Project 314

Acid Waters : Llyn Brianne Project

Project Record

Research Contractor :
National Rivers Authority, Welsh Region

National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Bristol
BS12 4UD

R&D Project Record 314/12/W

Further copies of this report are available from:

FWR

Foundation for Water Research, Allen House, The Listons,
Liston Rd, Marlow, Bucks SL7 1FD. Tel: 01628-891589, Fax: 01628-472711

NRA

National Rivers Authority

Acid Waters : Llyn Brianne Project

Project Record

E.C. Lloyd, M.J. Jenkins & A.P. Rogers

Research Contractor :
National Rivers Authority, Welsh Region

National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Bristol
BS12 4UD

Publisher
National Rivers Authority
Rivers House
Waterside Drive
Aztec West
Bristol. BS12 2UD

Tel: 01454 624400 Fax: 01454 624409

Dissemination Status
Internal : Released to Regions
External: Released to Public Domain

Statement of Use
This report assesses the effectiveness of catchment liming to treat acidification in upland catchments. The NRA will consider this information in developing or responding to proposals to protect or restore fisheries in these areas.

Research Contractor
This document was produced in-house under R&D Contract 314 by:

National Rivers Authority, Welsh Region
Plas-yr-Afon,
St. Mellons Business Park,
St. Mellons, Cardiff.
CF3 OLT.

Tel: 01222 770088 Fax: 01222 798555

NRA Project Leader
The NRA's Project Leader for R&D Contract 314 was:

Neil Weatherley - NRA Welsh Region

Additional Copies
NRA staff wishing to obtain further copies should contact their Regional R&D Coordinator. External persons should obtain copies from the Foundation for Water Research:

Tel: 01628 891589 Fax: 01628 472711

R&D Project Record 314/12/W

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

1. The principal objective of the project was to establish the effective duration of catchment liming treatments to mitigate stream acidification. This is a key factor determining the economics and feasibility of employing this form of river remediation in upland Britain. The focus of the project was a three year continuation of studies of experimental treatments in the upper River Tywi in mid Wales.

2. The main catchment treatments studied in this phase were:

   - Liming of a 34 ha moorland catchment at 9 t ha^{-1} in 1987.
   - Liming 4 ha of hydrological source areas in a 59 ha moorland catchment at 20 t ha^{-1} in 1988.
   - Liming 4 ha of source areas in a 33 ha conifer forest catchment at 30 t ha^{-1} in 1987.

3. The results demonstrated that catchment liming of acidified streams created mean chemical conditions suitable for the protection of acid sensitive biota, including brown trout, Salmo trutta L., for at least six years. However, acid episodes were not completely prevented after the first one to two years. This implied that some risk of biological damage was not eliminated although a parallel study of biological responses in the streams was inconclusive.

4. The conclusions were qualified by a number of factors. The experimental design lacked replication of catchments which would be expected to show variability in response to acidification and liming. The macroinvertebrate, macrofloral and fish populations showed little improvement in limed streams. This may be explained by the lack of replication, short-term study duration, and constraints on colonization and recovery unrelated to water chemistry. Reacidification and the return of acid episodes whilst biological recovery was being monitored, may also have inhibited population increases. Overall, the weakness of biological restoration cast some doubt on the effectiveness of the treatments.

5. Combined with other NRA projects, this study sets out the key management options for acidified surface waters. Active remedial measures include catchment liming, direct river liming and reservoir/river liming. Estimated monetary costs for the upper River Tywi indicate that catchment liming is the most expensive in this case and implications for wetland conservation interests could add qualitative costs. River and reservoir liming are cheaper and closer to the estimated monetary benefits of the improved fishery. However, the relative merits are catchment specific and the best technique for any scheme should be appraised on this basis.

6. The need for liming must be set in the context of controlling acidification by emissions reductions and adjusting catchment sensitivity by controlling land use. Recovery of surface waters with reductions in acidic emissions and deposition is uncertain but will probably be slow. Long-term trend analysis of stream chemistry of untreated reference streams in this study suggested minor changes over the past decade. Recovery is

predicted to be retarded further in afforested and replanted catchments as scavenging of atmospheric pollutants by trees tends to counteract deposition reductions. However, trends in stream chemistry here in a maturing conifer forest catchment were not significantly different from those associated with other land cover. Larger data sets may be needed to clarify such relationships.

7. Liming offers an option for the rapid recovery of water quality and fisheries. The feasibility, effectiveness and costs of catchment liming are site dependent. Sufficient information is now available to design treatments though the complexity of catchment hydrochemistry means there is some uncertainty in predicting the chemical effects, particularly on a large scale. There is also uncertainty in the biological response, so that any future studies or operational schemes should be monitored accordingly.

KEY WORDS

Acidification, afforestation, catchment, liming, source area, stream.

ACKNOWLEDGEMENTS

A number of staff at NRA Welsh Region South West Area assisted during the course of the project. The NRA National Laboratory Service at Llanelli provided all chemical analyses. Dr. A. Jenkins, Institute of Hydrology, gave assistance with trend analysis.

1. PROJECT DESCRIPTION

1.1 Introduction

Acidification of surface waters occurs as a result of acid deposition on areas of land where bedrock, soils and changes in land use, particularly to conifer afforestation, afford low buffering capacity to rainfall. Areas throughout Europe and North America are affected. In the UK these are mainly upland areas in mid and north Wales and western Scotland. Surface water acidification has detrimental effects on fish, aquatic invertebrates and flora, and birds. Consequently, the need to mitigate the effects of acidification has led to numerous liming studies, such as the current one.

Project study catchments were located in the headwaters of the River Tywi, West Wales, upstream of Llyn Brianne reservoir (Figure 1.1). Studies were initiated by the Welsh Water Authority in 1981 following the observation of poor juvenile salmonid survival in streams draining into Llyn Brianne. This was attributed to low pH, low calcium concentrations and high concentrations of aluminium in some streams. Following this initial work the Department of the Environment and Welsh Office funded research into the relationships between precipitation, geology, soils, vegetation, stream quality and land use. This work started in 1984 and continued until 1991 involving a number of organisations: Institute of Hydrology and Institute of Terrestrial Ecology; University College of Aberystwyth, Bangor, Cardiff, Lampeter and Swansea; Forestry Commission, Economic Forestry Group Ltd. and the Welsh Office, coordinated by National Rivers Authority, Welsh Region, and its predecessor. This work is reported in the book 'Acid Waters in Wales' (edited by Edwards, Gee and Stoner, 1990) and in the Llyn Brianne Final Report (1991). After 1989 most of the work was based on monitoring the effects of experimental land treatments, in particular the effects of direct application of neutralizing compounds to catchments (catchment liming). Such treatments were studied for a maximum of three and a half years to the end of this phase of the project work. From April 1991 to March 1994, continued monitoring of these land treatments has been funded by the NRA R&D programme and forms the basis for this project. The extension to the project was important primarily to determine the longevity and hence cost effectiveness of the remedial treatments. Associated research has been carried out by ITE into the effects of plot liming on vegetation and soil water chemistry. University of Wales College of Cardiff have monitored the aquatic ecology of study streams in the areas, funded by the Welsh Office.

1.2 Objectives

Overall the project was designed to investigate the impact of catchment liming treatments and land use change on stream chemistry, and to refine models for predicting the impacts of acid deposition and land use changes on the aquatic environment. This would be achieved by,

a) Continued investigation of the impact of catchment liming treatments on stream chemistry with a view to calculating the effective period of such treatments

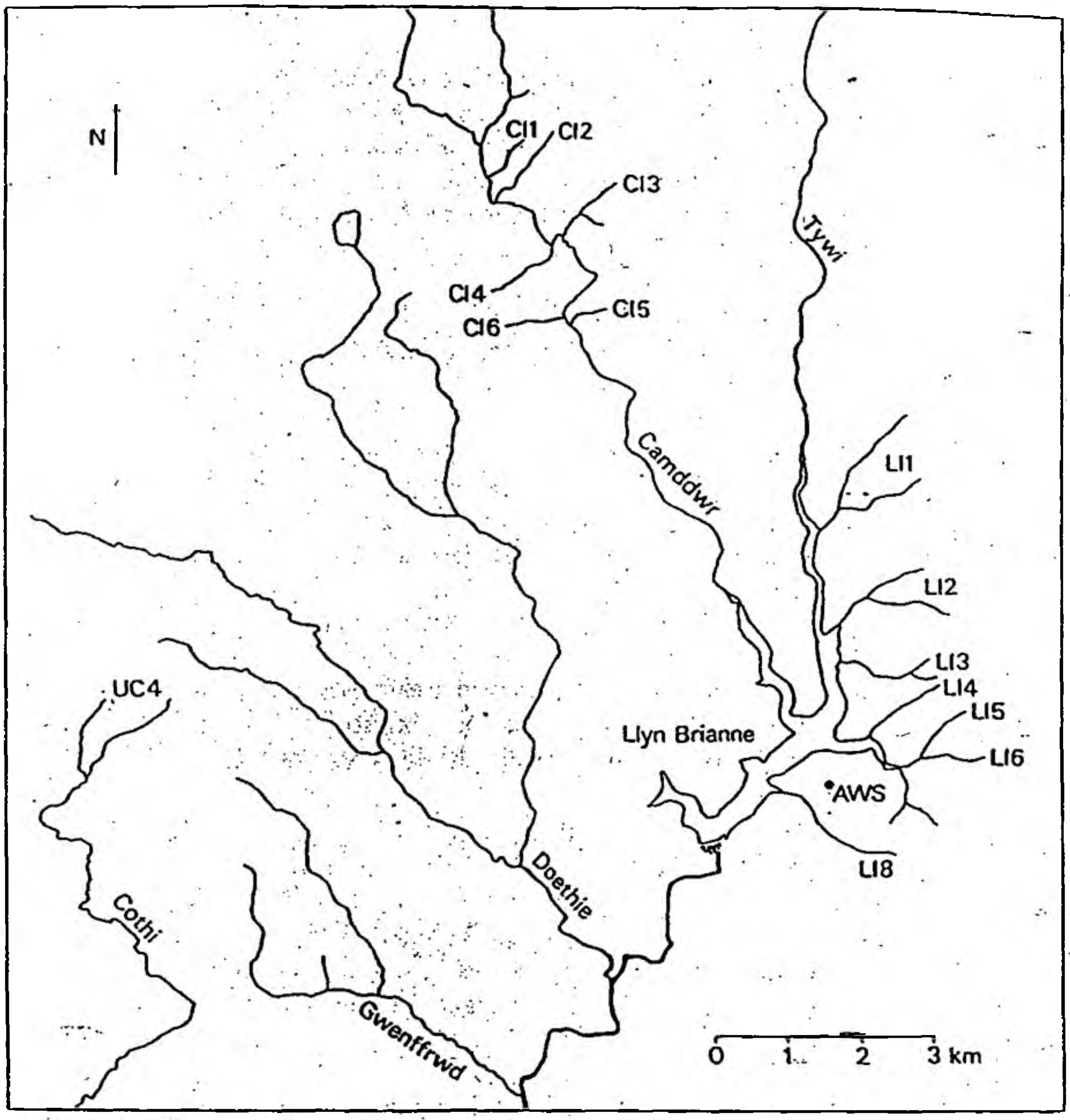
b) Investigation of the impact of canopy closure on stream water chemistry.

c) Investigation of stream chemistry in moorland and mature coniferous 'control' streams, providing data for national programmes on critical loads and MAGIC modelling.

Table 1.1 Llyn Brianne study catchments - description and treatments

Catchment	Land Use	Treatment	Treatment Date.	Catchment Area (ha)	Treatment area (ha) and % of catchment area
LI1	Closed canopy conifer forest	Reference	-	253	-
LI2	Closed canopy conifer forest	Bankside liming at 10 tonnes/ha	9/86	105	6(6%)
LI3	Closed canopy conifer forest	Source area liming (pelletized limestone), bankside clearance	11/88	64	32(50%)
LI4	Closed canopy conifer forest	Source area liming , 30 tonnes/ha	9/87	33	4(12%)
LI5	Unimproved unacidic moorland	Reference	-	66	-
LI6	Unimproved unacidic moorland	Reference	-	68	-
LI8	Open canopy conifer forest	Reference	-	66	-
CI1	Unimproved acidic moorland	Reference	-	15	-
CI2	Unimproved acidic moorland	Source area liming, 15 t/ha	6/88	59	4(7%)
CI3	Unimproved acidic moorland	Agricultural liming, 10 t/ ha	6/86	84	20(24%)

Catchment	Land Use	Treatment	Treatment Date	Catchment Area (ha)	Treatment area (ha) and % of catchment area
CI4	Unimproved acidic moorland	Contour ploughing	10/86	49	8 (16%)
CI5	Unimproved acidic moorland	Surface liming at 9 tonnes/ha	9/87	34	34 (100%)
CI6	Unimproved acidic moorland	Reference	-	72	-
UC4	Unimproved acidic moorland	Ploughing and planting with conifers	3/89	237	50 (21%)



AWS = auto weather station

Figure 1.1 Location of study catchments

1.3 Study area and catchment treatments

1.3.1 Study Area

Project studies were located in the headwaters of the River Tywi, West Wales, upstream of Llyn Brianne reservoir (Figure 1.1). Sites are some 90km from the sea and receive around 1800mm of rainfall per year. Bedrock geology in the area is mainly Ordovician and Silurian shales, grits and mudstones which are overlain by ferric stagnopodzol and brown podzolic soils. Land use in the area is dominated by Sitka spruce (*Picea sitchensis*) and Lodgepole pine(*Pinus cortortus*) planted in the late 1950s. Other land uses include improved agricultural land and unimproved moorland used for rough grazing. Full details of the area, study sites and treatments are given in Stoner et al., 1984; Weatherley and Ormerod, 1987. These are summarised in Table 1.1.

1.3.2 LI1 Conifer Forest Stream: Reference site

LI1 drains a mature coniferous forest catchments. It has the largest catchment area of all the study streams, covering 253 hectares. The water quality is characteristically poorly buffered with very low pH values consistently throughout the year, being more acidic than the streams draining moorland catchments. The low pH levels are coupled with high aluminium concentrations, higher than those of any other stream. Seasonality patters are evident at LI1 with reduced pH, and increased aluminium levels occurring during the winter. This stream has been monitored since 1981 as a reference for other afforested streams in the study. Discrete (spot) samples were collected initially on a weekly basis then bi-weekly.

1.3.3 LI2 Conifer Forest Stream: Bankside Liming

LI2, like LI1, drains a mature coniferous forest catchment. It has the second largest catchment of the forest streams covering an area of 105 hectares. The stream underwent 'bankside clearance and liming' treatment during the summer of 198. Banksides were cleared to a minimum total width of 15m on the main stream and 10m on each tributary. In September 1986, 60 tonnes of magnesium limestone, particle size 4mm - dust, were sprayed by helicopter over the cleared strips at a density of 10 tonnes per hectares. The total area treated was 6 hectares. The stream was spot sampled over a period of 6 years from April 1985 to June 1991. Detectable effects of the treatment were extremely short lived and monitoring of the stream was not continued in the current project.

1.3.4 LI3 Conifer Forest Stream : Pelletized Liming

Stream LI3 has a catchment area of 64 hectares. The catchment is acidic and prone to high fluxes of aluminium, although with a slightly greater buffering capacity than the reference and LI2 catchment.

Treatment of the catchment was carried out in November 1988 when nine hectares of the hydrological source area were limed with 105 tonnes of pelletized lime. Pellets were made from a combination of chalk, starch and bentonite, 4 x 3 x 8cm, and were intended to penetrate the forest canopy during aerial bombardment from a helicopter and slowly dissolve over several years. Three areas were bombarded with pellets: two areas were located in the afforested part of the catchment, covering an area of 6 hectares and received 60 tonnes of pellets; the third was a 3 ha area of boggy moorland which received 47 tonnes of lime.

The stream was monitored by fortnightly spot sampling for a period of eight years from October 1984 to October 1992.

1.3.5 LI4 Conifer Forest Stream : Source Area Liming

The LI4 catchment area is 33 hectares and of this, four hectares of unplanted peat, including the source, were chosen for intense liming treatment. 120 tonnes of fine powdered limestone were deployed at a rate of 30 tonnes per hectare during November and December of 1987. This stream has been monitored by spot sampling since 1981, on a biweekly basis.

1.3.6 LI5 Moorland Stream : Reference Site

The stream drains a moorland catchment of area 66 hectares and it of immediate acidity. It was monitored as a reference site in earlier phases of the project and is included here for completeness. LI5 was first monitored in 1981 but for the purposes of this study only data from 1984 have been used. Spot samples were taken fortnightly until monitoring finished in May 1991.

1.3.7 LI6 Moorland Stream : Reference Site

This moorland stream has been used as the control for other moorland streams in the Camddwr catchment. In contrast to the other moorland streams this is moderately well buffered, of comparatively high hardness, generally circumneutral pH and low dissolved aluminium levels. Monitoring by spot sampling originally started in 1981 and was continued until 1994 on a biweekly basis.

1.3.8 LI8 Young Forest Stream : Forest Growth/Reference Site

This stream drains a 66 hectare area of land that was planted as a coniferous plantation during the early 1970s. The catchment was used as a reference to assess the effect of canopy closure on the chemistry of the stream. MAGIC (Model or Acidification of Groundwater in Catchments) has been used to predict the trend in water quality for LI8 as the trees mature. This stream has been monitored by spot sampling since 1984, on a biweekly basis.

1.3.9 CI1 Moorland Stream : Reference Site

The catchment represents an unimproved acidic moorland stream - pH, dissolved calcium and alkalinity are all typically low. Spot samples were collected at CI1 initially on a weekly and subsequently biweekly basis from August 1985 to the end of December 1993.

1.3.10 C12 Moorland Stream : Source Area Liming

Source areas within the catchment were limed in June 1988 at a rate of 20 tonnes ha^{-1}, targeted at four hectares (7%) of the entire catchment. Discrete water quality monitoring commenced at CI2 in August 1984 and has continued on a weekly basis.

1.3.11 CI3 Moorland Stream : Agricultural Liming

The catchment was an unimproved acidic moorland stream. In May/June 1986 an area of 20ha (24%) of the catchment was treated following guidelines for pasture improvement in upland Wales. The area was ploughed, limed and reseeded following application of NPK fertiliser. Despite the addition of 200 tonnes of agricultural grade (4mm to dust) magnesium limestone to the catchment, the treatment did not have any significant effect on the water quality of the stream. Water quality monitoring commenced at CI3 in August 1984 and continued through to June 1991, the data are included here for reference purposes.

1.3.12 CI4 Moorland Stream : Reference Site

This catchment was originally intended to test the effects of forestry ploughing without planting. Treatment consisted of contour ploughing and drainage of 8ha of peat moorland (16% of the catchment) and was completed in October 1986. Further ploughing was abandoned because of soil instability and no effects on stream chemistry were detected. This site has subsequently served as a reference site. Discrete water quality monitoring commenced at CI4 in March 1984 and continues through to the present.

1.3.13 CI5 Moorland Stream : Catchment Liming

The complete catchment (34ha) of CI5 was treated with limestone at a rate of 9 tonnes ha^{-1} in September 1987. This stream has been subject to fortnightly spot sampling since January 1984.

1.3.14 CI6 Moorland Stream : Reference Site

CI6 is an acidic moorland stream, which was not monitored in the current project. Discrete (spot) samples were collected at CI6 on a biweekly basis from August 1984 to June 1991. Data are included here for completeness.

1.3.15 UC4 Moorland/Young Forest Stream : Reference Site with New Planting

This catchment is a reference site with a stream of intermediate acidity. Independently of the project, some 50ha of the catchment (21%) of UC4 was ploughed and planted with conifers in the spring of 1989. Monitoring commenced at UC4 in May 1985 and continued to the end of December 1993.

1.4 Stream Chemistry Methods

For the current project, discrete (spot) samples were collected from each study stream on a fortnightly basis. These were analysed for: pH (Skalar automated system); alkalinity

(Mettler/Metrohm autotitrator); conductivity (manual Phillips conductivity meter); hardness (calculated as 2.5* Ca + 4.11 *Mg); colour ammonia, total oxides of nitrogen, chloride, ortho-phosphate, silica and dissolved organic carbon (Automated colorimetric analyser); total and dissolved sulphate, dissolved magnesium and calcium (Inductively coupled plasma optical spectroscopy); dissolved fractions of aluminium, manganese, sodium, potassium, lead, cadmium, copper, nickel, iron, chromium and zinc (Inductively coupled plasma mass spectroscopy). Samples for analysis of dissolved metals were filtered in the field using 0.45m membrane filters.

Continuous monitoring in streams LI1 and CI2 was also undertaken. pH, conductivity and temperature were measured using pHOX 100 DPM multiparameter instruments which logged data at 15 minute intervals; pH measurement was by Russel combination glass electrode. Flow (stream height) was logged at 15 minute intervals via a pHOX 80pl unit. These sites also had Rock and Taylor autosamplers, triggered by periods of intense rainfall, to collect stream water samples during selected storm events.

1.4 Deposition methods

Bulk precipitation samples were collected on a weekly basis at Trawsnant weather station as part of the UK Acid Deposition Network (UKRGAR, 1990). Data available covers the years 1986 to 1993.

2. ASSESSMENT OF CATCHMENT TREATMENTS

2.1 Results of monitoring of limed catchments

2.1.1 LI3 Conifer Forest Stream : Pelletized Liming (Figures 2.1.3.i & ii)

Before liming, annual mean pH ranged from pH 4.8 to 5.4. After liming pH ranged from pH 5.8 the following year to pH 5.5 in 1991, though in some quarters, the mean remained around pH 5.0. Calcium levels rose significantly after the liming treatment. Mean $CaCO_3$ concentration during summers pre-liming was 2.2mg l^{-1}. During the summer immediately after liming the quarterly mean was 4.4mg l^{-1} $CaCO_3$. Calcium concentrations in LI3 have remained high since liming. Alkalinity, closely related to calcium, received a boost from liming and peaked in the summer of 1989 at 6.4mg l^{-1}. However, levels fell to those recorded in previous years during the winter. Alkalinity and calcium were also high in the summers of 1990 and 1991, but these periods were exceptionally dry. Aluminium concentrations for LI3 remained below 0.4mg l^{-1} for the whole of the winter 1988/1989, but climbed again in subsequent winters to over 0.6mg l^{-1}.

A previously reported study (Nisbet, 1991) showed that whilst the upper soil horizons were initially influenced by pelletized liming, this was only short lived. In two treated areas the reason for the poor results could be attributed to the failure of the pellets to disintegrate. However, at a moorland sub-catchment where pellets were applied drainage water was significantly more buffered for up to a year after liming. Possible reasons were the greater exposure to weathering and therefore better pellet disintegration, or alternatively the higher loading of lime applied to this area. Even here the desired long-term effect was not observed, primarily due to incomplete dissolution of the pellets.

2.1.2 LI4 Conifer Forest Stream : Source Area Liming (Figures 2.1.4.i & ii)

Before liming, mean pH at LI4 was 5.1, this rose to an average of pH 6.4 following treatment. Quarterly means prior to liming ranged from pH 4.8 to 5.3. Since liming, quarterly means ranged from pH 6.0 to 6.9. In contrast to the previous site, pH declined from 6.8 in April 1988 to pH 5.5 during a dry weather spell, rising again to around pH 7.0 after heavy rain. This suggested that the dominant input to the stream during dry weather was either acid groundwater or water from further down the catchment which was unaffected by liming. Statistical analysis for several patterns (Tables 2.1.15 and 2.1.16) showed there was no significant difference between winter and summer pH following liming. The pH of the stream has shown only a small decline with an annual mean of pH 6.3 in 1993, five to six years after liming. Also minimum pH values are rarely below pH 5.5.

