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Anthony H. Chapman

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A dissertation submitted to the University of Durham for the Degree of Master of Science in September 1970

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## ABSTRACT

The factors responsible for the input and output of four minerals in a large catchment system are examined and, where possible, their relative quantities are calculated or estimated. It is concluded that Man's effects on the nutrient fund are small in comparison with natural processes, with the possible exception of the application of agricultural fertilisers and particularly of Calcium.

CONTENTS

# INTRODUCTION

Several generalised statements have been made about Man's increasing tendency to promote both the eutrophication and the denudation of the natural environment. On the one hand inland watercourses are invariably the choice habitat for studies of eutrophication; on the other upland areas of Britain have often been cited as a community where traditional land-uses are held responsible for degrading the natural soil fertility. Pearsall (1950) claimed that "every animal carcase and its wool or hide represents .... a considerable reduction in upland fertility". Because of the low mineral content of hill vegetation such grazing encouraged a trend to acid mor soils or peats. "Further-more' he said, 'it looks as though grazing may be more exhausting to the soil than afforestation would be, because a timber crop takes a minimum of essential nutrients from the soil and re-circulates most of them."

Davidson and Wibberley (1956) said that of all hill-farming practices sheep-farming makes the most important contribution to the national economy. Hunter (1960) claimed that to say "that sheep are a degenerative factor on hill pastures is only a half-truth" because they do not so much provide a heavy loss of nutrients from the hill as a decline in grazing efficiency through disproportional grazing, thus manuring, preferences." He suggested that the application of manures and the increased complementary stocking by cattle would regenerate the pastures.

Despite such statements, few scientists have provided figures for the input and output of minerals over a wide area of landscape, although several, such as Ovington (1962), having closely studied the rate and nature of nutrient cycling in a particular ecosystem.

Crisp's (1966) study of the input and output of minerals for a small area of Pennine moorland contained within this particular water catchment has been the catalyst of this more theoretical and comprehensive study. Its aim is to attempt to draw together all the parameters involved in the through-put of the minerals Calcium (Ca), Sodium (Na), Phosphate (P) and Potash (K) within this area; further, to give approximate weights where possible and to indicate where this is impossible or impracticable within the scope of this study. Crisp concluded that whilst sheep-farming does have ecological effects on the moorland he was studying the principal factors responsible for the output of these minerals were the downstream flow of nutrients in solution and the loss of peat by erosion. His study area measured 83 ha of blanket-bog; the area under consideration in this study consists of 50,900 ha of diverse habitat almost entirely agricultural but managed under different farming practices. This study will demonstrate or suggest the comparative order of magnitude of the various sources responsible for the gain and loss of the four minerals by the catchment system as a whole.

## DESCRIPTION OF THE AREA.

Upper Teesdale, for the purposes of this study, is defined as that area contained within the water catchment of the section of the River Tees and its upper tributaries which feeds the River Guaging Station, maintained by the Northumbrian River Authority, just to the west (upstream) of Barnard Castle. The attached Maps, whose outline has been plotted and measured by the River Authority, demonstrate various facets of the area.

Pigott (1956) has described most of this area so illustratively as to warrant summary.

The catchment is located at the junction of the counties of Cumberland, Westmorland, Durham and the North Riding of Yorkshire on the eastern watershed of the Pennine hills. The upper reaches of the River Tees, and its tributaries, drain "an extensive area of desolate high-level moorland and eroding blanket-bog, entirely treeless and without habitation", largely consisting of eroding peat with the plant communities dominated by Calluna Vulgaris, Eriophorum Vaginatum, or a combination of both, as well as the grassland communities dominated by Agrostis festuca, Nardus stricta and Molinia caerulea. Land enclosed by stone-walls occurs as high as the 600 metre contour and such 'in-bye' land provides good grassland, particularly over the Carboniferous Limestone outcrops.

Below the 230 metre contour several villages and hamlets and one market-town, Middleton, occur in a district of declining population (as per 1961 census).

The rainfall of this catchment (as suggested on the map) increases rapidly westwards from about 32.5 inches (825.4 mm) per annum at Barnard Castle to as much as 90 inches (2,286 mm) per annum on the high fells. This is due to the 'rain-shadow effect' of the Pennine scarp in the face of the prevailing westerly winds. In the upper part snow tends to lie from January to May. Heavy storms are prevalent causing a rapid rise in the river level, sometimes by as much as between one and two metres in a matter of a few hours.

Manley (1945) observed that in the north Pennines a slight increase in elevation can markedly reduce the growing season. The sub-arctic climate tends to keep the tree-line low (probably about 600 metres) and contribute to the existence of rare Arctic-Alpine plants for which the dale is famed.

## PARAMETERS OF INPUT AND OUTPUT

### A. AGRICULTURE.

The traditional farming practices of the British uplands have been followed in Upper Teesdale for centuries since the clearance of the forests. The study area has been devoted entirely to stock-rearing with a certain amount of dairy-farming. Virtually no arable crops are grown; the small acreage recorded from the lower dale under the Ministry of Agriculture's June 1969 returns (150 ha) was mainly winter-feed for stock; no ploughing was undertaken that year in the upper dale.

Stobbs (1959) considered that at Middleton the characteristics of the upper dale - a large number of small farms, originally created for lead-miners in the 19th Century, competing for the better valley land and sharing the unimproved fell grazings - gave way to large farms, more characteristic of similar lowland areas, with a greater emphasis on dairying. The new Pennine Rural Development Board is encouraging the amalgamation of holdings into larger more viable units.

For the purposes of this study the area has been sub-divided into an Upper and Lower zone. The sub-catchment that drains into Dent Bank River Guaging Station (see maps) approximately coincides with this agricultural amelioration, the boundaries between the parishes of Middleton and

Newbiggin on the Durham side of the river and Holwick and Lunedale on the Yorkshire side, together with the 50 inches per annum rainfall isohyete. In the Upper Zone the area of enclosed pasture land is 11.5% of the total agricultural land but in the Lower Zone this increases to 29%.

However the pattern throughout the dale is one of three main enterprises: sheep, dairy cattle and beef-suckling herds. Newrick (pers. comm.), the local National Advisory Service Officer, considers that over the length of the dale there is only a gradual agricultural improvement in the valley bottom; the pattern of hill-sheep farming remains consistent throughout.

1. SHEEP.

Although one would expect the stocking rate of the hill-grazings to be uniform throughout the area, in fact it is calculated that it increases from 3 acres (1.214 ha) per breeding ewe in the Upper zone to 1.5 acres (0.607 ha) in the Lower; this is a further reflection of the agricultural improvement as one descends the catchment. Both stocking rates are low by some hill standards which are often expressed as 'the number of ewes per acre'.

The usual annual sequence of events is for the sheep to be grazed on the fells from June to October but, because of the severity of the climate and the paucity of vegetation, to be brought down to the inbye land from at least November to January and during any bad weather spells thereafter until lambing time. Lambing occurs in the inbye during April and it is usual for 80 lambs to be produced per 100 breeding ewes. Bad weather takes its toll of the flock; in some years 5% of the ewes and 10% of the lamb crop are lost and it can be more drastic than this. Wool-shearing takes place in July and August.

