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A RE-ASSESSMENT OF THE PHOSPHORUS LOADING TO LOCH LEVEN, (KINROSS, TAYSIDE) - 1995

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The 1995 Loch Leven Phosphorus Loading Assessment

This report is submitted as a *draft* final version, because I wish to develop further the conclusions and management recommendations. This is particularly in the light of loadings still to be calculated using continuous (daily) flow data to compare with the present estimates based on the 8-daily products of phosphorus concentrations and flow. Even so, I do not expect any conclusions from the extra analysis will differ to any marked extend to those based on the present findings.

Tony Bailey-Watts
10 December 1996

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Mr Iain Gunn, Dr Charlotte Bryant and Miss Nicola Wiltshire helped with catchment sampling at various times, and Miss Wiltshire was also heavily involved in the limnological programme.

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Summary

1. The estimated total external loading of phosphorus to Loch Leven in 1995 is 10.5 tonnes (*cf* 20.5 in 1985) - as total P (i.e. TP); run-off contributed 64.3% (*cf* 39.6%), treated sewage 29.4% (*cf* 25.9%), industry (woollen mill) to all intents and purposes '0%' (*cf* 30.6%), rain falling on the loch surface 2.8% (*cf* 2.0%) and roosting geese *ca* 3.5% (*cf* 1.8%). Equivalent figures for the immediately bio-available soluble reactive fraction (SRP) are: total 5.3 tonnes (*cf* 12.3) to which run-off contributed 44.7% (*cf* 28.7%), sewage 49.2% (*cf* 31.4%), industry '0'%' (*cf* 36.8%), rain 2.7% (*cf* 1.6%) and wildfowl *ca* 3.5% (*cf* 1.5%).

2. Of the 3090 kg loading originating at the sewage treatment works (*cf* 5323 in 1985), including 2600 kg SRP (*cf* 3847), Kinross North contributed 56.6% of TP (*ca* 38.7%) and 59.2% of SRP (*cf* 44.8%); the Kinross South works which contributed 26.2% of TP and 17.2% of SRP in 1985, no longer exists - as a consequence of diversion of its waste to the upgraded and expanded North works; also, whereas the old Milnathort system contributed 21.4% (*cf* 25.9%) TP and 20.4% (*cf* 28.9%) of the SRP, the new works contributed only 4.2% of the TP from the STWs as a whole, and only 1.5% of the SRP; the small Kinnesswood unit contributed 17.8% (*cf* 9.2% of the total STWs' TP and 18.8% (*cf* 9.1%) of the SRP. The TP loads are equivalent to daily values of 0.68g person^{-1} for Kinross North, 2.0 for the old Milnathort system (i.e. up to 23 September 1995), 0.8 for the new works, and 3.01g daily *per capita* for the Kinnesswood system. If this range of values (0.68-3.01) is compared with the span of 1.77-2.42g daily *per capita* obtained in 1985, the effects of the upgrading of the large works is evident. An additional benefit will be the eventual diversion of all of the Kinnesswood works waste out of the Leven catchment.

3. The mean, volume-weighted, concentration of P in water entering the loch is 1.5 (*cf* 2.4) times the mean in-loch concentration of 60µg TP l^{-1} (*cf* 63); in contrast to the situation found in 1985, internal loading of P in the form of phosphate ions released from the sediments, was significant in 1995: a conservative estimate suggests that in the absence of this release, the mean in-loch concentration would have been as low as 50µg TP l^{-1}. However, the loch still retains a considerable amount of P that it receives from one year to the next, although the retention estimated for 1995 is very low. A massive 7.3t TP (including 3.8t total soluble P of which 2.4t was in the form of SRP) left the loch *via* the outflow: the TP value is equivalent to an extraordinary 70% of the income (*cf*, 40% in 1985), while the SRP figure is 45% of the input (*cf* 12% in 1985).

4. Many aspects of the dynamics of P recorded in 1995 contrast with those found in 1985. This results from the quite different regimes of rainfall and flushing for example; over the period of study, the Loch Leven area received some 890mm rain - which is much less than the 1250mm measured in 1985. Similarly, the flushing rate in 1995 was some 2.25 loch volumes (*cf* >2.53 loch volumes in 1985). Also in contrast to 1985 when the input of water in land runoff and rain falling directly on the loch surface (134 x 10^6 m^3) was very similar to the output (131 x 10^6 m^3), the volume entering the loch in 1995 is estimated to lie between 113 x 10^6 m^3 and 122 x 10^6 m^3, while the annual volume flowing out of the loch was nearly 148 x 10^6 m^3. This difference is reflected in the substantial drop in water level recorded during 1995.

5. The loch functioned very differently in 1995 as compared with 1985. In spite of this, the values obtained for the following factors combined with the loch mean depth according to a Dillon and Rigler model, predicted the annual mean, in-loch concentration of 64µg TP l^{-1} (*cf* 63 in 1985) very well: the specific areal loading of TP (790mg m^{-2} *cf* 1,540 in 1985), the amount of TP

passing out of the loch expressed as a fraction of the loading (i.e. 0.3 *cf* 0.6), flushing rate (2.25 loch volumes *cf* 2.53) and taking account of the mean depth of the loch. There is reason to question these conclusions on a number of counts, however. Firstly, one might have expected the not inconsiderable, albeit short-term release of SRP from the sediments to indicate a deviation from the tenets of the Dillon and Rigler equation; however, this may be explained by the fact that the SRP is rapidly re-sorbed by the sediments once weather conditions favouring the release come to an end. Secondly, if the volume of water flowing out of the loch in 1995 is taken as the flushing rate i.e. 2.82 loch volumes as opposed to the inflowing volume which equates to 2.25 volumes, the data do not fit the model. Thirdly, bearing in mind the peculiar water level pattern observed in 1995, a similar 'mis-match' arises if the mean depth of the loch is taken as say, 3.4m rather than the 'traditional' 3.9m. Fourthly, whereas in 1985 the mean in-loch level of chlorophyll$_a$ (21μg l^{-1}) related to the equivalent value for TP (63μg l^{-1}) according to an OECD model, the pair of values obtained in 1995 i.e. 64μg TP l^{-1} and 34μg chlorophyll$_a$ l^{-1}) plainly do not.

6. Water quality gave cause for concern in 1995 - but almost exclusively as a result of a 4-week period from mid-July. A very noticeable bloom was dominated by one of the largest cyanobacteria - *Anabaena spiroides* - which had not been recorded in anything like the numbers estimated then, in the 30-year history of regular sampling of the loch. This development, and the release of P from the sediments, resulted in annual mean values for soluble reactive P and chlorophyll$_a$ that are considerably higher than those measured in 1985 i.e. 19μg l^{-1} *cf* 9μg l^{-1} and 34μg l^{-1} *cf* 21μg l^{-1}. Contrastingly, as indicated above, the total phosphorus values were virtually the same. There is reason, however, to be encouraged by the 1995 findings in at least two respects. Firstly, with UK temperatures in the summer of 1995 exceeding those of any year back to the 17th century, weather and weather-related conditions were much more conducive to the manifestation of phytoplankton than they were in 1985 with its very wet late summer and autumn. Secondly, an upgrading of one of the major sewage treatment works was not completed until late September 1995. Thirdly, it is likely that the phosphate released from the sediments in July 1995 elevated the annual mean chlorophyll$_a$ concentration from 27μg l^{-1} to the 34μg l^{-1} measured, and the TP concentration itself by some 14μg l^{-1} from a value of 50μg l^{-1}.

7. The qualified success stems from a combination of (i) the recommendations made by IFE on the basis of its long-term attention to the functioning of Loch Leven and its findings from the 1985 P loading assessment in particular, and (ii) the willingness of the statutory authorities to put these recommendations into practice. However, the specific areal P loading of *ca* 790mg m^{-2} estimated for 1995 (albeit approximately only 50% of the 1985 figure) is still considerably in excess of the ideal maximum values for a lake of approximately 4m mean depth. On the other hand, such statistics ignore the significance of the composition of the P entering the system: the latest campaign has reduced the external loading of bio-available SRP by some 7t, and the completion of the Milnathort works upgrade will reduce the inputs of this P fraction even further. Indeed, the mean concentrations of TP, SRP and chlorophyll$_a$ for 1996, are likely to be even less than the levels measured in 1995.

8.It is recommended that:

(i) the more or less weekly limnological surveillance be maintained; this should cover in-loch and outflow nutrient and chlorophyll$_a$ levels, and phytoplankton and zooplankton biomass and species composition

(ii) weekly or 8-daily P loading assessments for the main inflows be resumed on 1 January 1997

(iii) strict control on inputs of treated, but nevertheless P-rich, sewage be maintained, and wherever possible tightened

(iv) reasonable efforts to minimise the inputs of P in all forms coming off the land also be exercised; this concern stems from the fact that much of the apparent reduction in TP loading from the high 1985 value is a consequence of the low rainfall in 1995.

1 INTRODUCTION

1.1 Background to the study

This report presents the findings of a second 1-year (1995), quantitative and qualitative assessment of the inputs of phosphorus (P) to the shallow eutrophic Loch Leven, and the relationship between the loadings and the quality of water in the loch itself. The reader is referred to Bailey-Watts *et al* (1987) and Bailey-Watts and Kirika (1987) emanating directly from the previous assessment carried out in 1985 for background information on the *raison d'etre* of these studies, and a good deal of detailed presentation and discussion on the following: sampling sites and strategies, the measurement of stream flows, stream and loch nutrient concentrations, and the ecology including the species composition and dynamics of the phytoplankton and the temporal variation in total biomass. Only those features whereby the present study differs significantly from the approaches adopted in 1985, are described here.

More than 35% of the 84 publications reviewed by Bailey-Watts and Kirika (1996) and relating to Loch Leven, have been produced since 1987; of these, the following selection should be consulted for information on issues relating to the overall description of Loch Leven, P loadings, P limitation, and phytoplankton performance in relation to nutrients, zooplankton and fish: Armstrong, Fozzard and Sargent (1994); Bailey-Watts (1988b, 1990, 1994); Bailey-Watts, Gunn and Kirika (1993); Bailey-Watts and Kirika (1993, 1995); Bailey-Watts, Kirika, Bryant and Wiltshire (1994); Bailey-Watts, Kirika and Hakansson (1994); Bailey-Watts, Kirika, May and Jones (1990); Bailey-Watts, May and Kirika (1991); Bailey-Watts, Smith and Kirika (1989a,b); Bailey-Watts, and Wiltshire (1996); Blake (1989); Farmer *et al* (1994);. Gunn, May and Bailey-Watts (1994); LLAMAG (1993; May, Gunn and Bailey-Watts (1993) and Miller (1993).

The earlier study concluded that approximately 21 t TP entered the loch during 1985 - with *ca.* 8 t coming in diffuse runoff, 6.3 t from an industrial source (woollen mill), and a further 5.3 t from STWs. The report recommended that in order to stem the production of planktonic algae, priority attention should be given to reducing P inputs, and that the material issuing from the mill should be targeted as soon as possible. These recommendations were followed up, and it appears - on the basis of a continued surveillance - that virtually no P has entered the loch from the mill on the South Queich since the end of 1987, and possibly even earlier. P removal performance of the main STWs in the catchment has also been improved. As a result, the total P load was considered with some justification, to have been now less than that estimated from the 1985 study. In addition, the relative contribution from land runoff was likely to be greater than it was some 10 years ago, and as a consequence, the inputs from point sources is smaller than hitherto. The latter change was considered to be of special significance: relative to most runoff sources, STW effluent is much richer in soluble reactive P (SRP) - which is almost certainly the form of P that is most readily taken up by phytoplankton - and woollen mill effluent was relatively rich in soluble P compounds that were rapidly hydrolysed to SRP.

In spite of the assumed reductions in P loading, the loch continued to manifest phytoplankton blooms occasionally. Indeed, only in years (such as 1985 itself) in which the summer was very wet, and in more recent times, has the loch appeared less characteristically eutrophic. Rapid flushing in particular, mediates against the accumulation of algal cells produced and suppresses releases of P from the sediments, and subsequent accumulation of the nutrient in the overlying water column.

The relative lack of a response by the loch to reduced P loading was by no means surprising - especially considering the long legacy of mis-use laying down P in the sediments and thus maintaining the potential for the release of phosphate ions from these deposits. Nevertheless, it was thought that the current situation as regards the total P loading and the main sources of this nutrient, should be re-assessed. After all, a decade had elapsed since the first study was completed.

1.2 Aims and scope of the study

The main objectives of the new study were as follows:

- to assess the total phosphorus loading and the inputs of the particulate and soluble fractions, to the loch for the calendar year 1995; this has been undertaken, although the actual period of study was 26.1.95 to 29.1 96. It will be termed '1995' in this report.
- to distiguish between the various contributions to the total loading, by means of chemical sampling at 19 sites, on some 12 of which flow data will also be gathered; this has been achieved.
- to prepare a short summary of the analytical results by 31 March 1995; this was submitted on schedule.
- to prepare a draft final report of the findings, including comparisons with the P loading study of 1985/86, by 28 Feb 1996, and the final version by 31 March 1996; this deadline was not met - principally because the contract funding barely covered the costs of field and laboratory work; this was recognised by both parties, and a revised schedule culminated in the production of the present draft final report in mid-December 1996.
- to prepare outlines of manuscripts for publication in internationally-refereed journals, by 31 March 1996; though late, draft notes for manuscripts have been prepared and the following paper is in press: Foy R H and Bailey-Watts A E (1996). Observations on the spatial and temporal variation in the phosphorus status of lakes in the British Isles. *Soil Use and Management*.

2. SAMPLING METHODS WITH SPECIAL REFERENCE TO PROCEDURES CONTRASTING WITH THOSE ADOPTED IN 1985

2.1 General issues

The new project adopted most of the approaches followed in 1985. However, chemical sampling commenced on 26 January 1995, following (i) a re-inspection of the 1985 sampling sites, (ii) modification to the programme following e.g. diversion of all Kinross South sewage to the North works, and (iii) instalment of new staff gauges. The new programme also includes a sub-catchment in the upper South Queich drainage area which was not assessed as a separate entity in 1985/86. In addition, the 1995 campaign was executed in parallel with a project led by the (former) Forth River Purification Board focusing on P inputs in storm events, although no data have been forthcoming at the time of writing. Such phenomena are often 'missed' in schedules of regularly spaced sampling such as the 8-daily one adopted here. The Board was also responsible for the sampling programme aimed at assessing P loadings derived from the STWs.

Loch water level was recorded by IFE at a staff gauge in the harbour at Kinross - although that gauge was not levelled until well into the year's study. The Leven Trustees also recorded the level at the sluices.

A single determination of the following was made on each of two samples collected at each field site: total phosphorus (TP), total soluble P (TSP, which approximates to 'dissolved organic' P) and SRP (soluble reactive P). Dissolved silica (SiO_2 or soluble reactive silica - SRS), and nitrate-nitrogen (NO_3-N) were also measured but the information on these is not reported here. Data were logged, analysed and interpreted as in the earlier study, but they are presented in keeping with much-improved typescript and computer graphic facilities.

The 1995 'campaign' differed from the 1985 programme in the following ways:

- no new AQC exercise was carried out - since the two laboratories involved have already compared results to this end.
- as the mill contributes basically no P to the loch, its existence is virtually ignored in this report.
- a number of small watercourses e.g. on the north-east side of the catchment have not been gauged or sampled; their contributions to the hydraulic and phosphorus budgets have been calculated from the 1985 figures - corrected for the lower rainfall in 1995 and assuming a linear relationship between rainfall and the runoff of both water and P from the catchment.
- a similar approach to that described for the small ditches etc., has been adopted for assessing the inputs of P in rain falling directly on the loch surface.
- the inputs of P due to overwintering geese are assumed to be the same as those calculated for 1985.

2.2 Major river and stream sites

Figure 1 and **Table 1** indicate the overall sampling coverage and the points at which water discharge was also gauged. By adopting the sampling coverage indicated, all of the water entering the loch is accounted for.

Table 1. Proposed division of labour with respect to the project sampling programmes.

Loading source	Chemical sampling site	Flow gauging or recording
STW (FRPB	KINROSS NORTH	
	MILNATHORT	
CATCHMENT	S.QUEICH	RECORDER
STORM	N.QUEICH	RECORDER
EVENTS (FRPB)*	GAIRNEY WATER	RECORDER
	POW BURN	RECORDER
S.QUEICH	THE HECKS - Sa	neither
	QUEICH BRIDGE - Sc	RECORDER
	CARNBO - Se	STAFF GAUGE
N.QUEICH	BELOW BURGHER BRIDGE - Na	neither
	ABOVE BURGHER BRIDGE - Nb	neither
	LATHRO - Ne	RECORDER
FOCHY BURN	MILNATHORT - Nf	STAFF GAUGE
HATTON BURN	NEAR OLD RAILWAY BRIDGE - Nh	STAFF GAUGE
URY BURN	BEHIND WILLIE WILSON'S HOUSE - Ua	STAFF GAUGE
GAIRNEY WATER	GAIRNEY BRIDGE - Gb	STAFF GAUGE
	CARSEGOUR BRIDGE - Gc	STAFF GAUGE
BOG BURN	AT MAIN ROAD - Gu	neither
CAMEL BURN	BELOW FISH PONDS - Ca	neither
	LOTHRIES BRIDGE - Cc; re-sited to beside Tarhill	STAFF GAUGE
	FISH PONDS OUTFALL - Cp	neither
POW BURN	POWMILL - Pb	RECORDER
KINNESSWOOD BURN	GRAHAMSTONE FIELD DRAIN PUMP SITE - Kb; re-sited *ca* 200m upstream	STAFF GAUGE
	IN KINNESSWOOD - Kc	BUCKET
LOCH LEVEN	AT SLUICES - L	RECORDER

* no data available at the time of writing

2.3 Point sources of phosphorus (effluent from sewage treatment works - STWs)

A total of 3 works serve the towns of Kinross and Milnathort and the village of Kinnesswood. These are as follows:

(i) Kinross North STW is a modern works utilising an oxidation ditch and clarifier. It now serves an estimated population of 7,000 (*cf* 3,200 in 1985) and discharges directly into the loch at a point on the west side. The effluent from the former Kinross South septic tank which provided rudimentary treatment, and served an estimated population of 2,100 and discharged to the loch just south of the South Queich, has been completely diverted to the Kinross North works.

(ii) Milnathort STW is in the process of upgrading from the percolating filter arrangement serving an estimated population of 1,950 in 1985 to a facility including P-stripping and serving 1,225 people in 1995. The effluent still discharges to the North Queich between sampling sites Nb and Ne on that river, but the considerable 'clean-up' achieved by September 1996 is reflected very strongly in the stream P levels (see below).

(iii) Kinnesswood STW is a percolating filter works now serving an estimated population of *ca* 500, which is some 10% less than the figure estimated in 1985. It still discharges to the loch *via* a small ditch on the N.E. shore, but the effluent is soon to be diverted completely out of the catchment.

All these works serve combined sewerage systems. This means that foul sewage and surface water are carried by one sewer. The population figures quoted above were supplied by the Water Services Department of Tayside Regional Council.

2.4 Diffuse sources of phosphorus

2.4.1 Phosphorus inputs to the loch from land runoff

Assessment of diffuse losses of P from the land was approached as comprehensively in 1995 as it was in 1985. However, **Table 2** gives details on a number of differences between the two studies

2.4.2 Sediments

No new information on sediment P levels was obtained during 1995, but in contrast to 1985 during which rather little net releases of P from the sediments were evident, 1995 saw appreciable, though short-lived, recycling of phosphate. A quasi-quantitative assessment of the effects of this on the P budget of the loch is therefore attempted.

2.5 The loch and its outflow

In common with the 1985 programme, the main in-lake site sampled as part of the P loading study is located at the outflow (sluices). However, data generated jointly by IFE and the former FRPB enabled some attention to be paid also to open water stations.

Table 2: The sites sampled during 1995 for assessing runoff P losses: detailed information on factors influencing the selection of the sites, and interpretation of the data generated from them.