Alkalinity, with a preliming average of 1.6mg l^{-1} $CaCO_3$ showed a large increase the year following liming when the concentration rose to 11.4 mg l^{-1} $CaCO_3$. Over the next five years, 1989 to 1993, annual means for alkalinity declined from 6.3 to 5.0, still a significant improvement on pre-liming conditions. Seasonal variation in alkalinity concentrations (Tables 2.1.15 and 2.1.16) was not observed after liming.

Table 2.1.15 Seasonal means of selected determinands for 4 streams (Pre- and post-liming periods are indicated)

Stream	Year	Summer (01/04-30/09)				Winter (01/10-31/03)			
		pH	alk	[Ca]	[Al]	pH	alk	[Ca]	[Al]
L14	1985	5.06	1.21	1.80	0.15	4.99	1.08	1.85	0.19
	1986	5.00	1.14	1.81	0.18	4.99	1.27	1.85	0.27
	1987	5.18	1.65	2.10	0.17	6.10	5.71	4.71	0.15
	1988	6.52	10.02	6.71	0.08	6.75	12.93	6.66	0.08
	1989	6.28	5.98	4.79	0.05	6.34	5.20	5.12	0.09
	1990	6.56	6.96	5.01	0.06	6.34	4.18	5.27	0.10
	1991	6.39	4.64	4.45	0.10	6.35	4.04	4.76	0.05
	1992	6.20	4.35	4.24	0.09	6.29	4.40	4.08	0.07
	1993	6.35	5.13	4.11	0.06				
CI2	1985	4.88	1.17	0.72	0.16	5.18	1.55	0.83	0.15
	1986	5.17	1.48	0.84	0.13	5.01	1.42	0.83	0.15
	1987	5.26	1.86	0.82	0.15	4.73	0.76	0.71	0.19
	1988	6.46	11.39	5.58	0.14	6.82	10.23	4.98	0.10
	1989	6.77	9.91	4.57	0.12	6.18	4.48	3.16	0.12
	1990	6.44	5.83	2.90	0.16	5.92	2.59	2.61	0.12
	1991	6.25	4.52	2.32	0.16	5.94	2.56	1.85	0.09
	1992	6.28	4.19	1.96	0.10	6.03	3.08	1.52	0.09
	1993	6.24	4.19	1.55	0.10				
C13	1985	5.20	1.54	0.81	0.11	5.17	1.28	0.87	0.12
	1986	5.27	1.33	0.89	0.11	5.13	1.44	1.07	0.19
	1987	5.51	1.89	1.08	0.13	5.20	1.52	1.11	0.18
	1988	5.43	1.59	1.17	0.11	5.23	1.42	1.12	0.15
	1989	5.69	3.03	1.40	0.09	5.07	1.47	1.26	0.36
	1990	5.48	1.62	1.30	0.10	4.95	1.09	1.57	0.23
CI5	1985	5.23	1.47	0.78	0.13	5.25	1.40	0.85	0.14
	1986	5.30	1.44	0.90	0.12	5.14	1.48	0.91	0.24
	1987	5.42	2.42	1.31	0.14	6.44	4.81	3.38	0.07
	1988	6.42	4.76	2.83	0.06	6.29	3.77	2.81	0.08
	1989	6.47	5.40	2.87	0.05	6.00	2.72	2.81	0.08
	1990	6.40	3.54	2.55	0.06	6.00	2.72	2.68	0.07
	1991	6.34	3.51	2.27	0.06	5.88	2.22	2.93	0.11
	1992	6.23	3.29	2.15	0.04	5.95	2.51	2.34	0.09
	1993	6.31	4.23	1.77	0.03	6.00	3.11	1.92	0.05

Table 2.1.17 CI2 Post-liming calcium budget (7/88 - 12/92).

Year Quarter	Mean weekly loss of added calcium (kg)	Total loss of added Ca in quarter (kg)	% of initial dose
1988 JAN-MAR	0.00	0.00	
APR-JUN	10.45[a]	20.90	
JUL-SEP	167.05[a]	2171.65	
OCT-DEC	240.95[a]	3132.35	
TOTAL		5324.90	22.2
1989 JAN-MAR	140.56[a]	1827.28	
APR-JUN	19.43[a]	252.59	
JUL-SEP	10.96[a]	142.48	
OCT-DEC	45.45[a]	590.85	
TOTAL		2813.20	11.7
1990 JAN-MAR	89.26[a]	1160.38	
APR-JUN	40.23[a]	522.99	
JUL-SEP	25.82[a/b]	335.66	
OCT-DEC	46.17[a]	600.21	
TOTAL		2619.24	10.9
1991 JAN-MAR	21.69[a/b]	281.97	
APR-JUN	10.13[b]	131.69	
JUL-SEP	11.48[b]	149.24	
OCT-DEC	15.85[b]	206.05	
TOTAL		768.95	3.2
1992 JAN-MAR	19.62[a]	255.06	
APR-JUN	6.74[a]	87.62	
JUL-SEP	13.44[a]	174.72	
OCT-DEC	26.50[a]	344.50	
TOTAL		861.90	3.6

Total loss of added calcium since liming in June 1988 = 12.39 tonnes
= 52% of initial dose

(Total amount of limestone applied: 60 tonnes = 24 tonnes calcium)

CI2 flow derived from equations:

[a]CI2 flow (l/s) = 1633.6 (stage height + 0.05) $^{2.186}$ (from Walsh & Boakes 1991)

[b]CI2 flow (l/s) = (antilog (-1.45 + 0.9281$\log_{10}$ (LI1 flow + 1) - 1

where r^2 (based on mean daily flows at CI2 & LI1 in 1992) = 66.3%

than in summer (Tables 2.1.1 and 2.1.2).

Plots for CI2 of continuous monitoring data are shown in Figure 2.1.3.iii for April 1992 to January 1993. During the spring and early summer flows were low with only six spates. This was coupled with pH values of above 6.0. From August higher flows were associated with a drop in pH to between 4.0 and 5.0.

Calcium budget for CI2 following liming

A calcium budget for CI2 following liming was calculated using laboratory determined Ca concentrations and continuous flow data (Table 2.1.17; Figure 2.1.9.iv). A linear relationship ($r^2 = 66.3\%$) was determined between flume data at L11 and flow data at CI2. This relationship was used to estimate flows at CI2 for periods when the flow measurement instrument at CI2 was not in use. The total loss of added calcium from this catchment, since liming in 1988, was estimated at 12.4 tonnes (52% of the initial dose). The additional output of calcium in the first 18 months following liming was calculated to be 3.6 tonnes year $^{-1}$. This is in reasonable agreement with the figure of 3.8 tonnes year $^{-1}$ estimated for the same period at CI2 by Waters et al., (1991).

2.1.4 CI5 Moorland Stream : Catchment Liming (Figures 2.1.12.i & ii)

Pre-treatment values for pH were in the range pH 4.6-6.2 with annual means of between pH 5.1 and 5.2. Minima of pH 4.7 or below occurred in every year prior to liming.. Annual mean alkalinity values were between 1.4 and 1.6mg l^{-1} $CaCO_3$ and annual mean dissolved calcium concentrations were 0.8-1.0mg l^{-1}, with maxima to 1.6mg l^{-1}.

Following liming there was a step improvement in stream pH (mean pH increased from pH 5.2 to 6.4) with a corresponding rise in alkalinity of around 5mg l^{-1}, and a reduction in dissolved aluminium (mean reduced from 0.16 to 0.07mg l^{-1}). Reacidification at CI5 appears to have occurred at a slower rate than at CI2. Annual mean pH following liming remained between pH 6.1 and 6.4 with no minima below pH 5.0. Dissolved calcium and alkalinity concentrations have both declined, though not as rapidly as at CI2, and remained well above pre-treatment values, 1.88mg l^{-1} Ca and 4.11mg l^{-1} $CaCO_3$ for 1993 data. Mean dissolved aluminium remained low at 0.04-0.08mg l^{-1}.

Seasonality patterns are evident following liming for all of the determinands. Lower pH accompanied by increased aluminium characterised the winter period (Tables 2.1.15 and 2.1.16).

2.2 Longevity of effective treatment at CI2

2.2.1 Biological responses at CI2

The results of studies by the University of Wales College of Cardiff are summarized here (see Rundle et al., 1995). Following liming, densities of 0-group and I-group brown trout (Salmo trutta) increased significantly, in line with modelling predictions of the effect of liming on stream biology. However, similar changes also occurred in the adjacent reference stream, CI1, meaning that the effects of liming and natural variation in fish numbers could not be clearly separated. The taxon richness of acid-sensitive macroinvertebrates also increased in the limed stream, compared with its reference, but was still substantially lower than in naturally circumneutral streams (Rundle et al., 1995).

2.2.2 Storm event streamwater chemistry at CI2

Although the amount of storm event chemistry data from autosamplers was limited and flows may differ between these events, the effects of liming are indicated from selected chemical time series (Figure 2.1.9). Prior to liming, a drop in pH of about 0.5 units typically occurred with the onset of a storm event (Table 2.2) with a corresponding increase in the aluminium concentrations. Calcium concentrations remained fairly constant. However, immediately following liming, large releases of calcium in the order of 8mg l^{-1} occurred in response to significant increases in stream flow. This resulted in the maintenance of pH level and a transient decrease in aluminium concentrations. One year after liming the rise in calcium concentration was less pronounced but was still sufficient to prevent the pH falling and a consequent rise in aluminium concentrations. During 1993, five years after liming, storm events resulted in marginal increases in calcium concentration (less than 1mg l^{-1}) which were not sufficient to prevent the pattern of temporarily decreased pH and increased aluminium being re-established. However, the impact of storm events on water quality in 1993 was not as severe as before liming, in 1987.

2.3 Discussion

Results from two catchments (CI2 and CI5) indicated that catchment liming created mean chemical conditions (pH > 5.8) suitable for the protection of acid sensitive biota, including brown trout, for a duration of at least five or six years. Both treatments involved dosing of the hydrological source areas, previously concluded to be critical to effectively controlling stream chemistry (Llyn Brianne Final Report, 1992). There was some evidence that whole catchment liming was more long-lasting than source area liming as calcium concentrations were higher and aluminium concentrations lower to the end of the present reporting period. Calcium is important as it increases the tolerance of fish to acid-related toxicity, whilst lower aluminium concentrations will reduce toxic effects during any acid episodes (pH < 5.5).

Acid episodes recurred within two years of liming though their impact was uncertain, being dependent on a combination of their timing, severity, duration and frequency. Unmanipulated streams of similar mean pH are episodically acidic yet support moderate trout populations (Weatherley & Ormerod, 1991), suggesting that temporary failures in buffering may be damaging but not necessarily cause high mortality.

A parallel biological project showed limited change of macroinvertebrate, macrofloral and fish populations towards unimpacted status (Rundle et al., 1995). This may be explained by the relatively short-term study duration, and constraints on colonization and recovery related to dispersal abilities, rather than by water chemistry effects. Colonization processes appear important, as increases in invertebrate populations in the main River Tywi, downstream of Llyn Brianne after liming have occurred rapidly by downstream drift from source populations in unacidified tributaries (Evans, 1994). However,

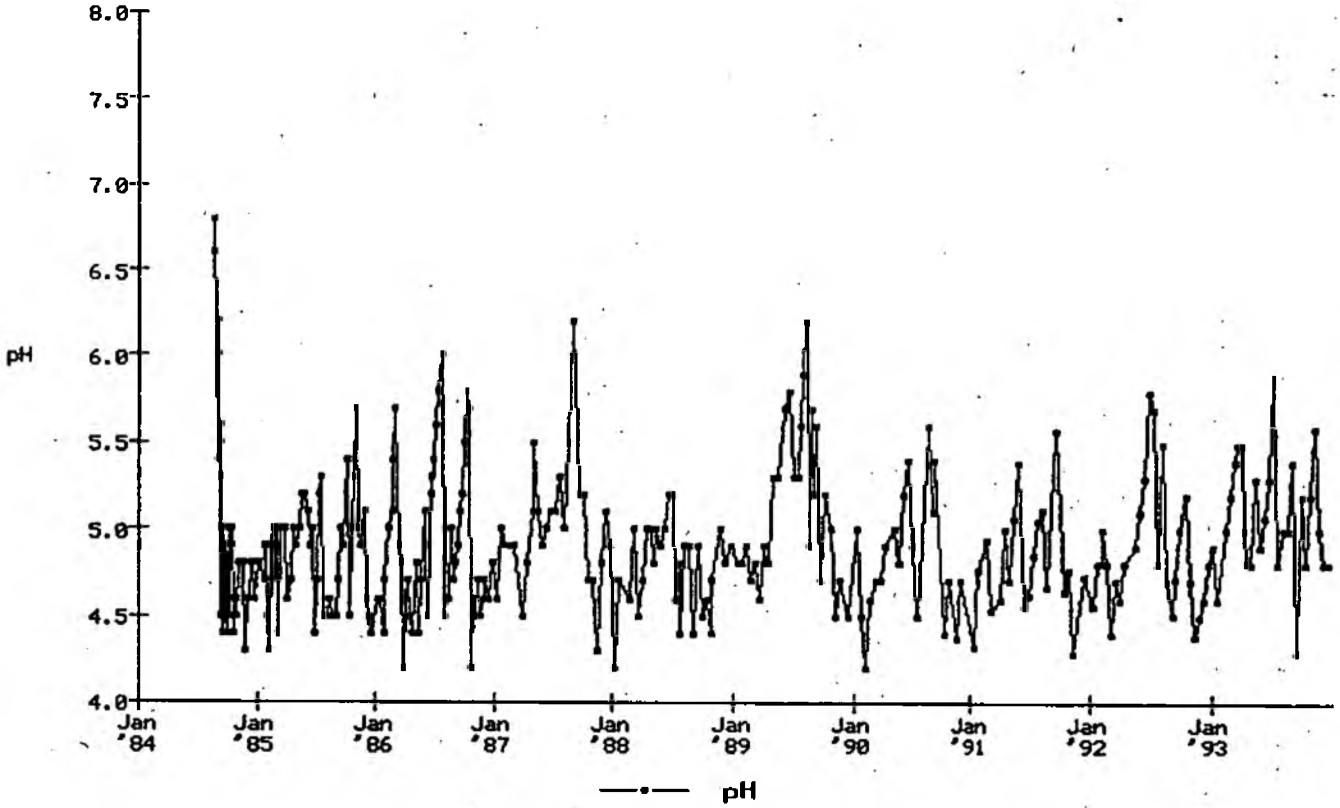
Table 2.2 Minimum pH values from autosamples during storm events at CI2

Date	Maximum stream height (m)	Minimum pH	
03/06/87	0.28	4.6	
17/06/87	0.30	4.7	
30/07/87	0.30	4.6	
13/08/87	0.30	4.8	
23/09/87	0.55	4.4	Pre-liming
27/12/87	-	4.4	(mean pH = 5.1)
23/01/88	0.48	4.5	
13/03/88	0.40	4.4	
01/05/88	0.20	4.6	
23/05/88	0.20	4.7	
10/07/88	0.35	6.7	
21/07/88	0.39	7.1	
18/08/88	0.57	7.0	
26/10/88	0.45	5.9	
08/11/88	0.33	6.6	
09/11/88	0.27	6.8	
02/03/89	0.43	6.7	Post-liming
29/06/89	-	4.5	(mean pH = 6.4)
19/10/89	0.62	5.8	
11/02/90	-	5.7	
15/05/90	-	6.2	
28/10/92	0.35	6.1	
03/04/93	0.33	6.0	
07/04/93	0.56	5.7	
24/04/93	0.21	6.1	

reacidification and the return of acid episodes whilst biological recovery was being monitored, may also have inhibited population increases. Overall, the weakness of biological restoration leaves some doubt about the effectiveness of the treatments.

Continued monitoring of the treated streams is recommended. Significant positive effects of the treatments on water quality were apparent to the end of the current project and the duration of effects should be established by a minimum level of monitoring. Monthly chemistry samples are recommended as adequate for this purpose.

Fig 2.1.1.i **Spot sample data for LI1 Aug'84 to Dec'93**



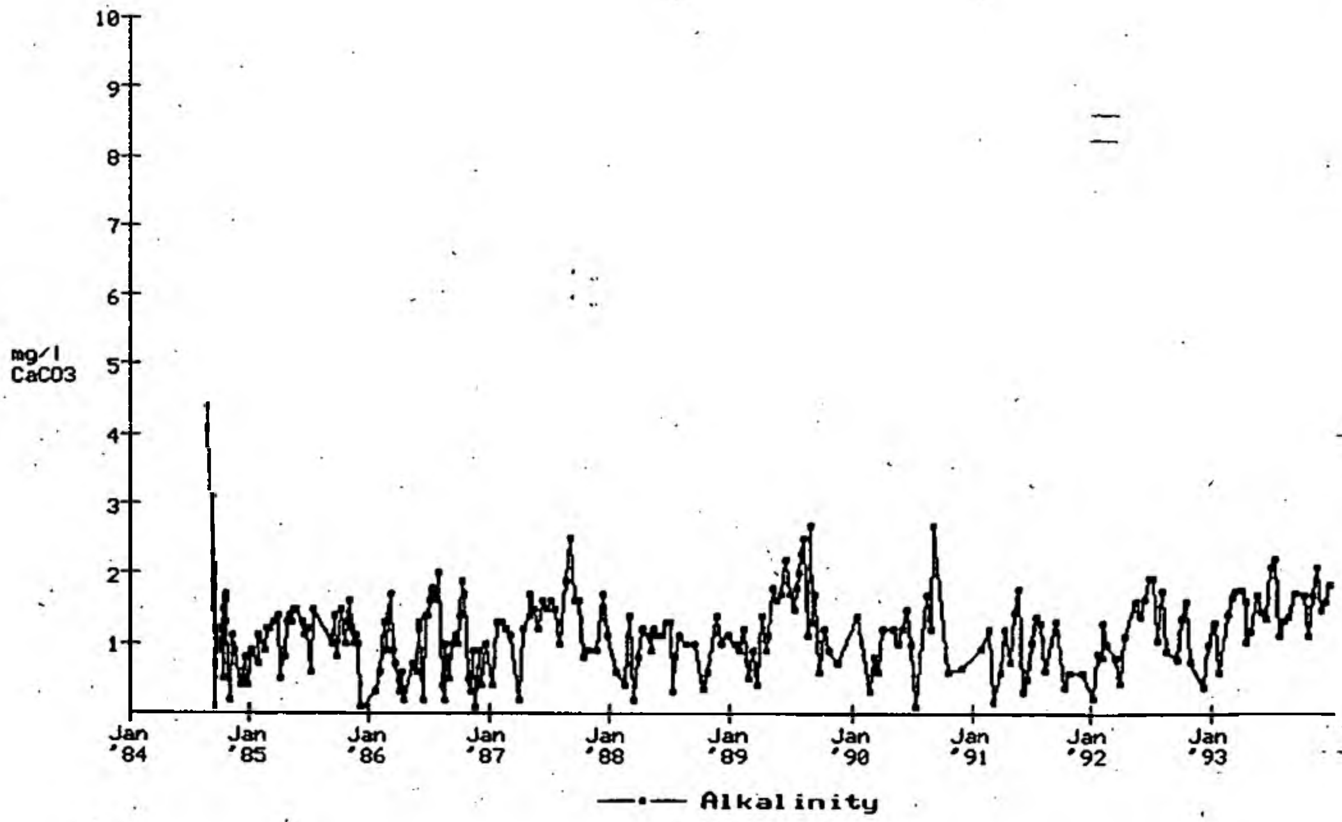
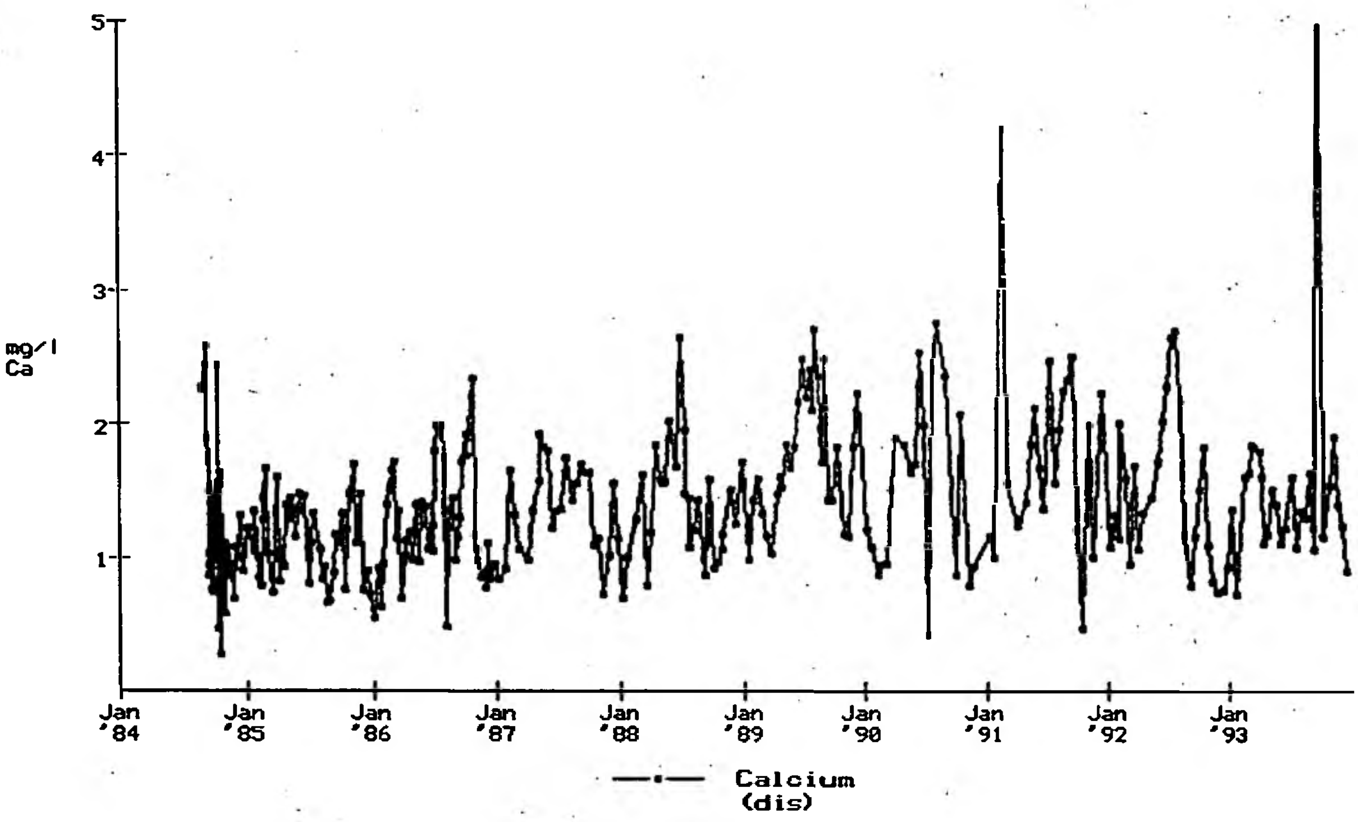


