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A COMPARISON OF THE PRESSURES ON, AND THE SENSITIVITY TO EUTROPHICATION OF TWO SCOTTISH FRESHWATER LOCHS OF SIMILAR VOLUME.

BY

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ABSTRACT.

The pressures, by way of nutrient loading, were assessed for two Scottish freshwater lochs of similar volume; Loch Leven in Tayside Region and St.Mary's in Borders Region. From these perceived pressures the sensitivity of each waterbody was evaluated.

A desk study approach was adopted, using a model adapted from Reckhow and Simpson (1980), and the results expressed in terms of monthly P loading, using a ten-year average loading (1981-91) and the loadings from the wettest and driest year within that ten year period. Landuse categories within each catchment were identified through questionnaires, Census data and map analysis, and the monthly loadings derived by assigning a phosphorus export coefficient to each category. The sensitivity was then assessed by relating the catchment loadings, and their nature (ie. point source or non-point source), to the physical features of the receiving waterbody.

Loch Leven was found to be the most vulnerable to eutrophication, with a P loading of 9-10 tonnes per annum and a specific areal loading of 0.72 g m^2. The largest proportion of P came from treated sewage with the remainder coming from agricultural runoff. Due to the morphology of Loch Leven ca. 50-60% of the P loading is retained in the loch. Contrastingly, St.Mary's Loch was found to be potentially less vulnerable due to the rainfall-runoff dependent nature of P loading and the ameliorating potential of intervening waterbodies. The annual P loading of this loch was only 0.9 tonnes, with a specific areal loading of 0.3 g m^2.

CHAPTER 1 INTRODUCTION.

1.1 Aims and Rationale.

The main aims of this study are as follows:

- investigation of the pressures, by way of nutrient loading, on a loch system through analysis of maps, aerial photographs and other catchment data, and to express these in terms of monthly loadings by adaptation of published annual models.

- to assess the sensitivity of the receiving waterbody to the perceived pressures and thus its vulnerability to eutrophication.

- to compare and contrast the pressures on, and likely sensitivity to, enhanced nutrient inputs, of two freshwater lochs of similar volume, using a ten-year average loading (1981-91) and the loadings from the wettest and driest year within that ten year period.

The two lochs studied were Loch Leven (52.4 x $10^6 m^3$ in Tayside Region, and St.Mary's Loch (57.1 x $10^6 m^3$ in Borders Region (Fig 1.1). General views of the catchments are given in Figures 1.2 - 1.5.

1.2 What is Eutrophication?

Eutrophication, or nutrient enrichment and its effects, is generally regarded as a problem of the middle and late stages of the twentieth century. The term eutrophication stems from the Greek word *eu* meaning 'well' and *trophos* meaning 'feeding'. The process within freshwaters is both a natural and culturally induced phenomenon. Natural eutrophication is a gradual, largely irreversible process associated with gradual accumulation of organic

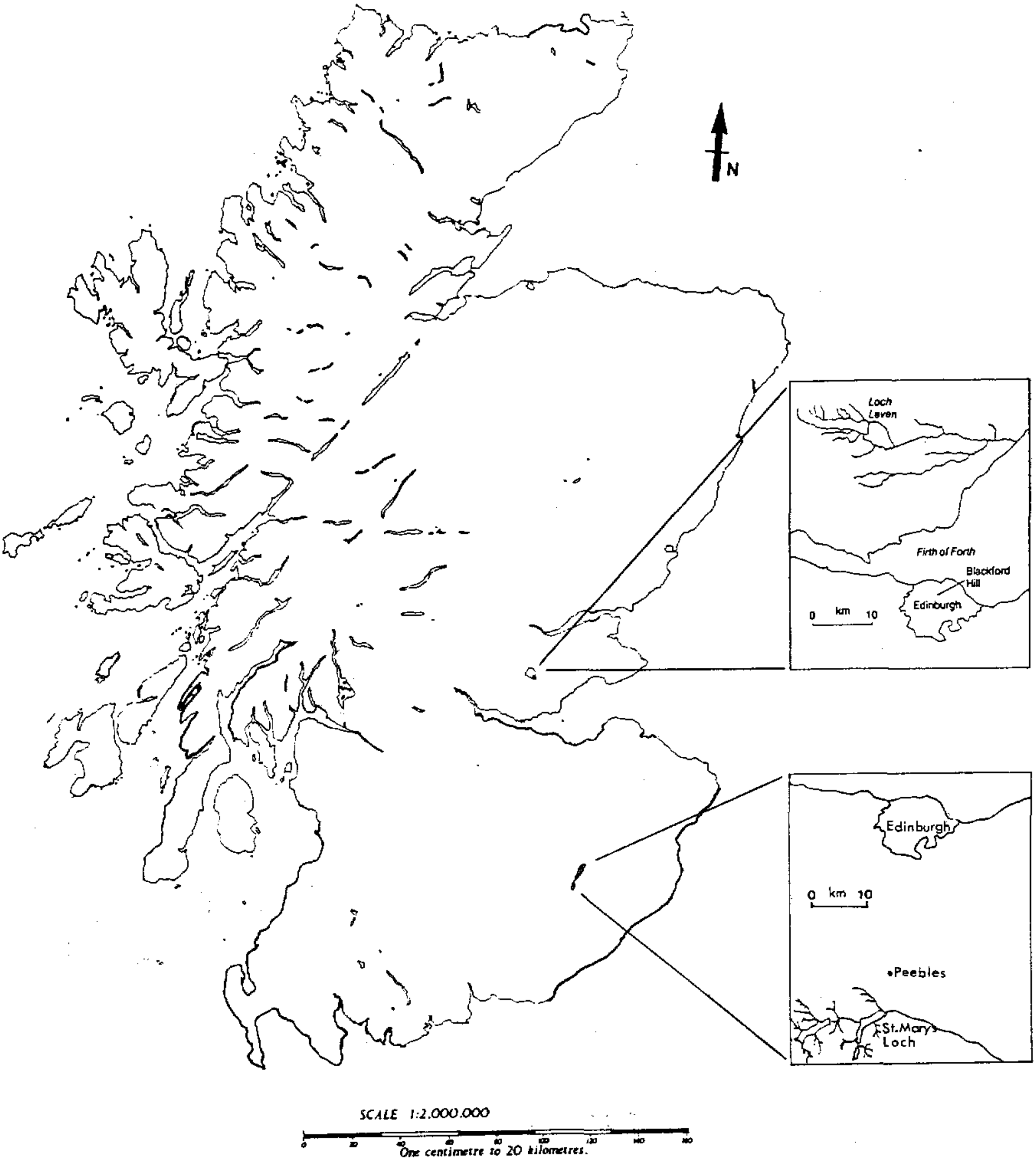

Fig. 1.1 The location of the two study sites.

matter and sediments in lake basins. Cultural eutrophication on the other hand, is often rapid, and possibly reversible process of nutrient enrichment and high biomass production, stimulated by cultural activities enhancing nutrient transport to lakes (Reckhow *et al*, 1980). Although regarded as a problem by many, and invariably equated to a form of pollution, eutrophication is actually exploited in many parts of the world to increase fish yields.

The term eutrophication is also used to describe the biological effects of an increased concentration of plant nutrient loading which lead to associated changes in the fauna and flora (Jeffries and Mills, 1990). In extreme cases, eutrophication can lead to the replacement of the original populations of diatoms and other algae by primarily blue-green algae (cyanobacteria). Blooms of these blue-greens can reduce light penetration leading to a decrease in the plant populations of the lake. Toxins produced by some phytoplankton species can also be a problem, as well as the water colour and odour.

In aquatic ecosystems the nutrients associated with the control of phytoplankton growth are nitrogen (N), phosphorus (P) and silica (SiO_2). Of these, P is regarded as being the key element as it often limits the biomass of aquatic plant populations and thus is important in controlling the biological productivity of natural waters (Makenthun, 1965; and Lee, 1973).

A multiplicity of factors are involved in determining the rate of cultural eutrophication including lake location and morphology, nutrient loading rates, the type of catchment, the ratio of the epilimnion to the hypolimnion, flushing rates and residence times (Dillon, 1975; Pionelli and Tonolli, 1965; Schindler *et al*, 1971; Vollenweider *et al*, 1974; and Wilson *et al*, 1975).

1.3 Background.

In studying eutrophication it is important to identify the source of nutrients, the loading rate and their fate within receiving waters. Recent research on the effect of catchment characteristics - landuse, land cover, geology, soils - and stream water quality determined that landuse practises influence the chemical and algal concentrations of receiving waters (Smart *et al*, 1981). Casterlin and Reynolds (1976) go on to say that whenever there is an increase in human activity in the catchment area of a lake, this results in an increase in nutrient loading from one source or another.

Nutrients supplied to a lake can be derived from a point source (eg. from sewage or industrial effluent) or a non-point source (eg. from catchment runoff or the atmosphere). The main diffuse sources of nutrients are from agricultural land and forestry plantations. Sharpley *et al* (1985) found that these activities significantly affected the P enrichment from rainfall to runoff. In base rich catchments losses of P may be relatively minor due to adsorption on soil particles (Bailey-Watts and Kirika, 1987). During storm events however, P derived from fertilizer applications and land cover comes into the waterbody mainly from surface runoff (Furrer and Gaucher, 1972), reducing leaching into the soil, depending on local topography.

The rate of nutrient influx to lakes has been shown to be a powerful predictor of their trophic state (Schindler, 1977; Rast and Lee, 1983). Nutrient output from the catchment, processed and transported by streams, is generally the most important biogeochemical source of nutrient influx to all but oligotrophic lakes (Vollemweider, 1968; Likens, 1985). Consequently, measurement of fluvial nutrient inputs to lakes is needed to relate a lake's trophic state to its catchment. Land and water management practices within the catchment, and treatment of wastewater discharge into streams are critical factors influencing the magnitude and seasonal patterns of nutrient loading to downstream waters (Galat, 1990).

The response of the receiving waterbody to nutrient influx is site specific and determines the vulnerability of the waterbody. Responses are dependent on the catchment characteristics, basin morphology and sensitivity factors, eg. catchment-to-loch ratio, flushing rate, water clarity etc.

In assessing eutrophication two basic approaches have been adopted: the first involving extensive, close-time interval sampling, and the second involving predictive modelling. The development of models applicable to eutrophication assessment and prediction began with Vollenweider's study of the relationships between P inputs to lakes and in-lake P concentrations (1968) and Sakamoto's (1966) study of relationships between lake P concentration and phytoplankton chlorophyll (Harper, 1992). These basic models were refined to incorporate estimates of catchment inputs; in-lake P retention; nutrient loading related to depth and flushing rate; and relationships between lake P and parameters such as N and chlorophyll 'a' concentration (Dillon and Rigler, 1974; Vollenweider, 1976; Krichner and Dillon, 1975; Reckhow *et al*, 1980).

Fig 1.2 Loch Leven from the Cleish Hills.

Fig 1.3 St.Mary's Loch from the south-west.

Fig 1.4 The Megget Water feeding into St.Mary's Loch.

Fig 1.5 The Sluices at the north-east end of St.Mary's Loch.

CHAPTER 2

2.1 Loch Leven

2.1.1 Status.

Loch Leven is an outstanding site for wintering and breeding wildfowl in Britain. It is the most important grey goose roost in Britain with internationally important number of Greylag and Pinkfooted Geese. It also holds nationally important wintering populations of several other species of wildfowl and has exceptionally high numbers of breeding ducks (Ratcliffe, 1977). It is largely on the strength of these wildfowl populations that the loch was given national and international conservation status. In March 1964 it was declared a National Nature Reserve by the Nature Conservancy (now Scottish Natural Heritage) under an agreement with the owner. It is also included in the first list of internationally important sites drawn up at the International Conference on the Conservation of Wetlands and Wildfowl held at Ramsar, Iran in 1971 (Morgan, 1974).

2.1.2 The Loch.

The loch is situated at longitude 3°30'W and latitude 56°10'N and the mean water level lies at an altitude of 107m above sea level in the fertile plain of Kinross. It was formed at the end of the last period of glaciation (ca. 10000-16000 B.P.) from kettle holes left in the glacial drift by the action of the retreating ice. Drift deposits lying to the east of the loch created an impoundment through which the River Leven, the main outflow, cut its way to the sea. The main body of the loch is characterized by large areas of shallows (< 5m), with the kettle holes being represented by the north and south deeps which are 23.2m and 25.5m respectively. Prior to 1830 the loch occupied an area of approximately 17.3 km^2, but due to subsequent drainage of the surrounding marshland and lowering of the water level by 1.4m this was reduced by 4 km^2 to the present area of 13.3 km^2. Since then the water levels have been controlled by sluices, and can fluctuate for a further 1.4m below the new high water level, depending on industrial demands downstream, (Morgan,1974). The main physical characteristics are summarized in Table 2.1 and the inflows to the loch are indicated in Figure 2.1.

2.1.3 The Catchment.

Topography.

The catchment boundary is defined by the hills to the west, south and north-east. The western hills rise to a height of approximately 500 m.a.s.l. whilst the hills to the south and north-east lie at a lower altitude of 300 - 400 m.a.s.l. The majority of the catchment area, (ca. 63%) lies between 107m and 180m and undulates before rising fairly steeply towards the boundary hills (Fig.2.2).

Geology and Drift.

The catchment is classified as a drift basin according to Hutchinson (1957), being formed in a shallow depression in sand and gravel deposits which overlie thick boulder clay. The solid geology can be divided into three distinct zones consisting of Old Red Sandstone, Carboniferous strata and Glacial deposits (Fig.2.3). The western hills are formed of volcanic lavas and debris of the Old Red Sandstone Period with faults and igneous intrusions complicating the structure. The hills of the smaller southern zone have a complex form with igneous sills intruding into carboniferous strata. A similar geology occurs along the north-eastern watershed (Smith,1974). The remaining area of the catchment abutting the loch is formed of glacial deposits.

Soil.

Brown forest and podsolic soils are dominant within the Leven catchment. They occur on the base-rich parent material such as drifts derived from Old Red Sandstone and carboniferous rocks. In the lower areas of the catchment both freely and imperfectly draining humic-iron podsols predominate, overlying fluvio-glacial sand and gravel. In the higher, wetter areas above 300m, skeletal brown forest soils and peaty soils predominate (Fig.2.4).

Climate.

The climate of this area is dominated by maritime air masses and is characterised by the lack of extremes - small temperature ranges, rain at any time of the year and the liability to wind at any time of the year. This leads to pronounced day-to-day changes in the weather, except when the influence of continental high pressure extends over Loch Leven, usually giving rise to an increased temperature range and reduced wind speed (Smith, 1974). The average temperature (1941-70) ranges between 2.5°C and 14.8°C with the highest temperatures in July and the lowest in January.

The average annual rainfall in this area is 1100mm, with a seasonal average maximum in July of 112mm and a minimum in April of 66mm (1941-70, Balado meteorological station).

Human Impact.

Within the catchment there are two major towns; Kinross and Milnathort in addition to which there are the smaller townships of Kinnesswood and Scotlandwell, all of which are situated near to the loch shore. There are a number of farmsteads within the catchment with the total number of holdings being recorded as 190 within the county of Kinross (Agricultural Census, 1991). Intensive agriculture predominates within the catchment, but there is some industry e.g. the woollen mill at Kinross.

2.2 St.Mary's.

2.2.1 Status.

The water chemistry of St.Mary's Loch is poor (oligotrophic) to moderately rich (mesotrophic). This chemistry is reflected in the range of aquatic organisms which are more similar to Highland freshwater systems than to any recorded in south east Scotland. In this regard the geographical locus of the site is quite unusual. In addition the Scottish rarity, Purple small-reed, (*Calamagrostis canescens*) has been recorded here amidst the rather sparse marginal and littoral fringing vegetation. The site has some local importance for breeding Wigeon and Great Crested Grebe. The combination of these factors resulted in the Nature Conservancy Council (now SNH) designating St.Mary's Loch as a Site of Special Scientific Interest (SSSI) in 1978 (Ratcliffe, 1977).

2.2.2 The Loch.

St.Mary's loch is situated at longitude 3°12'W and latitude 55°29'N and the mean water level lies at an altitude of 247m.a.s.l. The loch is fed by two other water bodies within the catchment, the Loch of the Lowes and Megget Reservior. Both St.Mary's Loch and the Loch of the Lowes were formed during the last period of glaciation due to burn deltas impounding the valley. Three main, natural dams are manifest: one situated at the head of the Loch of the Lowes, formed by the junction of the deltas of the Chaplehope burn and the Riskinhope burn; one at the lower end of St. Mary's Loch, due also to the junction of the deltas of two burns, the Kirkstead burn and the Thorny cleuch; one formed by the deltas of the Ox cleuch and the Thirlestone burn, which divided the big loch into two separate ones now represented by the Loch of the Lowes and St. Mary's Loch (Murry and Pullar, 1912).

St.Mary's Loch is the deepest loch south of the Highland Boundary Fault and is crescentic in outline, the narrower upper portion lying virtually north-south, while the wider lower portion lies along a north east-south west axis. The loch is divided into two basins separated by a sub-lacustrine ridge derived from deposition of material brought into the loch by the Megget Water. The deeper basin (ca.46.60m deep) is situated in the north-eastern part of the loch and was most likely formed due to the uniting of the Yarrow and Megget glaciers. The Loch of the Lowes is more rectangular in outline and lies almost north south at the head of St. Mary's Loch. The basin is simple and flat-bottomed in character.

Megget Reservoir was constructed on the Megget Water, the principle tributary to St.Mary's Loch and was operational by 1982. The mean water level lies at an altitude of 334m.a.s.l., some 87m above that of both St.Mary's Loch and the Loch of the Lowes. The main physical characteristics of all three water bodies are summarized in Table 2.1 and the main inflows are shown in Fig 2.5.

2.2.3 The Catchment.

Topography.

The catchment is defined by the Tweedsmuir hills to the north of Megget, to the east of the Loch of the Lowes and to the south of St.Mary's Loch. The area is dominated by rounded, steep-sided hills typically associated with the Southern Uplands. In general, the whole catchment lies above 180m.a.s.l. with ca.10% lying over 600m (see Fig. 2.6).

Geology and drift.

The area is composed predominantly of folded Ordovician and Silurian sedimentary rocks, mainly graywackes, siltstones and shales (Fig.2.7). In general these are well bedded and dip at high angles towards the N.W or S.E. The greywackes and siltstones form a series in terms of diminishing grainsize and increasing closeness of bedding planes. Igneous intrusions of a olderite character occur in a very few localities in the form of dykes up to 15m thick. The superficial deposits are mainly of alluvial and glacial origin, but there are some which arise from solifluxion, e.g. minor landslips, mudflows and screes.

Soil.

Peat and peat-derived soils such as peaty podzols and peaty gleys predominate, being promoted by high rainfall, cool temperatures and soil wetness. Blanket peat is extensively developed on the more gentle slopes and undulating ground. Brown forest soils are also present on the hills to the south of St.Mary's Loch (Fig.2.8).

Climate.

The climate is similar to that in the Loch Leven area, ie it is dominated by maritime air masses and is characterised by a lack of extremes. The average temperature (1941-70) ranges between 1.6°C and 13.5°C with the highest temperature in July and the lowest in January.

The average annual rainfall in the area is 1600mm.

Human Impact.

There are no major settlements within the catchment, the few houses present being scattered throughout. Other buildings include an hotel and an inn, both of which are situated on the banks of St.Mary's Loch. The Southern Uplands long-distance footpath also abuts the loch, bringing many walkers into the area during the summer, in addition to those tourists who visit the inn, the hotel or the cafe on the shores of the Loch of the Lowes. Water sport facilities are also available near the Tibbie Shiels Inn.

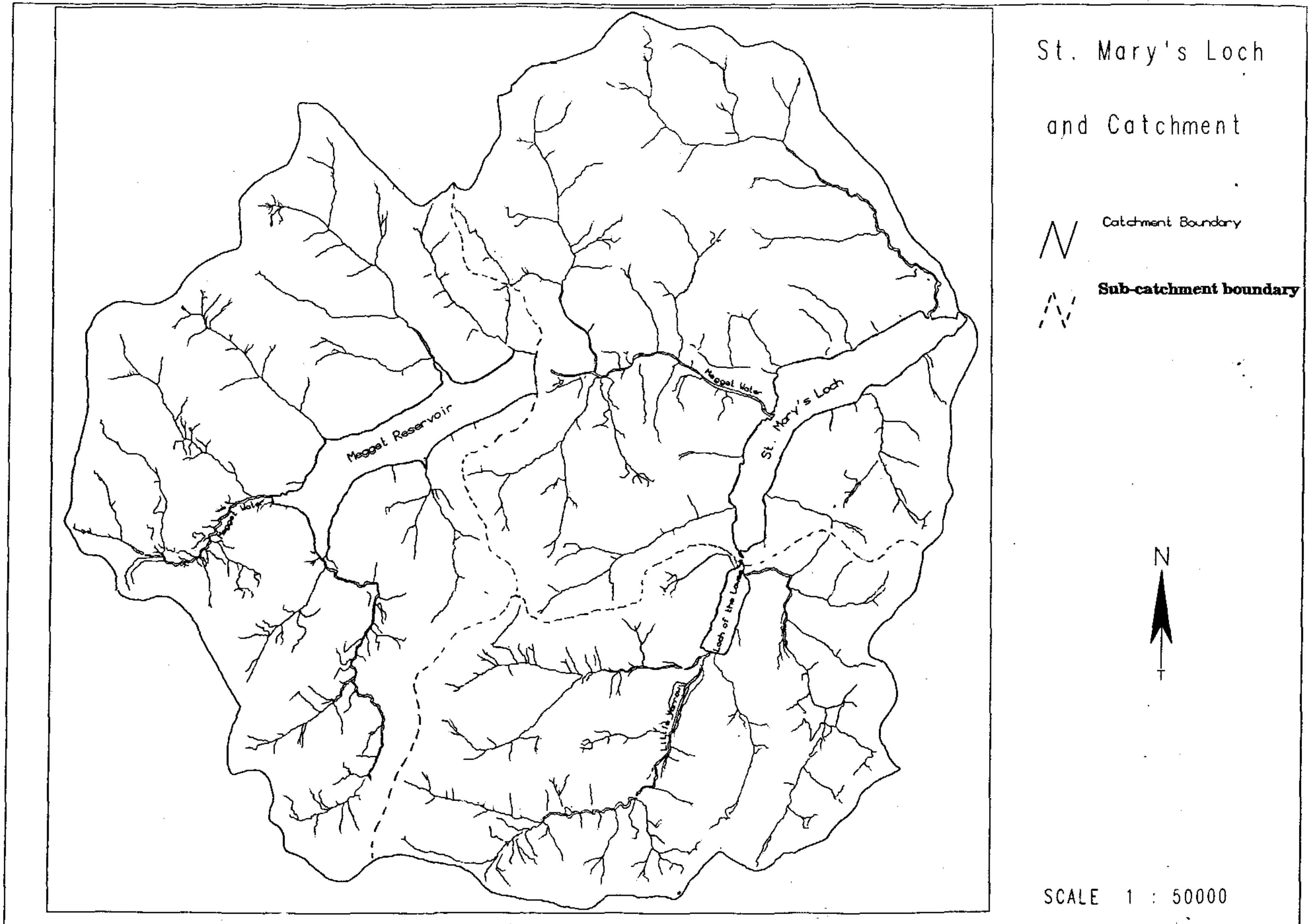

Fig. 2.5 The main inflows draining into St.Mary's Loch.