For the purposes of calculating the amounts of lamb and wool sold off the catchment each year it was estimated that 75% of the lamb crop was sold; 25% being ewe lambs were retained as replacements for the breeding flock. Some cast (old) ewes were replaced by purchased ewes and it was assumed that output and input balanced. Fat and store lambs sold between September and March average 65 lbs. (32.584 kg) liveweight; the chemical composition of such a carcase is:-

| | |
|---|---|
| Ca | 0.33 kg |
| P | 0.20 kg |

Na and K are negligible

A Swaledale ewe provides an average 3.25 lbs (1.617 kg) fleece each year whose chemical composition is:-

| | |
|---|---|
| Ca | 0.008 kg |
| K | 0.397 kg |

Na and K are negligible (per Crisp 1966)

Apart from supplementary feeding during the winter and at lambing time, the sheep graze the enclosed grassland, in conjunction with cattle, and the fells or hill-grazings.

Sugar-beet pulp, cereals, ewe cobs and sheep nuts are the popular concentrates fed, but for the purposes of this study it is taken that sheep nuts are fed throughout the area at the rate of 5 cwt (278.6 kg) per 100 sheep per annum.

## 2. DAIRY CATTLE.

The stocking rate of the dairy cows in the enclosed pasture land varies between 4 acres (2.037 ha) per cow in the Upper zone and 3 acres (1.214 ha) in the Lower. The corresponding sold milk production is 600 gallons and 800 gallons respectively (this is an artificial distinction; in reality there is a gradation). It is assumed that this amount is sold from the catchment. The 5% used for domestic consumption is additional to these figures.

0.75 calf is sold per dairy cow; some heifers are kept as herd replacements and the remainder, with the bull calves, are sold as stores or dairy heifers. The carcase composition of a 7 cwt (395 kg) store beast contains:-

| | |
|---|---|
| Ca | 5.040 kg |
| P | 2.785 kg |

Na and K are negligible (Agricultural Research Council 1965)

The dairy herd solely grazes the enclosed grassland and its diet is supplemented by 25 cwt (1,392 kg) each of cow cake and hay per head per annum. Their chemical composition is given in Table 5.

## 3. BEEF SUCKLING HERD.

These hardy animals are grazed on the fells for some of the year as well as the inbye. They produce and rear on average 0.75 calf each to a store beast weighing about 7 cwt (395 kg) on a comparatively meagre diet of grass, 25 cwt (1,392 kg) of hay and 3 cwt (167.16 kg) of cow cake, per annum.

## 4. STORE CATTLE.

These are fed 5 cwt (328.32 kg) of Sugar Beet pulp per head and 10 cwt (656.64 kg) of hay per head per annum. For the purposes of the calculations these form part of the 0.75 output per cow.

## 5. PASTURE MANAGEMENT.

Economics largely govern the extent to which the enclosed pasture is treated with artificial fertilisers. To quote the agent of one of the two main estates, referring to the upper dale, "the real problem in these difficult areas is of course drainage, and as long as there is inadequate drainage it is not very economic to apply artificial manures". Nevertheless it does occur, even in the upper dale, but only on some of the enclosed meadows. It is taken that all the grassland managed for hay is treated with artificial fertilisers each year at the average rate of 1 cwt/acre (28.1 kg/ha). The type appears to alternate between CCF (compound concentrated fertilisers) one year and Nitro-chalk the following, at least on some farms. CCF is used for the calculations whose chemical composition is given in Table 5.

In addition all the pasture land is treated with 10 cwt/acre (261.1 kg/ha) of Basic Slag every 5th year as well as receiving 2 tons/acre (5,500 kg/ha) of Ground Limestone every 8th year.

Hay is cut from June to September and the average yield employed in these calculations is 27.5 cwt/acre (7,179 kg/ha). It is calculated (see Table 6) that 788,000 kg and 2,475,000 kg are bought in to the Upper and Lower zones respectively.

## B. ROCK LEACHING.

Crisp (1966) was only able to assume that the marked difference between the input in precipitation and the output in the stream of the elements Ca, Na and K was caused by a solution from the rock and soil of the catchment. The difference between output and input for his 83 ha catchment gave :-

| | | |
|---|---|---|
| Ca | 3,716 kg | (44.77 kg/ha) |
| Na | 1,635 kg | (19.70 kg/ha) |
| K | 489 kg | ( 5.90 kg/ha) |

This suggests a massive contribution by the substrate of Ca and an appreciable one of Na and perhaps K. The figure of 44.77 kg/ha agrees remarkably well with that supplied by Hunter (pers. comm.) who found that limestone applied to land at the rate of 1 ton/acre took 10 years to leach completely away ( = 45.07 kg/ha/annum).

Below are reproduced the chemical analyses of limestone within this catchment area together with comparable figures for the other major bedrocks present.

% composition by weight

| | Limestone | Sandstone | Whin Sill |
|---|---|---|---|
| Ca | 34.9 ± 28.49 | 0.20 ± 16.39 | 6.36 - 8.87 |
| Na | 0.10 ± 0.08 | 0.06 - 3.35 | 2.03 - 2.39 |
| K | 0.10 ± 0.12 | 0.48 - 2.63 | 1.06 - 1.74 |
| P | 0.03 ± 0.02 | 0.06 - 0.42 | 0.22 - 0.46 |

(The data is reproduced from Clarke 1924 and Johnson and Dunham 1963).

It is evident that Ca is by far the most important element of all the surface rocks. The other elements would appear to be relatively insignificant.

The respective surface bedrocks of the catchment area are coloured in the map and occur for each zone in the following areal proportion :-

| | Upper | Lower |
|---|---|---|
| Limestone | 87% | 59% |
| Sandstone | 3% | 39% |
| Whin Sill (igneous) | 10% | 2% |
| | 100% | 100% |

To try and prophesy an order of Ca contribution by the limestone bedrock, Crisp's figures for the output of this element in the stream-water, extended to a 'per hectare' basis have been applied to the relative limestone area of each zone, and give :-

Upper - 849,000 kg

Lower - 775,500 kg

It is curious that although he found a major 'gain' in the stream-water of 19.70 and 5.90 kg/ha for Na and K respectively, the percentage composition of these minerals in the limestone underlying his catchment were only 0.10% each. This is quite disproportionate to the comparative figures for Ca (44.77 kg/ha and 34.9%). It would therefore seem less likely that the amounts of output of these elements calculated by extending Crisp's figures would be realistic. If so, they would be :-

| | | | | | |
|---|---|---|---|---|---|
| Na | - | Upper | 372,000 kg | Lower | 339,500 kg |
| K | - | Upper | 111,500 kg | Lower | 101,500 kg |

In the absence of experimental estimation of actual leaching rates on the site it is difficult to know what proportion of the output in solution in the river is derived from the rocks and soils of the catchment. One can only roughly estimate such output from the limestone; but the contribution of the sandstone and the Whin Sill is unknown. The problems of separating the various sources of the river's dissolved elements is discussed later.

