and generate certain hypotheses about suitability for various land uses.

A disadvantage to all this is that the components do not give a complete clustering of sites according to all the "significant" characteristics and, as a result, are of only limited use in pure land terms. A final clustering procedure of the factor score matrix has had to be sought and the results of this exercise are presented in the next chapter.

CHAPTER 11 - THE APPLICATION OF PRINCIPAL COMPONENT ANALYSIS TO LAND EVALUATION PROCEDURE; PART 3 SITE CLUSTERING

11.1 Introduction

The last two chapters have discussed the results obtained by using principal component analysis to reduce the number of variables under study to a more manageable number (component loadings), and to group these "significant" characteristics in spatial terms (component scores), so producing seven separate site inventories. This chapter discusses an extension of this analysis, whereby a clustering procedure is used to group the seventy one sites on the basis of the scores of each of the eight components extracted. The clusters, so produced, are then analysed in site resource inventory terms. The hoped for result of this procedure is the development of a better and more recognisable clustering of sites, for land use planning purposes, than took place by using cluster analysis alone.

The use of principal component analysis to reduce the number of variables followed by a cluster analysis on the component scores to group the sites is suggested by Everitt (1974) and Baxter (1976). Although this method has been used in geographical research, for example, by Knox (1974) using the cluster analysis of Mather (1969), to the author's knowledge there is no published source of its use in either soil or land evaluation research.

11.2 Transect Clustering Procedures

11.2.1 Choice of Technique

Although, in any agglomerative technique, individuals or groups of individuals are fused to those which are closest (or most similar), differences in patterns of linkage may arise when using different clustering methods. This has been indicated in Chapter 8 on Page 283. These differences arise "because of the different ways of defining distance (or similarity) between an individual and a group containing several individuals, or between two groups of individuals" (Everitt, 1974).

In order to investigate the potential of differing methods to produce worthwhile and recognisable site groupings from the component score matrix, for use as the basis for a site resource inventory, two different types of clustering technique were chosen for study. The first is the widely used method of Mather (1969), using Euclidean distance as a measure of similarity between the seventy one entities, and the second is the linkage analysis of Palmer (1974), preceded by a product-moment correlation analysis.

11.2.2 Clustering According to Mather (1969)

The clustering technique and computer program used are discussed in detail by Mather (1969). Basically the question posed is "are any groups of similar objects present in the selected data"? and such a question leads to the consideration of relationships between individual objects, i.e. Q-mode analysis. If these objects (in this case component scores) are considered as points in a Euclidean (i.e. non-curved) space, a definition of "similarity" may be obtained and site linkage can take place.

The results of the site clustering produced are shown by the dendrogram in Figure 11.1. For the purpose of producing a site inventory, the results are far from satisfactory. Fifty one sites are grouped together in one cluster at a level of 0.565, and only one other cluster contains as many as seven sites. Clearly, a meaningful inventory in land use terms cannot be produced with such an imbalance in clusters as a considerable variation in characteristics exists within this large group.

11.2.3 Clustering According to Correlation and Linkage Analysis

Product-moment correlation coefficients were calculated for the seventy one sites of the component score matrix, using the method of Sneath and Sokal (1973), as outlined in Chapter 8, Section 8.2 and then subjected to the linkage analysis of Palmer (1974), as discussed in Chapter 8, Section 8.5. The results of the site groupings obtained are shown in the dendrogram of Figure 11.2. By observation alone, the clusters are more recognisable in site inventory terms.

In order to determine the optimum number of clusters to extract, the same procedure was undertaken for this analysis as discussed in Chapter 8, Section 8.5. The graph of the stages that sites join a cluster is shown in Figure 11.3. Distinctive breaks in the plot are not as easy to distinguish as in the linkage analysis of Chapter 8, but are recognised at coefficients of 0.262, 0.554, 1.061, 1.619, 2.225, 2.761 and 3.235. Taking a suitable number of clusters to be about ten, as outlined in Chapter 8 on Page 272 the first five coefficients were discarded, as producing too many groups and single unallocated sites. The break at coefficient 3.235, on the other hand, extracts only three large groups. At 2.761, however, eight clusters are produced and this level was chosen for further analysis.

The results of the clustering were put in site resource inventory terms and are presented below -

11.3 Description of Clusters and Main Site and Soil Characteristics of Each, and Short Outline of Land Potential

Cluster 1

Sites : 42,70, 55, 54, 41, 1, 18, 45, 69, 71.

Location :

<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
1	3	30.0
5	1	10.0
6	6	60.0

The Permian Escarpment (Unit 6) dominates the cluster.

Main Site Characteristics

Angle of Slope : Moderately to steeply sloping predominates.
 Altitude : 46-146 m O.D., but mainly above 61 m O.D.
 Land Use : Permanent grass, arable, mixed woodland or scrub.
 Aspect : SSE-WNW.

FIG. 11.1 SITE DENDROGRAM (Mather, 1969)

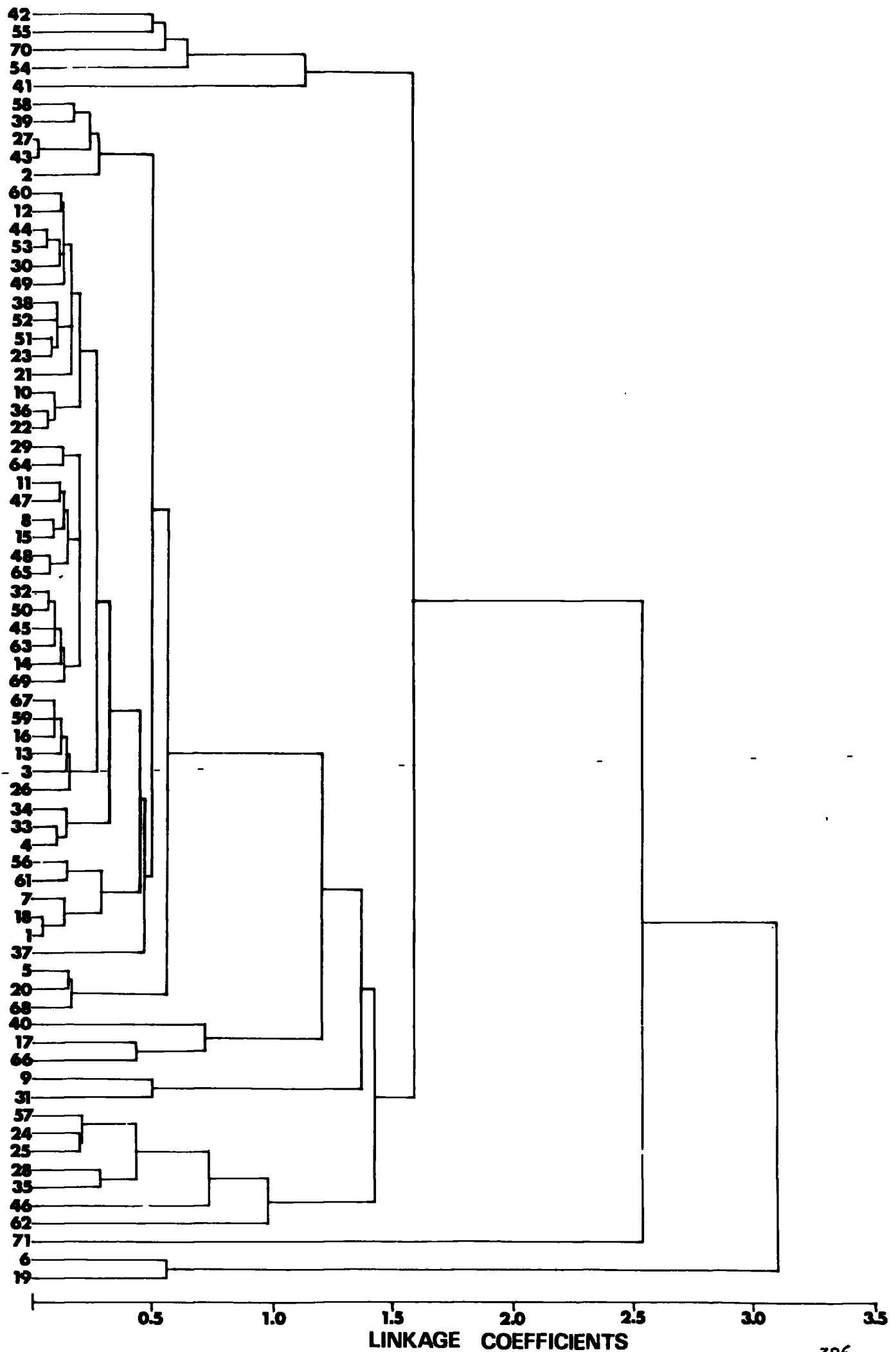


FIG.11.2 SITE DENDROGRAM (Palmer,1974)

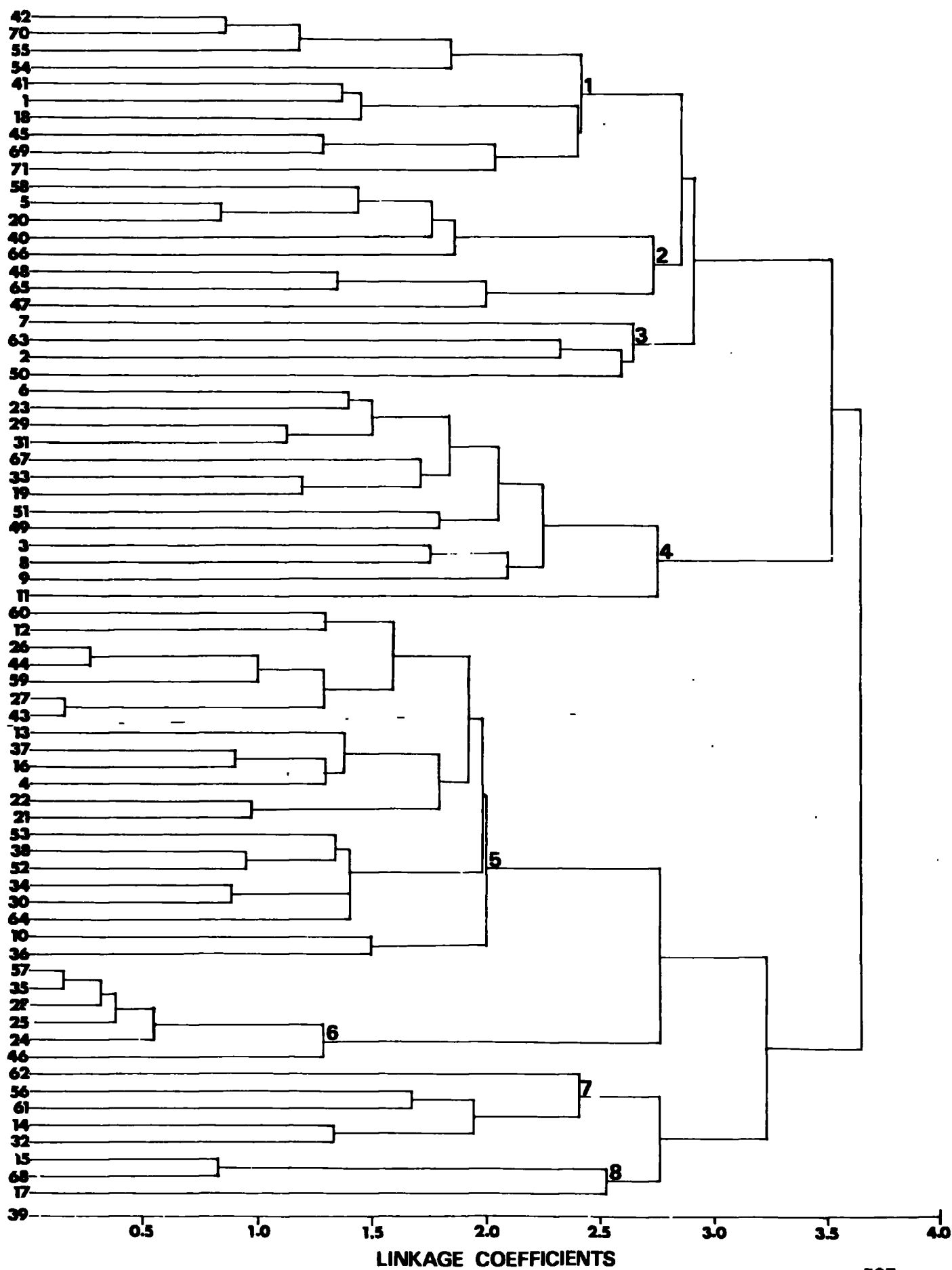
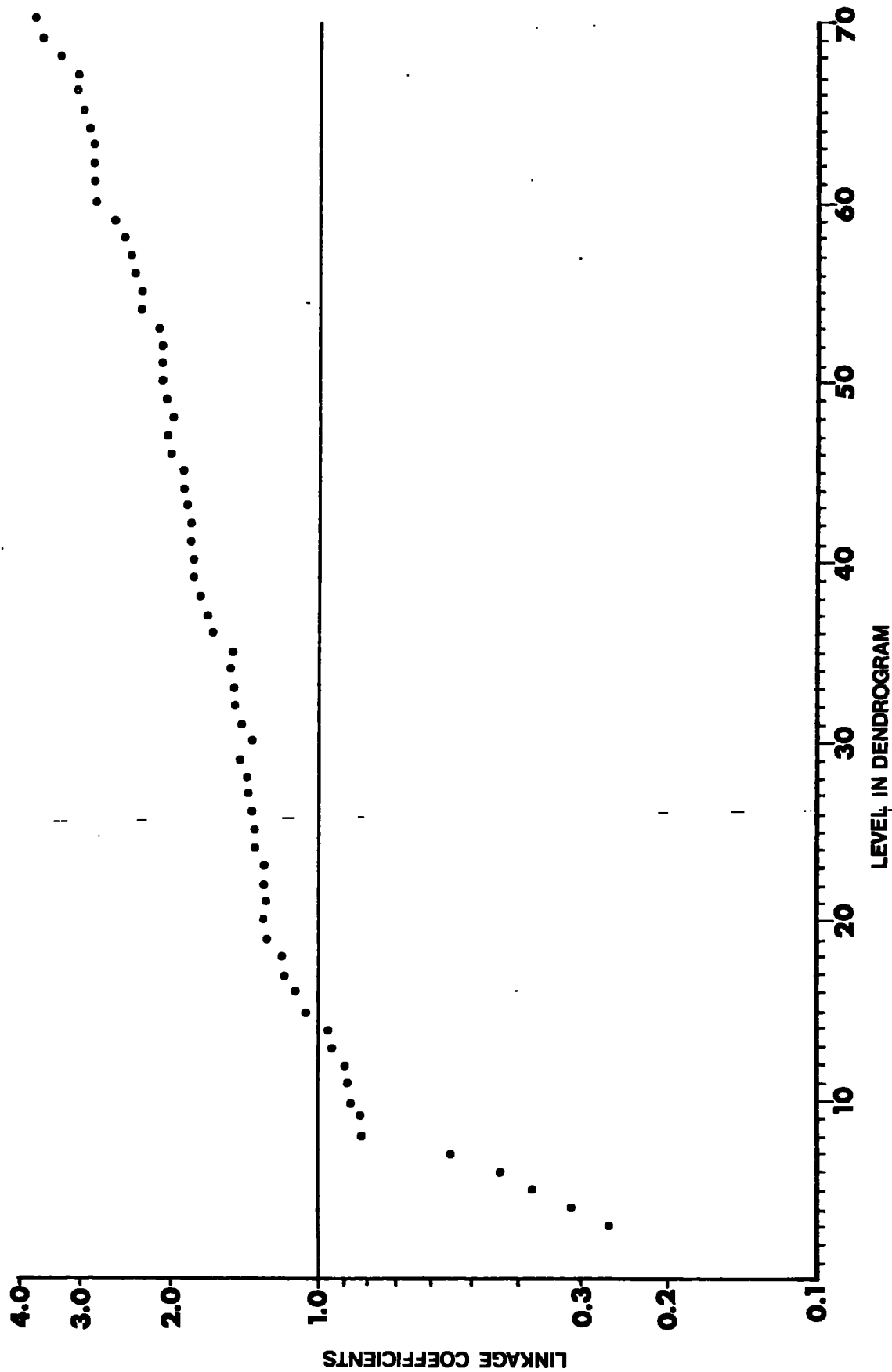


Fig11.3



Main Soil Characteristics

- Soil Type : Brown calcareous earth and brown rendzina predominate. Also, cambic stagnogley, cambic stagnohumic gley and typical (non-calcareous) alluvial gley.
- Texture : Loam, silty loam, silty clay loam, clay loam or, very rarely, loamy sand, (humose or mineral) in the topsoil, passing to silty clay loam or clay loam (very rarely loam or clay) in the subsoil. Mainly stony to extremely stony. Sometimes very rare stones.
- Structure : Moderately developed (apart from Site 71) crumb, granular, subangular or angular blocky in the surface horizon, passing to moderately developed subangular blocky lower horizons (very rarely crumb or prismatic).
- Depth : Brown calcareous and rendzina sites have depths to in situ rock of 55 cm or less. Other sites in excess of 100 cm. Rooting restrictions at all sites through shallow depth to rock, abundant stones or intractable drift.
- pH : Neutral or alkaline throughout, in eight of the sites. Two sites (18, 45) mainly slightly acid.
- Base Status : Moderate to high predominates, but occasionally low.
- Drainage : Well drained (excessive or free) or poor depending on site.
- Land Potential : Despite good nutrient status, rooting restrictions in the form of shallow depth to rock, abundant stones or poor drainage, and/or excessive slope, restrict agriculture. The calcareous sites may form tolerable arable land where slope permits. Coniferous forestry and building development are restricted at most sites because of limestone/depth or drainage factors. Amenity woodland and nature conservation potential is high.

Cluster 2

Sites : 58, 5, 20, 40, 66, 48, 65, 47.

Location :

<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
3	2	25.0
4	4	50.0
5	1	12.5
6	1	12.5

The western part of the transect dominates the location.

Main Site Characteristics

- Angle of Slope : Level to moderately sloping.
- Altitude : 30 - 137 m O.D.
- Land Use : Coniferous or deciduous woodland, grass or, more rarely, arable.
- Aspect : NNE - WNW.

Main Soil Characteristics

- Soil Type : Typical brown earth, typical brown alluvial and typical (non-calcareous) alluvial gley, cambic stagnogley, cambic stagnohumic gley, brown rendzina or disturbed soil.
- Texture : Loamy sand, loam, clay loam or silty clay loam (humose or mineral) in the topsoil, with loamy sand, sandy loam, silty clay or clay in the subsoil. Stone content variable; from very rare stones to extremely stony.
- Structure : Moderately weak to moderately developed, granular, subangular or rarely angular, throughout. Single grain or massive at depth.
- Depth : Depth to in situ rock in excess of 100 cm, apart from Sites 40 and 66.
- pH : Apart from Sites 47 and 48, which have some moderately acid horizons, pH varies from slightly acid to alkaline.
- Base Status : Base saturation varies from very low to moderate, apart from Site 40 which is very high in the topsoil.
- Drainage : Well drained (excessive or free) or occasionally poor depending on site.
- Land Potential : Nearly all sites have considerable limitations to agriculture; flooding risk, stone content, drainage or shallow depth are some of the factors affecting such a use. Forestry fares slightly better, but building construction and formal recreational pursuits are severely restricted. Informal recreation potential is good, in the form of amenity woodland, paths and trails. Nature conservation potential is also high.

Cluster 3

- Sites : 7, 63, 2, 50.
- Location : Lowlands West and East of the River Wear (Units 1 and 4).

Main Site Characteristics

- Soil Type : Cambic stagnohumic gley predominates; also cambic stagnogley.
- Texture : Humose or mineral clay loam in the topsoil, above loam, silty clay or clay in the subsoil. Very rare stones to stony.
- Structure : Moderately developed, medium or coarse subangular blocky or medium granular in the surface horizon, passing to medium to coarse subangular blocky, angular blocky or prismatic in lower horizons. Becomes massive.
- Depth : Depth to in situ rock in excess of 100 cm. Root restrictions in intractable drift.
- pH : Moderately acid to neutral throughout.
- Base Status : Base saturation is low to high, generally decreasing with depth.

Drainage : Poor.

Land Potential : Poor drainage and root restrictions, in the form of heavy textured lower horizons and parent material, at most sites, affects agriculture, although these problems are partially offset by the well structured humose topsoils of the stagnohumic gleys. Forestry is possible with drainage improvements, and the shallow slopes allow building and formal recreational developments after drainage measures have taken place.

Cluster 4

Sites : 6, 23, 29, 31, 67, 33, 19, 51, 49, 3, 8, 9, 11.

Location :

<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
1	1	7.7
2	2	15.4
3	2	15.4
4	5	38.5
5	1	7.7
6	1	7.7
7	1	7.7

The sites are widely distributed about the transect, but there is a bias towards locations in the centre and west.

Main Site Characteristics

Angle of Slope : Level to moderately sloping, apart from Sites 31 and 33 which are strongly and steeply sloping respectively.

Altitude : 30-137 m O.D. (mean = 225 m).

Land Use : Woodland and arable predominate (85% of sites). Remainder grass.

Aspect : NNE-NNW.

Main Soil Characteristics

Soil Type : Cambic stagnohumic gley and cambic stagnogley predominate (69.2% of sites). Also gleyic brown alluvial soil, typical (non-calcareous) alluvial gley and disturbed soil.

Texture : Mainly humose silty loam or silty clay loam (rarely loamy sand, loam or clay) in the topsoil, with clay loam, silty clay or clay (rarely loam or silty loam) in the subsoil. Very rare stones to slightly stony, apart from Site 23 which is very stony.

Structure : Moderately weak to moderately developed crumb, granular or subangular blocky surface horizon, passing to subangular blocky, angular blocky or prismatic lower horizons. Becomes massive or single grain (Site 19).

Depth : Depth to in situ rock in excess of 100 cm. Root restrictions in drift at depth.

pH : Variable, depending upon land use. Trend is for strongly to moderately acid under woodland and neutral to alkaline under arable.

Base Status : With certain exceptions, base saturation is very low or low in the topsoil, and only in Site 51 does the sub-soil status rise above the low category.

Drainage : Poor, apart from Sites 9 and 19 which are moderately well drained and imperfect respectively. Impeded at all sites.

Land Potential : Impeded drainage and poor nutrient status affects agricultural potential, but deep humose top horizons at the cambic stagnohumic gley sites assist rooting. Forestry potential is good if adequate drainage measures take place, but a majority of the sites are too poorly drained for building or formal recreation developments. Nature conservation and informal recreation potential is high where there is woodland.

Cluster 5

Sites : 60, 12, 26, 44, 59, 27, 43, 13, 37, 16, 4, 22, 21, 53, 38, 52, 34, 30, 64, 10, 36.

Location :

<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
1	3	14.3
2	1	4.8
4	7	33.3
6	3	14.3
7	7	33.3

The Lowlands East of the River Wear (Unit 4) and the Permian Plateau (Unit 7) account for two-thirds of the sites, with a general bias towards sites located in the east of the transect.

Main Site Characteristics

Angle of Slope : Level to gently sloping accounts for 81% of sites, but no site rises above moderately sloping.

Altitude : 37 m - 160 m O.D. (mean = 328 m).

Land Use : Arable (85.7% of Sites) or permanent grass.

Aspect : NE - NNW.

Main Soil Characteristics

Soil Type : Stagnogleyic brown earth (66.7% of sites), cambic stagnogley, cambic stagnohumic gley, gleyic brown alluvial soil, typical brown earth or disturbed soil.

Texture : Loam, silty loam, silty clay loam or clay loam (occasionally humose) in the topsoil, over clay loam, or rarely, loam, silty loam, silty clay loam, sandy clay loam or clay in the subsoil (clay loam predominates at most sites). Very rare stones to stony predominates. Occasionally very stony.

- Structure : Moderately weak or moderately developed, crumb or subangular blocky (occasionally granular) in surface horizons, passing to subangular or angular blocky in lower horizons. Massive with depth.
- Depth : Depth to in situ rock in excess of 100 cm.
- pH : Slightly acid to alkaline in the topsoil and subsoil. Occasionally moderately acid in the subsoil.
- Base Status : Low to moderate predominates in both the topsoil and subsoil.
- Drainage : Imperfect. Occasionally well drained (free), moderately well drained or poor.
- Land Potential : Generally good for agriculture and forestry. Subsidence risk and climatic exposure on the Magnesian Limestone restricts building development, but elsewhere good site and soil conditions for construction. Moderately good for formal recreation, despite poor drainage at certain sites, with potential for informal countryside recreation developments including camp sites.

Cluster 6

Sites : 57, 35, 28, 25, 24, 46, 62.

Location			
	<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
	2	1	14.3
	3	1	14.3
	4	2	28.6
	5	1	14.3
	6	1	14.3
	7	1	14.3

-The sites are widely spread about the transect.

Main Site Characteristics

- Angle of Slope : Level to moderately sloping, apart from Site 46 which is strongly sloping.
- Altitude : 30 - 142 m O.D.
- Land Use : Arable, apart from Site 62 which is deciduous woodland.
- Aspect : E - N.

Main Soil Characteristics

- Soil Type : Cambic stagnogley, cambic stagnohumic gley or typical (non-calcareous) humic alluvial gley.
- Texture : Loam, clay loam, or occasionally silty loam or silty clay loam, (humose or mineral), in the topsoil, over loam, clay loam or rarely sandy loam or silty clay loam in the subsoil. Very rare stones to stony.

Structure : Moderately developed (sometimes moderately weak) medium or coarse subangular blocky predominates, although occasionally prismatic in lower horizons. Massive at depth.

Depth : Depth to in situ rock in excess of 100 cm.

pH : Predominantly slightly acid or neutral throughout, but sometimes alkaline.

Base Status : Mainly low or moderate in the topsoil, rising to moderate to very high in the subsoil.

Drainage : Poor profile drainage on receiving sites.

Land Potential : Poor drainage, the result of site factors, inhibits agriculture and forestry, although, possibly because of the good structure and texture and reasonable nutrient status, the sites were under arable when surveyed. Drainage, subsidence risk on the limestone and, locally, flooding risk and slope, restrict building development and the provision of formal and informal recreation facilities; Nature conservation potential is high at certain sites.

Cluster 7

Sites : 56, 61, 14, 32, 15.

Location			
	<u>Physiographic Unit</u>	<u>No. of Sites</u>	<u>% of Sites in Cluster</u>
	2	1	20.0
	3	1	20.0
	5	1	20.0
	7	2	40.0

The sites are widespread among the Physiographic Units.

Main Site Characteristics

Angle of Slope : Gently to moderately sloping, apart from Site 56 which is strongly sloping.

Altitude : 27 - 118 m O.D.

Land Use : Permanent grass predominates; also arable or scrub.