Fig 2.1.1.ii Spot sample data for LI1 Aug'84 to Dec'93



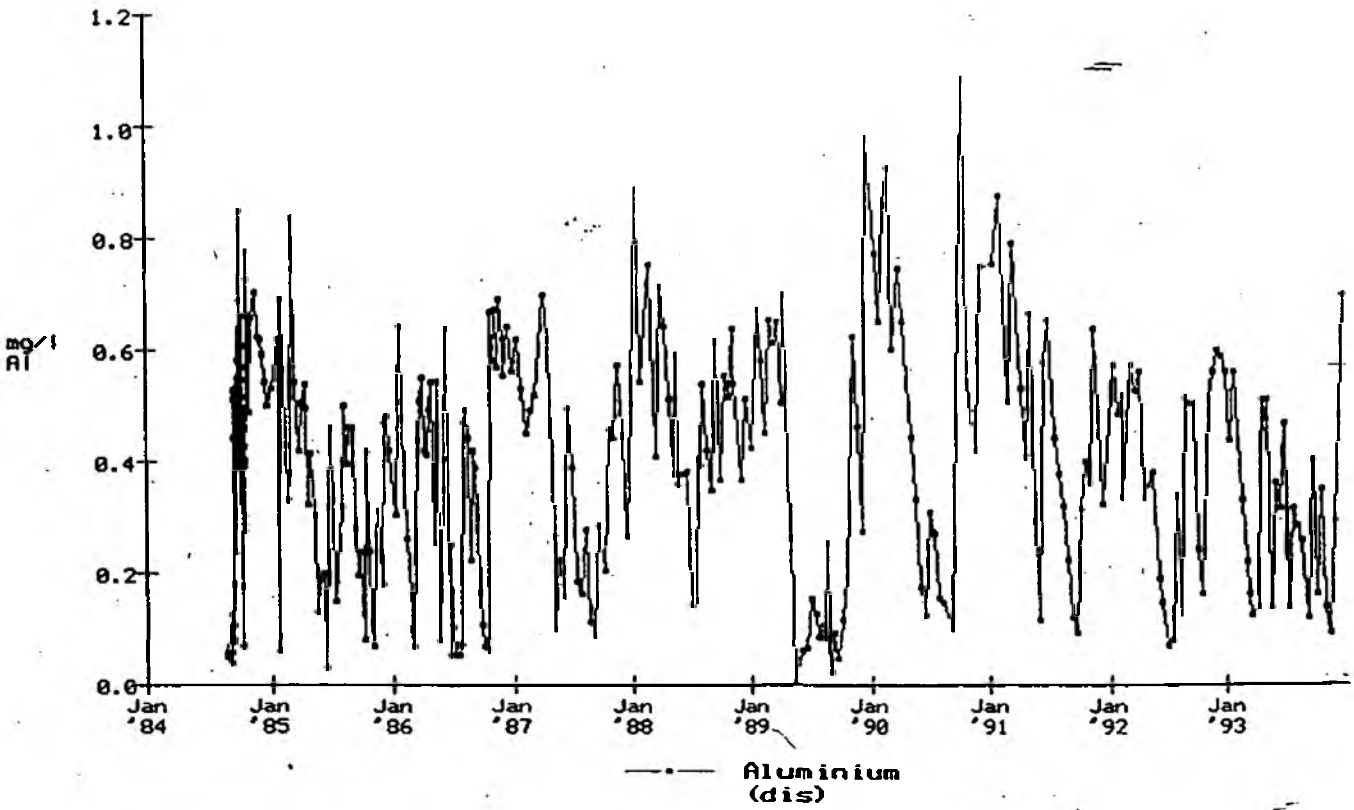
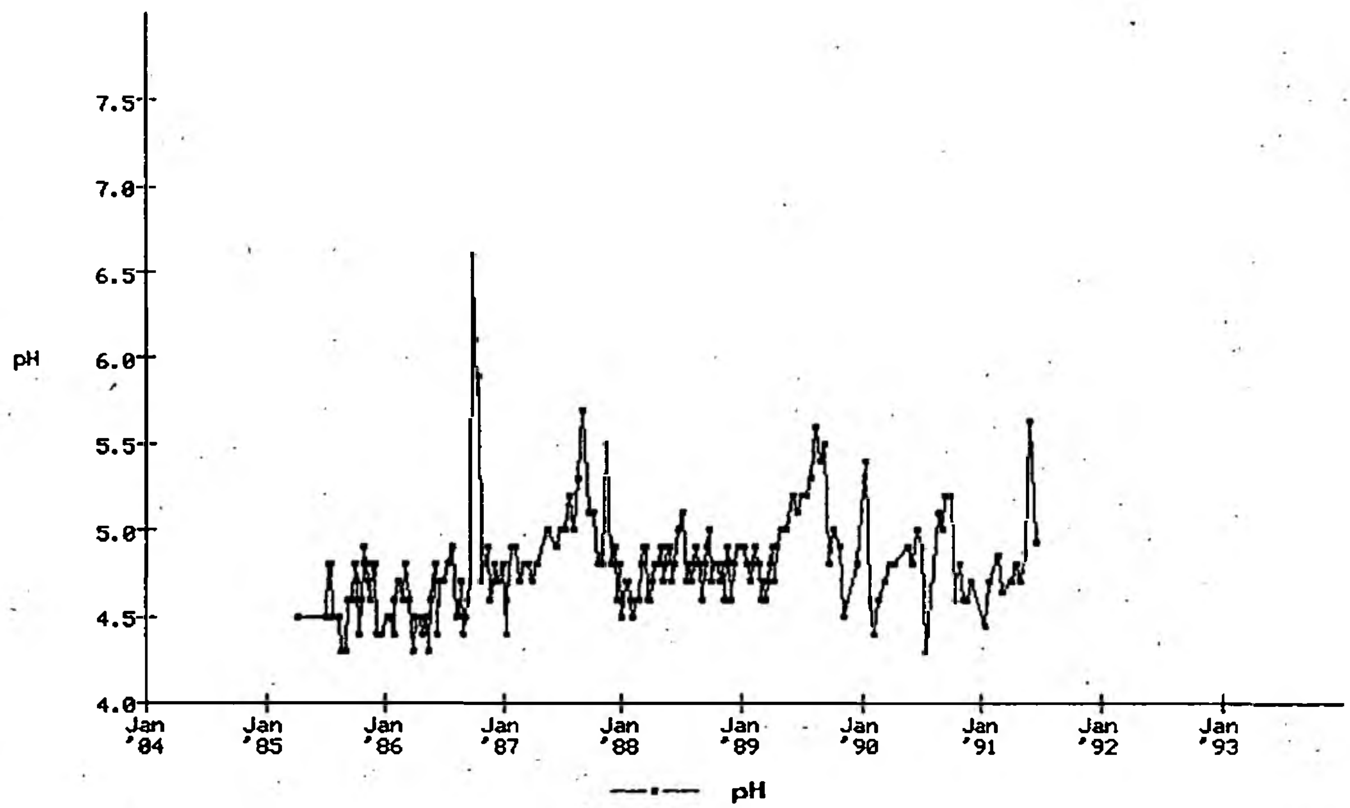


Fig 2.1.2.i Spot sample data for LI2 Mar'85 to June'91



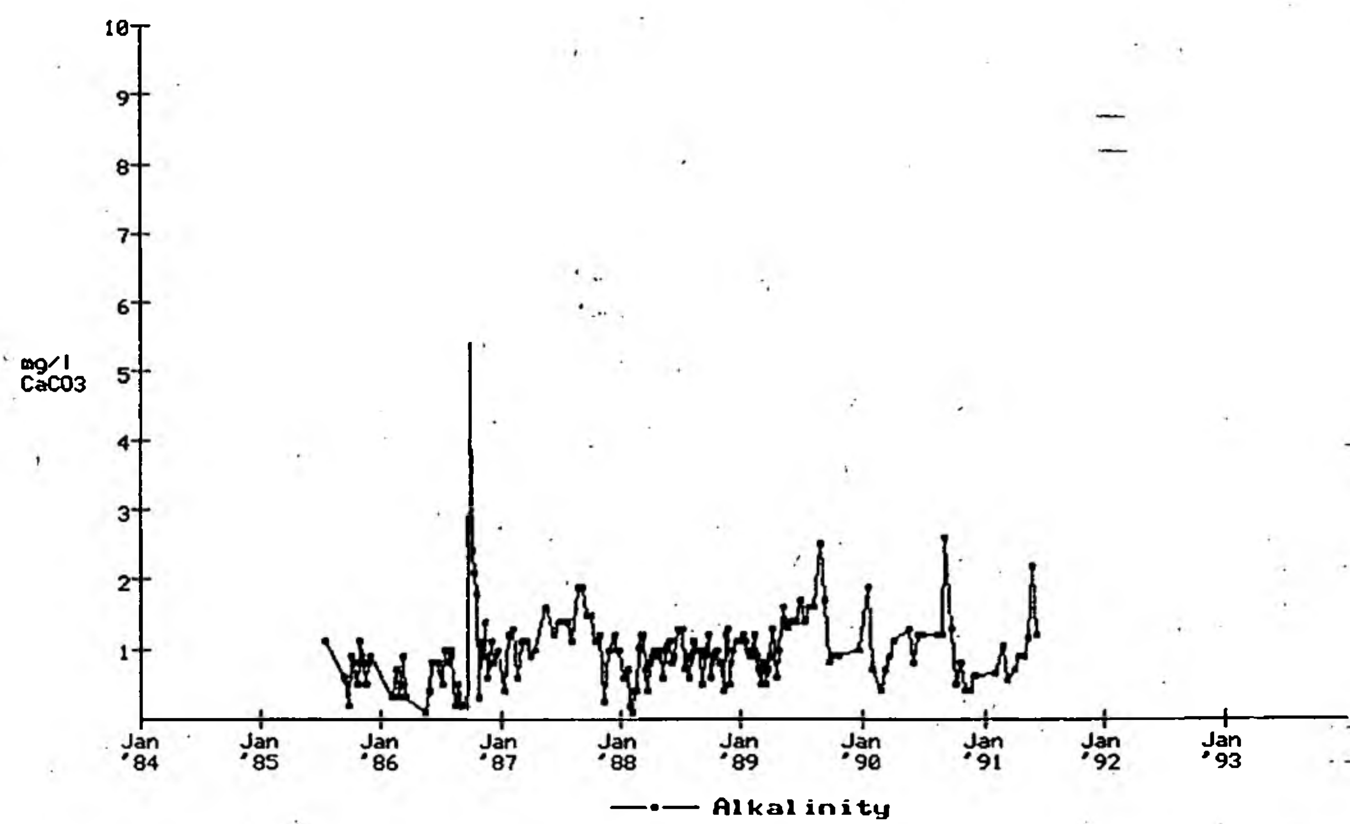
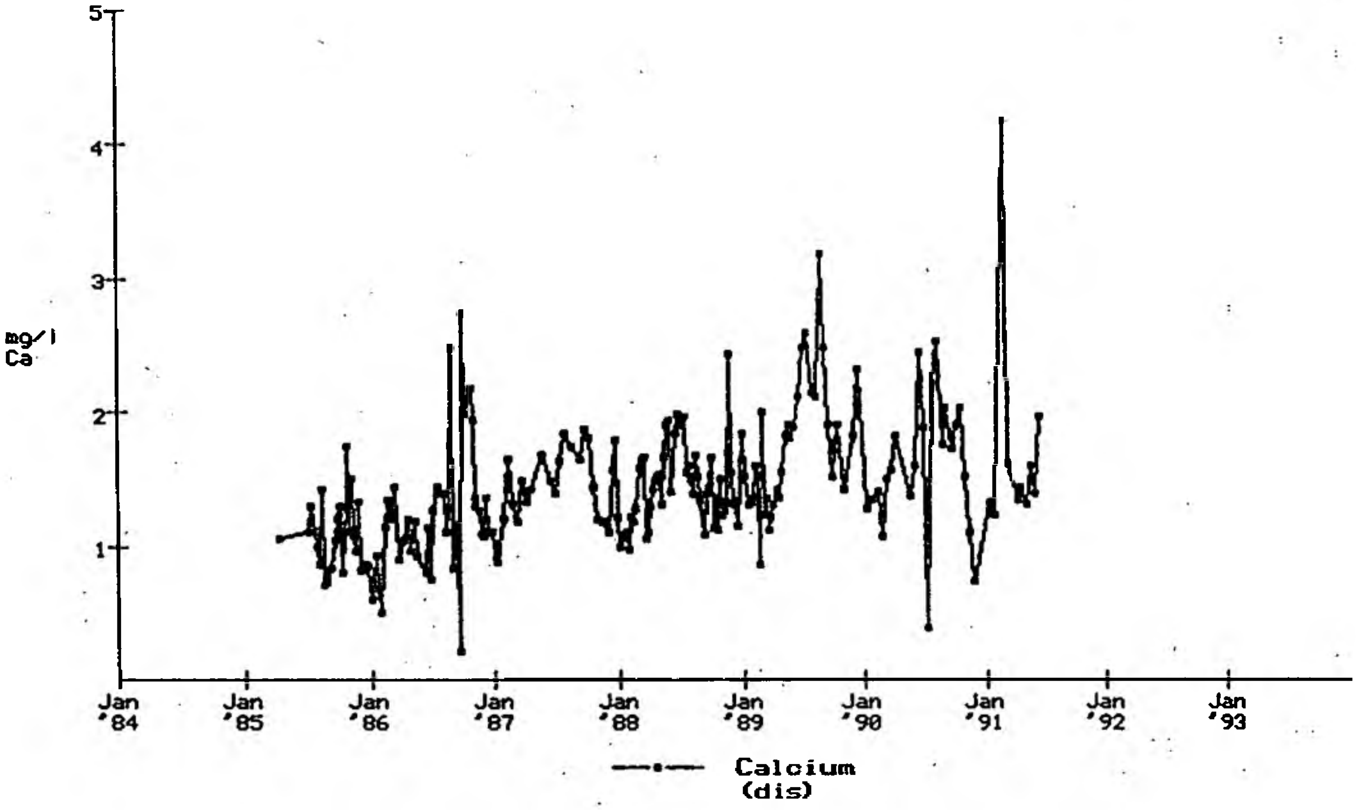


Fig 2.1.2.ii **Spot sample data for LI2 Mar'85 to June'91**



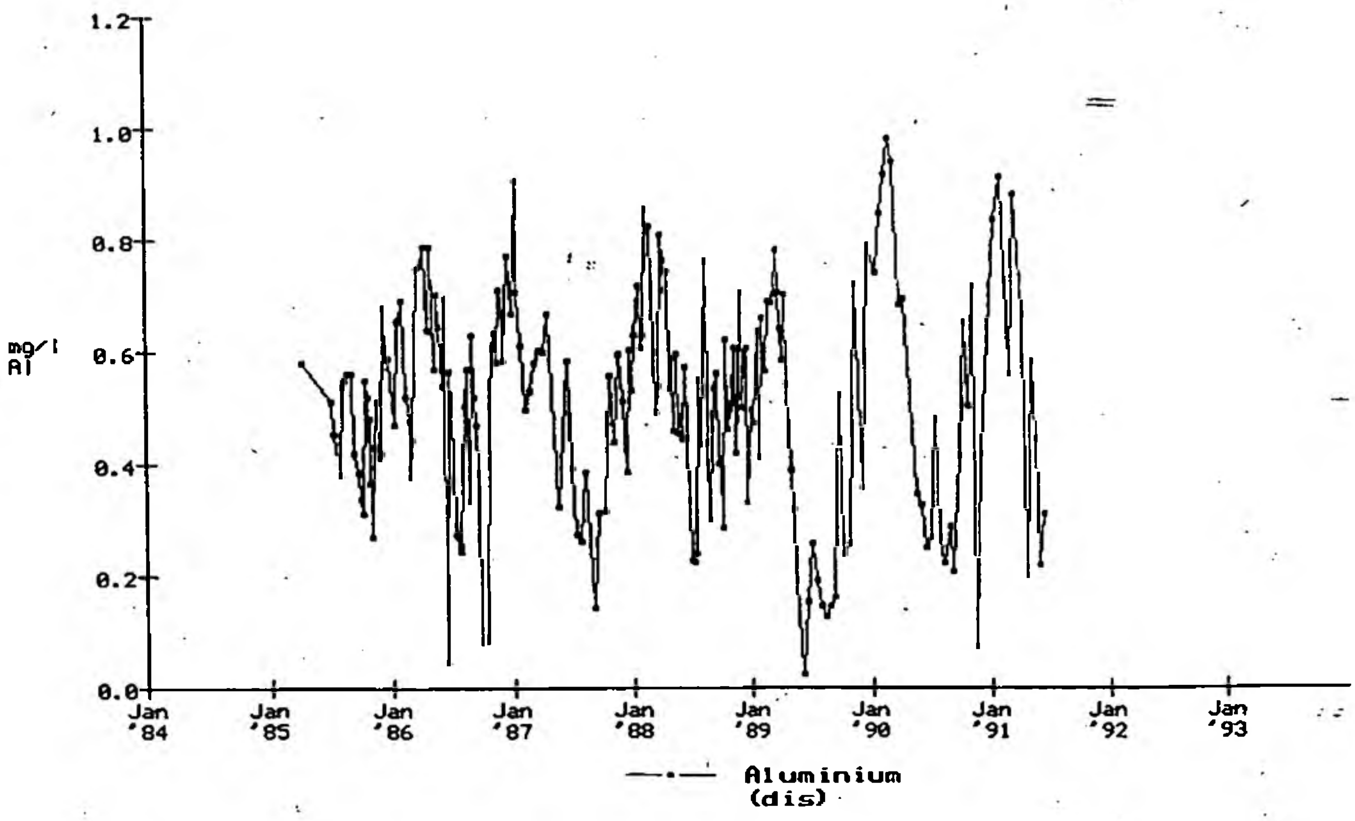
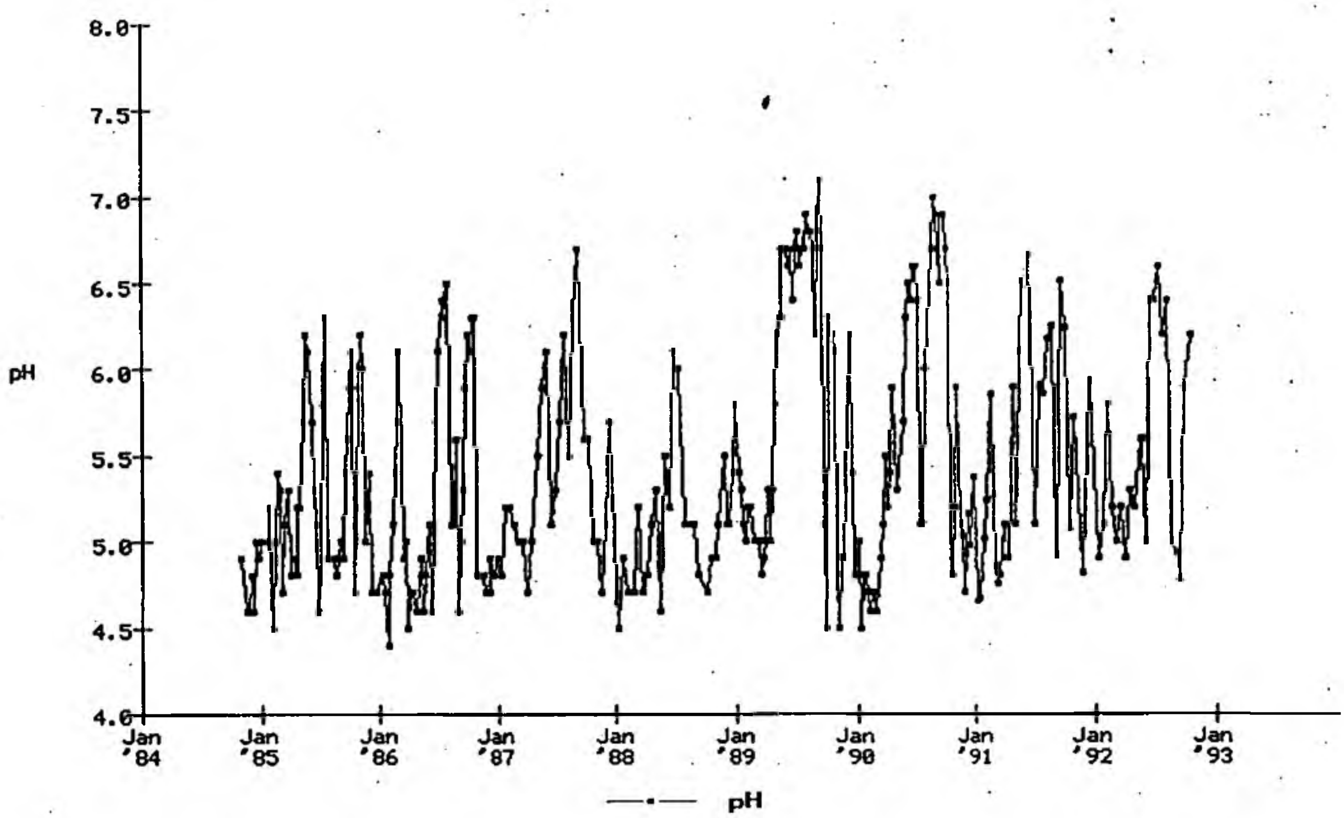