## C. PEAT EROSION.

Crisp (1966) found that peat erosion was one of only two significant sources of mineral output from his blanket-bog catchment. He described the difficulties of measuring such an output in the stream by filtering the particles from the water. Only during flood conditions did an appreciable amount of peat descend the stream and of this only about 20% was trapped by the filters. The technical difficulties of efficiently filtering suspended material from a considerably greater flow of water further down the river are obvious and, so far as is known, this has not been attempted.

In the absence of such data one can only crudely estimate what might be lost from the catchment in the watercourses by extending Crisp's figures. This would seem to be open to less inaccuracy than to estimate the area of actively eroding peat; the latter could be misleading in that peat which is removed by wind and/or water is likely to be deposited elsewhere in the catchment and its minerals re-cycled. Eroded peat-channels and hags tend to accumulate loose matter. Also the thickness of the peat varies from a few centimetres to as much as 4 metres or more.

For the purposes of this study it is assumed that the greater part of the agricultural land above the enclosed crops and grass zone is peat-covered. Pennington (1969) states that the Pennine blanket-peat descends to 1200 feet (365 m). To allow for limestone outcrops the figure of 80% of the total unenclosed area was taken. It was estimated that in the Upper zone 500 ha and in the Lower 2,200 ha were used by non-agricultural interests, namely towns, villages, industry, woods, communications and so on. In fact the total peat cover was estimated for each of the zones at about 18,700 ha. Employing Crisp's figure of an output of 93,000 kg for 83 ha (3,764 kg/ha) dry-weight of peat in the watercourse together with the chemical constituents of :-

| | |
|---|---|
| Ca | 0.00431 % of dry-weight of peat |
| Na | 0.00025 |
| P | 0.00040 |
| K | 0.00184 |

It was calculated for the Upper zone that peat erosion caused the following output :-

| | | |
|---|---|---|
| Ca | 60,000 | kg |
| Na | 4,000 | kg |
| P | 6,700 | kg |
| K | 31,000 | kg |

However because of the lower rainfall it was supposed that only 2,500 kg/ha left the Lower zone per annum, and this gave the following figures :-

| | | |
|---|---|---|
| Ca | 40,000 | kg |
| Na | 2,700 | kg |
| P | 4,400 | kg |
| K | 20,600 | kg |

More accuracy may be gained by recording the relative number of heavy rain-spells because peat-erosion by water only markedly occurs during flood conditions. Several other factors, such as sheep-treading, strong winds, and fires, will probably affect the rate of erosion, but these are practically immeasurable.

To illustrate the possible wide variation in the estimated total output of minerals through peat erosion one can compare calculations with those using Allen's (1964) figures; for example Ca (0.0015%) would come out at approximately one-third the above figure and K (0.0022%) would be higher by one-quarter, giving 20,000 kg Ca and 38,750 kg respectively in the Upper zone. Similarly if the estimate of 80% of the unenclosed agricultural area being peat-covered be reduced to, say, 50% the figures of output would be reduced to 37,500 kg and 19,300 kg respectively. It is therefore only possible to give a relative order of magnitude of this factor.

## D. HEATHER BURNING.

As is the case with other traditional upland management practices controversy surrounds that of muirburn. This is undertaken periodically to provide regenerated young shoots of Calluna vulgaris as palatable and nutritious sheep and grouse feed. The critical age at which the crop is burnt depends on its yield and its capacity to regenerate after the burn.

Some, such as McVean (1959), condemn this practice as being detrimental to both soil and vegetation. Such unpleasant effects as bare lichen-encrusted patches, gullying in bare and soft peat, sheet erosion and accentuated hagging of peat are cited as the consequences of injudicious burning. It should be confined only to suitable conditions. Pearsall (1950) observed that muirburn leads to vegetational change on the wetter moors which are grazed by sheep. The tough leaf-bases of Eriophorum, Juncus and Nardus will persist after the fire and, aided by the selective grazing of the young Calluna, will extend their dominance. Conway and Miller (1960) showed that where heather-moor containing an appreciable amount of Sphagnum is severely burnt the water-retention capacity of that area is diminished, leading to swift run-off and increased peat-erosion.

From the point of view of this study at least three papers have been published about the chemical effects of muirburn. Allen (1964) gave the order of loss from one burn as, approximately :-

| | | |
|---|---|---|
| Ca | (13 kg) | 0.1 kg/ha |
| P | ( 4 kg) | 0.1 kg/ha |
| K | (23 kg) | 1 kg/ha |

(the figures in brackets are the content of the crop whose yield was 10,000 kg/ha).

Only a proportion of the K went up in smoke; the remainder, as was the Ca and P, was leached by precipitation. The loss through leaching would depend on the retentive capacity of the particular soil (he was working within this catchment system) and he suggested that the normal plant-soil equilibrium is only temporarily upset by muirburn and, in any event, the amount lost is more than replenished by the inputs from precipitation, soil weathering and the process of decay.

This was largely confirmed by the study of Robertson and Davies (1965) who gave relatively higher figures for loss and gain of the elements but, nevertheless, established that, other than in a severe burn, losses were (apart from P) replaced by the input in precipitation. The maximum loss from a crop as heavy as 29,000 kg/ha was :-

| | |
|---|---|
| Ca | 28 kg/ha |
| P | 7 kg/ha |
| K | 43 kg/ha |

and the replenishment by rainfall over the 10 years' burning rotation would be 70, 0 and 43 kg respectively.

Chapman's (1967) study of 12 years old rotational

Calluna on a Southern dry heath came to the same conclusion : that rainfall replenished all the elements' losses over the period except that of P which suffered a net loss of 2.08 kg/ha.

The dissenting voice is McVean's who claims that "the rate of extraction of soil-fertility hastened by muirburn far exceeds the rate of replacement by soil-weathering, nitrogen fixation and the natural addition of plant nutrients from the atmosphere". His belief that the fall in grouse numbers in west Scotland during the past century is probably due to the reduction in heather there, because of muirburn, is an interesting contrast to the Report of the Nature Conservancy (1968) which suggests that the burning of small fires should reverse this decline.

It is difficult to give other than an approximate figure for the acreage of heather annually burnt in this study area. Information from the Strathmore Estate (Turnbull pers. comm.), who manage all or most of the southern side of the river, suggests that an average of ca. 300 acres (121.4 ha) of heather are burnt each year on a 10 years rotation. This varies according to the availability of suitable weather and sufficient manpower. If one allows for a maximum of, say, 500 acres (202.3 ha) being burnt annually in the study area, using the higher figures of Robertson and Davies (above) the order of loss is calculated as :-

| | |
|---|---|
| Ca | 6,000 kg |
| P | 1,400 kg |
| K | 8,700 kg (Allen's figures would give 200 kg). |

Robertson and Davies did observe that a severe burn could increase the loss of P by 39% which would make the total loss by leaching of 1950 kg. No figure is given for Na which, judging from Chapman's relative results, is negligible.

Only a proportion of the K will go up in smoke and it could be that this is deposited elsewhere in the catchment. It therefore seems that the net loss of these nutrients from the study area is negligible and could even be nil, allowing for the leachates from burning being re-cycled at a lower altitude in the system. The muirburn more drastically affects the nature of the plant community, when aided by biotic and climatic factors, than the nutrient fund of the soil.