Aspect : NNE - WNW.

Main Soil Characteristics

Soil Type : Cambic stagnogley, stagnogleyic brown earth, typical (non-calcareous) alluvial gley or disturbed soil.

Texture : Silty loam or clay loam (humose or mineral) in the topsoil, over clay loam, silty clay loam or clay in the subsoil. Very rare stones or slightly stony.

Structure : Moderately developed, fine crumb or medium subangular blocky in the surface horizon, passing to subangular blocky, angular blocky or prismatic in lower horizons. Becomes massive.

Depth : Depth to in situ rock in excess of 100 cm. Rooting restrictions in intractable drift.

pH : Slightly acid to neutral in the topsoil and subsoil, apart from Site 56 which is alkaline in the subsoil.

Base Status : Base saturation is low to moderate throughout.

Drainage : Poor, apart from Site 56 which is imperfect.

Land Potential : Poor drainage and intractable drift restricts agriculture, but forestry potential is good, apart from Site 61 which has a flooding risk. Building and formal recreation developments are restricted at most sites because of soil drainage, subsidence or flooding risks, but informal recreation potential, in the form of paths, trails and amenity woodland, is good.

Cluster 8

Sites : 68, 17, 39.

Location : Physiographic Units, 1, 5 and 6.

Main Site Characteristics

Angle of Slope : Level or moderately sloping.

Altitude : 61 - 152 m O.D.

Land Use : Permanent grass, arable or scrub.

Aspect : WNW - NNW.

Main Soil Characteristics

Soil Type : Typical (non-calcareous) alluvial gley, disturbed soil or stagnogleyic brown earth.

Texture : Loam, clay loam or clay (humose or mineral) in the topsoil, over clay loam or clay in the subsoil. Stone content variable.

Structure : Moderately developed, granular or subangular blocky in the surface horizon, passing to subangular blocky or prismatic in lower horizons. Becomes massive.

Depth : Depth to in situ in excess of 100 cm.

pH : Moderately acid to neutral, apart from Site 17 which has an alkaline subsoil.

Base Status : Base saturation is very low or low in the topsoil, but rises with depth.

Drainage : Moderately well drained or poor.

Land Potential : All the sites have limitations to arable agriculture in the form of poor drainage, poor nutrient status or intractable clay near to the surface. Forestry is less affected. Building and recreation is also restricted owing to soil and site factors.

11.4 Conclusions

The groupings produced by the use of principal component analysis followed by cluster analysis are significantly better in their interpretability than those produced by using cluster analysis alone in Chapter 8.

Firstly, there are less sites that show features alien to the trend of the cluster that they are in. The most significant problem is with Cluster 1 and to a lower extent with Cluster 2. Put in soil type terms, Cluster 1 is predominantly one of brown calcareous earth and brown rendzina sites, which have distinctive land use connotations. Other soil types are also included in the cluster, however. Their linkage with the brown calcareous sites is purely a matter of the level of linkage chosen, as at a level of 1.847 the brown calcareous sites (42, 70, 55 and 54) form a cluster of their own, but their linkage with the rendzina sites, and the inclusion of a rendzina site (40) in Cluster 2, is not as easy to explain. This must be put down to the inherent variability of site and soil characteristics and the subsequent problems of quantitative analysis using such data.

The second advantage is that the number of sites in each cluster shows a better balance. This is important to the interpretation of the sites in land use terms. Too few sites in a cluster increases the difficulties involved in the practical application of the data to planning problems, whilst too many sites will increase the possibility of the grouping of "alien" sites. Much, however, depends upon the nature of the sites being studied.

Thirdly, the clusters have proved capable of easier land potential interpretation, which is a reflection of their greater homogeneity of characteristics. Although, the method is for site and soil, and not purely soil, grouping, the analysis clusters soil type better than in the previous linkage analysis. For example, Cluster 4 groups the surface-water gley soils particularly well and Cluster 5 groups nearly all the stagnogleyic brown earth profiles. Cluster 1 has already been mentioned. Most of the characteristics show noticeable trends in each cluster, apart from aspect and % stones in the mineral topsoil which, although included in the inventory for comparative purposes, were removed from the component analysis.

It would appear that, despite the only moderate amount of variance extracted by the component analysis, the sites can be grouped tolerably well, by concentrating on just a few characteristics, embodied, for this analysis, in the components extracted. This factor has significant implications for future work in this area and, it could be argued, for other areas also. For further site and soil analysis in the Middle Wear Lowlands only the characteristics determined as important to the area by the component analysis need be studied, and for quantitative site grouping, only cluster analysis of the raw data is required.

A comparison of the dendrograms (Figures 11.1 and 11.2) using the two different clustering techniques illustrates the difficulties associated with the interpretation of results given by clustering techniques. Both are significantly different. In purely practical terms, the linkage technique of Palmer achieves better results for the purpose of this analysis than that of Mather (1969), but this does not invalidate the results of the latter, which may be pertinent to another type of study. Because different techniques are likely to give different solutions (unless the data are very clearly structured) a researcher should consider the validity of any clusters found (Everitt, 1974). It is submitted that the clusters produced by the analysis outlined above are valid as being capable of interpretation in site and soil terms.

PART 5

Chapter : 12

Chapter 12 - Conclusions and Summary

12.1 Introduction

In this chapter an assessment will be made of whether the aims of the author's study of land evaluation in the Mid - Wear Lowlands, as set out in the Introduction on Page iii, have been met. Conclusions will be drawn on the success or failure of the research together with general conclusions, and the possible course of further work outlined. An analysis will be made of the land capability of the Mid - Wear Lowlands transect for the selected land uses of agriculture, forestry, nature conservation, housing and industrial development and recreation. Finally, the future role of land evaluation in land use studies will be discussed and specific directions that research could follow will be suggested.

12.2 Discussion of Conclusions

12.2.1. The first aim of the thesis was to discuss the concept of land evaluation and to outline previous contributions; to which end Chapters 1 and 2 are devoted. Apart from "land evaluation" there exist many terms for what are essentially the same, or similar, techniques for analysing land as a resource. This is an unfortunate state of affairs; it does little to simplify and can only lead to confusion. To assist in the use of such techniques as a worthwhile practical tool for the natural resource or town and country planner, it is suggested that since the term "land evaluation" has wide connotations for analysis it is preferable as an overall name for the discipline.

Whilst land evaluation procedure may be divided into two broad categories of i) physical and ii) socio - economic - political, the author's research has been devoted to the former only. This does not imply that the latter are any less important and, in many instances, the expediency inherent in social, economic and political decisions, which frequently override purely physical arguments, with almost universally poor results, indicates that there is a need for much research to be done regarding socio - economic - political evaluations.

Physical land evaluation procedures divide fairly neatly into four broad approaches:

- i) Thematic or single feature mapping approach
- ii) Genetic approach
- iii) Composite units approach
- iv) Parametric approach

Of these four, three form the major underlying practical conceptual means of analysis - thematic, composite and parametric (the genetic approach being too broad for worthwhile land use planning), whilst of these three, thematic surveys, in dealing with only one attribute at a time, are limited in their practical application to land use problems.

To what scale of area and detail a specific approach is best suited is fundamental to its use and a wrong choice will produce poor and possibly misleading results. Nevertheless, despite the fact that, whilst it is broadly speaking true that parametric evaluations are better suited to detailed analysis than to wide reconnaissance, it is proposed that a flexible approach to scale should be used within the overall context of increasing detail from composite to parametric evaluation. When considering what approach to select, such factors as the extent of the present development of the area concerned, its infrastructure and political development, the availability of financial, manpower and technical resources and the use to which the study is to be put will also have to be taken into account

before a specific choice is made.

Previous contributions to land evaluation research and application have been many and varied. It is perhaps surprising to learn that the earliest embryonic concepts go back several hundred years, and that early regionalisation and genetic groupings were pursued well into this century. The composite unit idea is, however, a product of the U.S.A. of the 1920's, given impetus by the federal land projects started during the depression and 'New Deal' years of the thirties. Nevertheless, this work, notably in Michigan, appears not to have diffused much elsewhere, and when the Northern Australia Land Survey began in 1947 it was unknown to the researchers involved. Indeed, Bourne's work at Oxford, published in 1931, seems to have been undertaken independently of the American survey concepts. During the forties and fifties, the principal centre for composite unit research moved from the United States to Australia, and this was itself replaced during the 1960's by the Oxford/MEXE project in Great Britain. Since the War, research has also been undertaken in Canada, The Soviet Union, Germany and Japan.

During this century, and parallel to composite unit analysis, research has taken place on theoretical schemes or models of groups of land units which occur regularly in association over large and small areas. This line of research will undoubtedly have a direct affect on practical land evaluation procedure in the future as the research suggests that such models could provide a quick and economical synthesis of information.

The advances in remote sensing, field analysis and computer technology that have taken place, particularly during the past twenty years or so, have altered the course that land evaluation has taken, giving rise to new 'parametric analyses'. Although rising out of the concepts of the composite approach, the parametric approach has run parallel, and largely independently, of it.

Thus, land evaluation has developed from early regional groupings and has followed an 'evolutionary' path from qualitative to quantitative analysis as a result of advancements in technology. The two major approaches to evaluation, of composite and parametric techniques are now being actively developed side by side, although it is to the latter that attention is principally being focussed.

12.2.2. The second aim of the thesis was to investigate the role of the natural resource attributes of climate, landform, soil, vegetation, fauna and water, as defined by Stewart (1968), and their inherent parameters, as they affect land evaluation in Great Britain (Chapter 3).

In order to mitigate the problems of setting limiting values (or 'thresholds') to parameters when undertaking land capability analyses, the author suggests that it is useful to divide them into 'specific' and 'gradational' thresholds, and these in turn can be sub-divided into physical, economic and social thresholds.

The major conclusion to be drawn from Chapter 3, however, is that capability classifications for the land uses selected for consideration will inevitably be limited at present owing to the paucity of quantitative threshold data levels. Agriculture fares slightly better than the other uses, but the almost complete lack of housing and industrial data pertaining to Great Britain must be seen as a cause for concern in view of the continuing debate on urban encroachments in the countryside. Clearly, building development capability classifications must be used in conjunction with agricultural land classifications before realistic policies for any area can

be formulated. A negative approach based on the "conservation of the best agricultural land", will, from the outset, be doomed to failure since, in an area of intense urban pressure, political considerations of housing need invariably override those of providing food. The addition of a building development classification would allow, at least, a quantitative "decision" to be made, and the politicians' to have the facts before them as to the merits of a site.

To devise such threshold levels can be a long task, and there is always the danger of technological advance overtaking research programmes, but such data are essential and research must be done. Nevertheless, there is a great deal of qualitative information on threshold parameter levels for most land uses and certain parameters do not lend themselves directly to numerical assessment. It is inevitable, therefore, that some parametric evaluations will contain qualitative information. For example, on subsidence or flooding effects for housing classifications.

12.2.3. In the Introduction on Page iii it was suggested that there are two deficiencies of note in the literature; the first being in the use of point sample survey to enable a rapid evaluation of an area's characteristics and land use capability at a "strategic" level of survey, and the second being in the development of quantitative information inventory procedures which reduce the elements of subjectivity that are inherent in composite unit analysis. Research into the first of these deficiencies continues throughout parts 2 to 4 of the thesis and investigations into the second take place in Part 4.

It was concluded in Chapter 4, that in order to undertake a rapid point sample survey at a strategic level, a 500 m grid using a systematic random sampling technique, coupled with a 60 cm sampling depth for the soil pit and 90 and 100 cm augering depths for certain of the parameters selected for investigation was suitable. The time taken for the initial field soil and site data and soil sample collection in the transect was in the order of 30 full man-days. This allowed relevant data on which to base quantitative techniques to be used and detailed land capability assessments to be made.

In order to begin work on point sample surveys, the third aim of the thesis was to investigate the physical characteristics of the Mid-Wear Lowland transect on a thematic basis using point sample techniques. This type of approach produced detailed statements of the main physical attributes of the transect upon which to base quantitative land use potential analyses but in direct land capability terms did not tell us much. Subjective appraisals may be made of the effects of each attribute on land use, but that is all. In order to quantitatively assess land capability a parametric approach is required and this involves the parameters of natural resource attributes.

12.2.4. The fourth aim of the study was to investigate the land capability of the Mid-Wear transect for the selected land uses using point sample parametric land capability surveys at a strategic level of survey.

The first conclusion to be drawn from the research is that, before a capability system can be devised for a particular area, the requirements and applicability of the scheme, as to whether it should be nationally (or wider) or locally based, must be carefully considered, as these differences will affect the choice of parameters and classification. National classifications are favoured for agriculture, forestry, nature conservation and recreational development (camp sites and picnic areas) and local schemes for housing and industrial development, for the reasons stated in the various sections of Chapter 6.

Land capability surveys for agriculture are by far the most widely used for planning purposes in Great Britain and elsewhere. In Britain two schemes are commonly used; that of Bibby and Mackney (1969) as undertaken by the Soil Survey, and that of the Ministry of Agriculture (1966) although the U.S.D.A. classification (Klingebiel and Montgomery, 1961) is occasionally employed for ad-hoc projects. It is ridiculous that two public organisations should be using different systems to achieve the same end result, and one nationally agreed classification would be desirable, and it is noted that the Ministry and the Soil Survey are now working to this end. It has been proved by the author in Section 6.2.7.6 beginning on Page 170, that in the Mid-Wear Lowlands transect the Ministry's scheme shows significant defects, both in the survey results and classificatory grades, and it is suggested that the Bibby and Mackney system is the better of the two.

The modified system of Bibby and Mackney proposed by the author, when applied to the study transect, shows that Classes 3 and 4 are the most commonly encountered in the area, with resultant inherent problems for a wide variety of agricultural practice. The research has also shown that much work has still to be carried out on threshold levels; in particular on soil drainage relationships and soil erosion, both of which are especially unsatisfactory at present.

Forestry capability classifications are in their infancy in this country, a fact well indicated by Toleman (1974), and threshold levels are very problematical; a situation complicated by tree species. The nine parameters used in the authors scheme should, therefore, only be seen as provisional at present, and the "modifiable/unmodifiable" concept has been adopted as a result. Much research has still to be undertaken in defining the relative importance of various parameters as well as significant threshold levels for the growth. The point sample system when applied to the Mid-Wear transect has shown that only 38% of sites are of Classes 1 and 2 (suitable and conditionally suitable) for coniferous forestry. The spatial distribution indicates that production is suitable for specific well defined locations among areas unsuitable for worthwhile commercial growth.

Capability classifications for nature conservation that use habitat type as the schematic base, appear to have advantages over other evaluatory techniques. Whilst considering this premise, it became apparent that the systems of Tubbs and Blackwood (1971) and Helliwell (1969) both suffer from certain defects. Helliwell's system places agricultural land, with its many facets of ecological importance, in a low grade, whilst the Tubbs and Blackwood classification, on the other hand, does not give the importance of water to wildlife enough weight. It is considered that agricultural land must be given adequate attention in nature conservation classifications, and that the system devised by the author allows this to take place. Being capable of interpretation from aerial photographs, it enables large areas to be covered very rapidly and gives significant weighting to the vagaries of differing land uses. Further research needs to be undertaken on the method of scoring the features in a particular zone and into the benefits of increased quantification. In addition, because of the point sample basis, small areas of interest (water or woodland tracts, for example) may be overlooked, and an increase in survey radius of the sample site would alleviate this problem to an extent.

When the system is applied to the transect sites, the predominant agricultural land use is reflected in the dominance of low capability classes, but, unlike other systems, the accumulative significance of agriculture to nature conservation is not ignored. Areas of high significance do occur, but in well defined zones, and are especially associated with water bodies.

Land capability classifications for housing development have not been attempted in Great Britain on a definitive basis before, and there remains much work to be done on both the choice of parameters and threshold levels. Meanwhile, technological advances in building construction methods and materials is making the task more difficult. It is considered that, before a classification scheme can be formulated, the scale and type of dwelling must be defined and that, at a general strategic level of analysis, the most frequently encountered and important form of housing development, the public or private estate with units at a density of about twenty two to the hectare, is a meaningful scale at which to develop a scheme. Over half of the transect sites (54.9%) are suitable or conditionally suitable for housing, according to the system devised, and soil drainage and mining subsidence risk form the dominant subclass notations.

The proposed capability analysis for housing development, although suffering from the lack of quantitative threshold levels, appears to give a realistic assessment of potential. By using fundamental soil and environmental information as a basis, considerable time is saved at the strategic planning level by the omission of the time consuming analysis involved in investigating engineering properties of the sites. This more detailed work can be carried out once the possible housing locations have been identified. The approach adopted permits a rapid survey of overall potential for development in the transect area. A further advantage of the scheme is that it allows attention to be focussed on areas of higher class without initial value judgements on the desirability or not of specific locations entering the decision making process.

There is even less parameter and threshold information on which to base an industrial capability system than there is for housing. In addition, the wide range of building materials available, coupled with the many differing types and scales of industrial development, make the selection of parameters a difficult process. Considering the importance of industry to the national well-being, this should be seen as a cause for concern. The land capability system proposed by the author, in concentrating on site and soil information without the inclusion of engineering data or the consideration of specific types of industry, enables a rapid survey and analysis of potential to take place. This is especially the case when investigated in association with the housing capability system, as a significant number of parameters are held in common. Likewise, it is submitted that the division of development into "large-scale" and "small-scale" based on slope thresholds produces, in planning terms, a more meaningful classification than would occur if "industry" was considered as one general land use.

The survey shows that the area of the Mid-Wear Lowlands transect is not particularly suitable for industrial development, with nearly two-thirds of the sites being unsuitable for small-scale industry and over three-quarters not suitable for large-scale development.

Threshold parameter levels for many specific recreational developments, including camp sites and picnic areas, have been researched in some detail (for example, on slope, soil texture and drainage) and apart from agriculture, are more freely available than for the other land uses considered. The classification scheme devised indicates that the transect is a poor area for camp sites and picnic areas, with only a small number of individual sites having some potential. In common with the other land uses, attention can now be focussed on these better classed areas to aid future development at a detailed level.

Part 3, devoted entirely to the development of various parametric capability analyses, shows that, despite the lack of threshold data levels, land classifications can be attempted for a wider variety of land uses than are normally considered at present, and that a more comprehensive approach to survey in Britain would be of benefit. A great deal more information on land use capability has been gleaned by using the parametric approach than was possible using the thematic basis of study. Over the transect, the 500 m grid has allowed patterns of land capability classes to be extracted that are capable of interpretation, with the inherent parameters of each Physiographic Unit producing their own specific capability distributions. This level of sampling would appear successful for a strategic analysis.

In considering Part 3, it is very noticeable in the transect that there is an extremely small number of sites graded as Class 1 for the land uses under consideration, and this indicates that certain specific locations are worthy of further detailed investigation. Finally, this method of parametric capability classification lends itself to the use of computer modelling techniques, and it would be a comparatively easy task to develop a model which produces details of the capability for multi-land use of sites by merely entering certain parameter details.

12.2.5. The fifth and final aim of the thesis was to develop quantitative natural resource information inventory systems for the Mid-Wear Lowland transect using point sample survey methods at a strategic level of survey. This takes up Chapters 7 to 11 and forms Part 4.

It is considered that both the parametric and composite unit approaches to land evaluation have their own specific advantages as far as land use planning is concerned, but that a system which combines the flexibility for inventory purposes of composite boundaries with the quantitative nature of a parametric analysis would appear to hold a key to the advancement of the land evaluation discipline. In researching into the practicability of such a "numerical composite-parametric" method, two principal statistical techniques were used - cluster analysis and principal component analysis.

It is concluded that the first clustering technique undertaken, that of the linking of Pearson product-moment correlation coefficients by means of pair by pair highest affinity clustering, has produced recognisable groupings that are definable in both pedological and general non-classificatory land capability terms. The method proves not only useful in highlighting the complex relationships between sites, but enables problems concerning their management and land use potential to be analysed by means of an inspection of the clusters produced.

As this analysis is not a typical parametric capability classification for a specific land use, undertaken to define specific capability gradings, but is, in many ways, more akin to a composite information inventory evaluation, capability is inferred for most land uses for each cluster of sites. As indicated in Chapter 7 on Page 250, the advantages of both the parametric and composite approaches are, to an extent, encapsulated in one method - a quantitative approach allowing multi-land use site inventory assessment. The technique has, however, a considerable number of drawbacks in that, as the sites are clustered on a highest affinity basis, the number of groupings is large and in some cases clusters only refer to two sites.

characteristics will be as effective in distinguishing recognisable groupings as is a mass of unselected variables. This will inevitably entail selection and with it inherent subjectivity.

12.3. Future Trends in Land Evaluation

What of the future as far as land evaluation is concerned? It is concluded that the concept will play an ever increasing role in the planning of the world's resources and man's response to these resources in the future. With the rapid development of computer and photogrammetric technology, it is likely that advances in research will be focussed on the more quantitative aspects of the discipline, particularly in the use of advanced statistics and computer graphics, and this has been indicated in the discussion on future developments of the author's research outlined above.

It is clear that the thematic approach is limited in pure land use terms; but it is also clear that organisations such as the Soil Survey are committed to using such techniques. Regretfully, until there is more acknowledgement made of the fact that pure soil survey maps are of limited benefit in practical terms, without accompanying land capability assessments for a wide variety of land uses (not only for agriculture), much of the work of the Survey will be little used outside the academic sphere.

Thematic analyses do, however, provide an essential source of information on which to base further land capability work and will continue to fulfill this role in the future. The genetic approach, on the other hand, is unlikely to be used or developed as a practical land use planning technique for the reasons outlined in Chapter 1.

There is little doubt that the composite and parametric approaches offer the most potential for future research and development and practical use, but because of their ease of interpretation to the layman it is the latter that are likely to remain the most popular type of capability analysis despite the problems of setting threshold levels.

Yet, composite surveys, in having a greater flexibility for land use interpretation, would appear to hold more potential for further research. It is submitted that the land systems/facet technique would benefit, in particular, from work on the recognisability of land unit boundaries and on the storage and manipulation of data that is held by these units. It is to computer and statistical techniques that attention will have to be focussed in achieving these aims.

However, as far as physical land evaluation is concerned, the development of hybrid composite-parametric analyses and theoretical models of natural physiographic systems will likely provide the primary bases for advancement in the future. A flexibility of approach to land use interpretation coupled with a sound quantitative base inherent in these approaches is likely to become a necessity in an era of scarce economic and physical resources. The margins of error in the decision-making process, regretfully wide at present, must inevitably narrow.

Finally the importance of social, economic and political evaluations has been referred to in an earlier paragraph and, although much neglected at present, a good deal of valuable work will have to be done on these. It is to the linking of such analyses with physical evaluations that attention will be focussed eventually, as an extension of the integrated survey approach, and at this stage it is suggested that computer modelling would be worthy of investigation.

The use of principal component analysis followed by cluster analysis as a means of achieving a clearer and more realistic grouping of sites for resource inventory purposes, has produced better results than by using cluster analysis alone. Firstly, there are less sites that show features alien to the trend of the cluster that they are in, although the problem of the inherent variability of site and soil characteristics and the subsequent problems of quantitative analysis using such data remains.

The second advantage is that the number of sites in each cluster shows a better balance. This is important to the interpretation of the sites in land use terms. Too few sites in a cluster increases the difficulties involved in the practical application of the data to planning problems, whilst too many sites will increase the possibility of the grouping of "alien" sites. Much, however, depends upon the nature of the sites being studied.

Thirdly, the clusters have proved capable of easier land potential interpretation, which is a reflection of their greater homogeneity of characteristics. Although, the method is for site and soil, and not purely soil grouping, the analysis clusters soil type better than in the previous linkage analysis. Apart from aspect and % stones in the mineral topsoil which, although included in the inventory for comparative purposes, were removed from the component analysis, most of the characteristics show noticeable trends in each cluster.

It would appear that, despite the only moderate amount of variance extracted by the component analysis, the sites can be grouped tolerably well by concentrating on just a few characteristics, embodied, for this analysis, in the components extracted. This factor has significant implications for future work in this area and, it could be argued, for other areas also. For further site and soil analysis in the Middle Wear Lowlands only the characteristics determined as important to the area by the component analysis need be studied, and for quantitative site grouping, only cluster analysis of the raw data is required.

A comparison of the dendrograms (Figures 11.1 and 11.2) using the two different clustering techniques illustrates the difficulties associated with the interpretation of results given by clustering techniques. Both are significantly different. In purely practical terms, the linkage technique of Palmer achieves better results for the purpose of this analysis than that of Mather (1969), but this does not invalidate the results of the latter, which may be pertinent to another type of study. Because different techniques are likely to give different solutions (unless the data are very clearly structured) a researcher should consider the validity of any clusters found (Everitt, 1974). It is submitted that the clusters produced by the analysis outlined above are valid as being capable of interpretation in site and soil terms.

Much research remains to be done into these methods of quantitative analysis in order to attempt to overcome some of the problems indicated above. The author does not underestimate the difficulties inherent in doing this and in particular of dealing with the inherent problems of the heterogeneity of soil data. It is concluded that, as the results achieved will be as good as the data that is fed into the analyses, the selection of variables is all important. It is argued that a small group of carefully selected

The second clustering method, that of the application of a linkage algorithm developed by Palmer (1974) to cluster sites from the initial similarity matrix of correlation coefficients, produces a more analytical approach to the problem and introduces the concept of a hierarchy of sites. It is concluded that this technique, in reducing the number of clusters from sixteen to eight, gives a more manageable assessment of site resources and potential than that resulting from the highest affinity analysis. It has proved possible to recognise certain characteristics that make each cluster capable of interpretation in general land potential terms. Because of this reduction, there is an increase overall in sites per cluster.

The use of cluster analysis to construct a natural resource inventory of the seventy one transect sites that is capable of interpretation in general land potential terms has met, it is submitted, with a modicum of success. Both the techniques used to link the initial similarity coefficients between sites have produced clusters that show overall features in common - each shows a trend - and each cluster is capable of land potential interpretation.

Problems have emerged, however. Firstly there is the question of the correct number of site groupings to extract, and it has been suggested that this is essentially a matter of arbitrary choice. Apart from the difficulty of the recognisability of site and soil characteristics when a small number of clusters is used, too small a number increases the problems of interpretation for the user of the system. Likewise, too large a number of groups may mask crucial interrelationships between sites, but as a general rule, it is felt that too large a number is preferable to too small. The problem of the level of linkage and the type of sites clustered has been referred to in Section 8.5.3. on Page 283 and, because of the nature of the clustering system, this will remain a drawback.