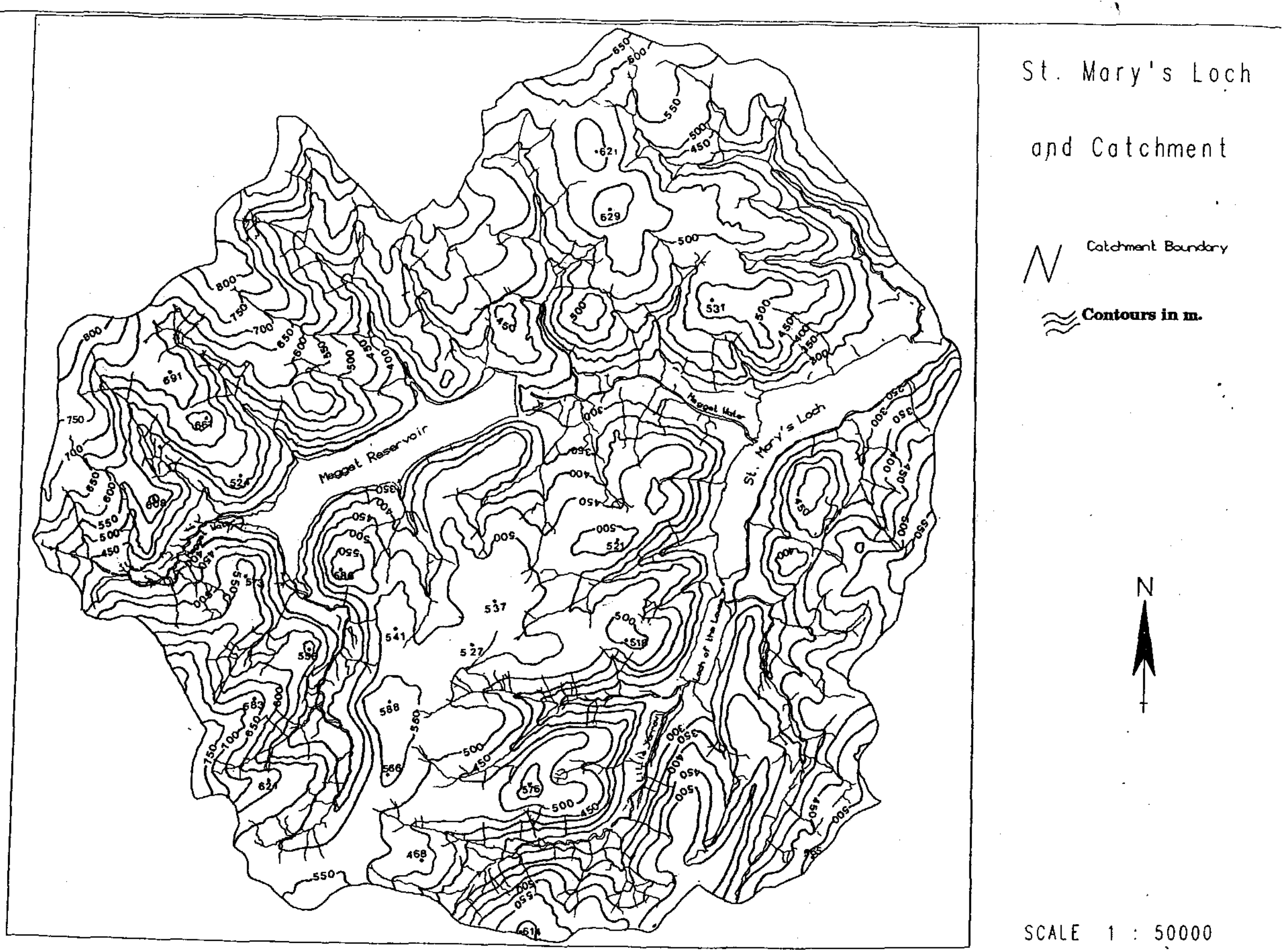

Fig. 2.6 Topography associated with the catchment of St.Mary's Loch.

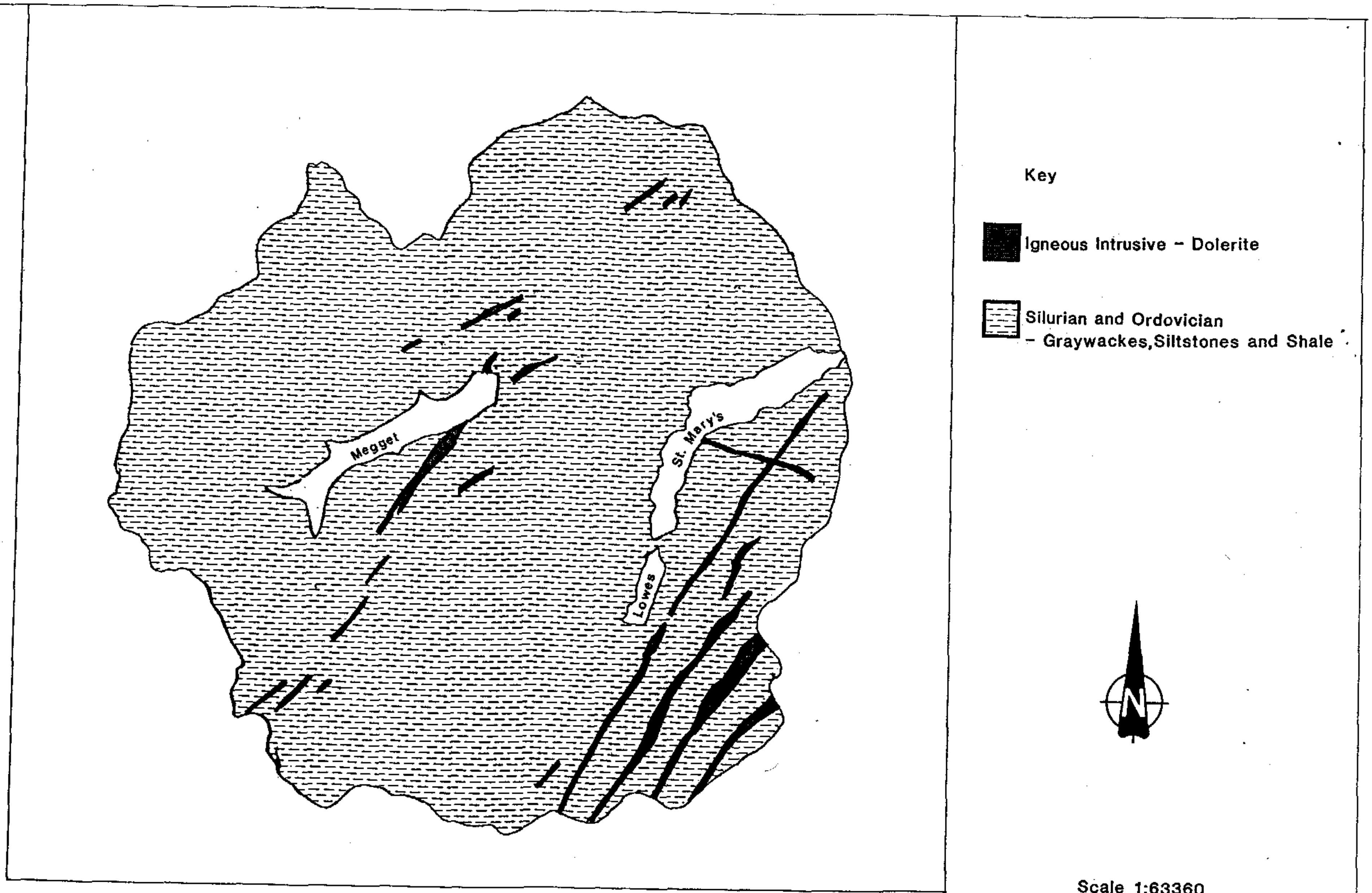

Fig. 2.7 Geology associated with the St.Mary's catchment.

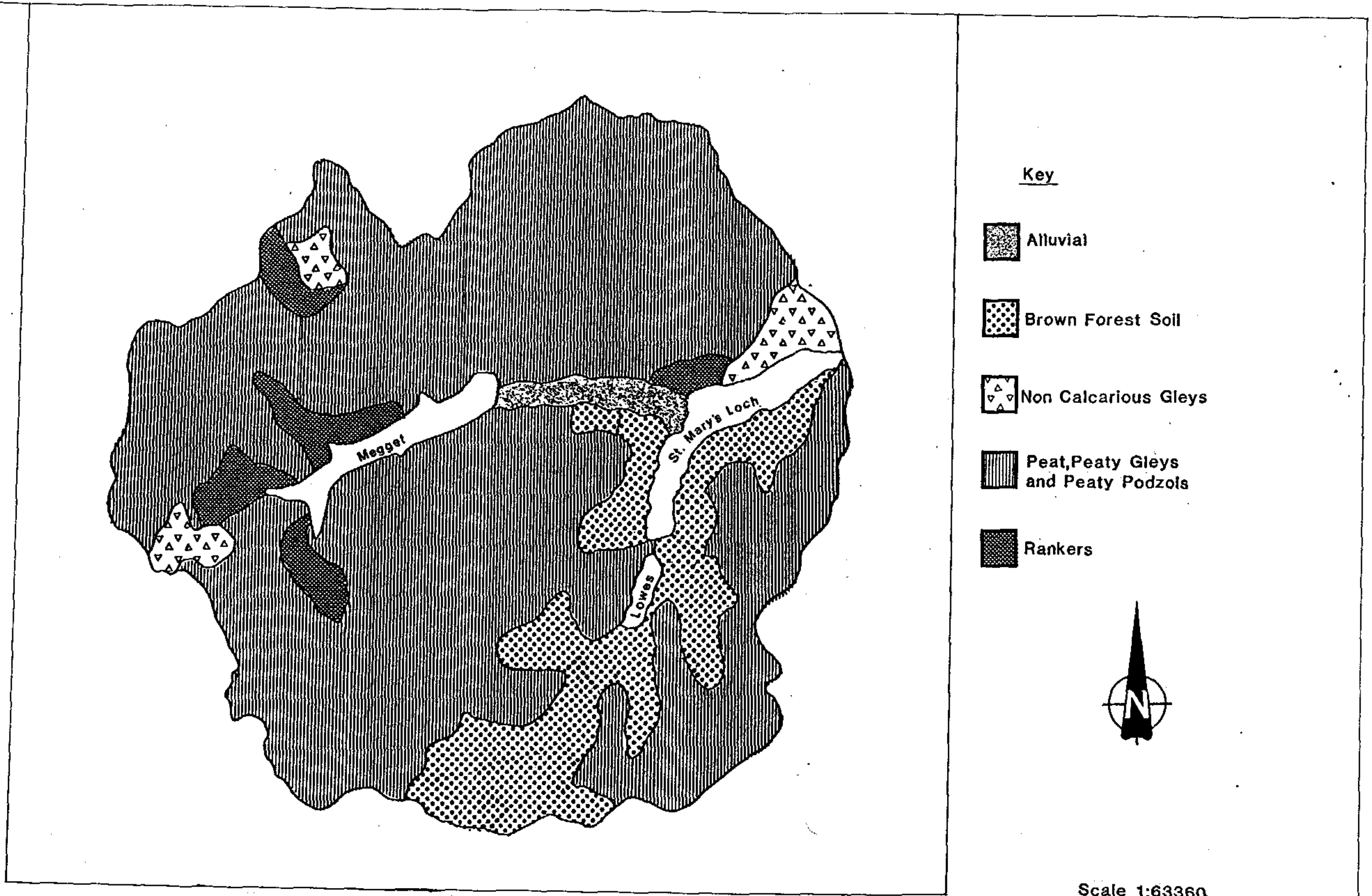

Fig. 2.8 Soils associated with the St.Mary's catchment.

Table 2.1: Physical characteristics of the study sites.

Catchment.	Leven.	St.Mary's.	Megget.	Lowes.
Catchment area (ha).	15870	10973	4201	2737
Loch area (ha).	1330	275	259	39
Loch vol. $x10^3m^3$	52400	57140	21000	4460
Mean depth (m).	3.9	22.3	-	11.1
Max depth (m).	25.5	47.0	-	17.7
Length (km).	5.9	4.9	-	1.4
Breadth (km).	2.3	0.8	-	0.4
No. of inflows.	9	13	8	4

CHAPTER 3 MATERIALS AND METHODS.

3.1.Source of Data.

3.1.1 O.S.Maps and Aerial Photographs.

The following Ordnance Survey maps and aerial photographs were used in connection with the study of the Loch Leven and the St.Mary's Loch catchments:

Loch Leven - O.S. 1:50 000
Sheet 58

Pathfinder Series of Great Britain 1:25 000;
Sheets NO 00/10 and NT 09/19.

Aerial photographs 1:24 000 taken in transects in 1988, provided for examination by the Scottish Office, Edinburgh.

St.Mary's - O.S. 1:50 000;
Sheets 73,74, and 79.

Pathfinder Series of Great Britain 1:25 000;
Sheets NT 01/11, NT 02/12, NT 21/31, and NT 22/32.

Aerial photographs 1:24 000 taken in transects in 1988 and 1989,provided for examination by the Scottish Office, Edinburgh.

3.1.2 Agricultural and Horticulture Census Data.

The Agricultural and Horticulture Census is taken annually by the Scottish

Office Agriculture and Fisheries Department. Questionnaires on farm holdings are sent out to occupiers of agricultural land with a view to producing national totals of agricultural production. The information given should be as at the 1st June unless otherwise stated. This information is strictly confidential, although summary data for individual parishes are made available to the public and were used in this study.

3.1.3 Landuse Questionnaires.

Where the above data were insufficient, as in the case of the St.Mary's catchment, questionnaires were sent out and returned by individual land owners . The information requested in these questionnaires included details of landuse types owned/managed, and the area of these within each sub-catchment. Information on animal stocking density, fertilisation regimes, and number of septic tanks within each sub-catchment was also requested.

3.1.4 Hydrological Data.

Within the Loch Leven catchment, runoff and gauged inflow data were insufficient for the years studied, and so gauged outflow data were used, assuming that in this case it was equal to inflow. The flow was derived from daily gaugings taken by the Forth River Purification Board (FRPB) at the sluices on the River Leven. These results are presented as megalitres of water passing over the sluice gates each month (see appendix 3). Monthly rainfall data from the Kinross meteorological station were also provided by the FRPB.

Within the catchment of St.Mary's Loch measurements of monthly rainfall, runoff and gauged river flow at two stations - Henderland and Craig Douglas - were provided by the Tweed River Purification Board (TRPB). In addition, estimated monthly inflow and outflow data were provided by the TRPB for the whole catchment and the sub-catchments of Megget reservoir and the Loch of the Lowes (appendix 3).

3.2 Data Analysis.

3.2.1 O.S. Maps and Aerial Photographs.

The 1:50 000 maps were used to define the boundaries of the catchment, sub-catchments and lochs; to identify outflows and to study the topography. The 1:25 000 maps were used to identify and produce a map of feeder streams. These maps were also used in combination with planimetry to calculate the following: area of the catchment and sub-catchments; loch surface area; areas <180m.a.s.l., 180-610m and >610m ; the extent of urban and forest (conifer) cover, where this information could not be obtained from other sources.

Aerial photographs were used in combination with other sources to determine landuse totals (in ha) for the two catchments.

Within the total catchment land area (ac), the landuse categories selected for this study were as follows:

Agricultural land
- arable land (ar)
- improved grassland (ig)

Forestry
- coniferous woodland plantations (cw)
- mixed woodland conifers and broadleaf (mw)

Rough grazing (rg)

Urban for sewage (ur)

Rural for septic tanks (ru)

Other land (ol)

Open water (ow)

3.2.2 Landuse Assessment - Census and Questionnaire.

Within the boundaries of the Loch Leven catchment there are five main parishes to be taken into consideration: Cleish, Fossoway, Kinross, Orwell and Portmoak, which comprise the former county of Kinross-shire. While the catchment is incorporated within the county, their boundaries do not coincide, the county being of considerably larger area.

In analyzing the census data the initial step was to calculate the total area of the individual parishes involved and the area common to both the catchment and the parishes. The parish land areas were then calculated using 1:25 000 maps and planimetry, and compared to the total land accounted for by the census (tc in ha). This was necessary as the census data does not take account of the land considered unsuitable for agriculture eg. open water, conifer plantations and urban areas; these were calculated separately. The remaining landuse categories eg. arable land, accounted for by the census were redistributed to give an estimated area of each within the catchment using the following equation:

eg. arable land,

$$\frac{ac - am}{tc} \times ar$$

Where: ac = total catchment land area (ha).

tc = total land accounted for in the Census (ha).

am = measured areas (ha) eg. open water etc.

$$\frac{(14\,540 - 997)}{17\,609} \times 5415$$

Livestock figures were not adjusted in this way as the animals tend to be mobile.

Due to the size of the two parishes associated with the St.Mary's catchment questionnaire returns were used to analyse landuse. The information received within each sub-catchment area was cross referenced with 1:25 000 maps, aerial photographs and site observations.

3.2.3 Estimation of Runoff, Total Inflow, and Flushing Rate.

From the gauged flow data provided by the FRPB for Loch Leven, monthly runoff (r, in mm) was estimated by dividing monthly gauged flow (V in Mm^3) by the sum of the areas of the catchment (ac) and the loch (al) in m^2, ie.

$$r = \frac{V}{(ac + al)}$$

Thus, for Jan 1990:

$$r = \frac{15.593}{(14540 + 1330) \ \text{x}10^6 m^2}$$

Monthly runoff figures for St.Mary's were provided by the TRPB.

The total monthly inflow for the catchment was estimated by multiplying the monthly runoff (mm) by the catchment area (ac, in m^2). This figure was then divided by the loch volume (V_l in Mm^3) to derive an estimate of monthly flushing rate.

3.2.4 Estimate of the Phosphorus Retention Coefficients.

It is important to gauge how much of the phosphorus entering the system is retained, (especially where intervening lochs occur within the catchment as at St.Mary's). P retention coefficients were calculated according to the empirical model of Kirchner and Dillon (1975), as data based on extensive, close-time interval sampling and P loading estimations at Loch Leven, fitted this model very closely and was applicable to this study. It's central term is q_s, the areal water loading, in units of m y^{-1}; this is the volume of water entering a loch, v_{in} (m^3 y^{-1}) divided by the surface area of the loch, A_l (in units of m^2). The model then predicts R from q_s according to:

$$R = 0.426e^{(-0.271qs)} + 0.574e^{(-0.00949qs)}$$

The application of this model is restricted to the estimation of annual P retention values. For the present purpose these retention values were applied to monthly P inputs from the catchment, assuming that R remained constant throughout the year.

3.2.5 Estimation of Monthly Nutrient Loading.

Monthly nutrient loadings were estimated from published loss rates and export coefficients. In this study nutrient loading was restricted to the consideration of total phosphorus (TP), and the coefficients given in Table 3.1 were those used to represent the expected annual P input to the loch system per unit of source. The P export coefficients were combined with calculated landuse areas as well as monthly runoff values to produce a monthly P load from each landuse area. Phosphorus contributions from treated sewage were taken as measured values from Bailey-Watts and Kirika (1987). The monthly P loss, M (kg) from all land uses in the catchment draining into the waterbody was estimated using a model by Reckhow and Simpson (1980), adapted to suit landuse categories in this study:

$$M = (EC_{cw}*A_{cw})+(EC_{mw}*A_{mw})+(EC_{ar}*A_{ar})+(EC_{ig}*A_{ig})+EC_{rg}*A_{rg})+(EC_{ru}*CY) + PSI$$

where: EC_{cw} = export coefficient for forest (plantation) land ($kg\ ha^{-1}\ month^{-1}$)

A_{cw} = area of forested land (ha)

EC_{mw} = export coefficient for woodland (mixed)

A_{mw} = area of woodland

EC_{ar} = export coefficient for arable land ($kg\ ha^{-1}\ month^{-1}$)

A_{ar} = area of arable land (ha)

EC_{ig} = export coefficient for improved grassland ($kg\ ha^{-1}\ month^{-1}$)

A_{ig} = area of improved grassland (ha)

EC_{rg} = export coefficient for rough grazing land ($kg\ ha^{-1}\ month^{-1}$)

A_{rg} = area of rough grazing land (ha)

E_{ru} = export coefficient for septic tank systems impacting the water-body ($kg\ (capita\text{-}year)\text{-}year)^{-1}$)

CY = number of capita years in the catchment served by septic tank systems impacting the water-body

PIS = point source input ($kg\ month^{-1}$)

It is important to note that landuse coefficients are supplied as annual values. In order to convert these values to monthly export coefficients the annual coefficients for the different landuse categories were converted to monthly values with a distribution identical to that of the monthly and annual runoff values. Runoff was chosen as the dependent factor due to the proven dependence of phosphorus export on runoff, as the primary transport mechanism, as reported in the literature (Bailey-Watts and Kirika, 1987). Firstly, for each year's data the appropriate annual export coefficient (ExCo) was weighted according to the ratio of the runoff in a particular year, to the mean annual runoff (MAR). Hence, for any particular year, the adjusted annual export coefficient is:

ExCo = ExCo * (annual runoff/MAR)

Thus in years in which the annual runoff is greater than MAR, the export coefficient will also be greater by the same proportion. The adjusted annual export coefficient above is further transformed into monthly values with a distribution equal to that of the monthly runoff values in any particular year. Hence, for any particular month of the year, the adjusted export coefficient, ExCo (kg ha^{-1} $month^{-1}$) is:

ExCo = ExCo * (monthly runoff/annual runoff)

The monthly phosphorus load, P (g m^{-2} $month^{-1}$), to the waterbody is given by:

P = M/AW

where AW = waterbody surface area

As the export coefficients for septic tanks and urban sewage are not dependent on runoff, they were converted to monthly values through division by twelve.

With regard to St.Mary's catchment it is insufficient to consider only the nutrient loading of the 'total' catchment, as this would lead to an over estimation of total P inputs, due to P retention in the intervening waterbodies, Megget Reservoir and the Loch of the Lowes. Conversely, the nutrient loading of the 'direct' catchment of St.Mary's would lead to an under estimation of the total inputs to St.Mary's Loch. With the exception of St.Mary's Loch therefore, the loadings of total P likely to enter from the 'total' catchment was estimated by incorporation of the P retention coefficients of Megget and the Lowes, into the calculations.

The loading from the land draining directly into St.Mary's Loch (the 'direct' catchment area) is defined as the 'direct' loading (Ld), as are the loadings from the land abutting Megget reservoir and the Loch of the Lowes within their respective sub-catchments. With regard to St.Mary's Loch both Megget and the Lowes catchments are defined as 'extended' catchments and the loadings from these are corrected using the P retention coefficient to derive the 'extended' loading (Le) draining into St.Mary's Loch. The total nutrient loading to St.Mary's Loch (Lt) will thus be:

$$Lt_{MY} = Ld_{MY} + Le_{MY}$$

The 'extended' loading Le for St.Mary's is then calculated as follows:

$$Le = (Ld_{MT}(1 - R_{MT})) + (Ld_{LW}(1 - R_{LW}))$$

where subscript: MT = Megget reservoir
LW = Loch of the Lowes
R = the P retention coefficient
Ld = the loading from the 'direct' catchments

By substitution, the 'total' nutrient loading to St.Mary's Loch will be:

$$Lt_{MY} = Ld_{MY} + ((Ld_{MT}(1 - R_{MT}) + (Ld_{LW}(1 - R_{LW}))$$

Table 3.1 Phosphorus losses (given as export coefficients, in kg ha^{-1} yr^{-1} unless otherwise stated) from various types of land.

Landuse	Export coefficient	Reference source
Arable	0.25	1, 2
Improved Grassland	0.41	3, 4
Rough Grazing	0.07	1, 2
Forestry	0.42	8
Woodland	0.15	5, 6
Septic tanks	1 kg/person/year	7

References

1.Cooke 1976; 2.Cooke and Williams 1973; 3.IoA and IFE 1990; 4.Stevens and Stewart 1981; 5.Hancock 1982; 6.Harper 1978; 7.Reckhow and Simpson 1980; 8.Harriman 1978; all cited in Bailey-Watts *et al* (1992).

CHAPTER 4. RESULTS.