## E. PRECIPITATION.

Following the work of Gore (1968) and Allen et al (1968) the quantity of nutrients in the rainfall is derived from the mineral concentration and the average annual quantity of rainfall.

The mean annual figures of Gore's from Moor House National Nature Reserve were taken and extended to the catchment of this study. It was assumed that, owing to the prevailing wind being westerly, the chemical composition of precipitation at Moor House was that generally applying to the whole of the part of Teesdale within this study area, which is removed from the influence of industrial pollution. The rainfall zones are shown on the accompanying plans, as plotted by the River Authority.

It must be emphasised that the figures for the nutrient content of precipitation employed for these calculations provide a crude approximation for the study area. Allen et al. showed how the mean readings from five contrasted British sites gave a Standard Error of as much as 8.4%. They also found that on some sites there was a positive correlation between the rainfall amount and the content of all the elements except P; high rainfall was associated with a greater quantity of elements and vice-versa. This was also found by Gore. They speculated that the high Ca figures could be due to the influence of agricultural lime which has the capacity of drifting great distances at considerable heights. This could well come from the intensively agricultural Eden Valley to the west of this Pennine catchment.

Gore describes the sampling errors which were revealed by subsequent measurements elsewhere due to factors such as snow, household dust and smoke, bird droppings and the polythene collecting bottles. This study employed his figures corrected for such errors, but makes no attempt to adjust them according to the positive correlation mentioned above. They are :-

| | | |
|---|---|---|
| Ca | 9.53 | kg/ha |
| Na | 32.14 | kg/ha |
| P | 0.27 | kg/ha |
| K | 2.27 | kg/ha |

for a rainfall of 73.232 inches (1860.5 mm). The average rainfall of the Upper zone is taken as 65 inches (1651 mm) and of the Lower 40 inches (1016 mm).

F. MISCELLANEOUS.

Crisp measured the output of minerals in animal matter leaving the catchment both in and on the stream. In this study such a measurement would be both impracticable and unimportant; it is assumed that animal movement occurs within the catchment and that immigration is balanced by emigration by means other than down the river.

The commercial growing of trees could provide both a means of input and output; input through a proportion of young trees brought in and planted together with any artificial fertilising during their establishment; output in the occasional removal of timber. However as there is less than 0.5% of woodland in this agricultural catchment such a parameter is dismissed in this study.

The only other contribution to mineral input is that made directly by Man. It is estimated that about 600 residents in the Upper zone and 1,200 in the Lower (Rural District Councils pers. comm.) are not served by mains sewerage. Most of these, in addition to casual visitors, must be applying sewage effluent and domestic waste to the catchment. A rough calculation of the annual output of Ca and P in the urine of a 1,000 people (100 kg and 180 kg respectively) suggests that this factor is likely to be relatively insignificant.

## RIVER EFFLUENT

The estimation of output in the river caused by rock and soil leaching is made difficult by the effluent from sewage works (marked on the map). The estimated resident populations served by mains sewerage are nil in the Upper zone and 3,000 in the Lower; this figure is supplemented by an unknown visiting population using the public conveniences. No industrial effluent is discharged within the area. If the total population using the mains (in the Lower zone) was, say, 6,000 averaged over the year, their urine output would only be in the region of 600 kg Ca and 1,100 kg P; a certain percentage would be removed by the sewage works. The contribution of domestic effluent is unknown but it could provide a certain P output. Similarly human urine would contribute appreciable amounts of Na.

The only river analyses, which are reproduced below, are from one or both of the two Guaging Stations of Dent Bank and Barnard Castle. Each is a random sample taken when the river-flow was low. They merely provide a figure from which to calculate an order of magnitude of the annual river discharge of elements. At least a full year's sampling under all river conditions is required for an accurate figure. The River Authority as a rule are only interested in measuring P of the study's four elements and, so far as is known, no other sampling of these is done. The samples shown were especially taken by the River Authority and the writer.

| Gauging Station | Average flow in cumecs (Smith 1970) | One random sample (in ppm) and derived annual discharge in kg | | | |
|---|---|---|---|---|---|
| | | Ca | Na | P | K |
| Dent Bank | 7.636 | 15.4 | 4.5 | 0.1 | 0.5 |
| | | 3,708 | 1,083 | 24 | 120.5 |
| Barnard Castle | 16.258 | 14.7 | 7.2 | 0.2 | 1.6 |
| | | 7,536 | 3,692 | 102.5 | 820.5 |
| Net output from Lower zone (BC less DB) | | 3,828 | 2,609 | 78.5 | 700 |

(annual discharge shown in 1,000's kg)

## RESULTS

The mineral equation could be arranged in the following manner :-

| OUTPUT in : | = | INPUT in : |
|---|---|---|
| River solution | | Precipitation |
| + Heather-burn | | + Stock feedingstuffs |
| + Peat erosion | | + Agricultural fertilisers |
| + Stock and their products | | + Roch leaching |
| + x | | + x |

Table 10 tabulates these parameters of input and output and demonstrates the respective balancing figure (underlined) of either input or output whose source can only be the subject for speculation.

Figures 1-4 graphically represent the relative importance of each of the parameters (in each zone) within this catchment area.

It is assumed in this study that both natural processes and the pattern of land use has not materially altered over the years so as to regard the catchment system as being in a "steady state" (the only change could be an increase in dairy-farming since the war). This means that those quantities of minerals which are retained in the system during a particular year are balanced by those released from it and which had entered the system previous to that year. No attempt has been made in this study to establish the rate of cycling.

It should be emphasised that the measurement of the river solution, particularly of sewage effluent, is useful purely for the purpose of trying to estimate the output of such factors as rock-leaching and it has no direct bearing on the nutrient fund of the catchment.

## DISCUSSION

As was expected at the conception of this study, on the whole the mineral equation is not balanced by the calculated or estimated figures. This must largely be explained by the inaccuracy of the estimations and the difficulties of measuring the factors of so large an area in a matter of only a few months.

Nevertheless the Na and K inputs and outputs for the Upper zone are relatively close with only a difference of 71,000 kg and 64,500 kg respectively.

The wide difference of 1,481,000 kg for Calcium in the Upper zone suggests that considerably heavier leaching occurs there than is estimated, unless the random sample of river concentration be too high for a year's average.

The difference of 552,500 kg for Na and 405,000 kg for K in the Lower zone suggests that a substantial input is derived from sewage effluent (for which no estimates have been attempted). Sandstone leaching could contribute an amount of each element.

The difference of 896,000 kg of Ca in the Lower zone could be partially explained by an over-estimation of fertiliser application at 3,488,000 kg; farmers may in practice apply ground limestone less frequently than is supposed. Similarly there could be an over-estimate of Phosphate fertiliser application in both the Upper and Lower zones to give differences of 123,750 kg and 217,750 kg respectively unless the river sample be too low for a year's average.

