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Institute of Freshwater Ecology

THE DEVELOPMENT OF A GIS-BASED CATCHMENT MODEL TO ASSESS THE EFFECTS OF CHANGES IN LAND USE ON WATER QUALITY

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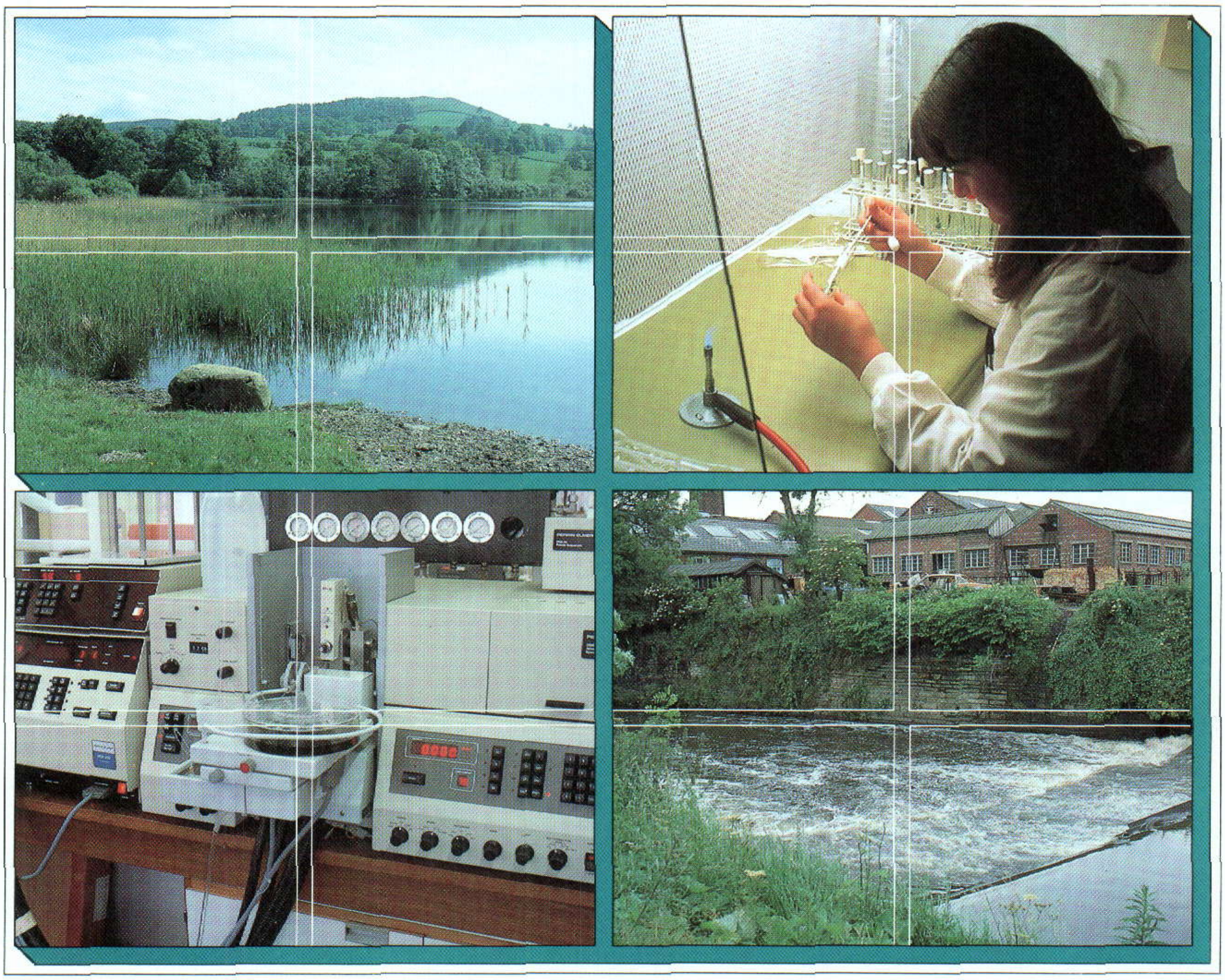
Final Report to National Rivers Authority, North West Region (March, 1995)



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THE DEVELOPMENT OF A GIS-BASED CATCHMENT MODEL TO ASSESS THE EFFECTS OF CHANGES IN LAND USE ON WATER QUALITY

The Institute of Freshwater Ecology is part of the Terrestrial and Natural Environment Research Council's Centre for Ecology and Hydrology.

SUMMARY

The catchment of Bassenthwaite Lake has been used to illustrate the potential use of Geographical Information Systems (**GIS**) in the management and control of eutrophication in freshwater lakes. Some of the cartographic capabilities of the GIS package (**ARC/INFO**) are illustrated in Figures 1, 3, 5, 6 and 7. The system was used to identify and quantify the main non-point sources of phosphorus (**P**) within the catchment using total phosphorus (**TP**) export coefficients from published sources. It was also used to examine the likely effects of changes in land use between 1972 and 1988 on the TP load to the Bassenthwaite Lake.

About 37% of the TP entering the lake appeared to originate from runoff. It was estimated that the relative importance of TP from this source would increase to more than 50% if the TP load from the Keswick sewage treatment works were reduced by 80%, as proposed.

By comparing the GIS predicted TP loads with the measured TP loads, it was possible to identify streams which received an additional TP input from point sources. Most of these were known to receive sewage effluent, but subcatchment 9 (Cottage Wood) seemed to have an additional TP load from an unidentified source. This was later found to be almost entirely due to two pollution incidents. These may have been caused by fertiliser spillage or septic tank overflow.

Changes in land use between 1972 and 1988 were easily identified using the GIS, although this would have been very difficult to do using traditional statistical techniques. From this information, there appeared to have been an increase of 3.7% in the TP load from diffuse sources, and an overall increase of 1.4% in total TP load, over this time period.

Correlation analyses suggested that the published export coefficients used in this study were not entirely appropriate for the Bassenthwaite catchment. Additional work is needed to develop export coefficients for specific use in this catchment. Because the work has been carried out on a digital database, these results could be easily incorporated into the existing GIS when better data become available.

This study clearly illustrates some of the applications of GIS to catchment management problem. The methods used have general application to other lake catchments and could easily be expanded to cover the whole area of the Lake District National Park.

CONTENTS

1. INTRODUCTION

1.1 Background

The prevention of pollution and the improvement of water quality has become an important issue over the past 30 years. Blooms of blue-green algae have become increasingly common, and these have raised public awareness of pollution and its effects on water quality. There are now many pressures, public and regulatory, on organisations such as the National Rivers Authority to improve the situation, especially in areas where water is used for public amenity purposes or drinking water supply.

The increased incidence of blue-green blooms is closely linked to nutrient enrichment (eutrophication), particularly the increase in phosphorus (P). In many waters, it has been shown that P availability is the main limiting factor on algal growth, so this nutrient is usually the first to be targeted for control. Over the past few years, efforts have been made to reduce the amount of P entering freshwater systems from point sources such as sewage treatment works (STWs) and industrial discharges. This is partly because these sources are easy to identify and control. As a result, P from non-point (diffuse) sources is becoming relatively more important and it is P from these sources which must now be considered if the total P load to many lakes is to be reduced still further.

In order to control non-point sources of P, it is necessary, first, to discover how much P is coming from diffuse sources and where it is coming from. This requires the manipulation and analysis of large volumes of spatial (geographical) data. This is very difficult to do by traditional methods, but can easily be achieved using a Geographical Information System (GIS).

3.1 Geographical information systems

A GIS can be defined as "An organised collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced data" (ESRI, 1992). In terms of the present study, it allows us to analyse the catchment of Bassenthwaite Lake, and its subcatchments, and answer questions which relate not only to the different attributes within the catchment (aspatial data) but also to their extent and location (spatial data). For example, we can determine the areal extent of a particular land use type, such as forest, and where that forest is, or how much P is coming off the catchment and where it is coming from. GIS is, thus, an extremely powerful tool which has many applications in the management of freshwater systems at the catchment and subcatchment level.

1.2 Aims of the project

The main aim of this project was to illustrate some of the applications of GIS in the regulation and management of freshwater systems. As an example, the system has been used to quantify non-point sources of P within the catchment of Bassenthwaite Lake and estimate the likely effect of changes in land use between 1972 and 1988 on water quality.

It was possible to do some preliminary analyses of the data on only one nutrient (P), in the time available for this project. Hopefully, later on, it will be possible to extend these analyses to other nutrients, and include some temporal variation in the predicted nutrient loadings and flows. The system could also be extended to evaluate possible management strategies (such as buffer strips) for relieving the eutrophication problem.

2. DATABASES

2.1 Rainfall data

Daily rainfall figures for 1993 were provided by NRA. These had been collected from 3 rain gauges within the Bassenthwaite catchment. Mean annual rainfall for the catchment was calculated from the average of these figures.

2.2 Water quality and flow data

Data on total phosphorus (**TP**) concentration and flow for the main feeder streams (**Table 1**) were supplied by NRA. These data had been collected as part of an intensive inflow monitoring programme (3 to 8-day intervals) carried out between January and August, 1993 (Hilton *et al.*, 1993). As such, this dataset was far more detailed than that routinely collected by NRA for this catchment. Daily TP loads for each stream were calculated as the product of the measured TP concentration and the daily flow. These products were then averaged and multiplied by 365 to give the annual TP load for each stream.

Total annual flow for each stream was estimated by multiplying the mean daily flow by 365. The annual flow at gauge 14 was less than that measured upstream at gauge 15. This was thought to be due either to an error in the readings taken at gauge 14, or their interpretation. Flow data from gauge 14 were, therefore, ignored in the analysis of the relationship between drainage area and flow (see **Sections 3.2** and **4.2**) and approximated from the flow/area relationship determined in **Section 4.2** for the remaining analyses.

Additional information on the location of possible sources of sewage effluent within the catchment was also provided by NRA, together with an estimate of the size (expressed as population equivalents) of each STW. The exact locations of flow gauges, water chemistry sampling points and likely sources of sewage effluent (**Figure 1**) were supplied by NRA as

National Grid coordinates. These were typed into ASCII files and incorporated into an ARC/INFO coverage using the GENERATE command.