4.1 Landuse.

4.1.1 Loch Leven.

With regard to the five parishes identified in section 3.2.2 approximately two-thirds of the land accounted for by the Census was found to be agricultural, with arable crops and improved grassland in approximately equal amounts. In the parish of Kinross arable crops and improved grassland account for over 90% of the land with an arable:grass ratio of ca. 2:3, whereas in Cleish and Portmoak they account for only just over 60% with a ratio of 1:2, (Table 4.3).

In all five parishes, grassland is mainly used for grazing, (Table 4.2), and supports approximately 57000 sheep and 11000 cattle. The arable land can generally be classified as mixed, with Winter and Spring barley and oilseed rape being the dominant crops.

Rough grazings account for approximately a fifth of the total land recorded and comprises over a third of the parishes of Cleish and Portmoak, (Table 4.1). In general rough grazings are found at altitudes greater than 180m and on the steeper slopes. Forestry plantations are also found in these areas,(eg. in the Cleish and Ochil hills), although they were not accounted for in the Census but were identified from O.S. maps.

The livestock of the parishes includes horses, goats, pigs, cattle, sheep and poultry, the latter three being the most abundant.

Discrepancies between measured parish land area (excluding areas of open water) and total land area accounted for in the Census were found, giving rise to ca. 20% of the total area being unaccounted for. In addition

Table 4.1: Agricultural census items recorded in June 1991 for the former county of Kinross-shire.

	Cleish	Fossoway	Kinross	Orwell	Portmoak
	ha % *	ha %	ha %	ha %	ha %
Total area of land.	1292.8 100	6180.1 100	2438.3 100	4357.4 100	3341.7 100.0
Total crops.	281.8 21.7	1027.9 16.6	1201.2 49.3	1640.9 37.7	1263.7 37.8
Bare fallow.	8.8 0.7	256.4 4.1	71.9 2.9	27.3 0.6	105.3 3.1
Total grassland.	537.9 41.6	3363.8 54.4	946.0 38.8	1693.9 38.9	725.1 21.7
Total crop and fallow.	289.6 22.4	1284.3 20.8	1273.1 52.2	1668.2 38.4	1369.0 41.0
Total crop and grassland.	827.5 64.1	4648.1 75.2	2219.1 91.0	3362.1 77.2	2094.1 62.7
Rough grazing.	444.9 34.4	1203.9 19.5	74.7 3.1	834.0 19.1	1090.0 32.6
Woodlands (mixed).	7.4 0.6	229.8 3.7	35.6 1.5	95.3 2.2	115.2 3.4
Other land.	12.0 0.9	98.3 1.6	108.9 4.5	66.0 1.5	42.4 1.3
Total livestock.	188700	163800	800400	15900	8900
No.of holdings.	20	65	33	47	25
Parish area. ha	2573.8	6411.3	4317.5	5281.3	3955.0
Total Lochs. ha	6.3	0.0	1330.0	3.1	50.0

* % of total land area accounted for in the Census

Table 4.2: Total grassland recorded in the June 1991 Census for the former county of Kinross-shire.

	Cleish	Fossoway	Kinross	Orwell	Portmoak
	ha % *	ha %	ha %	ha %	ha %
Total grassland.	537.9 100	3363.8 100	946.0 100	1693.9 100	725.1 100
For mowing.	130.0 24.2	755.0 22.4	382.7 40.5	545.4 32.2	215.3 29.7
For grazing.	407.5 75.8	2608.8 77.6	563.3 59.5	1148.5 67.8	509.8 70.3

* % of the total grassland recorded.

Table 4.3: Total Crops and Grassland recorded in the June 1991 Census for the former county of Kinross-shire.

	Cleish	Fossoway	Kinross	Orwell	Portmoak
	ha % *	ha %	ha %	ha %	ha %
Total crops and grassland.	827.5 100	4648.1 100	2219.1 100	3362.1 100	2094.1 100
Total crops and fallow.	289.6 35.0	1284.3 27.6	1273.1 57.4	1668.2 49.6	1369.0 65.4
Total grassland.	537.9 65.0	3363.8 72.4	946.0 42.6	1693.9 50.4	725.1 34.6

* % of the total crops and grassland recorded.

Table 4.4: Corrected Landuse Areas for the Leven Catchment.

Landuse area.	ha.	% Land.	% catchment.
Forestry (plantation)	726.8	5.0	4.6
Woodland (mixed).	371.7	2.6	2.3
Rough grazing.	2805.2	19.4	17.7
Improved grassland.	5588.6	38.7	35.2
Arable.	4525.4	31.3	28.5
Other land.	251.9	1.7	1.6
Urban.	183.4	1.3	1.1
Lochs.	1416.9	-	8.9
Catchment.	15870.0	-	100.00

approximately half the area of Cleish, Fossoway and Portmoak, and a third of Orwell lie outside of the catchment boundary. Due to these discrepancies Census items were redistributed and additional landuses included in accordance with information obtained from O.S. maps and aerial photographs. The area of different landuses within the catchment could thus be corrected using a factor derived from the percentage distribution in the Census data (see section 3.2.2), giving rise to the corrected catchment landuse data presented in Table 4.4.

In general, the Leven catchment can be regarded as predominantly agricultural with rough grazings and forestry plantations restricted to the boundary hills where the land rises above 180m and forms steeper slopes. The agricultural land abuts the loch with some mixed wood land bordering it to the east side.

4.1.2 St.Mary's Loch.

The predominant landuse within the catchment of St.Mary's Loch was found to be rough grazing, ca. 86% (Table 4.5). This land supports approximately 10500 blackface Ewes and 2100 Hoggs, (this figure is an under estimation as not all stocking densities were obtained for St.Mary's 'direct' catchment). While not insignificant forestry plantations account for about one-half of the remaining 14% of the catchment, the larger plantations abutting the Loch of the Lowes and St.Mary's Loch.

On a sub-catchment basis, the 'direct' catchment of both Lowes and St.Mary's support some forestry, (ca. 10% and 12% respectively), while that of Megget was found to consist almost entirely of rough grazing land with some mixed woodland abutting the reservoir. St.Mary's 'direct' catchment incorporates small areas of improved grassland which are drained by the main inflow, the Megget Water.

Table 4.5: Landuse areas for the Catchment of St.Mary's Loch and the 'direct' catchments of Megget, Lowes and St.Mary's. (Landuse values given as a) % of the total catchment area and b) as % of the sub-catchment area).

	St.Mary Total	Megget.	Lowes.	St.Mary direct
Landuse area.	ha % a.	ha % a. % b.	ha % a. % b.	ha % a. % b.
Forestry (plantation).	792.0 7.2	0.0 0.0 0.0	271.9 2.5 9.9	520.1 4.7 12.4
Woodland (mixed).	29.6 0.3	15.0 0.1 0.4	5.0 0.0 0.2	9.6 0.1 0.2
Rough grazing.	9515.3 86.7	3757.5 34.2 93.1	2417.6 22.0 88.3	3340.2 30.4 79.5
Improved grassland.	56.1 0.5	0.0 0.0 0.0	0.0 0.0 0.0	56.1 0.5 1.3
Rural.	25.0 0.2	3.5 0.03 0.1	3.5 0.03 0.1	18.0 0.2 0.4
Lochs.	555.0 5.1	259.0 2.4 6.4	39.0 0.4 1.4	257.0 2.3 6.1
Catchment.	10973.0 100	4035.0 36.8 100	2737.0 24.9 100	4201.0 38.3 100

Table 4.6: Average Annual Phosphrus Retention Coefficients Estimated and used in this study.

	10 yr. av. SD	1984	1989	1990
St.Mary's 'total'	0.371 +/- 0.096	-	0.382	0.363
Megget 'direct'	0.455 +/- 0.024	-	0.477	0.428
Lowes 'direct'	0.319 +/- 0.035	-	0.352	0.282
Leven 'total'	0.551 +/- 0.023	0.533	0.580	-

SD = Standard deviation of 1984, 1989 and 1990 P retention coefficient from the ten year average coefficient.

Table 4.7: Average fertilizer use in South East Scotland by crop (AFRC, 1990)

	overall kg/ha		
	N	P_2O_5	K_2O
Tillage crops			
winter wheat	203	70	82
spring barley	106	53	58
winter barley	170	69	83
oat	98	51	64
potatoes	174	171	253
turnips (stock)	68	121	117
kale & cabbage (stock)	85	68	75
oilseed rape	219	57	59
other roots and green crops	79	65	58
vegetables	100	164	162
small fruits	65	51	95
all tillage	144	67	80
Grass			
grazed only	85	12	14
cut for sillage	199	33	54
cut for hay	126	29	37
all grass	110	18	23
rough grazing + fertilizer	102	16	20
all crops and grass	130	47	57

4.2 Fertilizer Regimes.

Little information on the type, application time and quantities of fertilizer used on agricultural land was obtained through the questionnaire returns but a general guide of fertilizer types and composition is presented in Table 4.7 (from Winkler, 1991). Information, however was obtained from Tilhill Economic Forestry for the forest plantations on Bowerhope Estate and Bowerhope Law. The former was fertilized in compartments between 1971 and 1976 using GAFSA/POTASH Mix at an application rate of 150kg ha^{-1}. The latter was fertilized once, after the first seasons weeding, in September 1986. The fertilizer used was: 22.55 tonnes GAFSA and 4.90 tonnes GAFSA/POTASH Mix, and was applied by hand at the rate of 375 kg ha^{-1} in peaty areas, 575 kg ha^{-1} in areas of deeper peat and 180 kg ha^{-1} elsewhere (Schofield, Pers. comm.). A breakdown of planting times and species composition was also obtained for this area (Appendix 2).

4.3 Hydrology.

4.3.1 Inflow and Theoretical Flushing Rate.

Flushing rate, which is dependant on rainfall and surface runoff from the catchment, was found to vary between the lochs and the different years studied (Fig. 4.2).

On average (from the ten years' rainfall records) both St.Mary's and Loch Leven were found to be flushed twice a year ie. within a twelve- month period volumes of water equivalent to two loch volumes passed through both these waterbodies. At both sites one loch volume was passed through by the end of May and the second by the end of December. In 1989, a drier than average year, both lochs were again flushed twice but this time the flushing came earlier, the first loch volume going through by the end of March. The lochs were then not flushed again before the end of the year, giving rise to a longer water residence time within the lochs. In a wetter than average year, 1984 and 1990 for Loch Leven and St.Mary's Loch respectively, the former was flushed almost three times whilst the latter was flushed only a little over twice. As before both lochs were flushed once by the end of March. Loch Leven was then flushed again by the end of October and a third time by the end of the year.

Megget reservoir was found to be flushed three times on average, this rate decreasing to only 2.5 times in a drier than average year, 1989, and increasing to four times in a wetter than average year, 1990. In each case only one 'loch' volume passed through during the months of April to September, the rest being flushed out during the wetter winter months. In 1990 the reservoir appeared to be flushed twice in the first three months of the year, almost one volume being flushed through in February alone. In comparison, during the same period in 1989 only just over one volume had been flushed, February being the month of least inflow and having the lowest flushing rate in that period. These figures were, however, only theoretical as the flushing rate will be artificially controlled at all times by the dam and drawdown will be dependant on water supply demands to Edinburgh.

The Loch of the Lowes was found to have the highest flushing rate, being flushed five times on average and ranging from 6.5 times to 4.5 times in the wettest and driest years respectively. In each case the loch was only flushed once during the months of April to August/September, coinciding with the time of lower inflow, runoff and rainfall. In 1990, the wetter than average year, the Loch of the Lowes was flushed almost three times in the first two months of the year in comparison to only 1.5 times during the same period in 1989, a drier than average year. In March, however, due to exceptionally high rainfall, the loch was flushed once in this month alone.

From Figures 4.1 and 4.2 the relationship between inflow/runoff and loch

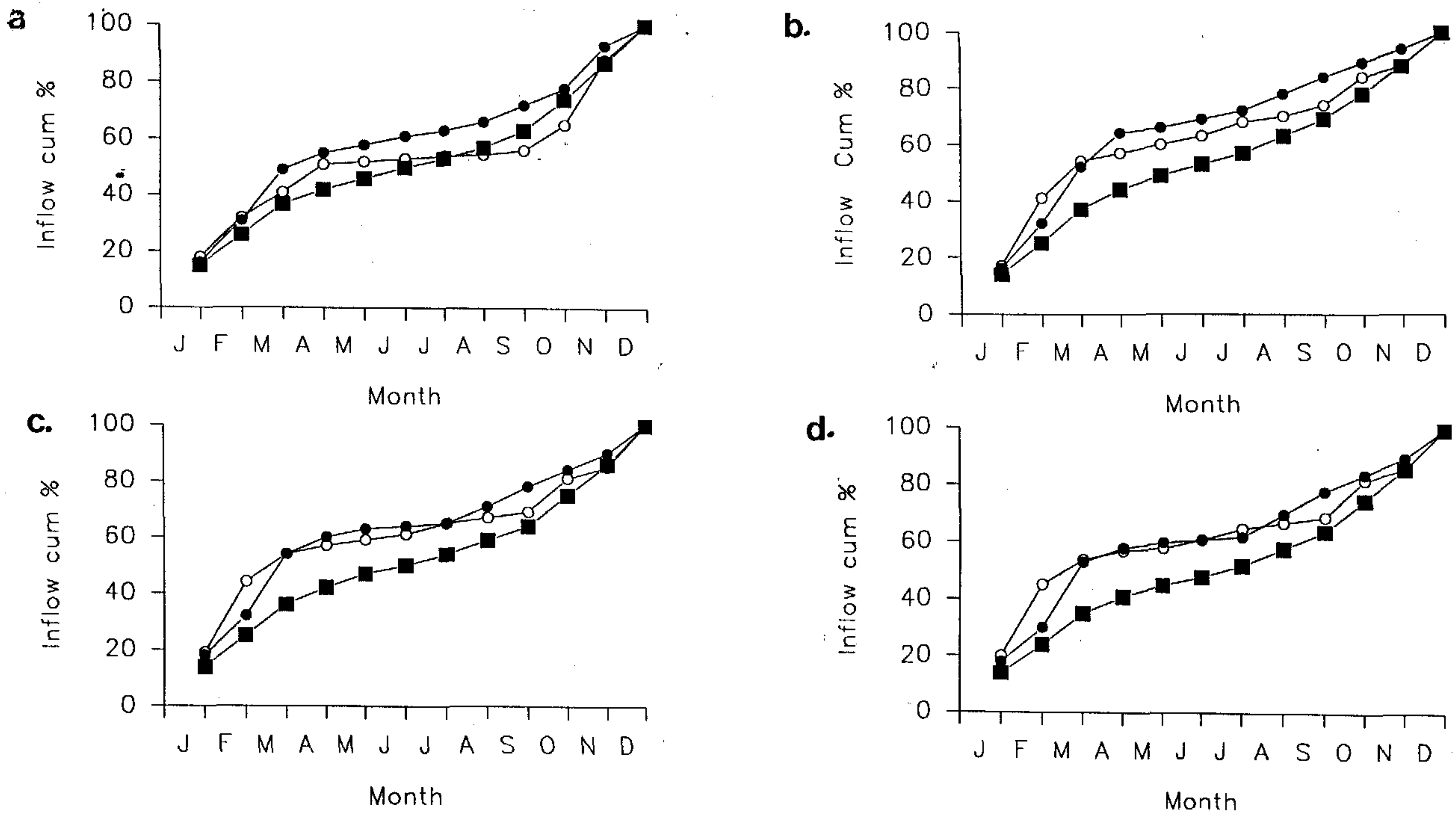

Fig 4..1 The cumulative annual inflow (%) to a. Loch Leven; b. St.Mary's Loch c. the Loch of the Lowes; d. Megget Reservoir, in an average year (■), in a wetter year (○), and in a drier year(●).

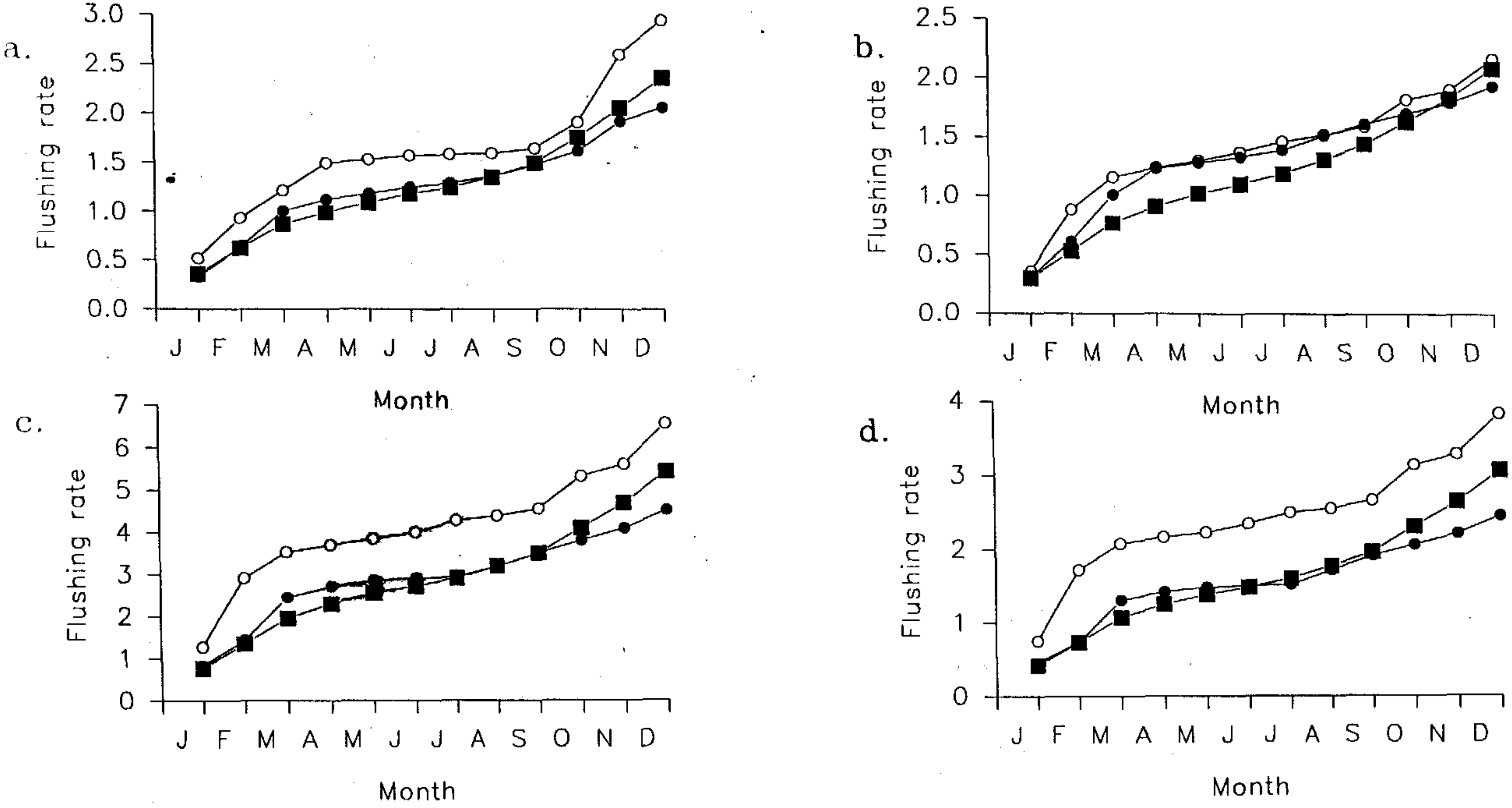

Fig 4.2 The flushing rate (in loch volumes) of a. Loch Leven; b. St.Mary's Loch; c. the Loch of the Lowes; d. Megget Reservoir, in an average year (■), in a wetter year (○), and in a drier year (●).

volume, and their influence in determining the flushing rate, can be clearly observed. In general, as inflow/runoff increase so too does the flushing rate, in a linear manner, due to the inter-relations between these parameters in the calculations used.

4.3.2 Areal Water Loading and Phosphorus Retention Coefficient.

The areal water loading was highest for the Loch of the Lowes, due to its high inflow:surface area ratio, and lowest for Loch Leven due to its low inflow:surface area ratio.

The annual Phosphorus retention coefficient gave an indication of the fraction of nutrient loading likely to be retained by the loch (Bailey-Watts and Kirika, 1987). P retention was found to be highest for Loch Leven and lowest for the Loch of the Lowes. In general the P retention coefficient deviated little from the mean, (see Table 4.6), retention being higher in the drier than average years and lower in the wetter than average years. This result was not unexpected as P retention is related to inflow and areal water loading (Kirchner and Dillon 1975).

4.4 Nutrient Loading.

Nutrient loading, which addresses the relationship between landuse and phosphorus export from the catchment to the receiving water-body, was found to vary between catchments and on a monthly basis (Figs 4.3 and 4.4).

4.4.1 TP Loading from the Catchment.

The total annual TP loading from the catchment for Loch Leven was ca. 9 t yr^{-1} (Fig. 4.3), an order of magnitude greater than the corresponding value for St.Mary's Loch ie. 0.9 t yr^{-1} (Fig 4.4). Expressed as areal phosphorus

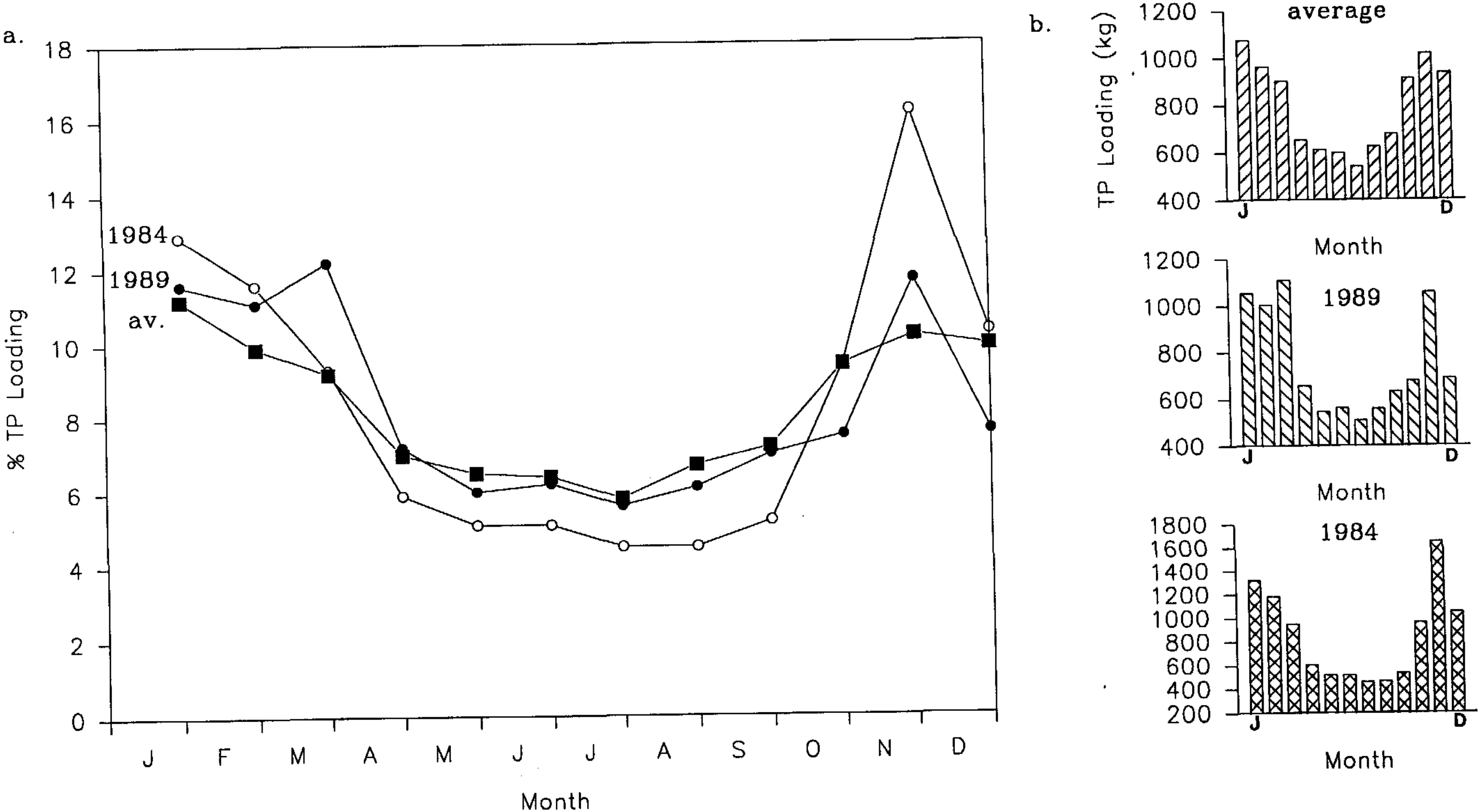

Fig 4.3 P loading to Loch Leven as a. a % of the total annual loading, and b. the amount in kg for an average year, a wetter year (1984), and a drier year (1989).