Fig 2.1.3.i **Spot sample data for LI3 Oct'84 to Oct'92**



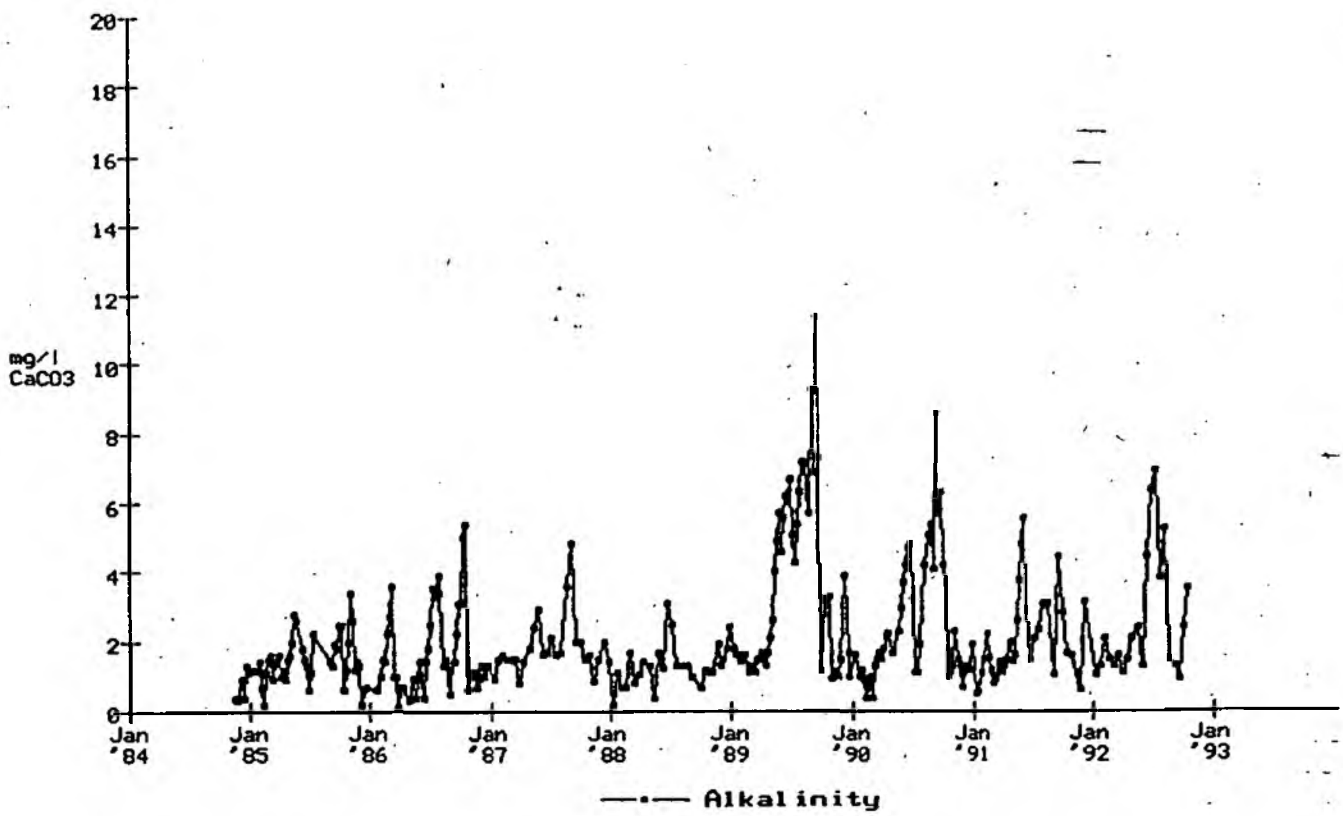
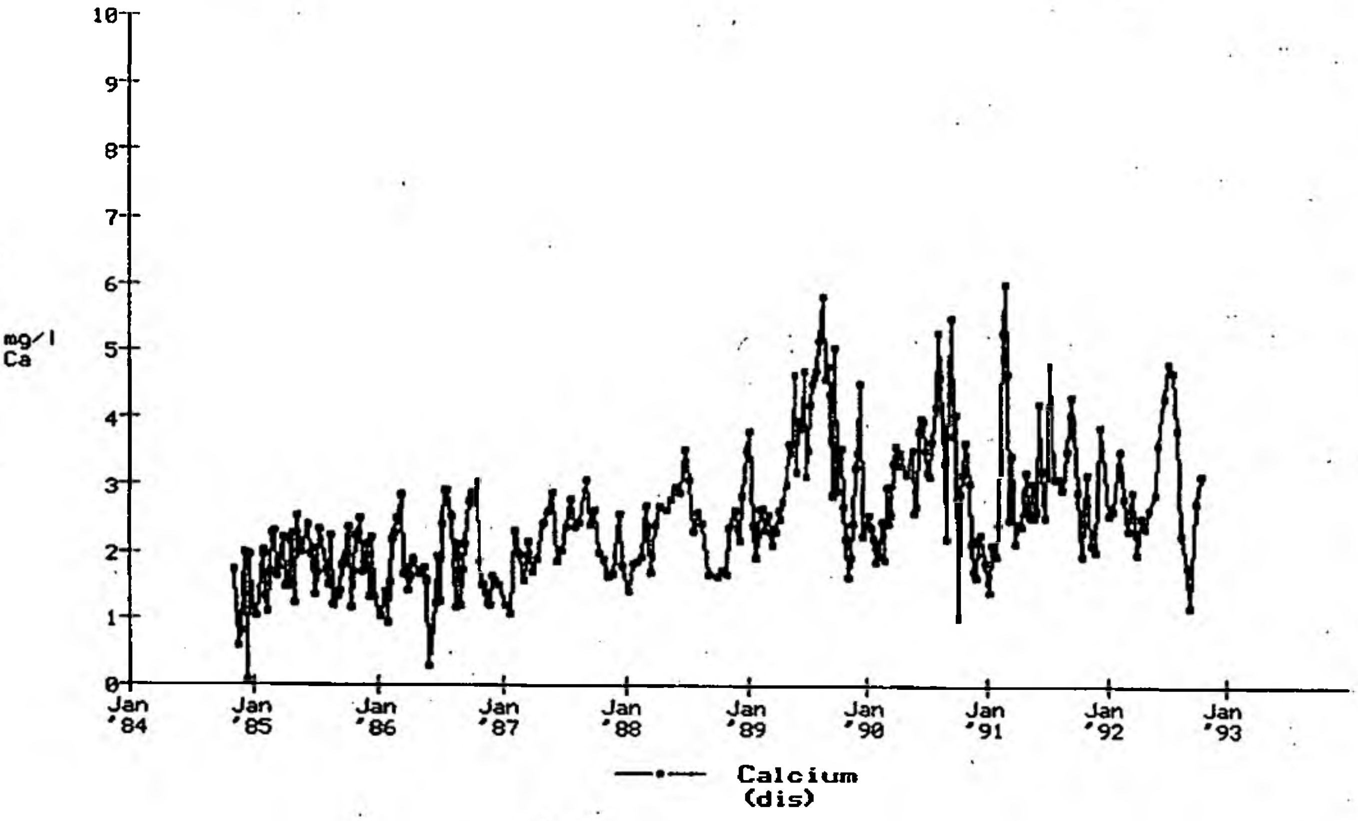


Fig 2.1.3.ii **Spot sample data for LI3 Oct'84 to Oct'92**



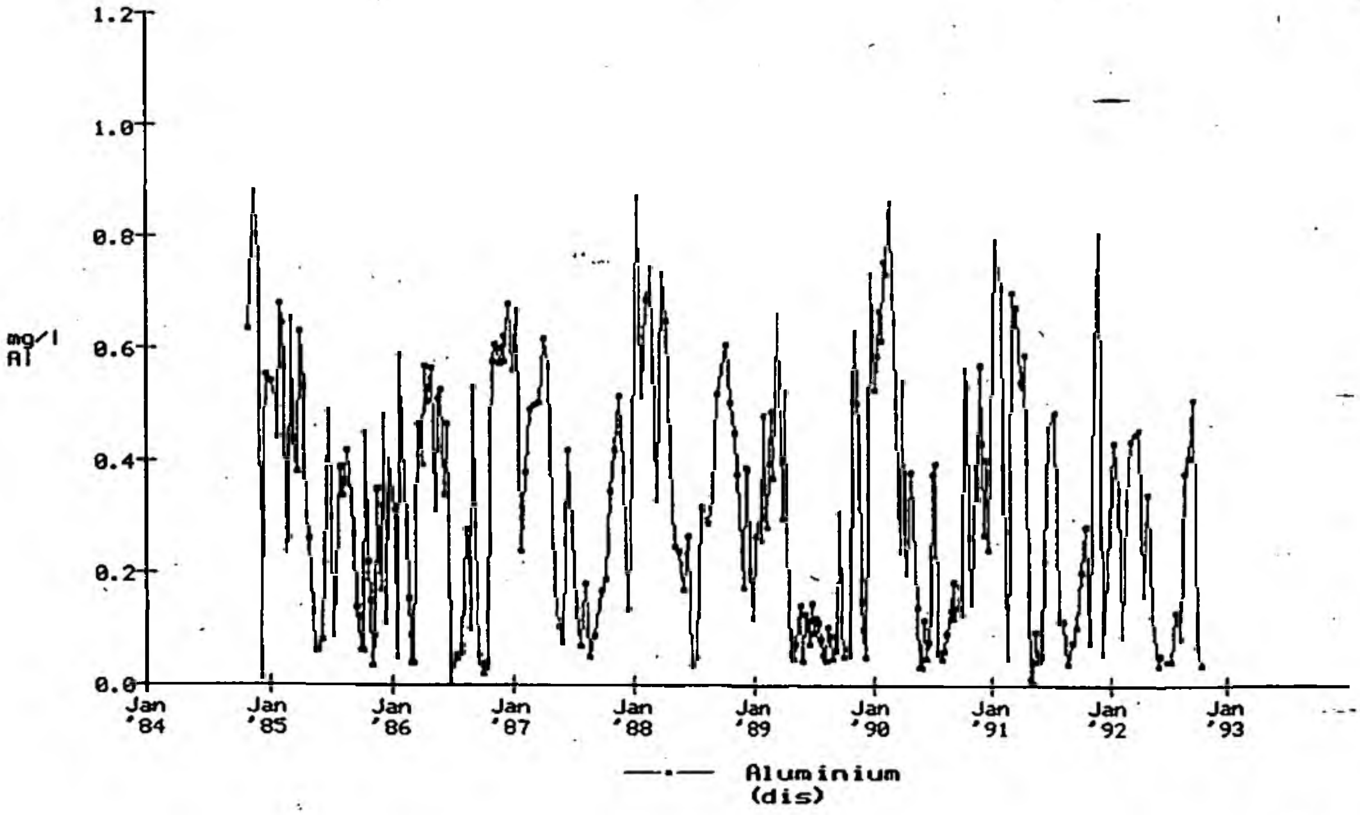
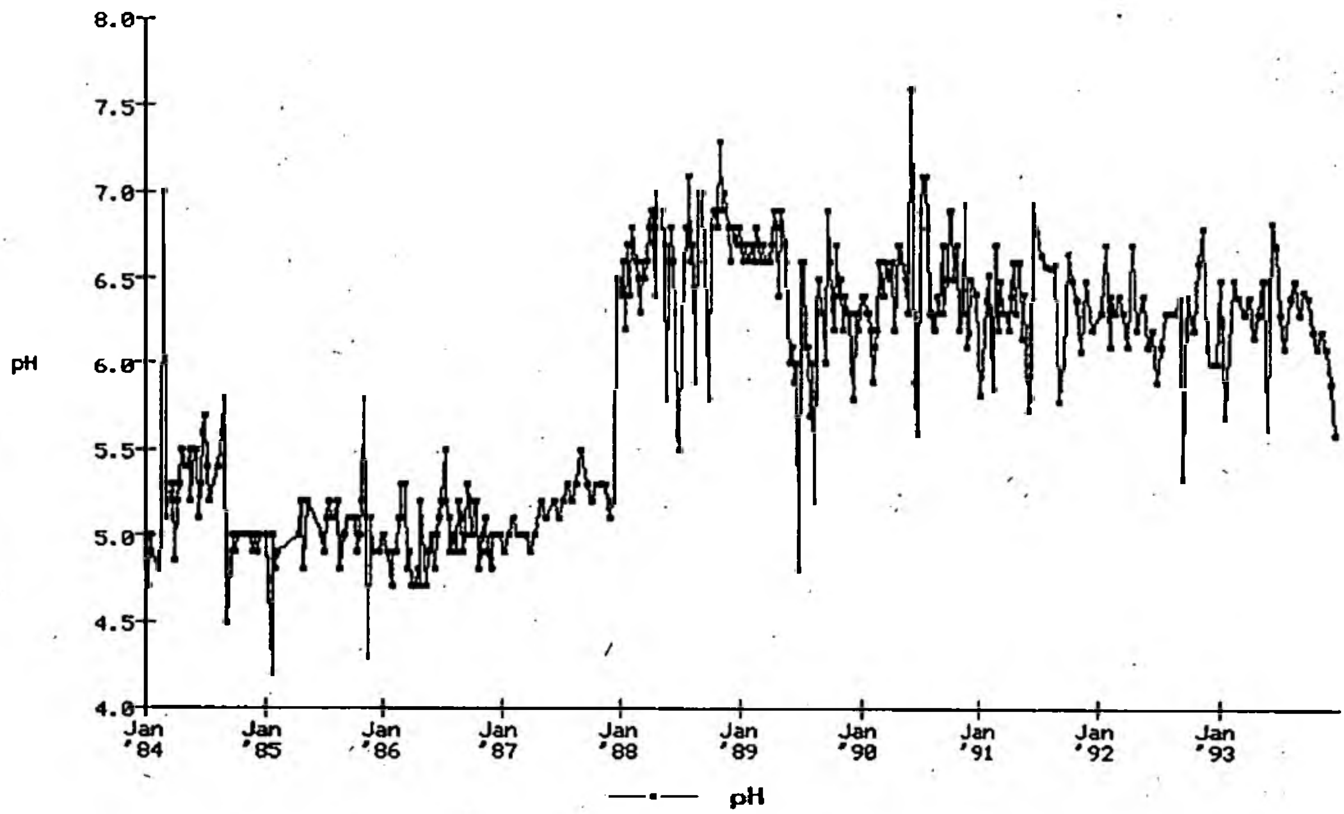


Fig 2.1.4.i Spot sample data for LI4 Jan'84 to Dec'93



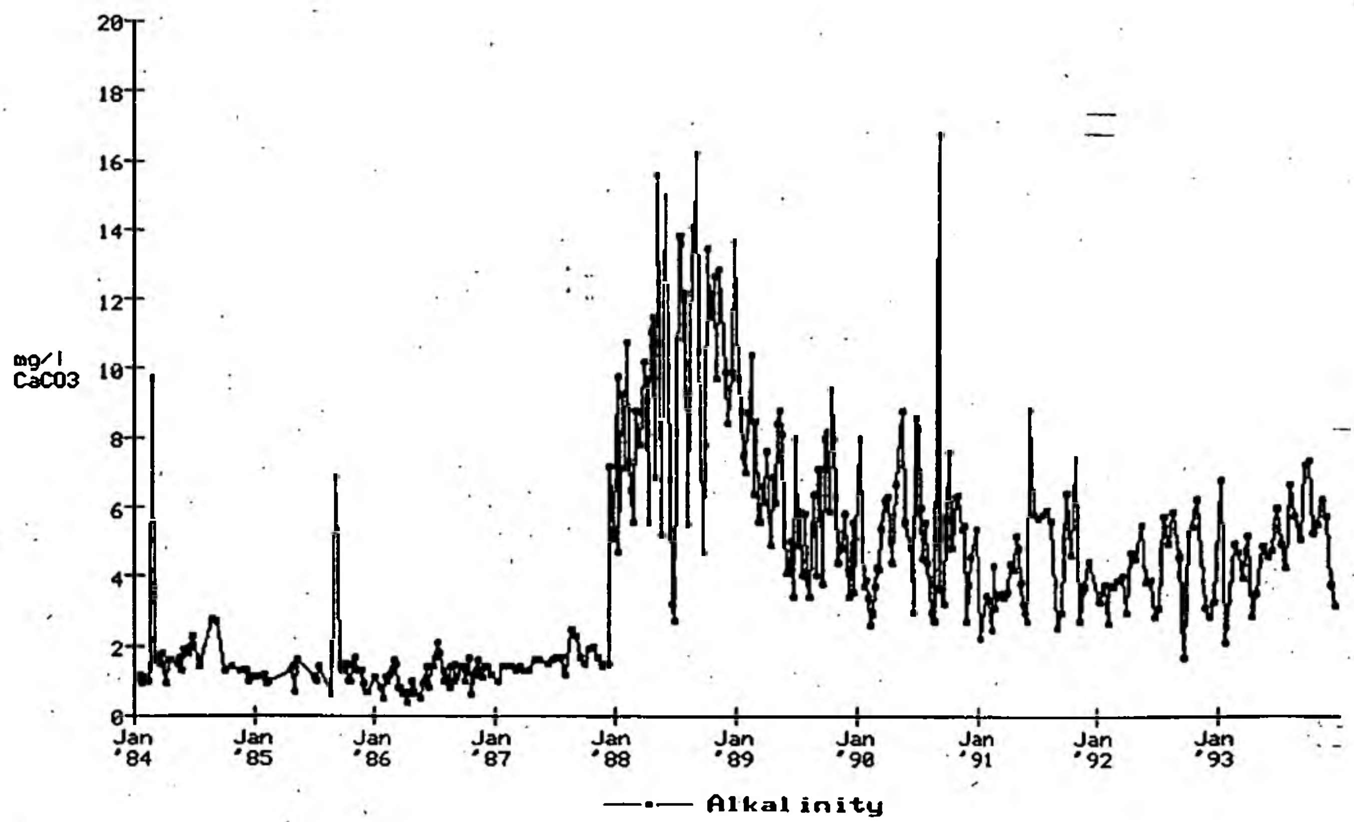
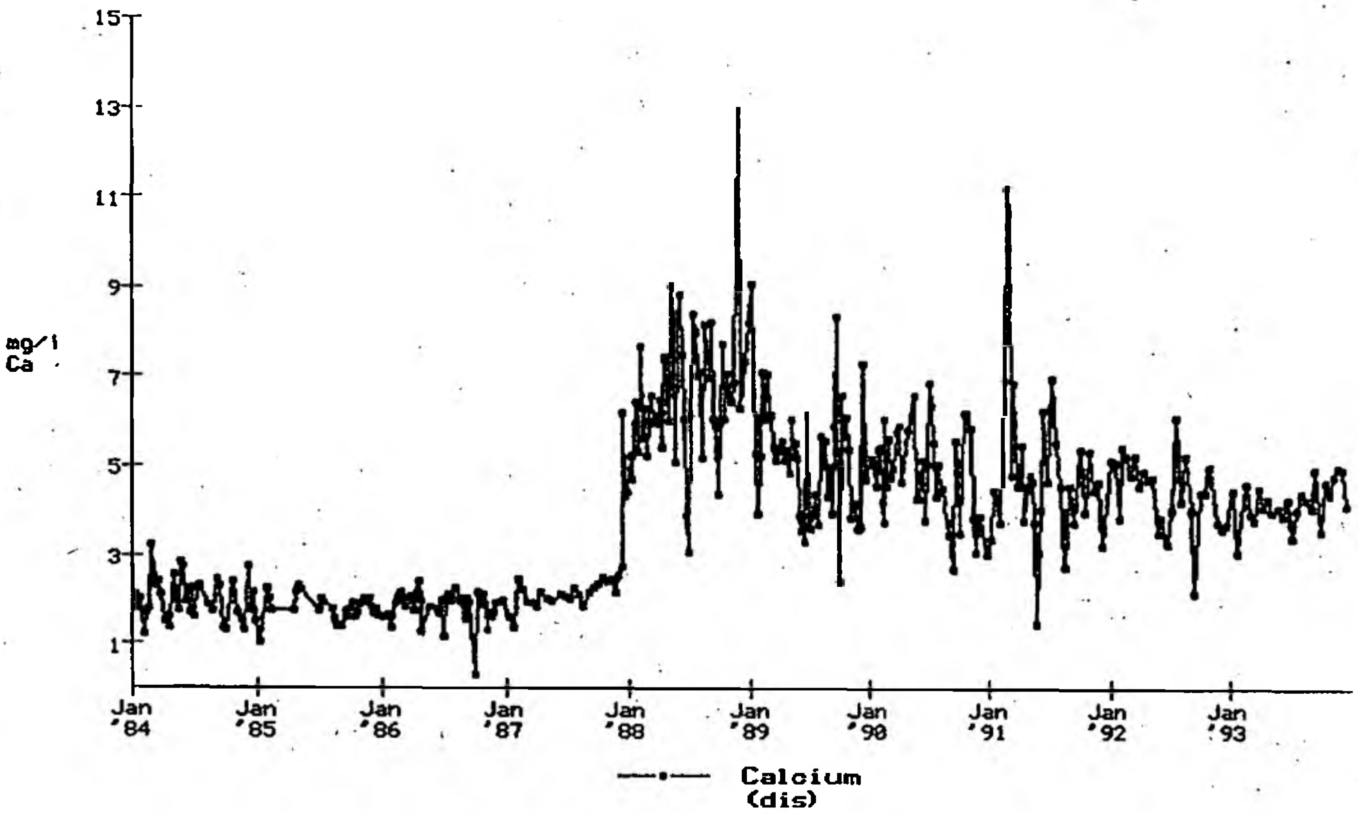


Fig 2.1.4.ii Spot sample data for LI4 Jan'84 to Dec'93



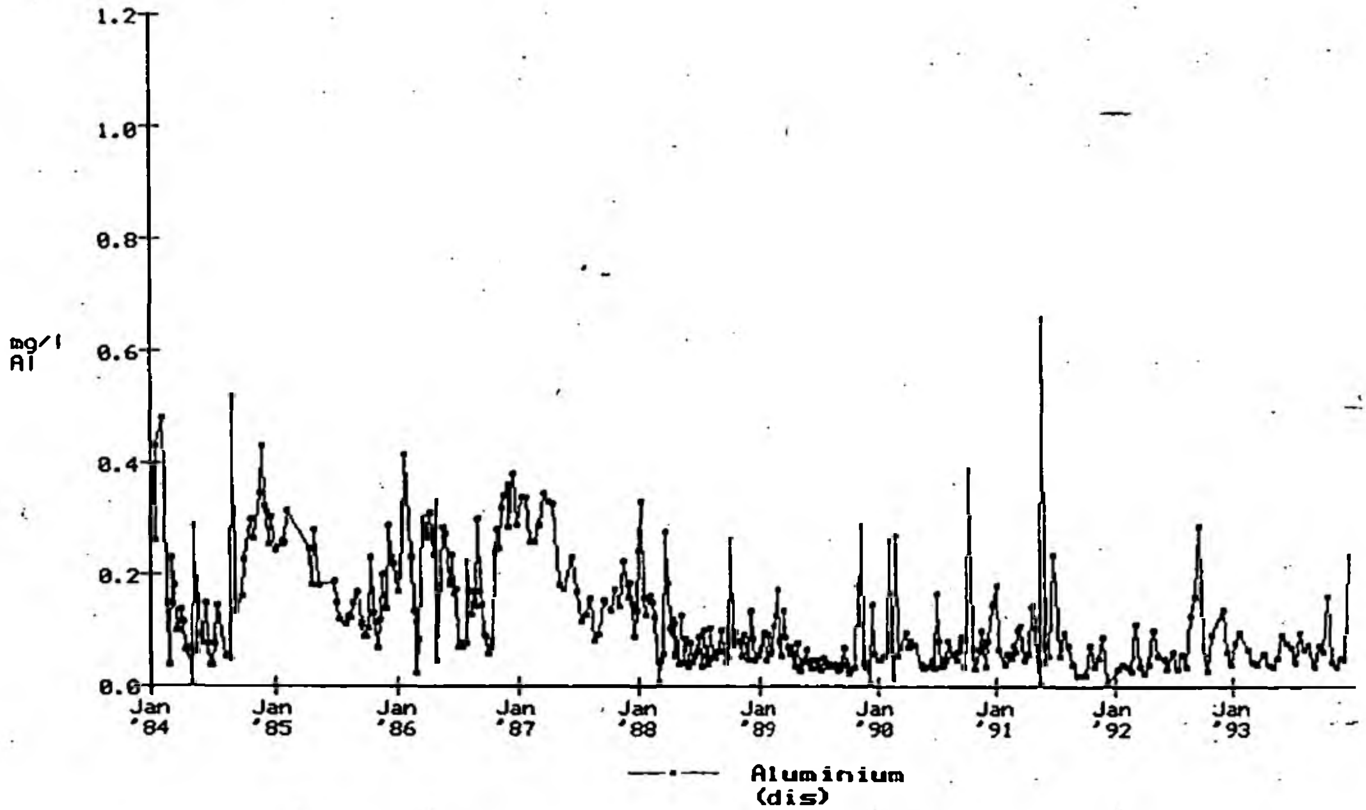
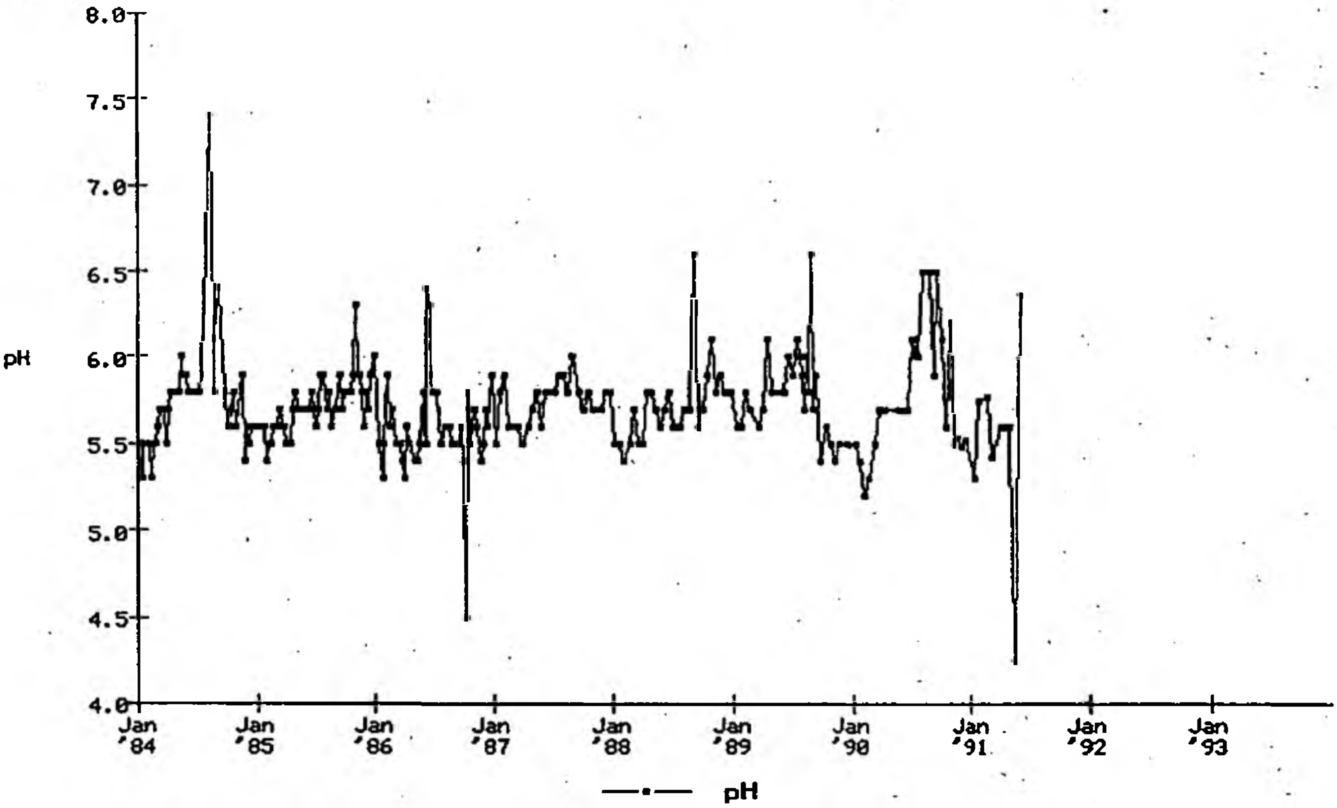