2.3 Catchment and subcatchment definitions

The catchment of Bassenthwaite Lake was manually interpreted from the stream network and elevation contours on a 1:50,000 Ordnance Survey Landranger Series paper map. Subcatchments were defined in relation to the position of the flow gauges on each inflow stream (**Figure 1**). As some flow gauges were situated a significant distance from the mouth of the stream, it was possible to assess the measured flow in relation to the actual area drained by defining subcatchment area in this way. As a consequence, a few small areas near the shore of the lake, do not form part of the stream subcatchments as defined in the present study. These account for less than 3% of the total area of the Bassenthwaite catchment.

The outlines of the catchment and subcatchments were entered into ARC/INFO by digitising. In this form, each outline was used as a 'cookie cutter', i.e. superimposed on other spatial datasets, such as those of land cover and elevation. (This allowed information about each subcatchment to be analysed separately.)

2.4 Elevation data

Elevation data were provided by the MacCaulay Land Use Research Institute (**MLURI**), Aberdeen. These data were originally digitised by the Mapping and Charting Establishment (**MCE**) from 1:250,000 Ordnance Survey paper maps. They were supplied in MCE proprietary format and were imported into ARC/INFO via an intermediate format (ERDAS v.7.4 16-bit LAN file). This could be read by ARC/INFO's raster data manipulation software (GRID) using a utility called IMAGEGRID.

The data were converted to a 2-dimensional matrix (raster) of elevation values where each raster element (pixel) represented an area 100 m by 100 m on the ground. These data described the topography of the catchment at 100-m intervals and could be manipulated by the digital terrain model analysis software in ARC/INFO to generate information on the slope and aspect of each pixel, and thus, for each subcatchment.

2.5 Land cover data

Land cover data for 1972 and 1988 were supplied by the Lake District National Parks Authority, Kendal, in SPANS raster format, with aresolution of 20.03m per cell. These data had originally been compiled from 1:25,000 scale aerial photographs of the area which had been interpreted, digitised and converted into thematic maps for the Countryside Commission, by Silsoe College, Bedfordshire. There was no utility available to export the data directly into ARC/INFO GRID, so, again, it was necessary to use an intermediate format (ERDAS v.7.4 8-bit LAN file) which could be read by ARC/INFO.

The two land cover sets were marginally mis-registered in the SPANS system and this lead to anomalies in the land use change data when the two datasets were compared. This was corrected in the transfer process so that changes in land use identified subsequently using ARC/INFO were due only to real changes or photo-interpretation error. The degree of photo-interpretation error in these datasets was thought to be very small (*ca.* 2-3%).

For the purposes of this study, it was assumed that there had been very little change in land use between 1988, when the aerial photographs were taken, and 1993, when the water quality data were collected.

2.6 Phosphorus export coefficients

The original land cover dataset contained 38 classes of land cover. For the present study, these were reduced to 12 land cover groups (**Table 2**). P export coefficients were obtained from the literature for each group, except 'inland bare rock' and 'other' (**Table 3**). P export from these sources was thought to be low and was, therefore, estimated to be approximately 0.1 kg TP ha^{-1} y^{-1} in both cases for the purposes of this study. It should also be noted that the values given for urban/rural settlement refers to runoff from these areas, but excluding TP losses *via* sewage treatment systems.

3. INVESTIGATIVE METHODS AND ANALYSIS

3.1 The GIS

This project was carried out using ARC/INFO, a Geographical Information System (GIS) which was developed by the Environmental Systems Research Institute Inc. (ESRI). The system was used to create a GIS of the catchment of Bassenthwaite Lake containing the following map overlays (coverages):

- lake outlines
- drainage networks
- catchment and subcatchment boundaries
- land use
- sewage treatment works locations
- rain gauge locations
- sampling sites.

These coverages were then be combined, subtracted or subsampled to perform the spatial analyses described below.

3.2 Spatial analyses

Accurate estimates of the extent of the entire catchment, and its constituent subcatchments, were obtained from the GIS. The relationship between measured annual stream flow and subcatchment area was investigated using the curve fitting utility in the SIGMAPLOT graphics software package. However, the readings from flow gauge 14, which is downstream of flow gauge 15 but registered a lower rate of flow, were ignored in these analyses.

The land cover data for 1988 were summarised in terms of absolute area and percentage cover for the entire catchment and each subcatchment. The TP load from each land use category was then predicted for each subcatchment, and for the catchment as a whole, by assigning the TP export coefficients obtained from the literature to each area in turn. The results were summed for each subcatchment and compared to the measured annual loads.

Areas of land cover which had changed between 1972 and 1988 were highlighted using analysis facilities available in ARC/INFO. The change in TP load which was likely to have resulted from these changes was estimated using the TP export coefficients for each land cover type obtained from the literature (**Table 2**).

The relationships between a variety of subcatchment characteristics including runoff volume, area, mean slope, land cover type, etc., were investigated by correlation analysis.

4. RESULTS

4.1 Catchment and subcatchment areas

The total area of the Bassenthwaite catchment, excluding areas of standing water, is 34,740 ha. Most of the subcatchments were less than 5000 ha. (range 38 ha. to 4624 ha.), although subcatchment 15 was very much larger (23,861 ha.) (**Table 4**). The latter included two large waterbodies (Derwentwater and Thirlmere), a water pumping system (within the catchment of Thirlmere), and several STWs (**Figure 1**), all of which complicated its hydrology and TP budget. Data from this subcatchment were thus of limited use in many of the analyses carried out. This largearea would need to be further sub-divided into more manageable units for any meaningful analyses to be carried out in any future studies.

4.2 The relationship between stream flow and catchment area

Figure 2 shows that there was a close linear relationship ($r^2 = 1.0$) between annual stream flow and drainage area within the catchment of Bassenthwaite Lake. This relationship was best described by the equation:

$$f = 1.2a$$

where f = annual flow (m^3)
a = subcatchment area (m^2)

The slope of this line (1.2) probably reflects the net precipitation in this area for 1993, i.e. mean rainfall (1.7 m yr^{-1}) less losses due to evapo-transpiration (approximately 0.45 m yr^{-1} (Institute of Hydrology, pers. comm.) and groundwater seepage. If so, the slope of the regression line would be expected to be steeper in wetter years and shallower in drier years.

4.3 Land cover 1988

Land cover for the entire catchment of the lake in 1988 is shown in **Figure 3**. More than half of the catchment is covered by upland moor, 21% by improved pasture and 12% by forestry (**Table 5**). There are also small scattered areas of rough grazing (5.2%), inland bare rock (4.8%), urban/rural settlement (1.8%), arable land (0.2%) and 'other' land uses (0.6%). Details of the areal extent and percentage cover of each land use type within each subcatchment are given in **Appendix I.**

4.4 Predicted TP inputs from diffuse sources in 1988

The estimated TP loss from each land cover type within the Bassenthwaite catchment is given in **Table 5.** Most of the phosphorus comes from upland moor, improved pasture and forestry in roughly equal amounts. A further 7.5% comes from urban/rural settlement runoff, while 5.8% is attributable to bogs and peat and the remaining land use types. In total, an estimated 6,800 kg TP yr^{-1} is lost in runoff from this catchment.

In reality, not all of the 6,800 kg TP yr^{-1} would reach Bassenthwaite Lake beacause something approximating to 50% of the material entering Derwentwater and Thirlmere will be retained. by these waters (Bailey-Watts *et al.*, 1992). The actual amounts 'intercepted' by these lakes were not taken into account because the TP retention coefficients for Derwentwater and Thirlmere were unknown. However, these factors should be taken into account in any future analyses.

4.5 Predicted TP inputs from point sources

As the total TP load to Bassenthwaite Lake, as estimated from the measured data, approximates to 18,400 kg yr^{-1} (**Table 7**), 11,600 kg TP yr^{-1} (i.e. 18,400 - 6,800 kg TP yr^{-1}) probably comes from other sources, such as industry, STWs and septic tanks. As this catchment lies within the Lake District National Park, there is little industry in the area and the contribution from this source is likely to be small. So, most of the TP which is not accounted for by in runoff from land is almost certainly due to human habitation, i.e. permanent residents and tourists.

Data supplied by NRA suggest that STWs within the catchment serve *ca.* 27,000 people. Of these, some 25,000 are served by the Keswick STW which contributes 6,900 kg TP yr^{-1}. This suggests that the *per capita* export of TP from this STW is about 0.28 kg TP yr^{-1}. If this figure is used for all STWs within the catchment, then STW effluent probably contributes only about 7,500 kg TP yr^{-1} to the total load to the lake. However, as the *per capita* TP export coefficient calculated for the Keswick STW is much lower than that given in the literature for other STW effluents (e.g. 1 kg TP $capita^{-1}$ yr^{-1} given by Harper, 1993) it seems likely that this large STW is more efficient at removing TP than the smaller STWs. If this is the case, the total TP contribution from STW effluent may be as high as 9000 kg TP yr^{-1}.

In addition, families in the more remote areas rely on septic tanks for the disposal of their sewage. While seepage from these tanks is an unknown quantity in terms of the whole TP budget it may contribute much of the TP which remains unaccounted for, i.e. approximately 2,600 - 4100 kg TP yr^{-1}).

It should also be noted that the above figures are very approximate because they are, mostly, calculated on the basis of TP export coefficients that were originally determined for other catchments which differ in character from that of Bassenthwaite Lake (see **Section 4.5**). The results could obviously be improved by deriving more appropriate TP export coefficients. This could be achieved, in part, by taking account of other factors which affect the rate of TP loss from particular types of land use (e.g. soil type and underlying geology, slope, local farming and forestry practices). Further improvement could only be attained by obtaining field data to validate which could also be used to validate the predictions.

4.6 The relationship between subcatchment features

The relationships between percentage cover of the different land use types and other catc hment characteristics, such as mean slope, area, annual TP load and annual flow, were investigated for subcatchments 1&2, 3-6, 8-13 using correlation analysis (**Table 6**). There was a significant positive correlation between annual flow and subcatchment area, as discussed in **Section 4.2.** However, there was also a positive correlation between annual flow and the percentage of upland moor. This is probably an artefact, created by the method of defining the subcatchments. All of the flow gauges, upon which the subcatchments were defined, were close to the edge of the lake. So, the larger subcatchments, which produced the greatest runoff volumes (flows), also tended to include more upland moor than the smaller subcatchments (see below). In addition, there was a marked positive correlation between flow and TP load in the streams. This probably reflects the fact that these variables are not independent, as TP load is calculated as the product of TP concentration and flow. The positive correlation between percentage of arable land and flow is more difficult to explain, but is probably due to the fact that the larger subcatchments tended to have higher percentage of arable land.