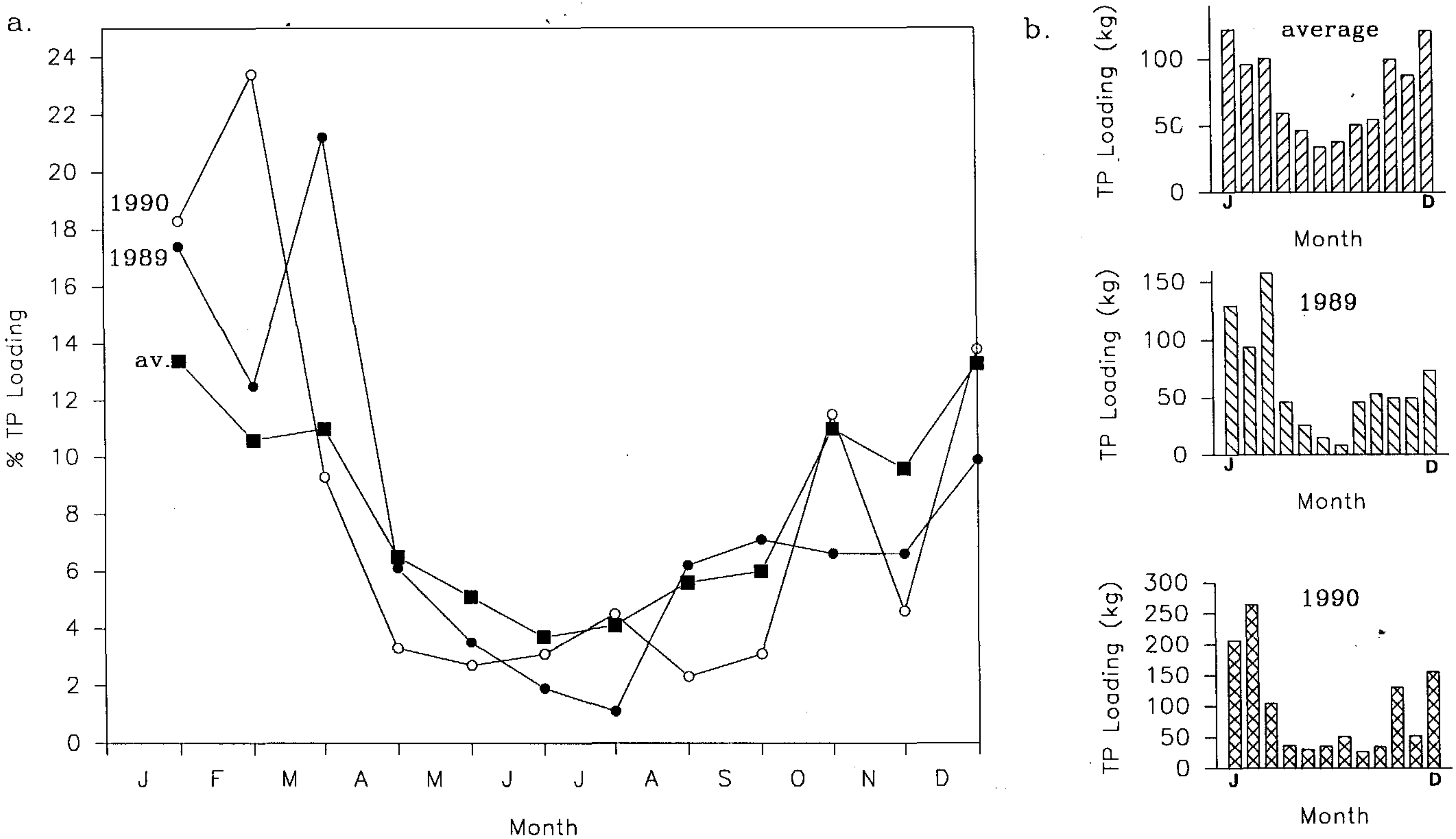

Fig 4.4 P loading to St.Mary's Loch as a. a % of the total annual loading, and b. the amount in kg for an average year, a wetter year (1990), and a drier year (1989).

loadings, the values were 0.72 and 0.33 g m^{-2} yr^{-1} for Loch Leven and St.Mary's Loch respectively. In the wettest year (1984 for Leven and 1990 for St.Mary's), these figures increased to 0.76 and 0.41 g m^{-2} yr^{-1}, and decreased in the driest year (1989) to 0.68 and 0.27 g m^{-2} yr^{-1} for Loch Leven and St.Mary's Loch respectively.

The greatest P loading to St.Mary's Loch was found to come from it's 'direct' catchment, while the 'direct' catchment of Megget contributed least (Fig 4.5, a-c).

On a monthly basis, January was found to be the month of maximum TP loading in an average year from both catchments, and June/July the months of minimum TP loading. The January areal TP loadings were 0.08 and 0.04 g m^{-2}, and the June/July were 0.04 and 0.01 g m^{-2} $month^{-1}$ for Loch Leven and St.Mary's Loch respectively. Interestingly the lowest monthly areal TP loading for Loch Leven in an average year was equal to the highest monthly areal TP loading for St.Mary's Loch.

In the wetter year of 1984 at Loch Leven the minimum areal TP loading was in July/August (0.03 g m^{-2} $month^{-1}$) and the maximum in January (0.10 g m^{-2}). In 1989, a drier than average year, the minimum areal TP loading occurred in the months of May, June and July (0.04 g m^{-2} $month^{-1}$) and the maximum in the months of January, March and November (0.08 g m^{-2} $month^{-1}$). For St.Mary's Loch the minimum areal TP loading in a wetter year,1990, occurred in the months of May, June, August and September (0.01 g m^{-2} $month^{-1}$), and the maximum in February (0.10 g m^{-2}). This was an unusual year in that it was the wettest year in a ten year period and yet had a reasonably dry summer. In 1989, an exceptionally dry year, the maximum areal TP loading was in January (0.05 g m^{-2}) and the minimum in July (0.003 g m^{-2}).

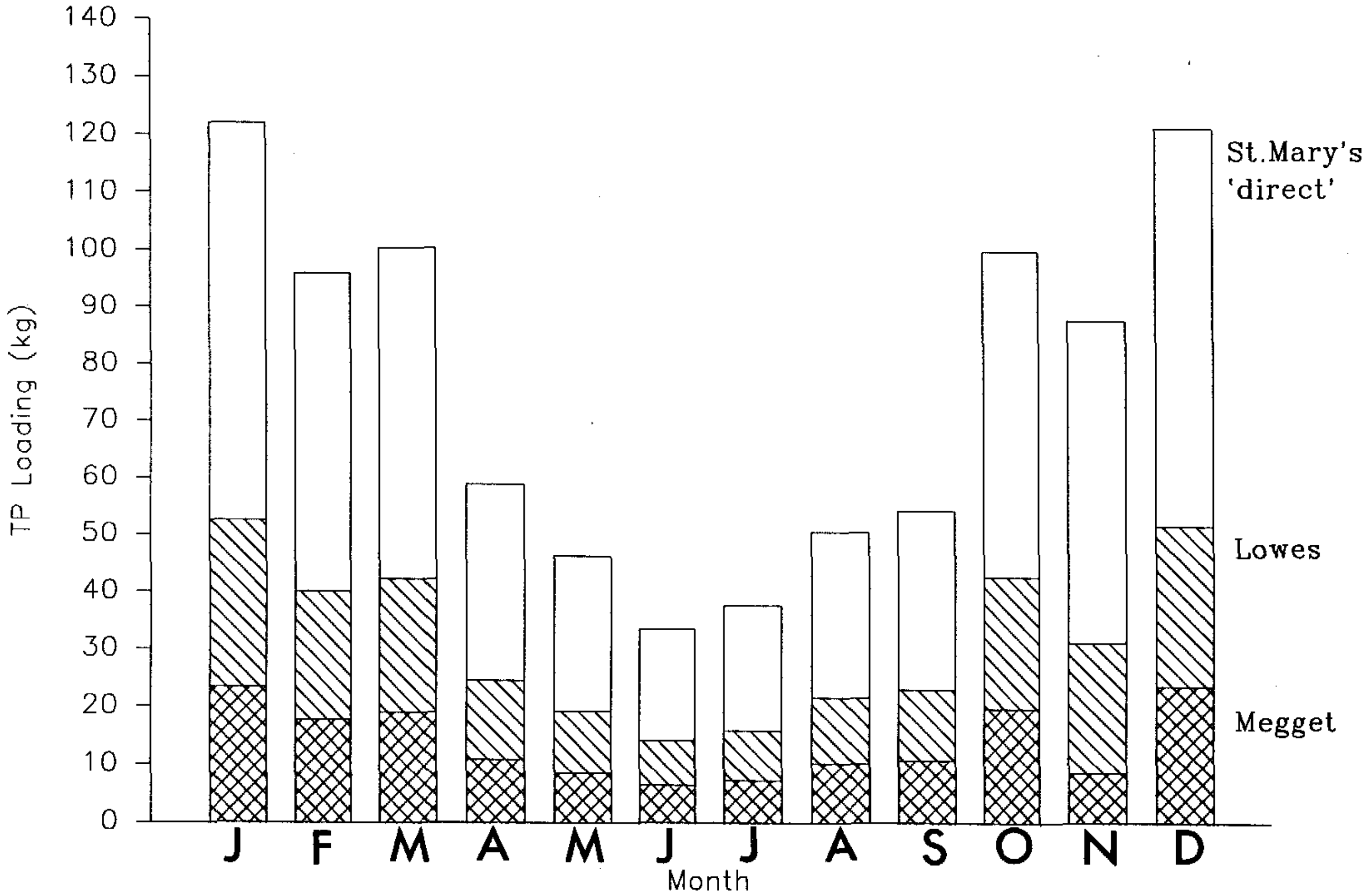

Fig 4.5a. Ten year average P loading to St.Mary's Loch from each of the sub–catchments

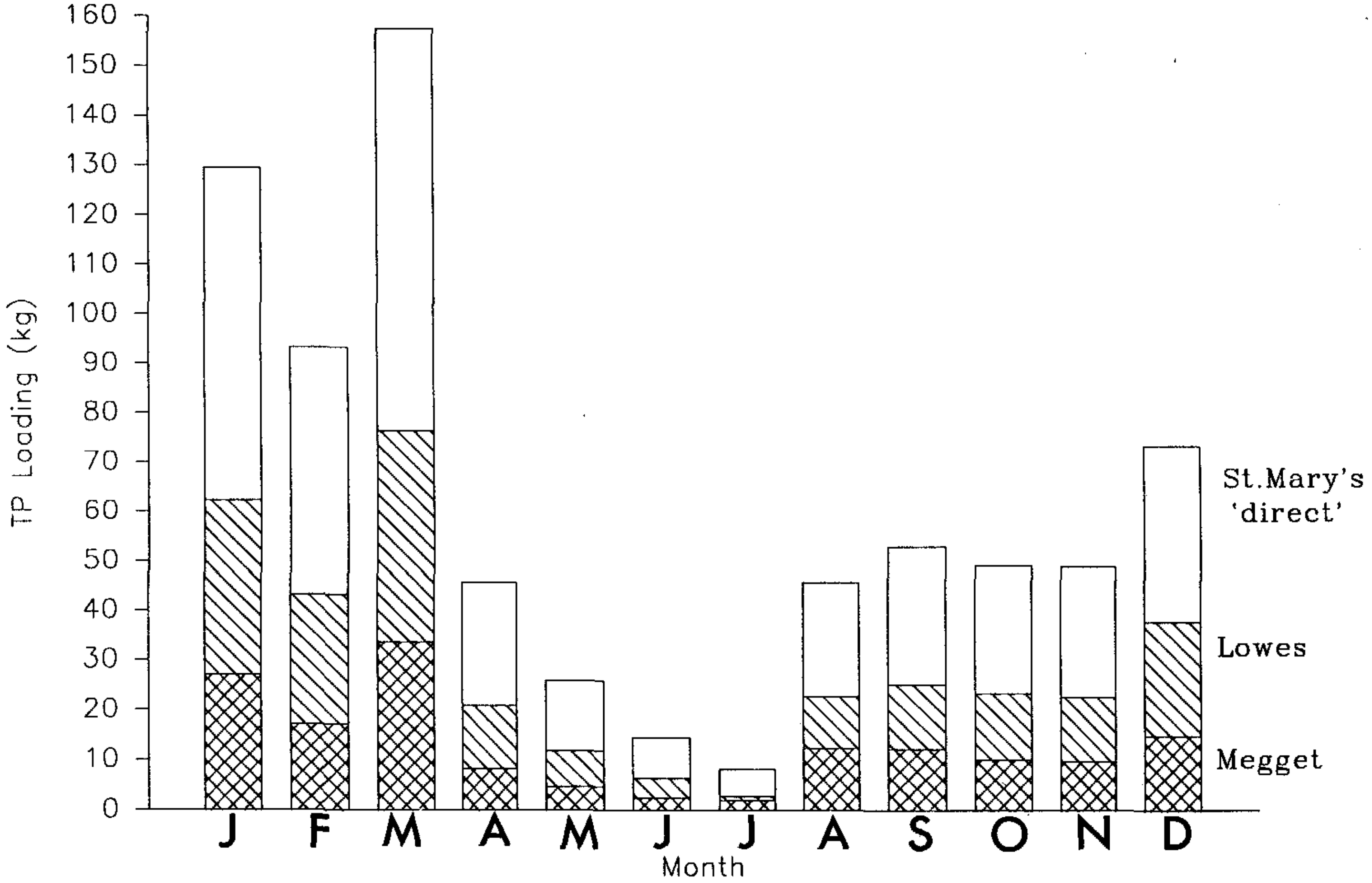

Fig 4.5b. P loading to St.Mary's Loch in 1989 from each of the sub-catchments.

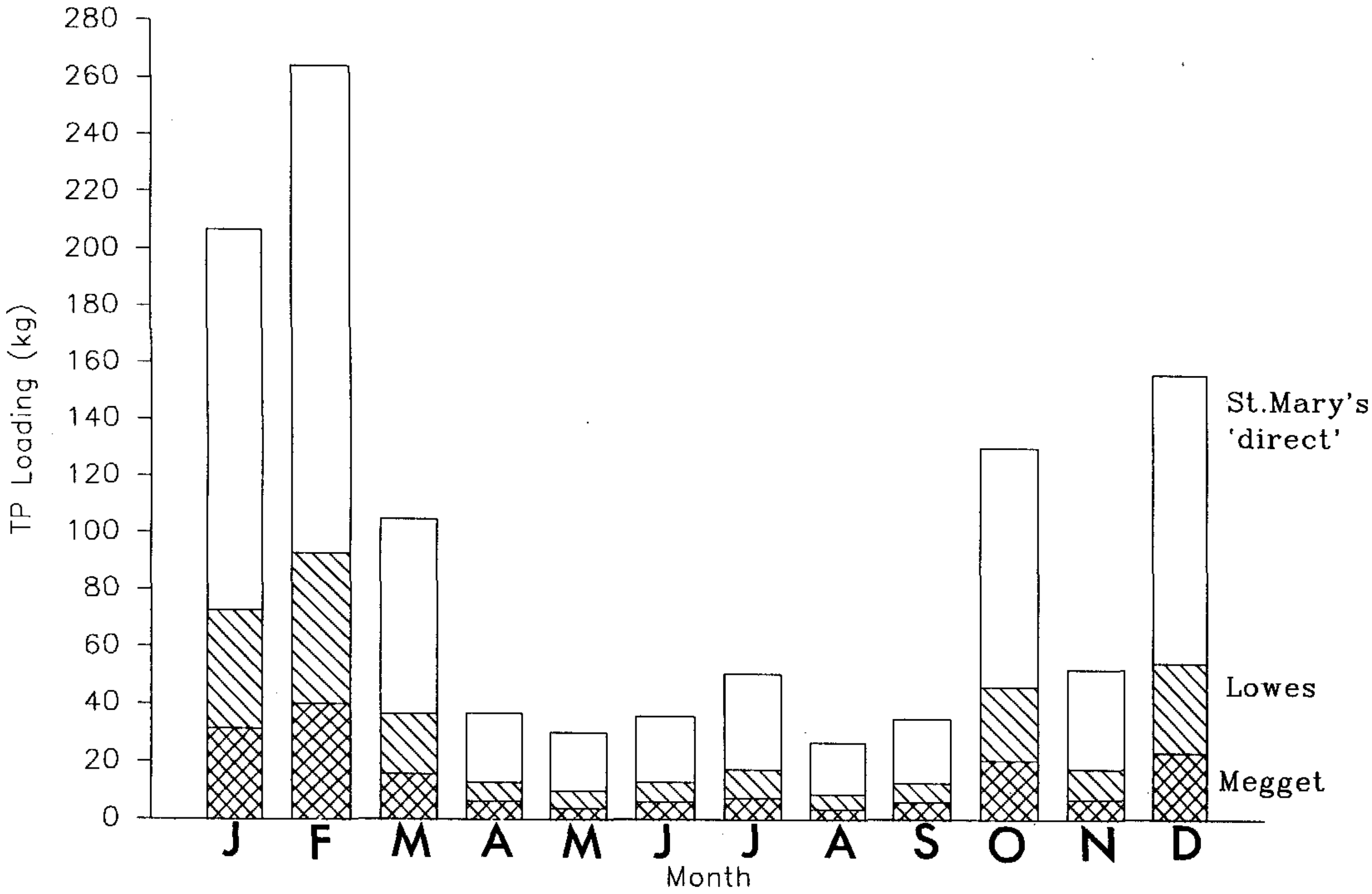

Fig 4.5c. P loading to St.Mary's Loch in 1990 from each of the sub-catchments.

4.4.2 The Components of the External TP Loading.

Phosphorus loading to St.Mary's Loch was entirely runoff dependent ie of a non-point source nature. Rough grazing land contributed over 55% of the TP burden which is perhaps not surprising, as it accounted for 87% of the catchment area (Fig. 4.6a). Of greater concern in this study was the fact that forestry plantations contributed over 30% of TP loading while accounting for only 7% of the land cover. The remaining 10% of the total loading was accounted for through septic tank seepages. This figure was most likely over-estimated as no account was taken of the soil retention capacity due to difficulties in obtaining a detailed enough soil map of the area. The contributions from external sources from each of the sub-catchments are shown in Fig. 4.7.

Contrastingly, point sources of TP, in the form of treated sewage, contributed the largest proportion (ca.56%) of the total input to Loch Leven (Fig. 3.6b). Diffuse runoff contributed a further 42%, while the remaining 2% can be attributed to over-wintering wildfowl (mainly Greylag and Pinkfooted Geese). In this case inputs via catchment runoff were probably under-estimated due to the possible 20% error in redistributing the Census data to take account of the catchment boundary and the choice of export coefficients used. Comparison with measured TP loading in this catchment (Bailey-Watts *et al*, 1987) would support this. No account was taken of industrial TP loading via the mill in Kinross as these inputs ceased in 1987. As a result loading figures for 1984 and the average year (derived from the ten years' rainfall data) will be under-estimates but are unlikely to alter the overall significance of the results.

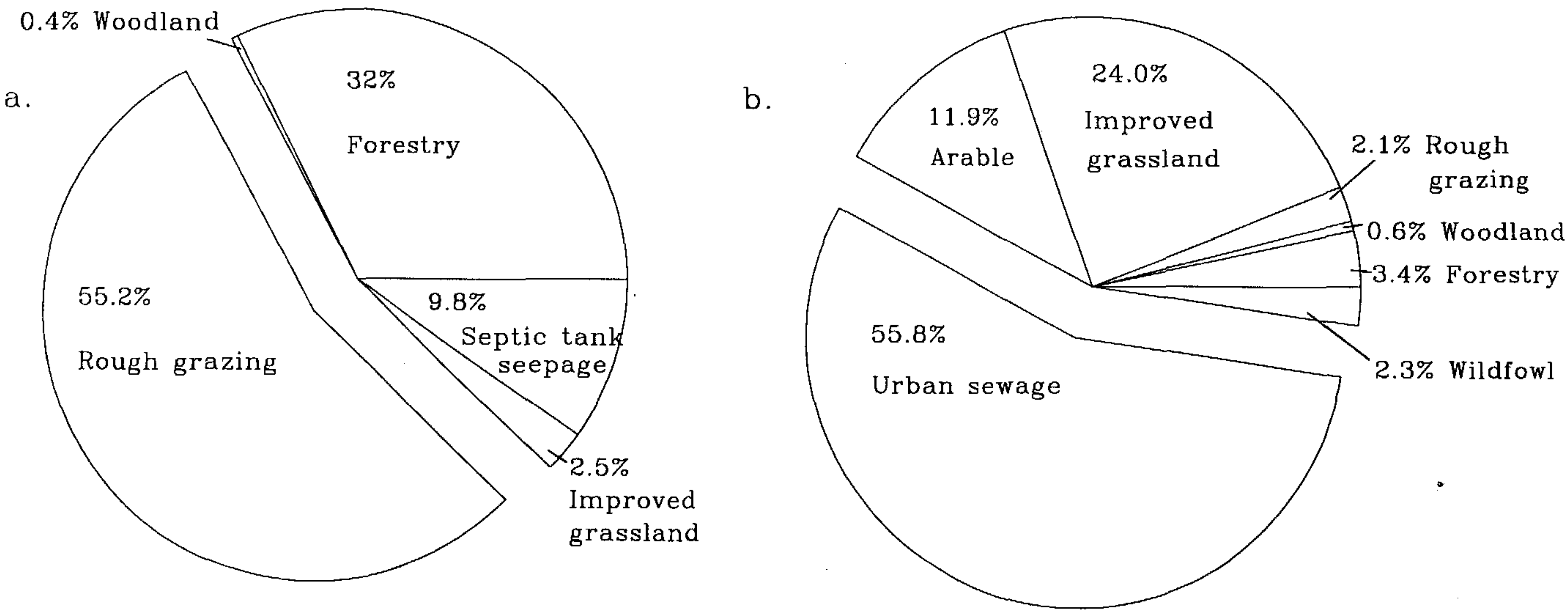

Fig 4.6 The components of the external TP loading to a. St.Mary's Loch and b. Loch Leven

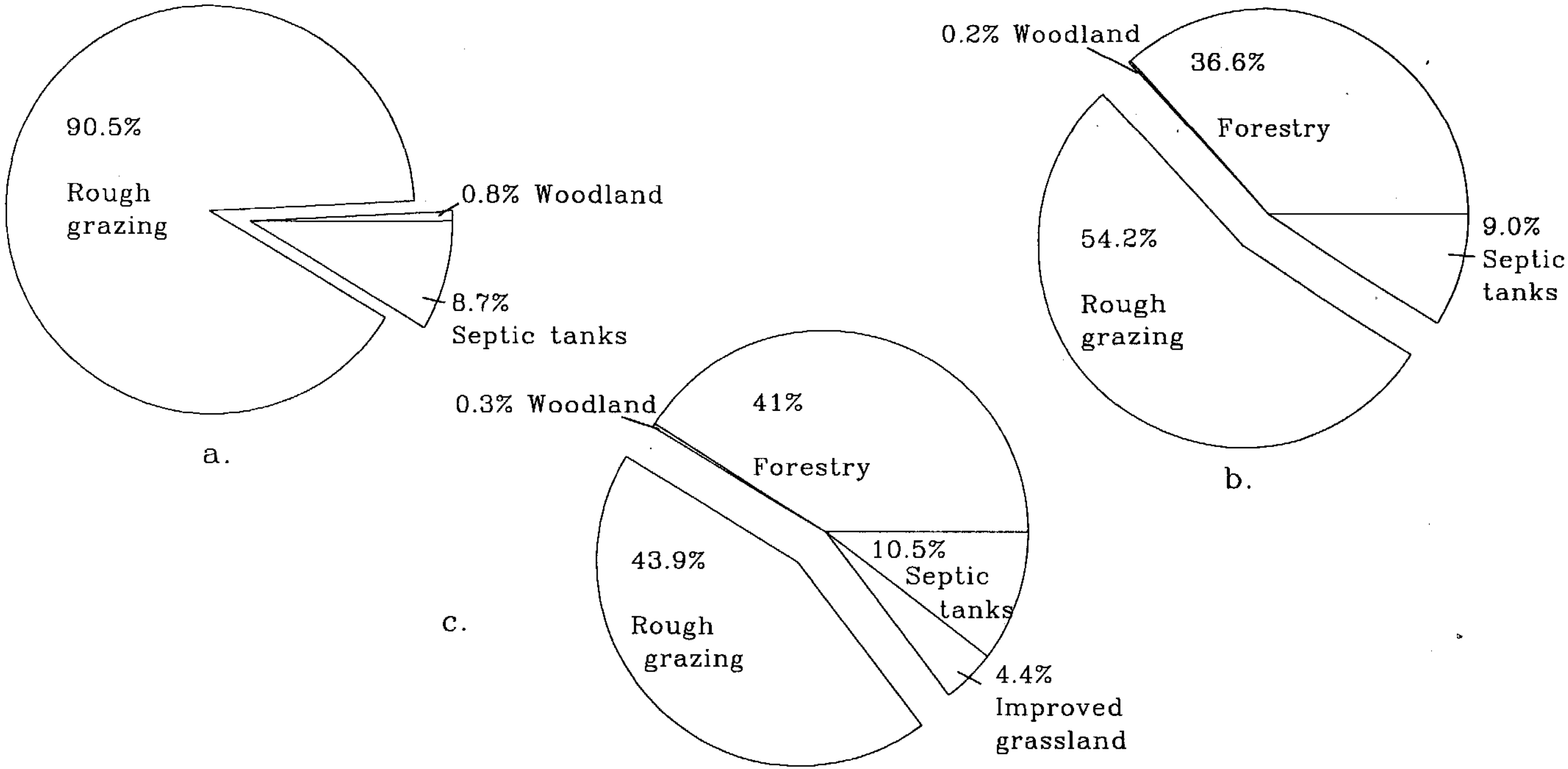

Fig 4.7 The components of the external TP loading from the 'direct' catchments of a. Megget; b. Lowes; and c. St.Mary's.