Fig 2.1.5.i Spot sample data for LI5 Jan'84 to May'91



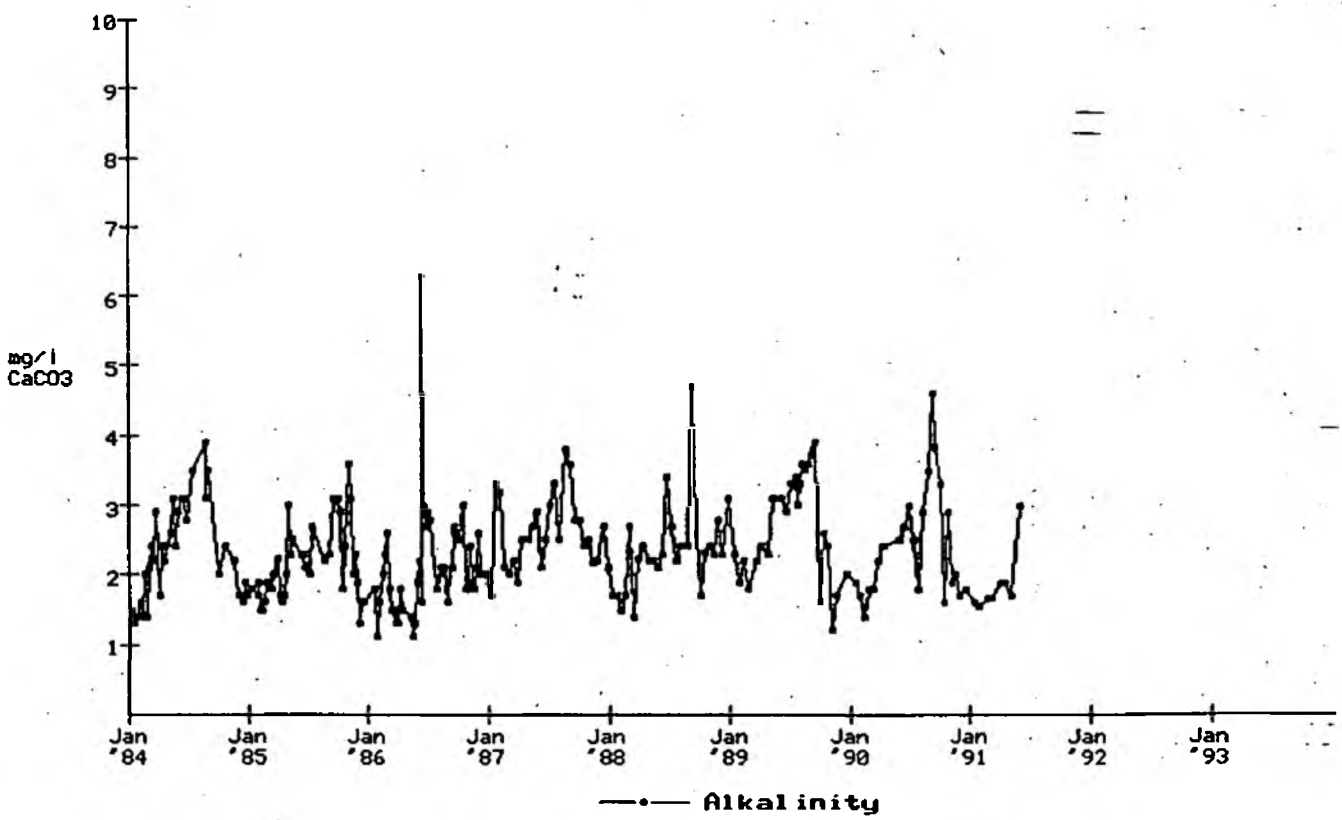
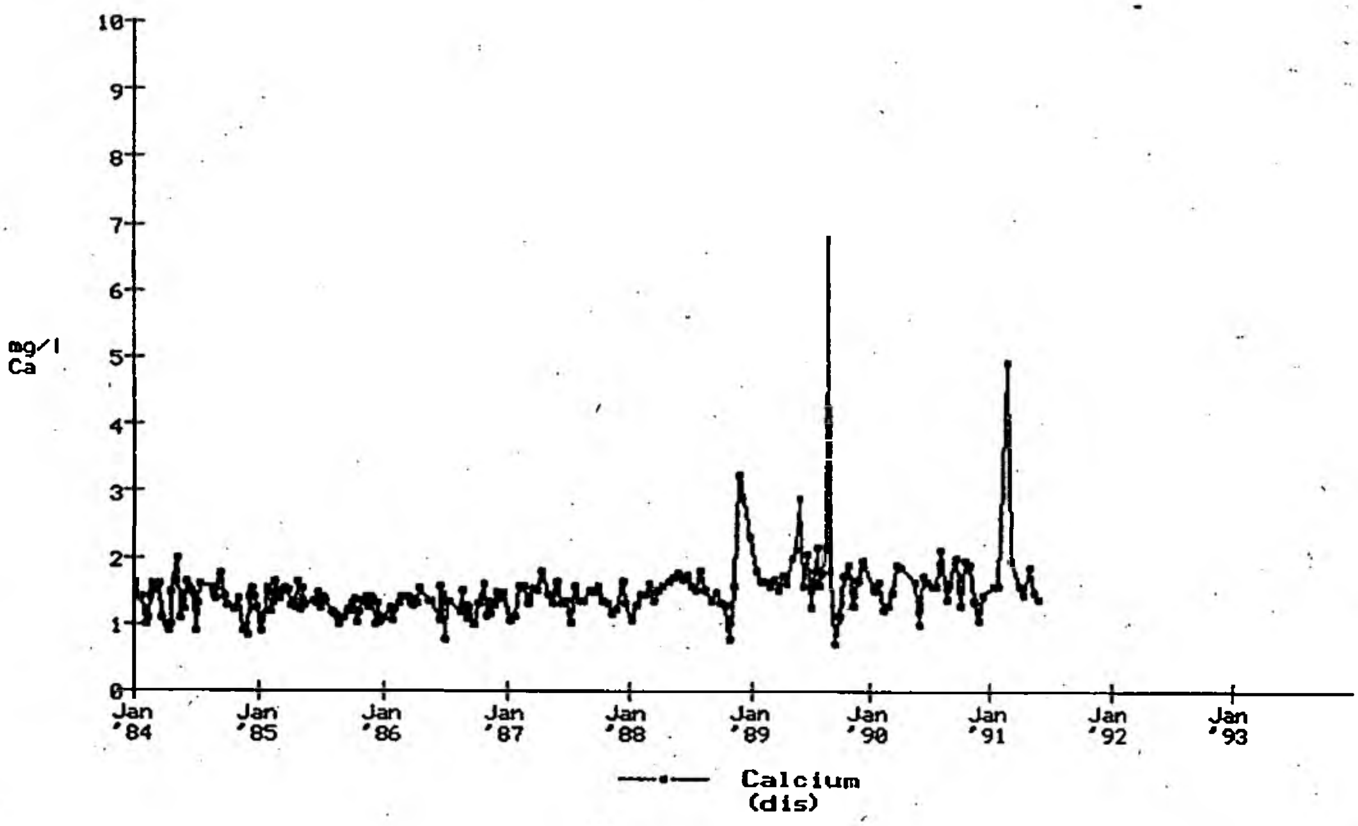


Fig 2.1.5.ii **Spot sample data for LI5 Jan'84 to May'91**



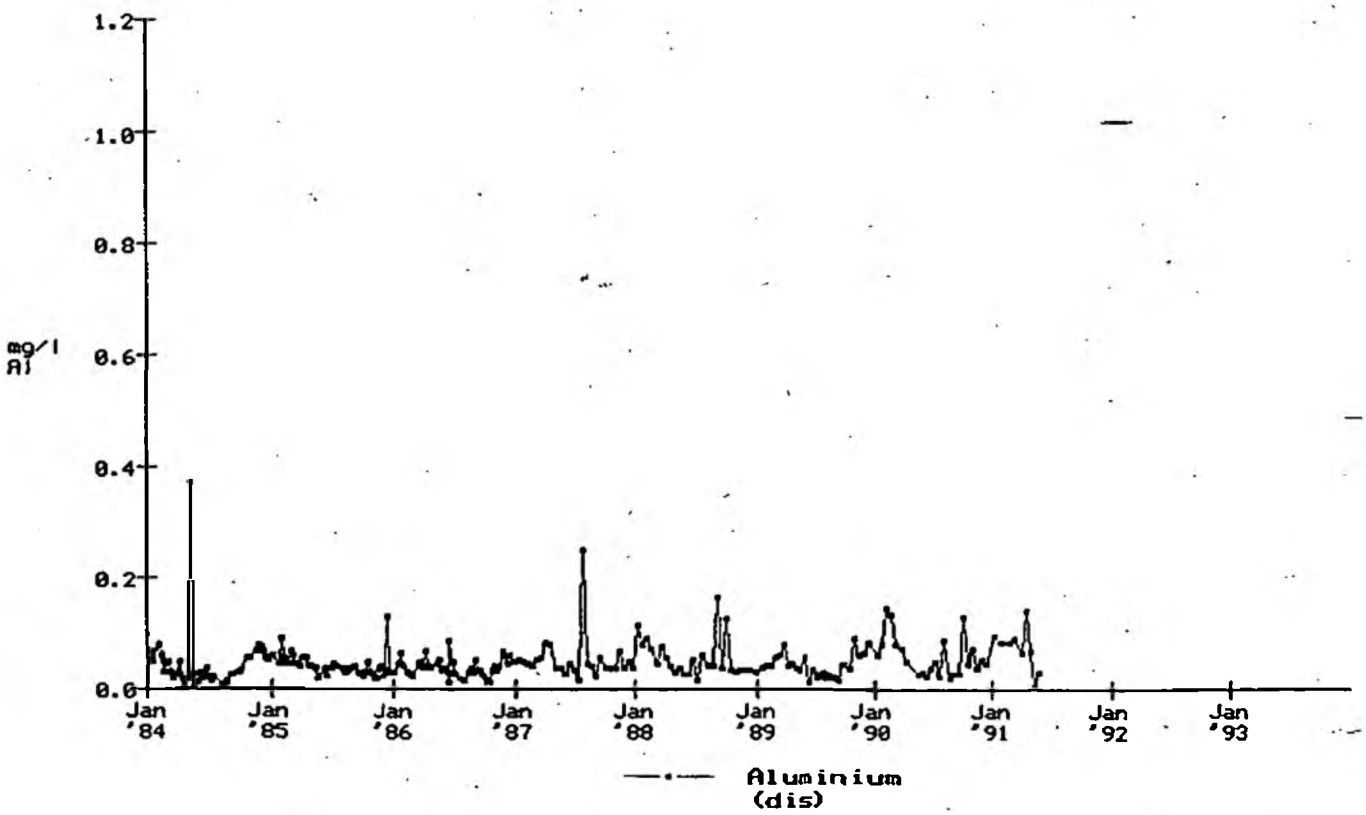
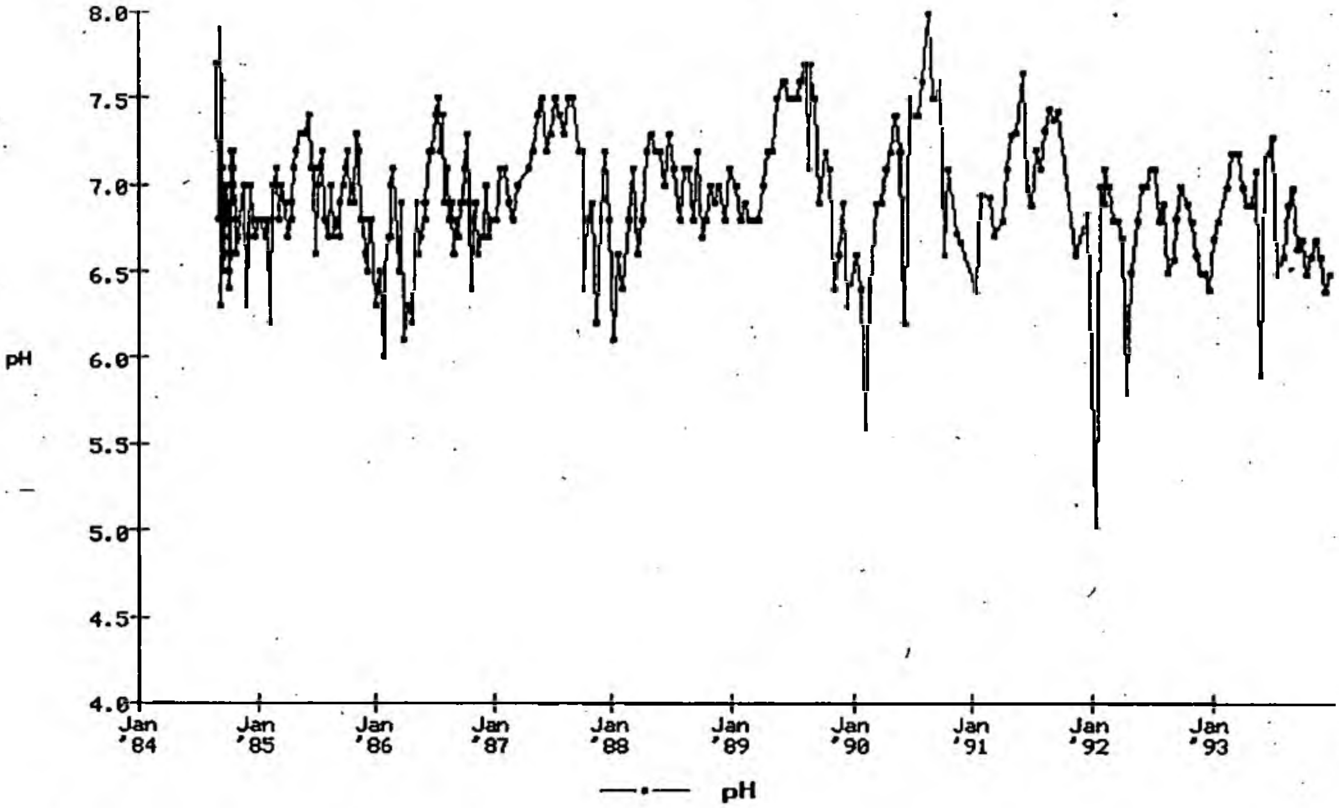


Fig 2.1.6.i Spot sample data for LI6 Aug'84 to Dec'93



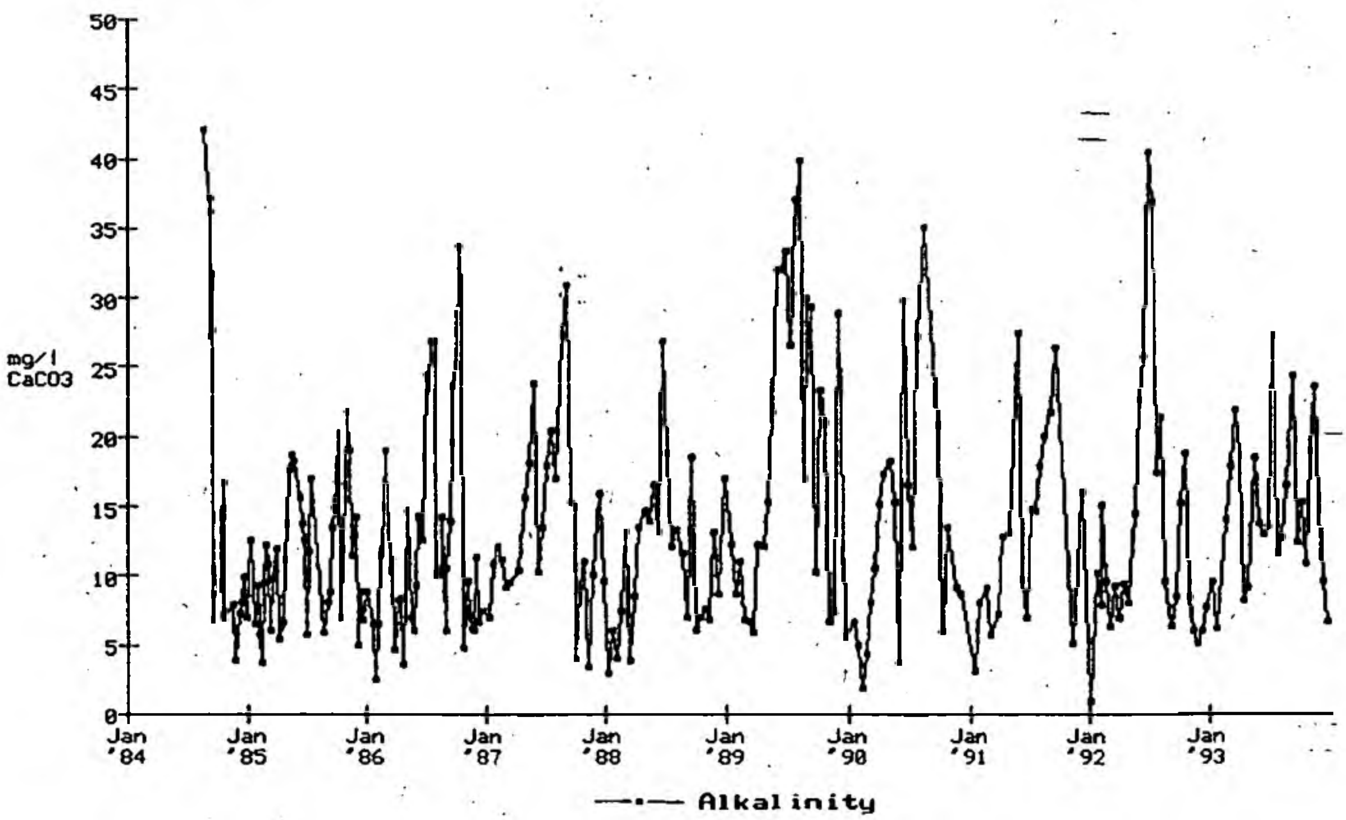
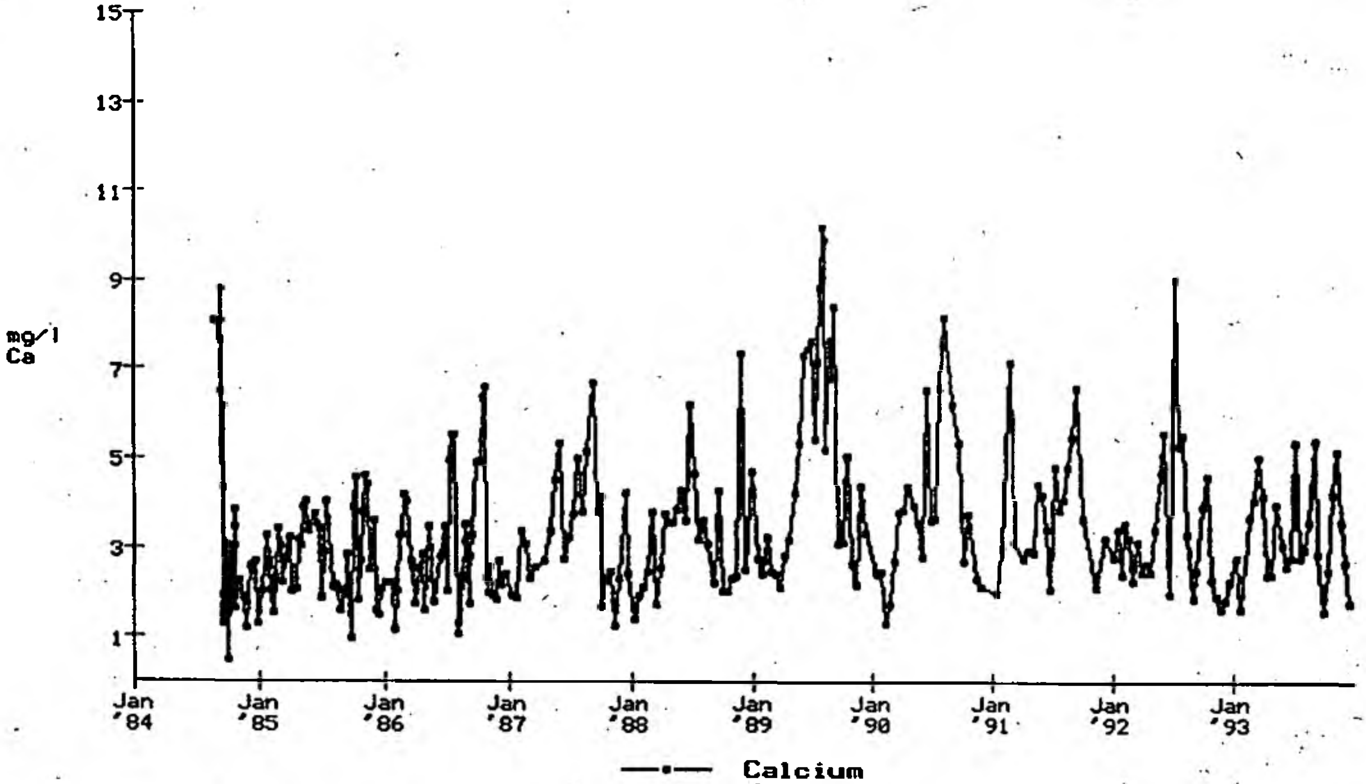