Ca: Camel Burn mouth	No direct measure of flow possible owing to discharge to the burn of a variable mixture of pumped loch water and borehole water passing through the fish-rearing ponds. Loadings are therefore calculated using three 'assumed' annual mean flows of 0.15, 0.10 and 0.05 cumecs - judged to be representative of the actual flow conditions. The loading value used in the final reckoning is based on 0.10 cumecs. The figure for the total annual discharge is taken as 2.24 M m^3, being halfway between 1.33 for Cc and 3.15 for the 0.10 cumecs scenario. This goes towards compensating for the re-cycled loch water.
Cc: Camel Burn. Originally situated at Lothries bridge, this site was repositioned downstream to behind Tarhill farm .	Although reckoned to be an unreliable site for flow gauging owing to extensive weed growth, flows for the even more unreliable site Kb are obtained partly by correlation with Cc .
Gb: Gairney Water, at Gairney Bridge .	Possibly affected by backwash from the loch but otherwise a straightforward site .
Gc: Gairney Water, Carsegour Bridge .	Quite weedy but otherwise straightforward .
Kc: Kinnesswood Burn (in the village) .	The very small burn is channelled in a ceramic conduit. Flow is estimated by timing the filling of a bucket with water from this source.
Kb: Kinnesswood Burn, Grahamstone farm. This site was moved some 200m upstream from its original position to avoid backwash from the loch and the influence of a pumped field-drain discharge. The site had to be repositioned again when the channel was dredged by the farm .	A very awkward site to gauge on account of extensive weed growth , low flows and very soft bottom sediment . Receives treated effluent from Kinnesswood STW at some point upstream .
L: The loch outflow, at the sluices .	Daily mean discharge and water level data supplied by the Loch Leven Board of Trustees *via* Tullis Russell & Co. Ltd. P export is calculated from the 47, 8-daily mean discharges on the day of sampling.
Ne: North Queich, at SEPA continuous gauging station at Lathro Farm.	Farming operations on 11.2.95 produced artificially high levels of particulate P at this site; this raised the total P level to 404 ug l^{-1} - out of all proportion to the flow at the time. As this 'pulse' of material did not reach site Nb downstream, it was felt justified to replace the very high P value with one of 30ug l^{-1} that reflected the prevailing flow and soluble P levels. The TP loading of 1,103 kg obtained from the measured concentration values is thus discarded in favour of a figure of 950 kg obtained by the substitution of the lower TP concentration for this one occasion.
Nf: Fochy/Back Burn, Milnathort.	Not a perfect site, but quite straightforward.
Nh: Hatton/Burleigh Burn, near former railway bridge.	Some problems with very low flows due to wide, shallow nature of the channel. Low flow values have been altered to give meaningful figures.

Nb: North Queich, a few metres upstream of its confluence with the Hatton.	This site is below the outfall of both Milnathort old and new STWs. As no flow data were available from the old works, a loading was estimated from the difference between the value obtained at this site and the sum of the values measured at Ne and Nf upstream . The value obtained - 659kg TP - corresponds reasonably well with the figure of 560kg derived from the mean spot sample TP concentration of 6.346mg l^{-1} and an assumed flow of 300 litres/person/day for 1,225 people over the 240 days of operation in this study. A similar exercise for the period 23.9.95 to the end of the study, concerning the new works, yielded a figure of 130kg TP. These values may be revised if more detailed flow/ effluent concentration data become available. (The quoted figure for the discharge at Nb includes the 300 litres/person/day).
Na: North Queich , below Burgher Bridge	Sampled some 100m below the outfall of the new works at Milnathort - in that the water would be better mixed there than at Nb, although reputedly prone to occasional backwash from the loch.
Pb: Pow/Green's Burn, at the new SEPA continuous gauging station at Powmill.	Straightforward site.
Sa: South Queich, at the 'Hecks' (just upstream of the former footbridge from the old railway station).	Sampled to see if there is any increase in P below the woollen mill .
Sc: South Queich, at the SEPA continuous gauging station , Queich Bridge, Kinross.	Straightforward site .
Se: South Queich, at Carnbo Bridge.	Sampled to give an indication of 'background' P levels, with little or no input from agriculture etc.
Ua: Ury Burn, Kinross Golf Course, behind Willie Wilson's house.	A generally very slow flowing stream, little more than a ditch, probably strongly influenced by backwash from the loch.

3. LABORATORY AND DATA ANALYTICAL METHODS

With very few, minor exceptions, the procedures and practices used for field sampling, laboratory analysis, and the analysis of the resulting data in 1995, were the same as those adopted in 1985 and described in the 1987 report. Apart from aspects such as AQC tests and sediment sampling which were not carried out in 1995, the sections on laboratory and data analytical methods in the 1985 report are repeated here for completeness.

3.1 Derivation of river height-discharge relationships (rating curves)

All the river sites relied upon the calibration of channel sections to derive a height-discharge relationship. These were produced by combining current meter gaugings over a range of flows by means of an iterative best-fit algorithm. This assumes a relationship between discharge (Q) and water level (H) of the following type for each calibration:

$$\mathbf{Q = b\ (H + a)}$$

The programme assumes a value for **a** and calculates **b** for a best fit line. The standard error of the mean relationship is calculated for the line produced and another value of **a** is chosen and the process repeated. The new standard error is compared to the previous one and the next value of **a** is chosen so as to optimise the standard error. When the standard error is at a minimum the final equation is produced.

The value of the optimised standard error is used as a guide to the need for more current metering at a particular site. In general the standard error of the mean relationship is accepted if it is less than 1.0; permanent river gauges are usually calibrated to a standard well above this. If the error is greater than 1.0, more gaugings are required to produce a useable calibration.

3.2 Chemical analytical methods

3.2.1 Routine phosphorus analyses

Phosphorus determinations on all stream waters and the loch (outflow), commenced within one hour of collecting samples at the last site on the sampling tour (total time 4 to 5 hours). Bailey-Watts (1986) and Bailey-Watts *et al* (1987) outline the analytical methods based on the spectrophotometric procedures described by Murphy and Riley (1962). Total amounts of P (TP), and the total soluble fraction (TSP) were each analysed in addition to the soluble reactive fraction (SRP). Unfiltered subsamples were used for TP and filtered subsamples for TSP and SRP. Concentrations of particulate phosphorus (PP) and soluble unreactive ('dissolved organic') P (SURP) were calculated according to:

PP = TP - TSP and SURP = TSP - SRP.

Analytical methods used by SEPA for determining P levels in sewage were similar to those used by IFE for the other waters. However, only TP and SRP were determined on the effluents. This is unfortunate in that the proportions of the three main components of total P i.e. SRP, PP and SURP, cannot be established for the effluents, although their effects can be assessed from IFE's analyses of stream samples taken above and below the discharge points.

3.2.2 Phytoplankton species composition and abundance

Plankton, concentrated by sedimentation after fixing with Lugol's iodine, has been examined and counted in order to estimate the population densities of the different species. Bailey-Watts and Wiltshire (1996) give details, and cite the taxonomic literature consulted for identification of the algae recorded in 1995.

Chlorophyll$_a$ concentration was used as an index of total algal biomass. For this purpose, the pigment was extracted with 90% methanol from phytoplankton concentrated by filtration onto Whatman GF/C glass-fibre discs. The equation proposed by Talling and Driver (1963) was used to convert spectrophotometric absorbances to concentrations of chlorophyll$_a$. No corrections were made for the presence of breakdown products of this pigment - such as pheophytins which could absorb light at wavelengths similar to the 665nm at which the reading for chlorophyll$_a$ is taken.

3.3 The calculation of phosphorus loadings

3.3.1 River and stream systems

The seasonal information developed from the 8-day records of stream discharges (Q) and P concentrations ([P]) as described in earlier sections, allow instantaneous loadings of P in runoff (PL_{ir}) to be calculated, i.e.:

$$\mathbf{Q \times [P] = PL_{\mathit{ir}}}$$

The mean loading over the year is the average of 47 instantaneous products corresponding to samplings carried out between 26 January 1995 to 29 January 1996 - although one value in December 1996 is linear interpolation as very severe weather and a vehicle breakdown prevented sampling.

As already demonstrated, loading data of this type were obtained for water courses draining 88% of the total catchment area, while the loadings from the remaining 12% were calculated assuming a loss of P per unit area of land the same as that estimated for the Pow Burn catchment.

Mathematical relationships between flows and measured concentrations, and thus loadings, of P were used to generate loadings for times at which only flow data were available. For the inflow sites Nd, Pc and Sc (**Figure 1**) for which flows were recorded every day at ½-hourly intervals, 'continuous' P loadings were generated in this way. The areas drained by these three systems together constitute 48% of the total catchment. Similar, daily, loading values were derived for three other sites - Gb, Nh and Ua. As flows, measured at the instant of sampling every 8 days at these sites, were highly correlated with those measured at one or other of the sites for which continuous flows were available, daily flows were generated. Daily P loadings were derived as before. The three additional sites together drain 28% of the total watershed. Thus, 'continuous' and 'instantaneous' loading information is available for water courses draining some 76% of the Loch Leven catchment. In calculating the annual P loadings based on the derived daily values, the corrections proposed by Ferguson (1986) were made. The continuous values probably provide the better indications of P loading, as the 8-day figures are likely to 'miss' important, short-lived. episodes of high flows, or spells of low flows - leading to under- or over-estimation of loadings respectively (see e.g. Smith and Stewart 1977).

3.3.2 Point-sources (sewage treatment works)

Sampling schedules for estimating the outputs of P from STWs were supplied by SEPA. These amount to 15, 24-hour composite samples taken from the Kinross works within the period of study. A further 4 sets of similar data from March to April 1996 were provided as estimates of the situation prevailing at the new Milnathort works.

Loadings (L, in e.g. mg P d^{-1} i.e. the products of concentration C, in mg P l^{-1} and mean flow Q, in l s^{-1}) from the STWs were calculated for each 24-h period covered by a sample, as follows:

$$\mathbf{L = C \times Q \times 0.0864}$$

There was no opportunity for generating 'continuous' loading figures for these point-sources; this is because, in contrast to the stream systems, there was little relationship between loading and flow from which to derive the continuous loading figures.

3.3.3 falling on the loch surface

As already indicated the (relatively minor) amounts of P introduced to the loch in precipitation were estimated on the assumption that the P *concentration* is the same as that measured in 1985 i.e. 25μg TP l^{-1} and 12μg SRP l^{-1}.

3.3.4 Wildfowl

The likely relatively minor amounts of P brought into the loch by over-wintering geese are assumed to be the same as those presented in the 1985 report.

3.3.5 Contributions from all sources - the total loading

The P contributions from all sources were summed to give an estimate of the total loading. Of greater significance, however, is how the contributions compared: only after this is established, can (further) sensible P control or other eutrophication reversal strategies be identified.

3.4 The calculation of losses of phosphorus *via* the outflow

Instantaneous values for the rate of export of P from loch *via* its outflow, were estimated from the 47 products of the P concentration and the mean discharge on the day of chemical sampling. In contrast to the majority of the stream sites, there was little relationship between P concentration and flow, or between loading and flow in the outflow. 'Continuous' export estimates of the type discussed in relation to the inflows (i.e. daily values over the year) can thus be calculated only by assuming linear changes in flow and P concentrations between each 8-day sampling interval. As such, this would give the same result as those derived from the 47 products of instantaneous rates of loss of water passing out of the loch, and the P concentrations in the water.

Loch Leven is characteristically generally well-mixed with regard to both particulate and dissolved matter. However, while this seemed to be certainly the case in 1985, 1995 manifested patchy distributions of gas-vacuolate cyanobacteria - especially during calm weather. Where dense aggregations formed near the outflow, samples at these times can obviously be viewed as over-estimates of the lake wide population. Such phenomena will therefore affect the interpretation of outflow losses and such parameters as P retention coefficients derived from them.

4. RESULTS

4.1 Issues of general relevance to the interpretation of the results

In addition to presenting the results for 1995, this project is mandated to compare the latest results with those obtained in 1985. The comparisons of main interest are concerned with the P loadings, and with the state of the loch itself as regards water quality parameters such as clarity and phytoplankton abundance as well as wider issues (not dealt with here) including macrophyte cover and invertebrate diversity. However, in interpreting any similarity with, or contrast between the two years in terms of the P loading *per se*, it is necessary to consider other influences. Of major significance are environmental factors other than those relating directly to the strategies adopted for reducing P inputs to the loch - as these affect P loadings and the extent to which the nutrient is sequestered by algae, and the degree to which the algal production is manifested as biomass ('blooms').

These considerations are especially important in the context of Loch Leven, because of the extreme inter-annual variability in the functioning of this waterbody. As examples, **Figures 2-4** use data on three main 'driving' variables - rainfall, loch water level, and an indication of the wind regime. Rainfall is likely to be reflected in the rates of input of water, particulates and solutes to the loch (and thus runoff, and the dilution of point-source nutrients), while rain in combination with water level changes will determine flushing rates and thus the rates of washout of planktonic algae, for example. In addition, wind determines water mixing patterns, the nature and extent of the fluxes of nutrients between the sediments and the overlying water - and the all-important conditions determining the success or otherwise of potentially toxic cyanobacteria to form surface scums. Bailey-Watts *et al* (1990, 1994) and Bailey-Watts and Wiltshire (1996) discuss many of these aspects and some of their impact on the sport fishery.

1985 was much wetter than 1995 (with 1250mm rainfall as against only 888mm), and especially so over the period for approximately 1 August to the end of September (Figure 2). Still, months such as February and October were much wetter in 1995. These contrasts are partially reflected in the differing patterns of change in loch level (Figure 3). In addition, however, the level of the loch fell more or less continually for a considerable part of 1995, i.e. from late February to mid-October, while the pattern in 1985 was one more regularly characterised by alternating increases and decreases in level. While a single daily recording of wind force may be an ideal description of wind conditions at the loch, the contrasting seasonal patterns shown in Figure 4 tend to 'tally' with what might be expected, given the information on rainfall. However, while the lack of any wind indicated for the latter part of June 1995 is a reasonable indicator of the prevailing conditions the lack of wind suggested for the first half of June 1985 corresponds to a period when no recordings were made.

4.2 Water volumes

4.2.1 River and stream inputs

Even the instantaneous flows (n = 47) of many of the feeder waters ranged over 1 to 2 orders of magnitude, and the mean values of this set of streams also varied to this extent i.e. from *ca* 0.02-1.07 $m^3 s^{-1}$ (**Figure 5**). Somewhat higher flows were recorded in 1985 i.e. means of 0.02-1.50 $m^3 s^{-1}$ and this is in keeping with the lower rainfall in 1995. As in 1985, the three largest inflows i.e. the South Queich (mean discharge 1.07 $m^3 s^{-1}$ at Sc), the North Queich (0.99 $m^3 s^{-1}$ at Ne) and the Gairney Water (0.76 $m^3 s^{-1}$ at Gb) constitute some 88% of the total water input from the land. The Pow Burn (0.004 $m^3 s^{-1}$ at Pb) adds just 4% to this. The total volume of water discharged to the loch from all of these gauged sites is 98.4 x 10^6 m^3 (**Table 3** gives details).

Table 3: Mean flow rates of stream sites gauged directly or by correlation with a gauged site; the total discharge is calculated from the sum of the values in bold type.

Site	Q ($l\ s^{-1}$) 1995	Total annual discharge ($m^3 \times 10^{-6}$)
Ne	630	20.1
Nf	243	7.7
Nh	114	3.6
Nb + MSTW	878	27.9
Na + MSTW	**993**	**31.6**
Se	333	10.6
Sc/Sa	**1070**	**34.0**
Gc	374	11.9
Gb	**796**	**25.3**
Pb	**129**	**4.1**
Cc	**41.9**	**1.3***
Ca	**100 assumed**	**3.2***
Kc	4.2	0.1
Kb	**27.5**	**0.9**
Ua	**20.1**	**0.5**

The total discharge from the sites that were flow-gauged (either directly, or indirectly by correlation with another site) i.e. Na, Sa, Gb, Pb, Ua and Kb, plus the 2.25 x 10^6 m^3 (being the mean of the two values asterisked in the Table) is:

98.4 x 10^6 m^3

The area of catchment from which this water was derived is 123 km^2 - leaving an ungauged area of 22 km^2. For completeness, the discharge from this small area has been calculated by assuming that the runoff of water per unit area of land is the same as that measured for the Pow Burn. This approach seems sensible in that the ungauged zones extend little from the loch itself - as does the Pow sub-catchment itself (at least, compared to the Queichs and the Gairney, for example). This approach results in an additional discharge of 8.7 x 10^6 m^3 - giving a total input of:

107 x 10^6 m^3

As another reflection of the lower rainfall in 1995, this input is somewhat lower than the 1985 value of 124.5 x 10^6 m^3 and the figure of 120.7 x 10^6 m^3 derived by Smith (1974).

There is cause to be reasonably confident in these figures bearing in mind the close correspondence between these discharge values and those that can be calculated for the three main stream sites for which ½-hourly level (and thus flow) data are available (**Table 4**).

Table 4: Annual discharges from the North and South Queichs and the Pow Burn in 1995: the results of three calculations compared.

watercourse	N. Queich	Pow Burn	S. Queich
annual discharge (x 10^{-6} m^3) calculated from 365 daily mean values each based on 48 ½-hourly readings	21.37	4.65	29.98
annual discharge (x 10^{-6} m^3) calculated from 47 values on the day of sampling and derived from 48 ½-hourly readings	20.14	4.35	27.73
annual discharge (x 10^{-6} m^3) calculated from 47 values on the day of sampling and derived from a single flow reading at the instant of sampling	20.05	4.10	34.04

The close correspondence between the different sets of results does not imply that continuous flow gauging operations can be dispensed with. Indeed, the agreement in the data is a chance one; some of the calculations of mean flows based on other 8-day sampling schedules, that is commencing on e.g. 27 January, 28 January and so on, instead of 26 January as in the case of this study, produced values that do not match as well with those based on the (365) daily records; examples are values of between 16.9 x 10^{-6} m^3 and 25.1 x 10^{-6} m^3 - as compared with the value of 20.14 x 10^{-6} m^3 in the previous Table - that would have been generated if the first sample on the North Queich had been taken on a day other than the 26 January.

Table 5: Examples of the varying degree to which flow regimes of streams in the Loch Leven catchment parallel one another.

y	m	x	c	coefficient of determination (r^2)
Q_{Sc}	0.6122	Q_{Gb}	+0.0004	0.8736
Q_{Pb}	0.8768	Q_{Nn}	-0.1917	0.7580
Q_{Ne}	0.9510	Q_{Ua}	-1.6076	0.6064

Regardless of size, the inflows exhibited similar seasonal patterns of variation in water discharge (**Figure 6**). **Table 5** shows that while the general seasonal patterns of flow in one stream is similar to those in other water courses, the actual degree of similarity varies. As examples, 87% of the variation in flow at site pm the South Queich is associated with the variation in flow recorded at site Gb on the Gairney Water. On the other hand the coefficients of variation obtained from relating flows at Ne on the North Queich and the much smaller Ury Burn (Ua) amount to only 60%.

4.2.2 Point-source effluents

The volumes of point-source effluents were small in comparison to the 'natural' inflows. The mean rates of discharge from the largest works (Kinross North) was 27 $l\ s^{-1}$, compared with 7.6 $l\ s^{-1}$ from the new Milnathort system and a low flow estimate of 1.5 $l\ s^{-1}$ and a high flow value of 2.6 $l\ s^{-1}$ from Kinnesswood. To put these into context, the mean flow of the smallest 'natural' feeder stream (the Ury Burn) was *ca* 20 $l\ s^{-1}$).

4.2.3 Rain falling on the loch surface

One millimetre of water falling over a square metre is equivalent to 1 litre. So, the 1995 rainfall of 888mm (*cf* 1250 mm in 1985) over the loch surface 13.3 km^2 (i.e 13.3 x $10^6 m^2$) gives a volume of 11.8 x 10^6 m^3 (*cf* the 16.6 x 10^6 m^3 that fell in 1985). This input, not corrected for losses in evaporation, is equivalent to nearly one-tenth of the total run-off (a net input) and one-quarter of the mean loch volume (see below). Corrected for evaporation (420mm x 1.2) the net volume of rainwater amounts to 5.1 x 10^6 m^3 (as compared with 9.93 x 10^6 m^3 in 1985).