Urban/rural development, improved pasture and rough grazing were significantly but negatively correlated with the mean slope of the catchment. Clearly, the more gently sloping parts of the catchment tended to be used for these purposes. In contrast, coniferous forests were positively correlated with average slope and were more commonly found on the more steeply sloping hillsides. Correlation analyses between different types of land use in this area suggests that the uplands in this area are dominated by forestry and moorland, while rough grazing, improved pasture and urban/rural settlement are more common on the lower slopes.

4.7 Some possible explanations for the differences between predicted and measured values of TP loss

Table 7 compares the measured TP load in each feeder stream with that predicted by using export coefficients. It has been assumed that the measured values (based on field samples) more accurately reflect the total TP load to the lake than the predicted values. The predicted values generally over-estimated TP load in the subcatchments which had no sewage effluent, and underestimated it in those subcatchments which did contain sources of sewage effluent. The exception to this was subcatchment 9 in which there had been two pollution incidents during the course of the field measurements (**Figure 4**); these events had markedly increased the normally low TP load to this stream. When the data corresponding to these events were excluded from the loading calculation, the mean annual figure (from land use) was only 46 kg. This value which was much closer to the GIS-predicted value of 19 kg TP yr^{-1} than the previous 'measured' value of

202 kg TP yr^{-1}. Although it was impossible to identify the cause of these pollution incidents from the available data, fertiliser spillages or overflows from a septic tank during heavy rainfall may be implicated. If it were the latter case, the close proximity of this septic tank to the stream might also explain the continuing high background TP load from this subcatchment (relative to that predicted to come from land runoff).

There is also evidence that some of the export coefficients used in this study did not accurately reflect the TP loss rates of some land use categories within this catchment. For example, when the data for the subcatchments without sources of sewage effluent (excluding subcatchment 9, see above), were examined by correlation analysis, it became clear that there was a strong correlation ($p < 0.05$) between over-estimation of the TP load and the percentage coniferous forest in the catchment (**Table 8**). This suggests that the published export coefficients for this type of land use (0.42 kg $ha.^{-1}$ yr^{-1}) was probably too high for use in this particular catchment. In addition, further analysis of subcatchment 11, which was 93% covered by improved pasture, suggested that the published export coefficient of 0.25 kg $ha.^{-1}$ yr^{-1} used for this type of land use in the present study was also too high. This figure significantly over-estimated the annual TP load to the stream draining this subcatchment. The field measurements indicate that the export coefficient for this type of land use, in this particular subcatchment, was probably closer to 0.15 kg $ha.^{-1}$ yr^{-1} and that this land may not be as 'improved' as it was, at first, thought to be.

4.8 Changes in land cover since 1972

Changes in land use within the different subcatchments were assessed by comparing the land cover survey data for 1972 with those for 1988. It is difficult to detect these changes by visual comparison of the land use maps for these two dates (e.g. *cf.* **Figures 3** and **5**), but relatively easy to do so using a GIS. This is because the overlay capability within the GIS allows us to highlight the areas of change between the two dates while suppressing those areas that have remained under the same land use regime (**Figures 6** and **7**). Quantitative measures of the extent of these changes, and an analysis of the type of change, can be determined from the overlay procedure.

Details of the land use changes within each subcatchment are given in Appendix I. In general, most of the changes were related to on-going forestry practices. Areas of cleared or new forest in 1972 had become mature forest by 1988, while many areas of established forest recorded in 1972 had been clear felled and, possibly, replanted by 1988. In addition, small areas of the catchment appeared to have changed from arable land to improved pasture. This result should be treated with caution, however, when viewed in relation to common farming practice over the period 1972 to 1988. During this period, farmers tended to convert land from pasture to arable where possible in order to take advantage of European agricultural subsidies. As the 'Set Aside' scheme was not instigated until 1988, it seems unlikely that these apparent changes could be explained by farmers taking arable land out of production. One possible explanation may be that this is not a real change in land use but a change in interpretation of the aerial photography for the two dates.

Some small increases in urban/rural settlement were also recorded in some subcatchments. The most noticable of these were due to the building of the Keswick by-pass and the development of a club house and golf course near Threlkeld (**Figure 7**). Other, smaller, changes included some new buildings, possibly housing developments, north-west of Applethwaite, in Bassenthwaite village and on the outskirts of Keswick.

4.9 Likely effects of changes in land cover on TP export

Table 9 shows the expected change in TP load to Bassenthwaite Lake from diffuse (land-use) sources within the catchment between 1972 and 1988, as calculated by the export coefficient approach. Clearly, in some subcatchments (e.g. 5, 18, 14) the changes seem to have resulted in a reduction in TP load to the streams. However, in others (e.g. 1&2, 4, 13, 15), the amount of TP coming from diffuse sources appears to have increased due to these changes. There seems to have been a net increase in total TP load to the lake of about 253 kg TP yr^{-1} due to the recorded changes. This represents increases of only 3.7% in the loading from diffuse sources, and 1.4% in the total loading.

5. DISCUSSION

This study has shown that it is possible to predict TP losses from land use within a catchment, using a GIS. However, the accuracy of those predictions depends on the TP export models used. Export coefficients obtained from the literature were used to predict the annual TP loss for each land use type in the Bassenthwaite catchment. When compared to the measured values, these values appeared to over-estimate TP losses from at least 2 types of land use (improved pasture and coniferous forest) within this catchment.

The degree of portability of export coefficients between catchments needs to be investigated. Most of the published values have been determined for a particular catchment under local conditions of climate, underlying geology and soil type, degree of soil waterlogging, slope, local forestry and farming practices, etc. Many of these factors are known to affect TP loss rates (Harper, 1993). As a result, large errors may occur when these values are applied to the same land use type in other catchments with different topography and soil characteristics. It is essential, therefore, that dependence on catchment characteristics be addressed if a more robust and universally applicable approach is to be adopted.

In the short term, the best answer to this problem is probably to determine TP loss coefficients for each type of land use within the catchment being studied. This can be achieved by defining subcatchments which are, primarily (i.e. more than 90%), of one particular land use type and estimating TP runoff from these through regular field visits. A GIS can help to define suitable subcatchments and sampling sites for such a study on the basis of land use, soil type, topography, stream network, etc. However, values determined in this manner would still relate only to the catchment for which they were determined. In the longer term, it would be better to understand the mechanisms which determine TP losses and use more complex models (such as those being developed by IFE (Tipping, in press)) to predict them. Then, the methods would be more applicable to different catchments than the existing export coefficients.

If we accept that the export coefficients used in this study were good enough to provide an overview of how much TP is coming from different sources within the catchment of

Bassenthwaite Lake, we can conclude that approximately 37% comes from land use runoff, 49% from STWs and the remaining 14% some unknown sources such as seepage from septic tanks. However, the accuracy of these figures could be improved if the GIS of this catchment were extended to include more appropriate TP export coefficients, P retention coefficients for Derwentwater and Thirlemere, the size and location of septic tanks, better estimates of the TP content of sewage effluent from the STWs, etc. If, as planned, the amount of TP coming from the Keswick STW is reduced by 80%, diffuse sources of this nutrient would then become relatively more important, contributing more than 50% of the remaining TP load to the lake.

In addition to predicting TP export from different sources, the GIS was also used to investigate the relationship between stream annual flow and drainage area. There was a close relationship between these variables during 1993 which seemed to be related to the level of precipitation. In general, the nature of the relationship suggested that it would be possible to predict annual flow for each feeder stream from flow measurements taken at a single site, or rainfall recorded within the catchment, if the exact area of each subcatchment were known.

Unfortunately, obtaining the relevant datasets for the Bassenthwaite catchment, and converting them to ARC/INFO format, was very time consuming. So, only a small amount of data analysis could be carried out in the remaining time available. For this reason, the soils and elevation data remain virtually unused, and the sources and annual loss rates of nutrients other than P, were not considered.

In the future, this work should be extended to include other nutrients, such as nitrate-N and silica, as these may also limit the production of certain components (species) of the phytoplankton at certain times of year. In addition, the possibility of integrating more complex runoff models into the existing GIS, particularly in relation to the possibility of incorporating runoff models which would predict temporal (daily/weekly?) changes of flow rates and nutrient concentrations in the feeder streams, should also be investigated. If successful, the latter approach would allow the GIS to be linked to a model such as PROTEC (Hilton *et al.*, 1993) which could then be used to predict the effect of these loadings on the water chemistry and phytoplankton concentrations of the receiving waters. Such a link would allow water resource managers to evaluate different catchment management scenarios in a cost-effective manner.

6. CONCLUSIONS

1. GIS is a useful tool for the analysis of spatial (geographic) data such as that associated with the management of lake and river catchments.

2. GIS provides a high quality cartographic output (maps) which enables complex spatial data to be presented in a simple, visual form.

3. Some indication of the level of nutrient loading from non-point sources within a catchment can be obtained using published export coefficients for the different land use types; however, these estimates could be improved significantly by using export coefficients which are more appropriate to the particular catchment under study.

4. Approximately 37% of the TP load to Bassenthwaite Lake probably comes from diffuse sources within the catchment; the relative contribution of TP from these sources would increase to more than 50% if the level of TP in effluent from the Keswick STW was reduced by 80%, as proposed.

5. The relatively small changes in land use within the catchment of Bassenthwaite Lake between 1972 and 1988 have probably increased the TP load from diffuse sources by less than 4.0%, and the total TP load by less than 2%.

6. There is a close relationship between catchment area and stream flow within the Bassenthwaite catchment.

7. GIS has the potential to provide a number of derived datasets which could be used in more complex models of catchment runoff, including those which predict temporal changes in nutrient concentration and load.