The second difficulty is the location of certain sites in clusters whose trend characteristics appear to bear little relation to their own inherent properties. Apart from the level of linkage, as mentioned above, this is basically a result of the essential variability of soil parameters coupled with the inclusion of site factors in the same system, so producing confusing results, for example, Site 66 in Cluster 6 of the linkage analysis on Page 280. It is possible that such a phenomenon could be avoided by using a different choice of parameters in the calculation, or by clustering sites on significant characteristics, as in the case with principal component analysis, rather than on all the characteristics with equal weight being placed on each.

The third problem is one of clustering; different clustering techniques producing slightly different patterns of site linkage within clusters. An example of this is the fact that Sites 56 and 69 are situated in Cluster 2 of the highest affinity analysis (Page 259) in association with Sites 7,12,28, 38,57 and 58, yet are linked in Cluster 1 of Palmer's linkage method (page 275) to totally different sites. Generally speaking, however, when the two types of analysis are compared, associations of sites remain remarkably constant.

Despite the above disadvantages to the method, it is now possible for a land resource planner or other researcher, to interrogate either of the two types of data bank to obtain information about the sites and their general capability. If necessary, he may then "home in" on a specific site or area for detailed planning purposes. Being of a quantitative nature, the system lends itself to the use of computer methods for interrogation, including the use of visual display unit and other means of graphical display and manipulation of the data bank.

A P P E N D I X 1

SOIL PROFILE DESCRIPTIONS

Site No.: 1

Subgroup: cambic stagnogley

Location: Low Newton Farm, Framwellgate Moor G.R.: 28534599

Altitude: 55m O.D. Slope: 3.4° Aspect: WNW (306°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal profile drainage; poor

Horizons:

cm

- 0 - 23 Apg Dark greyish brown (10 YR 4/2) friable silty loam with common faint very fine dark brown to brown (7.5 YR 4/4) mottles; moderately developed medium subangular blocky structure; very rare small stones of sandstone, shale and coal; debris; abundant fibrous roots of rotting barley; moist; sharp even boundary.
- 23 - 33 Bg Dark brown (10 YR 3/3) firm silty clay loam with common faint very fine dark brown to brown (7.5 YR 4/4) mottles; moderately developed medium subangular blocky structure; slightly stony with small stones as above; few fibrous roots; moist; sharp even boundary.
- 33+ BCg Greyish brown (2.5 Y 5/2) very firm silty clay with many prominent fine strong brown (7.5 YR 5/8) and olive grey (5 Y 5/2) mottles; stones as above; few fibrous roots; massive.

Site No.: 2

Subgroup: cambic stagnohumic gley

Location: Union Hall Farm, Framwellgate Moor G.R. 29084595

Altitude: 55m O.D. Slope: 0.1° Aspect: SW (214°)

Land use: permanent grass: Canopy: none Topex: moderately exposed

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 24 Apg/Bg Dark grey (10 YR 4/1) friable humose clay loam with common faint very fine brown to dark brown (7.5 YR 4/4) mottles; moderately developed coarse subangular blocky structure; very rare coal traces; debris; abundant fibrous roots; slightly moist; sharp undulating boundary.

24+ BCg Greyish brown (2.5 Y 5/2) firm clay with many prominent medium brownish yellow (10 YR 6/6) and olive grey (5 Y 5/2) mottles; stony with small stones of sandstone and coal; common fibrous roots; slightly moist; greyer with depth; massive.

Site No.: 3

Subgroup: cambic stagnohumic gley

Location: Union Hall Farm, Framwellgate Moor G.R.: 29384590

Altitude: 55m O.D. Slope: 0.1° Aspect: NNE (16°)

Land use: arable (oats) Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 17 Ap(g) Very dark grey (10 YR 3/1) friable humose silty loam with common faint very fine dark brown to brown (7.5 YR 4/4) mottles; moderately developed coarse subangular blocky structure; slightly stony with small stones of sandstone and coal; debris; abundant fibrous oats roots; moist; narrow merging boundary.
- 17 - 34 Bg Dark grey (10 YR 4/1) firm humose silty clay loam with common distinct fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse angular blocky structure; stones as above; common fibrous roots; moist; sharp even boundary.
- 34+ BCg Greyish brown (10 YR 5/2) firm silty clay with many prominent fine to medium brownish yellow (10 YR 6/6) and olive grey (5 Y 5/2)-mottles; stones as above; few fibrous roots; moist; massive.

Site No.: 4

Subgroup: stagnogleyic brown earth

Location: Union Hall Farm, Framwellgate Moor G.R.: 30244597

Altitude: 37m O.D. Slope: 6.3° Aspect: NE (50°)

Land use: arable Canopy: none Topex: very sheltered

Site drainage: normal Profile drainage: moderately well drained

Horizons
cm

0 - 25	Ap	Very dark grey (10 YR 3/1) friable loam; moderately weak medium subangular blocky structure; slightly stony with small stones of shale and sandstone; debris; abundant fibrous, few woody roots; slightly moist; narrow even boundary.
25 - 38	B1w	Very dark greyish brown (10 YR 3/2) friable clay loam; moderately developed medium subangular blocky structure; stony with small stones of sandstone, shale and coal; few woody and fibrous roots; slightly moist; merging even boundary.
38 - 61	B2w	Dark brown (10 YR 3/3) friable clay loam; moderately developed medium subangular blocky structure; stones as above; few woody roots; slightly moist; sharp even boundary.
61+	BCg	Yellowish brown (10 YR 5/4) firm clay loam with many distinct fine strong brown (7.5 YR 5/8) and olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 5

Subgroup: typical brown alluvial soil

Location: Mallygill Wood (N.T.), West Rainton G.R.: 30474605

Altitude: 30m O.D. Slope: 0.6° Aspect: WSW (241°)

Land use: deciduous woodland Canopy: present Topex: very sheltered

Vegetation: Acer pseudoplatanus; Rubus Sp.; Chamaenerion angustifolium;

Agrostis canina; Festuca rubra

Site drainage: normal Profile drainage: well drained (free)

Horizons

cm

1 - 0	L	Undecomposed leaf litter.
0 - 1	F	Rotted grasses; fleshy white roots.
1 - 9	Ah	Very dark brown (10 YR 2/2) very friable humose loamy sand; moderately weak medium granular structure; very rare small round stones; common fibrous roots; slightly moist; narrow undulating boundary.
9 - 18	B1w	Very dark grey (10 YR 3/1) very friable loamy sand; very weak medium granular structure; stones as above; few fibrous and woody roots; slightly moist; narrow undulating boundary.
18 - 47	B2w	Dark brown (10 YR 3/3) very friable loamy sand; <u>very weak fine granular structure</u> ; stones and roots as above; sharp even boundary.
47+	C	Dark brown (10 YR 3/3) very friable sand; very rare gravel; roots as above; slightly moist; single grain.

Site No.: 6

Subgroup: cambic stagnogley

Location: Mallygill Wood (N.T.), West Rainton G.R.: 31004600

Altitude: 52m O.D. Slope: 1.4° Aspect: S (191°)

Land use: deciduous woodland Canopy: present Topex: very sheltered

Vegetation: Quercus robur; Festuca spp.; Chamaenerion angustifolium;

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 4	F	Partly decomposed grass.
4 - 11	H	Black (2.5 Y 2/0) greasy humus with small amount of mineral matter; abundant fibrous and common woody roots; merging undulating boundary.
11 - 24	AB	Dark yellowish brown (10 YR 4/4) very firm clay; moderately developed very coarse subangular blocky structure; slight humose staining from above horizon in top 2 cm; very rare small stones of sandstone, shale and coal; abundant fibrous roots; moist; merging undulating boundary.
24 - 35	Bw	Dark yellowish brown (10 YR 4/4) very firm clay; moderately strong very coarse subangular blocky structure; slightly stony with small stones of sandstone, shale and coal; few woody and fibrous roots; merging undulating boundary.
35+	BCg	Dark brown (10 YR 4/3) very firm clay with common distinct very fine brown (7.5 YR 4/4) and greyish brown (2.5 Y 5/2) mottles; stones as above; few fibrous and woody roots; very moist; clay migration down some root channels; massive.

Site No.: 7 Subgroup: cambic stagnohumic gley
 Location: Moorhouse Farm, Rainton Gate G.R.: 31504596
 Altitude: 79m O.D. Slope: 2.3° Aspect: SSW (200°)
 Land use: arable Canopy: present Topex: moderately sheltered
 Vegetation: wheat below Fraxinus excelsior
 Site drainage: normal Profile drainage: poor

Horizons

cm

0 - 30	Ap	Very dark grey (10 YR 3/1) friable humose clay loam; moderately weak medium subangular blocky structure; slightly stony with medium rounded sandstone; debris; common fibrous and rare woody roots; slightly moist; sharp even boundary.
30 - 65	Bg	Brown to dark brown (10 YR 4/3) friable loam with common faint yellowish brown (10 YR 5/6) mottles; moderately weak medium subangular blocky structure; very rare stones of sandstone and coal; few roots as above; slightly moist; merging boundary.
65+	BCg	Yellowish brown (10 YR 5/4) firm clay with many prominent fine dark brown to brown (7.5 YR 4/4) and fine olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 8

Subgroup: cambic stagnohumic gley

Location: Field House Farm, Rainton

G.R.: 32264595

Altitude: 95m O.D.

Slope: 0.6°

Aspect: ENE (60°)

Land use: arable (turnips)

Canopy: none

Topex: moderately exposed

Site drainage: normal

Profile drainage: poor

Horizons

cm

- 0 - 15 Ap Very dark grey (10 YR 3/1) friable humose silty loam; moderately weak medium subangular blocky structure; very rare stones of sandstone, abundant coal; debris; few woody roots; worms; slightly moist; sharp even boundary.
- 15 - 22 AB(g) Very dark greyish brown (10 YR 3/2) firm loam with common faint very fine dark yellowish brown (10 YR 4/4) mottles; moderately developed medium subangular blocky structure; clay movement down fine root channels; slightly moist; narrow even boundary.
- 22 - 69 Bg Dark brown (10 YR 3/3) firm clay loam with many prominent fine brown to dark brown (7.5 YR 4/4) and faint grey (5 Y 5/1) mottles; moderately developed medium subangular blocky structure; stones as above; few woody roots; worms; slightly moist; merging boundary.
- 69+ BCg Yellowish brown (10 YR 5/4) firm clay with many prominent medium brown to dark brown (7.5 YR 4/4) and faint grey (5 Y 5/1) mottles; moist; massive.

Site No.: 9

Group: disturbed soil

Location: Field House Farm, Rainton Gate G.R.: 32554603

Altitude: 94m O.D. Slope: 2.8° Aspect: SSE (150°)

Land use: old orchard Canopy: present Topex: moderately exposed

Vegetation: apple trees and Festuca rubra

Site drainage: normal Profile drainage: moderately well drained

Horizons:

cm

0 - 5 F Decomposed grass and leaves

5 - 12 Ah Very dark greyish brown (10 YR 3/2) friable clay loam; moderately weak medium granular structure; very rare stones of sandstone and coal; debris; abundant fibrous and few woody roots; worms; moist; merging even boundary.

12 - 80 Dark brown (10 YR 4/3) friable clay loam; moderately weak medium granular structure; stones and debris as above; common fibrous and few woody roots decreasing with depth; worms; moist; merging boundary.

80+ Altered Upper Wear Clay.

Site No.: 10

Subgroup: stagnogleyic brown earth

Location: High Moorsley Farm, High Moorsley G.R.: 33134588

Altitude: 92m O.D. Slope: 3.5° Aspect: NNW (346°)

Land use: arable (wheat) Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: imperfect

Horizons

cm

0 - 28	Ap	Very dark brown (10 YR 2/2) very friable humose silty loam; moderately weak coarse crumb structure; slightly stony with small stones of sandstone, siltstone, metamorphic rock, Magnesian Limestone and coal; debris; common fibrous roots; worms; moist; sharp even boundary.
28 - 40	Bw	Very dark greyish brown (10 YR 3/2) friable loam; moderately developed medium subangular blocky structure; stones and roots as above; worms; moist; merging undulating boundary.
40+	BCg	Reddish brown (2.5 Y 4/4) firm clay loam with many prominent medium strong brown (7.5 YR 5/6) and common medium olive grey (5 Y 5/2) mottles; stones as above; moist; massive.
- - - - -

Site No.: 11

Subgroup: cambic stagnogley

Location: High Moorsley Farm, High Moorsley G.R.: 33464594

Altitude: 103m O.D. Slope: 5.9° Aspect: NW (317°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: poor

Horizons

cm

0 - 32	Ap	Very dark grey (10 YR 3/1) friable clay loam; moderately developed medium subangular blocky structure; slightly stony with small and medium stones of sandstone, siltstone, metamorphic rock, Magnesian Limestone and coal; debris; rotting barley stalks and roots; worms; moist; sharp even boundary.
32 - 42	Bg	Dark yellowish brown (10 YR 3/4) friable clay loam with common faint fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; moderately developed medium subangular blocky structure; stones as above; few fibrous roots; moist; merging undulating boundary.
42+	BCg	Olive brown (2.5 Y 4/4) firm clay with many distinct fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above increasing; few fibrous roots; moist; massive.

Site No.: 12

Subgroup: stagnogleyic brown earth

Location: High Moorsley Farm, High Moorsley G.R.: 33984602

Altitude: 133m O.D. Slope: 4.8° Aspect: N (356°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: imperfect

Horizons

cm

- 0 - 35 Ap/B Very dark greyish brown (10 YR 3/2) friable clay loam; moderately weak medium crumb structure; slightly stony with small stones of sandstone, shale, limestone and metamorphic rock and coal traces; rotted barley stubble; few worms; moist; sharp even boundary.
- 35+ BCg Dark yellowish brown (10 YR 4/4) firm clay loam with many faint very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles becoming distinct with depth; stones as above; moist; massive.

Site No.: 13

Subgroup: stagnogleyic brown earth

Location: High Moorsley Farm, High Moorsley G.R.: 34554610

Altitude: 119m O.D. Slope: 1.5° Aspect: ENE (78°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: moderately well drained

Horizons:

cm

0 - 28	Ap	Very dark greyish brown (10 YR 3/2) friable humose loam; moderately weak medium crumb structure; stony with small stones of shale and Magnesian Limestone and coal traces; debris; rotted roots (turnip); some worms; moist; sharp even boundary.
28 - 55	B1w	Dark brown (10 YR 3/3) firm loam; moderately developed medium subangular blocky structure; stones as above but increasing coal; few fibrous roots; rare worms; moist; merging undulating boundary.
55 - 75	B2w	Dark brown (10 YR 3/3) friable clay loam; moderately strong medium subangular blocky structure; stones as above; few fibrous roots; moist; sharp even boundary.
75+	BCg	Dark-yellowish brown (10 YR 4/4) firm clay loam with many distinct fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 14

Subgroup: cambic stagnogley

Location: Farm at Four Lane Ends, Hetton-le-Hole G.R.: 35044608

Altitude: 118m O.D. Slope: 2.6° Aspect: NE (36°)

Land use: permanent grass Canopy: none Topex: moderately exposed

Vegetation: field grasses

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 1 F Decomposed grass

1 - 18 Ah(g) Very dark greyish brown (2.5 YR 3/2) friable clay loam with common very faint very fine yellowish brown (10 YR 5/6) mottles; moderately developed medium subangular blocky structure; very rare small stones of sandstone and shale with coal traces; abundant fibrous roots; worms; moist; sharp even boundary.

18 - 32 Bg Yellowish brown (10 YR 5/4) firm clay with many distinct fine strong brown (7.5 YR 5/8) and olive grey (5 Y 5/2) mottles; moderately developed fine prismatic structure; stones as above; few fibrous roots; moist; merging even boundary.

32+ BCg Yellowish brown (10 YR 5/6) firm clay loam with many prominent medium strong brown (7.5 YR 5/8) and fine grey (5 Y 5/1) mottles; stones as above but increasing to slightly stony; moist; massive.

Site No.: 15

Group: disturbed soil

Location: Elemore Colliery, Easington Lane G.R.: 35434600

Altitude: 118m O.D. Slope: 4.5° Aspect: NNE (26°)

Land use: derelict pit site Canopy: none Topex: moderately exposed

Vegetation: Festuca rubra; Ranunculus bulbosus; Plantago media

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 17 Very dark greyish brown (2.5 Y 3/2) friable clay loam; variable stones of pit heap coal, sandstone and shale, occasional metamorphic rock; moderately developed medium subangular blocky structure; abundant fibrous roots; moist; sharp even boundary.

17+ Dark brown to brown (7.5 YR 4/4) firm clay loam with many prominent medium strong brown (7.5 YR 5/6) and grey to light grey (5 Y 6/1) mottles; stony, content as above; few roots; moist; massive.

Site No.: 16

Subgroup: typical brown earth

Location: Low Newton Farm, Framwellgate Moor G.R.: 28494560

Altitude: 61m O.D. Slope: 0.8° Aspect: WNW (294°)

Land use: arable (wheat) Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: well drained (free)

Horizons:

cm

0 - 19	Ap	Dark brown (10 YR 3/3) friable loam; moderately developed medium subangular blocky structure; very rare small round and subangular stones of sandstone; rotting stubble and common fibrous roots; moist; narrow even boundary.
19 - 38	B1w	Dark yellowish brown (10 YR 4/4) friable sandy loam; moderately developed medium subangular blocky structure; very rare stones as above; some fibrous roots; small yellow sand lenses less than 3 cm diameter; moist; merging even boundary.
38 - 84	B2w	Dark yellowish brown (10 YR 4/4) friable clay loam becoming sandier with depth; moderately developed medium subangular blocky structure; stones as above; very rare fibrous roots; larger yellower sand lenses 3 - 6 cm diameter; moist; merging boundary.
84+	BC	Yellowish brown (10 YR 5/4) friable sandy loam; moist; single grain.

Site No.: 17

Group: disturbed soil

Location: Old brickworks, Brasside G.R.: 28934550

Altitude: 61m O.D. Slope: 1.7° Aspect: WNW (301°)

Land use: scrub (derelict site) Canopy: none Topex: moderately exposed

Vegetation: Festuca rubra; Chamaenerion angustifolium; Rosa canina

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 1 F Decomposed grasses.

1 - 7 Black (10 YR 2/1) friable humose loam; moderately weak fine granular structure; very stony with sandstone, shale, limestone and coal; abundant fibrous roots; moist; sharp even boundary.

7 - 15 Yellowish brown (10 YR 5/6) firm clay loam with common faint strong brown (7.5 YR 5/6) mottles; moderately developed medium subangular blocky structure; stones as above; common fibrous roots and few woody; very moist; sharp even boundary.

15+ Coal and laminated clay intermixed.

Site No.: 18

Subgroup: cambic stagnohumic gley

Location: Union Hall Farm, Framwellgate Moor G.R.: 29504558

Altitude: 55m O.D. Slope: 0.5° Aspect: S (176°)

Land use: arable (oats) Canopy: present Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 17 Ap Very dark greyish brown (10 YR 3/2) friable humose clay loam; moderately developed fine subangular blocky structure; very stony with medium to large stones of sandstone and coal traces; debris; abundant fibrous roots; worms; slightly moist; narrow undulating boundary.
- 17 - 30 Bg Dark yellowish brown (10 YR 4/4) friable clay loam; with common distinct very fine brown to dark brown (7.5 YR 4/4) mottles; moderately developed fine subangular blocky structure; extremely stony with large to very large stones of sandstone; penetration very difficult; abundant fibrous roots and few woody; slightly moist; merging undulating boundary.
- 30+ BCg Greyish brown (2.5 Y 5/2) firm clay with many prominent medium brownish yellow (10 YR 6/6) and olive grey (5 Y 5/2) mottles; stones as above; slightly moist; massive.

Site No.: 19

Subgroup: gleyic brown alluvial soil

Location: Woodwell House Farm G.R.: 29964547

Land use: deciduous woodland Canopy: present Topex: very sheltered

Vegetation: Quercus robur; Acer pseudoplatanus; crataegus monogyna;

Oxalis acetosella; Festuca rubra

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

1 - 0	L	Litter of oak leaves dominant.
0 - 5	F	Rotted leaves and grasses; even boundary.
5 - 10	H	Dark humus; abundant medium woody roots; even boundary.
10 - 15	Ah	Very dark brown (10 YR 2/2) friable humose loamy sand; moderately weak medium subangular blocky structure; very rare small stones; abundant woody and common fibrous roots; moist; merging even boundary.
15 - 32	B1w	Dark brown (10 YR 4/3) very friable loam; moderately weak medium subangular blocky structure; stones as above; few woody roots; moist; merging even boundary.
32 - 45	B2w	Dark yellowish brown (10 YR 4/4) very friable loam; moderately weak medium subangular blocky structure; stones as above;— few woody roots; moist; sharp even boundary.
45+	Cg	Dark yellowish brown (10 YR 4/4) friable loam with many distinct fine strong brown (7.5 YR 5/8) and olive grey (5 Y 4/2) mottles; moist; single grain.

Site No.: 20

Subgroup: typical brown alluvial soil

Location: Black Wood, Woodwell House Farm G.R.: 30564558

Altitude: 30m O.D. Slope: 0.6° Aspect: ENE (62°)

Land use: permanent grass Canopy: none Topex: very sheltered

Vegetation: Festuca rubra; Trifolium sp.; Taraxacum officinale;

Rhizanthus sp.; Bellis perennis

Site drainage: normal Profile drainage: well drained (free)

Horizons:

cm

1 - 0	L	Undecomposed leaf litter.
0 - 1	F	Decomposed grasses.
1 - 8	Ah	Very dark greyish brown (10 YR 3/2) very friable humose loamy sand; moderately weak very fine granular structure; very rare small stones; common fibrous roots; slightly moist; sharp even boundary.
8 - 14	AB	Dark grey (10 YR 4/1) very friable humose loamy sand; very weak fine subangular blocky structure; stones as above; common fibrous roots; merging even boundary.
14 - 23	B1w	Dark greyish brown (10 YR 4/2) very friable loamy sand; very weak fine subangular blocky structure; stones and roots as above; slightly moist; merging even boundary.
23 - 48	B2w	Very dark greyish brown (10 YR 3/2) very friable sandy loam; very weak fine subangular blocky structure; stones as above; few fibrous roots; slightly moist; merging even boundary.
48+	C	Dark brown (10 YR 3/3) very friable sand; very rare gravel; few fibrous roots; slightly moist; single grain.

Site No.: 21 Subgroup: gleyic brown alluvial soil.
 Location: Low Grange Farm, Belmont G.R.: 31184548
 Altitude: 65m O.D. Slope: 2.3° Aspect: SSW (205°)
 Land use: arable Canopy: none Topex: very sheltered
 Site drainage: normal Profile drainage: moderately well drained

Horizons:

cm

0 - 26	Ap	Very dark grey (10 YR 3/1) friable humose silty clay loam; moderately weak fine subangular blocky structure; stony with small round stones of sandstone, siltstone, mudstone and coal; debris; rotted barley roots and stubble; worms; moist; sharp even boundary.
26 - 43	B1w	Very dark grey (10 YR 3/1) friable clay loam; moderately developed medium angular blocky structure; stony with small round stones as above; common fibrous roots; moist; narrow even boundary.
43 - 70	B2w	Dark greyish brown (10 YR 4/2) friable loam; moderately developed medium subangular blocky structure; slightly stony with sandstone, gravel and coal traces; few fibrous roots; moist; narrow boundary.
70+	BCg	Dark yellowish brown (10 YR 4/4) very friable silty clay loam with distinct common very fine brown to dark brown (7.5 YR 4/4) mottles; moist; massive.

Site No.: 22

Subgroup: stagnogleyic brown earth

Location: Homer House Farm, Rainton Gate G.R.: 31584553

Altitude: 79m O.D. Slope: 2.2° Aspect: WSW (246°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 26	Ap	Very dark grey (10 YR 3/1) friable clay loam; moderately strong medium subangular blocky structure; very strong with small to medium stones of siltstone, sandstone and coal; debris; rotting barley roots and stubble; moist; sharp even boundary.
26 - 40	Bw	Dark brown (10 YR 3/3) friable clay loam; moderately strong medium subangular blocky structure; slightly stony with small stones of sandstone and coal traces; few fibrous roots; moist; merging undulating boundary.
40+	BCg	Reddish brown (2.5 YR 5/4) firm silty clay loam with prominent fine strong brown (7.5 YR 5/8) and olive grey (5 Y 5/2) mottles becoming greyer with depth; sandstone and coal traces; moist; massive.

Site No.: 23

Group: disturbed soil

Location: Homer House Farm (near disused railway line) G.R.: 32004550

Altitude: 91m O.D. Slope: 0.6° Aspect: E (107°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 25 Ap Black (10 YR 2/1) gritty friable humose silty loam; moderately weak fine subangular blocky structure; very stony with gravel and small stones of coal, shale and sandstone; abundant fibrous roots; slightly moist; sharp even boundary.
- 25 - 39 Very dark grey (10 YR 3/1) firm gritty silty loam; moderately weak coarse angular blocky structure; stones as above; few fibrous roots; slightly moist; merging undulating boundary.
- 39 - 70 Dark brown (10 YR 3/3) firm gritty loam with common distinct very fine yellowish brown (10 YR 5/6) mottles; moderately strong coarse angular blocky structure; stones as above; few woody roots; very moist; merging undulating boundary.
- 70+ - Upper Wear Clay and coal intermixed.

Site No.: 24

Subgroup: cambic stagnogley

Location: Field House Farm, Rainton Gate G.R.: 32534553

Altitude: 87m O.D. Slope: 7.0° Aspect: E (85°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: receiving Profile drainage: poor

Horizons:

cm

- 0 - 29 Ap Dark brown (10 YR 3/3) friable clay loam; moderately developed coarse subangular blocky structure; slightly stony with small stones of sandstone and metamorphic rock; rotted grasses; worms; moist; sharp even boundary.
- 29 - 39 B1g Very dark grey (10 YR 3/1) friable clay loam with many prominent strong brown (7.5 YR 5/6) mottles; moderately developed coarse subangular blocky structure; stones as above with coal traces; worms; moister than above; merging undulating boundary.
- 39 - 53 B2g Very dark greyish brown (10 YR 3/2) friable clay loam with many prominent strong brown (7.5 YR 5/6) mottles; moderately developed coarse subangular blocky structure; stones as above; worms; moist; merging undulating boundary.
- 53+ BCg Dark yellowish brown (10 YR 3/4) friable clay loam with many prominent strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; worms; very moist; massive.

Site No.: 25

Subgroup: cambic stagnogley

Location: High Moorsley Farm, High Moorsley G.R.: 33104552

Altitude: 106m O.D. Slope: 0.9° Aspect: WNW (293°)

Land use: arable (wheat) Canopy: none Topex: moderately exposed

Site drainage: receiving Profile drainage: poor

Horizons:

cm

- 0 - 23 Ap Dark yellowish brown (10 YR 3/4) friable loam; moderately developed coarse subangular blocky structure; stony with small stones of sandstone, shale and coal traces; abundant fibrous roots; slightly moist; sharp even boundary.
- 23 - 38 Bg Very dark grey (10 YR 3/1) friable loam with many distinct fine reddish brown (5 YR 4/3) mottles; moderately weak medium subangular blocky structure; stones as above; few roots; slightly moist; narrow merging boundary.
- 38+ BCg Dark yellowish brown (10 YR 4/4) firm loam with common faint extremely fine reddish brown (5 YR 4/3) mottles; stones as above but in greater quantity; few roots; slightly moist; massive.