4.2.4 The total input of water

From the calculated values given above for gauged runoff, derived (ungauged) runoff and evaporation-corrected rain, the total input of water in 1995 was [98.4 + 8.7 + 5.1] x 10^6 m^3, or 112 x 10^6 m^3.

4.2.5 The loch

The volume of the loch at the modal water level is taken as 52.4 x 10^6 m^3 - as calculated by Smith (1974). However, in view of the somewhat peculiar water throughput regime in 1995 with a fall in surface water level over much of the year, there may be arguments for considering the loch as being say, 0.5m less than the usually accepted depth of 3.9m.

4.2.6 The outflow

The mean rate of export of water from the loch *via* the outflow, estimated from the mean daily flows on each of the 47 sampling days, was 4.7 $m^3\ s^{-1}$. This is equivalent to 148 x 10^6 m^3 for the whole year. This is appreciably more than the 131 x 10^6 m^3 measured in 1985. It is also larger than the net input of water in 1995; this is in keeping with the overall fall in water level referred to above.

4.3 Water chemistry with special reference to phosphorus

4.3.1 Feeder streams above sewage outfalls

(a) phosphorus concentrations

Concentrations of TP at feeder water sites above discharges of treated sewage ranged overall from <10μg P l^{-1} to *ca* 400μg P l^{-1} (**Figure 7**). The sites fall into two groups on the basis of annual mean concentrations. One group comprises sites Pb (Pow Burn), Nh (Hatton Burn), Gu (a small tributary of the Gairney Water) and Ua (the Ury Burn). All of these reflect their reasonably intensively managed agricultural catchments. Note too, that two of these areas generate annual mean TP levels that exceed that calculated for the loch itself. The second set of sites grouped on the basis of the annual TP concentration include those receiving runoff from generally less-rich areas. Examples are upper reaches of Gairney Water (Gb, Gc) and the South Queich - especially the far upper area (Se), and as low as a few tens of metres above the point at which mill effluent used to enter the stream.

Figure 8 shows the fluctuations in streams ranging from the small, upper stretch of the South Queich to the larger channels such as Gairney. Note that for most of the year, the TP levels in the loch (included in Figure 8) exceed most of the values in these streams which are not affected by sewage etc. Sampling sites that feature in Figures 6 and 8 also show the considerable differences that can occur in TP levels between the different streams, in spite of the general similarity in seasonal patterns of stream flow.

(b) variation in the contributions of soluble and particulate fractions of phosphorus from the land

It is important to consider the proportions of soluble and particulate components of the total P, because while virtually all fractions of P may eventually be utilised by algae, SRP is considered to represent the nutrient pool most immediately available for uptake (Kuhl 1974, Jordan in Smith 1983, and Bailey-Watts, Kirika and Howell 1990 for general considerations; Stewart and Alexander 1971 for Lough Neagh; and Bailey-Watts 1988 and Bailey-Watts, Kirika and Hakansson 1994 for Loch Leven). Knowledge of the composition of the P is also important, because the fractions differ in (i) concentrations and their seasonal changes, (ii) loadings, (iii) the relationships between concentrations, loadings and flow, and (iv) susceptibility to run-off from land. For present purposes it is sufficient to demonstrate that the waters feeding Loch Leven varied in their composition.

Table 6: The average percentage contributions of the three operationally defined fractions of phosphorus to the total levels in feeder streams unaffected by point-source inputs; data for the loch itself are also included for comparison.

site	**Cc**	**Gb**	**Gc**	**Gu**	**Kc**
mean%PP	33.1	33.9	36.9	15.6	45.9
mean%SRP	51.6	44.8	44.1	65.4	43.4
mean%SURP	15.3	21.2	19.0	19.0	10.8
site	**Ne**	**Ne(altered)***	**Nf**	**Nh**	**Pb**
mean%PP	50.0	31.9	26.1	18.9	35.1
mean%SRP	34.0	46.3	58.7	66.5	54.7
mean%SURP	16.0	21.7	15.1	14.6	10.1
site	**Sa**	**Sc**	**Se**	**Ua**	**the loch**
mean%PP	40.9	43.8	27.1	22.4	50.3
mean%SRP	29.4	34.9	45.8	67.6	31.4
mean%SURP	29.7	21.3	27.1	10.0	18.3

* these values differ from those given for Ne in assuming P levels commensurate with the prevailing flow regime, rather than the high inputs of P resulting from digging operations.

Table 6 illustrates the variation in the relative contributions of particulate and soluble P fractions to the total P levels in streams unaffected by sewage or other point-source effluents; data for the loch are also shown for comparison.

The Table suggests that the drainage areas of the Ury Burn (Ua), and parts of the Gairney (Gu) and the Halton Burn (Nh, in the North Queich) and yielding relatively substantial amounts of SRP (i.e. with values approximating to 66%). In contrast, corresponding values of half approximately this percentage have been obtained for the upper North Queich setting aside the effects of digging operations, and the lower reaches of the South Queich (Sa and Sc) although not the upper reach of this stream at Se. The Table also highlights the systems relatively laden with particles e.g. at Kc (on the Kinnesswood Burn), Ne (on the North Queich) -with values of *ca* 50% like that calculated for the loch itself). By the same token, it is plain that the stream entering the Gairney Water (at site Gu), the Halton Burn (Nh) are much clearer waters.

(c) phosphorus concentration-flow relationships in stream reaches unaffected by sewage and other phosphorus outfalls

Total P levels generally increased with stream flow (**Figure 9**), but in most cases, not in a consistent manner -even bearing in mind that the stream stretches featured in Figure 9 are classed as unaffected by point-source inputs of P which could be expected to influence the P concentration-flow relationship (see below). Coefficients of determination from linear correlations are thus too low to be of any significant predictive value. The 5 examples to which the data in Figure 9 relate suggest the following degrees to which variation in flows is associated with variation in TP level: only 6% for site Gb on the Gairney, 20% at Se on the South Queich but contrasting by 47% at Ne on the North Queich, 48% on Ury Burn at Sa and 57% on the South Queich at Sc. To illustrate, however, the enormous effect of even a single wide outlying value in such data sets, the coefficient of variation (r^2) value increases to 0.67 i.e. 67% from the 47% quoted above for Ne if the data points giving high P levels as a result of digging operations is omitted from the analysis.

4.3.2 Point-source effluents

(a) Phosphorus concentrations

Phosphorus concentrations in the point-source effluents entering the Loch Leven system, were extremely high, being more commonly expressed in mg l^{-1} *cf* $\mu g\ l^{-1}$ in run-off waters. As examples, the TP levels based on the 24-hour composite samples taken from the the new Milnathort STW effluent contained typically 0.2-1.4mg TP l^{-1} and 0.2-1.3mg SRP l^{-1}. As a consequence, P concentrations were considerably elevated in the receiving North Queich (**Figure 10a**). Only on the single occasion when soil washed into the North Queich at site Ne as a consequence of digging operations (referred to above) did TP levels above the works exceed the levels measured below the works. Once this STW had been upgraded with P removal facilities, however, a quite different situation was established, not least, with a considerable reduction in P levels to concentrations only marginally higher than those measured upstream of the STW.

(b)Variation in the contributions of soluble and particulate fractions of phosphorus in streams/stretches receiving STW effluent

Table 7 features information on the annual mean percentage contributions of the different forms of TP to TP levels at the three sampling sites known to receive STW effluent. The %SRP values are much higher at these stations than at those referred to in Table 6. The Kinnesswood Burn (Kb) is extremely rich in SRP (88%), and the values for the lower-most pair of sites on the North Queich (Nb, Na) approximated to 75% SRP. In contrast, Camel Burn water containing effluent from the fish ponds had average %SRP levels of only 43%.

(c) Phosphorus concentration-flow relationships in stream stretches receiving STW effluent

Inputs of high concentration and essentially low volume STW effluent also effect changes in the relationship between nutrient concentration and flow. For example, upriver of the outfall of the Milnathort STW effluent on the North Queich, TP concentration was very plainly positively correlated with flow, while downstream of the input the (commonly higher) concentrations of TP generally declined with increasing flow (**Figure 10b**).

Table 7: The average percentage contributions of the three operationally defined fractions of phosphorus to the total levels in feeder streams receiving sewage effluent.

site	Kb	Na	Nb
mean%PP	9	15	18
mean%SRP	88	77	74
mean%SURP	3	8	8

4.3.3 The loch and its outflow

The gross patterns of change in TP concentrations in 1995 are somewhat similar to those recorded in 1985 - especially up to mid-July (11a). This is of particular note bearing in mind the generally 'capricious' nature of Loch Leven (e.g. Bailey-Watts and Kirika, 1993; Bailey-Watts *et al.*, 1990; Bailey-Watts, 1974), and the differing seasonal regimes between 1995 and 1985 as regards hydraulic flushing and rainfall and water level. However, TP levels fluctuated somewhat differently in the second half of 1995, compared to the last six months of 1985. The major difference relates to the mid-July to mid-August period, with the 1995 exhibiting a very much higher TP maximum than 1985. That this contrast was due primarily to the release of phosphate ions detected as SRP, is plain from the plots in Figure 11b. TP levels in 1995 varied some 20-fold from *ca* 12 to 150 μg P l^{-1} about a mean value of 64 μg l^{-1}, while in 1985 they ranged much less -from 30 to 130 μg l^{-1} about a similar mean, i.e. of 63 μg l^{-1}. The mean SRP level in 1995 was 19 μg l^{-1}, with a minimum of *ca* 2 μg l^{-1} and a maximum of 106 μg l^{-1}. The mean and maximum values measured in 1985 were somewhat less i.e. 9 and 40 μg l^{-1}, while the minimum value was also *ca* 2 μg l^{-1}.

4.4 Phosphorus loadings (L) and related issues

4.4.1 Loadings in runoff and in the effluent from STWs discharging to streams

Table 8 provides information on the amounts of total P and the different P fractions entering the loch in runoff from the land, *and* in effluent from the STWs discharging to the streams i.e. Milnathort and Kinnesswood.

Table 8: The loadings to Loch Leven of total P and of the total soluble and soluble reactive fractions in runoff and in effluent from the Milnathort and Kinnesswood STWs; the sums of the asterisked values give the total loadings for each fraction.

Sampling site and additional information		inflow ($x\ 10^{-6}\ m^3\ y^{-1}$)		kg TP	kg TSP	kg SRP
***Ca: Camel Burn Mouth:** three assumed scenarios (due to fishpond effluent pipe) for annual mean flow: 0.15, 0.10 and 0.05 $m^3\ s^{-1}$		(i) 4.73 (ii) 3.15 (iii) 1.58		393 262* 131	227 152* 76	167 111* 56
Ca: Camel Burn (unreliable?)		1.33		72	45	33
***Gb:** Gairney Bridge		25.3		817*	478*	302*
Gc: Gairney - Carsegour Bridge		11.9		427	241	164
Kc: Kinnesswood Village		0.11		2.4	1.1	0.8
***Kb:** Kinnesswood - Grahamstone below STW outfall		0.87		553*	503*	486*
Ne: Nth. Queich Lathro	Includes "pulse" on 11.2.95 Excludes "pulse" on 11.2.95	20.0		1103 950	465 465	303 303
Nf: Fochy		7.74		396	223	170
***Nh:** Hatton		3.64		268*	207*	171*
***Nb:**	(i) Ne + Nf	(i) 27.8	1	2135	1315	1041
	(ii) Ne+Nf+MSTW low flow 1,225 people at 200 l d^{-1} each	(ii) 27.9	2	2145	1324	1049
	(iii) Ne+Nf+MSTW high flow 1225 people at 300 l d^{-1} each	(iii) 27.9	3	2151*	1328*	1053*
Ne + Nf + Nh:	With uncorrected Nh		1	1968	1398	1129
	With corrected Nh	31.4	2	1893	1346	1089
	With corrected Nh + low STW	31.5	3	1903	1355	1097
	With corrected Nh + high STW		4	1908	11359	1101
***Pb:** Powmill		4.10		481*	243*	188*
***Sa:** South Queich at the Hecks		34.0		2444*	1141*	742*
Sc: South Queich at the bridge, Kinross		34.0		2367	1071	731
Se: Carnbo		10.6		165	109	59
***Ua:** Green Hotel Golf Course		0.53		52*	39*	35*

The total P input from these sources is 7,028kg of which 3,088kg (44%) is in the form of SRP, 1,003kg (14%) as SURP (dissolved organic P), leaving 2,937kg (41%) particulate P. The contribution of STW effluent to these inputs is quite considerable: 1,340kg TP (i.e. 19%) including 1,060kg SRP (34%). Unfortunately, the TSP content of the STW effluents were not measured. As a result, it is impossible to estimate the contributions of either this or the particulate fraction to these inputs.

The TP and SRP loadings that can be attributed to runoff (albeit, including material from septic tanks) are thus, 5,688kg and 2,028kg respectively.

4.4.2 Runoff phosphorus loss coefficients

The estimates of the amounts of P running off the various subcatchments, give P loss coefficients. These quotients are of considerable value in extending the existing database on such features, which can be used to improve our ability to predict loadings for lakes where actual measurements are lacking.

The coefficients obtained from the subcatchments unaffected by sewage outfalls are shown in **Table 9**.

Table 9: Phosphorus loss coefficients based on the P losses estimated from a number of subcatchments unaffected by sewage outfalls.

Drainage system	Sub-catchment area (km^2)	Total P loading in 1995 (kg)	Total P loss rate ($kg\ ha^{-1}\ y^{-1}$)
Upper S. Queich	33.80	2767	0.70
Upper N. Queich	26.20	950	0.36
Halton Burn	7.25	268	0.37
Ury Burn	1.73	52	0.30
Fochy Burn	9.55	396	0.42
Gairney Water	30.71	817	0.27
Pow Burn	10.50	481	0.46

The figure of 0.7kg TP $ha^{-1}\ y^{-1}$ appears to be very high - possibly as a consequence of the massive early-year inputs of P referred to above. In contrast - but in keeping with the lower rainfall in 1995 as compared with 1985 - the other coefficients are considerably less than those reported for 1985 by Bailey-Watts and Kirika (1987).

4.4.3 Temporal and spatial variation in P loadings from the land

Seasonal fluctuations in TPL varied between the streams (**Figure 12a, b**), but there were broadly similar patterns of change regardless of size over the range encountered. Examples are the concurrence of peak flows in January, February, June, October, November and December. **Figure 13** develops these data by illustrating the manner in which the eventual annual loadings accrued, and in this case, how they differed in this regard with the situation found in 1985. The Figure uses data for site Sc which lies a few metres upstream of the point at which P-rich effluent used to be discharged from the mill. Results for other sites on this stream produce virtually identical graphs. Indeed, apart from the actual magnitude of the loadings, which differ with water course, the sigmoid curve characterises all sites. In 1995 a considerable proportion of the loading was achieved in late January and early February; this situation plainly contrasts with that found in 1985 in which a large percentage of the annual loading accrued in December.

For present purposes, the P loadings presented so far - and based on the 47 instantaneous flow/P concentration pairs of data - will be retained. However, they will be revised in the light of considerations relating to the derivation of 'continuous' P loadings, as indicated above. As a preliminary step towards improving the present loadings based on the instantaneous, 8-daily sampling values, however, it is worth realising that the two major increases in loading shown in Figure 13 i.e. one of approximately 1t TP in late January, and the other of 0.6t eight days later, assume that the loading-flow regimes measured, apply over the following 8-day sampling intervals. This may be the case where rather little change is apparent from one sampling occasion to another (as in the majority of the sampling intervals included in Figure 13). However, this assumption is unlikely to be correct where especially large changes such as the two identified above, are indicated. As an example of how such data could mislead, the annual TP loading of some 2.4t estimated for the South Queich could be reduced to 1.2t if the periods of high flows and P loadings corresponding to each of the two 8-day periods of concern were each considered to have prevailed for say, only two days.

4.4.4 Runoff loading-flow relationships

From the above remarks, it is essential that an attempt be made to improve on the present loading estimates based on instantaneous 8-daily loading-flow relationships. The prospect of doing this hinges largely on the mathematical relationships found between the instantaneous loadings and the corresponding flows measured/calculated on each of the 47 sampling occasions (see below). As it happens, the relationship between the two variables is very encouraging. A generally very close linear relationship between $\log_{10}$ instantaneous loadings and $\log_{10}$ flow was found for small streams such as the Ury Burn, as well as the larger watercourses e.g. North Queich (**Figure 14**). This is reflected in high coefficients of determination (r^2 values): Ne, 0.959; Gb, 0.823; Ua, 0.913; Sc, 0.938; Pb, 0.770.

4.4.5 Runoff loadings estimated from continuous flow data and derived figures for continuous P loadings (L_{cr}) compared to the values based on the 8-daily, instantaneous flow-P concentration measurements

The final report will attend to the calculation of daily ('continuous') P loadings. This will be done as described in the 1985 report, and suggested elsewhere in this report - by using the loading-flow relationships obtained from the 47, 8-daily samplings, and generating the continuous loadings from the continuous flow data. The results from the two loading assessment methods will be compared.

4.4.6 Point-sources (STWs - L_{sew})

(a) loadings

The following information on the amounts of P derived from the STWs was supplied by SEPA. The Kinross North works (serving 7,000 people) is estimated to have generated 1.7t TP over the year (i.e. 4.8 kg d^{-1}), of which 1.54t (88%) comprises SRP. The corresponding values for the old Milnathort works (1,225 people) - relating to the 240-day period to 23.9.96) are 0.6t TP (2.8 kg

d^{-1}), and 0.53t SRP (80% of TP) and 2.2 kg d^{-1}. Contrastingly, the new system at Milnathort (1,225 people and covering the rest of the year) yielded values of 0.13t TP (1.0 kg d^{-1}) including 0.04t SRP (33%) and equivalent to 0.3 kg d^{-1}. The Kinnesswood works (serving 500 people) is estimated to have introduced the following amounts of P to the loch: 0.55t TP or 1.5 kg day^{-1} including 0.8 t yr^{-1} 0.49t SRP (89%) or 1.3 kg d^{-1}.

(b) daily *per capita* estimates

Expressed as daily *per capita* outputs, the loadings described above, are as shown in **Table 10.**

Table 10: Daily *per capita* phosphorus outputs from the STWs.

Sewage treatment works	daily *per capita* TP output	daily *per capita* SRP output
Kinross North	0.68g	0.60g
Old Milnathort	2.03g	1.63g
New Milnathort	0.81g	0.25g
Kinnesswood	3.01g	2.68g

These figures can be compared with the following values obtained in 1985: 1.77g for Kinross North, 1.82g for Kinross South, 1.93g for Milnathort and 2.42g for Kinnesswood.

4.4.8 Rain falling onto the loch surface (L_{rain})

From the evaporation-corrected volumes of rain falling onto the loch, and assuming mean concentrations of 25μg TP l^{-1} and 12μg SRP l^{-1}, the estimated annual loadings are 0.295t TP and 0.142t SRP. The estimates for 1985 were 0.42 kg TP and 0.20 kg SRP.

4.4.9 Wildfowl (L_{wild})

The (minor) contribution from over-wintering wildfowl to loch in 1996 is assumed to be the same as that estimated for 1985 i.e. 0.366t TP and - assuming SRP constitutes 50% of this - 0.183t SRP.

4.4.9 Sediments

Any substance present at a uniform concentration of 1 μg l^{-1} throughout Loch Leven represents a total mass of approximately 50kg. Thus, the *net* release of phosphate ions equivalent to some 50 μg l^{-1} from the sediments during the hot weather in summer 1995 could amount to at least 2.5 *tonnes* SRP. However, Bailey-Watts and Wiltshire (1996) suggest that this influx represents only 50% of the actual release - bringing the total internal loading up to some 5 tonnes.

4.5 Losses of phosphorus *via* the outflow (L_{out})

The mean daily rate of export of TP from the loch *via* the outflow during 1995 was 231mg s^{-1} including 76mg s^{-1} in the form of SRP. The total weights exported amount to 7286kg TP and 2380kg SRP. TP value is somewhat less than that estimated for 1985, i.e. 8199 kg, while the SRP figure for 1985 is considerably more than that obtained in 1995, i.e. 1448 kg.