7. RECOMMENDATIONS

Our understanding and prediction of nutrient loss rates from diffuse sources within the Bassenthwaite catchment could be improved by:

- dividing subcatchment 15 into smaller subcatchments and taking account of the TP retention coefficients of Derwentwater and Thirlmere
- obtaining detailed information of the water pumping which is carried out in the catchment of Thirlmere
- including information about the location and size of septic tanks in each subcatchment
- carrying out field measurements which would improve our ability to select or determine TP loss rates from different land uses within the catchment
- improving predictions of the TP losses from STWs by taking account of seasonal variations in population due to tourism
- evaluating, developing and including more complex models of TP losses than are presently incorporated into the GIS
- including other nutrients

Once established, the GIS could be used to evaluate different management strategies (such as buffer zones, etc.) aimed at reducing eutrophication of waterbodies in this catchment. It would also provide a framework for a similar approach to be adopted elsewhere. Most of the datasets used in the present study have been subsets of much larger datasets covering the whole area Lake District National Park, and in some cases, the whole of Britain.

8. ACKNOWLEDGEMENTS

We thank the Lake District National Parks Authority, Kendal, for the data on land cover, the MacCaulay Institute, Aberdeen, for digital elevation data and the NRA for supplying the relevant field measurements and rainfall data. Some features of the maps in Figures 1, 3, 5, 6, and 7 are based on digital spatial data licenced from the Institute of Hydrology.

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FIGURES

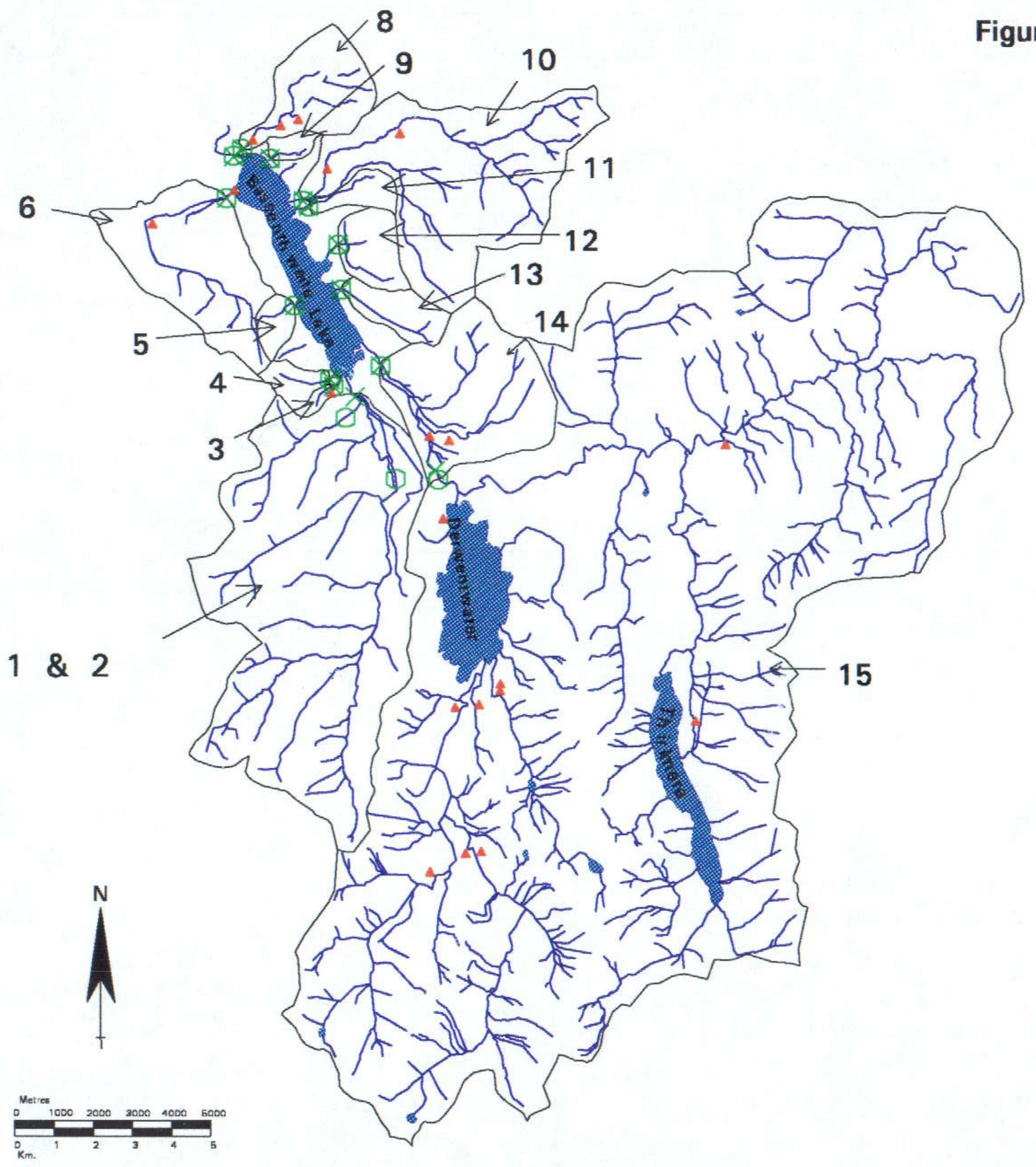
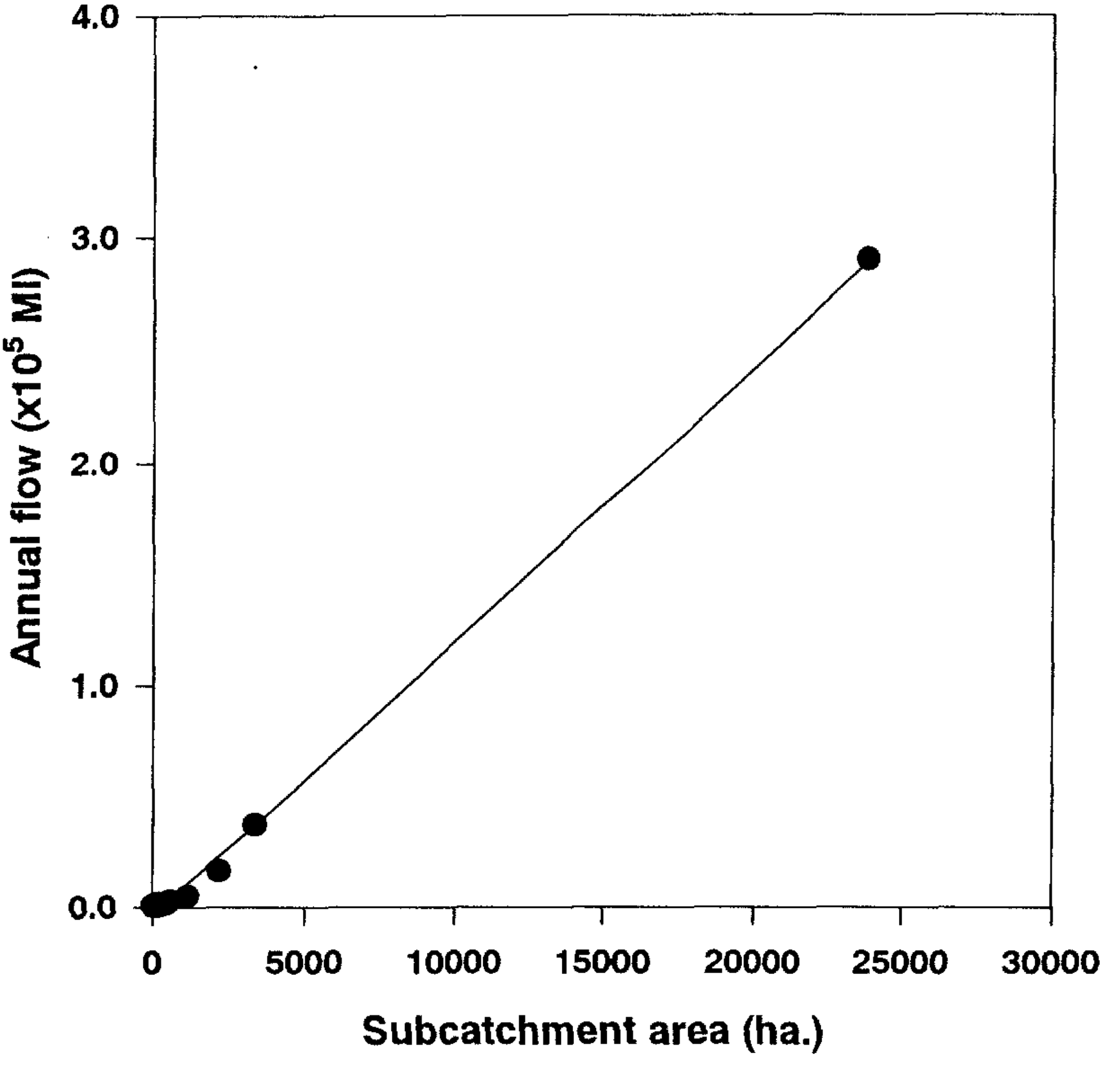


Figure 1. Bassenthwaite Lake and catchment showing subcatchments, flow gauges, water chemistry sampling points and known sources of sewage effluent.

Figure 2. The relationship between stream flow and drainage area for the subcatchments of Bassenthwaite Lake in 1993.