Site No.: 26

Subgroup: stagnogleyic brown earth

Location: High Moorsley Farm, High Moorsley G.R.: 33514554

Altitude: 155m O.D. Slope: 2.9° Aspect: WNW (305°)

Land use: arable Canopy: none Topex: very exposed

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

- 0 - 27 Ap/B Dark grey (10 YR 4/1) friable clay loam; moderately developed medium subangular blocky structure; stony with subangular and round stones of Magnesian Limestone, shale, sandstone, metamorphic rock and coal traces; rotted barley stubble; debris; many worms; moist; sharp even boundary.
- 27+ BCg Yellowish brown (10 YR 5/4) friable clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; few roots; few worms; moist; massive.

Site No.: 27

Subgroup: stagnogleyic brown earth

Location: High Moorsley Farm, High Moorsley G.R.: 33994551

Altitude: 160m O.D. Slope: 3.1° Aspect: ENE (63°)

Land use: arable Canopy: none Topex: severely exposed

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

- 0 - 33 Ap Very dark grey (10 YR 3/1) friable clay loam; moderately developed coarse subangular blocky structure; stony with small stones of shale, sandstone, Magnesian Limestone and metamorphic rock and coal traces; moist; sharp even boundary.
- 33+ BCg Dark yellowish brown (10 YR 4/4) clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; very stony as above; moist; massive.

Site No.: 28

Subgroup: cambic stagnogley

Location: High Moorsley Farm, High Moorsley G.R.: 34424555

Altitude: 142m O.D. Slope: 3.1° Aspect: N (355°)

Land use: arable (wheat) Canopy: none Topex: very exposed

Site drainage: receiving Profile drainage: poor

Horizons

cm

0 - 27	Ap	Dark grey (10 YR 4/1) friable clay loam; moderately developed medium subangular blocky structure; stony with small stones of Magnesian Limestone, sandstone, shale and metamorphic rock and coal traces; fibrous roots; worms; moist; sharp even boundary.
27 - 43	Bg	Dark yellowish brown (10 YR 4/4) friable clay loam with common faint extremely fine strong brown (7.5 YR 5/6) mottles; moderately developed medium subangular blocky structure; stones as above but rare large rounded sandstone also; worms; moist; sharp even boundary.
43+	BCg	Reddish brown (2.5 Y 4/4) very firm clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; rotted limestone; <u>very</u> moist; seepage to pit bottom; massive.

Site No.: 29

Subgroup: cambic stagnogley

Location: Hetton-le-Hole Farm G.R.: 34804530

Altitude: 137m O.D. Slope: 3.6° Aspect: SSW (197°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 26	Ap	Dark grey (10 YR 4/1) friable loam; moderately developed medium subangular blocky structure; slightly stony with small stones of sandstone, siltstone, Magnesian Limestone and metamorphic rock and coal; rotted grass roots; worms; moist; sharp even boundary.
26 - 34	Bg	Olive brown (2.5 Y 4/4) friable clay loam with many distinct fine strong brown mottles (7.5 YR 5/6); moderately developed medium subangular blocky structure; few roots; stones as above; moist to very moist; merging undulating boundary.
34+	BCg	Light olive brown (2.5 Y 5/4) firm clay with many prominent fine olive grey (5 Y 5/2) and a strong brown (7.5 YR 5/6) mottles; stones as above; very moist; seepage at boundary with Bg; massive.
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Site No.: 30

Subgroup: cambic stagnogley

Location: Low Newton Farm, Framwellgate Moor G.R.: 28644506

Altitude: 67m O.D. Slope: 2.3° Aspect: ENE (65°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 26 Ap/B Very dark grey (10 YR 3/1) firm clay loam; moderately developed medium subangular blocky structure; very rare stones of sandstone, shale, metamorphic rock and coal; rotting barley stubble; moist; sharp even boundary.
- 26+ BCg Yellowish brown (10 YR 5/6) firm sandy clay with many prominent strong brown (7.5 YR 5/6) and fine grey to light grey (5 Y 6/1) mottles; slightly stony with stones as above; few roots; very moist; very fine root channels; massive.
- - - - -

Site No.: 31

Subgroup: cambic stagnohumic gley

Location: Frankland Wood, Brasside G.R.: 29514499

Altitude: 38m O.D. Slope: 8.5° Aspect: E (85°)

Land use: mixed woodland Canopy: present Topex: very sheltered

Vegetation: Pteridium aquilinum; Chamaenerion augustifolium;

Quercus robur; Picea sitchensis

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 11	Oh	Black (10 YR 2/1) very friable humose loam; very weak very fine crumb structure; very rare stones of sandstone; abundant fibrous and few woody roots; worms; very moist; narrow even boundary.
11 - 21	ABg	Yellowish brown (10 YR 5/4) friable silty clay loam with humus staining in the top cm; common faint very fine yellowish brown (10 YR 5/8) mottles; moderately developed fine prismatic structure; stones as above; few fibrous and woody roots; moist; merging even boundary.
21 - 36	B1g	Yellowish brown (10 YR 5/4) firm silty clay loam with common distinct very fine yellowish brown (10 YR 5/8) and greyish brown (2.5 Y 5/2) mottles; moderately developed fine prismatic structure; stones as above; few fibrous and woody roots; merging even boundary.
36 - 70	B2g	Yellowish brown (10 YR 5/4) firm clay loam with many prominent fine yellowish brown (10 YR 5/6) and grey (5 Y 5/1) mottles; moderately developed medium prismatic structure; stones as above; few fibrous and woody roots; moist; merging boundary.
70+	BCg	Yellowish brown (10 YR 5/6) firm clay loam with many prominent yellowish brown (10 YR 5/6) and grey (5 Y 5/1) mottles; moist; massive.

Site No.: 32

Subgroup: cambic stagnogley

Location: Low Grange Farm, Belmont G.R.: 30004498

Altitude: 58m O.D. Slope: 2.3° Aspect: NNW (28°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 1	F	Decomposed grasses.
1 - 7	Ab(g)	Very dark grey (10 YR 3/1) friable humose silty loam with very faint rusty mottles; moderately developed fine granular structure; very rare stones of coal and sandstone; abundant fibrous roots; worms; slightly moist; merging even boundary.
7 - 29	AB(g)	Very dark greyish brown (10 YR 3/2) friable humose silty loam with common faint very fine yellowish brown (10 YR 5/6) mottles; moderately developed medium granular structure; slightly stony with large sandstone; common fibrous roots; slightly moist; merging even boundary.
29 - 63	B1g	Dark yellowish brown (10 YR 4/4) firm silty clay loam with common faint fine yellowish brown (10 YR 5/6) mottles; moderately strong coarse angular blocky structure; stones as above; few fibrous roots; slightly moist.
63+	BCg	Yellowish brown (10 YR 5/6) firm silty clay loam with many distinct fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; moist; massive.

Site No.: 33 Subgroup: typical (non-calcareous) alluvial gley
 Location: Grange Wood, Low Grange Farm, Belmont G.R.: 30574512
 Altitude: 49m O.D. Slope: 17.2° Aspect: N (357°)
 Land use: deciduous woodland Canopy: present Topex: very sheltered
 Vegetation: Rubus sp.; Chamaenerion angustifolium; acer pseudoplatanus;
Alnus glutinosa; Crataegus monogyna
 Site drainage: normal Profile drainage: poor

Horizons:

cm

2 - 0	L	Leaf litter.
0 - 3	F	Decomposed litter.
3 - 9	Ah(g)	Very dark grey (10 YR 3/1) friable humose silty clay loam with common very faint rusty mottles; moderately developed fine subangular blocky structure; very rare stones of sandstone and coal; abundant fibrous and common woody roots; worms; very moist; merging undulating boundary.
9 - 20	B1(g)	Dark brown (10 YR 3/3) firm silty clay with mottles as above; moderately developed medium subangular blocky structure; small sandstone fragments; common fibrous and woody roots; very moist; merging undulating boundary.
20 - 43 -	B2(g)	Strong brown (7.5 YR 5/6) firm silty clay with common faint very fine strong brown (7.5 YR 5/6) mottles; moderately developed medium prismatic structure; stones as above; few woody roots; worms; very moist; merging undulating boundary.
43+	BCg	Dark yellowish brown (10 YR 4/4) firm silty clay with many distinct fine strong brown (7.5 YR 5/6) and very fine light grey to grey (N6/-) mottles; coal and sandstone traces; rare woody roots; worms; very moist; massive.

Site No.: 34

Subgroup: cambic stagnogley

Location: Low Grange Farm, Belmont G.R.: 30994494

Altitude: 67m O.D. Slope: 1.2° Aspect: WNW (296°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 1 F Decomposed grasses.

1 - 10 Ah Very dark grey (10 YR 3/1) friable humose silty loam; moderately developed coarse granular structure; coal traces; abundant fibrous roots; worms; slightly moist; narrow merging boundary.

10 - 29 Bg Very dark greyish brown (10 YR 3/2) friable humose silty loam with common distinct brown to dark brown (7.5 YR 4/4) mottles; moderately developed medium subangular blocky structure; coal traces with quartz pebble; few fibrous roots; narrow even boundary.

29+ BCg Yellowish brown (10 YR 5/4) firm clay with many prominent large strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; shale, coal and sandstone traces; few fibrous roots; moist; massive.

Site No.: 35

Subgroup: cambic stagnohumic gley

Location: The Rift Farm, Belmont G.R.: 31434497

Altitude: 76m O.D. Slope: 2.9° Aspect: WNW (298°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: receiving Profile drainage: poor

Horizons:

cm

0 - 29	Ap	Very dark grey (10 YR 3/1) friable loam; moderately developed medium subangular blocky structure; slightly stony with small stones of sandstone, shale, metamorphic rock and coal; debris; rotted barley roots; moist; sharp even boundary.
29 - 37	Bg	Yellowish brown (10 YR 5/4) firm clay loam with common large prominent dark brown to brown (7.5 YR 4/4) and dark grey (5 Y 4/1) mottles; moderately developed fine angular blocky structure; very rare stones; worms; moist; merging undulating boundary.
37 - 51	BC1g	Yellowish brown (10 YR 5/4) very friable sandy loam with common distinct fine dark brown to brown (7.5 YR 4/4) and dark grey (5 Y 4/1) mottles; moderately developed medium subangular blocky structure; stones as above; moist; <u>single grain</u> ; <u>merging even boundary</u> .
51+	BC2g	Yellowish brown (10 YR 5/4) very friable sandy loam with common prominent fine yellowish brown (10 YR 5/6) and greyish brown (2.5 Y 5/2) mottles; stones as above; moist; single grain.

Site No.: 36

Subgroup: stagnogleyic brown earth

Location: Rift Farm, Belmont G.R.: 32034497

Altitude: 91m O.D. Slope: 1.5° Aspect: E (92°)

Land use: arable Canopy: none Topex: very sheltered

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 29	Ap	Very dark grey (10 YR 3/1) friable humose loam; moderately weak medium crumb structure; slightly stony with small stones of sandstone, shale, Magnesian Limestone and coal; debris; rotted barley roots; moist; merging even boundary.
29 - 35	AB	Dark brown (10 YR 3/3) friable loam; moderately developed medium subangular blocky structure; stones as above; moist; merging undulating boundary.
35 - 40	Bw	Dark yellowish brown (10 YR 3/4) friable loam; moderately developed medium subangular blocky structure; stones as above; moist; sharp undulating boundary.
40+	BCg	Yellowish brown (10 YR 5/6) very firm clay loam
-	-	with many prominent large yellowish brown (10 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 37

Group: disturbed soil

Location: Pittington Farm, Pittington G.R.: 32504493

Altitude: 79m O.D. Slope: 0.5° Aspect: E (92°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: well drained (free)

Horizons:

cm

0 - 33 Ap Dark brown (10 YR 3/3) friable loam; moderately weak medium crumb structure; very stony with fragments of sandstone and limestone; debris; rotted barley stubble; moist; merging undulating boundary.

33 - 61 Dark yellowish brown (10 YR 3/4) friable sandy loam; moderately weak medium angular blocky structure; rare stones; moist; sharp even boundary.

61+ Dark yellowish brown (10 YR 3/4) friable loamy sand; rare rounded stones; moist; structureless.

Site No.: 38

Subgroup: cambic stagnogley

Location: Pittington Farm, Pittington G.R.: 33014501

Altitude: 104m O.D. Slope: 1.9° Aspect: W (266°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 1	F	Decomposed grasses.
1 - 11	Ah	Very dark greyish brown (10 YR 3/2) friable humose clay loam; moderately weak medium subangular blocky structure; slightly stony with small stones of sandstone and coal traces; abundant fibrous roots; worms; moist; merging undulating boundary.
11 - 25	AB	Dark brown (10 YR 3/3) friable clay loam; moderately developed coarse subangular blocky structure; stones as above; common fibrous roots; worms; moist; merging undulating boundary.
25 - 31	Bg	Dark brown (10 YR 3/3) firm clay loam with many prominent fine yellowish brown (10 YR 5/6) and olive grey (5 Y 5/2) mottles; moderately developed coarse subangular blocky structure; stony with small stones of sandstone and coal; common fibrous roots; moist; merging undulating boundary.
31+	BCg	Dark yellowish brown (10 YR 4/4) very firm clay loam with many prominent medium yellowish brown (10 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; common fibrous roots; moist; massive.

Site No.: 39

Subgroup: stagnogleyic brown earth

Location: Hillside Farm, Pittington G.R.: 33524490

Altitude: 152m O.D. Slope: 4.6° Aspect: NW (314°)

Land use: arable (wheat) Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: moderately well drained

Horizons:

cm

0 - 24	Ap	Very dark greyish brown (10 YR 3/2) friable clay loam; moderately developed medium subangular blocky structure; slightly stony with small subangular stones of limestone and rounded metamorphic rock; abundant wheat roots; few worms; moist; sharp even boundary.
24 - 33	B1w	Dark brown (10 YR 3/3) friable clay loam; moderately developed medium subangular blocky structure; stones as above; very few roots; moist; merging even boundary.
33 - 65	B2w	Dark brown (10 YR 4/3) friable clay loam; moderately developed coarse subangular blocky structure; stones as above; moist; sharp boundary.
65+	BCg	Dark yellowish brown (10 YR 4/4) firm clay loam with many distinct fine strong brown (7.5 YR 5/2) and olive grey (5 Y 5/2) mottles; moist; massive.

Site No.: 40

Subgroup: brown (non-humic rendzina)

Location: Hillside Farm, Pittington G.R.: 33894493

Altitude: 137m O.D. Slope: 5.0° Aspect: SSE (164°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: shedding Profile drainage: well drained (excessive)

Horizons:

cm

0 - 15	Ap	Dark brown (10 YR 3/3) firm clay loam; moderately developed medium subangular blocky structure; extremely stony with Magnesian Limestone fragments, rare coal traces and metamorphic stones; rotting barley roots; some worms; moist; narrow undulating boundary.
15 - 20	Ap/C	Dark yellowish brown (10 YR 3/4) firm clay loam; moderately developed medium subangular blocky structure; extremely stony; small to large Magnesian Limestone fragments; moist; sharp even boundary.
20+	C	Pale yellow (2.5 Y 8/4) fragmented Magnesian Limestone with some dark yellowish brown (10 YR 4/4) very firm silty clay loam between limestone fragments.
- - - - -

Site No.: 41

Subgroup: brown (non-humic) rendzina

Location: Hillside Farm, Pittington G.R.: 34474500

Altitude: 128m O.D. Slope: 7.5° Aspect: SSE (166°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: shedding Profile drainage: well drained (excessive)

Horizons:

cm

0 - 21	Ap	Dark brown (10 YR 3/3) firm silty clay loam; moderately developed medium crumb structure; abundant Magnesian Limestone fragments; worms; moist; narrow undulating boundary.
21+	C	Pale yellow fragmented Magnesian Limestone (2.5 Y 8/4) with some dark yellowish brown (10 YR 4/4) firm silty clay loam between limestone fragments.

Site No.: 42

Subgroup: typical brown calcareous earth

Location: Elemore Wood G.R.: 35084491

Altitude: 130m O.D. Slope: 7.1° Aspect: SW (231°)

Land use: mixed N.C.B. plantation Canopy: present Topex: moderately sheltered

Vegetation: Festuca rubra; Acer pseudoplatanus (@ 5 years);

Pinus sylvestris (3-10 years); Larix decidua;

Crataegus monogyna

Site drainage: shedding Profile drainage: well drained (free)

Horizons:

cm

0 - 1 F Half decomposed grasses.

0 - 16 Ah Very dark greyish brown (10 YR 3/2) friable humose silty loam; moderately developed coarse subangular blocky structure; stony with Magnesian Limestone fragments; abundant fibrous roots; slightly moist; narrow undulating boundary.

16 - 46 Bw Dark yellowish brown (10 YR 4/4) firm clay loam; moderately developed medium subangular blocky structure; very stony with Magnesian Limestone fragments; common fibrous roots, few woody; moist; sharp irregular boundary.

46+ C Pale yellow (2.5 Y 9/4) fragmented Magnesian Limestone.

Site No.: 43

Subgroup: stagnogleyic brown earth

Location: Hetton-le-Hole Farm G.R.: 35534493

Altitude: 137m O.D. Slope: 2.8° Aspect: E (109°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 30	Ap	Very dark greyish brown (10 YR 3/2) friable clay loam; moderately developed medium subangular blocky structure; slightly stony with shale, sandstone and Magnesian Limestone and coal traces; rotting barley stalks and few fibrous roots; rare worms; moist; sharp even boundary.
30 - 40	Bw	Dark yellowish brown (10 YR 3/4) friable clay loam; moderately developed medium subangular blocky structure; slightly stony with shale, sandstone and Magnesian Limestone and coal traces; rare roots; moist; merging undulating boundary.
40+	BCg	Dark yellowish brown (10 YR 4/4) clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; slightly stony as above; moist; massive.

Site No.: 44

Subgroup: stagnogleyic brown earth

Location: Hetton le Hill Farm, Pitlington G.R.: 35934508

Altitude: 126m O.D. Slope: 0.8° Aspect: NE (50°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 27	Ap	Dark grey (10 YR 4/1) friable clay loam; moderately developed medium crumb structure; slightly stony with small stones of sandstone, shale, metamorphic rock and coal; rotted grass; moist; sharp even boundary.
27 - 35	Bw	Dark yellowish brown (10 YR 3/4) friable clay loam; moderately developed medium subangular blocky structure; stones as above; moist; merging undulating boundary.
35+	BCg	Yellowish brown (10 YR 5/4) firm clay loam with many distinct strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 45

Subgroup: cambic stagnogley

Location: Frankland Park Farm, Framwellgate Moor G.R.: 28574468

Altitude: 66m O.D. Slope: 3.7° Aspect: SW (235°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 18 Ah(g) Dark greyish brown (10 YR 4/2) firm clay loam with common faint very fine strong brown (7.5 YR 5/6) mottles; moderately developed coarse subangular blocky structure; very rare stones of sandstone, shale and coal traces; abundant fibrous roots; worms; moist; merging even boundary.
- 18 - 32 B(g) Dark brown (10 YR 4/3) firm clay loam with common faint fine strong brown (7.5 YR 5/6) mottles; stones as above; common fibrous roots; worms; moderately developed coarse subangular blocky structure; moist; merging even boundary.
- 32+ BCg Yellowish brown (10 YR 5/6) firm clay with many distinct fine strong brown (7.5 YR 5/8) and very fine grey to light grey (5 Y 6/1) mottles; slightly stony with small rounded sandstone; moist; massive.

Site No.: 46

Subgroup: cambic stagnohumic gley

Location: Frankland Park Farm, Framwellgate Moor G.R.: 29074952

Altitude: 49m O.D. Slope: 8.2° Aspect: E (80°)

Land use: arable (potatoes) Canopy: none Topex: very sheltered

Site drainage: receiving Profile drainage: poor

Horizons:

cm

- 0 - 18 Apg/Bg Dark greyish brown (10 YR 4/2) friable humose silty clay loam with common faint brown to dark brown (7.5 YR 4/4) mottles; moderately developed coarse subangular blocky structure; very rare small or very occasionally large stones of sandstone, shale and coal; debris; abundant fibrous roots; worms; sharp even boundary.
- 18 - 24 Bg Dark brown (10 YR 3/3) friable silty clay with many faint fine brown to dark brown (7.5 YR 4/4) mottles; strong medium prismatic structure; stones as above; worms; moist; intractable; merging even boundary.
- 24+ BCg Dark yellowish brown (10 YR 4/4) firm silty clay loam with many prominent fine brown to dark brown (7.5 YR 4/4) and grey (5 Y 5/1) mottles; stones as above but large round spheroidal ironstone and limestone fragments --- also; greyer with depth; moist; massive.

Site No.: 47

Subgroup: cambic stagnohumic gley

Location: Low Grange Farm, Belmont G.R.: 29584452

Altitude: 61m O.D. Slope: 6.3° Aspect: SSE (163°)

Land use: grass ley Canopy: none Topex: moderately sheltered

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 22	Ap	Dark greyish brown (10 YR 4/2) firm humose silty clay loam; moderately developed coarse angular blocky structure; very stony with small to medium stones of sandstone, shale and coal traces; debris; abundant fibrous roots; worms; slightly moist; sharp even boundary.
22 - 31	B1g	Dark brown (10 YR 3/3) firm clay with many distinct extremely fine strong brown (7.5 YR 5/6) mottles; moderately developed coarse angular blocky structure; stony with stones as above; common fibrous roots; slightly moist; merging even boundary.
31 - 38	B2g	Dark brown (10 YR 3/3) firm silty clay with many prominent medium strong brown (7.5 YR 5/6) and distinct olive grey (5 Y 5/2) mottles; moderately developed coarse angular blocky structure; very stony with stones as above; few fibrous roots; worms; slightly moist; merging even boundary.
38 - 71	B3g	Dark yellowish brown (10 YR 4/4) firm to very firm clay with many prominent medium strong brown (7.5 YR 5/6) and faint greyish brown (2.5 Y 5/2) mottles; moderately developed coarse angular blocky structure; very stony with stones as above; few fibrous roots; slightly moist; merging boundary.
71+	BCg	Yellowish brown (10 YR 5/6) very firm clay with many prominent medium strong brown (7.5 YR 5/6) and greyish brown (2.5 Y 5/2) mottles; moist; massive.

Site No.: 48

Subgroup: cambic stagnogley

Location: Low Grange Farm, Belmont G.R.: 29934452

Altitude: 64m O.D. Slope: 4.2° Aspect: NE (37°)

Land use: grass ley Canopy: none Topex: moderately sheltered

Vegetation: field grasses and clover

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 20 Ap(g) Dark greyish brown (10 YR 4/2) firm silty clay loam with common very faint very fine rusty mottles; moderately developed coarse angular blocky structure; very stony with small to medium stones of sandstone, shale and coal traces; abundant fibrous roots; worms; slightly moist; sharp even boundary.
- 20 - 29 Blg Dark brown (10 YR 3/3) firm clay with common faint fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse angular blocky structure; stony with stones as above; common roots; slightly moist; merging even boundary.
- 29 - 39 B2g Dark brown (10 YR 3/3) firm clay with many distinct fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse angular blocky structure; very rare stones as above; few fibrous roots; moist; merging even boundary.
- 39 - 71 B3g Dark yellowish brown (10 YR 4/4) firm silty clay with many distinct very fine strong brown (7.5 YR 5/6) and faint greyish brown (2.5 Y 5/2) mottles; moderately developed coarse angular blocky structure; stones as B2g; moist; iron staining; merging boundary.
- 71+ BCg Yellowish brown (10 YR 5/6) firm silty clay with many prominent fine strong brown (7.5 YR 5/6) and greyish brown (2.5 Y 5/2) mottles; moist; massive.

Site No.: 49

Subgroup: cambic stagnohumic gley

Location: Low Grange Farm, Belmont G.R.: 30614449

Altitude: 69m O.D. Slope: 0.6° Aspect: WNW (283°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 2 F Decomposed grasses.

2 - 28 Ahg Very dark grey (10 YR 3/2) very friable humose silty loam; moderately weak fine granular structure; very rare stones of sandstone and coal; abundant fibrous roots; worms; moist; sharp even boundary.

28 - 41 B1g Dark brown (10 YR 4/3) firm silty clay with common faint very fine dark yellowish brown (10 YR 4/4) mottles; moderately strong medium prismatic structure; stones as above; common fibrous roots; worms; moist; merging even boundary.

41 - 73 B2g Yellowish brown (10 YR 5/4) firm silty clay with many distinct very fine yellowish brown (10 YR 5/6) mottles; moderately strong coarse subangular blocky structure; stones as above; few fibrous roots; moist; merging boundary.

73+ BCg Yellowish brown (10 YR 5/6) firm silty clay with many distinct fine yellowish brown (10 YR 5/4) and olive grey (5 Y 5/2) mottles; moist; massive.

Site No.: 50

Subgroup: cambic stagnogley

Location: Ramside Hall, Belmont G.R.: 31074465

Altitude: 70m O.D. Slope: 1.4° Aspect: WSW (255°)

Land use: permanent grass Canopy: present Topex: moderately sheltered

Vegetation: Festuca rubra; Veronica persica

Site drainage: normal Profile drinage: poor

Horizons:

cm

0 - 8	Ahg	Very dark greyish brown (10 YR 3/2) friable clay loam with common faint very fine dark brown to brown (7.5 YR 4/4) mottles; moderately developed medium granular structure; clay movement down root channels; very rare stones of sandstone and shale and coal traces; abundant fibrous roots; worms; very moist; merging even boundary.
8 - 20	B1g	Very dark greyish brown (10 YR 3/2) friable clay with common distinct very fine strong brown (7.5 YR 5/6) mottles; moderately developed medium subangular blocky structure; clay movement down root channels; stones as above; worms; common fibrous roots; very moist; merging even boundary.
20 - 36	B2g	Dark brown (10 YR 3/3) firm clay with common distinct very fine dark brown to brown (7.5 YR 4/4) mottles; moderately developed medium prismatic structure; stones as above; few roots; worms; very moist; merging even boundary.
36+	BCg	Yellowish brown (10 YR 5/4) very firm clay with many prominent fine dark brown to brown (7.5 YR 4/4) and fine olive grey (5 Y 5/2) mottles; stones as above; few roots; worms; very moist; massive.