The 1995 estimates are based on the mean of 47 flows each 8 days apart. However, alternative calculations based on the mean of 365 daily outflow rates, gave P export values only 2.5% higher than those quoted above.

4.6 Phytoplankton

The changes in phytoplankton species composition and abundance observed in 1995 were quite different from those recorded in 1985. The following is the Summary of the report by Bailey-Watts and Wiltshire (1996).

The report details many aspects of the ecology of the phytoplankton of Loch Leven over 1995 as a whole, but pays major attention to the summer, particularly August when an enormous crop of large gas-vacuolate, blue-green algae developed and constituted the annual chlorophyll maximum; this combination of features has not been recorded before.

The development is attributed to spells of very warm, calm weather and associated releases of soluble reactive phosphorus and ammonia from the sediments which supported the prominent cyanobacteria as well as a less noticeable but diverse assemblage of smaller algae remaining in low population densities; this was on account of grazing by *Daphnia* which itself produced one of the densest populations ever recorded.

Phytoplankton developments outside the main period of interest were generally moderate, due to seasonal shortages of mainly phosphorus, but also, for some algal types, nitrate-nitrogen and silica. As a consequence, water clarity was relatively high with Secchi Disc readings of 2m or more for a total of 6 months.

The collapse of the summer (mainly *Anabaena*) population in August corresponded to a resumption of cooler, windier and wetter weather than had prevailed over the previous few weeks; however, cellular phosphorus-to-chlorophyll weight ratios at this time were among the lowest recorded over the year. Although the lowest Secchi Disc readings - *ca* 0.5 m - were measured at this time, light is not thought to have been the main cause of the wane in the *Anabaena* population.

Factor interactions of the type that culminated in the success of the large blue-green algae in 1995 are undoubtedly masking improvements in water quality e.g. decreases in mean concentrations of phosphorus and chlorophyll, that might be reasonably expected as a result of efforts to reduce phosphorus loadings to the loch - and cut back the inputs of bio-available, P-rich, point-sources in particular. However, a preliminary comparison of the 1995 findings with the preceding long run of data, indicates that currently, the loch is not noticeably deteriorating; indeed, some algal species and abundance changes (in winter, early spring and late autumn) suggest that conditions are improving. Certainly, a number of pigment and phosphorus values calculated from the 1995 data, are generally much lower than those obtained from the work carried out in the period 1985-1990 for example.

On the basis of the 1995 analyses, previous ideas on the significance to the ecology of the algae of (i) 'cascade' effects of fish stocking, and (ii) recycling of nutrients from the sediments, may have to be revised. In any event, however, considerable more work is

necessary to establish for example, the food preferences and feeding rates of fish and zooplankton. These and other field, laboratory and desk projects are proposed. Some suggestions are also made for improving on the sampling programme; of particular importance are those areas relating to the lakewide estimation of organisms and nutrients when these are very patchily distributed.

Some of even the main species in 1995 i.e. organisms that dominated the scene for reasonable periods, were quite different from the most prominant types in 1985. In addition to these qualitative contrasts, there are marked differences in the changes in total phytoplankton abundance (chlorophyll$_a$ concentration (**Figure 15**). The major differences to consider in relation to the P loading reductions that appear to have been achieved, are as follows:

- the January-to-March quarter of the year saw chlorophyll levels almost as low as those recorded over the same period in 1985.
- the average chlorophyll value over the April-to-June period 1995 was not as low as the corresponding figure for 1985, but the latter was extremely low in any event.
- the third quarter of the year in 1995 was of concern, but populations of the type of *Anabaena* referred to above often lead to over-estimates of lakewide phytoplankton densities, and of the particulate P associated with them; the pulses of algae and P were very short-lived.
- the average pigment concentration over the final 3-month period of 1995 was considerably less than that measured in 1985.

4.7 Total inputs of phosphorus, a phosphorus budget, and the phosphorus-chlorophyll relationship

4.7.1 The total external phosphorus loading

The present estimates suggest that the total input of P from external sources to Loch Leven in 1995 was 10.5 t, of which 5.4 t (51%) was in the form of SRP. **Figures 16a and b**, and **17a and b** show the contrasts between 1995 and 1985 as regards the tonnages of TP and SRP entering the loch and the percentage contributions from runoff, sewage treatment works, rain falling directly on the loch surface and over-wintering geese; the complete eradication of woollen mill effluent is also featured.

The main conclusions drawn from these findings are as follows:

- the 1995 TP and SRP loadings are substantially less than those estimated for 1985; indeed, reductions in TP and SRP inputs are 49% and 60% respectively
- inputs of TP in runoff have been reduced from the 8.2t in 1985 to 6.7t, while the total P from STWs has dropped from 5.3t to 3.0t; meanwhile, a mill TP input of *ca* 6.4t in 1985 has been eradicated completely
- inputs of SRP in runoff have been reduced from 3.4t to 2.5t, while the SRP from STWs has decreased from 3.8t to 2.6t; a mill SRP loading of 4.6t has, of course, also been eradicated.

As a result of these quantitative changes, the qualitative nature of the loading of P to the loch has changed dramatically. The earlier situation saw bio-available SRP - coming mainly from point-sources - dominating the P loads. The present situation is one in which most of the P is less bio-available in nature, and enters the system in a diffuse manner. This is very significant in that P-rich, point-source material brings in comparatively little water and so affects hydraulic flushing minimally. In contrast, runoff P is of poorer quality as far as algal production potential is concerned, and by definition, is accompanied by substantial volumes of water with the potential to flush to loch. Moreover, the P-rich, low-volume, point-source loadings generally enter the system at a more or less constant rate throughout the year, while the supply of the less P-rich, diffuse material is determined by rainfall patterns. In this respect, it must be emphasised that much of the estimated difference (reduction) in runoff P load between the two years, reflects the lower rainfall in 1995.

4.7.2 A phosphorus budget

The loch functioned very differently in 1995 compared to 1985. Nevertheless (as in the case of 1985) the estimated total P loading (L) and P export values in 1995 (calculated from the input of 10.5t and the output of 7.3t (**Figure 17**) predicted well the observed in-loch, annual mean TP concentration of 64µg l^{-1} for that year according to the Dillon and Rigler (1974) model. The Dillon and Rigler equation is as follows:

$$[TP] = L\,(1\text{-}R)/(z.\rho)$$

where:

- L is the total P loading (790 mg m^{-2} *cf* the figure of 1540 estimated for 1985
- R is the phosphorus retention coefficient or fraction of L retained by the loch (0.30 *cf* 0.60)
- z is the mean depth (3.9m) and
- ρ is the flushing rate or the annual volume of water passing through the loch expressed as number of loch volumes (2.25, being the inflow volume estimated rather than the discharge volume).

This combination of values results predicts a [TP] value of 64µg l^{-1} - extremely close to the figure observed.

4.7.3 Phosphorus-chlorophyll relationship

In contrast to the situation found in 1985, the relationship between the mean inflow TP concentration (i.e. total P loading divided by the total input of water: 90µg l^{-1} in 1995) and the observed annual mean chlorophyll$_a$ concentration of 34µg l^{-1}, do not agree with an OECD (1982) model. From the information already gained, an annual mean pigment concentration of *ca* 14µg l^{-1} is predicted, whereas a value of 34µg l^{-1} was calculated from the observed pigment levels.

Much of this discrepancy is thought to be due to the over-estimation of lake-wide population densities of gas-vacuolate blue-green algae, and especially certain times in summer when these organisms were aggregated near the outflow. There is a possibility too, that the abundances of these organisms are over-estimated whenever they are not distributed uniformly over depth (Bailey-Watts 1995).

5. SOME PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The loch functioned very differently in 1995 as compared with 1985. In spite of this, the values obtained for the following factors combined with the loch mean depth according to a Dillon and Rigler model, predicted the annual mean, in-loch concentration of 64µg TP l^{-1} (*cf* 63 in 1985) very well: the specific areal loading of TP (790mg m^{-2} *cf* 1,540 in 1985), the amount of TP passing out of the loch expressed as a fraction of the loading (i.e. 0.3 *cf* 0.6), flushing rate (2.25 loch volumes *cf* 2.53) and taking account of the mean depth of the loch. There is reason to question these conclusions on a number of counts, however. Firstly, one might have expected the not inconsiderable, albeit short-term release of SRP from the sediments to indicate a deviation from the tenets of the Dillon and Rigler equation; however, this may be explained by the fact that the SRP is rapidly re-sorbed by the sediments once weather conditions favouring the release come to an end. Secondly, if the volume of water flowing out of the loch in 1995 is taken as the flushing rate i.e.2.82 loch volumes as opposed to the inflowing volume which equates to 2.25 volumes, the data do not fit the model. Thirdly, bearing in mind the peculiar water level pattern observed in 1995, a similar 'mis-match' arises if the mean depth of the loch is taken as say, 3.4m rather than the 'traditional' 3.9m. Fourthly, whereas in 1985 the mean in-loch level of chlorophyll$_a$ (21µg l^{-1}) related to the equivalent value for TP (63µg l^{-1}) according to an OECD model, the pair of values obtained in 1995 i.e. 64µg TP l^{-1} and 34µg chlorophyll$_a$ l^{-1}) plainly do not.

Water quality gave cause for concern in 1995 - but almost exclusively as a result of a 4-week period from mid-July. A very noticeable bloom was dominated by one of the largest cyanobacteria - *Anabaena spiroides* - which had not been recorded in anything like the numbers estimated then, in the 30-year history of regular sampling of the loch. This development, and the release of P from the sediments, resulted in annual mean values for soluble reactive P and chlorophyll$_a$ that are considerably higher than those measured in 1985 i.e. 19µg l^{-1} *cf* 9µg l^{-1} and 34µg l^{-1} *cf* 21µg l^{-1}. Contrastingly, as indicated above, the total phosphorus values were virtually the same. There is reason, however, to be encouraged by the 1995 findings in at least two respects. Firstly, with UK temperatures in the summer of 1995 exceeding those of any year back to the 17th century, weather and weather-related conditions were much more conducive to the manifestation of phytoplankton than they were in 1985 with its very wet late summer and autumn. Secondly, an upgrading of one of the major sewage treatment works was not completed until late September 1995. Thirdly, it is likely that the phosphate released from the sediments in July 1995 elevated the annual mean chlorophyll$_a$ concentration from 27µg l^{-1} to the 34µg l^{-1} measured, and the TP concentration itself by some 14µg l^{-1} from a value of 50µg l^{-1}.

The qualified success stems from a combination of (i) the recommendations made by IFE on the basis of its long-term attention to the functioning of Loch Leven and its findings from the 1985 P loading assessment in particular, and (ii) the willingness of the statutory authorities to put these recommendations into practice. However, the specific areal P loading of *ca* 790mg m^{-2} estimated for 1995 (albeit approximately only 50% of the 1985 figure) is still considerably in excess of the ideal maximum values for a lake of approximately 4m mean depth. On the other hand, such statistics ignore the significance of the composition of the P entering the sysytem: the latest campaign has reduced the external loading of bio-available SRP by some 7t, and the completion of the Milnathort works upgrade will reduce the inputs of this P fraction even further. Indeed, the mean concentrations of TP, SRP and chlorophyll$_a$ for 1996, are likely to be even less than the levels measured in 1995.

It is recommended that:

(i) the more or less weekly limnological surveillance be maintained; this should cover in-loch and outflow nutrient and chlorophyll$_a$ levels, and phytoplankton and zooplankton biomass and species composition

(ii) weekly or 8-daily P loading assessments for the main inflows be resumed on 1 January 1997

(iii) strict control on inputs of treated, but nevertheless P-rich, sewage be maintained, and wherever possible tightened

(iv) reasonable efforts to minimise the inputs of P in all forms coming off the land also be exercised; this concern stems from the fact that much of the apparent reduction in TP loading from the high 1985 value is a consequence of the low rainfall in 1995.

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FIGURES

Figure 1

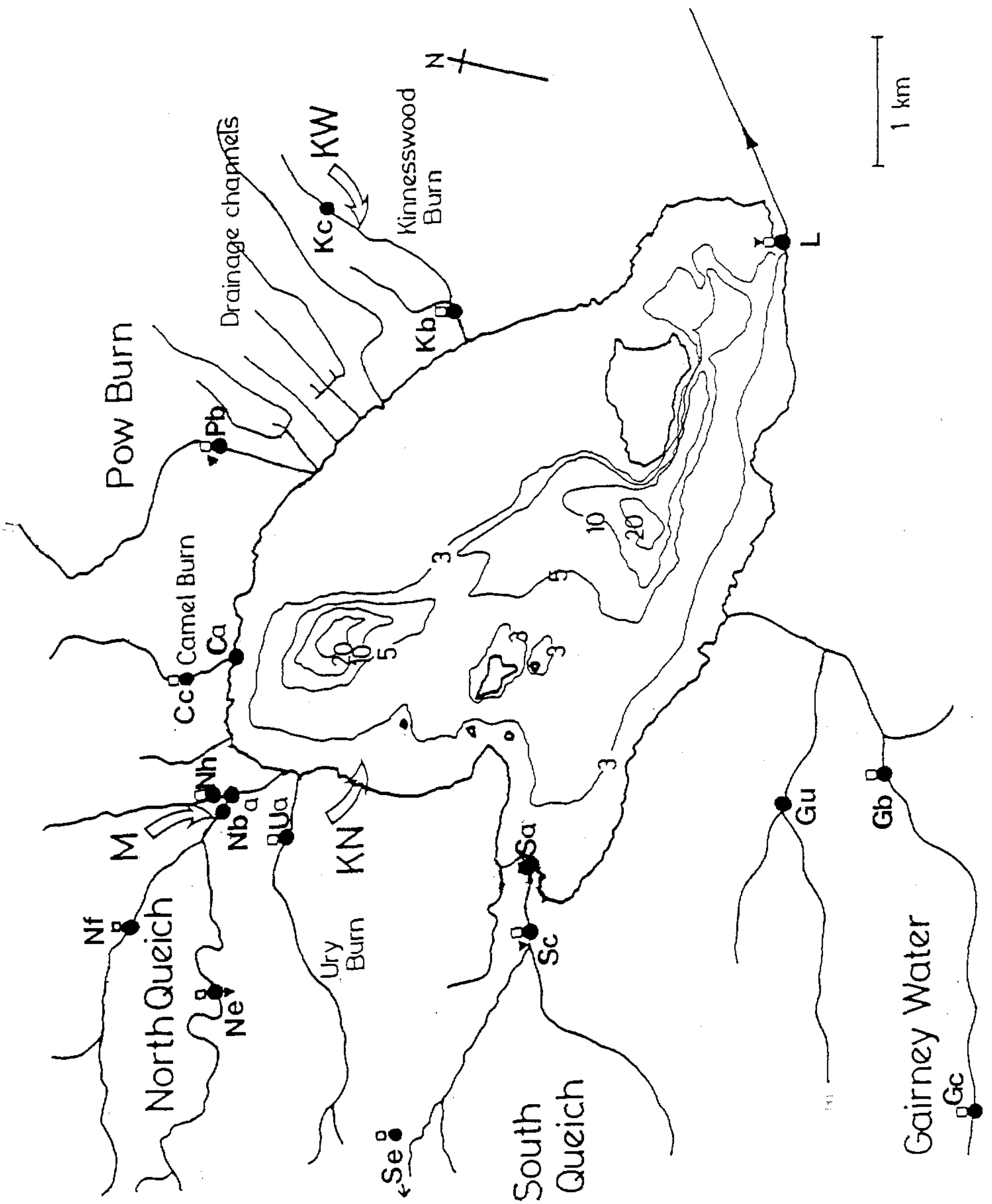


Figure 1 Loch Leven showing depth contours (in metres) , position of sites sampled during the P loading study (● , labelled with codes used in other figures and in the text) staff gauges (❑) , level recorders (▼) . Outfalls of treated sewage effluent (open arrows) - M , Milnathort; KW , Kinnesswood; KN , Kinross North .