It is evident that the input of elements, certainly of Ca, by rock-leaching is considerably greater than by all other factors except, in the case of Ca and possibly P, that by artificial fertilising. The former source is practically unlimited in an area of Carboniferous Limestone and it is possible that a greater quantity of elements is being leached from the rock than appears in the river solution. Agricultural sales deprive the catchment of a diminutive proportion of these elements, which amounts are amply replaced by agricultural practices, although it is uncertain what amount of manures, both organic and inorganic, contribute to the output in river solution.

It can be argued that a proportion of what mineral output in peat erosion there is was locked up ages ago; therefore this parameter is relatively unimportant in this context, as is heather-burning.

It is concluded that the nutrient bank of the catchment as a whole is not detrimentally affected by Man's activities when compared with natural processes. But this does not absolve him from causing localised ill-effects through land management practices such as were mentioned in the Introduction.

Judging by national trends in hill-country and conversations with local people, it would appear that the Upper Tees catchment is likely to maintain its present land-use pattern indefinitely even though the emphases may change.

Although increasing numbers of townsfolk are visiting the area for its several amenities the traditional way of farming is likely to continue. Holdings will continue to amalgamate, dairying is likely to diminish in importance under economic competition, and hill-sheep-farming and beef-cattle rearing will continue so long as the government maintains its specific subsidising (the mainstay of the farmer's income). Should the market for these products badly deteriorate or the hill-subsidies be removed then the stock will probably disappear from the fells and upper dale.

It is interesting to speculate on what will become of the area in such circumstances. In any event amenity and recreational demands are bound to rise together with that for further water impoundment. In view of the Forestry Commission's mandate to grow millions more acres of commercial timber, Teesdale as high as the 600 metres contour is as likely a target as any hill-land for new plantations. Such an industry would not be distracted by the inclement climate of the Upper zone. There is a relatively major State forest in an adjacent catchment.

The growing of timber may be more favourable than stock-farming for maintaining the nutrient fund because minerals are only removed in any quantity at the time of felling. These represent a loss per annum of :

| | |
|---|---|
| 15 kg/ha | Ca |
| 0.2 | Na |
| 14 | P |
| 7 | K |

for a mature Scots Pine (Pinus sylvestris) plantation (Ovington 1962).

In the present climate of opinion purely economic and social considerations will dictate what type of land-use prevails. The application of ecological principles in such circumstances could be likened to the repair of a worn face with cosmetics.

## NOTE TO TABLES AND FIGURES

The figures that follow represent the period of an average year. Those which are agricultural are largely derived from statistics and other information supplied by the Ministry of Agriculture.

The quantities of each parameter of input and output are shown in the Figures for each zone, side by side (left : Upper, right : Lower).

Table 1

LAND USE AREA (in ha)

| | Upper Zone | Lower Zone |
|---|---|---|
| Grass for hay | 1,100 | 3,100 |
| Grass for grazing | 1,350 | 4,750 |
| Total Grass | 2,450 | 7,850 |
| Arable | - | 150 |
| Hill grazings | 18,750 | 19,200 |
| Total agricultural | 21,200 | 27,200 |
| Non-agricultural | 500 | 2,000 |
| Sub-catchment | 21,700 | 29,200 |

Table 2

NUMBERS OF STOCK

| | Upper zone | Lower zone |
|---|---|---|
| SHEEP (to nearest 500) | | |
| Breeding ewes | 15,500 | 29,500 |
| Other adults | 500 | 1,000 |
| Total | 16,000 | 30,500 |
| Stocking rate | 1 / 1.214 ha | 1 / 0.607 ha |
| | | |
| CATTLE (to nearest 100) | | |
| Dairy cows | 800 | 3,600 |
| Suckler cows | 800 | 2,150 |
| Store cattle | 700 | 2,750 |
| Total | 2,300 | 8,500 |
| Stocking rate | 1 / 2.037 ha | 1 / 1.214 ha |

## Table 3

## STOCK DIETS AND PRODUCTION

in kg/head (unless otherwise stated) /annum

| | | | | |
|---|---|---|---|---|
| Adult sheep (allowing for lambs) | 125.37 | 328.32 / 100 sheep nuts | 0.6 lamb/ ewe @ 32.584 | 1.617 Wool |
| Suckler cows (allowing for calves) | 1,392.9 | 167.15 cow cake | 0.75 calf @ 395 | - |
| Dairy Cows (allowing for calves and herd replacements) | 1,392.9 | 1,392.9 cow cake | 0.75 calf or heifer @ 395 | 600 galls (Upper)<br>800 galls (Lower) milk |
| Store Cattle | 656.64 | 328.32 sugar beet pulp | sold @ 395 | - |

Table 4

## AGRICULTURAL FERTILISERS APPLICATION

Combined Concentrated Fertiliser - 12.5 % P, 12.5 % K.

Applied to all grass for hay every 5th year @ 261.1 kg/ha

( Nitro-Chalk - 33.33 % Ca )

Often applied in alternate years to CCF to all grass for hay @ 28.18 kg/ha.

Basic Slag - 14 % P, 40 % Ca

Applied to all grass every 5th year @ 261.1 kg/ha

Ground Limestone - 60 % Ca

Applied to all grass every 8th year @ 5,500 kg/ha

Ground Rock Phosphate - 50 % Ca, 30 % P

An estimated 350 tons is applied to grass in the wetter areas.

(Upper : 200 ha Lower : 80 ha) instead of Basic Slag @ 557.2 kg/ha

Table 5

CHEMICAL CONTENTS (in kg)

| STOCK & THEIR PRODUCTS | Ca | Na | P | K |
|---|---|---|---|---|
| Fat or store lamb of 32.584 kg | 0.33 | - | 0.20 | - |
| Wool (1.617 kg fleece) | 0.008 | - | - | 0.397 |
| Store calf of 395 kg | 5.04 | - | 2.785 | - |
| Milk (% composition) | 0.17 | - | 0.20 | 0.20 |
| **STOCK FEEDINGSTUFFS (% composition)** | | | | |
| Hay | 1.0 | - | 0.50 | 1.60 |
| Cow cake and sheep nuts contains : | | | | |
| 17 parts Barley | 0.07 | - | 0.84 | 0.57 |
| 1.5 parts Ground Nut Cake | 0.20 | - | 1.30 | 1.50 |
| 1.5 parts Soya Bean Meal | 0.30 | - | 2.10 | 1.90 |
| Sugar Beet Pulp | 1.20 | - | 0.17 | 1.34 |
| **FERTILISERS (% composition)** | | | | |
| CCF | - | - | 12.5 | 12.5 |
| (Nitro Chalk) | 33.33 | - | - | - |
| Basic Slag | 40 | - | 14 | - |
| Ground Limestone | 60 | - | - | - |
| Ground Rock Phosphate | 50 | - | 30 | - |

(a blank indicates that the element is either absent or negligible)

Table 6

HAY BUDGET (in 1,000 kg)

| | Upper zone | Lower zone |
|---|---|---|
| Estimated Consumption | | |
| Adult sheep | 2,000 | 3,800 |
| Dairy cows (including calves) | 1,114 | 5,015 |
| Suckler cows (including calves) | 1,114 | 3,000 |
| Store cattle | 460 | 1,806 |
| Total | 4,688 | 13,621 |
| Less amount grown (estimated) | 3,900 | 11,146 |
| = bought in and consumed | 788 | 2,475 |