Site No.: 51

Subgroup: cambic stagnohumic gley

Location: Rift Farm, Belmont G.R.: 32034497

Altitude: 89m O.D. Slope: 2.4° Aspect: WNW (302°)

Land use: grass ley Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 33 Ap(g) Very dark greyish brown (10 YR 3/2) friable humose silty loam with very faint yellowish brown (10 YR 5/8) mottles; moderately developed medium crumb structure; slightly stony with small stones of shale; abundant roots of grass and clover; worms; moist; sharp even boundary.
- 33 - 66 Bg Dark yellowish brown (10 YR 4/4) firm loam with faint yellowish brown (10 YR 5/8) mottles; moderately developed subangular blocky structure; sandstone and shale traces; few woody roots; moist; merging boundary.
- 66+ BCg Yellowish brown (10 YR 5/6) firm clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; few woody roots; moister than above horizons; massive.
-

Site No.: 52

Subgroup: stagnogleyic brown earth

Location: Pittington Farm, Pittington G.R.: 31944456

Altitude: 85m O.D. Slope: 1.4° Aspect: E (101°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 29	Ap	Very dark greyish brown (10 YR 3/2) friable loam; moderately weak medium subangular blocky structure; slightly stony with small stones of sandstone, shale and coal; debris; rotting potatoes/roots; moist; sharp even boundary.
29+	BCg	Yellowish brown (10 YR 5/4) firm clay loam with many prominent medium strong brown (7.5 YR 5/8) and olive grey (5 Y 5/2) mottles; slightly stony with small stones of sandstone; moist; massive.

Site No.: 53

Subgroup: stagnogleyic brown earth

Location: Pittington Farm, Pittington G.R.: 32464440

Altitude: 87m O.D. Slope: 2.9° Aspect: WNW (303°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: imperfect

Horizons

cm

- 0 - 29 Ap/B Very dark greyish brown (10 YR 3/2) friable humose loam; moderately developed medium subangular blocky structure; stony with small stones of sandstone, limestone, metamorphic rock and coal; rotted barley roots; debris; worms; moist; sharp even boundary.
- 29+ BCg Dark yellowish brown (10 YR 4/4) firm loam with many prominent fine yellowish brown (10 YR 5/6) and grey (5 Y 5/1) mottles; very stony with small stones of sandstone and coal; moist; worms; massive.

Site No.: 54

Subgroup: typical brown calcareous earth

Location: Pittington Farm, Pittington G.R.: 33024452

Altitude: 122m O.D. Slope: 8.1° Aspect: WSW (242°)

Land use: permanent grass Canopy: none Topex: moderately sheltered

Vegetation: field grasses

Site drainage: shedding Profile drainage: well drained (free)

Horizons

cm

0 - 1	F	Decomposed grasses.
1 - 23	Ah	Very dark grey (10 YR 3/1) friable humose silty clay loam; moderately developed medium subangular blocky structure; stony with small stones of sandstone, shale, limestone, and metamorphic rock and coal traces; abundant fibrous roots; worms; moist; merging undulating boundary.
23 - 46	Bw	Very dark greyish brown (10 YR 3/2) humose silty clay loam; moderately developed medium subangular blocky structure; stones as above increasing down horizons; few fibrous roots; moist; sharp even boundary.
46+	C	Pale yellow (2.5 Y 8/4) fragmented Magnesian Limestone.

Site No.: 55 Subgroup: typical brown calcareous earth
 Location: Hillside Farm, Pittington G.R.: 33614459
 Altitude: 130 O.D. Slope: 12.8° Aspect: SSE (156°)
 Land use: permanent grass Canopy: none Topex: very sheltered
 Vegetation: field grasses
 Site drainage: shedding Profile drainage: well drained (free)

Horizons:

cm

0 - 10	Ah	Very dark grey (10 YR 3/1) very friable loam; moderately developed medium granular structure; stony with limestone fragments; abundant fibrous roots; worms; moist; narrow undulating boundary.
10 - 32	B1w	Dark brown (10 YR 3/3) friable clay loam; moderately developed medium subangular blocky structure; few fibrous roots; stony with Magnesian Limestone fragments and coal traces; worms; moist; narrow even boundary.
32 - 50	B2w	Dark yellowish brown (10 YR 3/4) friable clay loam; moderately developed medium subangular blocky structure; stones as above; few fibrous and woody roots; moist; sharp even boundary.
50+	C	Pale yellow (2.5 Y 8/4) fragmented Magnesian Limestone.

Site No.: 56

Subgroup: stagnogleyic brown earth

Location: Hillside Farm, Pittington G.R.: 33994446

Altitude: 93m O.D. Slope: 8.4° Aspect: SSW (195°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: normal **Profile drainage:** imperfect

Horizons:

CM

0 - 30 Ap Very dark greyish brown (10 YR 3/2) firm humose silty loam; moderately developed medium subangular blocky structure; slightly stony with small stones of sandstone; debris; barley stubble; moist; sharp even boundary.

30 - 58 Bw Dark greyish brown (10 YR 4/2) very firm clay loam; moderately developed coarse subangular blocky structure; slightly stony with small stones of sandstone, shale and coal; few fibrous roots; moist; sharp even boundary.

58+ BCg Dark greyish brown (2.5 Y 4/2) very firm silty clay loam with many distinct fine yellowish brown (10 YR 5/6) and dark grey (5 Y 4/1) mottles; stones as above; very moist; massive.

Site No.: 57

Subgroup: cambic stagnogley

Location: Hillside Farm, Pittington G.R.: 34504450

Altitude: 101m O.D. Slope: 1.6° Aspect: WSW (238°)

Land use: arable Canopy: none Topex: moderately sheltered

Site drainage: receiving Profile drainage: poor

Horizons:

cm

- 0 - 34 Ap(g) Very dark grey (10 YR 3/1) firm clay loam with rare ochreous mottles; moderately developed coarse subangular blocky structure; very rare stones of sandstone and coal; rotting barley stubble; common worms; wet; water seepage; sharp even boundary.
- 34 - 47 Bg Dark brown (10 YR 3/3) firm clay loam with common faint extra fine brown to dark brown (7.5 YR 4/4) mottles; moderately developed coarse subangular blocky structure; stony with small stones of sandstone, shale and coal; few barley roots; very wet; sharp even boundary.
- 47+ BCg Olive (5 Y 4/3) firm sandy clay loam with many prominent medium yellowish brown (10 YR 5/6) and dark grey (5 Y 4/1) mottles; common large sandstone stones, also coal and shale; very wet with puddle in pit bottom; massive.

Site No.: 58

Group: disturbed soil

Location: Elemore Hall, Pittington G.R.: 34994450

Altitude: 112m O.D. Slope: 0.9° Aspect: WSW (259°)

Land use: N.C.B. plantation Canopy: present Topex: moderately sheltered

Vegetation: Festuca rubra; Picea sitchensis

Site drainage: normal Profile drainage: well drained (free)

Horizons:

cm

0 - 1 Decomposed grasses.

1 - 14 Dark brown (10 YR 3/3) firm loam; moderately developed coarse subangular blocky structure; very rare stones; abundant fibrous roots; very moist; narrow undulating boundary.

14 - 66 Brown (7.5 YR 4/4) firm loam; moderately developed coarse subangular blocky structure; rare stones of Magnesian Limestone and brick traces; few roots; very moist; even boundary.

65+ Brown (7.5 YR 5/4) friable sandy loam; very rare stones; moist; single grain.

Site No.: 59

Subgroup: stagnogleyic brown earth

Location: Hetton le Hill Farm, Pitlington G.R.: 3543446I

Altitude: 137m O.D. Slope: 0.7° Aspect: SSW (210°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 27	Ap	Very dark greyish brown (10 YR 3/2) friable clay loam; moderately developed medium crumb structure; slightly stony with small stones of sandstone, shale limestone and coal traces; rotted barley stubble; rare worms; moist; sharp even boundary.
27 - 35	Bw	Dark yellowish brown (10 YR 3/4) friable clay loam; moderately developed medium subangular blocky structure; stones as above; rare worms; moist; merging undulating boundary.
35+	BCg	Dark yellowish brown (10 YR 4/4) firm clay loam with many faint fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles, passing to distinct mottles with depth; stones as above; worms; moist; massive.

Site No.: 60

Subgroup: stagnogleyic brown earth

Location: Immediately east of Elemore Wood G.R.: 36004450

Altitude: 126m O.D. Slope: 2.9° Aspect: SE (146°)

Land use: permanent grass Canopy: none Topex: moderately exposed

Vegetation: field grasses

Site drainage: normal Profile drainage: imperfect

Horizons:

cm

0 - 15	Ah	Very dark grey (10 YR 3/1) friable humose clay loam; moderately developed fine subangular blocky structure; very rare stones; abundant fibrous roots; very moist; merging undulating boundary.
15 - 41	Bw	Dark yellowish brown (10 YR 3/4) firm clay loam; moderately developed coarse subangular blocky structure; very rare stones of sandstone; common fibrous roots; very moist; merging undulating boundary.
41+	BCg	Dark yellowish brown (10 YR 4/4) firm clay loam with many distinct very fine strong brown (7.5 YR 5/6) and olive grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 61 Subgroup: typical (non-calcareous) alluvial gley
 Location: River Wear floodplain, Kepier G.R.: 28554399
 Altitude: 27m O.D. Slope: 3.2° Aspect: WNW (303°)
 Land use: permanent grass Canopy: none Topex: very sheltered
 Vegetation: field grasses and clover; Plantago lanceolata
 Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 16	Ahg	Dark brown (10 YR 3/3) friable clay loam with common faint very fine strong brown (7.5 YR 5/6) mottles; moderately developed fine granular structure; slightly stony with small stones of sandstone, shale and coal; abundant fibrous roots; slightly moist; undulating merging boundary.
16 - 30	B1g	Very dark greyish brown (2.5 Y 3/2) firm clay with many prominent fine brown to dark brown (7.5 YR 4/4) and grey (5 Y 5/1) mottles; moderately developed medium prismatic structure; stones as above but slightly less; few fibrous roots becoming less down horizon; slightly moist; narrow undulating boundary.
30 - 41	B2g	Light olive brown (2.5 Y 5/4) firm clay loam with many prominent medium yellowish brown (10 YR 5/6) and fine grey (5 Y 5/1) mottles; moderately strong medium prismatic structure; coal and sandstone traces; few fibrous roots; narrow undulating boundary.
41+	Cg	Pale olive (5 Y 6/3) firm clay loam with many prominent medium brown to dark brown (7.5 YR 4/4) and grey (5 Y 5/1) mottles; coal and sandstone traces; very few fibrous roots; moist; massive.

Site No.: 62

Subgroup: typical (non-calcareous) humic
alluvial gley

Location: River Wear Gorge, Kepier G.R.: 28994393

Land use: deciduous woodland Canopy: present Topex: very sheltered

Vegetation: mature Fraxinus excelsior and Acer pseudoplatanus;
Festuca rubra; Melandrium dioicum; Urtica dioica

Site drainage: receiving Profile drainage: poor

Horizons:

cm

0 - 18	Ah	Very dark grey (10 YR 3/1) friable humose silty loam; moderately developed medium subangular blocky structure; stony with large stones of sandstone and small shale and coal; common large woody roots; worms; very moist; merging undulating boundary.
18 - 39	B(g)	Very dark greyish brown (10 YR 3/2) friable humose silty clay loam with common faint very fine yellowish brown (10 YR 5/6) mottles; small stones of sandstone, shale and coal; common large woody roots; moderately developed coarse subangular blocky structure; very moist; merging undulating boundary.
39+	Cg	Black (10 YR 2/1) friable humose loam with many distinct fine reddish brown (5 YR 4/4) mottles; very stony with small coal fragments but no sandstone visible; possibly contaminated by coal outcrop at base of sandstone bluff; roots as above; very moist; weakly massive.

Site No.: 63

Subgroup: cambic stagnohumic gley

Location: Low Grange Farm, Belmont G.R.: 29514421

Altitude: 62m O.D. Slope: 2.0° Aspect: SSE (154°)

Land use: arable (barley) Canopy: none Topex: moderately sheltered

Site drainage: normal Profile drainage: poor

Horizons:

cm

- 0 - 24 Ap(g) Dark greyish brown (10 YR 4/2) friable humose clay loam with very faint very fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse subangular blocky structure; very stony with small stones of sandstone, shale and coal; debris; abundant fibrous barley roots; moist; sharp even boundary.
- 24 - 33 Bg Dark greyish brown (2.4 Y 4/2) friable humose silty clay loam with common faint very fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse angular blocky structure; very stony with small stones as above; few fibrous roots; moist; merging even boundary.
- 33+ BCg Light olive brown (2.5 Y 5/4) firm silty clay with many prominent medium strong brown (7.5 YR 5/6) and fine grey to light grey (5 Y 6/1) mottles; stones as above; moist; massive.

Site No.: 64

Subgroup: cambic stagnohumic gley

Location: Hilltop Farm, Belmont G.R.: 31364396

Altitude: 91m O.D. Slope: 2.8° Aspect: W (270°)

Land use: arable Canopy: none Topex: moderately exposed

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 23	Apg	Very dark greyish brown (10 YR 3/1) firm humose silty loam with many distinct fine dark reddish brown (2.5 YR 3/4) mottles; moderately developed medium subangular blocky structure; very rare stones; debris; common fibrous roots; moist; sharp even boundary.
23 - 43	Bg	Very dark greyish brown (2.5 Y 3/2) friable humose silty loam with many prominent medium dark reddish brown (2.5 YR 3/4) and fine grey (5 Y 5/1) mottles; moderately weak medium subangular blocky structure; stony as above; common fibrous roots; few worms; moist; merging even boundary.
43+	BCg	Dark greyish brown (2.5 Y 4/2) firm clay loam with many prominent fine reddish brown (5 YR 4/4) and very fine olive-grey (5 Y 5/2) mottles; stones as above; moist; massive.

Site No.: 65 Subgroup: typical (non-calcareous) alluvial gley
 Location: Pittington Farm, Pittington G.R.: 32074411
 Altitude: 78m O.D. Slope: 5.7° Aspect: WNW (305°)
 Land use: permanent grass Canopy: none Topex: very sheltered
 Vegetation: Festuca rubra; Ranunculus sp.; Veronica sp.;
 Crataegus monogyna
 Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 12	Ah(g)	Very dark grey (10 YR 3/1) very friable humose loam with common faint fine dark brown to brown (7.5 YR 4/2) mottles; moderately weak fine subangular blocky structure; very rare small stones of sandstone and shale; abundant fibrous roots; worms; moist; merging even boundary.
12 - 30	B(g)	Very dark greyish brown (10 YR 3/2) very friable humose loam with common faint fine dark brown to brown (7.5 YR 4/2) mottles; moderately weak fine subangular blocky structure; stones and roots as above; moist; merging even boundary.
30+	BCg	Dark greyish brown (2.5 Y 4/2) friable loamy sand with many distinct fine strong brown (7.5 YR 5/6) and dark grey (5 Y 4/1) mottles; stones as above; few roots; very moist; single grain.

Site No.: 66

Subgroup: typical brown earth

Location: Ladys' Piece Lane, Pittington G.R.: 32504422

Altitude: 91m O.D. Slope: 2.0° Aspect: NNE (15°)

Land use: deciduous woodland Canopy: present Topex: moderately exposed

Vegetation: Fraxinus exelsior; Crataegus monogyna

Site drainage: normal Profile drainage: well drained (free)

Horizons:

cm

1 - 0 L Leaf litter.

0 - 1 F Half decomposed leaf litter.

1 - 10 Ah Very dark grey (10 YR 3/1) very friable humose sandy loam; moderately weak fine crumb structure; very stony with angular sandstone fragments; common fibrous and woody roots; rare worms; slightly moist; merging even boundary.

10 - 22 AB Very dark grey (10 YR 3/1) very friable humose loam; moderately developed very fine crumb structure; very stony with angular sandstone fragments of increasing size and coal traces; common fibrous and rare woody roots; slightly moist; merging even boundary.

22 - 56 Bw Dark brown (10 YR 3/3) friable loam; moderate to moderately weak fine subangular blocky structure; very stony with angular sandstone fragments; rare woody and fibrous roots; merging irregular boundary.

56+ C Weathered fragmented sandstone with some very coarse dark yellowish brown (10 YR 3/4) gritty sand between; slightly moist.

Site No.: 67

Subgroup: cambic stagnogley

Location: The Moor, Pittington G.R.: 33994402

Altitude: 109m O.D. Slope: 3.8° Aspect: NE (54°)

Land use: N.C.B. plantation Canopy: none Topex: moderately exposed

Vegetation: Festuca rubra; Chamaenerion angustifolium; Pinus
sylvestris (@ 5-10 years)

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 2	F	Decomposed grasses.
2 - 5	H	Black (10 YR 2/1) humus with small amounts of mineral matter; abundant fibrous roots; even undulating boundary.
5 - 25	Ap(g)	Dark yellowish brown (10 YR 4/4) firm clay with very faint rusty mottles; moderately developed medium subangular blocky structure; very rare sandstone traces; common fibrous roots; very moist; even undulating boundary.
25+	BCg	Yellowish brown (10 YR 5/6) firm clay with many prominent strong brown (7.5 YR 5/6) and light olive grey (5 Y 6/2) mottles; very rare sandstone and coal traces; few woody and fibrous roots; very moist with water seepage at pit bottom; massive.

Site No.: 68 Subgroup: typical (non-calcareous) alluvial gley
 Location: Hillside Farm, Pittington G.R.: 34504398
 Altitude: 99m O.D. Slope: 1.5° Aspect: N (352°)
 Land use: permanent grass Canopy: none Topex: moderately exposed
 Site drainage: normal Profile drainage: poor.

Horizons:

cm

0 - 10	Ah	Very dark greyish brown (10 YR 3/2) firm humose clay; moderately developed coarse granular structure; very rare stones; abundant fibrous roots; common worms; moist; merging even boundary.
10 - 20	B(g)	Dark brown (10 YR 3/3) firm clay with common faint very fine yellowish brown (10 YR 5/6) mottles; moderately developed coarse primistic, breaking to moderate developed coarse and medium subangular blocky structure; very rare stones of sandstone and coal; abundant fibrous roots; worms; moist; merging even boundary.
20+	Cg	Dark greyish brown (2.5 Y 4/2) very firm clay with many prominent medium yellowish red (5 YR 5/8) and grey (N 6/-) mottles; stones as above; few roots; very moist; massive.

Site No.: 69

Subgroup: typical (non-calcareous) alluvial gley

Location: Hillside Farm, Pittington G.R.: 34954401

Altitude: 105m O.D. Slope: 2.9° Aspect: SSW (204°)

Land use: permanent grass Canopy: none Topex: moderately exposed

Vegetation: field grasses

Site drainage: normal Profile drainage: poor

Horizons:

cm

0 - 9	Ah(g)	Dark greyish brown (10 YR 4/2) friable humose clay loam with common faint very fine strong brown (7.5 YR 5/6) mottles; very rare stones of sandstone; few fibrous and woody roots; moderately developed coarse angular blocky structure; worms; moist; narrow even boundary.
9 - 25	Bg	Dark brown (10 YR 3/3) firm clay loam with common faint fine brown to dark brown (7.5 YR 4/4) mottles; moderately developed medium prismatic structure; stones as above; few fibrous and woody roots; worms; moist; merging even boundary.
25+	BCg	Dark greyish brown (2.5 Y 4/2) firm silty clay with many prominent fine yellowish red (5 YR 5/8) and grey to light grey (N 6/-) mottles; stones as above; - few fibrous roots; worms; moist; massive. -

Site No.: 70 Subgroup: typical brown calcareous earth
 Location: Elemore Dene, Pittington G.R.: 35414398
 Altitude: 116m O.D. Slope: 2.0° Aspect: (205°)
 Land use: N.C.B. plantation Canopy: present Topex: very sheltered
 Vegetation: Festuca rubra; Chamaenerion angustifolium; Bromus sterilis;
 Acer pseudoplatanus; Picea sitchensis
 Site drainage: shedding Profile drainage: well drained (free)

Horizons:

cm

1 - 0	L	Undecomposed leaf litter.
0 - 11	Ah	Very dark grey (10 YR 3/1) friable humose silty loam; moderately developed fine granular structure; stony with small stones of Magnesian Limestone and very rare igneous rock; common fibrous roots; worms; moist; narrow even boundary.
11 - 22	B1w	Very dark greyish brown (10 YR 3/2) friable humose silty clay loam; moderately developed fine subangular blocky structure; extremely stony with small stones of Magnesian Limestone; large rare woody and few small woody roots; moist; merging undulating boundary.
22 - 39	B2w	Dark yellowish brown (10 YR 3/4) firm humose silty clay loam; moderately developed fine subangular blocky structure; extremely stony with Magnesian Limestone fragments; worms; moist; narrow undulating boundary.
39+	C	Pale yellow (2.5 Y 8/4) fragmented Magnesian Limestone with some dark yellowish brown (10 YR 4/4) very firm silty clay loam between limestone fragments.

Site No.: 71

Subgroup: brown (non-humic) rendzina

Location: Low Haswell Farm, Haswell G.R.: 36114384

Altitude: 145m O.D. Slope: 16.7° Aspect: WNW (285°)

Land use: scrub Canopy: none Topex: moderately exposed

Vegetation: Festuca sp.; Veronica sp.; Primula veris; Crataegus monogyna

Site drainage: shedding Profile drainage: well drained (excessive)

Horizons:

cm

0 - 5	F	Decomposed grasses.
5 - 16	Ah	Very dark brown (10 YR 2/2) very friable humose loamy sand; moderately weakly developed fine crumb structure; Magnesian Limestone fragments; abundant fibrous roots; worms; slightly moist; merging even boundary.
16 - 25	Bw	Very dark grey (10 YR 3/1) very friable humose loam; moderately weak fine crumb structure; Magnesian Limestone fragments; common fibrous roots; worms; slightly moist; sharp even boundary.
25+	C	Pale yellow (2.5 Y 8/4) fragmented Magnesian Limestone with some very dark grey (10 YR 3/1) loam between limestone fragments.

A P P E N D I X 2

SOIL ANALYTICAL DATA

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C.	% Base Satur- ation	pH H2O CaCl2	
			Int. USDA	% Sand	Int. USDA	% Silt							Ca	Mg	K	Na	H				
1	Ap _g	0-23	41.21	28.37	25.53	38.56	33.27	7.58	3.39	11.10	5.74	9.90	9.77	2.75	1.01	0.50	10.2	24.24	57.92	6.8	6.5
	B _g	23-33	35.45		25.18		39.37		3.27	9.50	4.43	7.63	8.29	1.00	0.27	0.47	1.58	11.60	86.38	6.6	6.3
	BC _g	33+	12.30		34.70		53.01		2.28	7.58	1.84	3.17	7.50	1.19	0.33	1.28	5.18	15.49	66.56	6.6	6.2
2	Ap _g / B _g	0-24	43.85	29.37	22.66	37.15	33.48	6.73	3.35	13.38	7.65	13.20	10.04	0.95	0.29	0.90	7.80	19.97	60.95	6.4	6.0
	BC _g	24+	15.29		18.36		66.35		6.50	8.14	1.82	3.14	3.59	1.35	0.18	0.93	21.60	27.66	21.90	4.8	4.3
3	Ap(g)	0-17	46.86	32.01	29.75	44.60	23.39	7.21	3.04	15.29	6.37	10.98	10.85	2.19	1.19	0.84	8.30	23.38	64.50	6.7	6.3
	B _g	17-34	36.98		32.69		30.32		7.27	15.64	7.98	13.76	4.80	0.98	0.53	0.93	28.25	35.49	20.41	5.4	4.9
	BC _g	34+	32.44		25.96		41.60		2.55	6.76	3.19	5.50	1.78	0.74	0.34	0.76	26.18	29.80	12.15	4.7	4.2
4	Ap	0-25	65.56	58.40	15.10	22.25	19.35	3.62	2.20	10.48	5.11	8.81	3.17	0.96	0.98	0.71	9.50	15.33	38.02	5.6	5.1
	B1w	25-38	61.85		13.57		24.58		1.88	9.93	4.18	7.21	2.15	0.49	0.47	0.85	23.2	27.16	14.57	5.3	4.7
	B2w	38-61	62.95		11.30		25.74		1.96	6.85	3.31	5.70	1.79	0.37	0.37	0.82	29.72	33.07	10.13	4.9	4.4

Site	Horizon	Thick-ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Ignition	% Carbon	% Organic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Saturation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
5	Ah	1-9	79.70	52.10	11.21	38.81	9.10	13.41	1.49	11.35	6.82	11.77	5.41	1.53	0.80	0.47	22.00	30.20	27.16	6.1	5.6
	Blw	9-18	81.42		11.72		6.86		1.17	8.58	4.41	7.60	4.36	1.32	0.62	0.47	23.00	29.77	22.75	6.2	5.6
	B2w	18-47	86.35		7.17		6.48		0.66	5.53	2.41	4.16	3.01	0.93	0.40	0.46	23.00	27.80	17.28	6.5	5.9
	C	47+	89.00		3.00		8.00		0.60	4.00	0.40	0.60	1.81	0.52	0.06	0.90	20.0	23.29	14.13	6.6	5.9
6	H	4-11							4.32	33.46			3.82	1.42	1.17	0.85	66.8	74.06	9.80	4.3	3.9
	AB	11-24	28.04	19.05	20.66	29.66	51.29	6.00	2.13	8.51	2.57	4.43	0.90	0.36	0.46	0.45	24.00	26.17	8.28	4.2	3.6
	Bw	24-35	30.63		18.35		51.02		2.07	7.70	2.76	4.76	0.84	0.46	0.41	0.35	31.30	33.37	6.20	4.3	3.7
	BGg	35+	28.66		19.45		51.88		2.09	7.45	1.25	2.16	0.67	0.45	0.36	0.22	18.58	20.28	8.37	4.2	3.7
7	Ap	0-30	53.19	33.40	23.68	43.47	23.13	6.03	1.96	11.54	6.73	11.60	5.67	1.49	0.55	0.49	9.10	17.31	47.42	5.6	5.1
	Bg	30-65	65.09		14.62		20.28		1.39	5.31	2.21	3.81	5.22	1.95	0.08	0.93	19.60	27.79	29.47	6.5	6.1