Fig 2.1.6.ii Spot sample data for LI6 Aug'84 to Dec'93



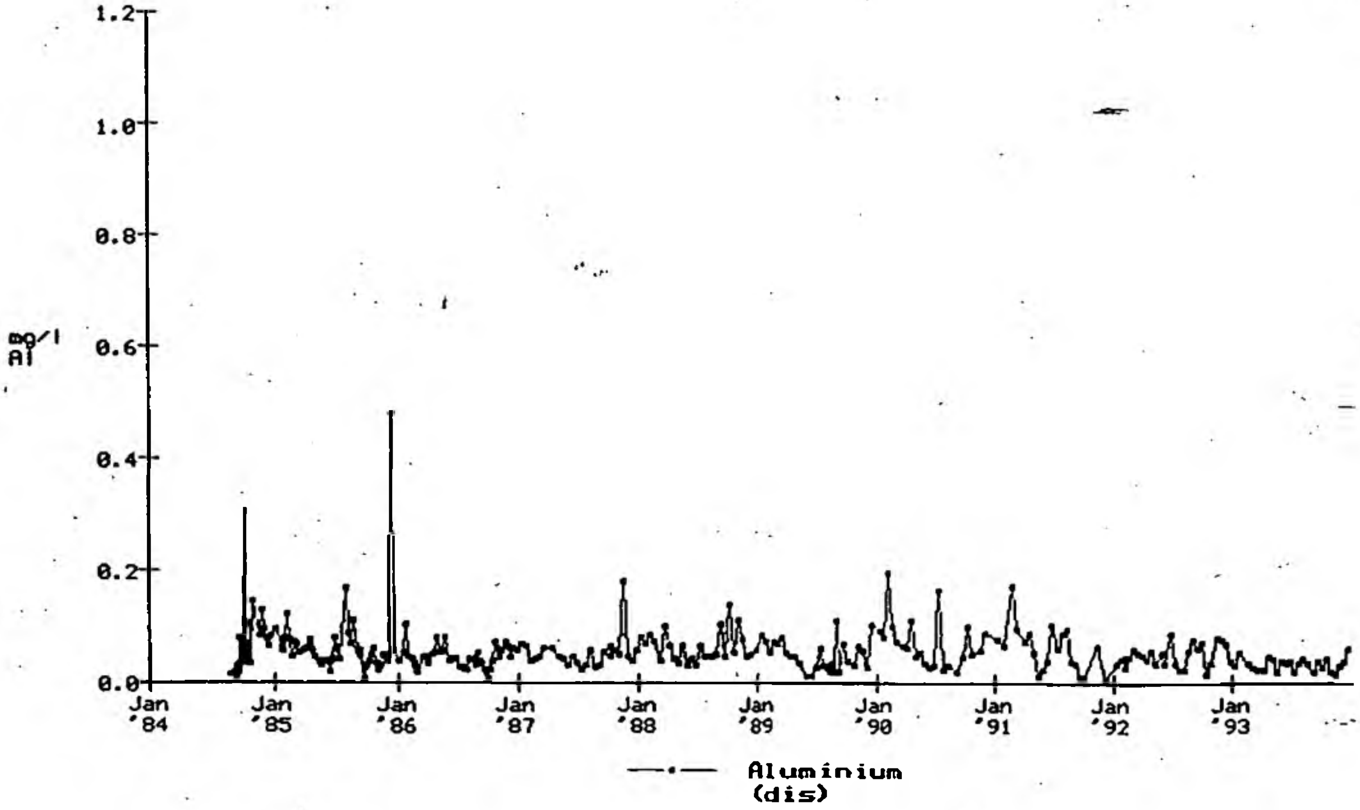
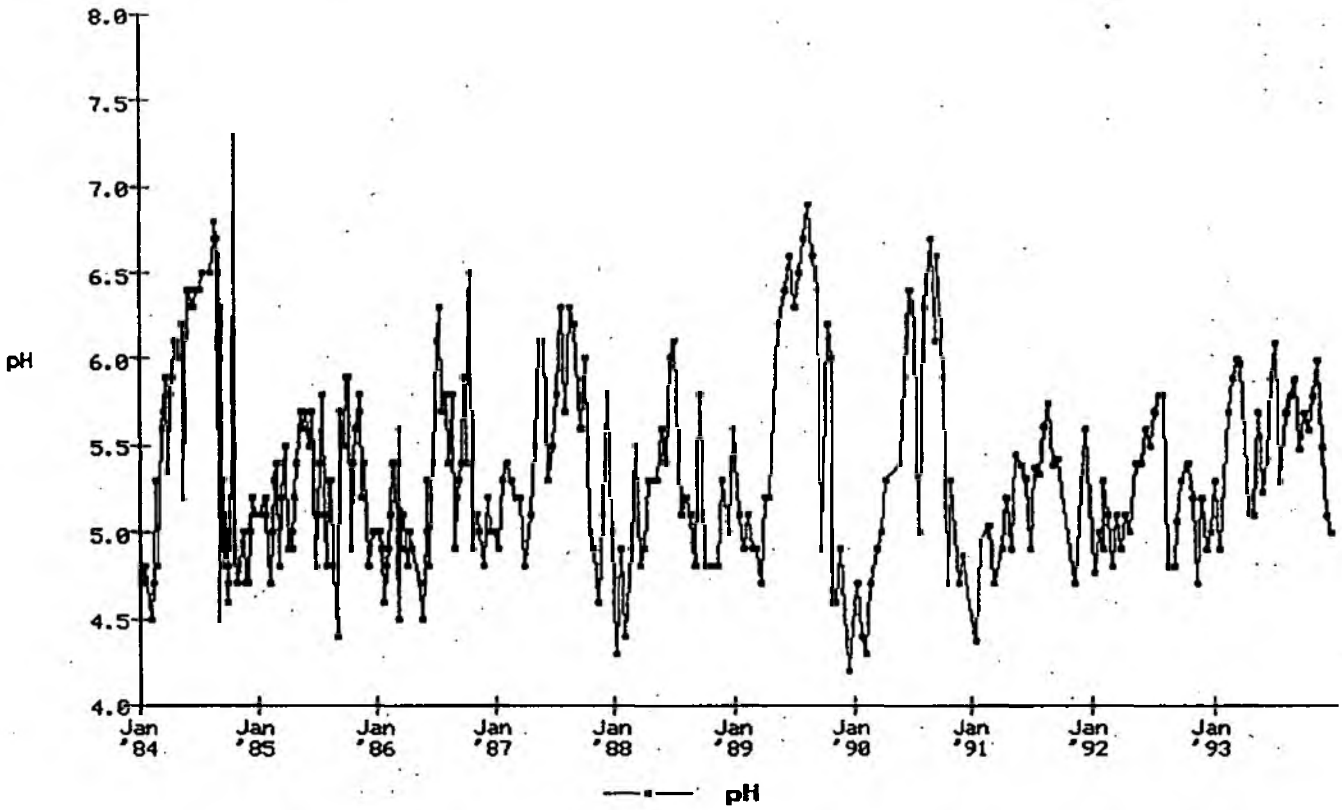


Fig 2.1.7.i **Spot sample data for LI8 Jan'84 to Dec'93**



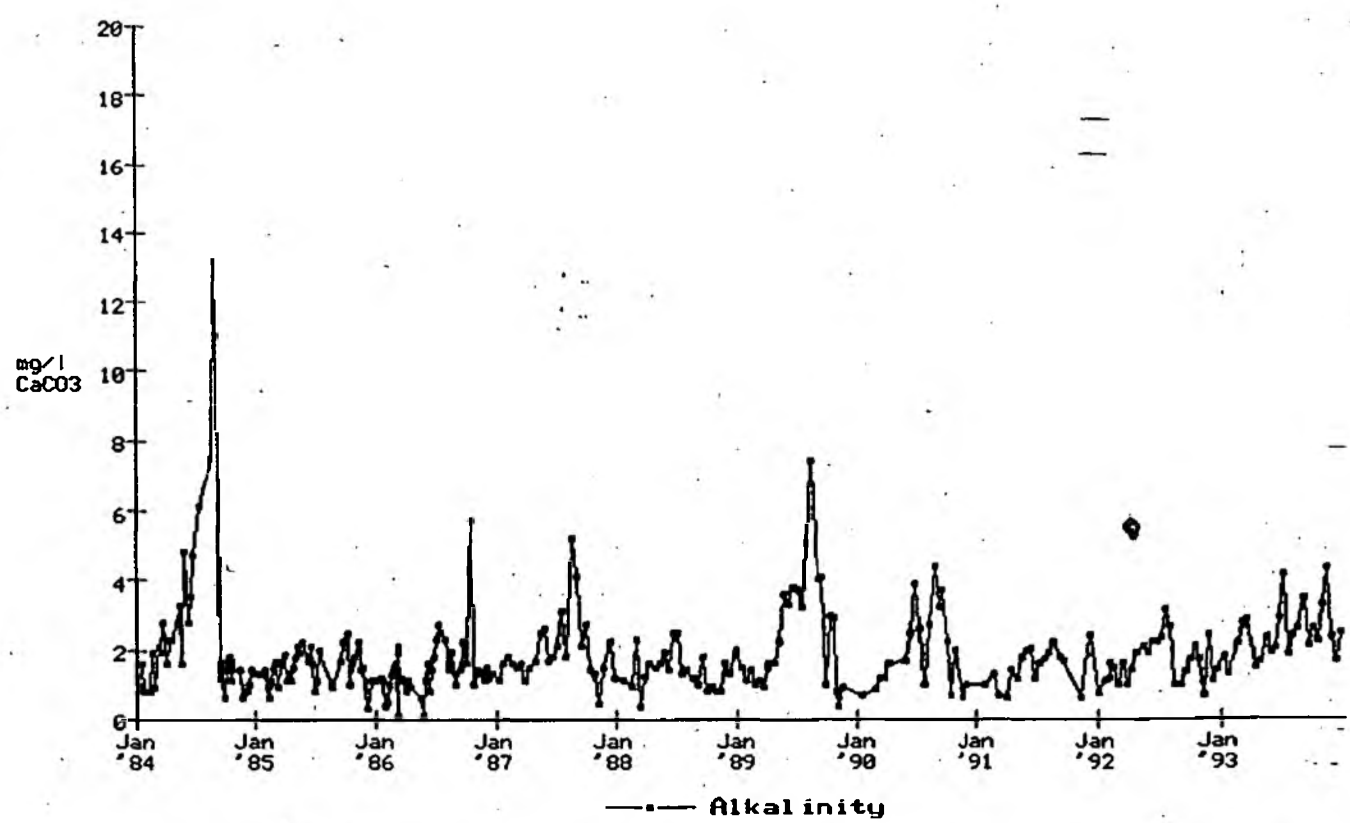
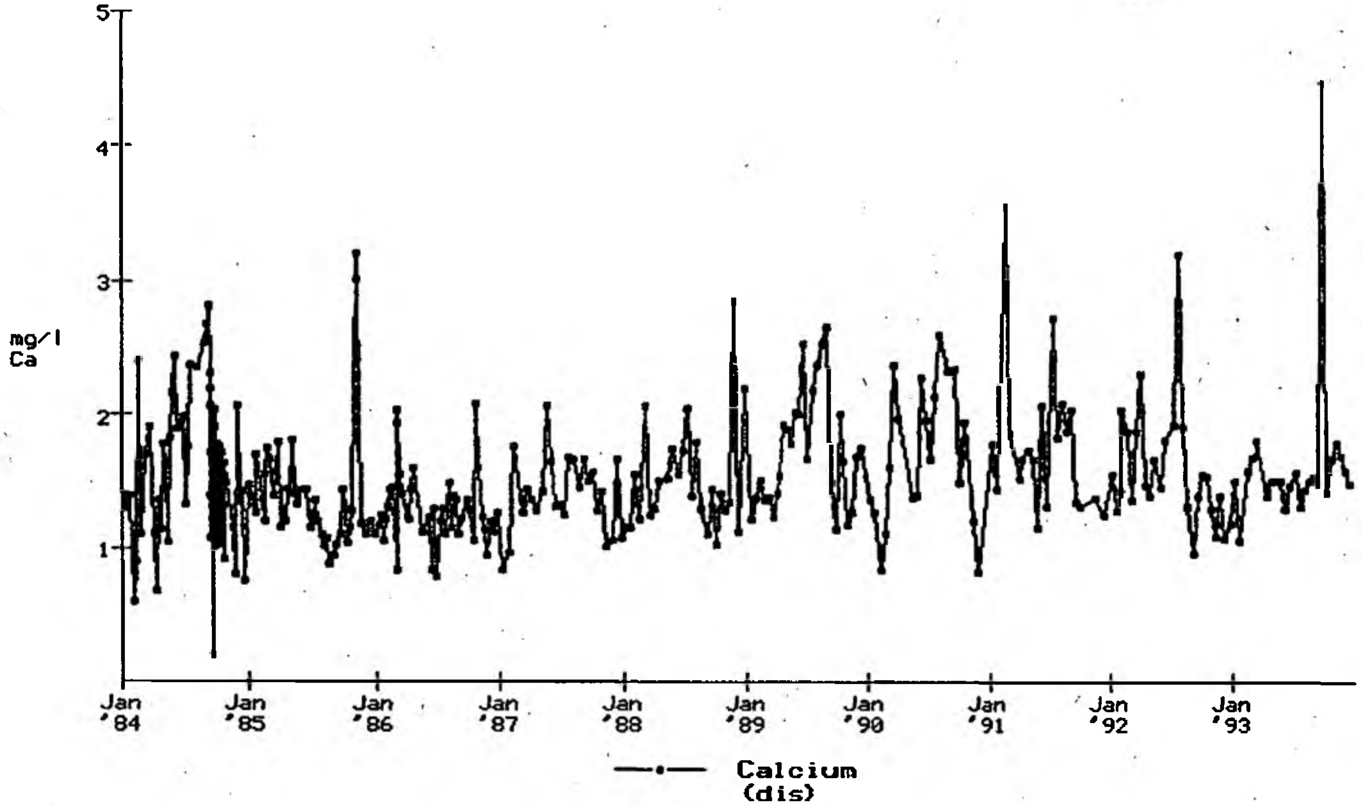


Fig 2.1.7.ii **Spot sample data for LI8 Jan'84 to Dec'93**



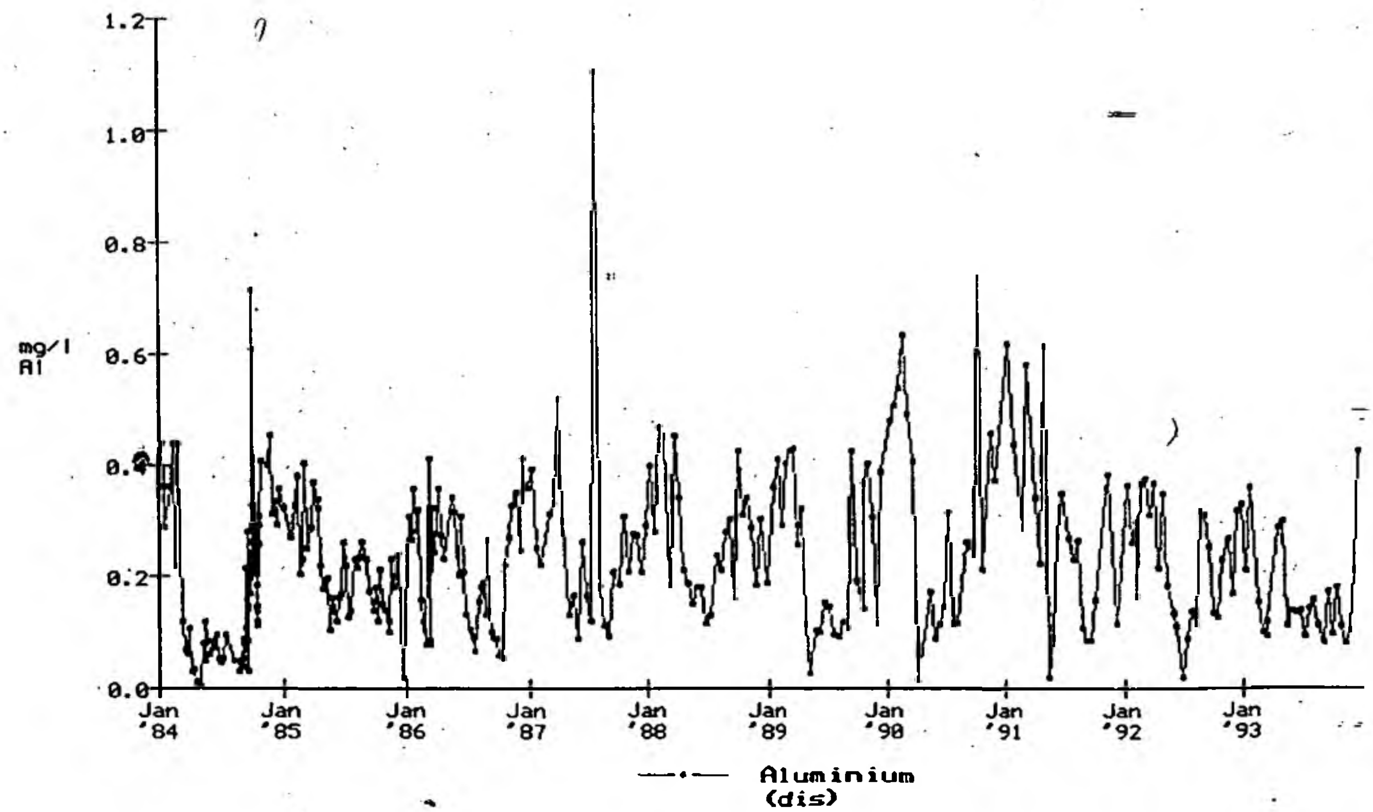
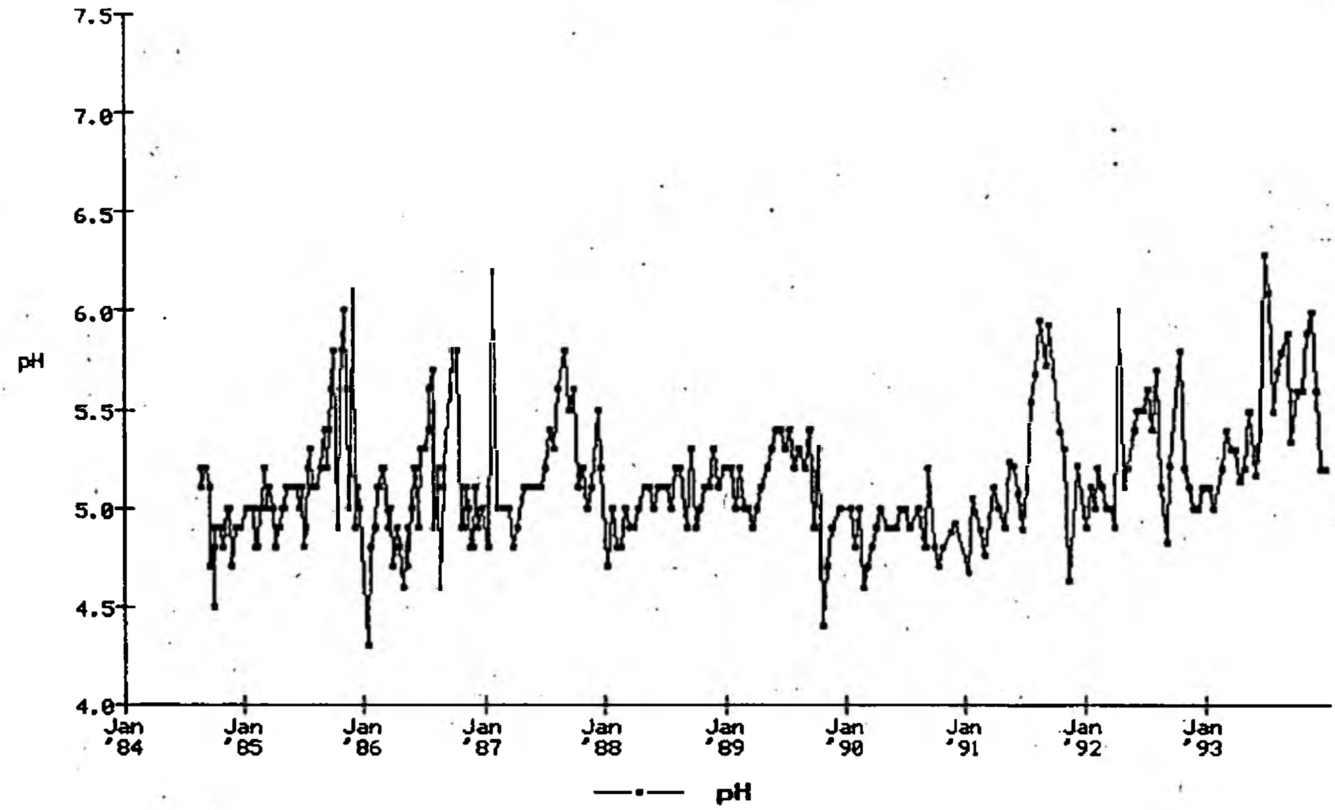