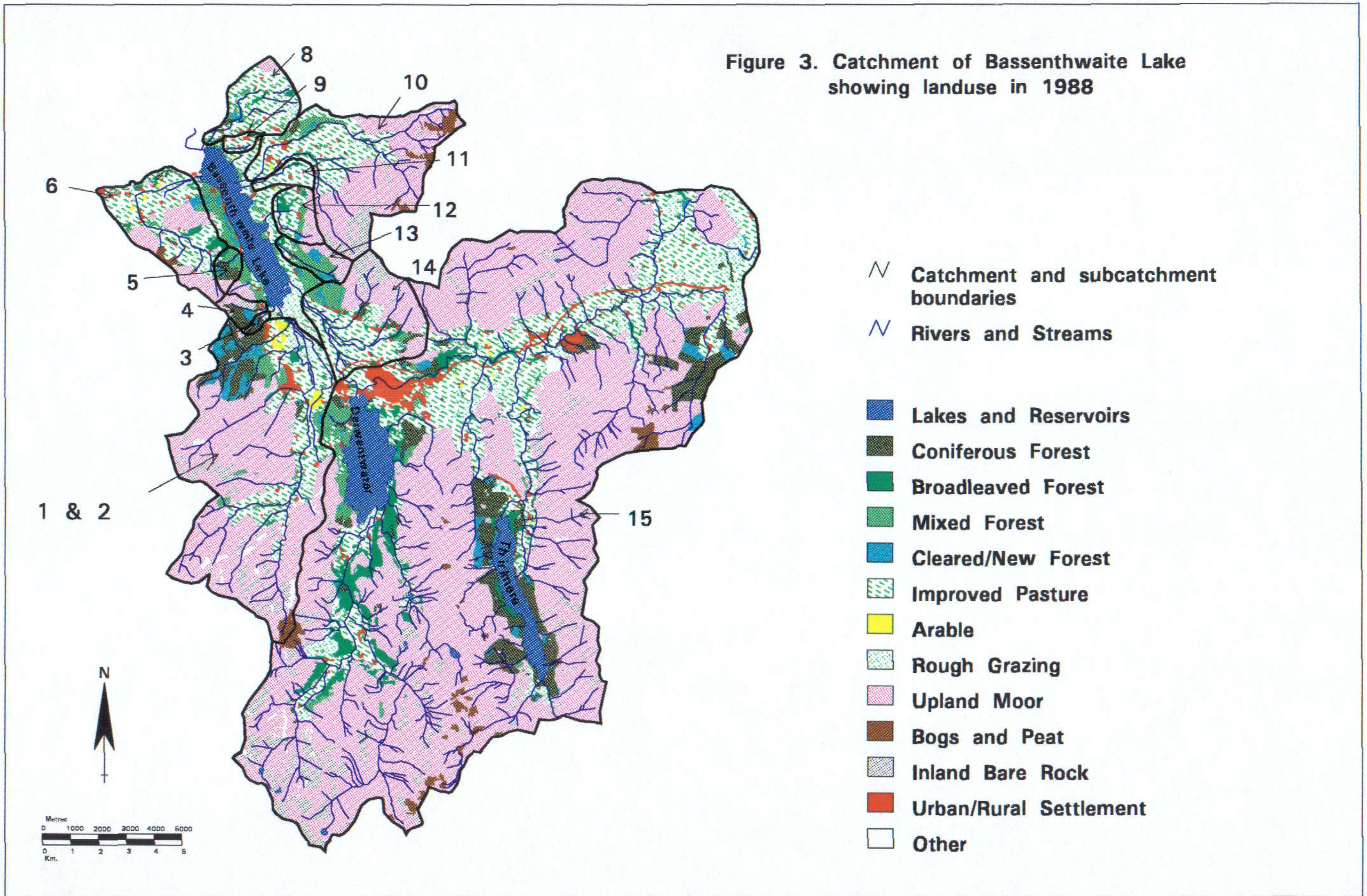


Figure 3. Catchment of Bassenthwaite Lake showing landuse in 1988

Figure 4. TP load in the main stream draining subcatchment 9 for the period January to August, 1993.