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA	% Clay					Ca	Mg	K	Na	H			H2O	CaCl2
8	Ap	0-15	49.40	32.14	25.75	43.00	24.85	2.63	15.16	7.88	13.59	9.77	0.84	2.10	0.91	25.58	39.21	34.76	7.4	6.9
	AB(g)	15-22	59.17		21.69		19.13	1.74	12.45	5.00	4.62	7.66	0.51	1.82	0.83	4.18	15.00	72.16	8.1	7.6
	Bg	22-69	57.80		18.06		24.14	1.74	11.13	4.30	7.41	7.32	0.51	1.99	0.86	26.00	36.69	29.14	8.1	7.5
9	Ah	5-12	53.65	32.06	18.76	40.35	27.59	2.71	14.17	5.92	10.21	3.09	0.31	0.78	0.32	27.04	31.54	14.26	4.9	4.4
		12-80	49.19		17.41		33.40	1.55	7.77	3.98	6.87	2.31	0.18	0.55	0.24	24.00	27.28	12.02	5.0	4.4
10	Ap	0-28	50.04	39.39	28.53	39.18	21.43	2.38	19.35	5.81	10.02	9.87	1.03	0.53	0.41	19.86	31.70	37.35	7.4	7.1
	Bw	28-40	61.39		17.39		21.22	1.23	9.52	2.96	5.11	7.76	1.14	0.50	0.58	16.42	26.40	37.81	7.7	7.3
	Bcg	40+	47.20		21.22		31.58	1.59	5.69	1.48	2.55	7.66	1.68	0.39	0.54	6.40	16.68	61.63	8.0	7.4
11	Ap	0-32 at 5 cm	51.91	40.69	18.65	29.87	29.44	1.91	10.14	5.11	8.81	9.60	1.68	0.49	0.41	20.22	32.40	37.59	7.5	6.8
	Ap	at 30cm										→ 9.50	1.60	0.40	0.40	19.66	31.56	37.63	7.5	6.8
	Bg	32-42	60.44		16.58		22.98	1.66	6.30	2.65	4.56	8.89	1.57	0.37	0.71	5.60	17.15	67.34	6.9	6.5
	Bcg	42+	42.89		16.52		40.59	1.76	6.00	1.21	2.08	8.34	1.93	0.38	0.64	33.80	45.09	25.04	7.1	6.7

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satur- ation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H				
12	Ap/B	0-35	52.31	38.04	22.15	36.42	25.55	5.70	1.90	9.35	5.30	9.13	12.94	1.11	0.37	0.49	21.62	36.53	40.81	8.0	7.5
		at 5 cm																			
	A/B	at 30cm											12.50	1.10	0.30	0.50	20.85	35.25	40.86	8.0	7.5
		35+	44.68			21.43		33.89		1.80	6.45	1.31	2.25	9.67	1.31	0.43	0.55	7.60	19.57	61.17	8.1
13	Ap	0-28	61.99	42.50	19.07	38.57	18.94	6.40	1.77	12.00	6.51	11.23	7.69	2.25	0.37	0.49	20.70	31.50	34.28	6.5	6.2
	B1w	28-55	62.11		16.77		21.12		1.51	9.10	3.53	6.09	7.04	1.67	0.23	0.42	21.40	30.76	30.42	6.4	6.1
	B2w	55-75	60.51			17.08		22.41		1.28	6.45	4.28	7.79	1.41	0.17	0.37	17.60	27.35	35.65	7.2	6.8
14	Ah(g)	1-18	55.02	38.11	15.09	31.99	29.90	8.25	1.81	9.31	4.84	8.35	5.96	1.63	0.75	0.70	28.00	37.05	24.42	6.3	5.8
	Bg	18-32	56.25		11.10		32.66		1.40	6.77	2.92	5.04	7.25	1.45	0.68	0.68	25.34	35.40	28.42	7.0	6.8
	BCg	32+	62.52		10.04		27.44		1.32	5.65	2.21	3.81	6.03	1.55	0.62	0.59	14.50	23.29	37.74	7.2	6.7
15		0-17	52.90	34.01	17.75	36.64	29.35	7.34	4.72	11.07	5.89	10.15	3.76	1.12	0.29	0.26	19.68	25.12	21.64	5.6	5.1
		17+	49.11		18.67		32.23		2.07	5.39	1.84	3.17	5.41	1.89	0.67	0.66	26.80	35.45	24.40	6.8	6.6

Site	Hori- zon	Thick- -ness cm.	% Sand		% Silt		% Clay	%v. Fine Sand	% Moisture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C.	% Base Saturation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
16	Ap	0-19	69.57	59.76	10.98	20.79	19.45	9.25	2.09	7.67	4.15	7.15	4.42	1.18	0.55	0.51	11.20	17.86	37.30	6.3	5.8
	Blw	19-38	76.36		5.49		18.15		1.28	5.54	3.06	5.28	2.60	0.78	0.49	0.38	5.12	9.37	45.36	5.1	4.9
	B2w	38-84	69.23		8.61		22.16		1.26	5.55	3.13	5.39	2.47	0.55	1.34	0.60	8.60	13.56	36.59	5.1	4.6
17		1-7	85.07	73.20	7.90	19.76	7.04	10.59	2.24	25.00	12.80	22.07	3.71	0.82	0.79	0.32	31.8	37.44	15.06	6.8	6.3
		7-15	42.47		22.09		35.43		1.67	14.17	4.15	7.16	6.44	1.38	0.11	0.36	2.40	10.68	77.54	8.1	7.6
18	Ap	0-17	58.21	51.03	17.38	24.56	24.41	8.63	2.49	13.23	7.33	12.64	3.83	0.94	0.66	0.80	23.34	29.57	21.07	5.5	5.0
	Bg	17-30	56.09		13.10		30.82		1.74	8.94	3.98	6.86	1.79	0.66	0.38	0.87	13.40	17.11	21.67	4.8	4.4
	BCg	30+	34.50		23.00		42.50		1.74	8.94	3.90	6.80	1.60	0.50	0.30	0.81	10.60	13.81	23.24	4.7	4.3
19	Ah	10-15	69.39	55.99	21.79	35.19	8.82	10.01	2.97	16.80	7.65	13.19	0.54	0.59	0.30	0.73	36.72	38.87	5.54	3.9	3.4
	Blw	15-32	66.47		12.81		20.71		1.32	5.04	2.58	4.45	0.12	0.18	0.10	0.75	23.28	24.44	4.73	4.1	3.6
	B2w	32-45	68.22		15.49		16.29		1.26	4.49	2.58	4.45	0.35	0.20	0.08	0.68	11.02	12.34	10.66	4.3	3.8
	Cg	45+	68.83		13.55		17.62		1.23	4.10	5.62	9.69	0.13	0.26	0.22	0.84	25.34	26.8	5.45	4.5	3.9

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Mois- ture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
20	Ah	1-8	86.78	66.51	5.70	25.96	7.53	17.01	1.67	10.03	6.33	10.91	4.79	1.24	0.13	0.76	9.36	16.27	42.47	6.3	5.8
	AB	8-14	83.22		9.25		7.53		1.67	10.20	6.13	10.57	4.99	1.11	0.09	0.79	12.40	19.37	35.99	5.5	4.8
	Elw	14-23	84.02		8.66		7.32		1.14	6.23	3.05	5.26	3.33	0.51	0.08	0.64	5.50	10.06	45.33	5.4	4.8
	B2w	23-48	82.09		7.42		10.49		0.83	4.76	1.94	3.34	3.07	0.66	0.08	0.89	8.34	13.05	36.10	5.8	5.2
	C	48+	89.74		3.22		7.04		0.60	3.07	0.40	0.68	1.81	0.52	0.07	0.93	21.68	25.01	13.30	6.2	5.6
21	Ap	0-26	42.87	29.51	29.50	42.86	27.63	4.81	2.70	15.60	7.14	12.32	10.56	2.98	0.51	0.26	22.60	36.92	38.78	7.1	6.8
	Elw	26-43	50.32		20.38		29.30		2.38	13.31	5.62	9.69	8.92	2.33	0.14	1.05	19.80	32.24	38.59	7.6	7.3
	B2w	43-70	54.79		23.42		21.78		1.76	6.54	2.10	3.62	7.10	1.78	0.23	0.49	20.20	29.80	32.21	7.4	7.0
22	Ap	0-26	54.37	40.92	20.00	33.45	25.63	7.78	1.83	12.46	5.83	10.05	7.81	1.59	0.40	0.46	19.74	30.00	34.21	6.4	5.9
	Bw	26-40	52.05		21.90		26.06		1.75	12.04	4.47	7.70	8.22	1.76	0.22	0.46	18.62	29.29	36.42	7.3	6.8
	BCg	40+	24.75		35.55		39.70		1.66	4.72	0.60	1.04	8.41	3.62	0.21	0.41	31.50	44.16	28.67	7.6	7.1

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satur- ation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
23	Ap	0-25	55.79	42.38	26.89	40.29	17.32	5.30	3.99	22.11	7.53	12.98	11.97	3.49	0.23	0.95	3.21	19.85	83.83	6.7	6.4
		25-39	53.17		25.04		21.79		2.35	16.89	5.61	9.67	9.57	2.60	0.33	0.72	4.81	18.03	73.32	7.6	7.1
		39-70	62.95		16.75		20.30		1.47	7.52	1.79	3.09	9.16	2.01	0.11	1.17	13.60	12.46	26.06	8.2	7.7
24	Ap	0-29	56.93	44.71	17.16	29.38	25.90	7.05	1.79	8.34	4.52	7.80	4.12	1.63	0.31	0.85	8.00	14.91	46.35	5.7	5.2
	Blg	29-39	53.84		22.10		24.06		1.56	8.44	4.37	7.53	5.86	1.32	0.12	0.80	17.62	25.73	31.53	6.1	5.7
	B2g	39-53	60.73		15.29		23.98		1.59	7.42	3.78	6.52	6.41	1.49	0.10	1.12	7.70	16.82	54.22	6.6	6.1
	BCg	53+	60.93		15.32		23.74		1.27	5.21	2.35		5.24	1.21	0.08	0.83	14.40	21.76	33.82	6.6	6.1
25	Ap	0-23	59.26	45.00	21.92	36.18	18.82	7.50	1.83	10.17	4.80	8.27	9.17	1.65	0.29	0.89	0.00	12.01	100.00	7.9	7.4
	Bg	23-38	64.50		16.26		19.23		1.22	4.22	1.35	2.32	5.84	0.93	0.10	0.77	4.00	11.64	65.64	7.7	7.2
	BCg	38+	72.68		11.07		16.25		1.03	3.91	1.21	2.08	5.32	0.97	0.08	0.21	1.62	8.20	80.25	7.7	7.3
26	Ap/B	0-27	51.52	37.25	21.23	35.50	27.25	4.21	1.94	10.80	5.56	9.58	0.34	1.67	0.40	0.59	18.94	21.94	13.66	7.1	6.5
	BCg	27+	56.63		20.29		23.08		1.56	5.22	1.17	2.01	7.50	1.96	0.34	0.58	18.88	29.25	35.45	7.4	7.1

Site	Horizon	Thickness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Ignition	% Carbon	% Organic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Saturation	pH	
			Int.	USDA	Int.	USDA	%						Ca	Mg	K	Na	H			H2O	CaCl2
27	Ap	0-33	54.51	42.07	18.20	30.64	27.29	5.00	1.94	9.81	4.56	7.87	8.31	1.46	0.36	0.43	18.20	28.76	36.72	6.3	5.9
		5cm																			
	Ap	30cm											> 8.00	1.00	0.31	0.41	16.04	25.76	36.72	6.3	5.9
28	BCg	33+	49.74		16.85		33.41		1.70	6.28	1.32	2.28	8.43	1.91	0.29	0.56	8.20	19.39	57.70	6.8	6.3
	BCg	43+	47.47		18.59		33.94		2.17	6.85	1.91	3.28	7.46	3.40	0.26	0.49	21.20	32.81	35.39	7.1	6.7
29	Ap	0-27	52.23	36.96	21.78	37.06	25.99	5.80	1.79	8.79	4.48	7.72	8.39	2.26	0.37	0.53	25.40	36.95	31.26	6.9	6.4
	Bg	27-43	49.51		18.36		32.14		1.79	6.09	2.88	4.97	1.56	3.03	0.59	0.43	3.18	14.80	78.52	7.1	6.6
30	BCg	43+	47.47		18.59		33.94		2.17	6.85	1.91	3.28	7.46	3.40	0.26	0.49	21.20	32.81	35.39	7.1	6.7
	BCg	34+	34.56		23.23		42.21		1.73	7.06	1.49	2.57	8.63	3.25	0.46	0.71	46.9	59.95	21.77	7.7	7.2
31	Ap/B	0-26	59.82	46.78	15.53	28.58	24.64	5.59	1.88	7.30	4.13	7.13	6.46	1.37	0.23	0.39	7.20	18.39	60.84	7.9	7.4
	BCg	26+	65.04		6.59		28.38		1.61	3.96	0.90	1.56	4.43	0.59	0.40	0.48	6.30	12.21	48.40	8.0	7.5
31																					
	Oh	0-11							10.43	47.37	19.16	33.03	0.91	0.89	1.62	0.68	66.80	70.90	5.78	4.1	3.5
	AFg	11-21	36.92	17.95	26.34	45.32	36.73	7.51	1.99	6.57	3.65	6.29	0.11	0.14	0.50	0.16	27.04	27.95	3.25	4.1	3.6
	Blg	21-36	36.89		25.06		38.05		1.82	5.23	1.43	2.47	0.04	0.11	0.33	0.15	22.68	23.30	2.67	4.2	3.7
486	B2g	36-70	41.18		24.26		34.56		1.73	4.90	1.29	2.23	0.07	0.12	0.19	0.43	36.42	37.23	2.18	4.2	3.7

Site	Hori- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satur- ation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
32	Ah(g)	1-7	39.70	23.65	34.60	50.65	25.70	3.90	3.11	18.47	7.64	13.17	10.84	2.34	0.22	1.16	9.96	24.52	59.38	5.7	5.3
	AB(g)	7-29	42.26		35.30		22.44		2.50	15.18	6.92	11.93	7.05	1.63	0.17	1.01	12.76	22.61	43.56	5.3	4.8
	B1g	29-63	40.98		30.51		28.51		2.22	6.69	2.70	4.66	9.99	1.59	0.14	0.92	14.30	26.93	46.91	7.3	6.9
33	Ah(g)	3-9	31.66	22.38	33.93	43.20	34.41	6.20	2.94	15.57	6.48	11.17	8.31	2.66	0.91	1.03	17.38	30.30	42.64	5.3	4.9
	B1(g)	9-20	24.35		31.17		44.48		2.07	10.05	4.47	7.70	4.09	1.76	0.59	0.28	18.40	25.12	26.77	5.1	4.4
	B2(g)	20-43	18.58		25.40		56.03		1.84	7.68	6.90	11.90	1.79	1.51	0.49	0.16	36.00	39.97	9.92	4.8	4.2
	BCg	43+	14.57		31.02		54.41		2.22	8.12	1.92	3.31	3.74	3.20	0.46	0.80	34.00	42.20	19.43	4.7	4.2
34	Ah	1-10	50.49	35.98	27.95	42.46	21.56	7.56	3.51	15.99	7.53	12.99	10.90	4.36	0.35	0.93	13.20	29.71	55.57	6.7	6.3
	Bg	10-29	43.57		31.38		25.05		2.59	15.99	6.79	11.71	11.19	3.62	0.20	1.00	13.04	29.04	55.10	6.6	6.3
	BCg	29+	32.84		17.66		49.50		2.22	7.02	1.35	2.33	7.04	2.31	0.40	0.90	5.04	15.69	67.88	7.5	7.0
35	Ap	0-29	55.76	42.87	22.59	35.48	21.65	5.00	2.26	11.54	6.32	10.90	9.55	3.02	0.30	0.37	21.60	34.84	38.01	6.8	6.2
	Bg	29-37	61.42		12.58		26.00		1.23	5.16	1.29	2.23	6.27	2.36	0.07	0.22	13.40	22.32	39.97	7.1	6.7
	BC1g	37-51	84.93		4.49		10.59		0.62	2.88	1.07	1.85	2.97	1.25	0.15	0.28	2.60	7.26	64.19	7.4	7.1
	BC2g	51+	83.90		5.47		10.63		0.63	3.19	0.37	0.64	2.76	1.18	0.31	0.58	26.10	30.94	15.64	7.1	6.8

Site	Horizon	Thick-ness cm.	% Sand		% Silt		% Clay	% v. Fine Sand	% Moisture	% Loss on Ignition	% Carbon	% Organic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Saturation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
36	Ap	0-29	60.58	47.52	20.65	33.71	18.77	6.86	1.97	14.45	6.73	11.61	7.04	1.98	0.41	0.36	7.38	17.17	57.01	6.4	5.9
	AB	29-35	59.28		21.07		19.65		1.68	14.08	5.42	9.35	7.75	2.02	0.41	0.35	23.70	34.24	30.77	6.8	6.4
	Bw	35-40	59.37		19.38		21.25		1.26	8.83	3.05	5.26	7.04	1.90	0.29	0.35	1.02	10.59	90.37	7.5	7.1
	BCg	40+	57.10		14.88		28.02		1.20	4.83	1.62	2.79	5.52	1.87	0.43	0.59	20.44	28.85	29.15	7.6	7.1
37	Ap	0-33 at 5 cm	61.25	49.59	24.07	35.73	14.68	9.45	2.19	16.50	7.25	12.51	8.74	1.75	0.92	1.03	17.38	29.82	41.71	7.6	7.2
	Ap	at 30cm																			
		33-61	78.38		7.07		14.55		1.00	4.27	2.01	3.46	→ 8.70	1.70	0.91	1.01	17.18	29.50	41.75	7.7	7.3
38	Ah	1-11	49.02	37.80	24.10	35.32	26.88	6.77	1.95	11.81	6.98	12.04	5.68	1.70	0.44	0.54	13.72	22.08	37.86	5.3	4.9
	AB	11-25	50.10		20.39		29.50		1.71	10.18	5.83	10.06	6.52	1.44	0.46	0.51	12.80	25.89	50.56	5.8	5.3
	Bg	25-31	54.85		17.04		28.11		1.53	6.94	3.04	5.24	5.33	1.07	0.33	0.58	15.65	22.96	31.85	5.9	5.4
	BCg	31+	47.31		19.47		33.22		1.76	6.65	1.87	3.23	6.66	2.14	0.25	0.37	12.80	22.23	42.41	6.1	5.6

Site	Horizon	Thickness cm.	% Sand Int. USDA	% Silt Int. USDA	% Clay	% V. Fine Sand	% Moisture	% Loss on Ignition	% Carbon	% Organic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Saturation	pH	
											Ca	Mg	K	Na	H			H2O	CaCl2
39	Ap	0-24	59.63	47.46	28.00	24.55	10.71	7.22	3.66	6.32	2.66	0.91	0.34	0.28	19.22	23.41	17.90	5.0	4.3
	Blw	24-33	59.50		15.00	24.51		7.24	3.75	6.46	2.77	0.84	0.40	0.37	12.00	16.40	26.81	4.9	4.4
	B2w	33-65	65.17		13.41	21.41		4.97	0.84	1.45	3.97	1.46	0.29	0.51	24.00	30.24	20.63	6.0	5.5
40	Ap	0-15	48.49	33.04	35.63	31.33	8.95	10.25	4.10	7.07	9.77	3.89	0.59	0.25	0.00	14.50	100.00	7.6	7.1
	Ap/C	15-20	46.94		19.84	33.23		11.66	4.92	8.48	10.78	4.15	0.64	0.63	19.00	35.21	46.04	7.9	7.6
	C	20+	41.46		31.22	27.31		13.93	2.52	4.34	9.19	3.96	0.40	0.62	42.00	56.17	25.22	8.0	7.5
41	Ap	0-21	36.34	21.80	46.05	32.15	9.53	15.90	5.83	10.06	11.19	4.84	0.40	0.59	11.78	28.79	59.09	7.8	7.4
42	Ah	0-16	49.77	33.97	43.84	22.19	13.03	16.04	7.14	12.31	14.40	4.56	1.04	0.62	18.38	39.00	52.88	7.5	7.1
	Bw	16-46	46.67		23.49	29.84		13.04	4.80	8.27	7.03	3.70	0.49	0.34	0.0	11.57	100.00	7.5	7.2
43	Ap	0-30	54.28	40.05	33.33	26.62	14.11	8.55	4.54	7.83	7.41	2.21	0.24	0.40	21.70	31.97	32.12	7.1	6.6
	Bw	30-40	54.81		18.53	26.66		7.11	3.02	5.21	4.75	1.70	0.78	0.46	10.60	18.30	42.07	5.8	5.3
	Bcg	40+	47.01		20.04	32.95		6.51	1.75	3.03	4.91	2.13	0.26	0.48	5.82	13.60	57.21	6.1	5.4

Site	Hor- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
44	Ap	0-27	50.34	37.11	20.78	34.00	28.89	6.49	1.68	9.42	5.15	8.88	9.22	1.70	0.43	0.62	23.98	35.95	33.30	6.9	6.5
	Bw	27-35	49.73		18.68		31.59		1.75	6.90	2.90	5.00	7.29	1.29	0.31	0.46	8.42	17.78	52.63	6.8	6.5
	Bcg	35+	41.77		23.16		35.07		1.69	6.52	1.72	2.96	6.82	2.00	0.25	0.43	21.02	30.53	31.15	6.9	6.4
45	Ah(e)	0-18	40.22	22.45	24.04	41.82	35.73	8.28	2.11	10.04	5.50	9.47	6.74	2.20	0.31	0.34	7.42	17.01	56.39	6.3	5.8
	B(e)	18-32	44.68		21.59		33.72		1.91	7.46	3.69	6.35	5.02	1.29	0.30	0.35	25.04	32.00	21.74	5.9	5.4
	Bcg	32+	40.78		17.07		42.15		1.78	6.05	0.55	0.95	3.77	1.24	0.27	0.35	5.08	10.71	52.57	5.8	5.2
46	Ap/Bg	0-18	36.93	20.46	29.25	45.73	32.82	5.89	2.89	14.92	7.53	12.98	6.41	1.75	0.55	0.43	14.60	23.75	38.52	5.6	5.2
	Bg	18-24	10.42		30.71		58.87		2.50	8.90	1.87	3.23	5.44	2.51	0.36	0.34	10.4	19.05	45.43	5.5	5.0
	Bcg	24+	34.48		26.22		39.30		1.78	7.23	2.07	3.57	3.45	2.34	0.28	0.29	6.92	23.28	70.27	5.7	5.1
47	Ap	0-22	36.94	22.49	25.70	40.15	37.35	3.93	3.09	12.61	6.46	11.14	7.90	3.02	0.36	0.79	19.18	31.25	38.63	6.6	6.2
	B1g	22-31	33.62		24.26		42.12		2.48	7.99	3.11	5.36	3.66	1.68	0.26	0.94	31.40	37.94	17.23	5.2	4.6
	B2g	31-38	23.08		26.14		50.77		2.23	7.53	2.42	4.18	3.67	1.63	0.21	0.84	18.80	25.15	25.25	4.9	4.5
	B3g	38-71	30.01		24.83		45.16		2.12	7.65	2.70	4.66	3.88	1.61	0.56	0.73	13.22	20.10	34.23	5.0	4.5

Site	Hor- zon	Thick- -ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Gross Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Saturation	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H				
48	Ap(g)	0-20	37.65	24.85	26.61	39.40	35.74	4.82	3.09	14.99	5.00	10.34	3.72	1.63	0.35	0.83	19.92	26.44	24.67	4.7	4.2
	B1g	20-29	29.76		24.62		45.83		3.11	11.35	4.03	6.95	1.83	0.84	0.33	0.81	33.28	37.10	10.05	4.3	3.9
	B2g	29-39	28.38		23.44		48.19		3.25	9.37	3.20	5.53	2.24	1.16	0.34	0.81	23.40	27.95	16.27	4.4	3.9
	B3g	39-71	19.22		26.62		54.16		4.24	10.01	3.35	5.78	3.42	1.67	0.44	0.97	29.40	35.90	18.11	4.6	4.2
49	Ahg	2-28	57.79	41.60	30.72	46.91	11.49	4.41	4.29	21.87	6.99	12.05	12.86	4.28	0.16	1.37	7.04	25.71	72.62	6.4	6.2
	B1g	28-41	28.73		27.54		43.74		2.87	11.09	4.26	7.35	9.37	3.62	0.20	1.11	24.62	38.92	36.74	7.1	6.7
	B2g	41-73	21.98		27.98		50.04		2.64	7.56	1.84	3.17	9.14	4.89	0.21	1.05	22.80	38.08	40.13	7.2	6.9
50	Ahg	0-8	43.14	28.11	20.60	35.62	36.26	3.83	2.82	14.53	6.06	10.45	5.04	0.70	0.44	0.43	29.80	36.41	18.16	5.3	4.8
	B1g	8-20	38.92		20.34		40.74		3.53	13.11	6.57	11.33	5.19	0.96	0.29	0.46	26.50	33.40	20.66	5.5	5.0
	B2g	20-36	44.36		17.97		37.66		3.94	9.67	4.65	8.01	6.19	1.15	0.20	0.48	21.60	29.63	27.09	5.9	5.4
	BCg	36+	44.72		12.56		42.72		1.96	6.52	1.33	2.30	5.30	0.89	0.21	0.46	2.84	9.70	70.72	6.4	6.0
51	Ap(g)	0-33 at 5cm	50.47	36.42	29.56	43.61	19.97	7.17	1.74	15.84	6.38	11.00	10.79	1.94	0.37	0.57	18.40	32.07	42.62	7.8	7.4
	Ap(g)	at 30cm											10.01	1.80	0.36	0.51	17.02	29.70	42.66	7.8	7.4
	Bg	33-66	58.14		20.77		21.10		1.23	8.65	2.74	4.72	8.32	1.46	0.17	0.48	0.0	10.43	100.00	8.3	7.8
	BCg	66+	58.14		19.71		22.15		1.20	5.33	1.55	2.68	8.66	1.61	0.17	0.56	0.0	11.00	100.00	8.3	7.7

Site	Hor- zon	Thick- ness cm.	% Sand		% Silt		% Clay	%V. Fine Sand	% Mois- ture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H				
52	Ap	0-29	62.21	49.78	20.46	32.89	17.33	8.26	1.91	11.96	5.62	9.68	7.92	2.47	0.31	1.11	21.02	32.84	35.00	7.4	7.0
	BCg	29+	48.84		19.14		32.01		1.42	5.50	1.70	2.92	6.34	2.42	0.53	0.80	28.94	39.03	25.86	7.7	7.3
53	Ap/B	0-29	61.59	49.31	18.79	31.08	19.61	8.53	1.50	9.60	5.83	10.05	7.77	2.91	0.40	0.40	2.40	13.88	82.71	7.2	6.7
	BCg	29+	64.88		16.27		18.85		1.32	5.72	2.71	4.67	6.78	2.59	0.23	0.26	11.40	21.26	46.38	7.3	6.8
54	Ah	1-23	33.85	19.47	38.21	52.59	29.95	5.70	2.60	20.03	7.30	12.59	13.62	4.30	0.45	3.52	2.79	24.68	88.69	7.7	7.3
	Bw	23-46	27.49		33.20		39.32		2.43	15.62	7.26	12.51	14.29	5.83	0.29	0.56	1.94	22.91	91.53	8.0	7.5
55	Ah	0-10	65.92	48.91	20.85	37.85	13.23	14.30	2.37	13.10	3.59	6.20	11.51	4.30	0.18	1.09	27.00	44.08	38.75	7.1	6.6
	Blw	10-32	53.90		22.53		23.57		1.92	10.96	4.93	8.50	9.27	4.11	0.22	0.46	1.82	15.88	88.54	7.4	7.1
	B2w	32-50	50.74		21.00		28.26		1.92	8.96	3.84	6.62	10.25	3.60	0.32	0.83	31.10	46.10	32.54	7.7	7.3
56	Ap	0-30	51.58	35.62	26.93	42.89	21.49	6.74	2.27	14.00	6.91	11.91	12.44	4.49	0.46	0.83	23.08	41.30	44.11	7.3	6.8
	Bw	30-58	49.67		20.94		29.39		2.02	10.44	4.33	7.46	10.04	3.72	0.34	0.87	25.00	39.97	37.45	7.8	7.4
	BCg	58+	30.35		30.51		39.14		2.29	10.76	2.94	5.07	13.25	4.56	0.24	1.22	13.80	19.26	33.06	8.1	7.6