Fig 2.1.8.i Spot sample data for CI1 Aug'84 to Dec'93



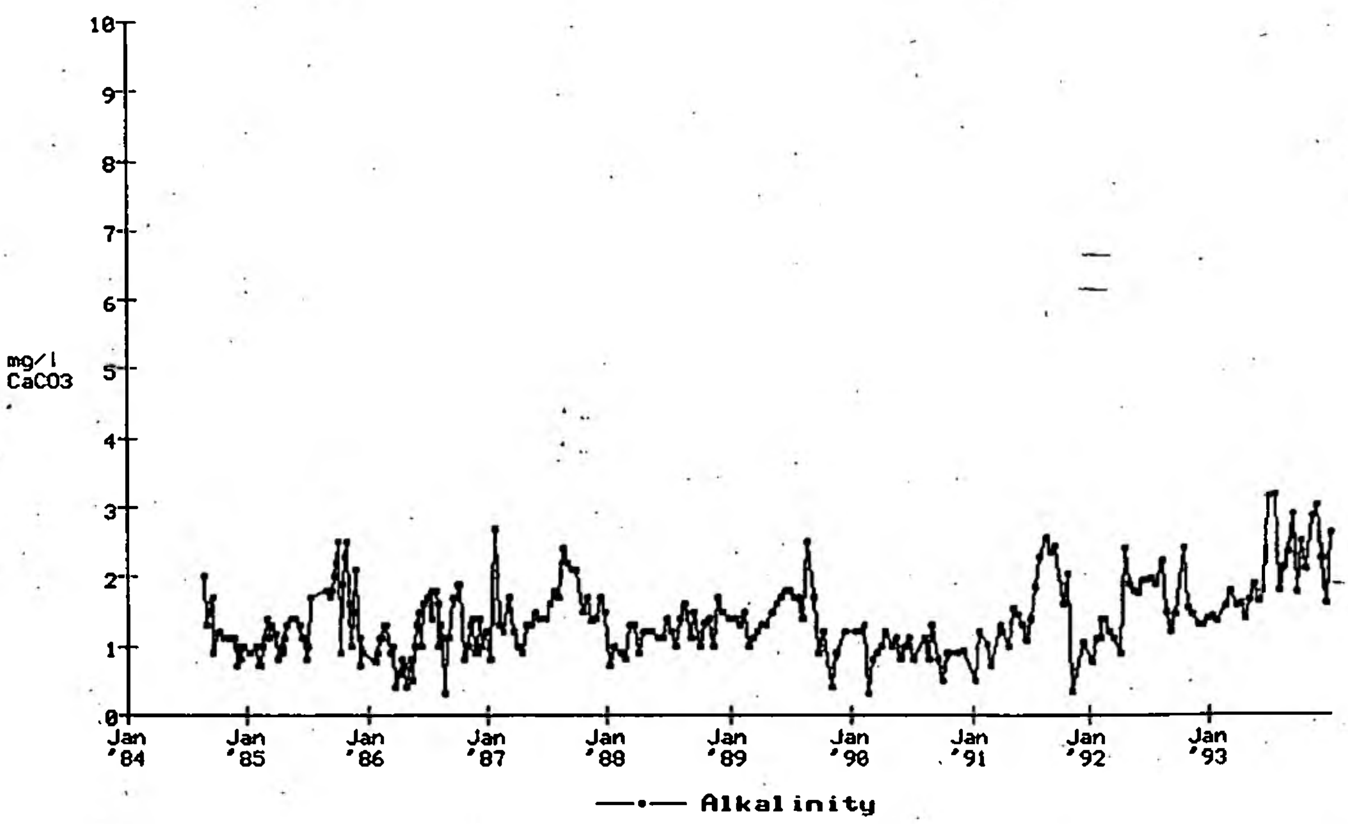
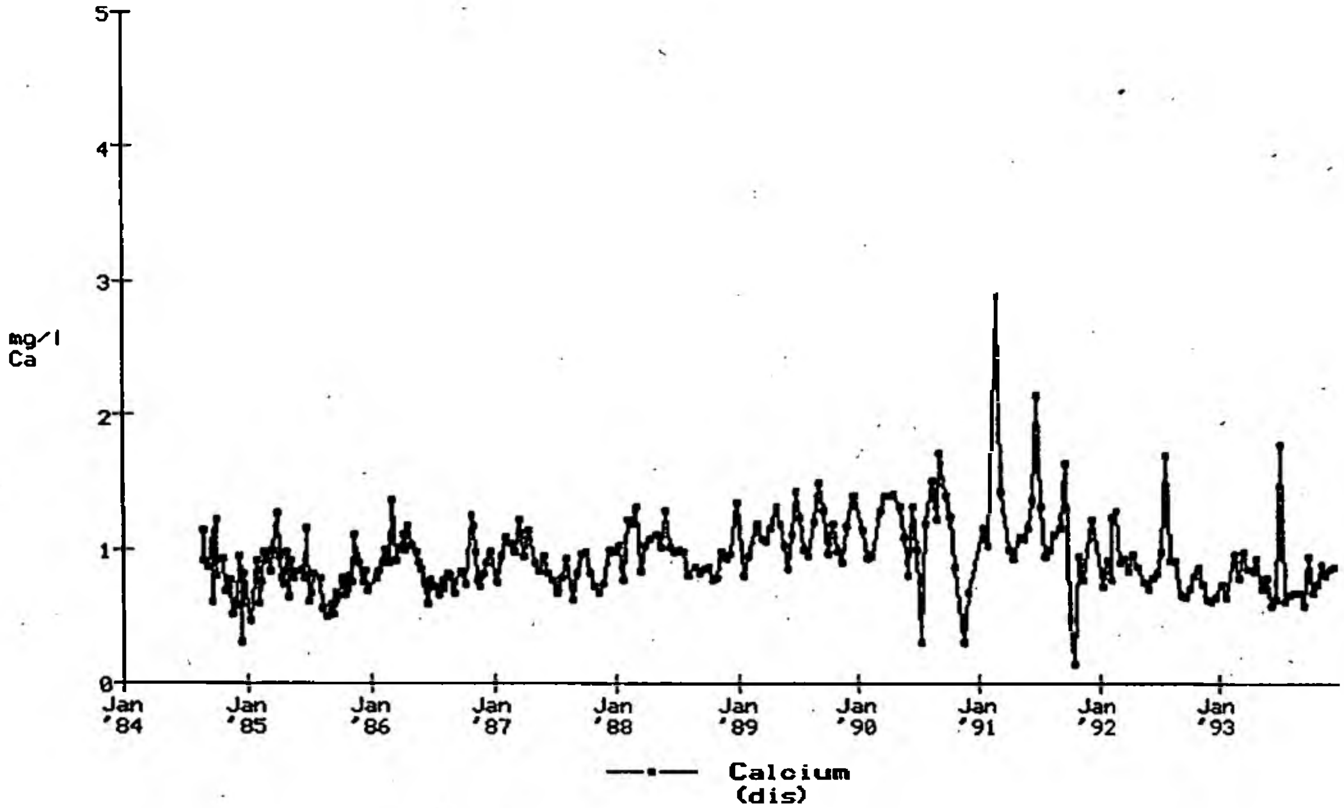


Fig 2.1.8.ii Spot sample data for CI1 Aug'84 to Dec'93



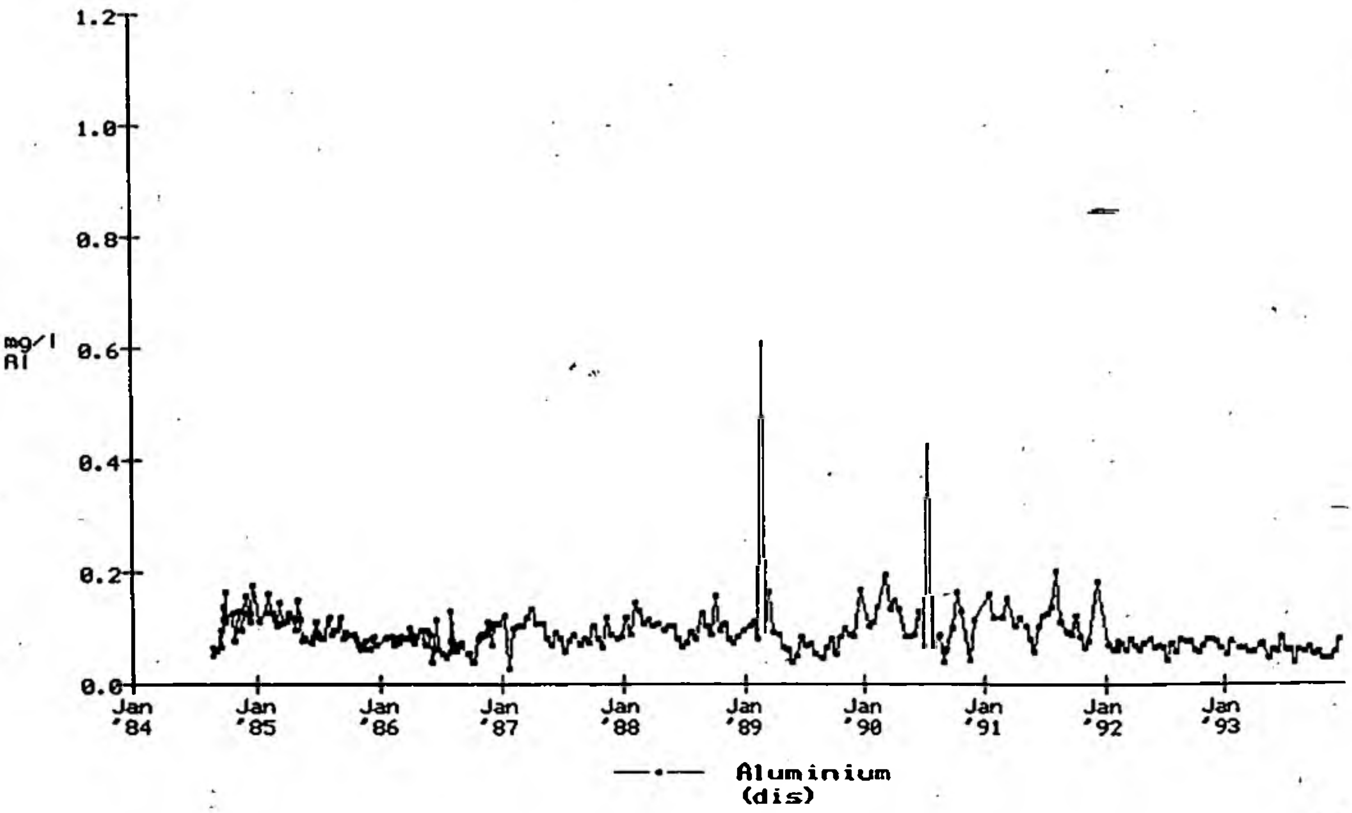
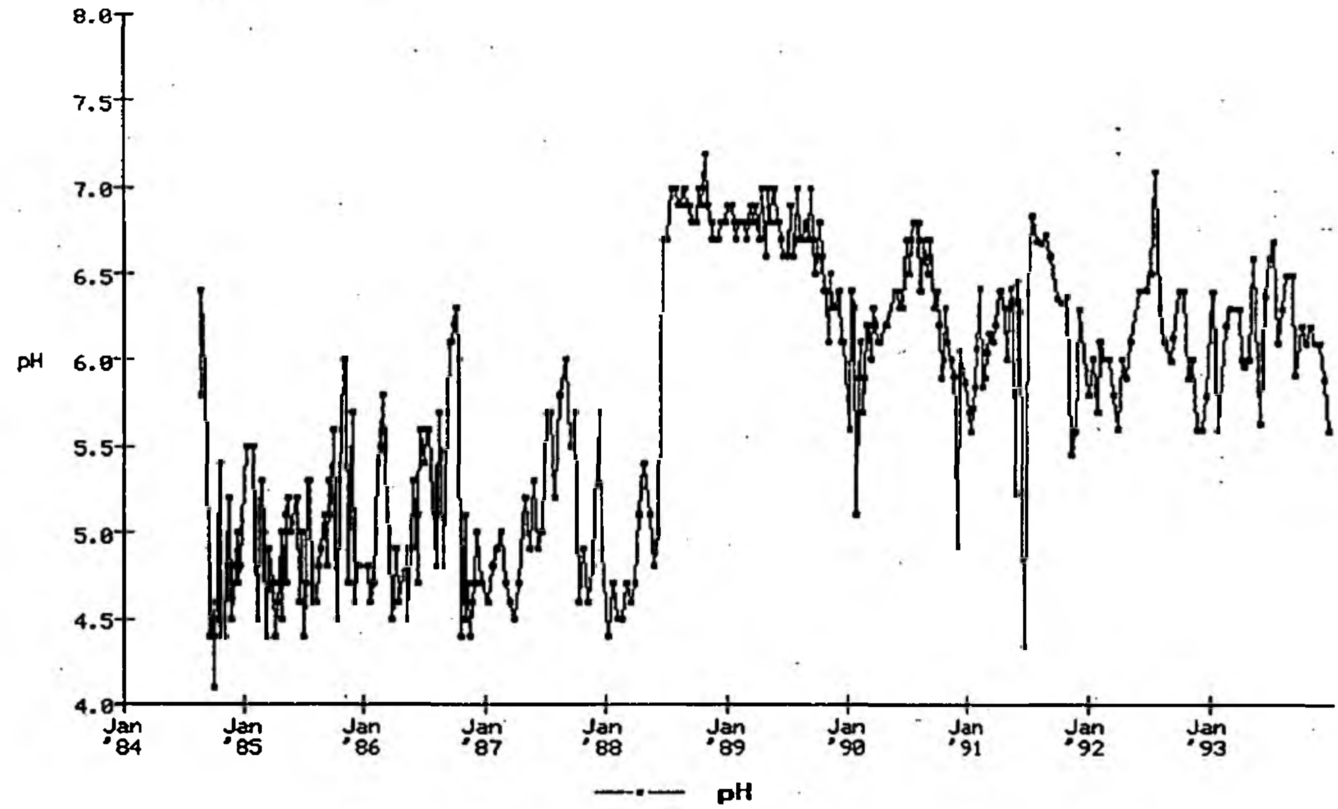


Fig 2.1.9.i Spot sample data for CI2 Aug'84 to Dec'93



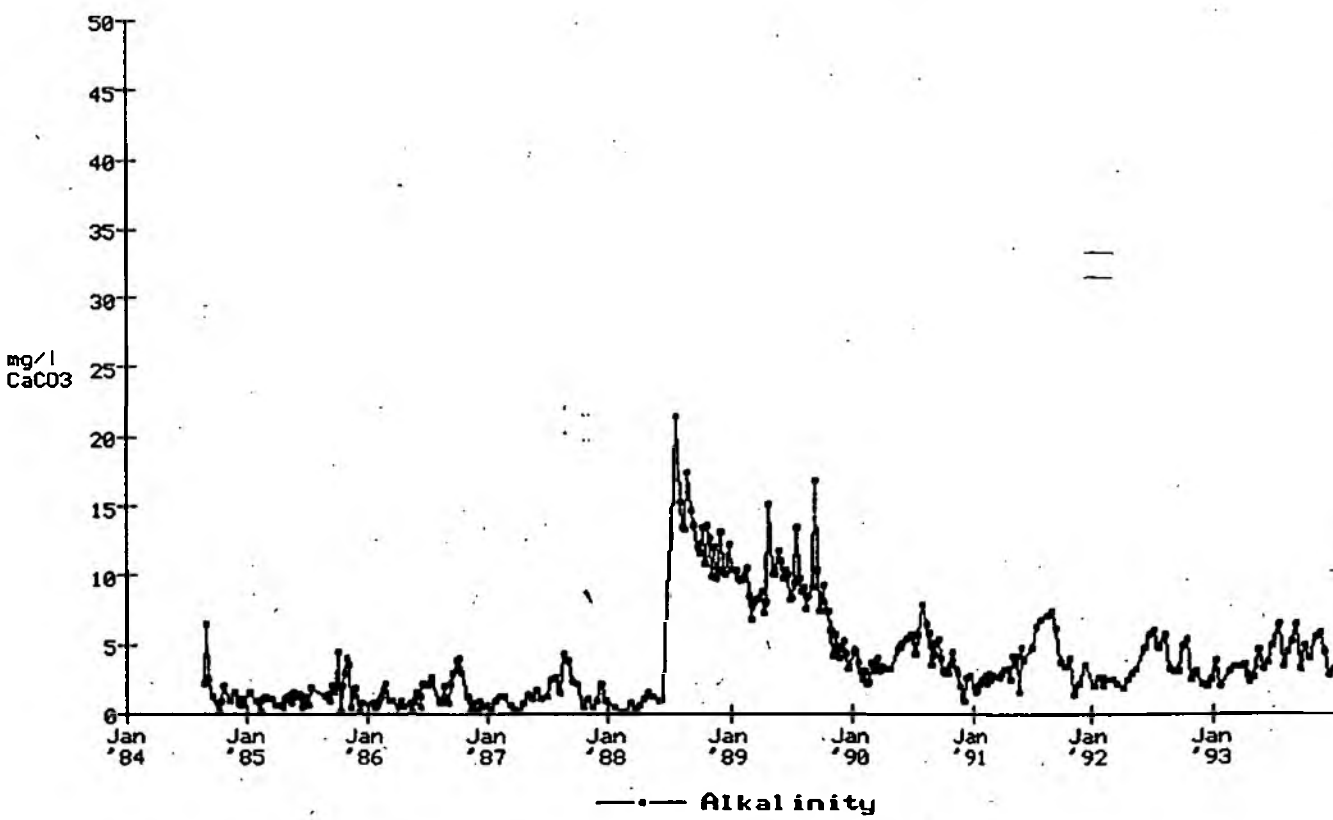
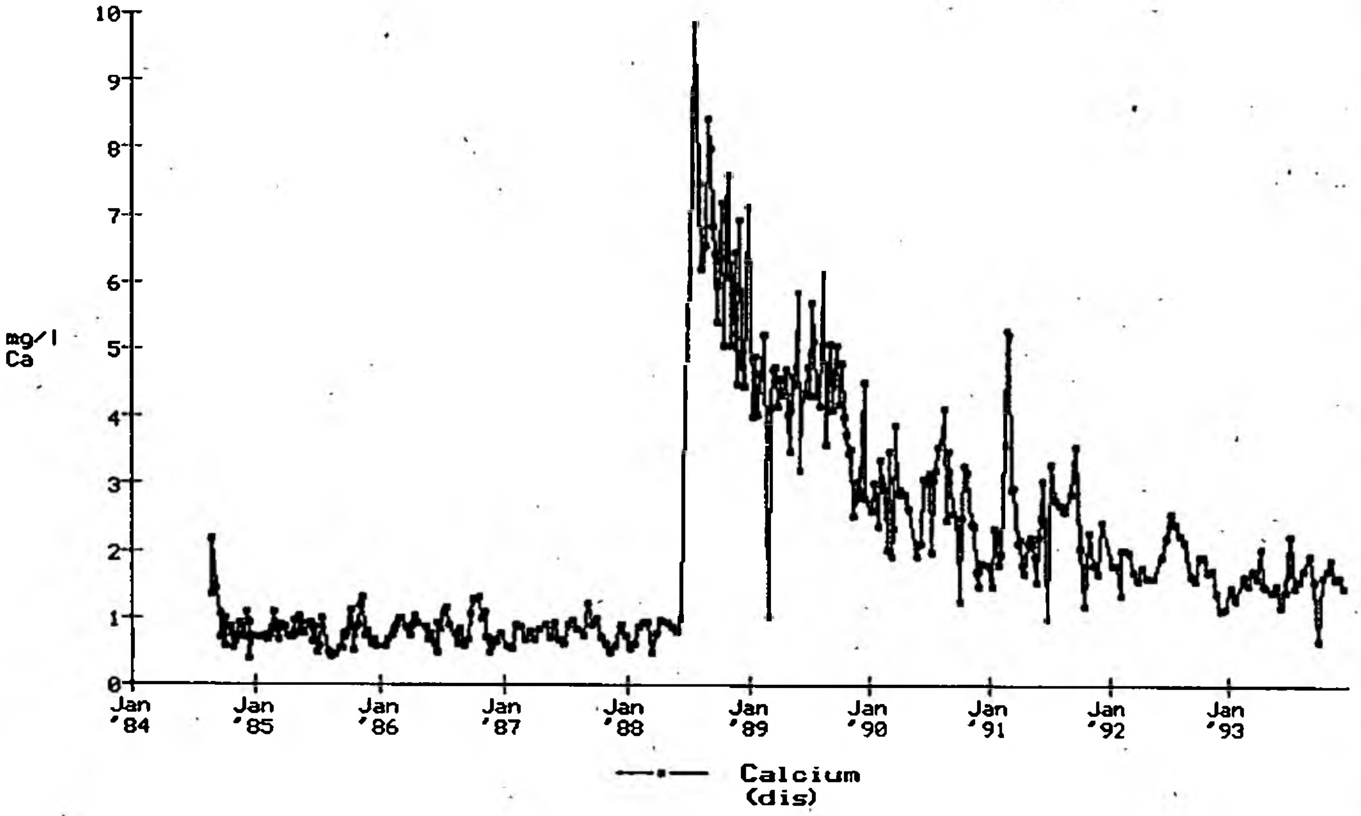
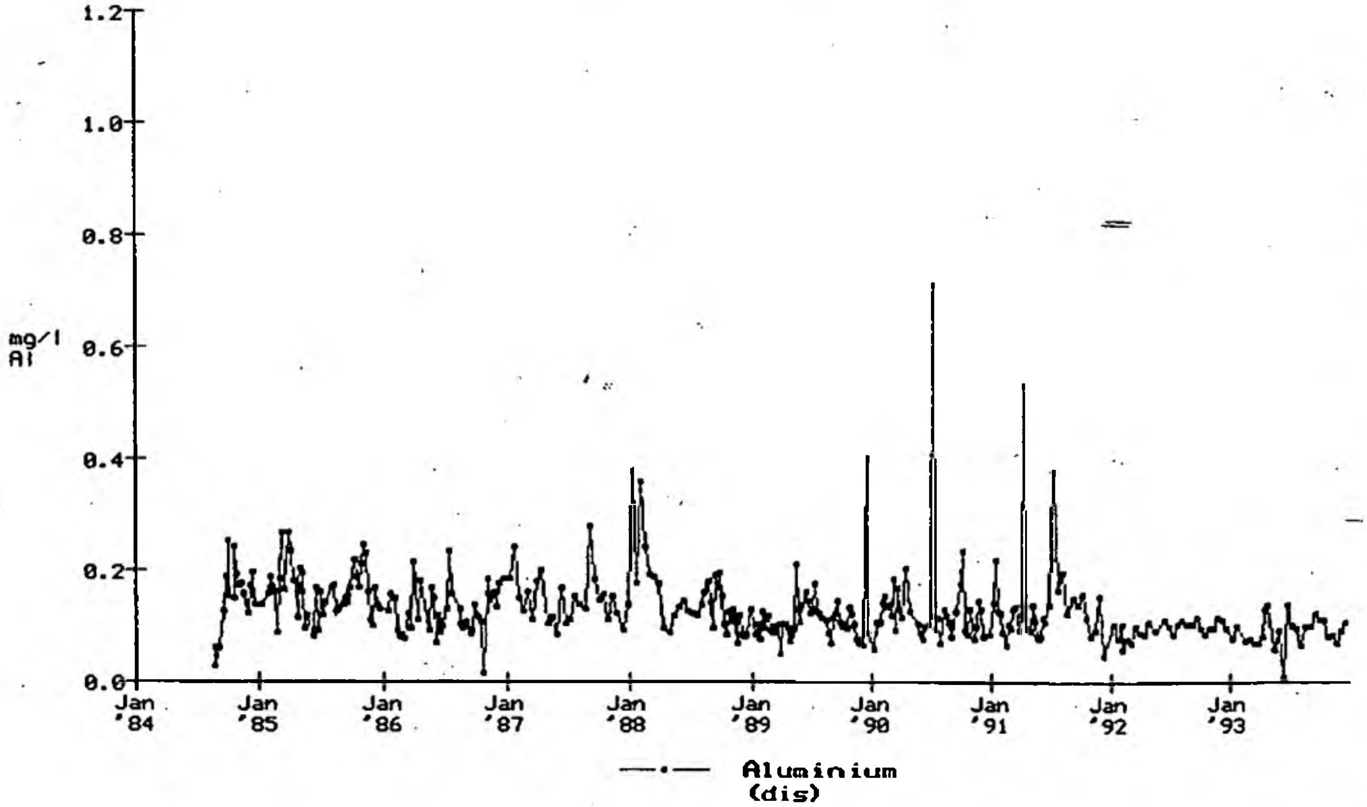