Figure 2

Daily rainfall at Balado (Loch Leven): 1985 and 1995 compared

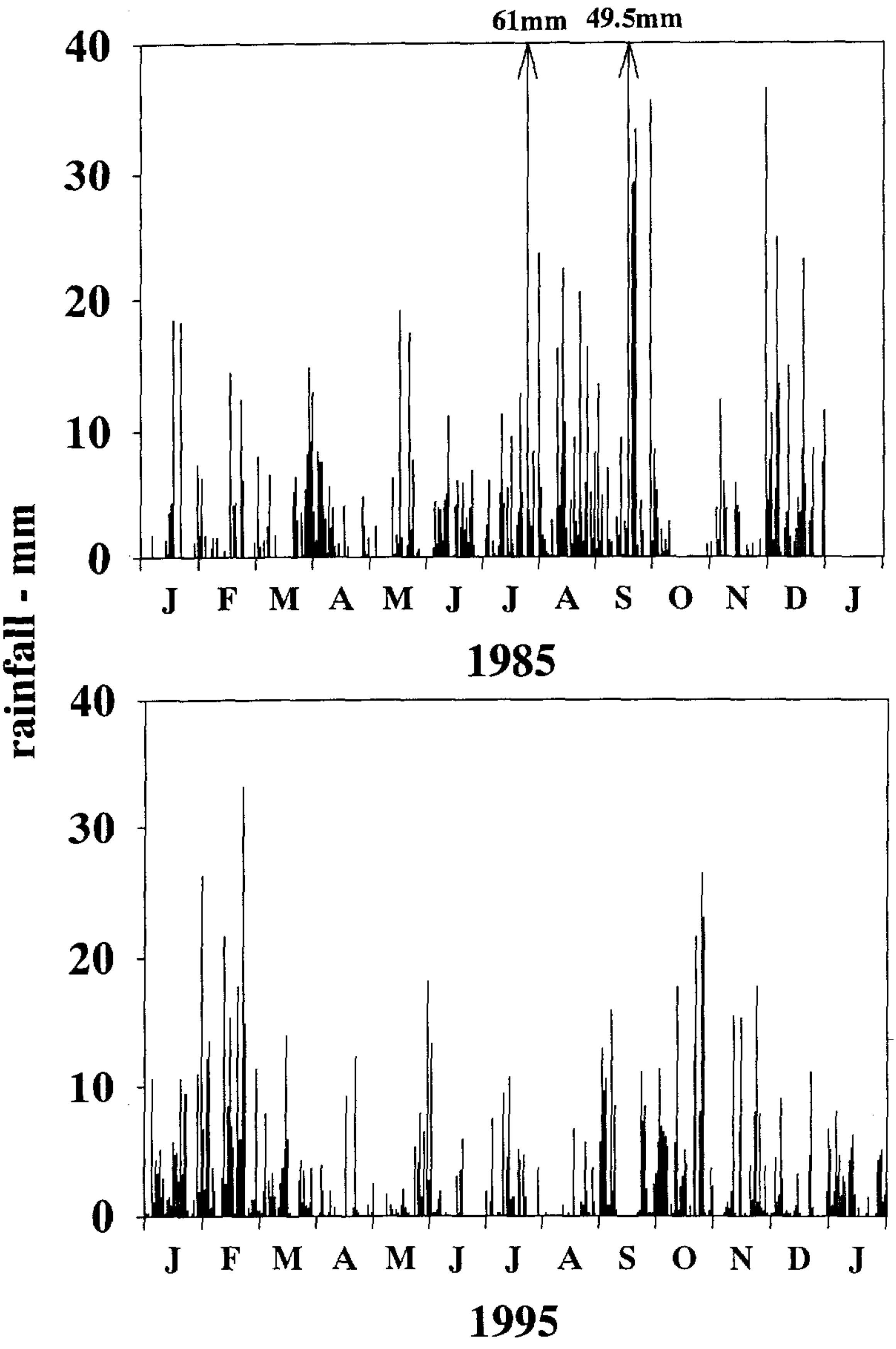


Figure 3

Fluctuations in loch level: 1985 and 1995 regimes compared

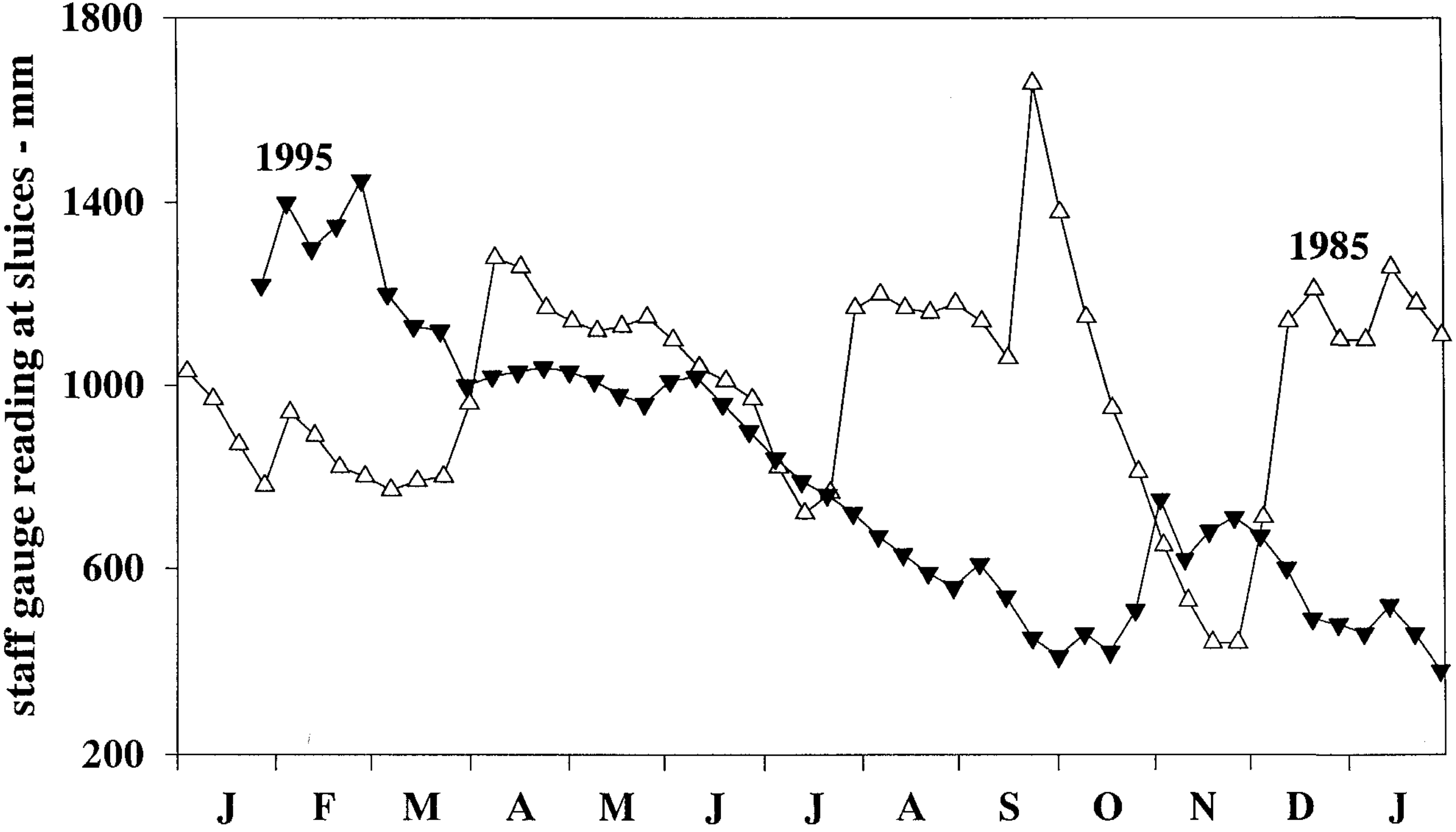


Figure 4

Fluctuations in wind force as indicated by readings recorded daily at 09.00h: 1985 and 1995 compared

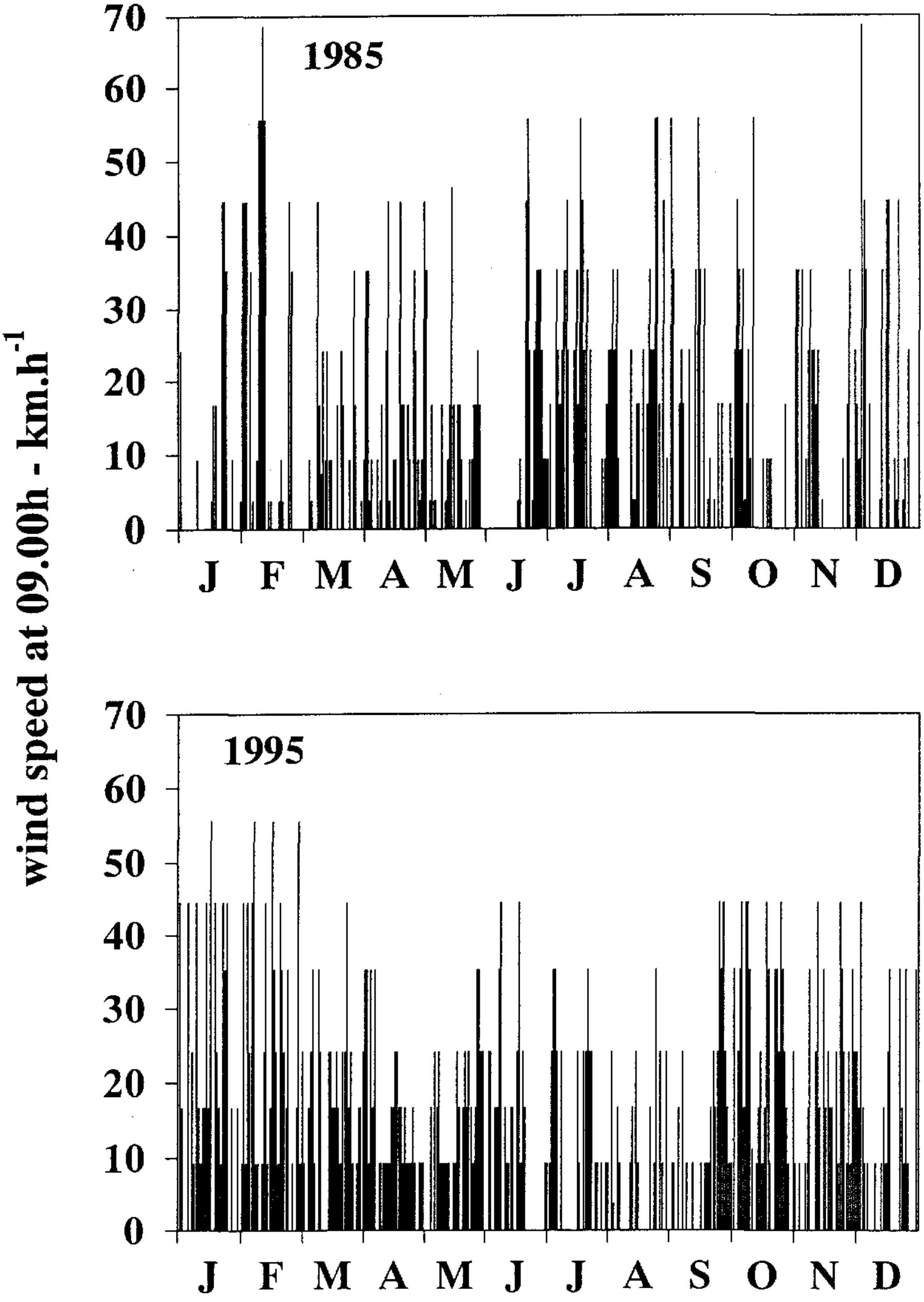


Figure 5

Loch Leven flows 1995: ranges and mean flows

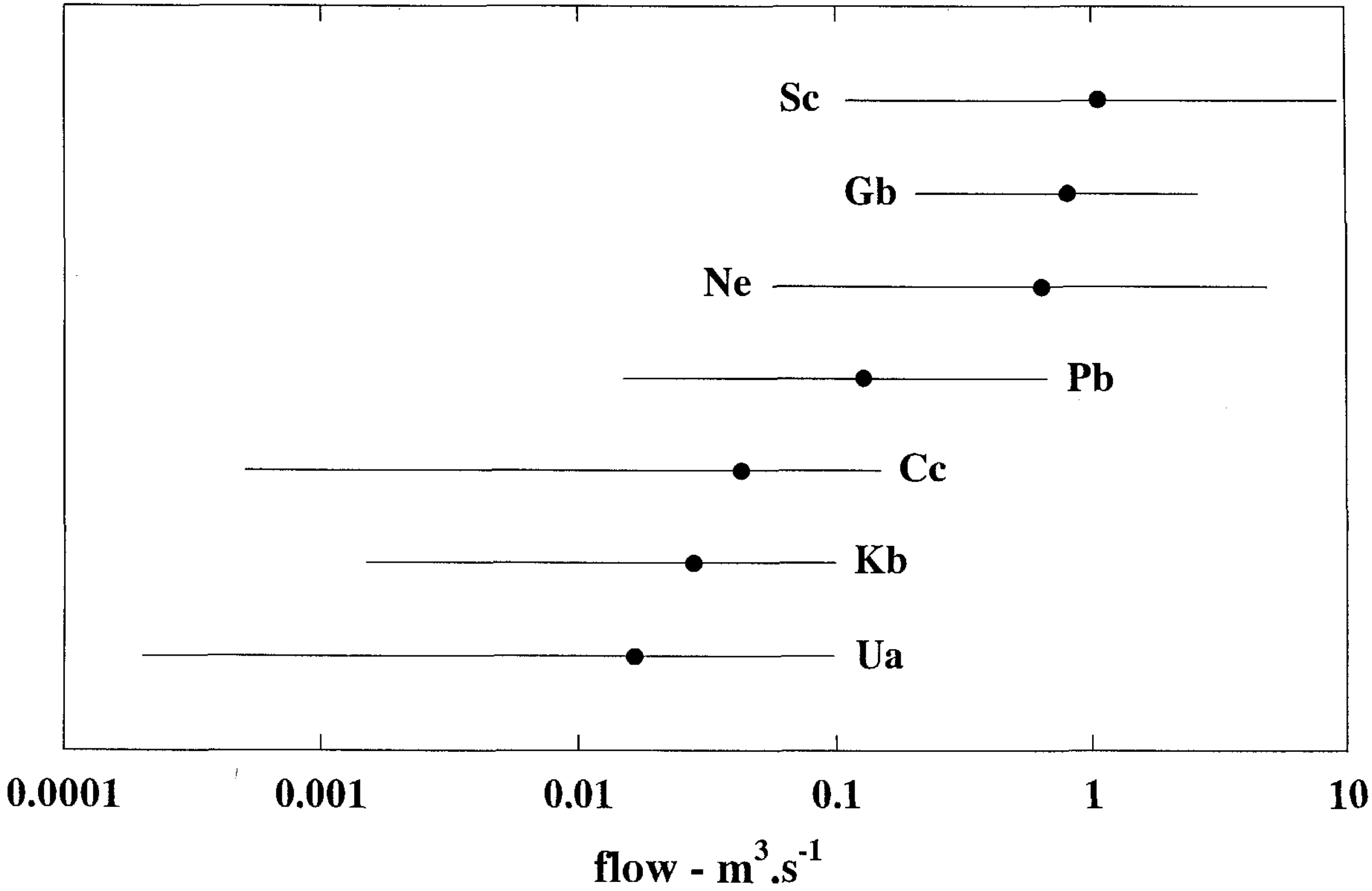


Figure 6

variation in flows measured in three feeder streams of contrasting size

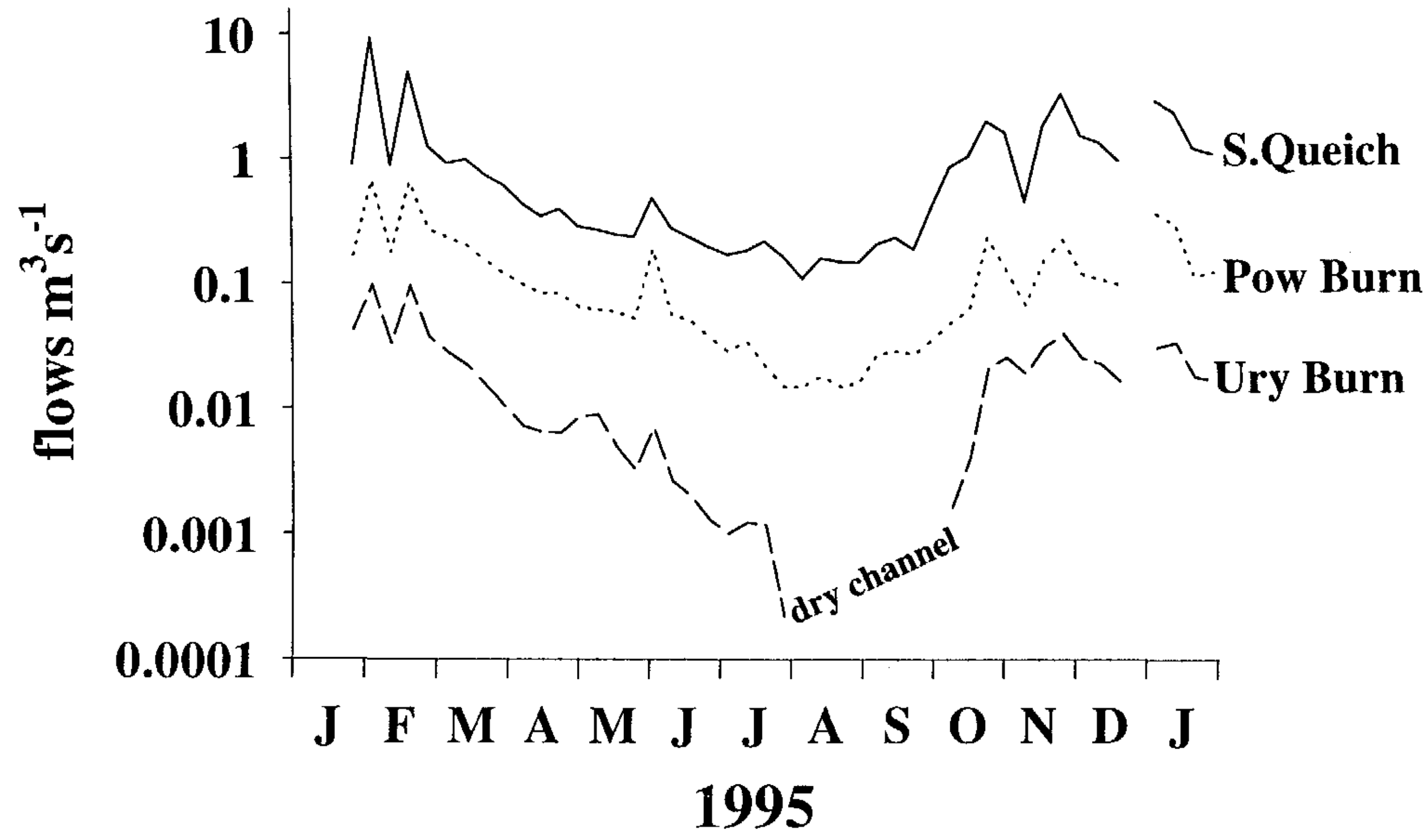


Figure 7

the ranges and mean levels of total P in Loch Leven and inflows not affected by effluent outfalls

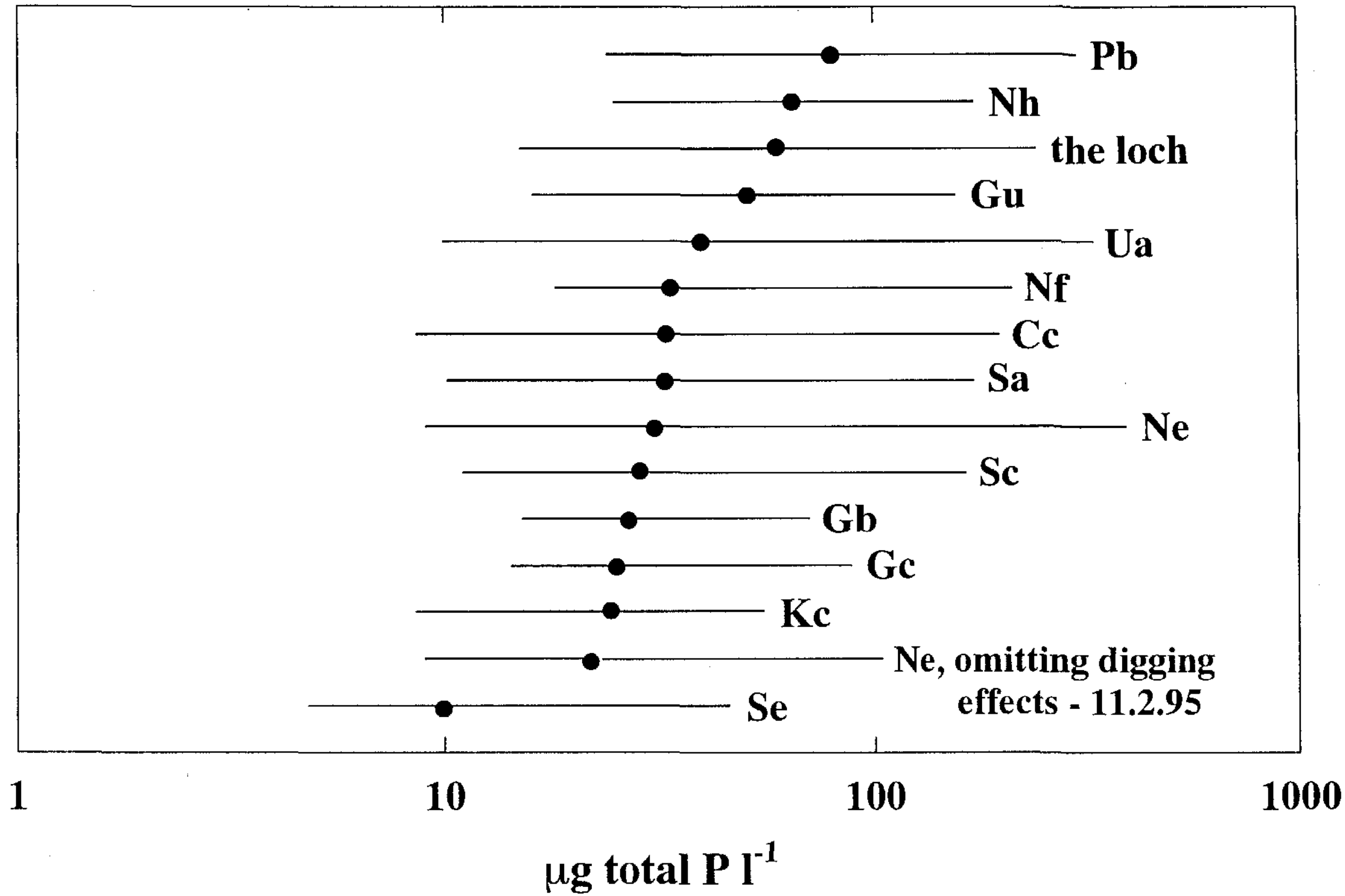


Figure 8

Fluctuations, during 1995, in total P levels in Loch Leven and the upper reaches of some of its feeder streams