CHAPTER 5 DISCUSSION AND CONCLUSION.

5.1 General Discussion of Results.

5.1.1 Hydrology.

Despite the apparent differences in the catchments draining into Loch Leven and St.Mary's Loch, and the morphology of the lochs themselves, the systems are surprisingly similar in the total amount of water flowing into the system. The flushing rates, and indeed the flushing volumes ie. the amount of 'new' water entering a system per unit of time, are very similar. The greatest differences in the flushing rate between the two lochs occurred in the wetter years studied (1984 and 1990). While rainfall in these years was similar in both catchments, it generated a greater total inflow to Loch Leven due to the larger catchment, and thus had a direct effect on the flushing rate. In the drier year (1989) rainfall was higher within the catchment of St.Mary's Loch, but because this is smaller than the drainage area of Leven, and there was some storage in Megget Reservoir, both lochs received a similar total inflow. In addition to the annual rainfall the seasonal distribution is very important, as it determines how early or late in the year the lochs are flushed. Clearly both catchments are influenced by a highly variable climate resulting in considerable differences in flushing rate and flushing volume from year to year, and indeed from month to month.

The importance of the flushing rate (p) cannot be over emphasised. Apart from the obvious influence on the amounts of nutrients running off the land, flushing controls the time during which water entering the loch remains there, before passing down the outflow. In this way, seasonal variation in p within a water body, and differences in the general regime between waters, are likely to have strong influences on the sequence of phytoplankton; only the relatively rapid- growing species can establish themselves under high flushing conditions (Bailey-Watts *et al*, 1992).

5.1.2 Phosphorus Retention.

Indications are that many waters are likely to retain 40-50% of the total P they receive, with highly flushed lochs retaining less and low flushed ones retaining more (a range from 10 - 90% retention has been reported for Scottish freshwater lochs by Bailey-Watts *et al*, 1992). Although little difference was found in the flushing rate, as discussed above, there was a marked difference in P retention; St.Mary's Loch is likely to retain up to 30% of incoming P, while Loch Leven is likely to retain 50-60% of incoming P. This difference is due to the fact that Loch Leven has the larger surface area of the two lochs and R is a function of the areal water loading, q_s.

5.1.3 Nutrient Loading.

It is clear that the two catchments differ greatly in their nutrient loading. This is partly due to catchment landuse practises, but also due to the nature of the loading eg. whether it is largely rainfall dependent or independent (non-point source or point source respectively). It is important to appreciate that temporal patterns in the delivery of, in this case, P will vary according to the source and will impact differently on the receiving waterbody accordingly.

Most of nutrient sources from agricultural areas, forests and septic tank systems enter the surface water network at rates, and in seasonal patterns influenced largely by rainfall-runoff. Sources from industrial areas and sewage treatment works, (ie. point sources) enter the loch in a manner more or less independent of precipitation-evaporation patterns (Bailey-Watts *et al*, 1992). Runoff-controlled inputs, which dominate the St.Mary's catchment, exhibit erratic patterns of delivery in keeping with varied weather regimes, while varied schedules of fertilizer applications will also affect the loading seasonality. By contrast, the supplies from sewage treatment works, such as those of Kinross, Milnathort and Kinnesswood, presently a major feature in the P loading to Loch Leven, show relatively unchanging loading patterns. Nevertheless, variations in the patterns may occur according to day-of-the-week or summer/winter influxes of tourists in some areas. (Bailey-Watts and Kirika, 1987; Bailey-Watts *et al*, 1987 and Bailey-Watts, 1990).

Phosphorus is not very mobile and enters aquatic systems from catchment runoff, primarily in particulate forms, adsorbed onto inorganic silt and clay particals in base-rich catchments (Harper, 1992). Lesser amounts are in particulate organic form in detritus, and the smallest fraction is dissolved phosphate (Holtan *et al*, 1988; Golterman, 1973).

5.2 Potential Vulnerability.

5.2.1 Loch Leven.

With regard to the physical characteristics of the lochs, (mean depth, surface area etc.), Loch Leven is likely to be the most vulnerable. While it has a flushing rate similar to that of St.Mary's Loch, it has a far greater surface area and a relatively small mean depth, giving rise to a better light-environment for photosynthetic organisms eg. algae. If the loch were any deeper, algae would be circulated more often in the dark (unlit) water, while if it were shallower the loch would be subject to wind-induced turbulence which may bring light-occluding material from the bottom into circulation. The loch is also potentially more vulnerable due to the fact that a major proportion of the TP loading is from sewage treatment works, and thus will continue to enter the loch at times of low flow where a large proportion of it may remain for up to seven months of the year. This has implications in terms of P availability during the two major algae peaks observed in many water-bodies. Bailey-Watts (1992) reported that the first of these normally starts in mid February with lengthening days, and when all nutrients are at/near their annual maximum,and when low temperatures suppress potential grazers of algae. During this period P is often reduced to growth-limiting levels resulting in a decline in the algae population. The second pulse often occurs in summer, when P at least, is replenished from treated sewage even if rainfall runoff from agricultural land remains low. This summer pulse may come later if the only P loading was from catchment runoff. In addition, a large proportion of the P in sewage effluent is in the form of soluble reactive phosphorus, the fraction which is directly available for algal growth (Ryden *et al.*,1973; Stevens and Stewart 1982a,b). To compound this loading pattern, the P retention within the loch is high; 50-60% depending on annual rainfall.

In terms of the specific areal loadings of P (in units of g m^2) in relation to depth, the 'permissible' loading for Loch Leven is 0.07 g m^2 and the 'dangerous' or critical loading is 0.13 g m^2 according to Vollenweider (1968). The estimated value found in this study, 0.72 g m^2, clearly exceeds the critical load thus classifying the loch as highly eutrophic. Holden (1976) found values for the period 1968-72 to be between 0.5 and 1.0 g m^2 and Bailey-Watts *et al* (1987) reported a value of 1.54 g m^2, suggesting that while significant reductions in P loading have been made over the years, (eg. by the woollen mill in Kinross) a reduction by a factor of five is still required to avoid eutrophication.

5.2.2 St.Mary's Loch.

In contrast to Loch Leven, St.Mary's Loch is potentially less vulnerable due to the rainfall-runoff dependent nature of P loading and the ameliorating potential of Megget Reservoir and the Loch of the Lowes. These reduce the potential effects of catchment eutrophication by 'absorbing' a certain amount of P otherwise destined for St.Mary's. These water-bodies retain ca.

40% and 30% respectively of the P loading from their 'direct' catchments.

The largest proportion of P loading came via St.Mary's 'direct' catchment, mainly due to the presence of substantial areas of forestry plantation, although loading from this source was probably over estimated due to the export coefficient used (Bailey-Watts pers. comm.). These are of concern mainly due to fertilizer runoff in the first three years after planting (Harriman, 1978). Although, this is no longer an issue in the catchment the area may well be replanted in the future after the present timber is extracted. After extraction (probably within the next decade), surface water flow will be increased due to the absence of canopy interception and uptake through the roots and extra P export may occur due to soil erosion and release of P locked up on the soil lattice. Williams and Hoare (1987) reported that soil erosion may increase loads of P when catchments are cleared, with a yield of 4-40 kg P ha^{-1} yr^{-1}. The eroded material varies markedly in the bioavailability of its P, topsoils often having the highest levels of available P.

Using Vollenweider's classification for specific areal P loading for a loch of mean depth of 22m the 'permissible' loading is up to 0.25 g m^2 per annum and the 'dangerous' or critical load up to 0.50 g m^2 per annum. St.Mary's Loch is thus classified as oligotrophic with a specific areal P loading value of 0.33 g m^2, just above that of the 'permissible' loading value. There is still need for careful management at this site as the specific areal P loading exceeds that regarded as 'permissible' especially as inflows from Megget and its 'direct' catchment are determined by external factors.

5.3 Potential Weaknesses in the Modelling Approach.

5.3.1 Agricultural and Horticultural Census Data.

While the Census gives a good indication of the national and regional distributions of agricultural activities, its usefulness varies from item to item and in identifying landuse within loch catchments. Details of landuse type and area are frequently fairly accurate throughout the year but, due to the mobility of livestock, animal numbers are not. Animals may be sired in one part but reared and fattened elsewhere. The Census does take some account of this, but cannot gauge all changes in the livestock numbers.

In terms of identification of landuse within a particular loch catchment, this study, and others (eg. Winkler, 1991), highlights the difficulties incorporating Census data within the catchment boundaries. Land accounted for in the census rarely coincides with the parish area, let alone the catchment as a whole. Census data are provided on a parish-only basis and redistribution of Census items leads to large error terms, even when cross-referencing with other sources of information eg. aerial photographs and O.S. maps. In addition, an occupier is permitted to make a single return for a number of associated, separate holdings under his/her control; the returns may therefore be grouped within one parish, even though some of the land to which they refer might lie in another parish. The data provided in the Census can thus be regarded as being poor in local detail while providing a good overall indication of landuse and landuse changes (Hotson, 1988).

5.3.2 Rainfall/Runoff Dependent Nutrient Loading.

In this study the predicted rainfall/runoff dependent loading for the Loch Leven catchment was found to be approximately half that measured in 1985 (Bailey-Watts and Kirika, 1987). In addition to the possible error incurred through redistribution of parish items to fit the catchment boundary, the choice of export coefficients used to predict P loss from different land cover types can help explain the discrepancies between measured and predicted losses. The average catchment runoff loss rate estimated from measured data was 0.60 kg ha^{-1} yr^{-1}, ranging from 0.40 to

1.67 kg ha^{-1} yr^{-1} for different parts of the catchment. In comparison, the average runoff loss rate found in this study for the same catchment was 0.40 kg ha^{-1} yr^{-1}, ranging from 0.07 kg ha^{-1} yr^{-1} for rough grazing land to 0.42 kg $ha^{-1}yr^{-1}$ for forestry plantations.

In this study estimates of runoff losses did not take account of fertilizer applications and the subsequent loss of phosphorus. Cooke and Williams (1970) and Cooke (1976) reported that after spring fertilisation, surface waters contained more P and after heavy rain this was washed into receiving waters, introducing P that would not otherwise reach these waters. They also found that the largest P losses occurred when fertilizer was applied to wet soil. All these variations can be accounted for when estimating export coefficients from measured data, but are less easily incorporated into predicted estimates. The discrepancies between average catchment export coefficients estimated for Loch Leven illustrates one of the difficulties involved in predicting nutrient loading from published P loss rates.

Reckhow and Simpson (1980) addressed this problem by classifying export coefficients for particular land cover types into high, low and mid range estimates. The appropriate export coefficient is then assigned depending on conditions present in the study catchment. A nonparametric error analysis is then carried out to supplement predictions of P concentration, and give an indication of the value of the information provided by the model.

5.3.3 Further Study.

1. The model used could be further refined by including estimates of atmospheric P inputs and estimating the soil retention coefficient for septic tank seepages using values from Reckhow *et al* (1980). An error analysis could also be carried out to assess the value of the information provided by

the model using the same method devised by Reckhow an Simpson (1980).

2. The present study could be expanded to include estimates of soluble reactive phosphorus (SRP) and nitrates using published export coefficients. Fertilizer regimes could also be incorporated into the model to give an indication of when increased nutrient loading may occur during the year.

3. Using measured data, in a similar way to Kirchner and Dillon (1975), an empirical model for monthly P retention could be derived and incorporated into the existing model to provide improved estimates of monthly nutrient loadings, especially where intervening lochs complicate these loadings.

5.4 Conclusions.

From considerations of catchment hydrology, monthly nutrient loading, flushing rate, phosphorus retention coefficients and the physical characteristics of the lochs, the following conclusions can be drawn:

- Loch Leven is potentially more vulnerable to eutrophication as the largest TP contribution from the catchment enters via treated sewage, which remains more-or-less constant throughout the year. The shallow nature of the loch gives rise to a high P retention and provides an ideal light environment for photosynthetic organisms eg. algae.

- Contrastingly, St.Mary's Loch is potentially less vulnerable due to the rainfall/runoff dependent nature of the P loading and the less favourable physical environment for photosynthetic organisms such as algae.

In terms of the modelling approach adopted, the general conclusion is that the estimation of nutrient loading through the use of export coefficients cannot provide a real figures of nutrient loading, but can give an indication of the sensitivity of receiving waterbodies, which may identify lakes which require further, *in situ* investigation.

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APPENDIX 1.

PARISH RETURNS FOR THE AGRICULTURAL AND HORTICULTURAL CENSUS,

1st. JUNE 1991.

SCOTTISH OFFICE AGRICULTURE AND FISHERIES DEPARTMENT

Agricultural and Horticultural Census 1st June 1991

Notice requiring information by 15th June 1991

AGRICULTURE ACT 1947, SECTION 78 (AS AMENDED).

As the occupier you must complete and return this form. The information you give should be as at 1st June 1991 except where otherwise stated. The completed form must be returned as soon as possible but no later than 15th June 1991.

The information you provide is strictly confidential and cannot be disclosed without your written consent, except as specified in section 80 of the above Act and section 12 of the European Communities Act 1972.

Section 81 of the Agriculture Act states that anyone who fails to complete and return the form shall be liable, on summary conviction, to a fine not exceeding £400. Penalties are also prescribed for knowingly or recklessly furnishing false information.

SCOTTISH OFFICE AGRICULTURE AND FISHERIES DEPARTMENT,
Economics and Statistics Unit,
Pentland House, 47 Robb's Loan, Edinburgh EH14 1TW
Tel: 031-244 6147-6156

L P Hamilton, Secretary

Holding description

Name and address

OR PRESENT OCCUPIER

CHANGE OF ADDRESS/POSTCODE. If the postal address is different from that shown above, please give correct address below.

Address ....

....

....

.... *Postcode* ....

1. AREA OF HOLDING. The area figures below are those on our records. They include:

a. Land owned by you.

b. Seasonal lets - land on this farm let seasonally (for 364 days or less) to another person for cropping or grazing, at 1st June.

c. Full tenancy - land rented by the occupier from another person for a full year or more for cropping or grazing, at 1st June.

Hectares (to nearest 0.1)

Area you own	•
Area you rent from another person under a full tenancy	•
Total area	•

2. CHANGES IN AREA OF HOLDING. If the area of the holding differs from that shown above, please give details of changes. Exclude land you rent seasonally (for 364 days or less) at 1st June.

Land you have taken over:

Name of land .... Code no ....

Parish .... Area acquired .... Hect.

Name and address ....

of previous occupier ....

....

....

Land you have given up:

Name of land .... Code no ....

Parish .... Area given up .... Hect.

Name and address ....

of new occupier ....

....

....

		FOR OFFICIAL USE			
C.O.	C.				
	A.				

3. LAND TO WHICH THIS FORM RELATES. The land to which this form relates includes **land owned by you, land which you let seasonally (for 364 days or less) to another person, and land rented by you on a full tenancy (for one year or more).**

Land set aside under the "Set Aside" scheme should be included in your total area and entered at items 39, 48 or 49.

Enter below the area you own and the area you rent on a full tenancy. Include any Set Aside land, woods, roads, yards and farm buildings. If land is rented from a near relative or family trust or any business or concern in which you have an interest enter the area in item 10. Crofters should normally return their land as rented.

The 'owned' (item 11), 'rented on a full tenancy' (items 7 and 10), and 'total' (item 12) areas must agree with the figures in question, unless land has been taken over or given up (question 2 below left). Enter areas as at 1st June 1991.

Hectares (to nearest 0.1)

Area you own		11	•
Rented by you on a full tenancy	from an outside concern	7	•
	from a near relative or a concern in which you have an interest	10	•
Total area of land		12	•

4. SEASONAL RENTS. If you let or rent any land seasonally to or from another person for cropping or grazing, show the area below. If the let is not for a specific area but, e.g. involves payment for grazing on a per head of livestock basis, please estimate the area used. **Enter area at 1st June 1991.**

Hectares (to nearest 0.1)

Area you **let seasonally** (ie for 364 days or less) to another person for cropping or grazing	1	•
Area of land **rented seasonally** (ie for 364 days or less) from another person for cropping or grazing at 1st June 1991 **(THIS LAND SHOULD NOT APPEAR ELSEWHERE ON THIS FORM)**	2	•

5. LABOUR - OCCUPIER AND SPOUSE. If you and, or your spouse are doing farm work (including office work) please tick the relevant boxes below for yourself and your wife or husband. Part time work is work for less than 40 hours each week.

If you have more than one farm do not enter yourself and your spouse on more than one return.

If the farm is run by a partnership or company enter details of only one of the working partners or directors as the occupier and his, or her spouse if doing farm work. Enter other working partners or directors in the Section headed ALL OTHER LABOUR (overleaf).

OCCUPIER

Occupier- if doing farm work	Working full-time on holding		177	
	Part time	½ time or more	178	
		less than ½ time	179	

SPOUSE OF OCCUPIER

Spouse of occupier-if doing farm work	Working full-time on holding		182	
	Part time	½ time or more	183	
		less than ½ time	184	

CROPS

6. Enter the area, including headlands and ditches, of each crop at 1st June 1991. Land being prepared for a crop should be returned as under that crop.

Hectares (to nearest 0.1)

Wheat		14	•
Triticale		15	•
Barley	Winter	16	•
	Spring (including bere)	18	•
Oats		20	•
Mixed grain for threshing (only mixtures of wheat, barley, and oats or any two of these)		22	•
Rape for oilseed	Winter	19	•
	Spring	23	•
Potatoes intended mainly for **SEED**		24	•
Potatoes intended mainly for **WARE**	Earlies intended for harvesting on or **by 31st July**	25	•
	Main crop intended for harvesting **after 31st July**	26	•
Peas for Combining		28	•
Turnips and swedes for stock feeding (**Not** for human consumption)		29	•
Kale and Cabbage for stock feeding (**Not** for human consumption)		30	•
Rape for Stockfeeding (**Not** oilseed rape)		31	•
Fodder Beet		32	•
Other Crops for Stock Feeding (**Not** grass)		34	•
Vegetables for Human Consumption grown in the open (must agree with item 68)		35	•
Orchard Fruit - apples, plums, etc., for sale or manufacture. Include land planted with maiden trees but exclude fruit stocks (see item 80).		36	•
Soft Fruits, (must agree with item 76)		37	•
Other Crops not included above (**Not** Grass) Include here **Glasshouse Crops**, Item 84, and areas of unspecified crops, including mixed crops (other than vegetables or soft fruit at 67 and 75), which are too small to be shown separately. (see also foot of column).		38	•
Bare Fallow - land left uncropped for the season.		39	•
TOTAL CROPS AND FALLOW		40	•

Item 38 (other Crops). If crops other than glasshouse crops, bulbs, flowers and nursery stock are included, please enter the **total** area in the box below.

Hectares (to nearest 0.1)

Unspecified Crops - total area	41	•

Please name any major unspecified crops, e.g. flax, 5 hectares, in the space below.

GRASSLAND

7. Land should be shown as "Grassland" where productive grasses, clovers, etc., are dominant. Land which cannot normally be cultivated or is dominated by poor quality grasses, heather, bracken, etc., should be returned as "Rough Grazing".

Hectares (to nearest 0.1)

FOR MOWING this season	**Under 5 years old** (including grass sown this year without a nurse crop)	42	•
	5th year grass and older (i.e. sown in 1986 or earlier)	43	•
FOR GRAZING this season	**Under 5 years old** (including grass sown this year without a nurse crop)	44	•
	5th year grass and older (i.e. sown in 1986 or earlier)	45	•

TOTAL CROPS AND GRASS (total of item 40 and items 42 to 45)	46	•

Rough Grazings - Mountain, Hill, Moor, Deer Forest situated within the farming unit, whether enclosed or not. **Do not include** woods, roads, etc., a share in common grazing or any land taken by you for the season.	47	•
Woodlands - (other than commercial orchards)- situated within the farming unit for shelter belts, fencing materials, other farm uses and for commercial or amenity purposes.	48	•
Other Land i.e. roads, yards, buildings (excluding glasshouses), ponds, derelict land etc.	49	•

TOTAL AREA OF ALL LAND to which this form relates (total of items 46 and 47 to 49; must also agree with item 12).	50	•

VEGETABLES FOR HUMAN CONSUMPTION GROWN IN THE OPEN

8. **Do not give** number of rows or plants. **Include** under the appropriate crop land prepared for it but **not yet planted.**

Hectares (to nearest 0.1)

Peas for canning, freezing or drying (**Not** green peas for market or peas for stock feed).		52	•
Beans for canning, freezing or drying (**Not** fresh beans for market or beans for stock feed).		53	•
Leeks (including land prepared for the crop)		55	•
Turnips and Swedes for human consumption		56	•
Cabbages and Savoys for human consumption (include land prepared for the crop)	Summer/Autumn	57	•
	All other	58	•
Brussels Sprouts (include land prepared for the crop)		59	•
Calabrese		60	•
Cauliflower and Broccoli-Heading Varieties (include land prepared for the crop)		61	•
Carrots		63	•
Lettuce		64	•
Rhubarb		65	•
Other Vegetables - grown in the open (**Not** tomatoes or other glasshouse crops)		66	•
Mixed Vegetables - areas which as individual crops are too small to be shown separately		67	•
TOTAL VEGETABLES (must agree with item 35)		68	•

Please see over →

SOFT FRUIT

9. **Exclude** spawn beds, runner beds and young plants intended for sale. (These should be entered at item 80).