Site	Hor- zon	Thick- ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Mois- ture	%Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
57	Ap(g)	0-34 5cm	47.53	37.32	19.63	29.84	32.84	5.87	2.06	10.42	5.98	10.31	7.91	2.28	0.46	0.63	23.18	34.47	32.75	7.1	6.4
	Ap(g)	30cm											7.90	2.10	0.40	0.61	22.39	33.40	32.95	7.1	6.4
	Bg	34-47	65.32		10.19		24.49		1.51	6.42	2.91	5.02	6.11	1.52	0.23	0.45	22.00	30.30	27.39	7.4	6.7
	BCg	47+	69.95		5.07		24.98		1.54	5.67	2.10	3.62	5.89	1.81	0.29	0.49	18.40	26.87	31.52	6.9	6.3
58		1-14	68.25	54.41	16.42	30.26	15.33	12.37	1.77	8.93	5.77	9.94	9.92	3.32	0.62	0.51	25.58	39.96	35.98	7.2	6.8
		14-66	67.96		12.50		19.54		1.33	4.07	1.68	2.89	4.64	2.20	0.35	0.46	6.00	13.56	55.77	7.1	6.7
59	Ap	0-27	48.44	36.26	21.55	33.73	30.01	6.47	1.50	7.28	3.26	5.63	7.54	1.92	0.55	0.36	4.40	14.77	70.22	7.2	6.6
	Bw	27-35	48.30		19.96		31.74		1.45	6.15	2.48	4.27	7.13	2.09	0.40	0.30	5.39	15.31	64.80	7.3	6.8
	BCg	35+	45.30		19.93		34.76		1.74	6.81	2.28	3.93	7.50	2.35	0.31	0.51	6.80	17.48	61.09	7.7	7.1
60	Ah	0-15	45.44	30.95	23.03	37.51	31.53	7.05	1.95	10.97	7.37	12.70	4.37	1.56	0.95	0.39	27.96	35.24	20.65	5.4	5.0
	Bw	15-41	51.12		19.51		29.37		1.40	6.89	3.10	5.35	3.92	1.30	0.84	0.37	20.60	27.04	23.80	5.4	4.7
	BCg	41+	51.00		18.01		30.99		1.39	6.70	3.00	5.20	3.10	1.00	0.60	0.20	18.20	23.1	21.21	5.2	4.6

Site	Hor- zon	Thick- ness cm.	% Sand Int. USDA	% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C Base Satur- ation	pH		
				Int. USDA	USDA							Ca	Mg	K	Na	H		H2O	CaCl2	
61	A _g	0-16	58.53	37.05	13.47	34.95	5.37	1.79	11.96	3.83	6.60	5.30	1.23	0.11	0.90	20.60	28.14	26.79	5.8	5.2
	B1 _g	16-30	45.00		18.50			1.92	6.61	1.99	3.43	6.47	1.85	0.12	0.83	18.94	28.21	32.87	6.1	5.5
	B2 _g	30-41	50.46		17.52			1.44	4.60	0.92	1.58	5.02	1.72	0.10	0.85	6.20	13.90	55.39	6.2	5.6
	B _{cg}	41+	37.45		24.32			1.91	5.70	1.12	1.93	4.97	2.29	0.15	1.00	20.38	28.79	29.21	6.2	5.7
62	A _h	0-18	38.82	21.40	37.89	55.31	8.21	2.44	16.35	7.76	13.37	8.85	1.92	0.85	0.98	12.78	25.38	49.65	5.8	5.3
	B(g)	18-39	33.84		32.63			2.18	16.57	6.64	11.44	7.79	1.49	0.46	1.03	8.22	19.00	56.73	5.8	5.2
	C _g	39+	69.30		12.43			3.44	24.09	6.90	11.90	8.46	1.68	0.29	1.13	12.42	23.98	48.21	5.8	5.3
63	A _p (g)	0-24	46.09	28.47	24.82	42.44	6.22	2.37	13.59	6.26	10.79	9.91	2.12	0.43	0.27	16.30	29.03	43.84	6.8	6.5
	B _g	24-33	42.78		25.42			2.27	9.74	7.30	12.59	8.77	2.44	0.46	0.40	7.80	19.88	60.76	7.0	6.6
	B _{cg}	33+	26.79		25.42			2.31	6.79	1.79	3.09	9.03	3.24	0.37	0.35	5.00	17.99	72.21	7.1	6.6
64	A _{pg}	0-23	52.56	39.41	26.79	39.94	6.71	2.67	13.10	7.49	12.92	6.85	0.94	1.48	0.82	31.80	41.89	24.08	6.3	5.9
	B _g	23-43	51.90		27.13			2.73	11.91	6.64	11.44	5.30	0.77	1.28	0.89	33.00	41.24	19.97	5.9	5.5
	B _{cg}	43+	38.95		23.30			2.30	7.87	3.93	6.77	6.11	0.97	1.10	0.83	32.98	41.99	21.43	6.4	6.0

Site	Hor- zon	Thick- -ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Mois- ture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	Exchangeable Cations Me/100g					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA	%						Ca	Mg	K	Na	H			H2O	CaCl2
65	Ah(g)	0-12	61.77	40.03	24.77	46.51	13.46	5.97	3.41	17.57	7.28	12.55	11.59	1.00	0.56	0.41	21.80	35.36	38.35	6.0	5.6
	B(g)	12-30	64.71		20.32		14.97		3.82	13.19	6.79	11.71	11.64	0.96	0.21	0.40	17.60	30.81	42.88	7.1	6.6
	Bcg	30+	77.79		12.01		10.21		2.01	7.68	4.77	8.22	7.91	0.86	0.58	0.82	28.32	38.49	26.42	7.3	6.8
66	Ah	1-10	77.03	63.17	9.02	22.88	13.95	6.23	3.34	25.00	10.34	17.83	7.25	2.81	0.75	0.84	28.80	40.45	28.80	6.4	5.9
	AB	10-22	62.10		17.16		20.74		1.83	14.68	6.67	11.50	4.72	1.52	0.68	0.75	15.80	23.47	32.69	6.3	5.8
	Bw	22-56	66.59		13.08		20.33		1.04	7.41	3.01	5.19	6.06	1.70	0.62	0.80	23.40	32.59	28.21	7.8	7.2
67	H	3-5							3.74	26.84			6.82	2.11	0.84	0.62	26.20	36.60	28.42	4.6	4.3
	Ap(g)	5-25	41.11	28.5	20.65	33.26	38.24	7.85	1.68	8.50	4.60	7.93	1.17	0.46	0.44	0.42	27.42	29.91	3.33	4.6	4.1
	Bcg	25+	21.14		22.34		56.52		1.77	7.22	1.44	2.49	4.81	3.15	0.46	0.57	30.20	39.19	22.94	5.4	4.9
68	Ah	0-10	43.88	35.26	17.87	26.49	38.26	1.72	4.85	25.08	11.36	19.59	11.19	5.80	0.91	0.72	25.00	43.62	42.69	6.1	5.7
	B(g)	10-20	7.74		35.22		57.04		4.27	22.45	7.12	12.27	19.87	5.84	0.79	0.74	19.76	47.01	57.97	6.7	6.4
	Cg	20+	5.99		22.10		71.91		3.71	14.73	4.78	8.24	13.55	5.51	0.62	0.97	21.90	42.55	48.54	6.9	6.6

Site	Hori- zon	Thick- -ness cm.	% Sand		% Silt		% Clay	% V. Fine Sand	% Moisture	% Loss on Igni- tion	% Car- bon	% Or- ganic Matter	<u>Exchangeable Cations</u> Me/100g					C.E.C	% Base Satu- ration	pH	
			Int.	USDA	Int.	USDA							Ca	Mg	K	Na	H			H2O	CaCl2
69	Ah(g)	0-9	51.67	30.13	22.20	43.74	26.14	8.04	3.43	13.00	7.25	12.51	10.72	2.85	0.36	0.37	19.79	38.09	37.54	6.6	6.1
	Bg	9-25	43.10		23.89		33.02		3.32	10.79	5.15	8.88	9.97	2.95	0.27	0.43	18.20	31.82	42.81	6.5	5.9
	BCg	25+	31.46		27.95		40.59		3.33	9.63	3.45	5.95	11.22	6.81	0.56	0.53	3.40	22.53	84.91	6.3	5.8
70	Ah	0-11	38.95	24.51	38.84	53.29	22.20	6.09	3.08	24.16	9.90	17.07	12.54	4.65	0.59	0.62	19.20	37.60	48.93	7.5	7.1
	B1w	11-22	38.08		33.24		28.58		2.44	20.18	8.32	14.34	11.29	4.37	0.43	0.46	0.0	16.55	100.00	7.2	6.9
	B2w	22-39	28.99		36.60		34.41		2.13	21.50	6.36	10.96	11.47	4.07	0.29	0.56	0.0	16.40	100.00	7.5	7.2
71	Ah	5-16	75.64	46.62	14.57	43.59	9.79	5.87	5.58	25.00	12.69	21.88	13.62	7.94	0.59	0.46	14.00	36.62	61.77	7.6	7.3
	Bw	16-25	67.94		18.06		14.00		3.30	24.50	10.67	18.40	10.25	7.73	0.47	0.48	12.20	31.13	60.81	7.8	7.4

A P P E N D I X 3

THE ASSESSMENT OF SOIL EROSION POTENTIAL

APPENDIX 3 THE ASSESSMENT OF SOIL EROSION POTENTIAL

3.1 Introduction

In Britain, the potential of soils to erode as a result of man's agricultural activities has received very little attention in the past from farmers, Ministry officials and soil scientists alike. However the work of R.P.C. Morgan (1974) has indicated that soil erosion induced by agricultural practice is occurring with increasing frequency.

Whilst the occurrence of the more spectacular processes of wind erosion are well known and documented, the incidence of water erosion has received scant attention. During the summer of 1973, Morgan (1974) recorded sheet and rill erosion on lowland arable land in Kent, Devon, Cambridgeshire and Bedfordshire, and reported gully erosion becoming prevalent in upland areas, whilst in 1976 Brown pinpointed dangers of sheet, rill and gully erosion on steep, newly reclaimed land in the Clwydian Hills of eastern Clwyd. Water erosion is nothing new, however, and since the 1930's evidence has been presented for the development of rills during heavy winter rains on cultivated sandy and chalk soils in eastern England.

The erosion process involves two broad stages; firstly the loosening or detachment of soil particles or groups of particles from the main body of the soil by frost and other weathering processes, tillage, animals or human pressure; secondly the transportation or removal of these particle or particle groups from their position. This removal takes place through the action of wind, water and gravity.

As water falls on the land surface, and drains away through surface runoff, it erodes by the action of the splash itself (splash erosion) and the scouring action of flow (scour erosion) (Symonds, 1968). Rain consists of drops of many different sizes, and heavy rain contains many of the larger drops of 3 to 6mm in diameter. Most drops fall at a maximum velocity of 9.1m per second when they strike the ground, but if there is a driving wind this may be increased. The amount of soil set in motion by each drop is directly proportional to the square of its velocity; thus fine sand particles can be removed by fine rain whilst heavy rain can lift particles of several millimeters in diameter. On sloping surfaces particles bounce further downslope than upslope and as the angle increases a greater proportion of the particles are thrown in a downslope direction (Morgan, 1974).

After a seed bed has been prepared, the soil surface is relatively smooth and compact and this compaction is further enhanced by rain-beat resulting in capping. Infiltration into the soil is low and runoff occurs more rapidly, and once the protective coat is broken the friable soil underneath is readily removed by sheet flow and by concentrated flow in rills and gullies which "entrain the soil particles and wash them downslope" (Morgan, 1974).

Erosion by runoff varies with the energy of moving water (the velocity on slight slopes being small compared with that of falling rain) but increases rapidly as slope becomes more marked. Thus rain-fall intensity, soil texture and condition and slope are the more important physical features affecting erosive power.

However, erosion is as much related to conditions of crop and land management as it is to the physical factors such as rainfall or slope steepness (Morgan, 1974). As the social and economic climate changes, so does the pattern of crop and land management. The practice of continuous cropping increases the likelihood of erosion considerably, the increase being due to several factors. Firstly, continuous cultivation reduces the organic matter content of the soil, which in turn reduces the stability of soil structure. Secondly, cultivation inevitably leaves the soil bare for some period of the year, which frequently coincides with the season of heaviest rainfall or strongest winds. Thirdly, the plant cover is reduced, hence soil is less protected from splash erosion. Likewise, hedgerows and other protective barriers are removed as land holding consolidation increases field size, and in regions of light soils wind erosion may result. The increase of land reclamation procedures in hill land will also inevitably have an increased affect on the amount of erosion experienced (Evans, 1976; pers.comm.).

3.2 The Quantitative Assessment of Erosion Potential

In the transect, a quantitative investigation of water erosion potential was undertaken using the preliminary work of Morgan (1974) and an application of the U.S.D.A./A.R.S. Universal Soil-Loss Equation.

3.2.1. Textural Erosion Assessment

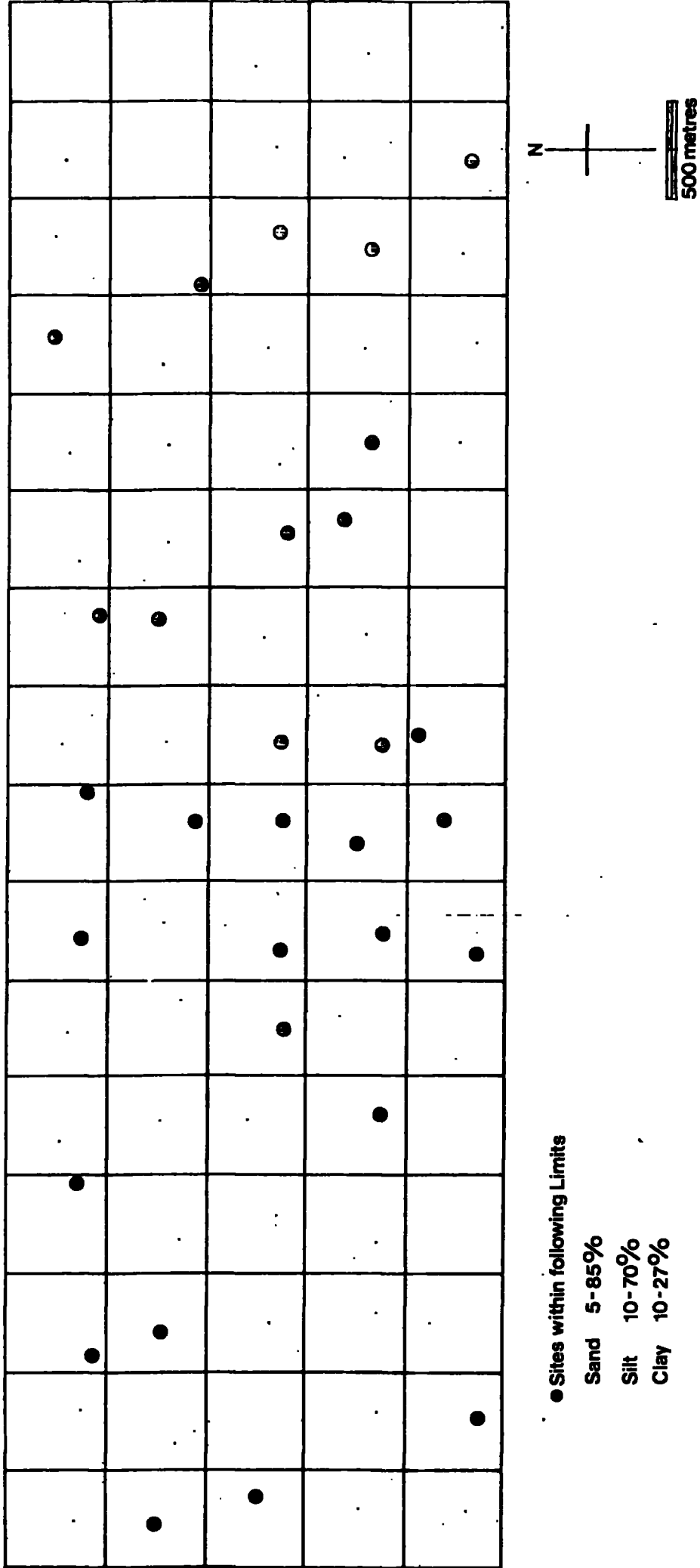
The preliminary analysis by Morgan of forty eight sites in England where erosion has been recorded, shows that it is most frequent on soils over marls and fine grained sandstones of the Silurian, Devonian and Keuper successions; on Lower Greensand; and on shallower drift soils over chalk and on silty brickearths; none of which are represented in the transect. He also states that the analysis of soil texture at eroded sites in these areas, mapped on a soil series level, shows that clay forms between 10 and 25% of the soil mass, silts between 10 and 70% and sand between 5 and 85%.

Soils with less than 10% clay absorb water rapidly, and as a result runoff and subsequent erosion will be rare. At the other extreme, where the clay content exceeds 25% the surface clods are coherent and, as well as being resistant to rain splash, are too large to be moved by sheet wash and rilling, except under exceptional conditions.

Within the transect, 42.3% (30) of the sites fall between Morgan's upper and lower textural limits (as defined on the U.S.D.A. textural system). Of the forty one sites not included thirty seven are ruled out because they have a clay content exceeding 25% and four are excluded because they have a clay content of less than 10%. The latter grouping is confined to three alluvial profiles in the Wear Gorge (Sites 5, 19, 20) and one brown rendzina profile on the limestone (Site 71).

Figure A.3.1 shows the distribution of the affected sites.

Fig A.3.1 Sites within Morgan's (1974) Textural Groupings



3.2.2. Universal Soil-Loss Equation

3.2.2.1 Method

Hudson (1971) states that, although a methodical system of land classification will indicate, in general terms, the kind of land use, within the bracket of "arable farming" wide variations of detail are found. Different ways of cropping can have very significantly different effects on the amount of soil erosion and a "numerical assessment of the soil loss under particular management practices is a useful weapon in the armoury of the soil conservationist."

Since the 1930's, research programmes in the United States have attempted to quantify the erosion effect of cropping practices, so that for given circumstances erosion could be predicted. The accumulation of knowledge over the years, and the work of scientists such as Zingg (1940), Smith (1941), Browning et al. (1947), Van Doren and Bartelli (1956), Wischmeier, Smith and Uhland (1958) and Wischmeier and Smith (1962) have made it possible for the Agricultural Research Service of the Soil Conservation Service of the United States Department of Agriculture to do this by means of the Universal Soil-Loss Equation (U.S.D.A./A.R.S., 1965).

The empirical factor relationships incorporated in the equation were established from analyses of more than 10,000 plot-years of runoff and soil loss data assembled from forty seven research stations in twenty four states (Wischmeier, 1955).

The equation was devised under the following basic conditions which influence the rate of erosion; namely: rainfall pattern, length of growing season, soil characteristics, prior erosion, land use history and topography. Upon these conditions the individual farmer may elect to apply any one of numerous feasible conditions of cropping system and conservation practice (Wischmeier and Smith, 1962).

The Universal Soil-Loss estimating equation is as follows:

$$A = R \times K \times L \times S \times C \times P$$

Where A = soil loss in tons per acre

R = rainfall erosivity index; a function of local rainstorm characteristics

K = the soil erodibility factor; a number affecting the liability of a soil type to erode

L = the slope length factor

S = the slope angle factor

C = the crop management factor

P = the conservation practice factor.

Factor A is measured in tons per acre (short tons of 2,000 lb) and is the annual soil loss which occurs under the conditions defined by the terms of the equation. When the equation is used for selecting suitable farming practices the value of A is the "soil loss tolerance"; i.e. the amount of erosion which can be tolerated without productivity deteriorating; values ranging from about 1 to 5 tons per acre per year are acceptable in the United States (Hudson, 1971), but no limit has been set for this country.

3.2.2.2. The Soil Loss Equation applied to the Transect Sites

i) Details of the Equation

As the type of land use varies throughout the transect, it would be futile to calculate the soil-loss equation for the actual land use at each site, since comparisons between sites would be meaningless. Thus, the equation has been used to calculate the potential erodibility of all the sites assuming a uniform land use of bare fallow exposed to the same conditions of rainfall type and intensity.

The equation is, therefore, a modified form of the full calculation:

$A = K \times L \times S \times P$ and is described in detail below.

Soil Erodibility (K)

The inherent erodibility of a soil is a complex property which is dependent upon both its infiltration capacity and on its capacity to resist detachment and transportation by rainfall and runoff. Wischmeier and Mannering (1969) show that the significant soil properties in accounting for erosion are the primary and interaction effects of percentage sand, percentage silt, clay ratio, organic matter content, aggregation index, antecedent soil moisture, bulk density, pH of surface and subsoil, soil structure (coded from profile description), thickness of granular soil layer, volume of pore space filled by air, presence or absence of loessial mantle, and clay skins on ped surfaces.

Research, combining the factors relating to water infiltration and particle detachment and transport, is limited. However the work of Middleton et al. (1932-34), Voznesensky and Artsuni (1940), O'Neal (1952) and Peele et al. (1945) led to the dimensionless soil erodibility factor K, whose value could only be expressed relative to some benchmark soil serving as a common base (Wischmeier and Mannering, 1969).

For any given soil and area, individual-storm erosion losses are proportional to the rainfall parameter- EI^3 (the erosion-potential index for a specific rainstorm), and the amount of eroded soil per EI unit differs substantially between soils. Thus, for a standard unit plot of 22.13m, with a uniform lengthwise slope of 9% in continuous fallow, tilled up and down the slope, the slope of the computed least squares regression line of soil loss on storm EI values is the value of K for a particular soil.

K is essentially a measure of the total effects of a combination of properties. "Some of these properties influence the soils capacity to infiltrate rain, and therefore help determine amount and rate of runoff; some influence its capacity to resist detachment and transport by the erosive forces of falling raindrops and flowing water, and thereby determine the soil content of the runoff. The interrelations of these variables are highly complex." (Wischmeier and Mannering, 1969).

The research of Wischmeier and Mannering shows that soils that are high in silt, low in clay and low in organic matter are the most erodible, and normally a soil becomes less erodible with a decrease in the silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction. However, the textural variations must be considered in relation to existing levels of other physical and chemical properties, and when this is done it is found that erodibility is often so sensitive to small changes in particle-size distribution that conventional textural classifications are too broad to serve as a reliable guide to capacity to resist erosion. Silt loams, for example, (using the U.S.D.A. system) include about threequarters of the range for all soils.

Further research by Wischmeier, Johnson and Cross (1971) has resulted in the discovery of a statistical parameter M, the product of percentage silt and percentage sand and silt, which reflects the influence of particle-size interrelations, so simplifying the empirical expression of a soils erodity as a function of fifteen soil properties and their interrelations.

They state that five soil parameters are necessary to determine soil erodibility in the form of the factor K; these are % silt plus very fine sand, % sand greater than 0.10 mm, organic content matter, structure and permeability, and are discussed below.

Although Wischmeier et al. note that they found that erodibility increased generally with increasing silt content and decreased with greater sand, clay and organic matter, these parameters, either singly or in combination, proved disappointing in predicting erodibility. Nevertheless, two findings proved crucial. Firstly it was discovered by analysis that particles in the very fine sand category (U.S.D.A. = 0.05 - 0.10mm) behave more like silt than sand. When silt was redefined to include very fine sand and sand was redefined to include particles between 0.10 - 2.00 mm, the prediction values of the two parameters improved-substantially.

The relationship of erodibility to a given silt or clay content depends considerably on the particle-size distribution in the rest of the soil mass and the levels to which other properties are combined in the soil; hence the large number of independent variables in the regression equation referred to above. The second finding got around this problem in adequately describing the whole particle-size distribution for a given soil and is the designated parameter M outlined above. This accounted for 85% of the variance in observed K values for the 55 "rainulator - tested soils", its relationship to erodibility being curvilinear. For soils with a low or medium silt fraction the M increase for each additional percentage silt depends on the soils sand-to-clay ration. Thus as sand content becomes high, silt content decreases and M declines in value but remains a function of the silt-to-clay ratio, whereas when clay content is high, M has a low-value which is a function of the sand-to-silt ratio.

Within an organic matter range of 0 to 4% (Walkley and Black, 1934, determination), Wischmeier et al. confirmed the work of Mannering (1967) and Wischmeier and Mannering (1969) that soil erodibility tends to decrease appreciably as organic matter increases and that the magnitude of organic matter is related to texture. Relationships above the 4% organic matter levels were not determined.

Soil structural strength was found not to significantly affect erodibility, possibly, because of its dependence on moisture control and the observers' judgement. Structural type and size, however, influence erodibility and there are indications that the magnitude of the effect of structure type and size may be influenced by structural strength and pH.

The above four parameters, together with permeability, which "usually can be deduced from routine profile descriptions", were developed by Wischmeier et al. into an erodibility model which was then translated into a nomograph (Figure A.3.2.) which enables the reading off of the values of K according to the five parameters. The higher the value for K the higher is the erodibility of the soil. This was undertaken for the transect sites and is described later in this section.

Length of Slope (L) and Angle of Slope (S)

The rate of soil erosion by water is affected by both slope length and angle. The two effects have been evaluated separately in research and are represented in the equation by L and S respectively. However, when land has mechanised protection works the effective length of slope is the distance between channel terraces (Hudson, 1971). The distance is a function of slope and consequently the two variables are connected, and it is convenient to have a combined factor L S to represent the effect of both in the equation. To explain this combined factor it is easier to first consider each separately.

Angle of Slope

A.W. Zingg (1940) concluded that soil loss was proportional to the 1.49 power of slope, or

$$X_c = 0.065 S^{1.49}$$

in which X_c = coded total soil loss

S = land slope in percent.