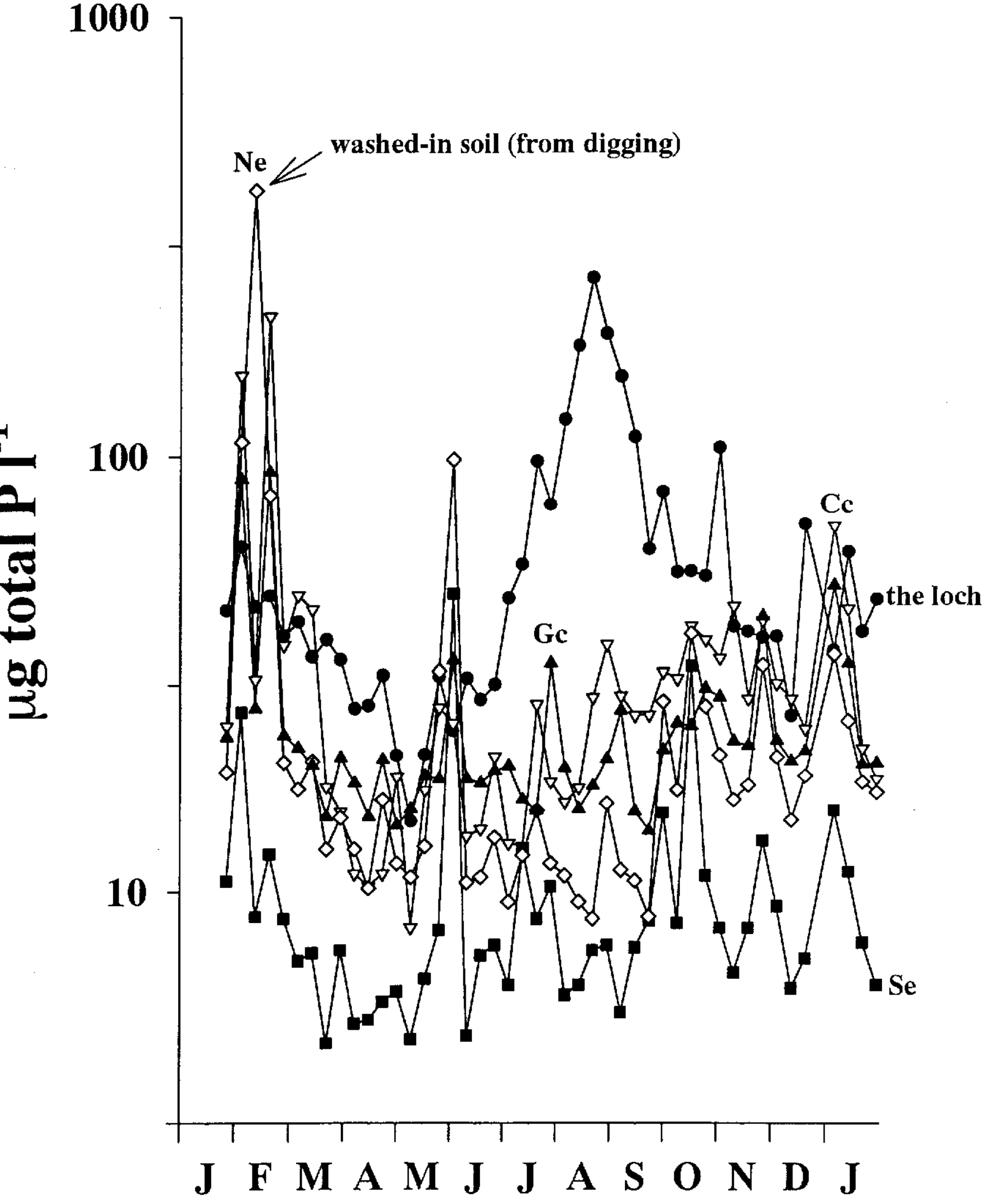


Figure 9

The relationship between the concentration of total P and the flow measured at the time of chemical sampling in stream stretches unaffected by point-source outfalls of P

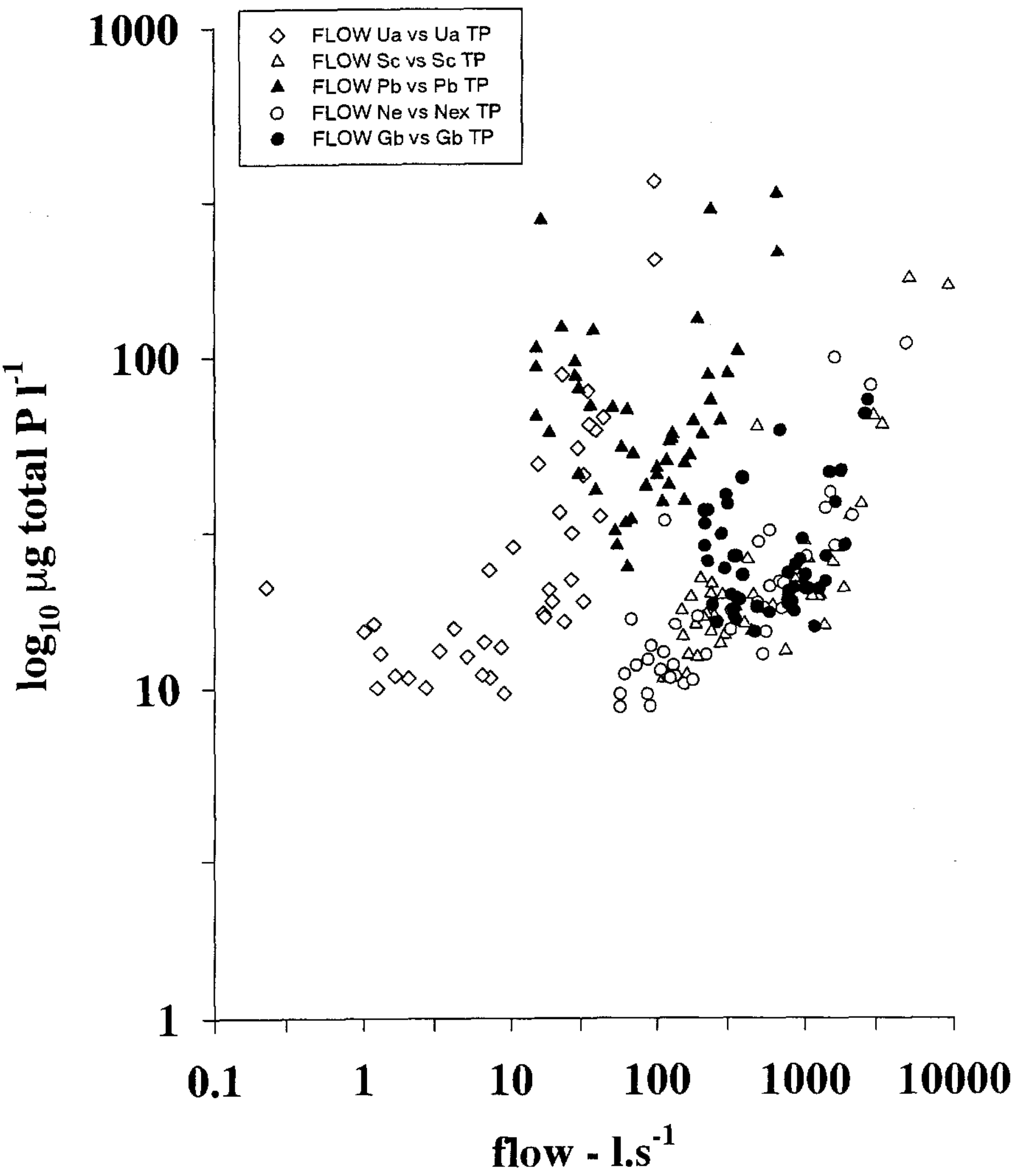


Figure 10(a)

The contrasting changes in the concentrations of total P above and below the Milnathort STW until the new works came into operation in September 1995

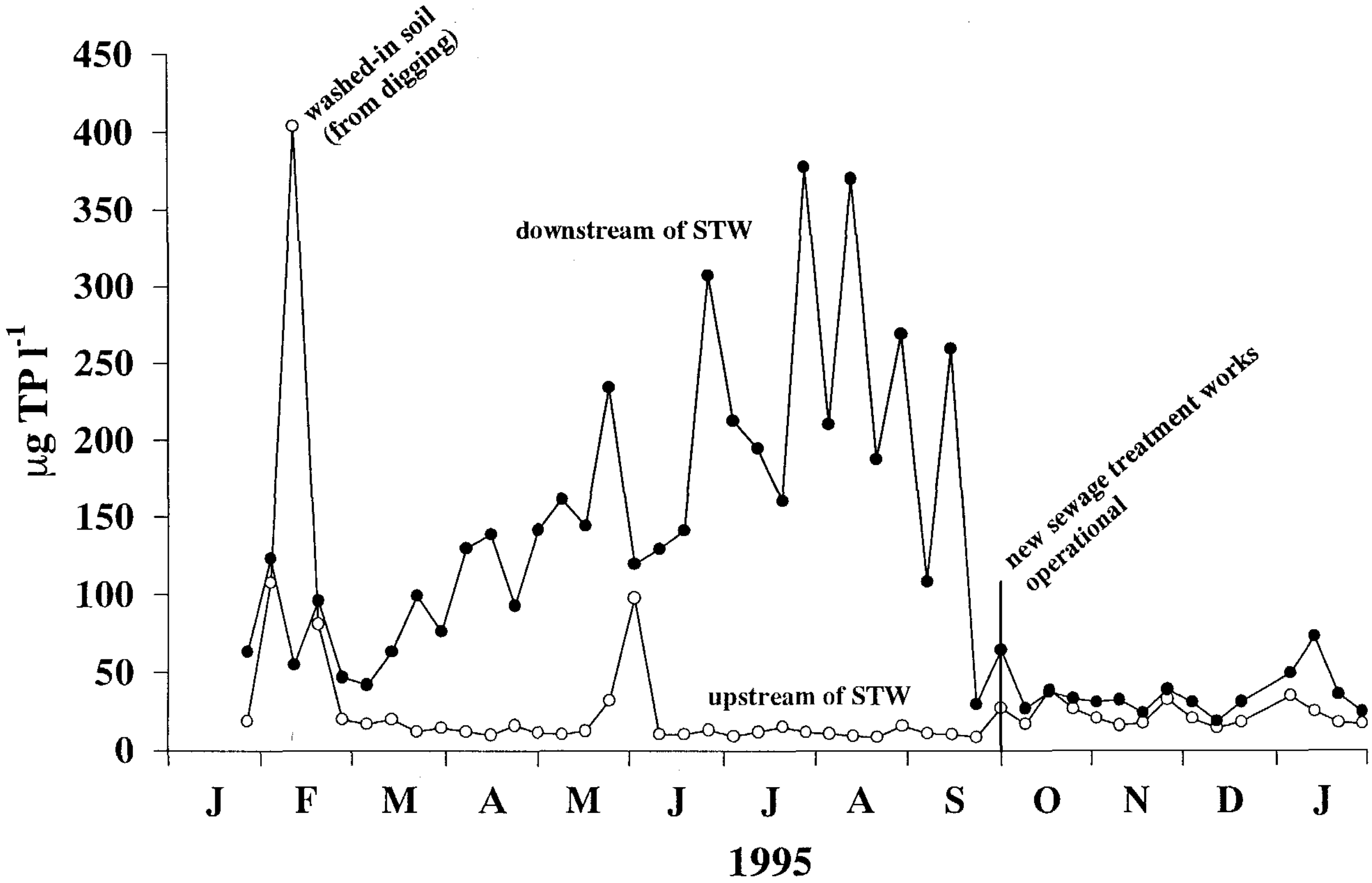


Figure 10(b)

The relationship between P concentration and flow: situations above (Ne) and below (Nb) the input of Milnathort STW effluent

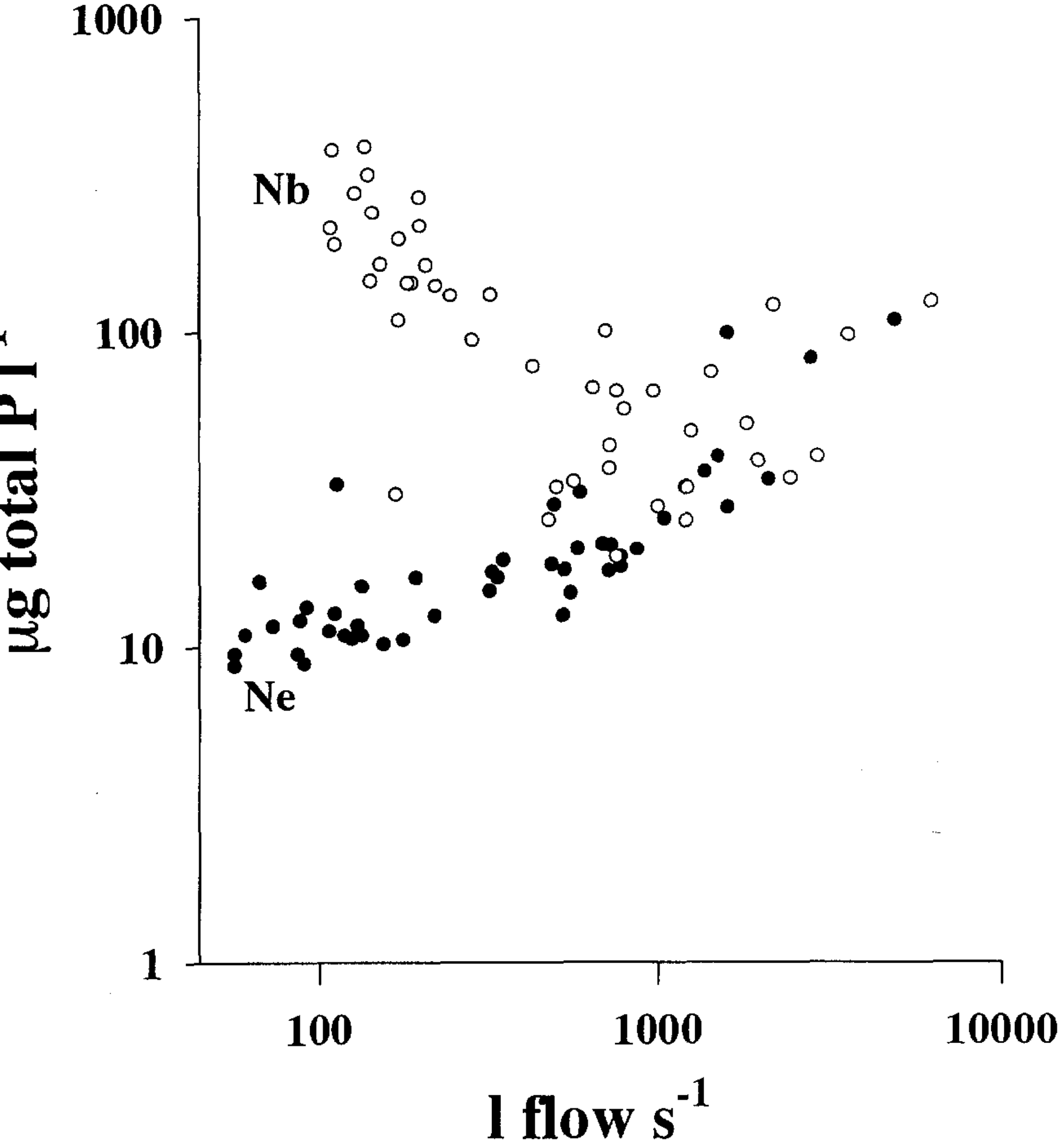


Figure 11(a)

Seasonal changes in the concentrations of total P in Loch Leven at site L near the outflow

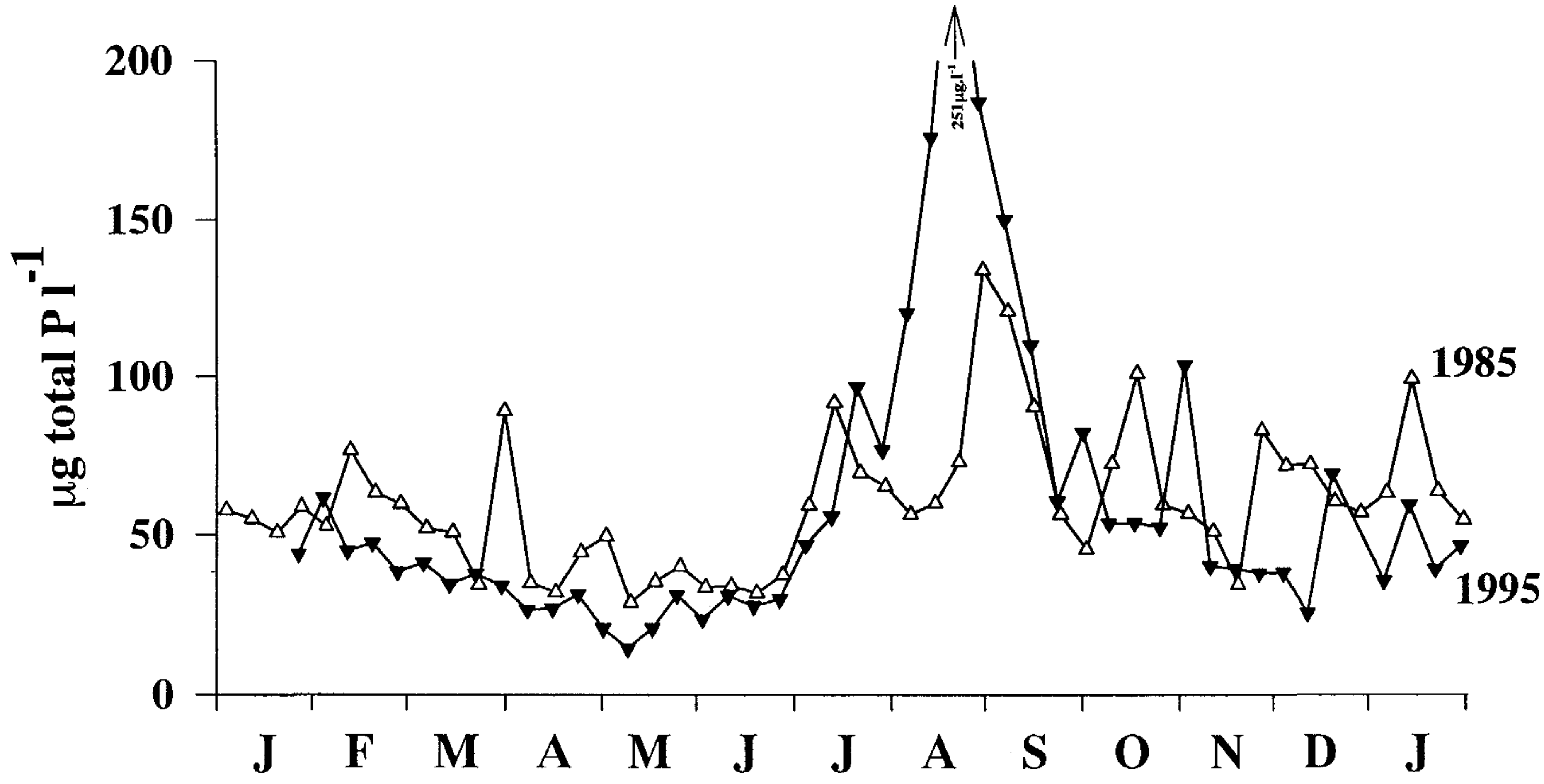


Figure 11(b)

Seasonal changes in the concentrations of soluble reactive P in Loch Leven at site L near the outflow