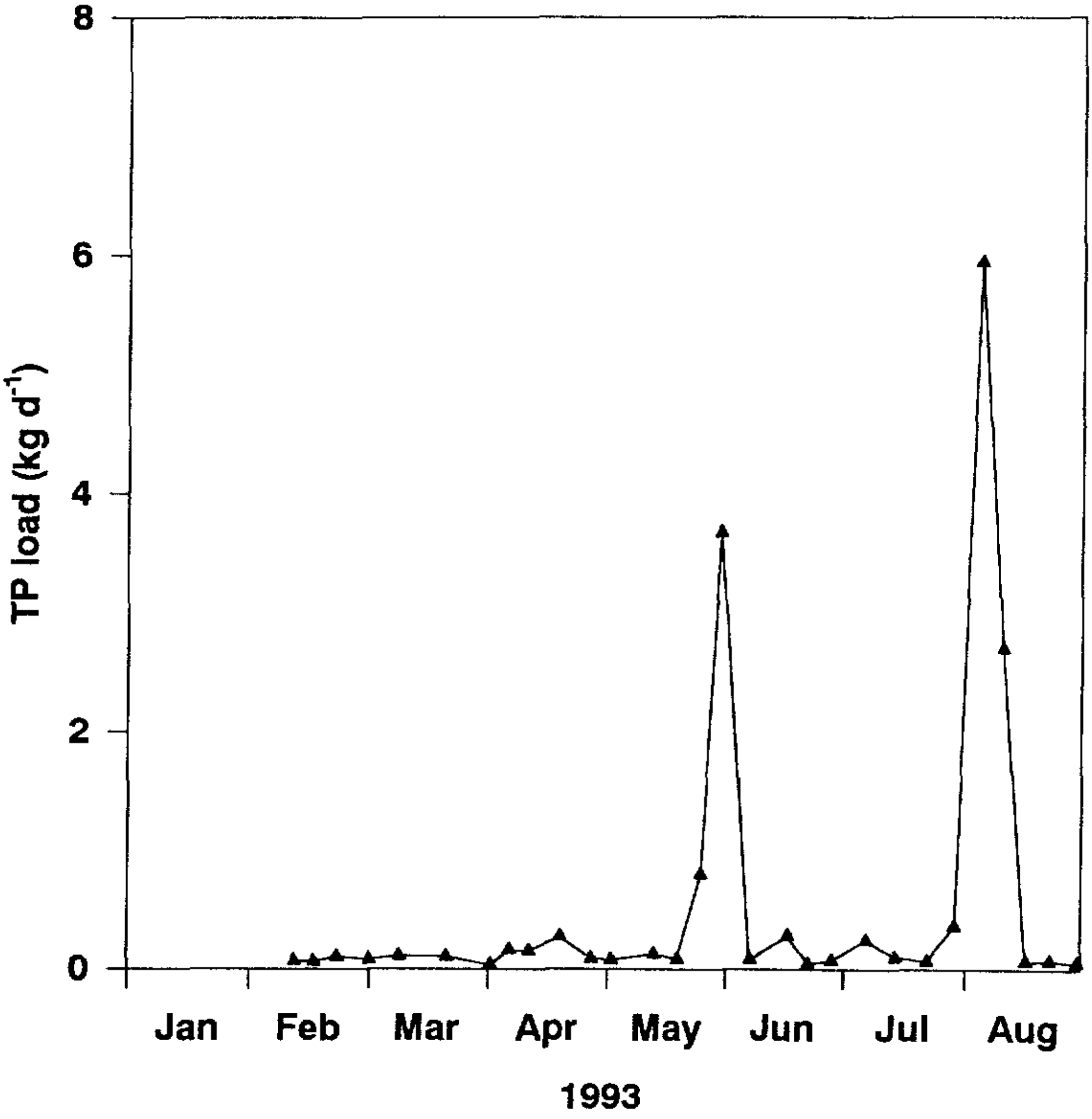


Figure 5. Catchment of Bassenthwaite Lake *showing landuse in 1972*

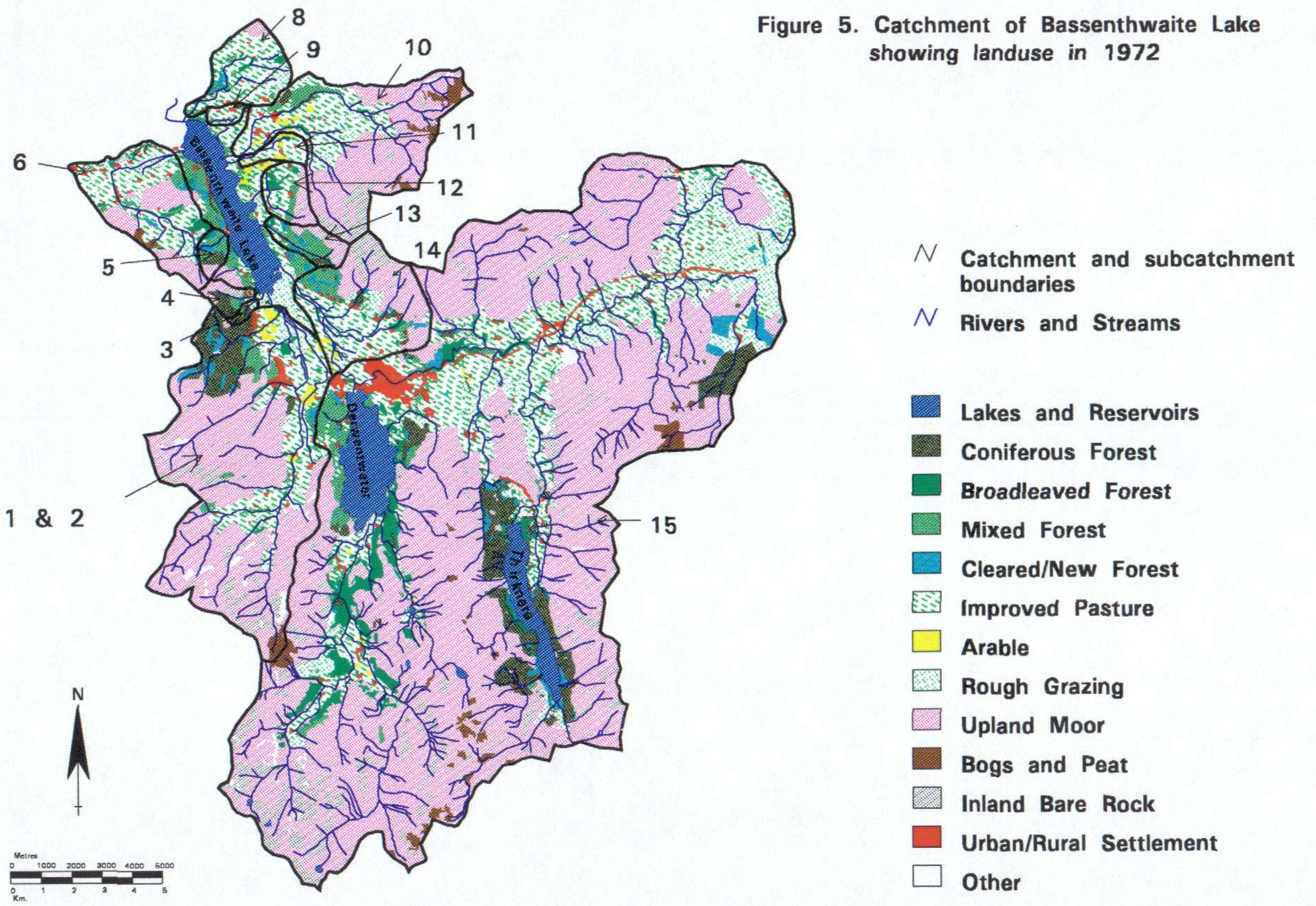
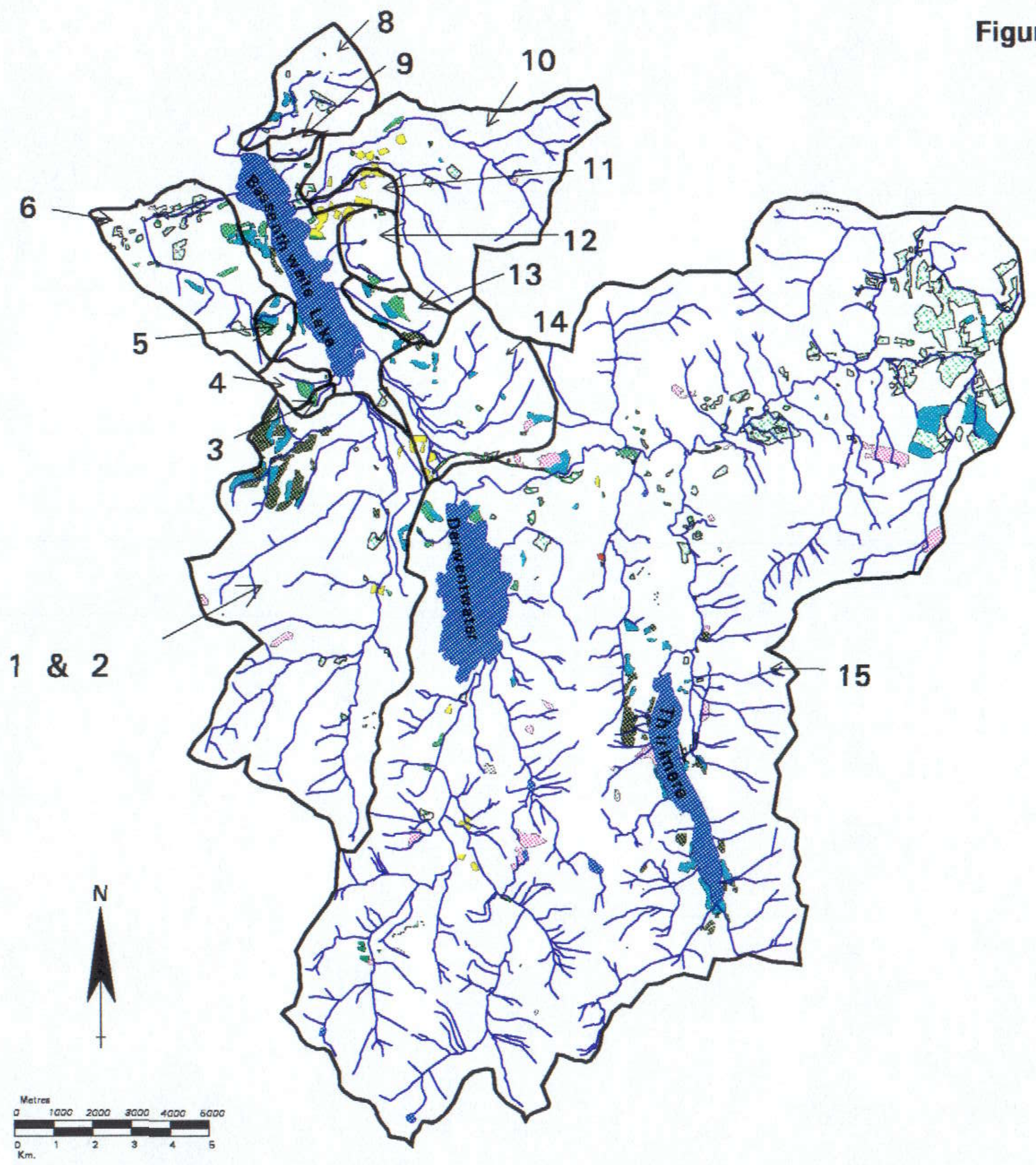


Figure 6. Catchment of Bassenthwaite Lake showing areas of landuse in 1972 which had changed by 1988



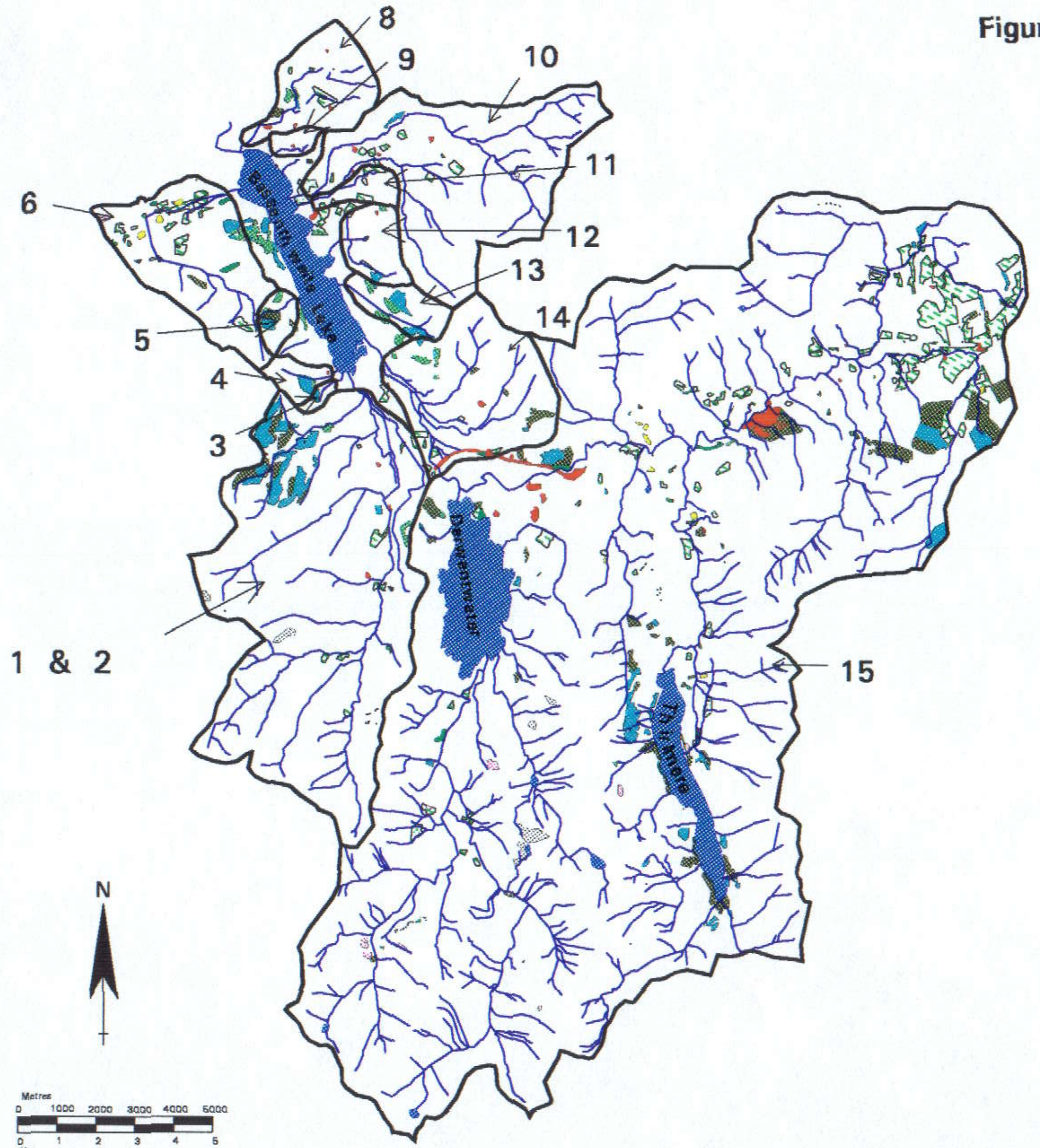


Figure 7. Catchment of Bassenthwaite Lake showing areas of landuse in 1988 which had changed since 1972

TABLES

Table 1. The position of flow gauges and water chemistry sampling points on the inflows to Bassenthwaite Lake; their corresponding subcatchment numbers are also shown.

Subcatchments	River/Beck	Site(s)	NGR
1 & 2	Newlands/Chapel Beck	Braithwaite (flow only)	NY24052393
		Aqueduct (flow only)	NY22742552
		below confluence (chemistry only)	NY23002600
3	Un-named beck	d/stream Thornthwaite STW	NY22452626
4	Beckstones Gill	Powter How	NY22382646
5	Beck Wythop	u/stream A66	NY21462834
6	Dubwath Beck	u/stream A66	NY19733106
8	Coal Beck	Caravan site weir	NY20133230
9	Un-named beck	Cottage Wood	NY20823207
10	Halls Beck	Scarness	NY21693100
11	Pooley Beck	Scarness	NY21823086
12	Un-named beck	u/stream Broadness farm	NY22552991
13	Skill Beck	St Begas Church	NY22652878
14	River Derwent	Lowstock Bridge	NY23622683
15	River Derwent	Portinscale	NY25122390

Table 2. Land use groupings used in the present study in relation to the original classifications.

Land use group (this study)	Original classification (LNDPA)	
Arable:	18 Cultivated land	
Bogs & peat:	8 Blanket peat/grass moor	
Broad-leaved forest:	1Broad-leaved forest	
Cleared/new forest:	5 Clear felled/newly planted forest	
Coniferous forest:	2 Coniferous forest	
Improved pasture:	19 Improved pasture	
Inland bare rock:	26 Inland bare rock	
Mixed forest:	3 Mixed forest 4 Scrub	
Other:	16 Eroded mineral soils 34 Quarries & mineral workings	35 Derelict land 38 Unclassified land
Rough grazing:	11 Lowland heath	20 Rough pasture
Urban/rural settlement:	32 Urban boundary 33 Transport routes	37 Isolated pubs, services etc. 36 Farmsteads
Upland moor:	6 Upland heath 7 Upland grass moor 9 Bracken 12 Upland heath/grass mosaic	13 Upland heath/bracken mosaic 14 Upland heath/blanket peat mosaic

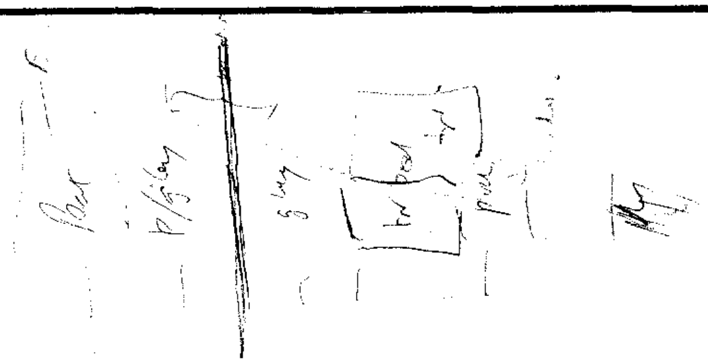


Table 3. Land use categories and related export coefficients used in the present study.