## Table 7

## INPUT THROUGH STOCK FEEDINGSTUFFS

### in 1,000 kg

| | Ca | | P | | K | |
|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Lower |
| Cattle concentrates | 4.0 | 16.15 | 50.3 | 216.5 | 45.6 | 194.8 |
| Sheep concentrates | 0.050 | 0.1 | 2.1 | 4.0 | 1.75 | 3.4 |
| Total hay | 7.9 | 24.7 | 4.0 | 12.4 | 12.5 | 39.6 |
| Total | 12.0 | 41.0 | 56.5 | 233.0 | 60.0 | 238.0 |

(Na is negligible)

Table 8

TOTAL FERTILISERS INPUT

in 1,000 kg

| | Ca | | P | | K | |
|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Lower |
| CCF | - | - | 2.5 | 7.0 | 2.5 | 7.0 |
| (Nitro Chalk) | 10.5 | 29.5 | - | - | - | - |
| Basic Slag | 47.0 | 162.5 | 16.5 | 57.0 | - | - |
| Ground Rock Phosphate | 140.0 | 56.0 | 83.5 | 33.5 | - | - |
| Ground Limestone | 1,011.0 | 1,240.0 | - | - | - | - |
| Total | 1,208.0 | 3,488.0 | 102.5 | 97.5 | 2.5 | 7.0 |

(Na is negligible)

Table 9

## OUTPUT IN STOCK AND THEIR PRODUCTS

in 1,000 kg

| | Ca | | P | | K | |
|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Lower |
| CATTLE | | | | | | |
| Calf/store | 6.0 | 21.2 | 3.3 | 11.7 | - | - |
| Milk | 4.0 | 24.0 | 4.8 | 28.8 | 4.8 | 28.8 |
| SHEEP | | | | | | |
| Lamb | 3.1 | 6.0 | 1.9 | 3.6 | | |
| Wool | 0.25 | 0.5 | 0.1 | 0.2 | 1.2 | 2.3 |
| Total | 10.0 | 51.0 | 10.0 | 44.0 | 6.0 | 31.0 |

Table 10

## TOTAL OF INPUTS AND OUTPUTS (in 1,000 kg)

| | Upper | Lower | | Upper | Lower |
|---|---|---|---|---|---|
| CALCIUM | | | | | |
| River solution | 3,708 | 3,828 | Precipitation | 233 | 509.5 |
| Heather-burn | 5 | 1 | Stock feeds | 12 | 41 |
| Peat erosion | 60 | 40 | Fertilisers | 1,208 | 3,488 |
| Stock etc. | 10 | 51 | Roch leaching | 849 | 777.5 |
| | - | 896 | | 1,481 | - |
| | 3,783 | 4,816 | | 3,783 | 4,816 |
| SODIUM | | | | | |
| River solution | 1,083 | 2,609 | Precipitation | 786 | 1,719.5 |
| Heather-burn | - | - | Stock feeds | - | - |
| Peat erosion | 4 | 2.5 | Fertilisers | - | - |
| Stock etc. | - | - | Rock leaching | 372 | 339.5 |
| | 71 | | | - | 552.5 |
| | 1,158 | 2,611.5 | | 1,158 | 2,611.5 |
| PHOSPHATE | | | | | |
| River solution | 24 | 78.5 | Precipitation | 6.5 | 14.5 |
| Heather-burn | 1.25 | 0.25 | Stock feeds | 56.5 | 233 |
| Peat | 6.5 | 4.5 | Fertilisers | 102.5 | 97.5 |
| Stock etc., | 10 | 44 | Rock leaching | - | - |
| | 123.75 | 217.75 | | - | - |
| | 165.5 | 345 | | 165.5 | 345 |

## Table 10 (Continued)

| | Upper | Lower | | Upper | Lower |
|---|---|---|---|---|---|
| **POTASH** | | | | | |
| River solution | 120.5 | 820.5 | Precipitation | 55.5 | 121.5 |
| Heather-burn | 7.5 | 1 | Stock feeds | 60 | 238 |
| Peat | 31 | 20.5 | Fertilisers | 2.5 | 7 |
| Stock etc. | 6 | 31 | Rock leaching | 111.5 | 101.5 |
| | 64.5 | | | | 405 |
| | 229.5 | 873 | | 229.5 | 873 |

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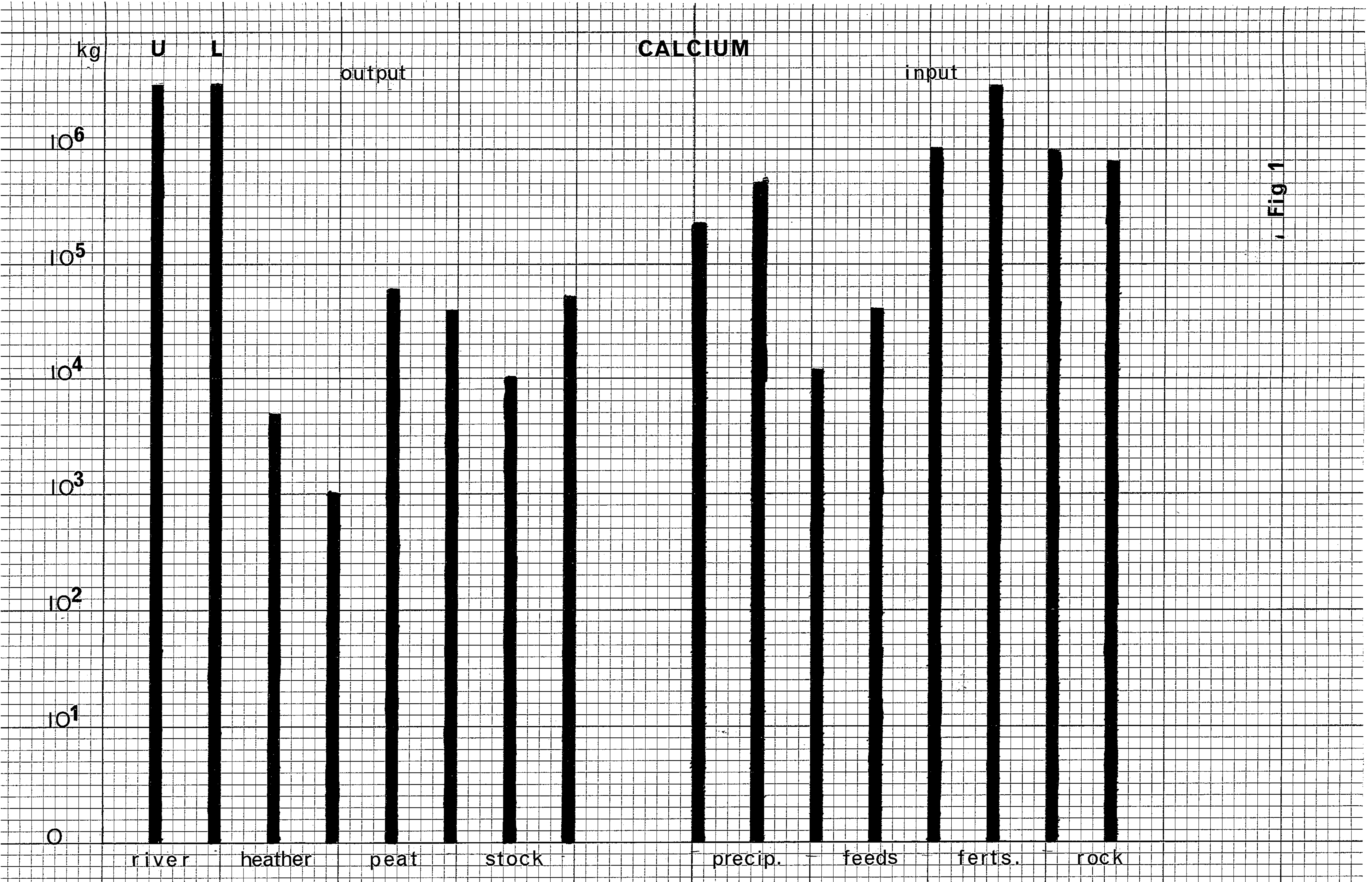