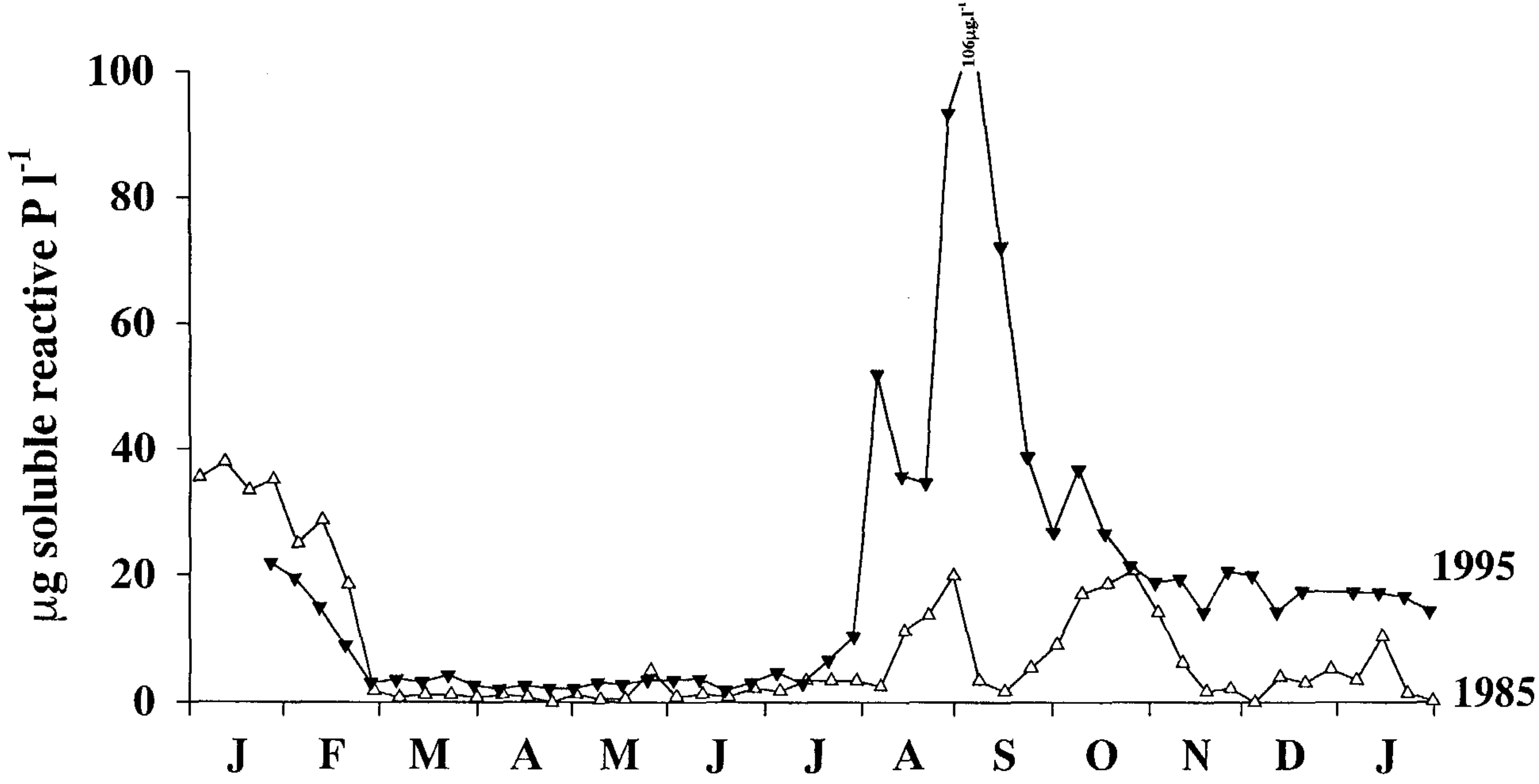


Figure 12(a)

Seasonal variation in total P loading at sites above point-source inputs: based on instantaneous loadings from sampling at 8-day intervals

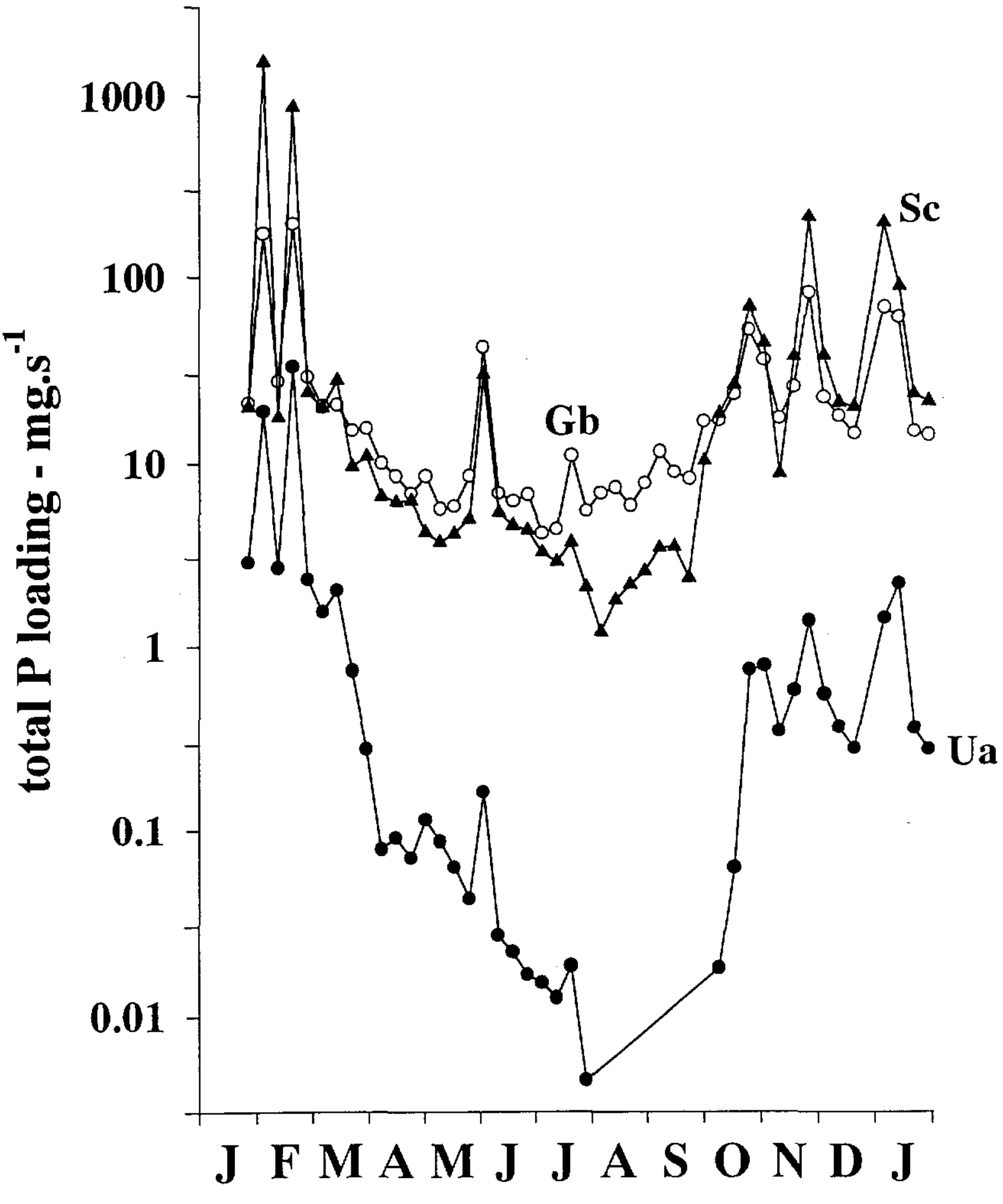


Figure 12(b)

Seasonal variation in total P loading at sites above point-source inputs: based on instantaneous loadings from sampling at 8-day intervals

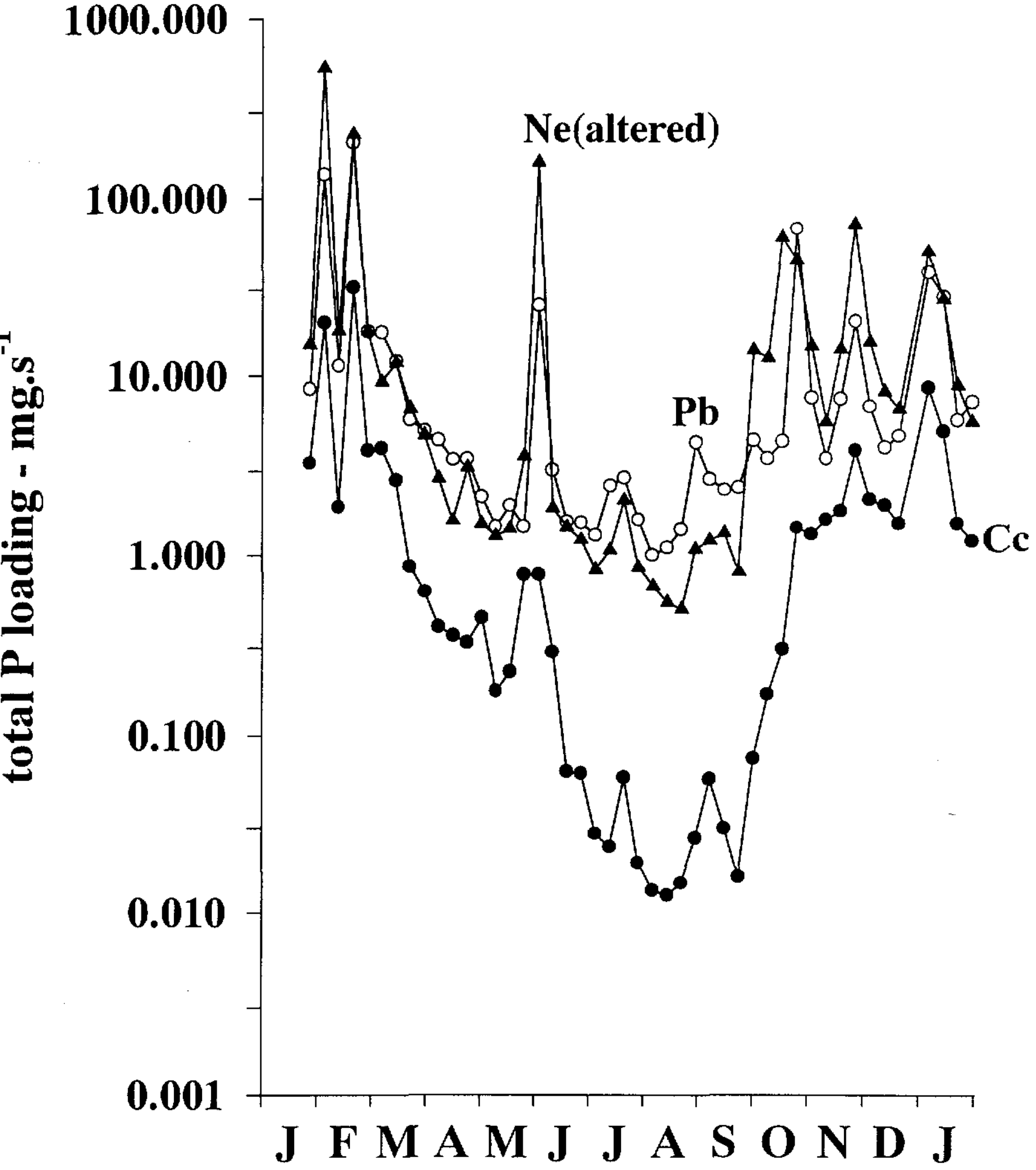


Figure 13

Cumulative loadings in the South Queich (Sc): the contrast between 1985 and 1995

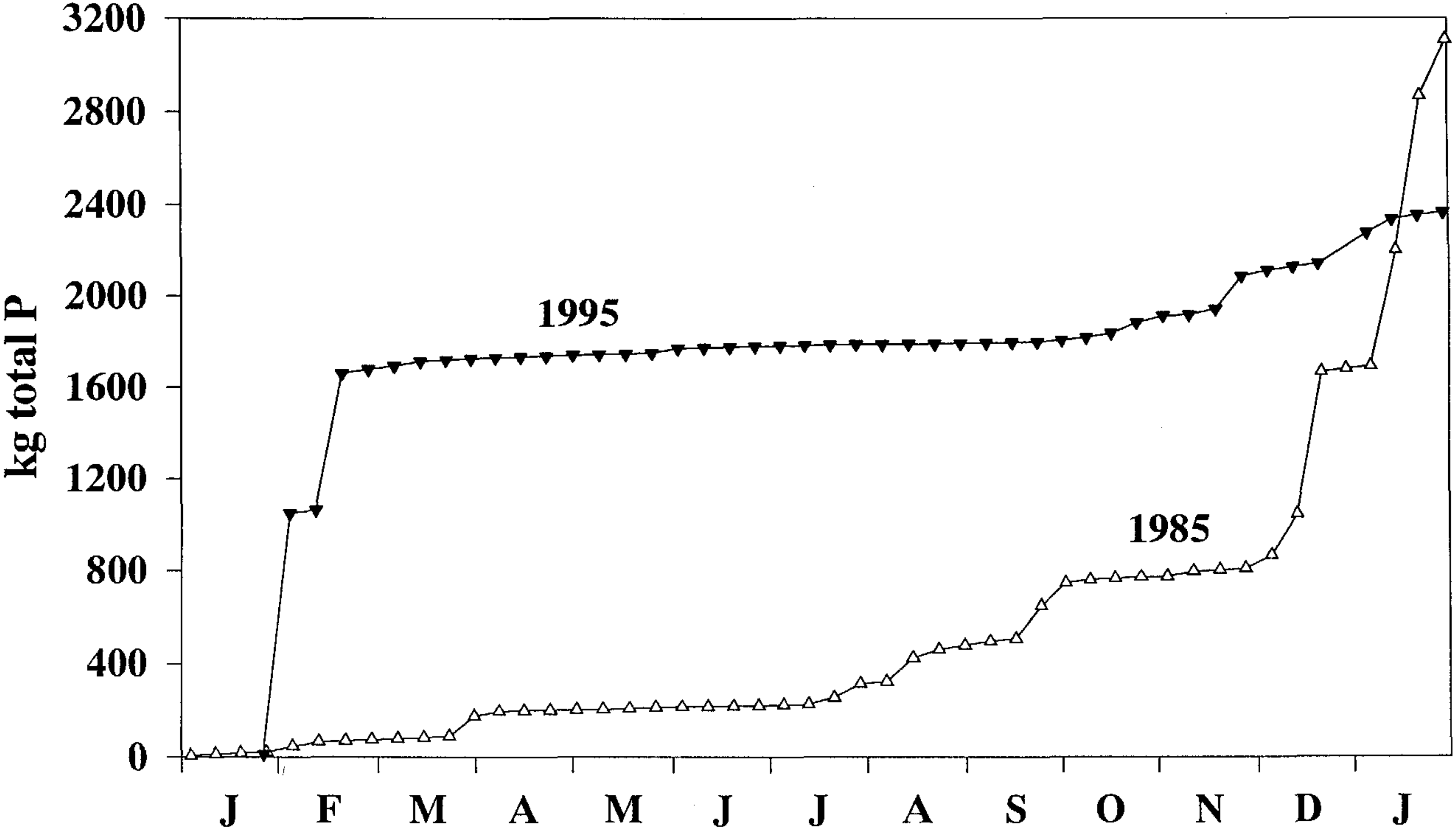


Figure 14

The relationship between total P loading and flow in 5 feeder waters of Loch Leven

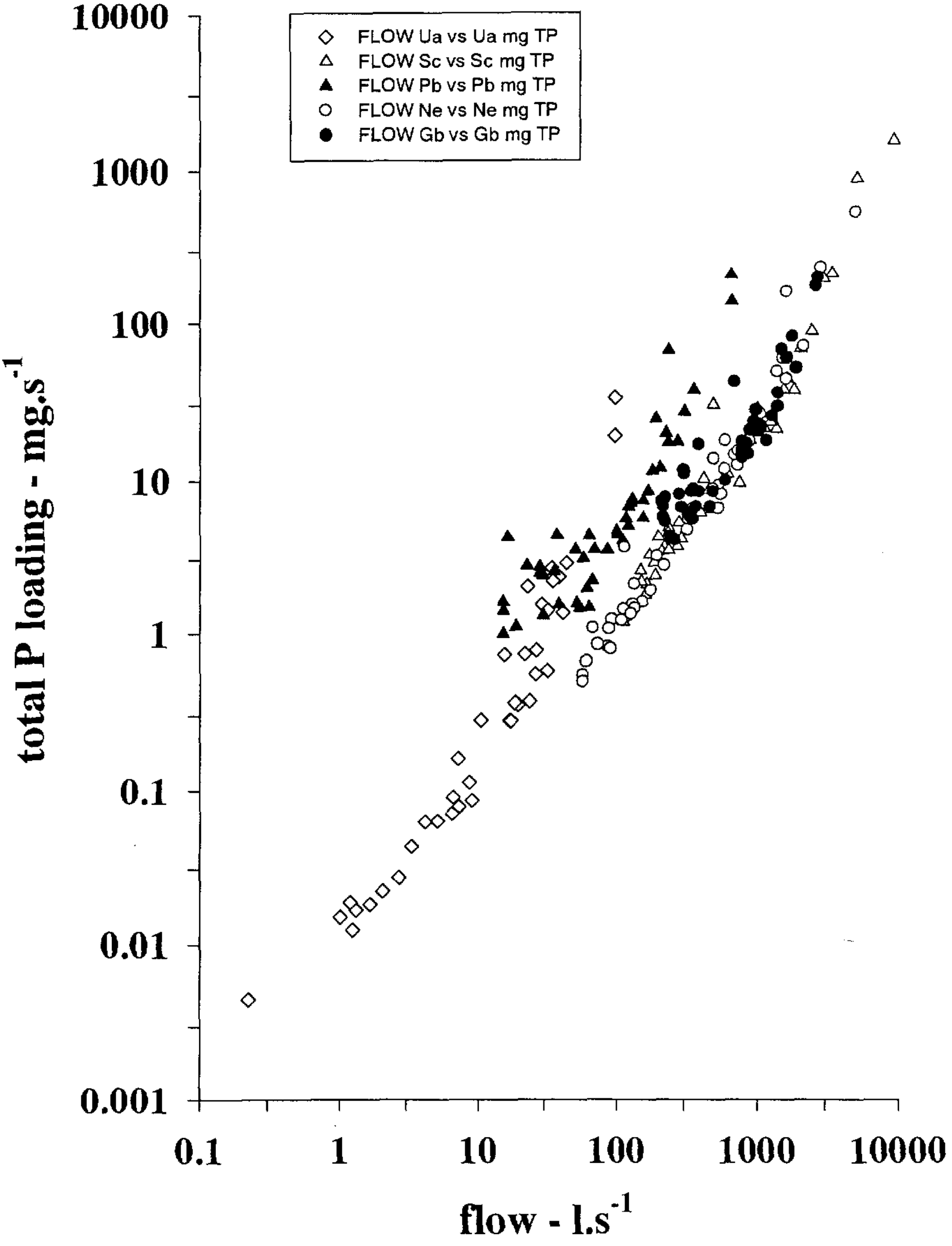


Figure 15

Seasonal changes in total phytoplankton biomass in Loch Leven: sluices (outflow) sampling site , 1985 and 1995 compared

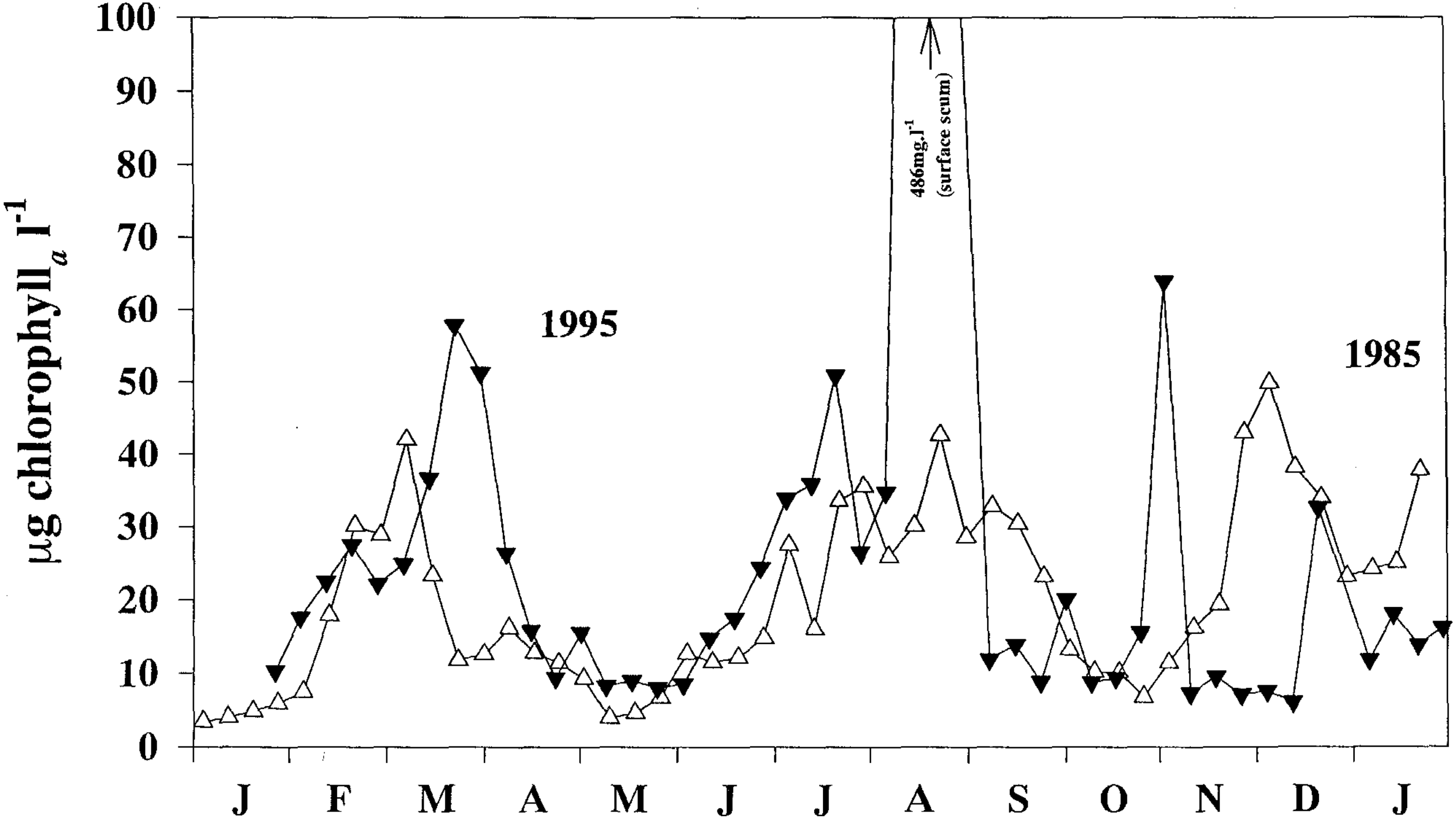


Figure 16(a)