ARC/Info Land-use Code	Land class category	TP Export Coefficient (kg ha^{-1} yr^{-1})	Reference
100	Urban/rural settlement (runoff, only)	0.83	*Bailey-Watts, Sargent , Kirika & Smith (1987)*
200	Upland moor	0.1	*Harper & Stewart (1987)*
300	Improved pasture	0.25	*Harper & Stewart (1987)*
400	Coniferous forest	0.42	*Harriman (1978)*
500	Cleared/new forest	2.0	*Harriman (1978)*
600	Broadleaved forest	0.15	*Dillon & Kirchner (1975)*
700	Mixed forest	0.15	*Hancock (1982); Dillon & Kirchner (1975)*
800	Bogs & peat	1.0	*Casey, O'Connor & Green (1981)*
900	Inland bare rock	0.1	
1000	Rough grazing	0.07	*Cooke & Williams (1973)*
1100	Arable	0.25	*Cooke & Williams (1973)*
1200	Other	0.1	

Table 4. Total area of each subcatchment of Bassenthwaite Lake.

Subcatchment	Area (ha.)
1 & 2	4624
3	38
4	129
5	121
6	1165
8	598
9	74
10	2188
11	147
12	284
13	252
14	1298
15	23861

Table 5. Land use and associated annual TP losses in the catchment of Bassenthwaite Lake in 1988.

Land Use Category	Code	Area 88 (ha)	%	Estimated TP losses (kg/yr)	%
Urban/rural settlement	100	614	2	510	7
Upland Moor	200	18,560	53	1,856	27
Improved pasture	300	7,233	21	1,808	26
Coniferous forest	400	1,628	5	684	10
Cleared/new forest	500	465	1	930	14
Broadleaved forest	600	923	3	138	2
Mixed forest	700	1,189	3	178	3
Bogs & peat	800	398	1	398	6
Inland bare rock	900	1,668	5	167	2
Rough grazing	1,000	1,790	5	125	2
Arable	1,100	74	0	19	0
Other	1,200	199	1	20	0
		34,742		6,834	100

Table 6. Correlation analysis of the relationship between percentage of each land use type, annual flow, mean slope and annual TP load for subcatchments 1 & 2, 3-6 and 8-13. Significant correlations ($p<0.05$, $n=11$) are shown in bold, italic type.

	Annual Flow	Area	Mean Slope	Urban/Rural Settlement	Upland Moor	Improved Pasture	Coniferous Forest	Cleared/new Forest	Broadleaved Forest	Mixed Forest	Bogs & Peat	Inland Bare Rock	Rough Grazing	Arable	Annual TP Load
Ann Flow (Ml)	1.00														
Area (ha.)	***0.99***	1.00													
Mean slope	-0.02	-0.06	1.00												
Urban/Rural Development	-0.14	-0.13	***-0.60***	1.00											
Upland Moor	***0.74***	***0.75***	0.41	-0.31	1.00										
Improved Pasture	-0.26	-0.23	***-0.87***	0.50	***-0.61***	1.00									
Coniferous forest	-0.21	-0.26	***0.57***	-0.29	-0.23	-0.47	1.00								
Cleared/new forest	-0.23	-0.29	***0.83***	-0.45	0.05	***-0.77***	***0.63***	1.00							
Broadleaved forest	-0.24	-0.21	0.02	-0.22	0.01	0.03	-0.27	-0.08	1.00						
Mixed Forest	-0.27	-0.31	0.35	-0.20	-0.01	-0.45	-0.02	***0.65***	0.24	1.00					
Bogs & Peat	0.43	0.51	-0.06	-0.13	***0.58***	-0.10	-0.28	-0.41	-0.16	-0.32	1.00				
Inland Bare Rock	0.35	0.34	0.50	-0.12	***0.71***	***-0.56***	0.03	0.27	-0.37	-0.05	0.32	1.00			
Rough Grazing	0.20	0.30	***-0.66***	0.36	0.05	0.51	***-0.58***	***-0.76***	0.26	-0.41	0.44	-0.34	1.00		
Arable	***0.74***	***0.76***	-0.26	-0.10	0.40	0.12	-0.29	-0.38	-0.14	-0.42	0.26	0.01	0.34	1.00	
Ann TP Load	***0.87***	***0.90***	-0.30	0.06	0.53	0.01	-0.32	-0.44	-0.22	-0.39	0.47	0.13	***0.56***	***0.64***	1.00

Table 7. The relationship between measured annual TP load and that estimated to be due to runoff in the inflows of Bassenthwaite Lake during 1988.

Subcatchment	Measured TP load (kg yr^{-1})	Estimated TP load from runoff (kg yr^{-1})	% of measured TP load *not* accounted for by land use runoff estimates	Sewage Treatment works?
1 & 2	952	1021	-7%	
3	104	19	+82%	✔
4	10	54	-440%	
5	12	49	-308%	
6	385	268	+30%	✔
8	535	150	+72%	✔
9	202	19	+91%	
10	486	419	+14%	✔
11	22	37	-68%	
12	35	64	-83%	
13	68	90	-32%	
14 + 15	15,600	274+4159 = 4433	+72%	✔
Total:	18,411	6623		

Table 9. Summary of the percentage change in land use, and corresponding change in TP load from diffuse sources, within each subcatchment of Bassenthwaite Lake between 1972 and 1988.

Subcatchment	Area Change %	TP export 1972 (kg/y)	TP export 1988 (kg/y)	TP Change (kg/y)
5	19.40	33.98	19.29	-14.69
13	17.18	39.13	57.06	17.93
11	12.80	4.69	4.68	-0.01
4	11.20	4.34	26.18	21.84
3	9.31	0.53	7.09	6.56
6	8.38	34.51	44.94	10.43
1 & 2	4.93	178.27	276.63	98.36
8	4.80	22.76	9.86	-12.89
12	4.40	2.66	4.40	1.74
14	4.24	50.85	28.93	-21.92
10	1.90	8.74	16.71	7.97
15	0.43	62.84	200.65	137.81
9	0.16	0.03	0.10	0.07
Total				253.20

Appendix I. Summary of landuse and predicted TP Loss rates within the subcatchments of Bassenthwaite Lake during 1988.

a) *Subcatchments 1 & 2*

Land use category	Total Area (ha.)	% Area	TP Loss (kg/yr)	% TP Loss
Upland Moor	2558.5	55.3	255.8	25.1
Improved pasture	787.1	17.0	196.8	19.3
Coniferous forest	262.3	5.7	110.2	10.8
Inland bare rock	255.6	5.5	25.6	2.5
Rough grazing	197.3	4.3	13.8	1.4
Mixed forest	151.0	3.3	22.7	2.2
Cleared/new forest	137.9	3.0	275.8	27.0
Other	83.5	1.8	8.4	0.8
Urban/rural settlement	62.8	1.4	52.2	5.1
Arable	49.2	1.1	12.3	1.2
Bogs & Peat	42.1	0.9	42.1	4.1
Broadleaved forest	36.1	0.8	5.4	0.5
Total	**4623.3**	**100**	**1020.9**	**100**

b) *Subcatchment 3*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Coniferous forest	22.8	59.9	10	50.3
Improved pasture	10.2	26.8	3	13.4
Cleared/new forest	3.3	8.6	7	34.3
Mixed forest	0.8	2.2	0	0.6
Upland Moor	0.8	2.0	0	0.4
Urban/rural settlement	0.2	0.6	0	0.9
Total	**38.0**	**100.0**	**19**	**100.0**

e) *Subcatchment 6*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	540.9	46.4	135	50.5
Upland Moor	331.7	28.5	33	12.4
Rough grazing	117.5	10.1	8	3.1
Broadleaved forest	50.1	4.3	8	2.8
Mixed forest	37.0	3.2	6	2.1
Bogs & peat	25.2	2.2	25	9.4
Urban/rural settlement	24.5	2.1	20	7.6
Coniferous forest	13.3	1.1	6	2.1
Cleared/new forest	12.5	1.1	25	9.3
Arable	6.7	0.6	2	0.6
Other	5.1	0.4	1	0.2
Inland bare rock	0.5	0.0	0	0.0
Total	1165.1	100.0	268	100.0

f) *Subcatchment 8*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	430.5	72.0	108	71.6
Rough grazing	48.6	8.1	3	2.3
Mixed forest	38.4	6.4	6	3.8
Upland Moor	33.1	5.5	3	2.2
Broadleaved forest	21.6	3.6	3	2.2
Urban/rural settlement	12.4	2.1	10	6.8
Cleared/new forest	7.1	1.2	14	9.5
Coniferous forest	6.0	1.0	3	1.7
Arable	0.0	0.0	0	0.0
Total	597.8	100.0	150	100.0

g) *Subcatchment 9*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	56.2	76.3	14	73.1
Mixed forest	9.8	13.3	1	7.6
Urban/rural settlement	4.2	5.7	3	18.0
Rough grazing	3.5	4.8	0	1.3
Total	**73.7**	**100.0**	**19**	**100.0**

h) *Subcatchment 10*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Upland Moor	1048.8	47.9	105	25.0
Improved pasture	640.3	29.3	160	38.2
Inland bare rock	173.4	7.9	17	4.1
Rough grazing	103.6	4.7	7	1.7
Bogs & peat	86.5	4.0	87	20.7
Mixed forest	73.7	3.4	11	2.6
Urban/rural settlement	19.0	0.9	16	3.8
Coniferous forest	13.7	0.6	6	1.4
Other	12.9	0.6	1	0.3
Broadleaved forest	9.3	0.4	1	0.3
Cleared/new forest	3.4	0.2	7	1.6
Arable	3.0	0.1	1	0.2
Total	**2187.5**	**100.0**	**419**	**100.0**