Hectares (to nearest 0.1)

Strawberries	70	•
Raspberries	71	•
Blackcurrants	72	•
Mixed and Other Kinds of soft fruit including the areas of soft fruits named above which as individual crops are too small to be shown separately.	75	•
TOTAL SOFT FRUIT (must agree with item 37)	76	•

BULBS, FLOWERS AND NURSERY STOCK GROWN IN THE OPEN

10. **Do not give** number of plants.

Hectares (to nearest 0.1)

Bulbs grown for the production of dry bulbs and/or cut flowers **in the open**		77	•
Other flowers for cutting **in the open** not from bulbs including land prepared for the crop		78	•
Hardy Nursery Stock	**Fruit Stocks** - spawn beds, runner beds and stool beds and young plants intended for sale	80	•
	Roses and Rose Stocks	81	•
	Ornamental trees and shrubs (not forest trees-include these in item 48)	82	•
	Other nursery stock (herbaceous *plants, alpines etc., not forest* trees-include these in item 48)	83	•
TOTAL (include also in item 38)		84	•

GLASSHOUSES AND TOMATOES

See metric conversion tables.

Sq. metres

GLASSHOUSES *in use*	"Walk-in" Plastic Structures	85	
	Glass clad structures	86	
	Tomatoes	87	

Include total hectares of glasshouse crops in item 38.

HAY, STRAW AND SILAGE STOCKS

11. Include stocks left over from previous seasons and any which have been bought in.

Tonnes (nearest tonne)

Hay, on holding at 1st June, 1991 (Tonnes)	91	
Straw, on holding at 1st June, 1991 (Tonnes)	92	
Silage, on holding at 1st June, 1991 (Tonnes)	93	

LIVESTOCK

Enter livestock belonging or hired to you (or to your workers or family, unless these persons make an agricultural return in their own right), **whether on your farm or elsewhere. Include livestock** you are keeping and managing **on contract** for someone else. Enter livestock sent for sale on 31st May or 1st June.

Exclude any of your **livestock kept on contract for you** by another farmer **or on hire to another farmer** and any **livestock** owned by another farmer which are **temporarily on your farm** but which you are not managing on contract.

FARMED DEER

12. **Exclude wild or park deer** which cannot be gathered, identified, recorded and handled.

Number

Deer of all ages and types	94	

HORSES

13. Number

Horses used for agricultural or horticultural purposes	95	
All other Horses and Ponies	96	

GOATS

14. Number

Female goats which have kidded	97	
All other goats	98	

CATTLE

15. Number

Cows and Heifers in milk				**Dairy**	100	
				Beef	101	
Cows in Calf but not in milk				**Dairy**	102	
				Beef	103	
Heifers in Calf for the first time	2 years old and over			**Dairy**	104	
				Beef	105	
	Under 2 years old			**Dairy**	106	
				Beef	107	
Bulls for Service	2 years old and over				108	
	1 year old and under 2				109	
All Other Cattle	2 years old and over	**Male**			110	
		Female	**for Breeding**	**Dairy**	111	
				Beef	112	
			Not for breeding		113	
	1 year old and under 2	**Male**			114	
		Female	**for Breeding**	**Dairy**	115	
				Beef	116	
			Not for breeding		117	
	6 months old and under 1 year			**Male**	118	
				Female	119	
	Under 6 months old			**Male**	120	
				Female	121	
TOTAL CATTLE					122	

CALVES SOLD AND BOUGHT DURING THE LAST YEAR

16. Enter the **number** of calves (i.e. under 1 year old) **sold and bought** during the last year.

Number

Calves sold between 1st June, 1990 and 1st June, 1991	**Under 6 months** including calves for immediate slaughter	133	
	6 months old and under 1 year	134	
Calves Bought between 1st June, 1990 and 1st June, 1991	**Under 6 months** at time of purchase	135	
	6 months old and under 1 year at time of purchase	136	

IRISH CATTLE BOUGHT

17. Number

Cattle you bought directly, or almost directly, from the Irish Republic or Northern Ireland during the year from 1st June, 1990 to 1st June, 1991	**for Breeding**	137	
	for Feeding	138	

SHEEP

18. Do not enter your share in a Sheep Stock Club, the Club Secretary will complete a return for these sheep.
Enter at *item 139 only* those **Ewes and Gimmers which have survived** until 1st June and still belong to you.

			Number
Ewes used for breeding in 1990/91 season **(Actual Number at 1st June, 1991).**		139	
Rams to be used for service in 1991		140	
Other Sheep 1 year *old and over*	For breeding	141	
	Other	143	
Lambs (please estimate if not yet counted)		144	
TOTAL SHEEP		145	

PIGS

19. Enter you own pigs and pigs being kept under contract on your farm.

			Number
Sows in Pig		146	
Gilts in Pig		147	
Other Sows for breeding		148	
Barren Sows for fattening		149	
Gilts 50Kg (110lb) and over, not yet in pig, but **expected to be used for breeding**		150	
Boars being used for service		151	
All Other Pigs (not entered above)	110Kg (240lb) liveweight *and over*	152	
	80Kg (175lb) and under 110Kg (240lb) liveweight	153	
	50Kg (110lb) and under 80Kg (175lb) liveweight	154	
	20Kg (45lb) and under 50Kg (110lb) liveweight	155	
	under 20Kg (45lb) liveweight	156	
TOTAL PIGS		157	

POULTRY

20. Exclude game birds. Enter your own poultry and poultry being kept under contract on your farm.

				Number
Fowls for producing eggs for eating	**Pullets** and **Hens** in the laying flock	**Pullets - Fowls** in first laying season	158	
		Hens - other fowls including those in moult	159	
	Growing pullets - day old to point of lay		161	
Fowls for breeding	**Pullets and Hens** of all ages (kept or being reared) mainly for producing hatching eggs		162	
	Cocks of all ages kept (or being reared) for breeding		163	
Fowls being reared for the table - **broilers and other table birds including table cockerels**			164	
Other Poultry (ducks, geese, *guinea fowl*)			167	
Turkeys of all ages - including breeding stock			169	
TOTAL POULTRY			170	

ALL OTHER LABOUR EXCLUDING OCCUPIER AND SPOUSE (see question 5)

21. This section relates only to persons working for you on 1st June 1991 including those that were sick or on holiday that day.
Exclude anyone working under THE YOUTH TRAINING SCHEME (unless they were employed and paid for by you), school children, non-farm workers working on buildings, installing plant or carrying out contract work, and gardeners or estate workers who do no farm work.
Enter all persons doing farm work including drainage, ditching, maintenance and repair work and transport of farm goods. If you have more than one farm do not enter your labour on more than one return.
Part-time workers are those who do farm work each week but for less than 40 hours each week.
Casual and seasonal workers are those actually working on 1st June doing work of a temporary or seasonal nature; including labour supplied by gangmasters.

				Number
FULL-TIME REGULAR STAFF employed on 1st June, 1991	***Males*** - 20 years old and over	*Hired*	188	
		Members of Occupier's family	189	
	Males - under 20 years old	Hired	190	
		Members of Occupier's family	191	
	Females	Hired	192	
		Members of Occupier's *family*	193	
PART-TIME REGULAR STAFF employed on 1st June, 1991	**Males**	Hired	194	
		Members of Occupier's family	195	
	Females	Hired	196	
		Members of Occupier's family	197	
Casual and Seasonal Workers employed on 1st June, 1991		Males	198	
		Females	199	
TOTAL REGULAR AND CASUAL STAFF (excluding occupier and spouse)			200	

22. OTHER HOLDINGS IN THE SAME OCCUPANCY

Please give the Code Nos. under which you, your Company or Partnership make agricultural census returns for other holdings.	172	
	173	
	174	
	175	
	176	
If Code Nos. not known enter addresses here:		

DECLARATION

I declare that the information that I have given on this form to be correct to the best of my knowledge and belief.

Signature of occupier ....

Surname (capitals please) .... *Christian names (capitals please)* ....

Date ....: *Telephone no (please include area phone code)* ....

If the signature is not that of the addressee, please say why eg "manager", "new owner", "occupier abroad" etc.

....

PLEASE RETURN THIS FORM IN THE ENCLOSED PRE-PAID ENVELOPE. NO STAMP IS REQUIRED

For official use:

Q	D	Ex	D

RUN DATE 20/01/92 AGRICULTURAL CENSUS JUNE 91 TABLE JC15 (AGSJPARS)

PARISH NO. = 489 PORTMOAK PARISH SUMMARY NO. OF HOLDINGS = 25

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
1	143.7	2	119.1	3	-	4	-	5	-	6	-
7	519.0	8	-	9	-	10	490.2	11	2332.5	12	3341.7
13	-	14	241.7	15	7.2	16	172.0	17	-	18	431.4
19	112.8	20	62.7	21	-	22	-	23	15.3	24	8.8
25	-	26	92.4	27	-	28	-	29	9.0	30	5.5
31	-	32	5.8	33	-	34	-	35	93.8	36	-
37	4.0	38	1.3	39	105.3	40	1369.0	41	-	42	185.1
43	30.2	44	222.5	45	287.3	46	2094.1	47	1090.0	48	115.2
49	42.4	50	3341.7	51	-	52	8.5	53	-	54	-
55	-	56	8.5	57	2.5	58	-	59	-	60	36.0
61	1.3	62	-	63	21.0	64	10.0	65	-	66	2.0
67	4.0	68	93.8	69	-	70	0.8	71	2.6	72	0.2
73	-	74	-	75	0.4	76	4.0	77	1.3	78	-
79	-	80	-	81	-	82	-	83	-	84	1.3
85	-	86	-	87	-	88	-	89	-	90	-
91	83.0	92	103.0	93	83.0	94	-	95	-	96	31.0
97	2.0	98	2.0	99	-	100	236.0	101	229.0	102	30.0
103	87.0	104	14.0	105	17.0	106	-	107	8.0	108	7.0
109	1.0	110	33.0	111	21.0	112	3.0	113	18.0	114	238.0
115	60.0	116	10.0	117	164.0	118	65.0	119	57.0	120	69.0
121	80.0	122	1447.0	123	-	124	-	125	-	126	-
127	-	128	-	129	-	130	-	131	-	132	-
133	25.0	134	7.0	135	1.0	136	-	137	-	138	-
139	2864.0	140	84.0	141	544.0	142	-	143	47.0	144	3900.0
145	7439.0	146	1.0	147	-	148	-	149	-	150	1.0
151	-	152	-	153	-	154	-	155	-	156	-

PARISH NO. = 489 PARISH SUMMARY NO. OF HOLDINGS = 25

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
157	2.0	158	-	159	-	160	-	161	-	162	-
163	-	164	-	165	-	166	-	167	5.0	168	-
169	-	170	5.0	171	-	177	10.0	178	2.0	179	2.0
180	-	181	-	182	2.0	183	1.0	184	-	185	-
186	-	187	-	188	13.0	189	8.0	190	1.0	191	1.0
192	-	193	-	194	-	195	1.0	196	1.0	197	1.0
198	16.0	199	4.0	200	46.0						

RUN DATE 26/01/92 AGRICULTURAL CENSUS JUNE 91 TABLE JC15 (AGSJPARS) PAGE 931

PARISH NO. = 488 ORWELL PARISH SUMMARY NO. OF HOLDINGS = 47

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
1	268.5	2	160.1	3	-	4	-	5	-	6	-
7	228.6	8	-	9	-	10	739.0	11	3389.8	12	4357.4
13	-	14	237.9	15	-	16	151.8	17	-	18	799.1
19	118.6	20	37.6	21	-	22	-	23	65.3	24	83.6
25	-	26	33.6	27	-	28	8.1	29	41.8	30	29.1
31	5.8	32	-	33	-	34	-	35	23.3	36	-
37	-	38	5.3	39	27.3	40	1668.2	41	4.8	42	372.3
43	173.1	44	328.9	45	819.6	46	3362.1	47	834.0	48	95.3
49	66.0	50	4357.4	51	-	52	23.3	53	-	54	-
55	-	56	-	57	-	58	-	59	-	60	-
61	-	62	-	63	-	64	-	65	-	66	-
67	-	68	23.3	69	-	70	-	71	-	72	-
73	-	74	-	75	-	76	-	77	-	78	-
79	-	80	-	81	-	82	-	83	-	84	-
85	2428.0	86	2889.0	87	-	88	-	89	-	90	-
91	130.0	92	219.0	93	73.0	94	-	95	1.0	96	41.0
97	7.0	98	41.0	99	-	100	374.0	101	667.0	102	57.0
103	32.0	104	63.0	105	6.0	106	10.0	107	12.0	108	16.0
109	3.0	110	27.0	111	-	112	32.0	113	19.0	114	122.0
115	43.0	116	43.0	117	144.0	118	289.0	119	196.0	120	441.0
121	324.0	122	2920.0	123	-	124	-	125	-	126	-
127	-	128	-	129	-	130	-	131	-	132	-
133	49.0	134	332.0	135	261.0	136	3.0	137	-	138	-
139	4683.0	140	144.0	141	1057.0	142	-	143	322.0	144	6569.0
145	12775.0	146	10.0	147	-	148	4.0	149	2.0	150	2.0
151	1.0	152	-	153	-	154	-	155	-	156	25.0

PARISH NO. = 488

PARISH SUMMARY

NO. OF HOLDINGS = 47

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
157	44.0	158	10.0	159	78.0	160	-	161	-	162	-
163	3.0	164	-	165	-	166	-	167	15.0	168	-
169	-	170	106.0	171	-	177	19.0	178	5.0	179	11.0
180	-	181	-	182	-	183	3.0	184	9.0	185	-
186	-	187	-	188	23.0	189	7.0	190	2.0	191	-
192	4.0	193	1.0	194	4.0	195	3.0	196	6.0	197	2.0
198	13.0	199	10.0	200	75.0						

RUN DATE 20/01/92

PARISH NO. = 487 KINROSS

AGRICULTURAL CENSUS JUNE 91

PARISH SUMMARY

TABLE JC15 (AGSJPARS)

NO. OF HOLDINGS = 33

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
1	158.5	2	180.7	3	-	4	-	5	-	6	-
7	174.6	8	-	9	-	10	307.3	11	1956.4	12	2438.3
13	-	14	112.3	15	-	16	54.6	17	-	18	642.7
19	71.4	20	104.4	21	-	22	-	23	6.4	24	46.1
25	10.1	26	39.5	27	-	28	-	29	31.1	30	10.9
31	48.2	32	-	33	-	34	-	35	21.8	36	-
37	0.4	38	1.3	39	71.9	40	1273.1	41	0.8	42	337.6
43	45.1	44	240.8	45	322.5	46	2219.1	47	74.7	48	35.6
49	108.9	50	2438.3	51	-	52	14.2	53	-	54	-
55	-	56	4.0	57	-	58	-	59	-	60	-
61	-	62	-	63	3.6	64	-	65	-	66	-
67	-	68	21.8	69	-	70	-	71	0.4	72	-
73	-	74	-	75	-	76	0.4	77	-	78	-
79	-	80	-	81	-	82	-	83	-	84	-
85	-	86	4840.0	87	-	88	-	89	-	90	-
91	122.0	92	171.0	93	100.0	94	-	95	-	96	7.0
97	-	98	-	99	-	100	147.0	101	76.0	102	26.0
103	12.0	104	17.0	105	-	106	52.0	107	-	108	2.0
109	2.0	110	209.0	111	-	112	-	113	4.0	114	197.0
115	116.0	116	19.0	117	118.0	118	99.0	119	134.0	120	22.0
121	125.0	122	1377.0	123	-	124	-	125	-	126	-
127	-	128	-	129	-	130	-	131	-	132	-
133	97.0	134	8.0	135	104.0	136	-	137	-	138	-
139	1527.0	140	40.0	141	355.0	142	-	143	269.0	144	2065.0
145	4256.0	146	-	147	-	148	-	149	-	150	-
151	-	152	-	153	-	154	-	155	-	156	-

PARISH NO. = 487 PARISH SUMMARY NO. OF HOLDINGS = 33

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
157	-	158	35.0	159	42.0	160	-	161	-	162	10.0
163	2.0	164	794612.0	165	-	166	-	167	10.0	168	-
169	-	170	794711.0	171	-	177	16.0	178	2.0	179	6.0
180	-	181	-	182	2.0	183	2.0	184	8.0	185	-
186	-	187	-	188	28.0	189	6.0	190	-	191	-
192	-	193	1.0	194	2.0	195	2.0	196	2.0	197	1.0
198	-	199	1.0	200	43.0						

PARISH NO. = 486 FOSSOWAY PARISH SUMMARY NO. OF HOLDINGS = 65

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
1	309.6	2	111.0	3	-	4	-	5	-	6	-
7	506.7	8	-	9	-	10	121.5	11	5551.9	12	6180.1
13	-	14	154.8	15	-	16	37.2	17	-	18	576.0
19	31.1	20	1.2	21	-	22	-	23	66.2	24	12.5
25	-	26	10.1	27	-	28	-	29	24.9	30	70.2
31	40.3	32	3.2	33	-	34	-	35	-	36	-
37	0.2	38	-	39	256.4	40	1284.3	41	-	42	481.7
43	273.3	44	881.9	45	1726.9	46	4648.1	47	1203.9	48	229.8
49	98.3	50	6180.1	51	-	52	-	53	-	54	-
55	-	56	-	57	-	58	-	59	-	60	-
61	-	62	-	63	-	64	-	65	-	66	-
67	-	68	-	69	-	70	-	71	0.2	72	-
73	-	74	-	75	-	76	0.2	77	-	78	-
79	-	80	-	81	-	82	-	83	-	84	-
85	25.0	86	-	87	-	88	-	89	-	90	-
91	488.0	92	73.0	93	665.0	94	-	95	-	96	115.0
97	2.0	98	2.0	99	-	100	325.0	101	790.0	102	51.0
103	251.0	104	80.0	105	51.0	106	28.0	107	18.0	108	24.0
109	2.0	110	24.0	111	70.0	112	10.0	113	2.0	114	359.0
115	69.0	116	62.0	117	504.0	118	240.0	119	284.0	120	309.0
121	353.0	122	3906.0	123	-	124	-	125	-	126	-
127	-	128	-	129	-	130	-	131	-	132	-
133	99.0	134	260.0	135	57.0	136	28.0	137	-	138	-
139	10896.0	140	299.0	141	1696.0	142	-	143	120.0	144	15860.0
145	28871.0	146	1.0	147	-	148	-	149	-	150	-
151	-	152	-	153	-	154	10.0	155	7.0	156	-

PARISH NO. = 486 PARISH SUMMARY NO. OF HOLDINGS = 65

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
157	18.0	158	48.0	159	61.0	160	-	161	15.0	162	33683.0
163	3367.0	164	93720.0	165	-	166	-	167	17.0	168	-
169	-	170	130911.0	171	-	177	21.0	178	8.0	179	7.0
180	-	181	-	182	5.0	183	2.0	184	14.0	185	-
186	-	187	-	188	28.0	189	16.0	190	4.0	191	2.0
192	-	193	4.0	194	6.0	195	3.0	196	1.0	197	1.0
198	7.0	199	1.0	200	73.0						

RUN DATE 20/01/92 | AGRICULTURAL CENSUS JUNE 91 | TABLE JC15 (AGSJPARS) | PAGE 925

PARISH NO. = 485 CLEISH | PARISH SUMMARY | NO. OF HOLDINGS = 20

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
1	82.4	2	4.0	3	-	4	-	5	-	6	-
7	30.1	8	-	9	-	10	404.0	11	857.7	12	1291.8
13	-	14	33.3	15	-	16	12.1	17	-	18	176.4
19	8.1	20	11.6	21	-	22	-	23	16.2	24	-
25	-	26	8.9	27	-	28	-	29	14.2	30	-
31	-	32	-	33	-	34	-	35	-	36	-
37	-	38	-	39	8.8	40	289.6	41	-	42	80.7
43	49.7	44	93.6	45	313.9	46	827.5	47	444.9	48	7.4
49	12.0	50	1291.8	51	-	52	-	53	-	54	-
55	-	56	-	57	-	58	-	59	-	60	-
61	-	62	-	63	-	64	-	65	-	66	-
67	-	68	-	69	-	70	-	71	-	72	-
73	-	74	-	75	-	76	-	77	-	78	-
79	-	80	-	81	-	82	-	83	-	84	-
85	-	86	-	87	-	88	-	89	-	90	-
91	32.0	92	20.0	93	-	94	-	95	-	96	13.0
97	4.0	98	8.0	99	-	100	85.0	101	305.0	102	10.0
103	50.0	104	10.0	105	16.0	106	5.0	107	5.0	108	7.0
109	1.0	110	-	111	-	112	4.0	113	-	114	54.0
115	20.0	116	12.0	117	23.0	118	179.0	119	126.0	120	75.0
121	78.0	122	1065.0	123	-	124	-	125	-	126	-
127	-	128	-	129	-	130	-	131	-	132	-
133	13.0	134	192.0	135	30.0	136	-	137	-	138	-
139	1385.0	140	42.0	141	248.0	142	-	143	13.0	144	1887.0
145	3575.0	146	-	147	-	148	-	149	-	150	-
151	-	152	-	153	-	154	-	155	-	156	-

PARISH NO. = 485

PARISH SUMMARY

NO. OF HOLDINGS = 20

ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY	ITEM	QUANTITY
157	-	158	-	159	10.0	160	-	161	-	162	-
163	-	164	183932.0	165	-	166	-	167	12.0	168	-
169	-	170	183954.0	171	-	177	6.0	178	1.0	179	3.0
180	-	181	-	182	1.0	183	2.0	184	6.0	185	-
186	-	187	-	188	7.0	189	5.0	190	-	191	-
192	-	193	-	194	-	195	2.0	196	1.0	197	-
198	2.0	199	-	200	17.0						

APPENDIX 2.

WRITTEN QUESTIONNAIRE RETURNS FOR ST.MARY'S CATCHMENT.

BOWERHOPE ESTATE

Planting began 1970 and concluded 1976. The area was previously unplanted.

Planting Years:

Compartment	
1,2,3,4,5,6,7,8,9a	1970
9b,10a,10b,11a	1972
11b,12,13 (13.6 ha)	1973
13 (3.9 ha), 14a,15,16 (12.1 ha), 17a (4.2 ha), 18a	1974
16 (0.4 ha), 17a (0.8 ha), 17b, 18b, 19, 20, 21	1975
14b, 17a (0.5 ha), 17c	1976

NB Compartment 22 is unplantable

Of the Estate area (340.5 ha) 79% is planted up. The remainder is unplantable land or bare land.

Conifers occupy 99.7% of stocked area
Broadleaves occupy 0.3% of stocked area

Conifer crop

85% — Sitka spruce
5% — Lodgepole pine
5% — Scots pine
4% — Japanese and European larch
1% — Norway spruce 2 Douglas fir

Fertiliser

Compartment	Application Rate	Year	Type
3,5 (peat areas)	150 kg/ha	1971	GAFSA/POTASH Mix
13,14a (peat areas)	150 kg/ha	1974	GAFSA
14b	150 kg/ha	1976	GAFSA
16 (on P75 area)	150 kg/ha	1976	GAFSA
17a,b,c,18a,b, 19,20,21	150 kg/ha	1976	GAFSA

BOWERHOPE LAW ESTATE

The whole estate was planted from April - June 1986 with 99% mixed conifers and 1% mixed broadleaves.