The components of the total loading of phosphorus in all forms to Loch Leven: 1985 and 1995 compared

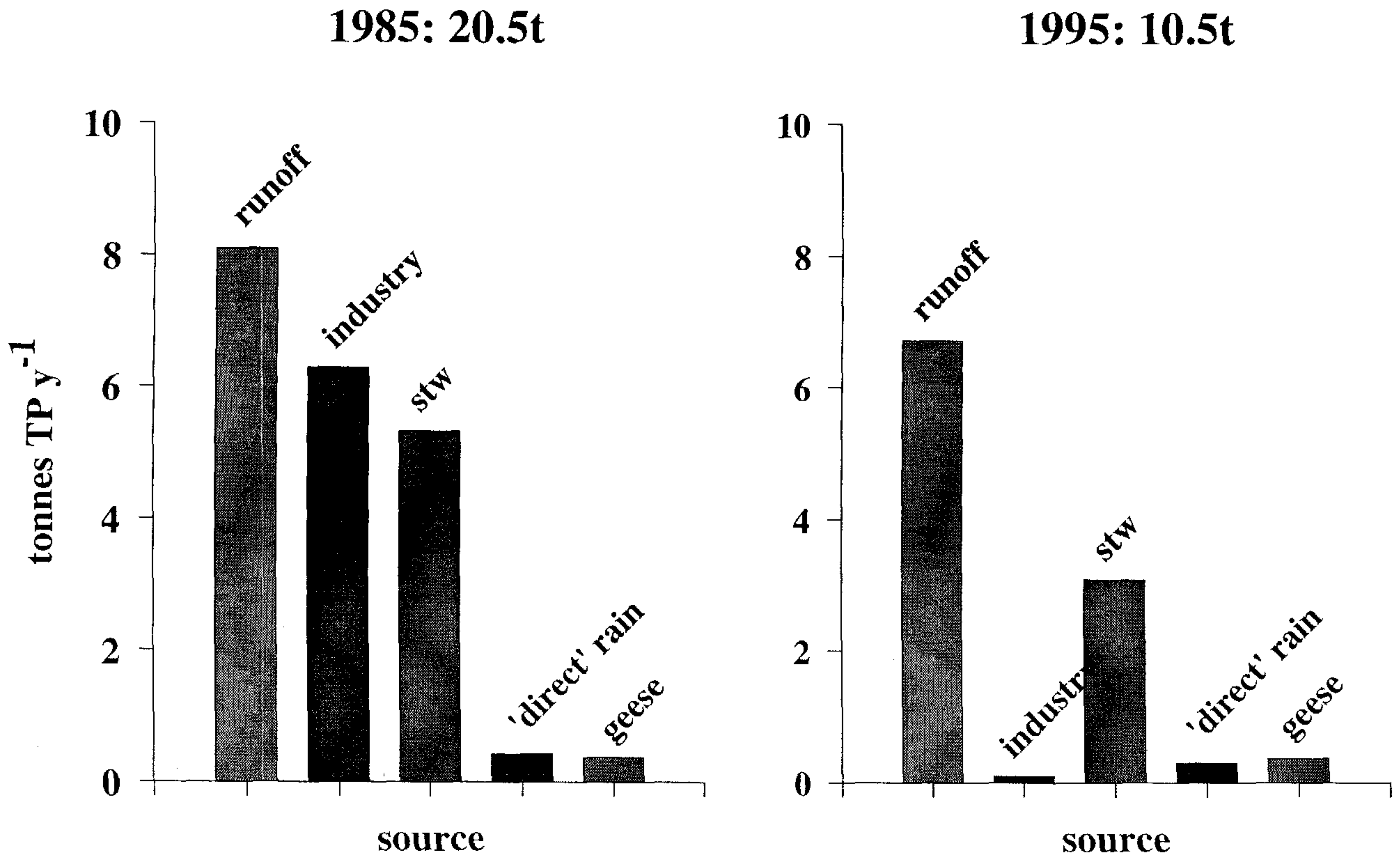
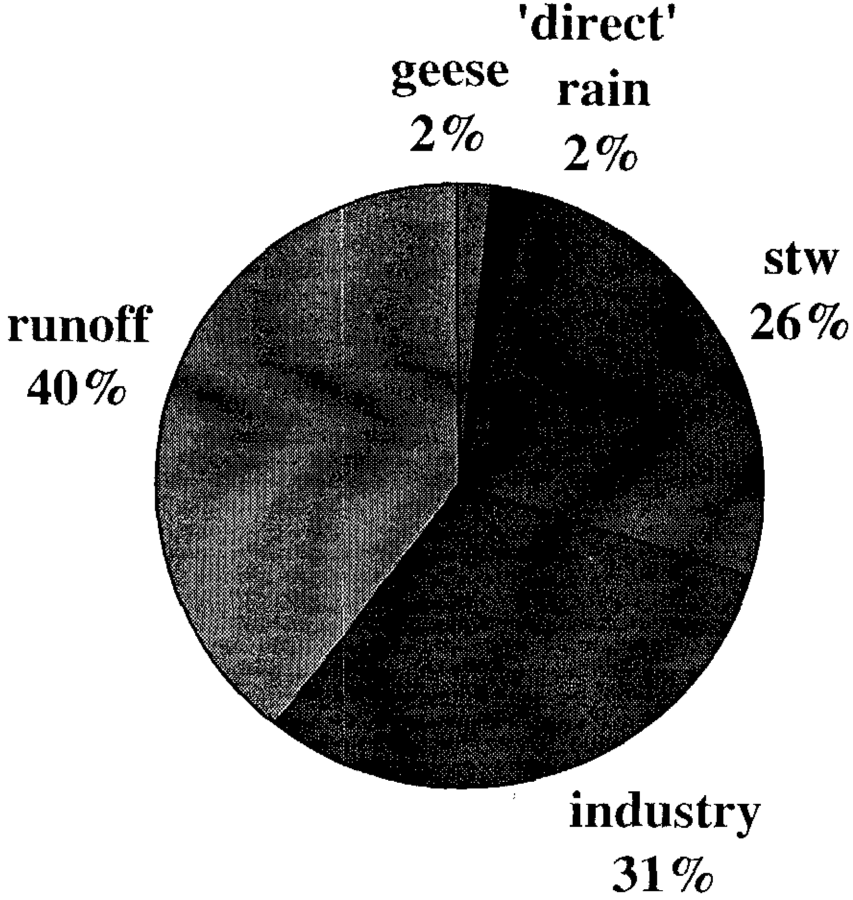


Figure 16(b)

% contributions to the total loading of all forms of phosphorus to Loch Leven: 1985 and 1995 compared

1985: 20.5 tonnes TP



1995: 10.5 tonnes TP

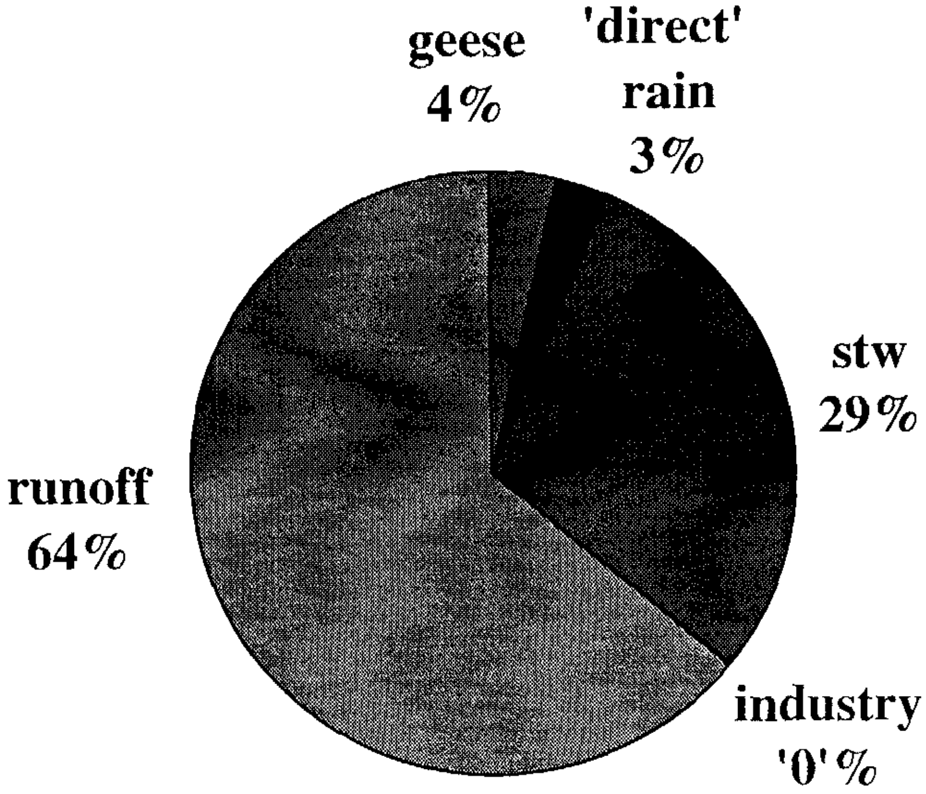


Figure 17(a)

The components of the total loading of soluble reactive phosphorus to Loch Leven: 1985 and 1995 compared

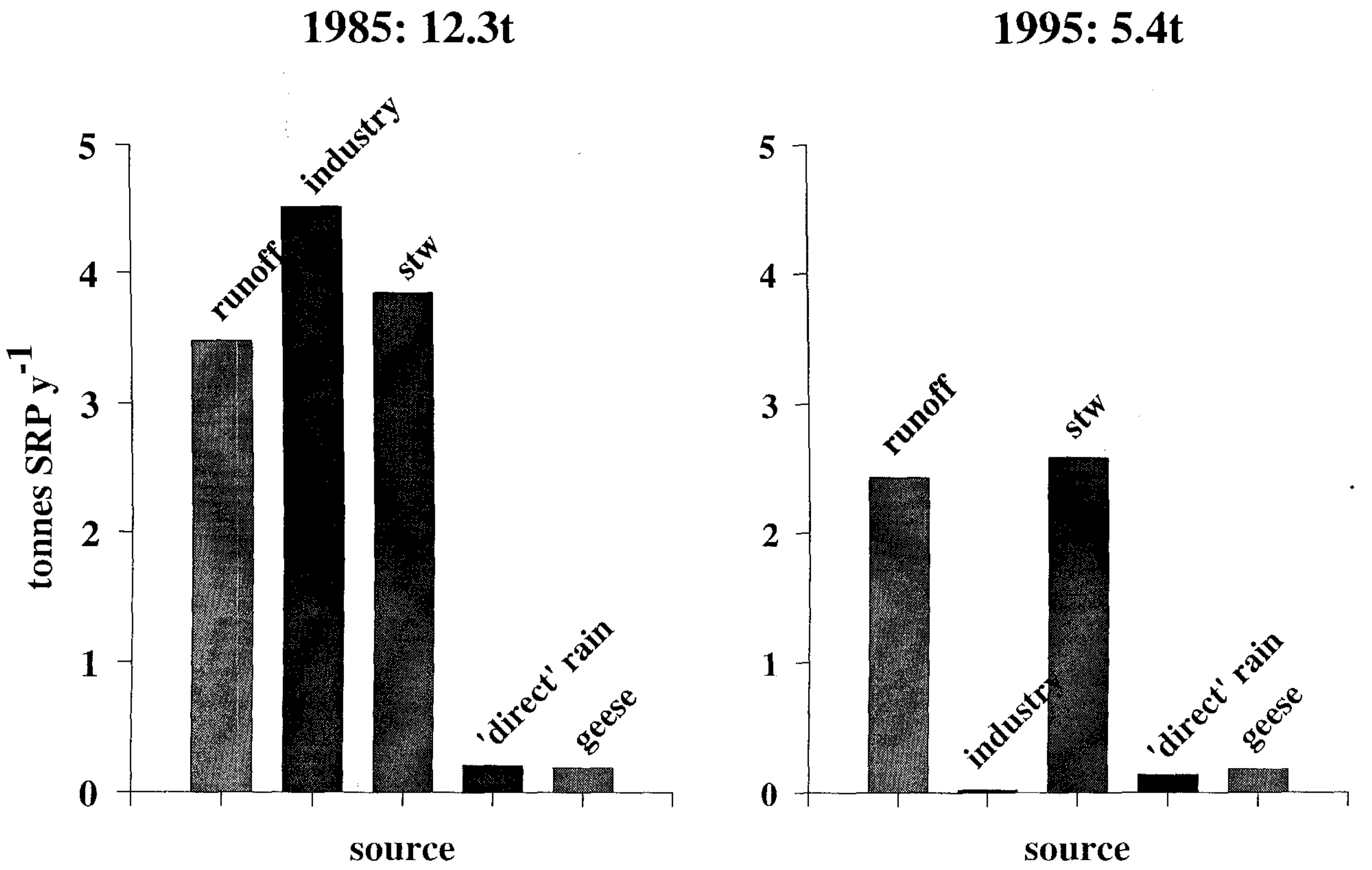
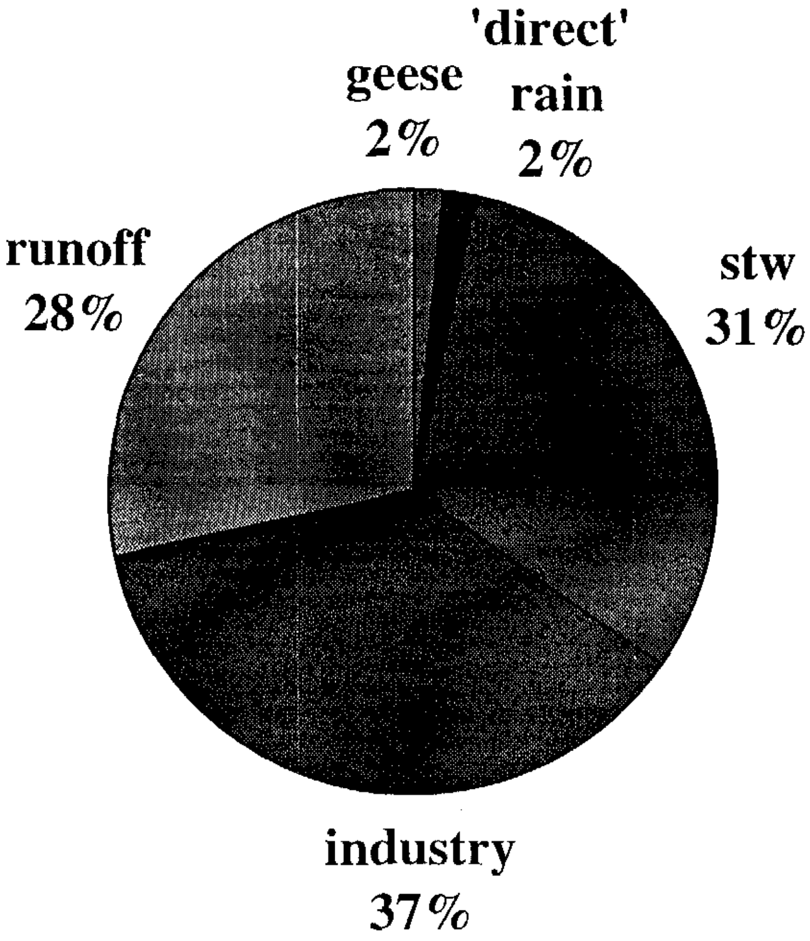


Figure 17(b)

% contributions to the total loading of soluble reactive phosphorus to Loch Leven: 1985 and 1995 compared

1985: 12.3 tonnes SRP



1995: 5.4 tonnes SRP

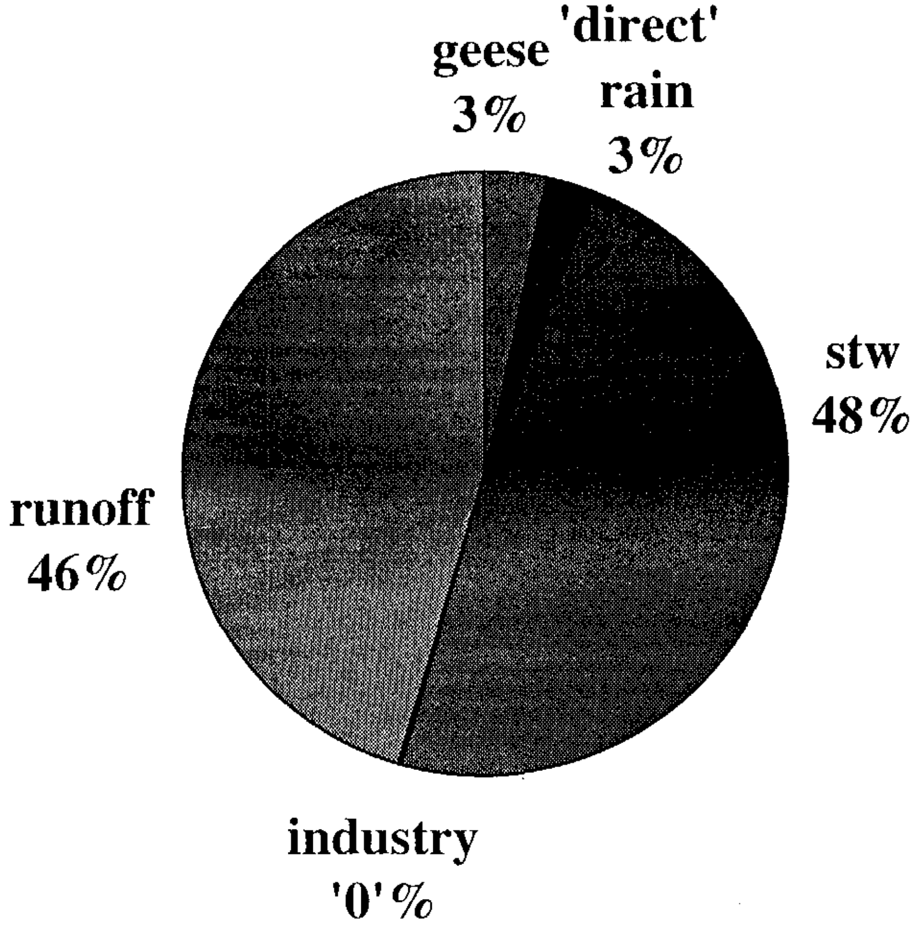


Figure 18

Bar chart illustrating the annual (1995) loadings of total P (TP) and of soluble reactive P (SRP) to Loch Leven from various external sources; the annual export of P from the loch via the outflow is also compared to the total input