i) *Subcatchment 11*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	136.1	92.9	34	93.3
Rough grazing	4.0	2.7	0	0.8
Broadleaved forest	2.6	1.8	0	1.1
Urban/rural settlement	1.7	1.1	1	3.8
Arable	0.9	0.6	0	0.6
Mixed forest	0.6	0.4	0	0.3
Upland Moor	0.6	0.4	0	0.2
Total	**146.5**	**100.0**	**37**	**100.0**

j) *Subcatchment 12*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	124.1	43.6	31	49.2
Upland Moor	81.0	28.5	8	12.8
Mixed forest	27.2	9.5	4	6.5
Broadleaved forest	25.1	8.8	4	6.0
Arable	10.6	3.7	1	1.2
Inland bare rock	5.8	2.0	1	0.9
Cleared/new forest	5.4	1.9	11	17.1
Urban/rural settlement	4.3	1.5	4	5.7
Coniferous forest	1.1	0.4	0	0.7
Total	**284.5**	**100.0**	**63**	**100.0**

k) *Subcatchment 13*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Mixed forest	93.9	37.3	14	15.6
Upland Moor	77.1	30.6	8	8.5
Improved pasture	33.0	13.1	8	9.1
Cleared/new forest	28.4	11.3	57	63.0
Inland bare rock	12.8	5.1	1	1.4
Broadleaved forest	4.8	1.9	1	0.8
Urban/rural settlement	1.6	0.6	1	1.4
Rough grazing	0.2	0.1	0	0.0
Total	**251.7**	**100.0**	**90**	**100.0**

l) *Subcatchment 14*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Improved pasture	491.3	37.8	123	44.8
Upland Moor	412.8	31.8	41	15.0
Inland bare rock	114.2	8.8	11	4.2
Mixed forest	99.7	7.7	15	5.4
Rough grazing	65.4	5.0	5	1.7
Coniferous forest	39.4	3.0	17	6.0
Urban/rural settlement	34.0	2.6	28	10.3
Broadleaved forest	26.1	2.0	4	1.4
Cleared/new forest	15.3	1.2	31	11.2
Total	**1298.1**	**100.0**	**274**	**100.0**

m) *Subcatchment 15*

Land use category	Total Area (ha.)	%Area	TP Loss (kg/yr)	% TP Loss
Upland Moor	13902.1	58.3	1390	33.4
Improved pasture	3680.2	15.4	920	22.1
Coniferous forest	1193.1	5.0	501	12.0
Inland bare rock	1090.7	4.6	109	2.6
Rough grazing	1072.8	4.5	75	1.8
Standing water	881.9	3.7	0	0.0
Broadleaved forest	728.2	3.1	109	2.6
Urban/rural settlement	420.2	1.8	349	8.4
Mixed forest	339.3	1.4	51	1.2
Bogs & peat	244.5	1.0	245	5.9
Cleared/new forest	198.6	0.8	397	9.6
Other	97.6	0.4	10	0.2
Arable	11.7	0.0	3	0.1
Total	**23861.0**	**100.0**	**4159**	**100.0**

Appendix II. Summary of land use changes between 1972 and 1988 in the subcatchments of Bassenthwaite Lake.

Subcatchment 1 & 2

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Upland moor	10.3	0.2	1.03
Improved pasture	2.1	0.0	0.52
Coniferous forest	126.0	2.7	52.90
Cleared/new forest	60.0	1.3	120.04
Mixed forest	0.4	0.0	0.06
Rough grazing	19.6	0.4	1.37
Arable	9.4	0.2	2.35
Total	227.8	4.9	178

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	2.1	0.0	1.73
Upland moor	0.1	0.0	0.01
Improved pasture	27.1	0.6	6.77
Coniferous forest	55.1	1.2	23.12
Cleared/new forest	122.0	2.6	244.02
Mixed forest	11.2	0.2	1.68
Inland bare rock	10.3	0.2	1.03
Total	227.8	4.9	277

Subcatchment 3

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Mixed forest	3.5	9.3	0.53
Total	3.5	9.3	0.53

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Cleared/new forest	3.5	9.3	7.09
Total	3.5	9.3	7.09

Subcatchment 4

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	0.3	0.2	0.08
Cleared/new forest	1.2	0.9	2.32
Mixed forest	12.9	10.0	1.94
Total	14.4	11.2	4.34

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	0.3	0.2	0.27
Coniferous forest	0.1	0.0	0.03
Cleared/new forest	12.9	10.0	25.71
Mixed forest	1.2	0.9	0.17
Total	14.4	11.2	26.18

Subcatchment 5

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Coniferous forest	0.4	0.3	0.16
Cleared/new forest	16.4	13.6	32.82
Mixed forest	6.7	5.5	1.00
Total	23.4	19.4	33.98

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	0.0	0.0	0.01
Coniferous forest	10.4	8.6	4.38
Cleared/new forest	7.0	5.8	14.00
Mixed forest	6.0	4.9	0.89
Total	23.4	19.4	19.29

Subcatchment 6

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Upland moor	1.4	0.1	0.00
Improved pasture	8.6	0.7	2.14
Coniferous forest	0.5	0.0	0.23
Cleared/new forest	12.4	1.1	24.77
Mixed forest	17.6	1.5	2.64
Rough grazing	67.6	5.8	4.73
Total	108.1	8.4	34.51

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	0.0	0.0	0.03
Upland moor	3.8	0.3	0.00
Improved pasture	65.1	5.6	16.26
Coniferous forest	5.1	0.4	2.15
Cleared/new forest	11.3	1.0	22.57
Broadleaved forest	7.1	0.6	1.06
Mixed forest	7.2	0.6	1.08
Rough grazing	2.0	0.2	0.14
Arable	6.6	0.6	1.64
Total	108.1	8.4	44.94

Subcatchment 8

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	1.0	0.2	0.26
Coniferous forest	0.1	0.0	0.05
Cleared/new forest	10.6	1.8	21.22
Mixed forest	0.7	0.1	0.10
Rough grazing	16.3	2.7	1.14
Total	28.7	4.8	22.76

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	2.3	0.4	1.91
Improved pasture	15.1	2.5	3.78
Coniferous forest	4.7	0.8	1.97
Cleared/new forest	0.7	0.1	1.32
Mixed forest	5.9	1.0	0.88
Total	28.7	4.8	9.86

Subcatchment 9

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	0.1	0.2	0.03
Total	0.1	0.2	0.03

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	0.1	0.2	0.10
Total	0.1	0.2	0.10

Subcatchment 10

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Upland moor	1.0	0.0	0.00
Improved pasture	10.4	0.5	2.60
Cleared/new forest	0.4	0.0	0.80
Mixed forest	3.8	0.2	0.56
Rough grazing	11.0	0.5	0.77
Arable	16.0	0.7	4.01
Total	42.6	1.9	8.74

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	1.9	0.1	1.58
Improved pasture	27.0	1.2	6.75
Coniferous forest	0.4	0.0	0.17
Cleared/new forest	3.8	0.2	7.52
Mixed forest	0.0	0.0	0.00
Inland bare rock	1.0	0.0	0.10
Rough grazing	8.5	0.4	0.59
Total	42.6	1.9	16.71

Subcatchment 11

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	0.1	0.0	0.02
Arable	18.7	12.8	4.67
Total	18.8	12.8	4.69

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	18.7	12.8	4.67
Mixed forest	0.1	0.0	0.01
Total	18.8	12.8	4.68

Subcatchment 12

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	1.7	0.6	0.42
Cleared/new forest	0.3	0.1	0.67
Mixed forest	5.4	1.9	0.81
Rough grazing	2.9	1.0	0.20
Arable	2.2	0.8	0.55
Total	12.5	4.4	2.66

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	0.2	0.1	0.15
Improved pasture	5.3	1.9	1.32
Cleared/new forest	5.4	1.9	10.86
Mixed forest	1.7	0.6	0.25
Total	12.5	4.4	4.40

Subcatchment 13

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Coniferous forest	12.0	4.8	5.03
Cleared/new forest	15.9	6.3	31.80
Mixed forest	15.4	6.1	2.31
Total	43.2	17.2	39.13

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Improved pasture	0.0	0.0	0.01
Cleared/new forest	27.3	10.9	54.68
Mixed forest	15.9	6.3	2.38
Total	43.2	17.2	57.06

Subcatchment 14

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Upland moor	4.4	0.3	0.44
Improved pasture	9.5	0.7	2.36
Coniferous forest	3.8	0.3	1.58
Cleared/new forest	21.5	1.7	43.06
Mixed forest	0.0	0.0	0.01
Rough grazing	6.8	0.5	0.47
Arable	13.5	1.0	3.37
Total	59.5	4.2	51.29

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	10.3	0.8	8.56
Upland moor	0.0	0.0	0.00
Improved pasture	18.0	1.4	4.50
Coniferous forest	15.5	1.2	6.51
Cleared/new forest	3.8	0.3	7.58
Broadleaved forest	1.4	0.1	0.20
Mixed forest	10.4	0.8	1.56
Total	59.5	3.8	28.93

Subcatchment 15

Land Use 1972	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	1.9	0.0	1.58
Upland moor	38.2	0.2	0.00
Improved pasture	40.0	0.2	10.01
Coniferous forest	70.9	0.3	29.77
Cleared/new forest	4.5	0.0	8.99
Broadleaved forest	5.6	0.0	0.85
Mixed forest	32.0	0.1	4.81
Inland bare rock	7.8	0.0	0.78
Rough grazing	50.7	0.2	3.55
Arable	10.1	0.0	2.52
Other	3.2	0.0	0.32
Total	264.9	0.4	62.84

Land Use 1988	Total Area (ha.)	Total Area (%)	TP loss (kg/yr)
Urban/rural settlement	71.6	0.3	59.45
Upland moor	16.3	0.1	0.00
Improved pasture	11.0	0.0	2.75
Coniferous forest	12.6	0.1	5.27
Cleared/new forest	61.4	0.3	122.83
Broadleaved forest	16.2	0.1	2.43
Mixed forest	5.0	0.0	0.75
Inland bare rock	29.3	0.1	2.93
Rough grazing	33.3	0.1	2.33
Arable	7.6	0.0	1.90
Other	0.2	0.0	0.02
Total	264.6	0.3	200.65