Of the conifers:

86%	—	Sitka spruce
12%	—	Japanese larch
1%	—	Lodgepole pine
1%	—	Scots pine

The estate was previously unplanted. The area was fertilised once, after the first season's weeding, in September 1986.

Fertiliser used was:

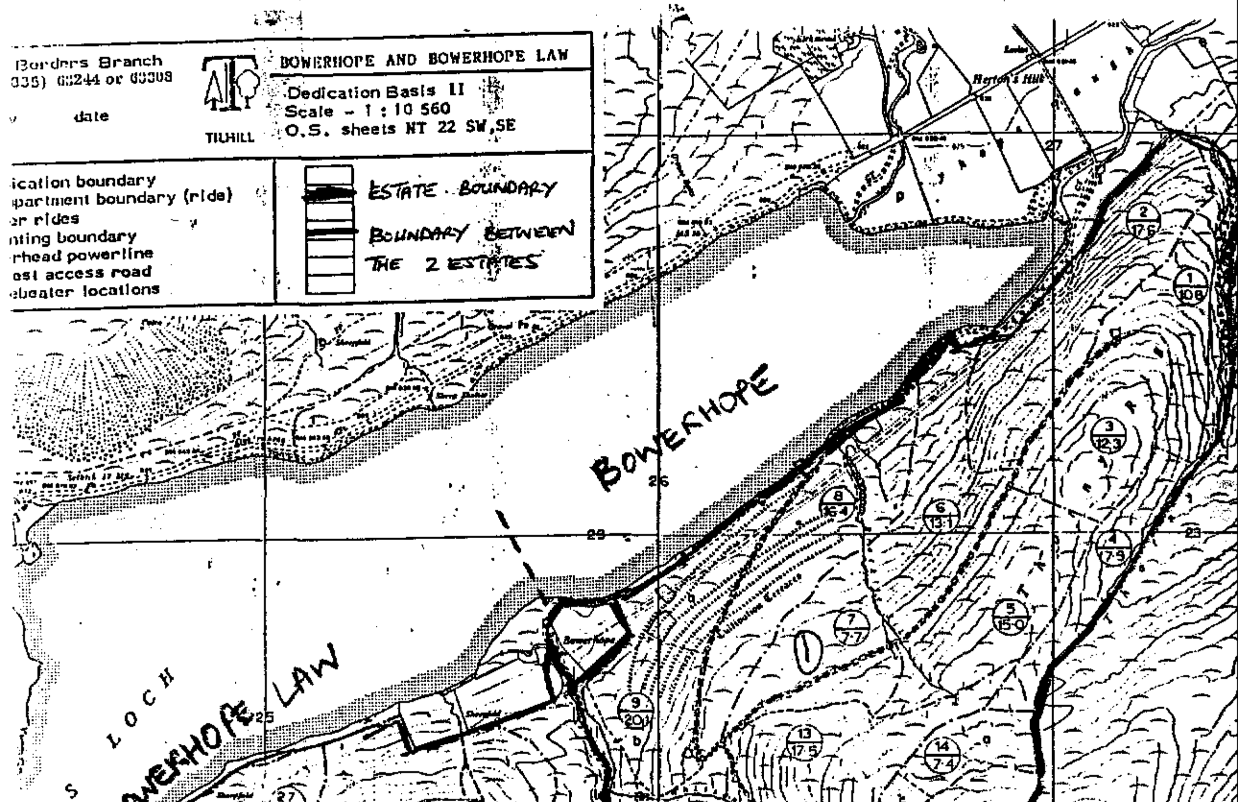
22.55 tonnes	GAFSA
4.90 tonnes	GAFSA/POTASH Mix

Fertiliser was hand applied at the rate of:

Peaty areas (approximately 4.3 ha)	-	375 kg/ha
Deeper peats (approximately 7.1 ha) (Cpts. 22,23,26 and 31)	-	575 kg/ha
Elsewhere	-	180 kg/ha

Total area of estate is 157.6 ha of which 126.7 is planted. The top of the estate is unplanted and is dominated by peaty soils and heather vegetation.

MAP REDUCED TO 70% OF ORIGINAL



The Wemyss and March Estates Management Co. Ltd.

LORD NEIDPATH, ARICS. Chairman
DAVID H. BENSON
LADY ELIZABETH BENSON
THE LORD CHARTERIS OF AMISFIELD, GCB. GCVO. OBE. QSO.
THE EARL OF WEMYSS AND MARCH, KT. LLD. DUniv. JP. Consultant

Secretary and Factor to the Trustees:
R. R. GLEDSON, BSc. ARICS.

REGISTERED IN SCOTLAND: No. 45528

Registered Office: ESTATES OFFICE,
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EAST LOTHIAN,
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Tel. ABERLADY 201 (STD CODE 087 57)
Fax. ABERLADY 620 (STD CODE 087 57)

Our ref: 57

17th June 1992

Miss A. Meachan,
c/o Dr. A.E. Bailey-Watts,
Institute of Freshwater Ecology,
c/o The Institute of Terrestrial Ecology,
Bush Estate,
PENICUIK,
Midlothian,
EH26 0QB.

Dear Miss Meachan,

St. Mary's Loch Catchment Area

Thank you for your letter which I received on the 16th June. I enclose a plan showing the Estate boundary and areas of woodland on the Estate, also the approximate locations of the private septic tanks. I hope that this information is of use to you.

You also asked for other information by sub catchment area:

1. Area 1: Megget Reservoir

Forestry	Small areas totalling c. 15 ha mixed species Conifers and Broadleaves
Grazing	Continuously grazed by c. 5,000 Blackface Ewes and 1,000 Hoggs
Covers	Farms of Winterhopeburn, Meggethead, Syart (part) Cramalt and Craigierig (Part)
Septic Tanks	7 shown on plan used 12 months per annum

2. Area 2: St. Mary's Loch

Forestry	2 main plantations as shown totalling 22 ha P72 mainly Sitka Spruce with some Japanese Larch and other Conifers Small blocks totalling 5 ha around Henderland Farm
Grazing	Continuously grazed by c. 3,000 Blackface Ewes and 600 Hoggs
Covers	Farms of Henderland, Syart (Part), Craigierig (Part), Chapelhope (part)
Septic Tanks	6 as shown on plan There may be others associated to council houses at Cappercleuch 4 houses

3./

Miss A. Meachan,
c/o Dr. A.E. Bailey-Watts,
Institute of Freshwater Ecology,
c/o The Institute of Terrestrial Ecology,
Bush Estate,
PENICUIK,
Midlothian,
EH26 0QB.

17th June 1992

3. Area 3: Loch of the Lowes

Forestry	11 plantations totalling 175 ha predominantly Sitka Spruce with other Conifer species P63-77 In addition small blocks mainly in the area of Riskinhope Farm totalling 5 ha Mixed Conifers and Broadleaves
Grazing	by 2,500 Blackface Ewes and 500 Hoggs
Covering	Farms of Riskinhope and Chapelhope (part)
Septic Tanks	7 as shown on plan.

Yours sincerely,

Factor.

APPENDIX 3.

HYDROLOGICAL DATA.

Table A3.1: Hydrological data for the Loch Leven catchment (FRPB).

Year Month	Rainfall mm.	Runoff mm.	Gauged flows Mm^3.	Inflow $x10^3m^3$.
1981 Jan	53.6	88.7	14.041	14041.2
Feb	54.5	54.0	8.548	8548.2
March	119.9	100.3	15.877	15877.5
April	17.9	21.6	3.419	3419.3
May	70.1	14.9	2.359	2358.7
June	72.9	25.4	4.021	4020.8
July	62.6	11.5	1.820	1820.4
Aug	12.0	2.5	0.396	395.7
Sept	192.1	10.9	1.725	1725.5
Oct	120.9	104.5	16.542	16542.3
Nov	113.4	95.8	15.165	15165.1
Dec	52.3	42.3	6.696	6696.1
1982 Jan	85.2	126.8	20.072	20072.4
Feb	50.1	70.6	11.176	11176.0
March	103.0	109.8	17.381	17381.3
April	25.9	27.0	4.274	4274.1
May	51.4	20.2	3.198	3197.7
June	77.8	10.5	1.662	1662.1
July	32.4	5.1	0.807	807.3
Aug	80.1	8.5	1.345	1345.5
Sept	118.1	40.5	6.411	6411.1
Oct	128.2	117.9	18.663	18663.6
Nov	132.7	120.5	19.075	19075.1
Dec	113.6	132.4	20.959	20958.9
1983 Jan	167.2	179.3	28.383	28383.2
Feb	25.2	54.2	8.580	8579.9
March	65.1	62.9	9.957	9957.1

April	50.5	32.7	5.176	5176.4
May	96.3	50.2	7.947	7946.7
June	60.3	37.4	5.920	5920.4
July	9.4	5.9	0.934	934.0
Aug	29.8	4.5	0.712	712.3
Sept	115.9	23.7	3.752	3751.7
Oct	135.7	117.3	18.569	18568.6
Nov	31.4	71.1	11.255	11255.1
Dec	140.5	100.1	15.846	15845.8
1984 Jan	149.7	171.0	27.069	27069.3
Feb	57.0	137.0	21.687	21687.1
March	111.4	91.4	14.469	14468.6
April	18.4	31.3	4.955	4954.8
May	50.7	14.1	2.232	2232.0
June	52.5	14.1	2.232	2232.0
July	32.3	2.5	0.396	395.7
Aug	33.8	3.4	0.538	538.2
Sept	121.7	16.2	2.564	2564.5
Oct	158.6	87.7	13.883	13882.9
Nov	277.0	230.2	36.409	36440.7
Dec	988.0	112.2	17.761	17761.3
1985 Jan	59.2	51.2	8.105	8105.0
Feb	28.3	49.2	7.788	7788.4
March	77.1	43.0	6.807	6806.9
April	70.0	67.5	10.685	10685.2
May	59.8	20.7	3.277	3276.8
June	70.7	14.6	2.311	2311.2
July	159.2	46.4	7.345	7345.1
Aug	161.0	93.3	14.770	14769.4
Sept	201.4	141.9	22.463	22462.8
Oct	26.7	61.0	9.656	9656.3

Nov	75.3	40.0	6.332	6332.0
Dec	154.6	173.0	27.386	27385.9
1986 Jan	135.2	143.7	22.756	22755.6
Feb	30.7	76.8	12.153	12152.7
March	90.8	57.9	9.167	9167.1
April	76.7	48.5	7.682	7682.3
May	140.2	97.5	15.437	15437.4
June	70.7	71.4	11.300	11299.4
July	58.3	18.2	2.887	2887.4
Aug	74.5	45.5	7.202	7202.65
Sept	40.9	21.2	3.351	3351.2
Oct	83.7	23.3	3.693	3693.1
Nov	139.9	79.3	12.551	12551.6
Dec	188.0	117.9	18.666	18665.1
1987 Jan	107.7	97.2	15.394	15394.7
Feb	65.3	76.4	12.092	12092.54
March	105.8	56.5	8.940	8939.2
April	74.6	56.6	8.957	8956.6
May	45.1	26.1	4.136	4136.4
June	112.8	51.5	8.153	8152.4
July	58.6	25.5	4.031	4030.3
Aug	82.4	26.7	4.222	4221.9
Sept	80.5	45.6	7.216	7215.3
Oct	127.2	113.7	17.993	17992.4
Nov	52.3	88.9	14.067	14066.5
Dec	87.0	72.0	11.391	11391.3
1988 Jan	125.7	114.9	18.188	18188.7
Feb	61.2	133.8	21.175	21174.2
March	55.9	46.6	7.382	7381.5
April	74.1	45.6	7.217	7216.9
May	56.2	35.7	5.660	5659.2

June	17.0	24.7	3.913	3913.2
July	190.1	25.3	4.003	4003.4
Aug	121.1	91.5	14.491	14490.8
Sept	80.5	86.3	13.658	13658.1
Oct	132.6	82.3	13.031	13031.3
Nov	73.8	81.8	12.944	12944.2
Dec	53.5	78.7	12.467	12466.2
1989 Jan	97.9	108.4	17.162	17161.3
Feb	111.2	100.2	15.856	15855.3
March	128.7	122.3	19.356	19355.3
April	32.7	41.5	6.572	6572.6
May	21.0	20.1	3.186	3186.6
June	61.3	23.7	3.758	3758.0
July	17.3	12.8	2.034	2034.2
Aug	128.5	22.1	3.503	3503.2
Sept	54.0	36.8	5.825	5825.4
Oct	99.2	45.5	7.210	7210.6
Nov	37.5	98.5	15.593	15592.6
Dec	69.0	47.5	7.513	7512.9
1990 Jan	218.6	95.8	15.162	15162.0
Feb	188.0	181.9	28.796	28796.3
March	97.4	127.3	20.154	20153.2
April	49.8	32.7	5.177	5176.4
May	33.9	24.2	3.838	3837.2
June	155.4	24.4	3.869	3868.8
July	34.6	35.1	5.560	5559.5
Aug	83.8	56.0	8.860	8860.0
Sept	48.8	27.0	4.282	4282.0
Oct	170.8	102.9	16.289	16289.1
Nov	61.6	81.9	12.968	12967.9
Dec	124.5	55.8	8.836	8836.3

Table A3.2 Hydrological data for the St.Mary's catchment (TRPB).

YEAR	MONTH	RAINFALL MM HEND.	RAINFALL MM CRAIG.	RUN-OFF MM HEND.	RUN-OFF MM CRAIG.	GAUGED FLOWS CUMECS HEND.	GAUGED FLOWS CUMECS CRAIG.	INFLOWS MEGALITRES MEGGET	INFLOWS MEGALITRES LOWES	INFLOWS MEGALITRES ST.MARY'S	OUTFLOWS MEGALITRES MEGGET	OUTFLOWS MEGALITRES LOWES	OUTFLOWS MEGALITRES ST.MARY'S
1982	JAN	167	166	222	209	4.654	9.041	10034	3971	22325	8872	3971	22754
	FEB	215	210	188	176	4.379	8.442	8498	3344	19970	8348	3344	21247
	MAR	214	210	195	183	4.086	7.935	8814	3477	19576	7789	3477	19971
	APL	20	23	30	32	0.612	1.375	1356	608	3162	1167	608	3461
	MAY	98	101	53	46	1.002	1.878	2396	874	4857	1910	874	4726
	JUN	129	119	38	33	0.41	1.078	1718	627	2699	782	627	2713
	JUL	77	85	62	59	0.477	1.744	2802	1121	4173	909	1121	4389
	AUG	113	112	21	21	0.301	0.793	949	399	1819	574	399	1996
	SEP	164	170	96	86	0.67	2.45	4339	1634	6019	1277	1634	6166
	OCT	245	246	239	204	1.483	5.281	10803	3876	14006	2827	3876	13291
	NOV	257	262	268	242	3.12	8.132	12114	4598	20077	5948	4598	20466
	DEC	229	229	256	213	1.3	5.14	11571	4047	13992	2478	4047	12936
1983	JAN	256	260	195	201	1.217	5.828	8814	3819	13179	2320	3819	14668
	FEB	58	63	64	66	0.539	2.219	2893	1254	4682	1028	1254	5585
	MAR	168	169	146	134	0.854	3.581	6599	2546	8894	1628	2546	9013
	APL	106	102	93	82	1.017	2.664	4204	1558	6701	1939	1558	6705
	MAY	153	151	134	129	1.116	3.881	6057	2451	9310	2127	2451	9768
	JUN	73	73	53	48	0.773	1.8	2396	912	4375	1474	912	4530
	JUL	39	41	10	9	1.679	1.86	452	171	4724	3201	171	4681
	AUG	33	35	8	4	2.231	2.236	362	76	5877	4253	76	5628
	SEP	121	122	47	41	1.476	2.278	2124	779	5812	2814	779	5733
	OCT	308	280	238	211	1.444	5.568	10758	4009	14258	2753	4009	14013
	NOV	32	29	33	31	0.562	1.214	1492	589	2985	1071	589	3055
	DEC	211	216	163	152	0.933	4.103	7368	2888	9998	1779	2888	10326
1984	JAN	284	295	170	162	3.075	6.524	7684	3078	15950	5862	3078	16419
	FEB	125	119	185	168	4.412	8.036	8362	3192	19653	8411	3192	20225
	MAR	136	129	104	101	4.368	6.554	4701	1919	16180	8327	1919	16495
	APL	31	30	64	56	1.296	2.397	2893	1064	6107	2471	1064	6033
	MAY	16	14	18	18	1.255	1.666	814	342	4096	2392	342	4193
	JUN	71	66	19	15	1.56	1.834	859	285	4722	2974	285	4616
	JUL	38	34	25	10	2.115	2.018	1130	190	5883	4032	190	5079
	AUG	41	40	9	7	1.848	1.973	407	133	5053	3523	133	4966
	SEP	135	123	33	25	1.513	1.92	1492	475	5104	2884	475	4832
	OCT	219	218	125	111	1.461	3.628	5650	2109	9285	2785	2109	9131
	NOV	348	334	314	270	2.009	7.292	14193	5130	18655	3830	5130	18352
	DEC	175	158	172	157	0.916	4.11	7774	2983	10206	1746	2983	10344
1985	JAN	75	72	68	57	0.455	1.508	3074	1083	4017	867	1083	3795
	FEB	20	20	61	63	0.411	2.014	2757	1197	4206	784	1197	5069
	MAR	114	121	69	57	0.935	1.971	3119	1083	5238	1782	1083	4961
	APL	122	99	133	130	0.963	3.904	6012	2470	8971	1836	2470	9825
	MAY	84	87	51	38	1.152	1.718	2305	722	4837	2196	722	4324
	JUN	79	82	53	40	0.704	1.365	2396	760	3798	1342	760	3435
	JUL	166	167	100	89	0.929	2.684	4520	1691	6828	1771	1691	6755
	AUG	335	326	270	220	3.245	7.114	12204	4180	19292	6186	4180	17904
	SEP	208	220	227	197	3.882	7.776	10260	3743	19759	7400	3743	19570
	OCT	141	142	129	118	2.708	5.088	5831	2242	12809	5162	2242	12805
	NOV	113	116	73	62	0.673	1.867	3300	1178	4822	1283	1178	4699
	DEC	274	277	269	233	5.636	10.088	12159	4427	26028	10744	4427	25389

1986	JAN	212	200	183	167	2.539	5.916	8272	3173	14837	4840	3173	14889
	FEB	32	30	32	36	0.789	1.753	1446	684	3813	1504	684	4412
	MAR	205	185	208	181	3.953	7.422	9402	3439	19137	7536	3439	18679
	APL	99	95	95	77	2.069	3.463	4294	1463	9127	3944	1463	8716
	MAY	289	264	252	213	5.253	9.166	11390	4047	24050	10014	4047	23069
	JUN	87	87	78	76	1.02	2.758	3526	1444	6408	1944	1444	6941
	JUL	77	74	4	10	1.05	1.419	181	190	3173	2002	190	3571
	AUG	200	181	151	121	1.095	3.19	6825	2299	8856	2087	2299	8029
	SEP	24	26	23	23	1.417	1.945	1040	437	4759	2701	437	4896
	OCT	216	195	123	99	1.899	3.605	5560	1881	9798	3620	1881	9073
	NOV	318	288	284	245	4.548	9.355	12837	4655	23861	8670	4655	23544
	DEC	371	341	330	279	6.781	11.939	14916	5301	31249	12927	5301	30048
1987	JAN	93	95	116	113	5.478	7.922	5243	2147	19607	10443	2147	19938
	FEB	80	75	47	50	0.866	2.16	2124	950	4712	1491	950	4910
	MAR	173	162	136	124	1.336	3.85	6147	2356	9619	2547	2356	9690
	APL	99	91	119	110	0.859	3.206	5379	2090	7703	1585	2090	7808
	MAY	69	63	24	24	0.943	1.496	1085	456	3603	1798	456	3765
	JUN	126	123	90	73	1.134	2.448	4068	1387	6547	2092	1387	5962
	JUL	128	122	62	57	0.865	2.023	2802	1083	5060	1649	1083	5091
	AUG	153	139	81	71	0.799	2.202	3661	1349	5594	1523	1349	5542
	SEP	159	143	114	95	1.154	2.931	5153	1805	7702	2129	1805	7139
	OCT	210	194	181	158	1.709	4.765	8181	3002	12274	3258	3002	11992
	NOV	129	122	105	97	2	4.071	4746	1843	9954	3690	1843	9915
	DEC	188	172	130	113	1.502	3.691	5876	2147	9490	2863	2147	9289
1988	JAN	249	228	225	205	4.842	9.001	10170	3895	22603	9230	3895	22653
	FEB	166	152	172	163	3.939	7.622	7774	3097	18199	7025	3097	17946
	MAR	135	124	106	94	1.177	3.019	4791	1786	7710	2244	1786	7598
	APL	76	73	72	70	1.318	2.904	3254	1330	6865	2431	1330	7073
	MAY	80	79	39	44	0.812	1.884	1763	836	4273	1548	836	4742
	JUN	20	22	10	14	1.048	1.472	452	266	3369	1933	266	3585
	JUL	246	236	132	114	1.268	3.429	5966	2166	8945	2417	2166	8630
	AUG	195	175	112	94	1	2.722	5062	1786	7260	1906	1786	6851
	SEP	153	143	111	107	2.124	4.499	5017	2033	10772	3918	2033	10958
	OCT	169	158	154	141	1.941	4.823	6961	2679	12011	3700	2679	12138
	NOV	91	86	52	55	1.501	2.861	2350	1045	6578	2769	1045	6968
	DEC	130	117	120	113	1.022	3.422	5424	2147	8269	1948	2147	8612
1989	JAN	217	196	211	194	3.071	6.9	9537	3686	17545	5854	3686	17366
	FEB	203	188	130	141	3.871	7.63	5876	2679	16922	7141	2679	17345
	MAR	265	249	265	237	4.291	9.014	11978	4503	22806	8180	4503	22686
	APL	71	68	58	64	3.777	5.368	2622	1216	12821	6968	1216	13074
	MAY	62	56	28	32	0.544	1.36	1266	608	2989	1037	608	3423
	JUN	58	53	9	14	0.925	1.37	407	266	3056	1706	266	3337
	JUL	41	37	5	5	1.231	1.331	226	95	3383	2347	95	3350
	AUG	222	192	91	60	1.397	2.097	4113	1140	6564	2663	1140	5278
	SEP	117	99	90	74	0.821	2.179	4068	1406	5801	1515	1406	5307
	OCT	133	116	72	68	0.799	2.226	3254	1292	5444	1523	1292	5602
	NOV	52	46	69	68	0.787	2.327	3119	1292	5413	1452	1292	5668
	DEC	142	134	111	100	1.085	3.08	5017	1900	7777	2068	1900	7752

1990	JAN	346	343	348	299	2.195	7.844	15730	5681	20583	4184	5681	19742
	FEB	394	387	449	386	4.136	12.246	20295	7334	29886	7122	7334	27838
	MAR	109	106	165	145	3.49	6.328	7458	2755	16153	6653	2755	15926
	APL	67	64	40	41	1.045	2	1808	779	4716	1928	779	4871
	MAY	56	56	28	33	0.721	1.561	1266	627	3490	1374	627	3929
	JUN	147	145	54	38	0.75	1.303	2441	722	3814	1384	722	3174
	JUL	84	82	69	63	0.781	2.062	3119	1197	5147	1489	1197	5190
	AUG	102	98	25	27	0.757	1.395	1130	513	3280	1443	513	3511
	SEP	85	81	53	37	0.905	1.432	2396	703	4159	1670	703	3488
	OCT	250	238	221	181	1.612	4.822	9989	3439	13181	3073	3439	12136
	NOV	67	66	64	67	0.585	2.193	2893	1273	4849	1079	1273	5341
	DEC	230	227	252	223	1.543	5.928	11390	4237	15112	2941	4237	14919
1991	JAN			216	205	2.494	6.833	9763	3895	16629	4754	3895	17197
	FEB			123	115	1.371	4.029	5560	2185	9257	2361	2185	9159
	MAR			173	167	2.576	6.162	7820	3173	14931	4911	3173	15508
	APL			135	131	1.933	4.882	6102	2489	11489	3566	2489	11891
	MAY			14	20	0.892	1.469	633	380	3273	1700	380	3697
	JUN			60	42	0.78	1.337	2712	798	4091	1439	798	3256
	JUL			51	42	0.84	1.397	2305	798	3735	1220	798	3516
	AUG			16	21	0.853	1.419	723	399	3224	1626	399	3571
	SEP			28	21	1.07	1.388	1266	399	3776	1974	399	3381
	OCT			140	109	1.036	2.832	6328	2071	8104	1975	2071	7127
	NOV			261	244	1.602	6.847	11797	4636	16315	2955	4636	16676
	DEC			160	149	0.961	4.055	7232	2831	9919	1832	2831	10206
								307088	117078	558353	183244	117078	554232

Table A3.3: Average Estimated Monthly Inflow, Flushing Rate and Areal Water Loading for; a. St Marys 'total' Catchment.