CALCIUM
kg
U
L
output
input
10⁶
10⁵
10⁴
10³
10²
10¹
0
river
heather
peat
stock
precip.
feeds
ferts.
rock
Fig 1


Fig 1

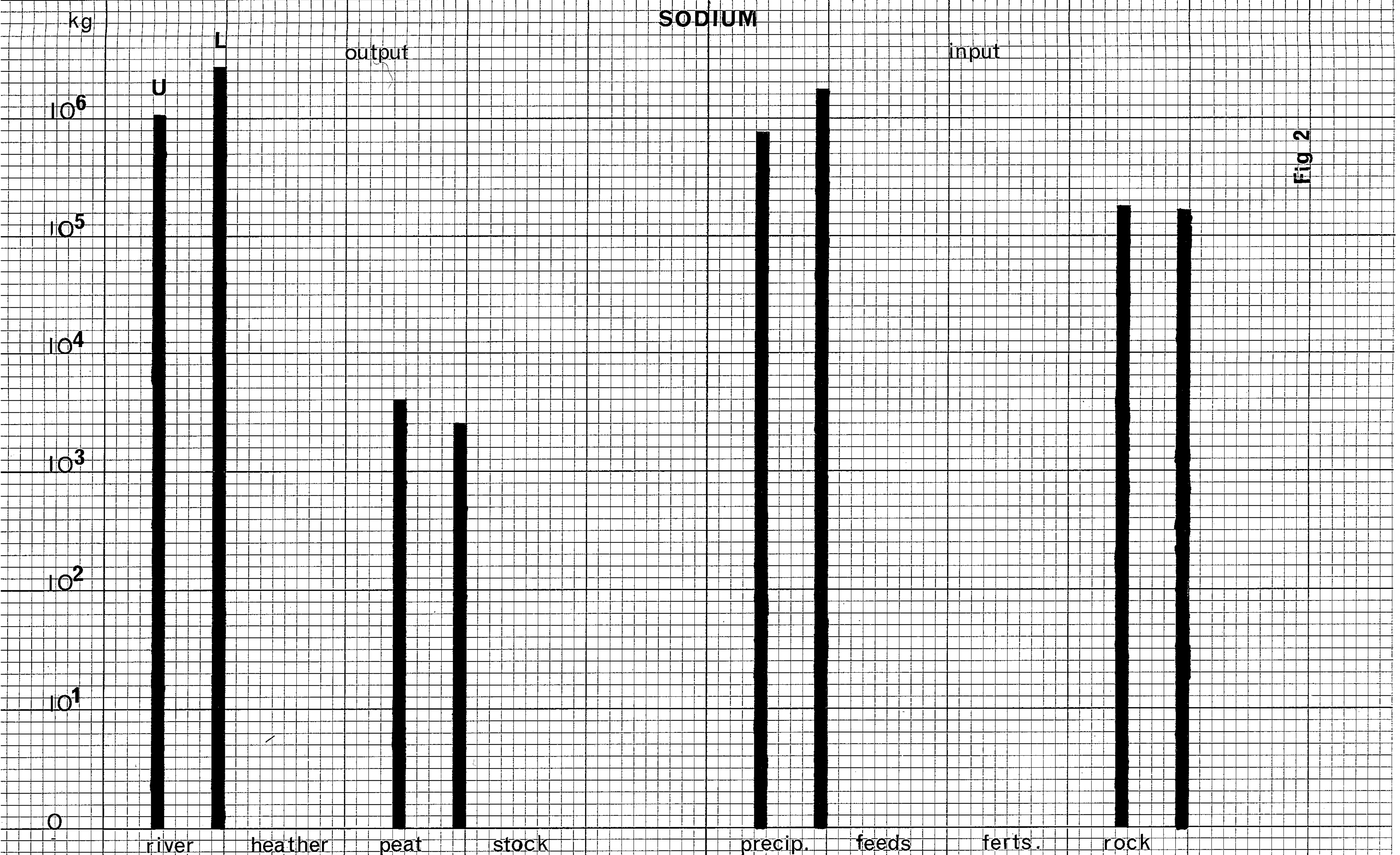
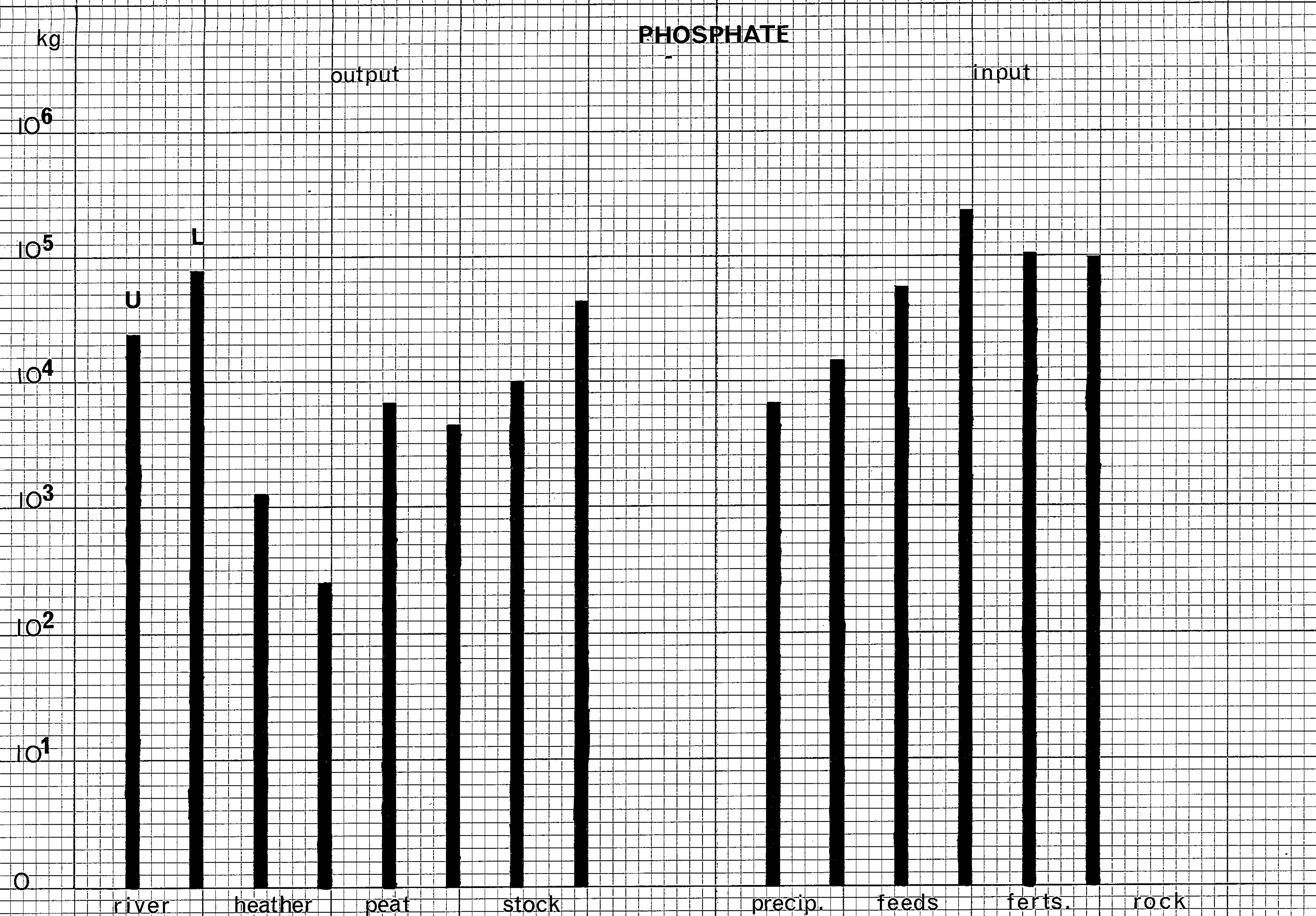