In 1946, the Musgrave Committee (Musgrave, 1947) recommended the use of 1.35 power of percentage slope and in 1957 Smith and Wischmeier proposed the relation:

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613}$$

Where s = percentage slope

S = slope factor in the erosion equation.

The amount of erosion is not directly proportional to the steepness of slope, but rises rapidly as slope increases in a parabolic curve, represented by the equation:

$$A = 0.43 + 0.30S + 0.04S^2$$

Where A = soil loss in tons per acre

S = percentage slope

as suggested by Wischmeier, Smith and Uhland (1958). This is illustrated in Figure A.3.3.

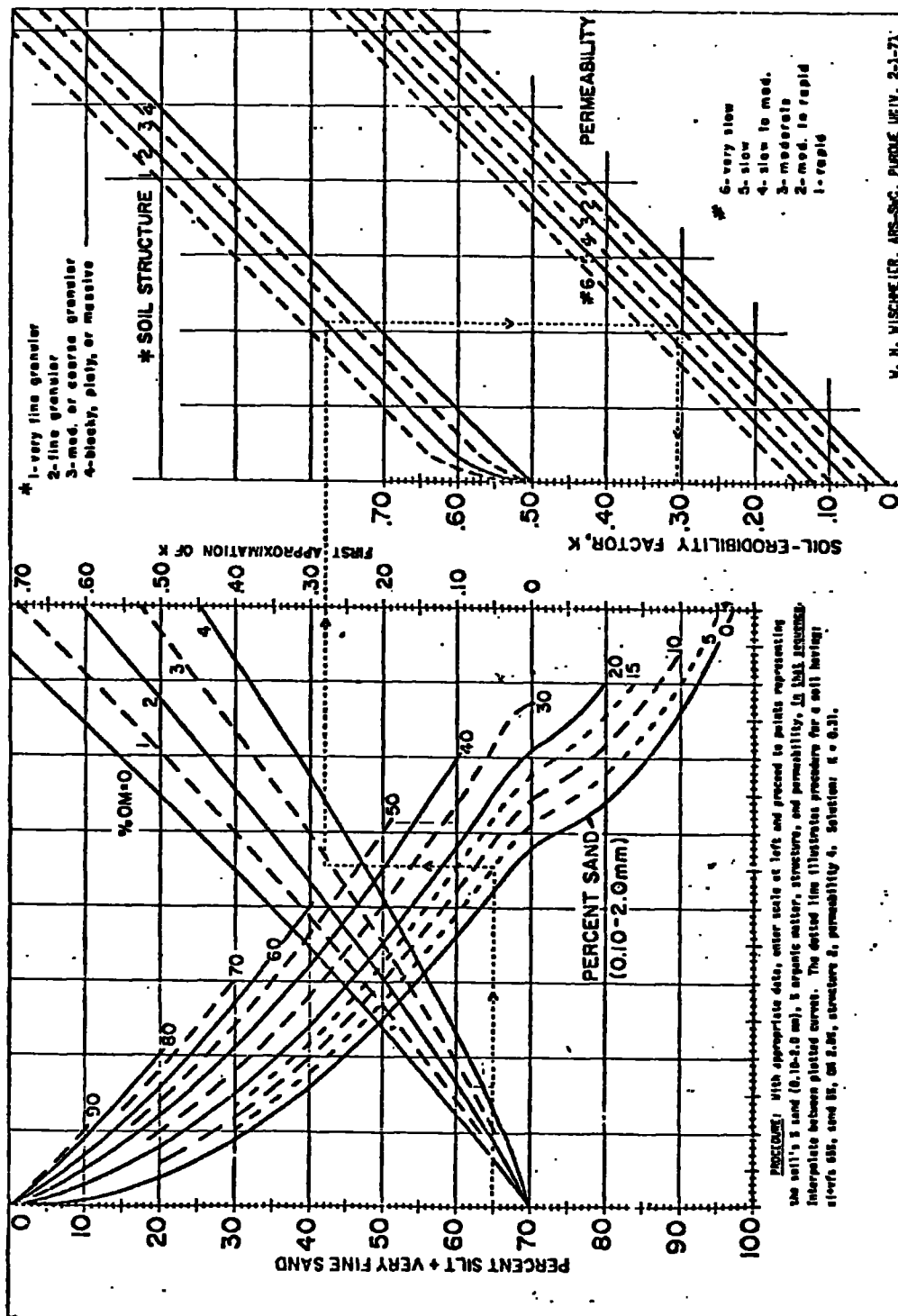
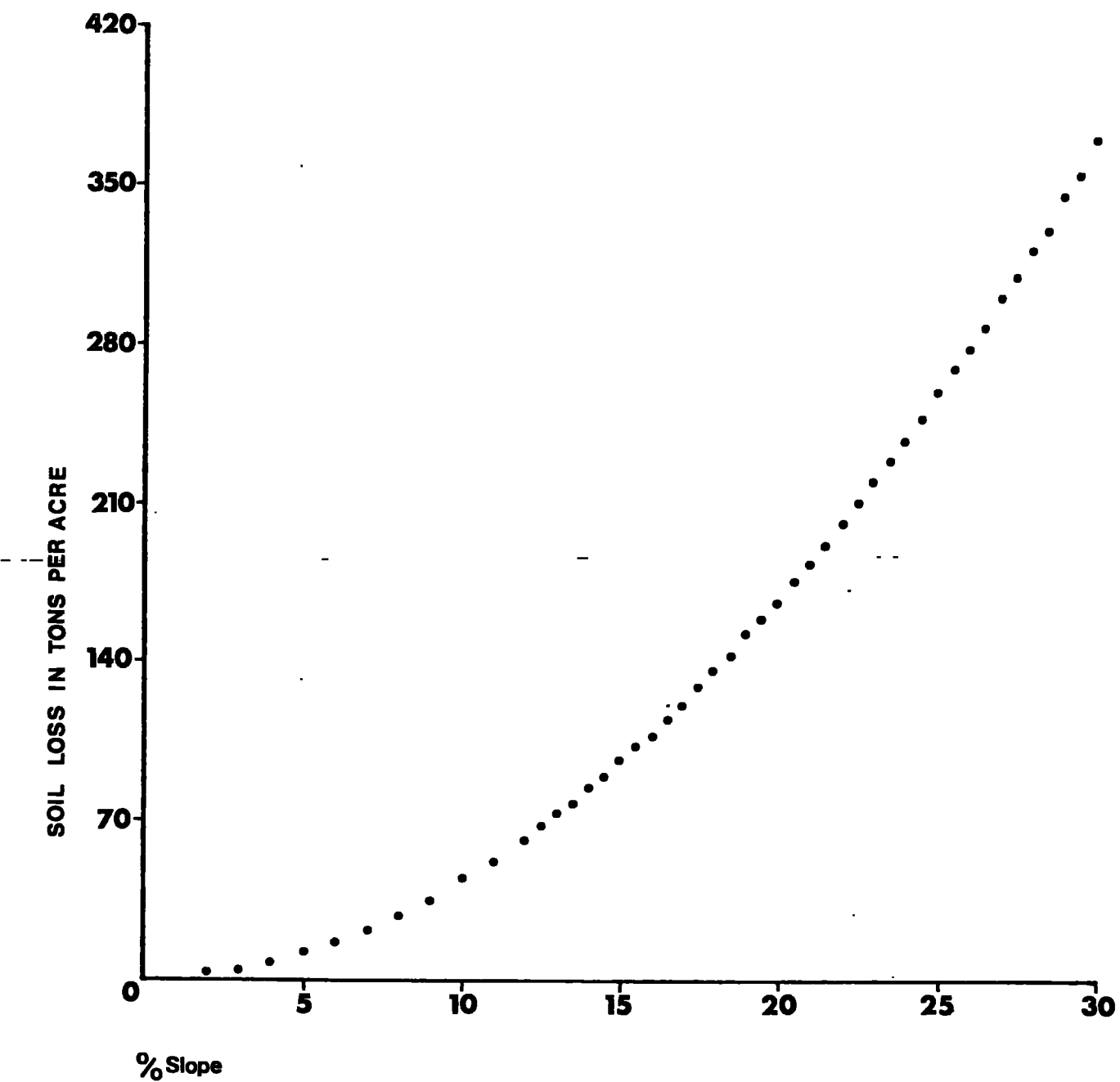


Figure A.3.2 Soil erodibility nomograph (after Wischmeier, Johnson and Cross, 1971)

**Fig A.3.3 The Relationship Between Erosion
and Angle of Slope**
(PLOTTED AFTER WISCHMEIER, SMITH AND UHLAND, 1958)



Length of Slope

The length of slope has a similar effect upon soil loss; in a long slope the surface runoff increases in both its velocity and depth. Thus, soil-erosion will occur which would not be present on a shorter length of slope, or where the effective down-hill slope is reduced to the distance between channel terraces. Hudson (1971) suggests that, in this case, when expressing the soil loss as a function of length of slope, it is necessary to differentiate between the total soil loss and soil loss per unit area, as the longer slope will have a greater total soil loss because it is bigger. Therefore, in Zingg's equation:

$$X = CL^n$$

where X = total soil loss

C = a constant

L = length of slope

n = an exponent; Zingg's value for n is 1.6

but X is the total soil loss. In the more usual form of the equation:

$$E \propto L^b,$$

where E = soil loss per unit area, then the value of b would be 0.6 for Zingg's data and the form would be as in Figure A.3.4.

In the Universal Soil-Loss Equation, the factor LS is the expected ratio of soil loss per unit area on a field slope to corresponding loss from the basic 9% slope, 72.6 ft (22.1m) long. Figure A.3.5. shows the relationship computed by solving the following equation (U.S.D.A., 1965):

$$LS = \sqrt{\lambda(0.0076 + 0.0053s + 0.00076s^2)}$$

where λ = field slope length in feet

s = slope in percent.

Conservation Practice (P)

The standard conditions under which the basic equation is formulated are of bare fallow cultivated straight up and down the steepest slope. In general, whenever sloping land is to be cultivated and exposed to erosive rains, the protection offered by close vegetation or crop growth needs to be supported by practices which slow the runoff water, so reducing the amount of soil it can carry. The most important of these practices for cropland are contour tillage, strip cropping on the contour, terrace systems and stabilized waterways (U.S.D.A. 1965). Consequently the factor P in the equation is the ratio of soil loss with the supporting practice to the soil loss with up-and-down-hill culture.

Hudson (1971) suggests that observation and experiment indicate that contouring is most effective on middle range slopes varying from 2 to 7% and are less effective on flatter and steeper slopes. The P values adopted for contour cultivation without other mechanised protection works are as follows:

Fig A.3.4 The Relationship Between Erosion and Length of Slope
(AFTER HUDSON, 1971)

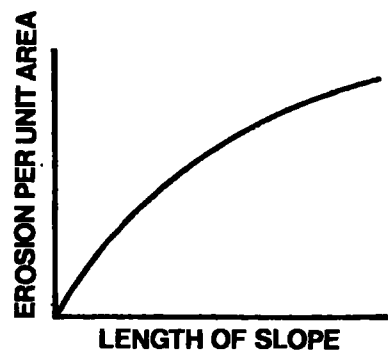
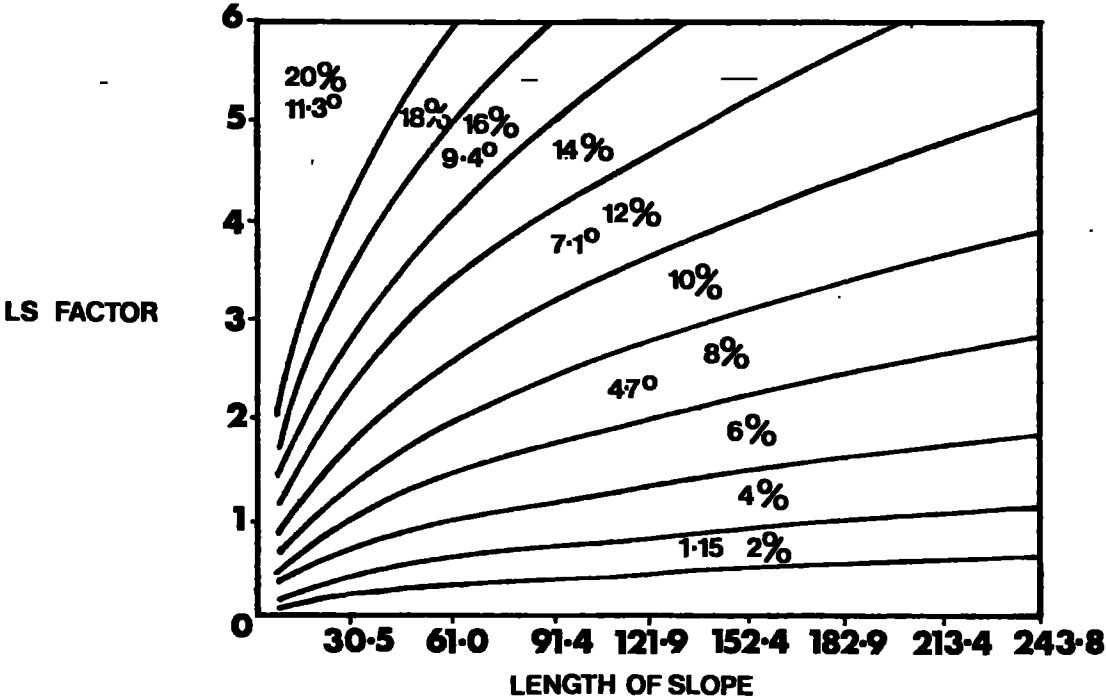


Fig A3.5 Slope-effect Chart (topographic factor LS)
(AFTER U.S.D.A., 1965)



<u>Slope %</u>	<u>P value</u>
1 - 2	0.60
2 - 7	0.50
7 - 12	0.60
12 - 18	0.80
18 - 24	0.90

If contour listing is practised (i.e. throwing up small ridges while cultivating on the contour) the P value may be reduced by 50%, but only for the crop stage periods when the ridges will be effective. Terracing and contour ridging are accounted for by adjusting the LS value.

ii) Results of the Equation

The Soil Erodibility Factor (K)

To enable a reading for K to be formulated for the seventy one transect sites, two points are of note. Firstly only the top mineral horizon was analysed, it being the zone of most susceptibility to erosive forces. Secondly Wischmeier, Johnson and Cross (1971) state that, whether or not K declines further when organic matter levels exceed 4% has not been determined and, consequently for the nomograph reading the 4% curve has had to be taken as a constant for all the sites, as each have a topsoil organic content in excess of 4%.

Five sites have a K reading of over 0.3; Site 62 (with the highest reading of all at 0.35), Site 65 (0.33), Site 69 (0.32), Site 3 (0.32) and Site 7 (0.30). The first three are all groundwater gley soils with a silty loam or loam texture (under U.S.D.A. classification) and the latter two are surface-water gleys with a loamy texture. Table A.3.2. shows the results obtained.

The mean erodibility factor is 0.232 with standard deviation of 0.052 and coefficient of variation of 20.4%, which shows a substantial constancy of erodibility between profiles. Figure A.3.6, which shows the factor mapped out according to the standard deviations from the mean, indicates a trend for less erodible topsoils to be located in the eastern part of the transect. To the west, particularly near the Wear Gorge (Unit 3) and Lowlands East of the River (Unit 4), the soils show a higher potential erodibility and a greater variation in potential erodibility between sites. 46.5% of all sites are situated with + 1 standard deviation, and 31.0% within - 1 standard deviation, showing a general even spread.

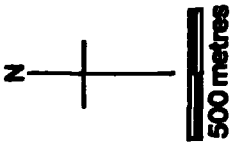
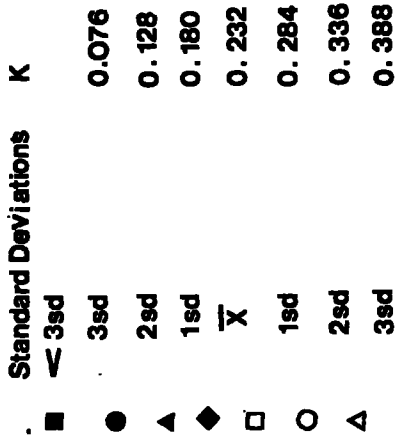
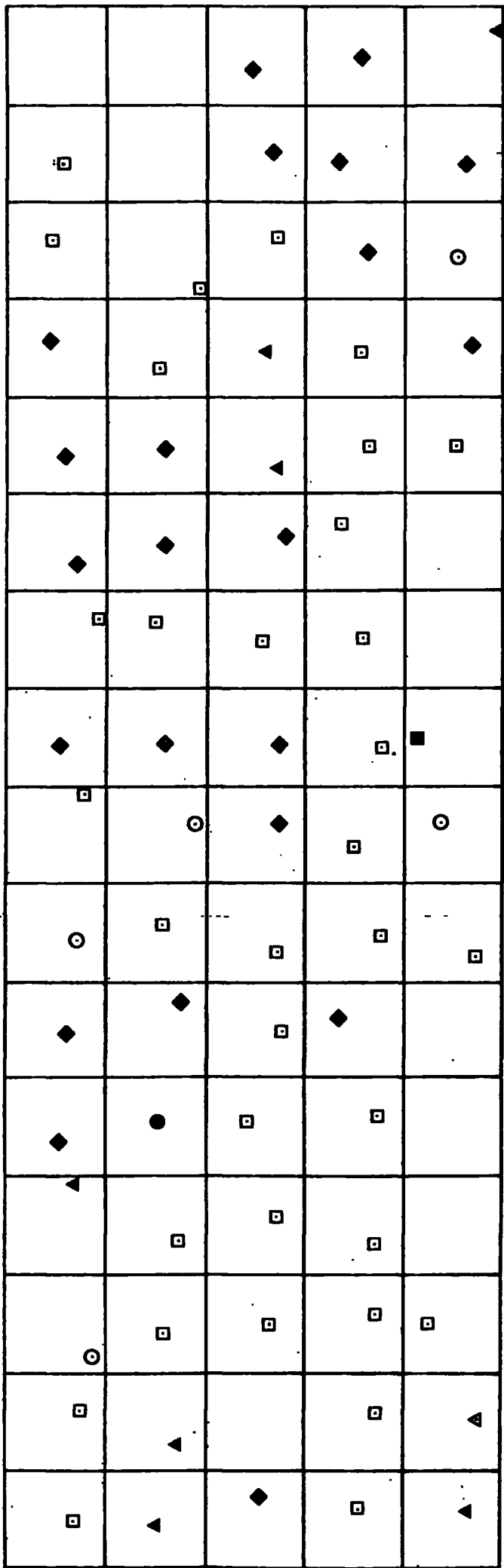
Soil Loss (A)

Taking the factors L, S and P together with K gives an assessment of erosion potential when a soil conservation practice is employed. As soil erosion is not considered to be a problem by landowners in the Durham area, and as conservation practices are unlikely to be employed, for example, contour ploughing, the calculation of A, extracting P from the equation, is likely to give a more accurate assessment of potential soil loss (Table A.3.2.).

Table A.3.2. Results of the Universal Soil-Loss Equation

K	LS	P	Soil Loss with P (Tons per acre)	Soil Loss without P (Tons per acre)	Site	K	LS	P	Soil Loss with P (Tons per acre)	Soil Loss without P (Tons per acre)
.28	2.09	.5	.29	.58	38	.25	3.95	.6	.59	.99
.27	.07	.6	.01	.02	39	.19	4.46	.6	.53	.89
.32	.07	.6	.01	.02	40	.15	4.46	.6	.40	.67
.14	3.36	.6	.28	.47	41	.15	2.75	.6	.25	.41
.21	8.2	.9	1.55	1.72	42	.26	6.20	.8	1.29	1.61
.21	3.9	.8	.66	.82	43	.22	.34	.6	.04	.07
.30	2.0	.5	.30	.60	44	.19	.55	.6	.06	.10
.28	.55	.6	.09	.15	45	.26	3.56	.6	.55	.93
.18	1.75	.5	.16	.31	46	.27	8.14	.8	1.76	2.20
.25	4.87	.6	.73	1.22	47	.24	1.34	.6	.19	.32
.20	8.12	.8	1.30	1.62	48	.24	.54	.6	.08	.13
.23	3.05	.6	.42	.70	49	.27	.55	.6	.09	.15
.20	1.87	.5	.19	.37	50	.20	1.70	.5	.17	.34
.24	1.50	.5	.18	.36	51	.28	1.75	.5	.24	.49
.26	1.35	.5	.17	.35	52	.24	1.30	.5	.16	.31
.14	.34	.6	.03	.05	53	.24	1.70	.5	.20	.41
.16	.55	.6	.05	.09	54	.24	8.00	.9	1.73	1.92
.26	.55	.6	.09	.14	55	.24	9.60	.9	2.07	2.30
.26	4.48	.8	.93	1.16	56	.27	5.50	.8	1.19	1.48
.10	3.80	.6	.23	.38	57	.25	.90	.5	.11	.22
.22	1.65	.5	.18	.36	58	.23	.55	.6	.08	.13
.24	2.77	.6	.40	.66	59	.18	.50	.6	.05	.09
.29	.07	.6	.01	.02	60	.18	2.55	.5	.23	.46
.23	2.77	.6	.38	.64	61	.17	5.58	.6	.57	.95
.28	4.15	.6	.70	1.16	62	.35	5.58	.6	1.17	1.95
.22	5.10	.6	.67	1.12	63	.27	2.15	.6	.35	.58
.20	1.60	.5	.16	.32	64	.28	1.26	.5	.18	.35
.26	1.30	.5	.17	.34	65	.33	4.40	.6	.87	1.45
.26	3.20	.6	.50	.83	66	.06	1.50	.5	.04	.09
.23	.68	.6	.09	.16	67	.26	2.20	.5	.29	.57
.27	3.10	.6	.50	.84	68	.21	.40	.6	.05	.08
.24	2.75	.5	.33	.66	69	.32	2.10	.5	.34	.67
.25	10.00	.9	2.25	2.50	70	.20	3.50	.8	.56	.70
.26	.54	.5	.07	.14	71	.17	6.50	.8	.88	1.10
.25	2.70	.5	.34	.67	$\bar{x}$	.232			.449	.661
.21	1.15	.5	.12	.24	sd	.052			.509	.601
.21	.07	.6	.01	.01	V	.224			1.134	.909

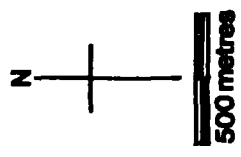
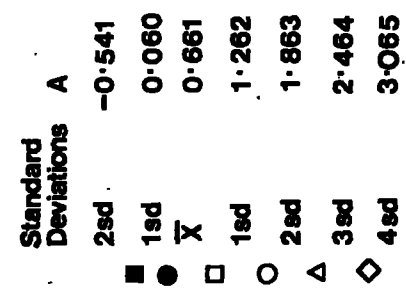
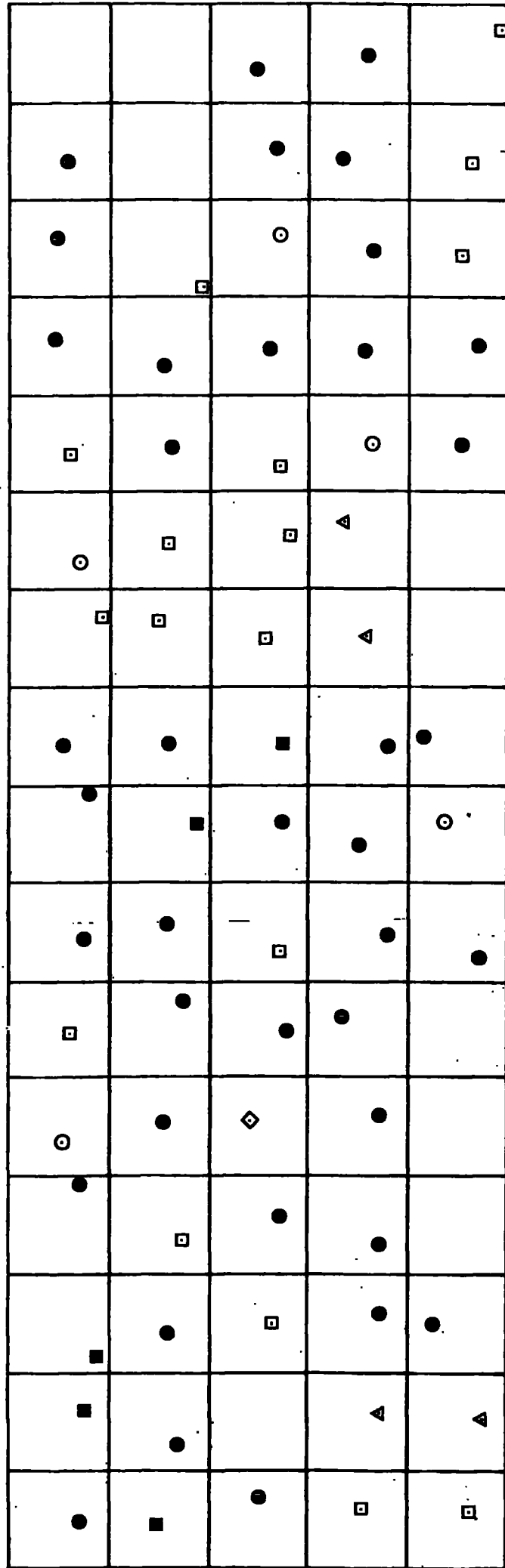
Fig A.3.6 Soil Erodibility Factor (k)



The figure without conservation practice gives a mean value of 0.661 tons per acre with a range varying from 2.50 at Site 33 to 0.01 at Site 37. The standard deviation is 0.601 and coefficient of variation 90.9%, less than that experienced with a conservation practice, indicating that conservation measures would be more of an effect in terms of prohibiting soil loss at some sites than at others. This variability is four times greater than that taking the inherent soil properties alone (K) into consideration. In terms of soil loss, only Sites 55 and 46 have a potential loss over 2 tons per acre.

Figure A.3.7 shows the sites mapped out according to the standard deviations from the mean. Overall, there is a decline in soil loss westwards, reversing the slight trend exhibited when the soil factor K only is considered. The effects of greater slopes in the east are thus felt. Sites such as 69, however, which are located on gentle slopes, but which have a higher K, are located in a positive direction from the mean suggesting that soil is the dominant factor rather than slope in this case. The majority of sites situated in the Wear Gorge in the west also show positive deviations from the mean, as do Sites 45 and 46 nearby. The area with the least erosion potential is at Framwellgate Moor in Unit 1, on the level to gently sloping laminated clay and sands and gravels; the sites located on the former being affected more by shallow slope than the soil factor, which is on the high side.

Fig.A.3.7 Soil Loss in Tons Per Acre Without Conservation Practice P



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