Month	Inflow $x10^3m^3$.	Flushing rate.	Areal H_20 loading.
Jan.	16927.5	0.30	6.59
Feb.	13130.0	0.23	5.11
March.	14024.4	0.24	5.46
April.	7766.2	0.14	3.02
May.	6477.8	0.11	2.52
June.	4287.9	0.08	1.67
July.	5105.1	0.09	1.99
Aug.	6681.9	0.12	2.60
Sept.	7366.3	0.13	2.87
Oct.	11117.0	0.19	4.33
Nov.	11350.9	0.20	4.42
Dec.	14204.0	0.25	5.53
Year.	118439.0	2.08	46.11

Table A3.3 (cont.): b. Megget.

Month.	Inflow $x10^3m^3$	Flushing rate.	Areal H_2O loading.
Jan.	8832.1	0.42	3.41
Feb.	6558.5	0.31	2.53
March.	7082.9	0.34	2.74
April.	3792.4	0.18	1.46
May.	2897.5	0.13	1.12
June.	2095.5	0.10	0.81
July.	2350.5	0.12	0.91
Aug.	3543.6	0.17	1.37
Sept.	3715.5	0.18	1.43
Oct.	7331.5	0.35	2.83
Nov.	6884.1	0.33	2.66
Dec.	8872.7	0.42	3.43
Year.	63956.8	3.05	24.70

Table A3.3 (cont.): c. Lowes.

Month.	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	3442.8	0.77	8.83
Feb.	2591.6	0.58	6.64
March.	2703.7	0.61	6.93
April.	1506.7	0.34	3.86
May.	1134.3	0.25	2.91
June.	746.7	0.17	1.92
July.	870.2	0.19	2.23
Aug.	1227.4	0.28	3.15
Sept.	1341.4	0.30	3.44
Oct.	2660.0	0.60	6.82
Nov.	2623.9	0.59	6.73
Dec.	3290.8	0.74	8.44
Year.	24139.5	5.42	61.90

Table A3.3 (cont.): d. Loch Leven.

	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	18631.90	0.36	1.40
Feb.	14785.20	0.26	1.11
March.	12948.90	0.25	0.97
April.	6411.20	0.12	0.48
May.	5128.90	0.10	0.39
June.	4717.30	0.09	0.35
July.	2976.00	0.06	0.22
Aug.	5603.80	0.11	0.42
Sept.	7123.50	0.14	0.54
Oct.	13550.50	0.26	1.02
Nov.	15640.00	0.30	1.18
Dec.	14753.60	0.28	1.11
Year.	123220.70	2.35	9.91

Table A3.4: Estimated Monthly Inflow, Flushing Rate and Areal Loading for: a. St Marys 'total' Catchment in 1989 and 1990.

1989 Month.	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	17545.0	0.31	6.83
Feb.	16922.0	0.30	6.58
March.	22806.0	0.40	8.87
April.	12821.0	0.22	4.99
May.	2989.0	0.05	1.16
June.	3056.0	0.05	1.19
July.	3383.0	0.06	1.32
Aug.	6564.0	0.12	2.55
Sept.	5801.0	0.10	2.26
Oct.	5444.0	0.09	2.12
Nov.	5413.0	0.09	2.11
Dec.	7777.0	0.14	3.03
Year.	110521.0	1.93	43.01
1990			
Jan.	20583.0	0.36	8.01
Feb.	29886.0	0.52	11.63
March.	16153.0	0.28	6.28
April.	4716.0	0.08	1.83
May.	3490.0	0.06	1.36
June.	3814.0	0.07	1.48
July.	5147.0	0.09	2.00
Aug.	3280.0	0.06	1.28
Sept.	4159.0	0.07	1.62
Oct.	13181.0	0.23	5.13
Nov.	4849.0	0.08	1.89
Dec.	15112.0	0.26	5.88
Year.	124370.0	2.16	48.39

Table A3.4 (cont.): b. Megget 'direct' in 1989 and 1990.

1989 Month.	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	9537.0	0.45	3.68
Feb.	5876.0	0.28	2.27
March.	11978.0	0.57	4.62
April.	2622.0	0.12	1.01
May.	1266.0	0.06	0.49
June.	407.0	0.02	0.16
July.	226.0	0.01	0.09
Aug.	4113.0	0.20	1.59
Sept.	4068.0	0.19	1.57
Oct.	3254.0	0.15	1.26
Nov.	3119.0	0.15	1.20
Dec.	5017.0	0.24	1.94
Year.	51483.0	2.44	19.88
1990			
Jan.	15730.0	0.75	6.07
Feb.	20295.0	0.97	7.84
March.	7458.0	0.35	2.88
April.	1808.0	0.09	0.70
May.	1266.0	0.06	0.49
June.	2441.0	0.12	0.94
July.	3119.0	0.15	1.20
Aug.	1130.0	0.05	0.44
Sept.	2396.0	0.11	0.92
Oct.	9989.0	0.48	3.86
Nov.	2893.0	0.14	1.12
Dec.	11390.0	0.54	4.40
Year	79915.0	3.81	30.86

Table A3.4 (cont.): c. Lowes 'direct' in 1989 and 1990.

1989 Month.	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	3686.0	0.83	9.45
Feb.	2679.0	0.60	6.87
March.	4503.0	1.01	11.55
April.	1216.0	0.27	3.21
May.	608.0	0.14	1.56
June	260.0	0.06	0.68
July.	95.0	0.02	0.24
Aug.	1140.0	0.26	2.92
Sept.	1406.0	0.31	3.60
Oct.	1292.0	0.29	3.31
Nov.	1292.0	0.29	3.31
Dec.	1900.0	0.43	4.87
Year.	20083.0	4.51	51.48
1990			
Jan.	5681.0	1.27	14.57
Feb.	7334.0	1.64	18.80
March.	2755.0	0.62	7.06
April.	779.0	0.17	2.00
May.	627.0	0.14	1.61
June.	722.0	0.16	1.85
July.	1197.0	0.27	3.07
Aug.	513.0	0.11	1.31
Sept.	703.0	0.16	1.80
Oct.	3439.0	0.77	8.82
Nov.	1273.0	0.28	3.26
Dec.	4237.0	0.95	10.86
Year.	29260.0	6.54	75.01

Table A3.4 (cont.): d. Loch Leven in 1984 and 1989.

1984 Month.	Inflow $x10^3m^3$.	Flushing rate.	Areal H_2O loading.
Jan.	27069.30	0.52	2.03
Feb.	21687.10	0.41	1.63
March.	14468.60	0.28	1.10
April.	14954.80	0.28	1.09
May.	2232.00	0.04	0.17
June.	2232.00	0.04	0.17
July.	395.80	0.01	0.03
Aug.	538.20	0.01	0.04
Sept.	2564.50	0.05	0.19
Oct.	13882.90	0.26	1.04
Nov.	36440.70	0.69	2.74
Dec.	17761.30	0.34	1.33
Year.	154227.20	2.93	11.56
1989.			
Jan.	17161.30	0.33	1.29
Feb.	15855.30	0.30	1.19
March.	19355.30	0.37	1.45
April.	6572.60	0.12	0.49
May.	3186.60	0.06	0.24
June.	3758.00	0.07	0.28
July.	2034.10	0.04	0.15
Aug.	3503.20	0.07	0.26
Sept.	5825.40	0.11	0.44
Oct.	7210.60	0.14	0.54
Nov.	15592.50	0.30	1.17
Dec.	7512.90	0.14	0.56
Year.	107568.00	2.05	8.06

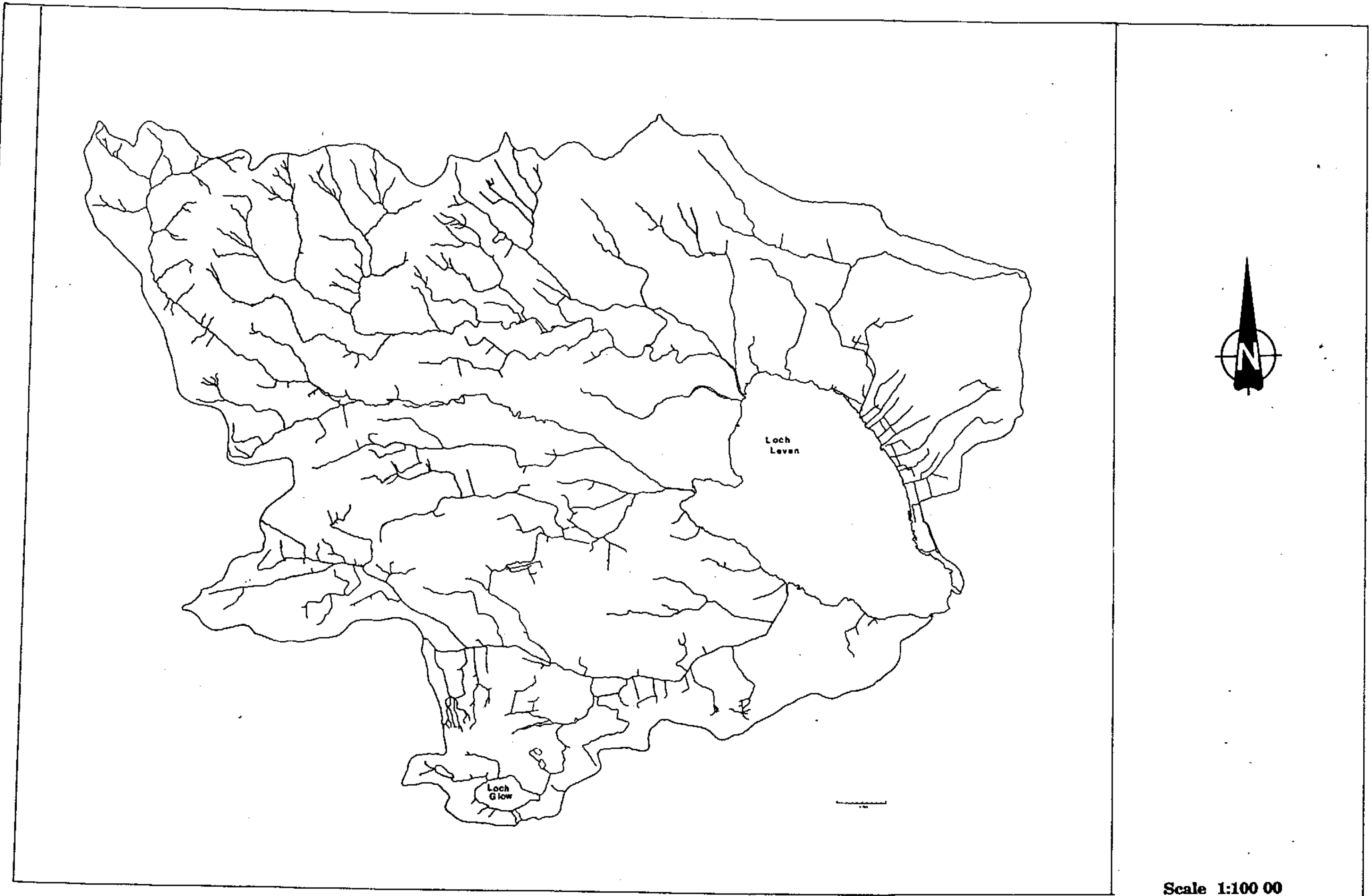

Fig. 2.1 The main inflows draining into Loch Leven.

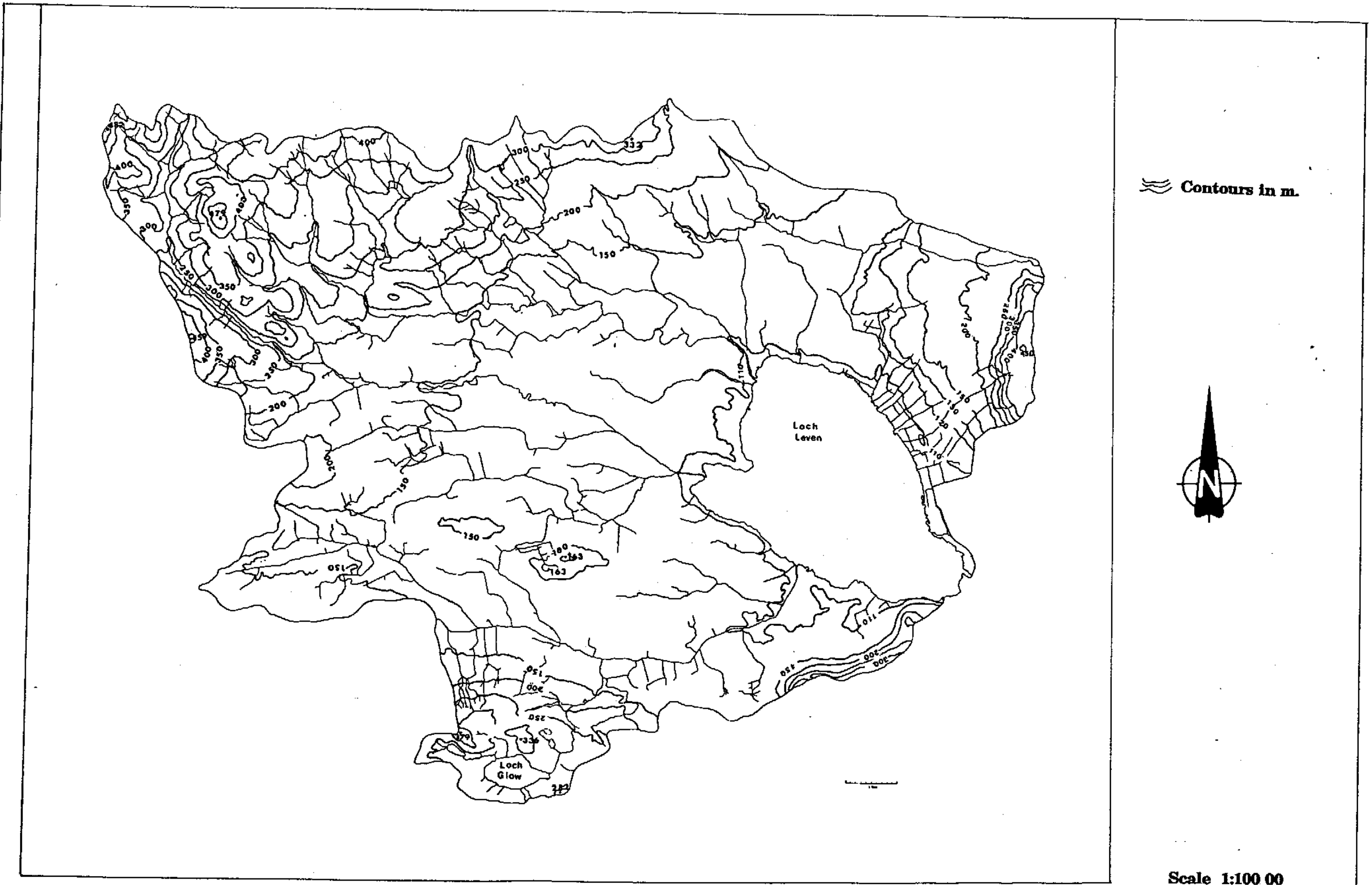

Fig. 2.2 Topography associated with the Loch Leven catchment.

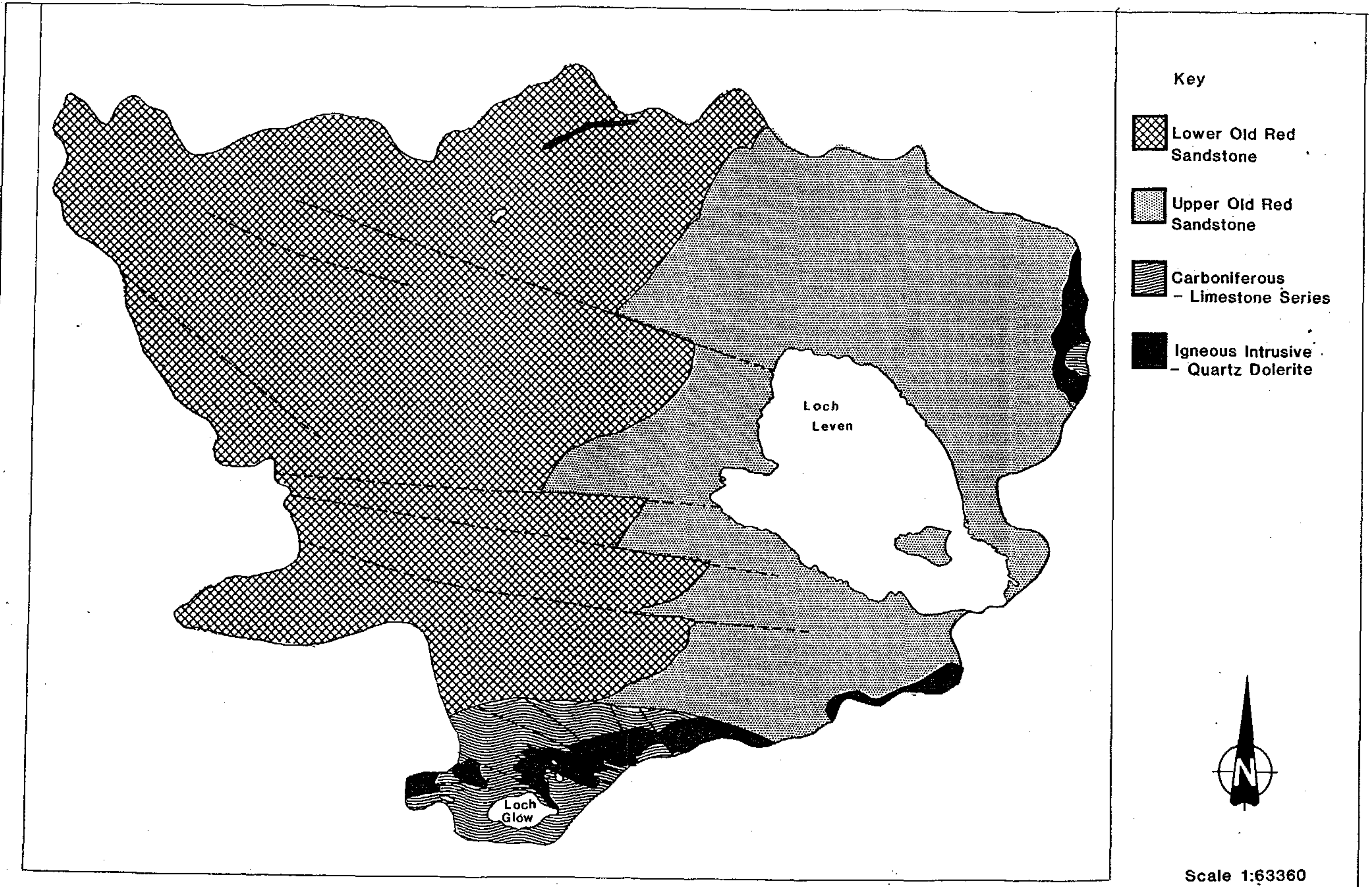

Fig.2.3 Geology associated with the Loch Leven catchment.

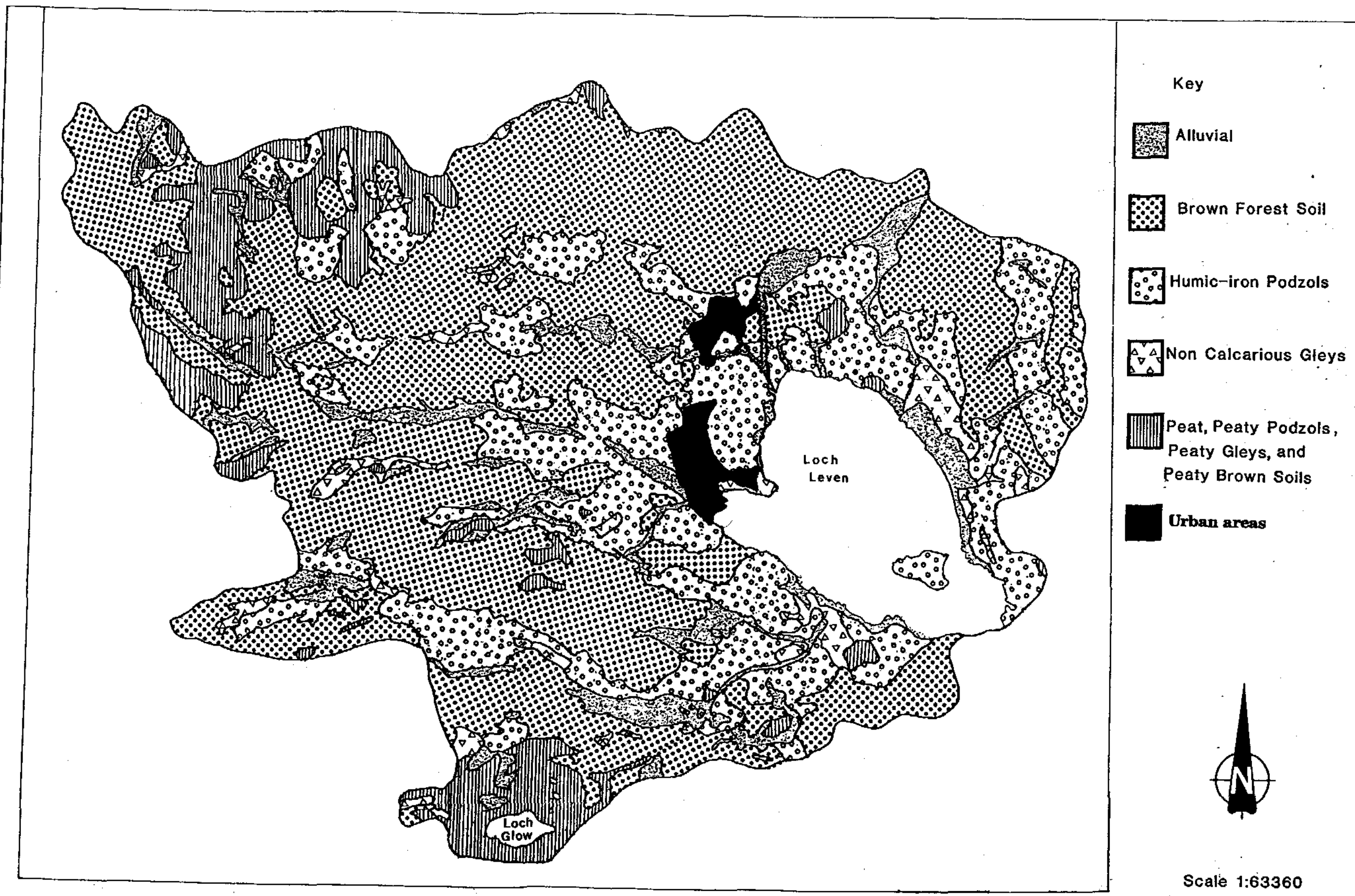

Fig.2.4 Soils associated with the Loch Leven catchment.