SODIUM
kg
output
input
U
L
IO6
IO5
IO4
IO3
IO2
IO1
0
river
heather
peat
stock
precip.
feeds
ferts.
rock

Fig 2

Fig 2



PHOSPHATE
kg
output
input
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
0
U
L
river
heather
peat
stock
precip.
feeds
ferts.
rock

Fig 3

Fig 3

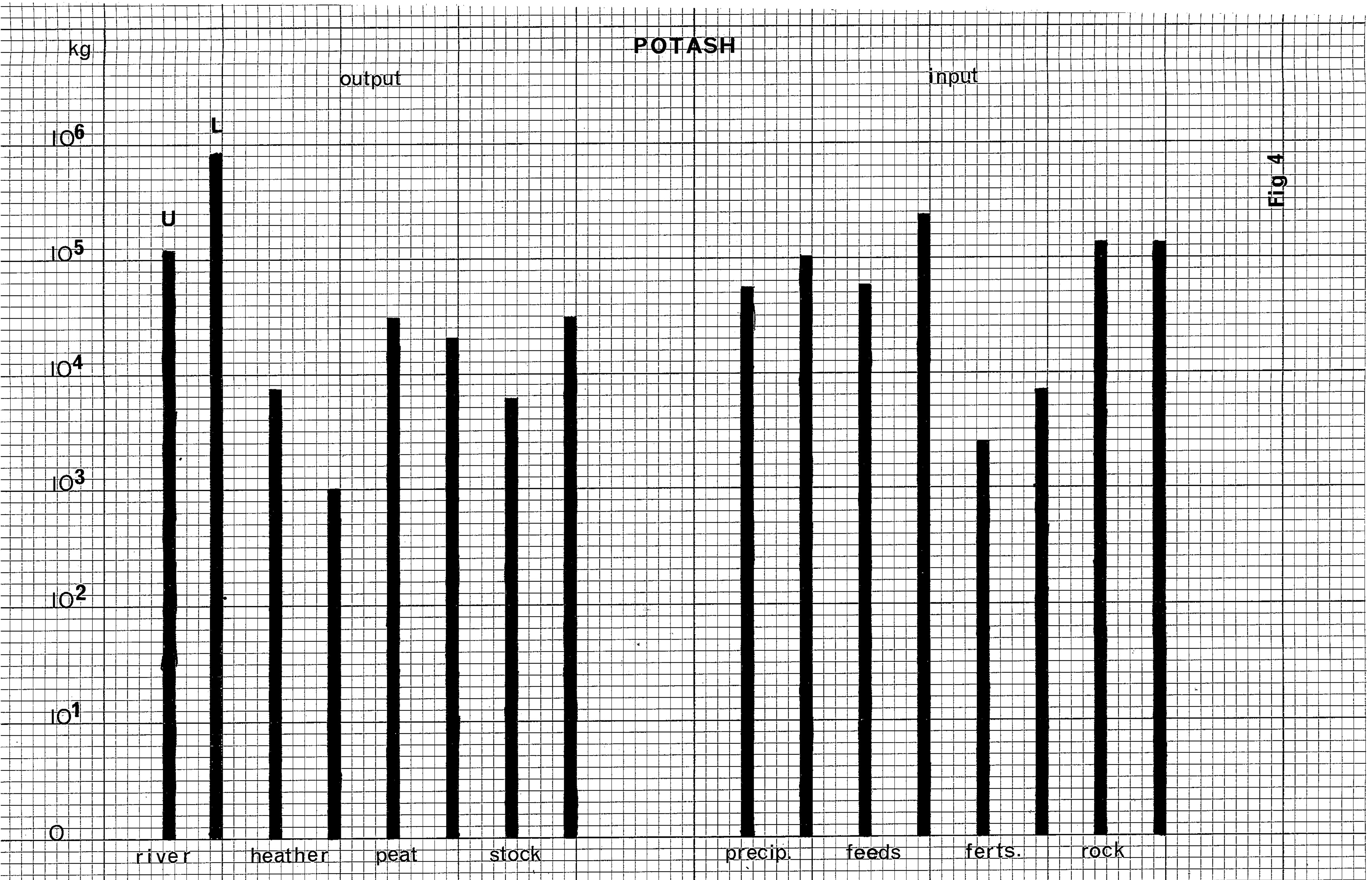

POTASH
kg
output
input
U
L
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
$10^1$
0
river
heather
peat
stock
precip.
feeds
ferts.
rock
Fig 4

Fig 4


THE UPPER
TEES CATCHMENT
KEY
Surface Bedrock
BLUE Limestone
RED Whin Sill (igneous)
ORANGE Sandstone
Scale : 1" to 1 mile
CATCHMENT BOUNDARY
SUB-CATCHMENT
RIVERS
RAINFALL
LAND USE
TROUT BECK
MAIZE BECK
R. TEES
G.S.
G.S.
DENT BANK
MIDDLETON IN TEESDALE
BARNARD CASTLE
G.S.
R. TEES
70"
70"
50"
50"
32.5"
32.5"

# AGRICULTURAL LAND USE AREAS