Fig 2.1.9.ii Spot sample data for CI2 Aug'84 to Dec'93





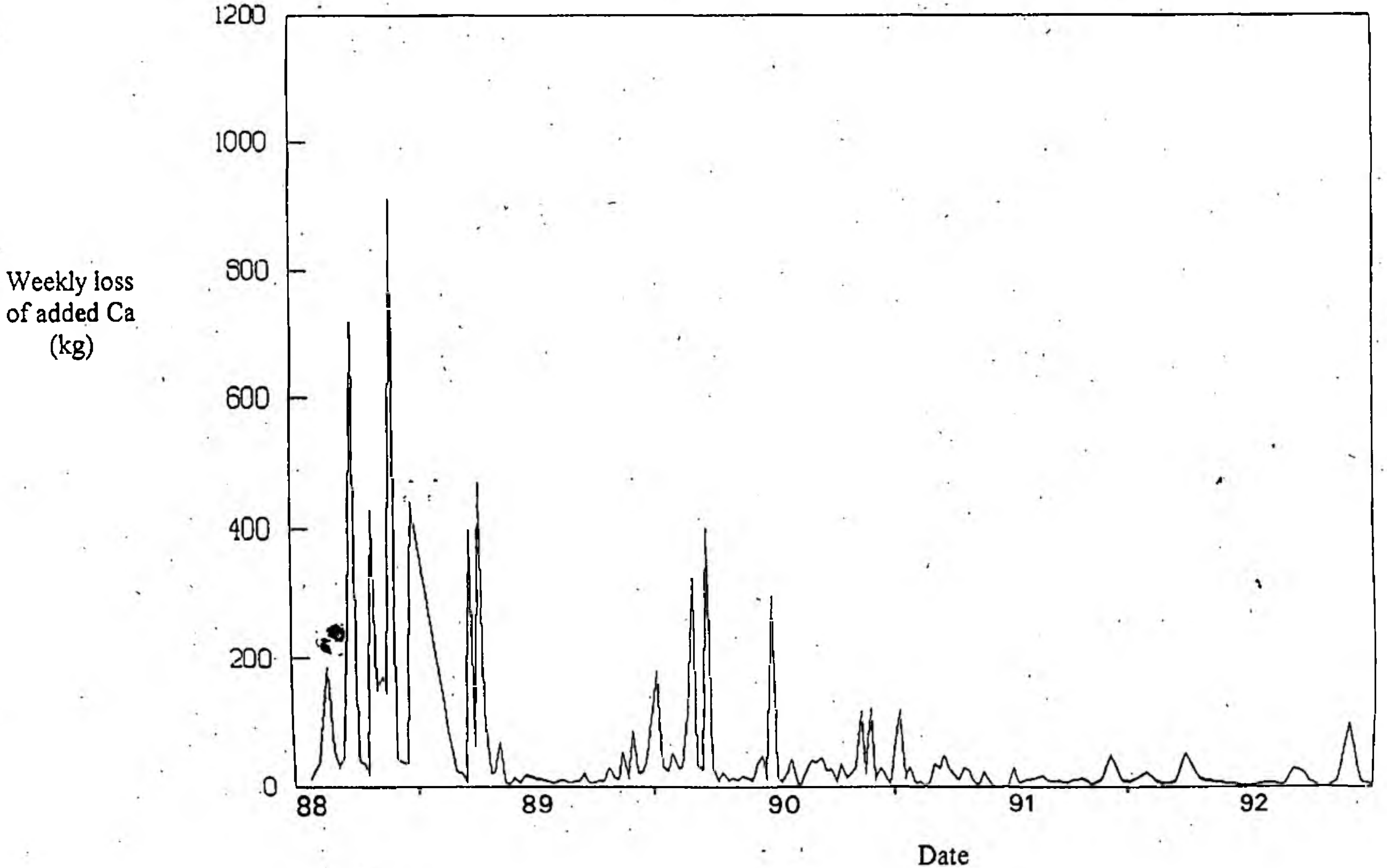
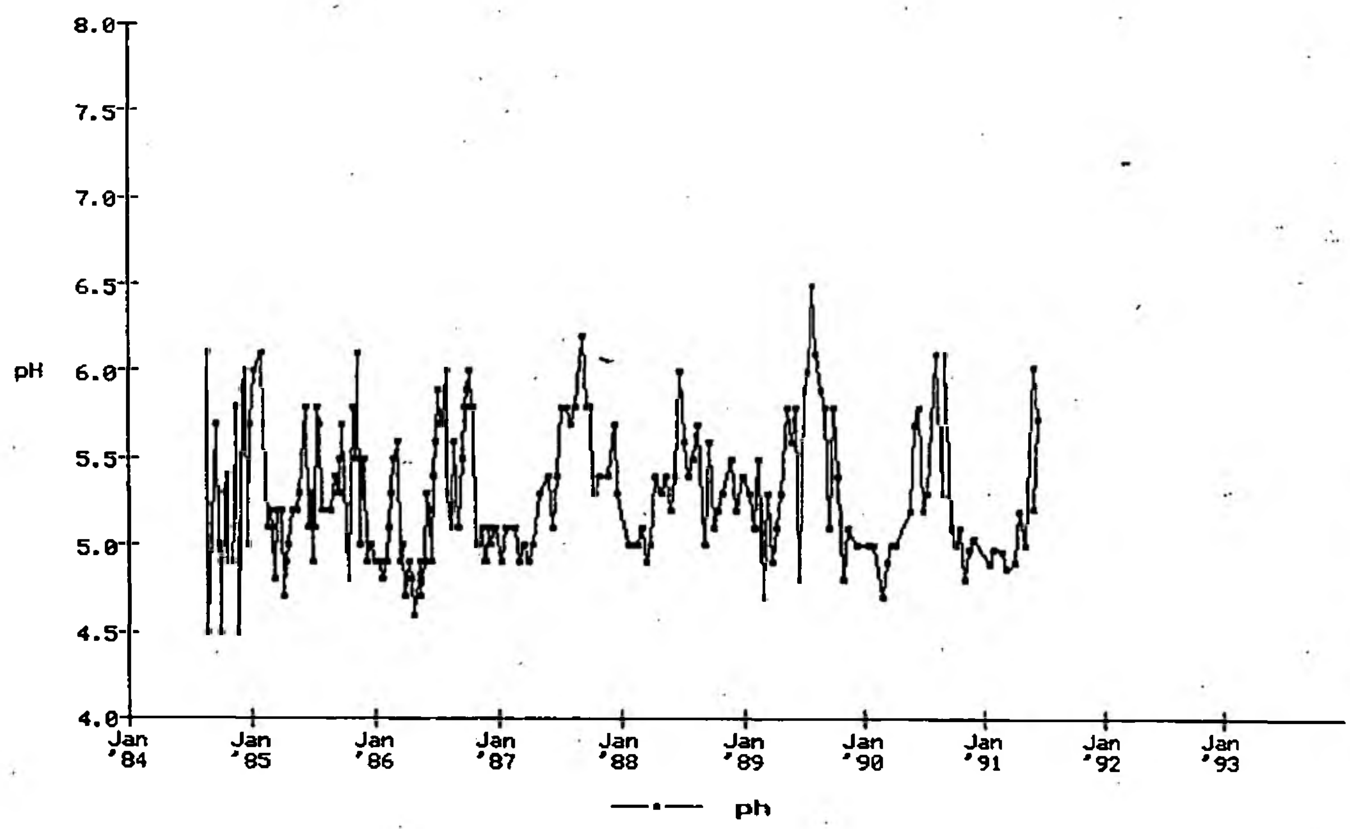


Figure 2.1.9.iii Post-liming Calcium budget for CI2

Fig 2.1.10.i **Spot sample data for CI3 Aug'84 to June'91**



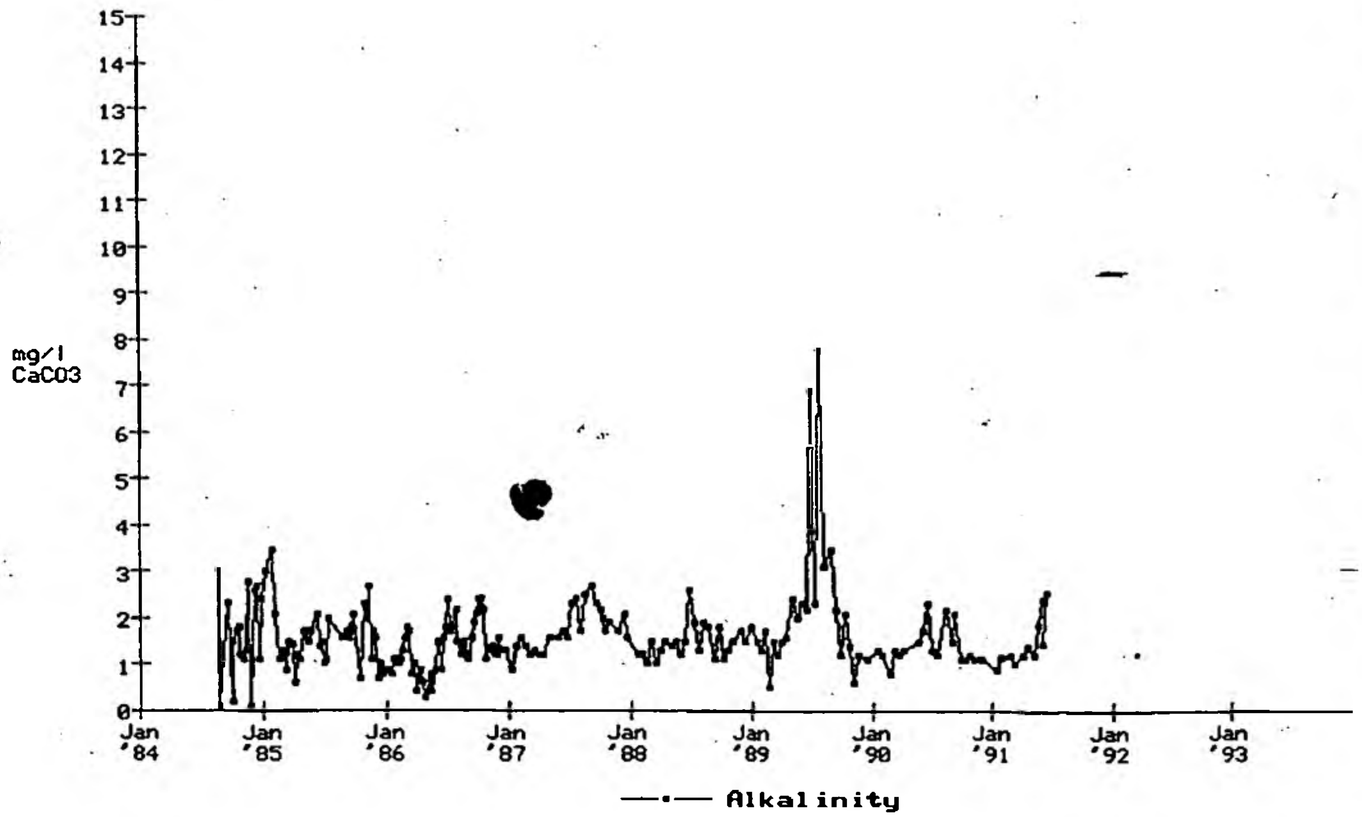
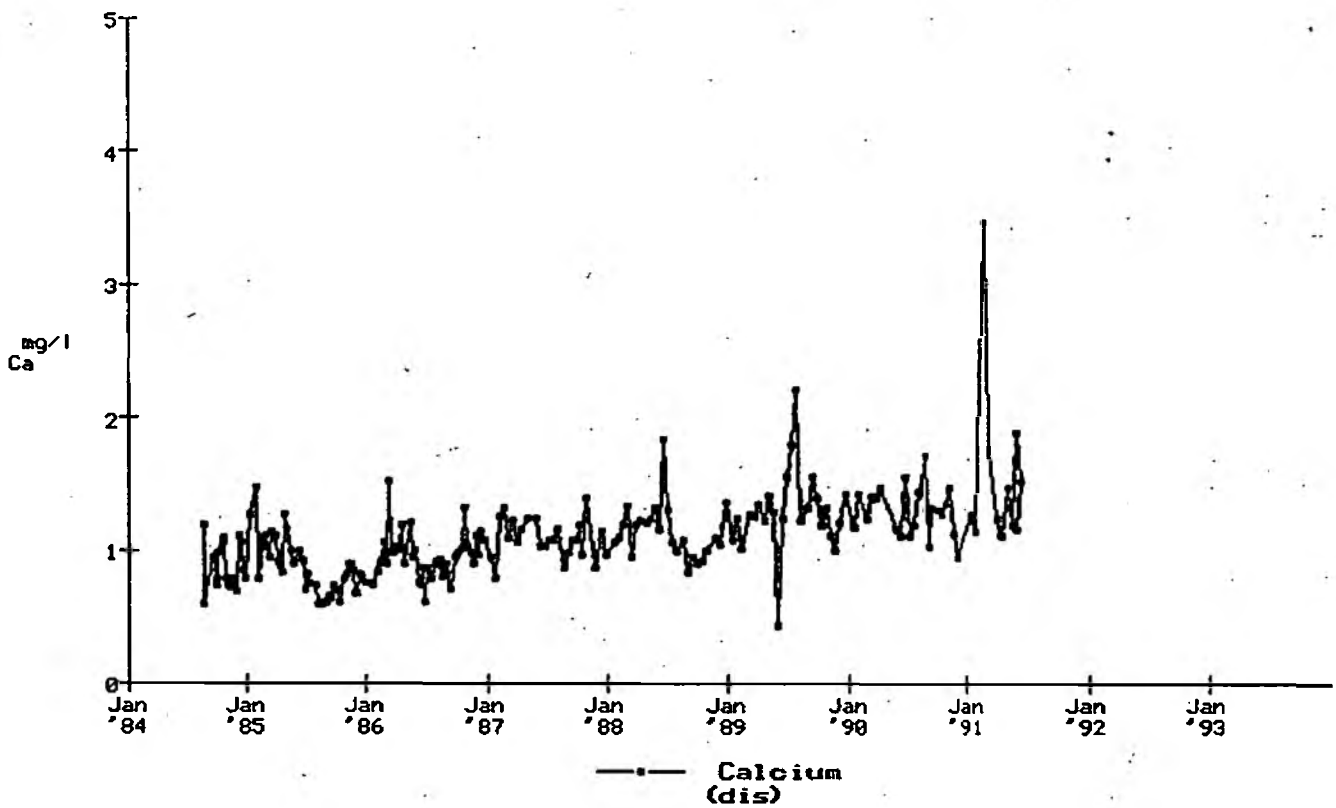


Fig 2.1.10.ii Spot sample data for CI3 Aug'84 to June'91



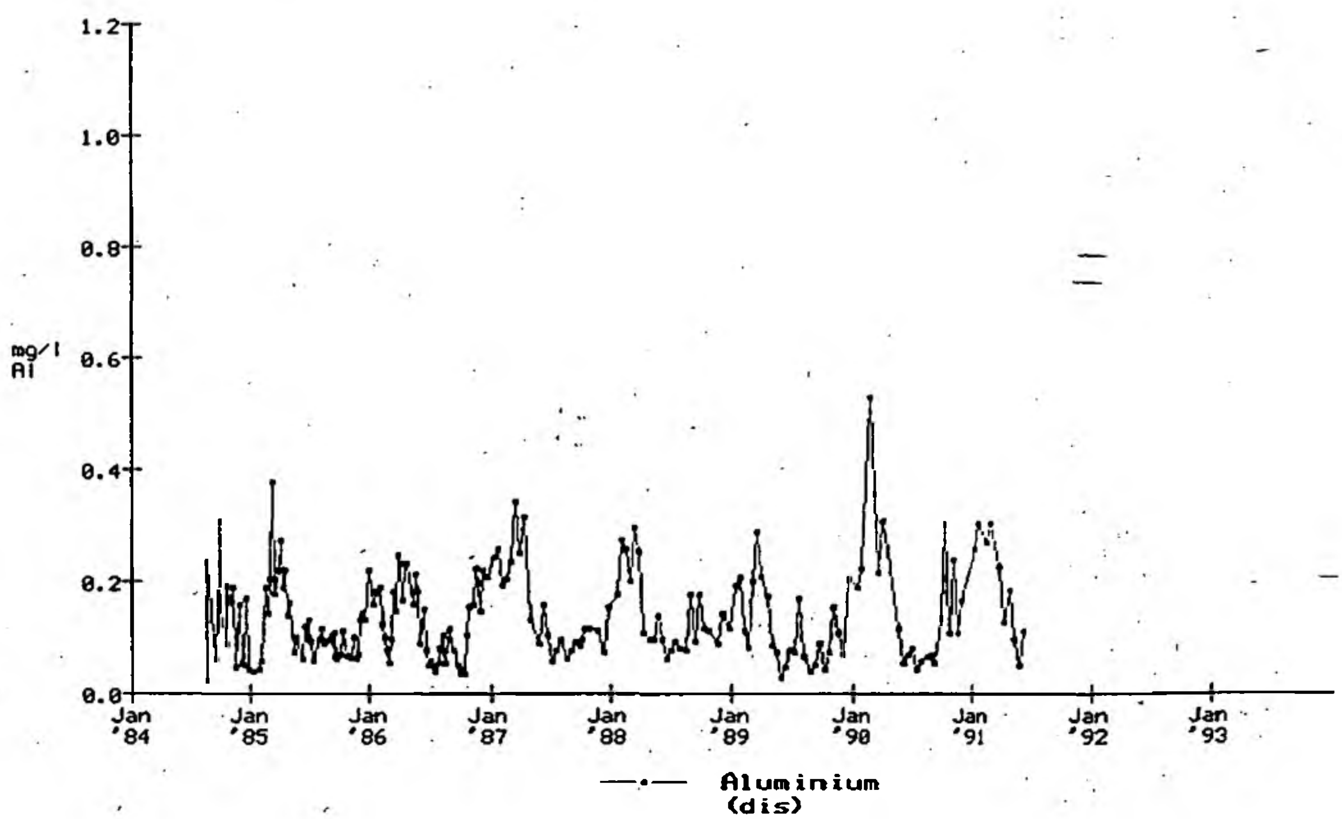
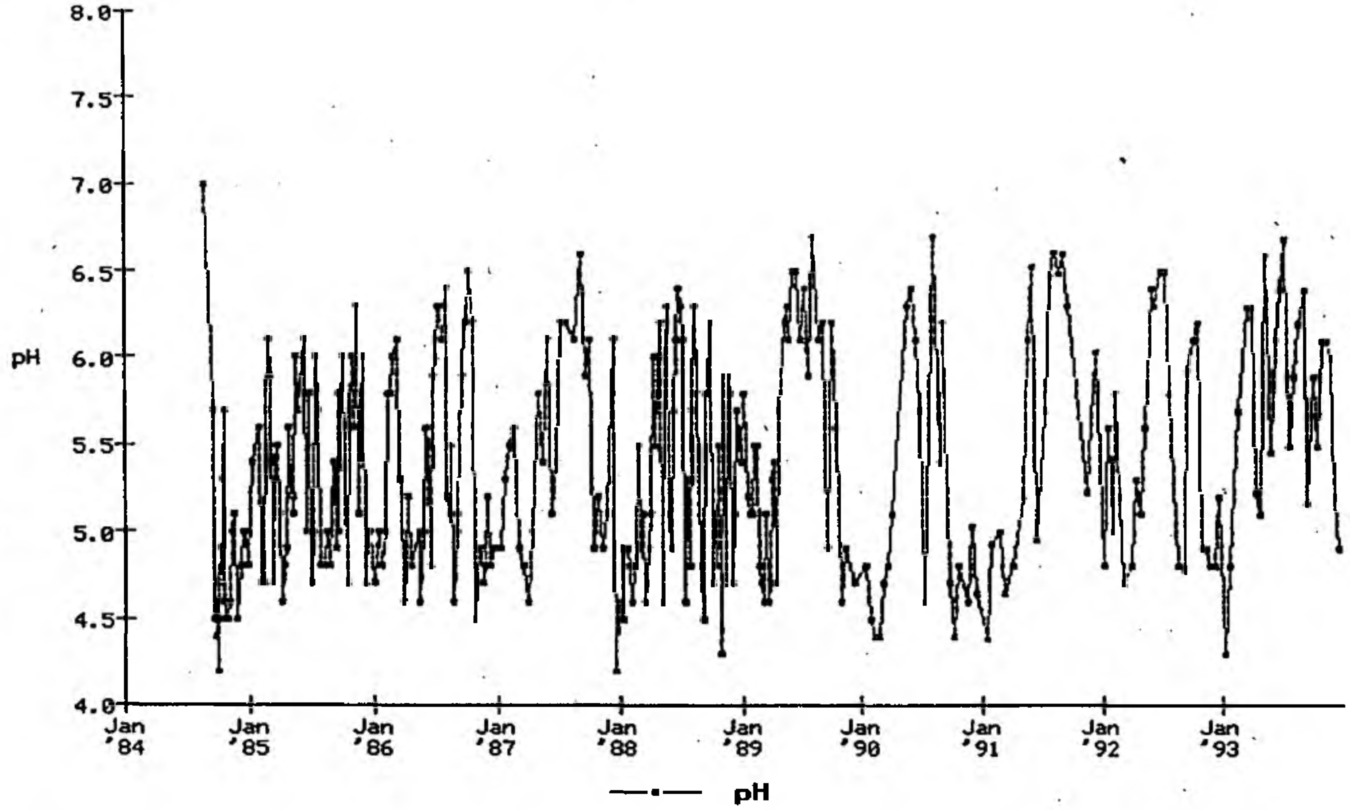


Fig 2.1.11.i Spot sample data for CI4 Mar'84 to Dec'93



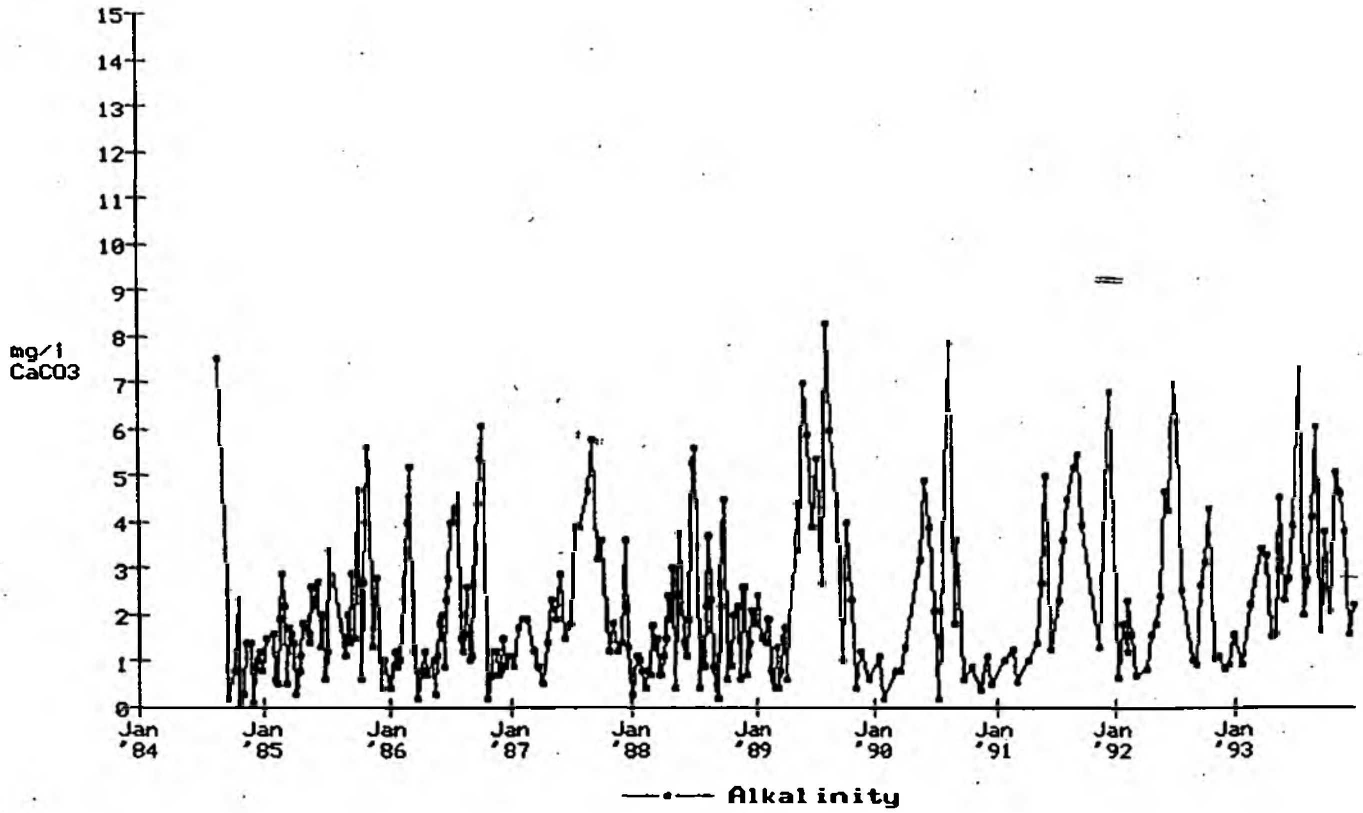
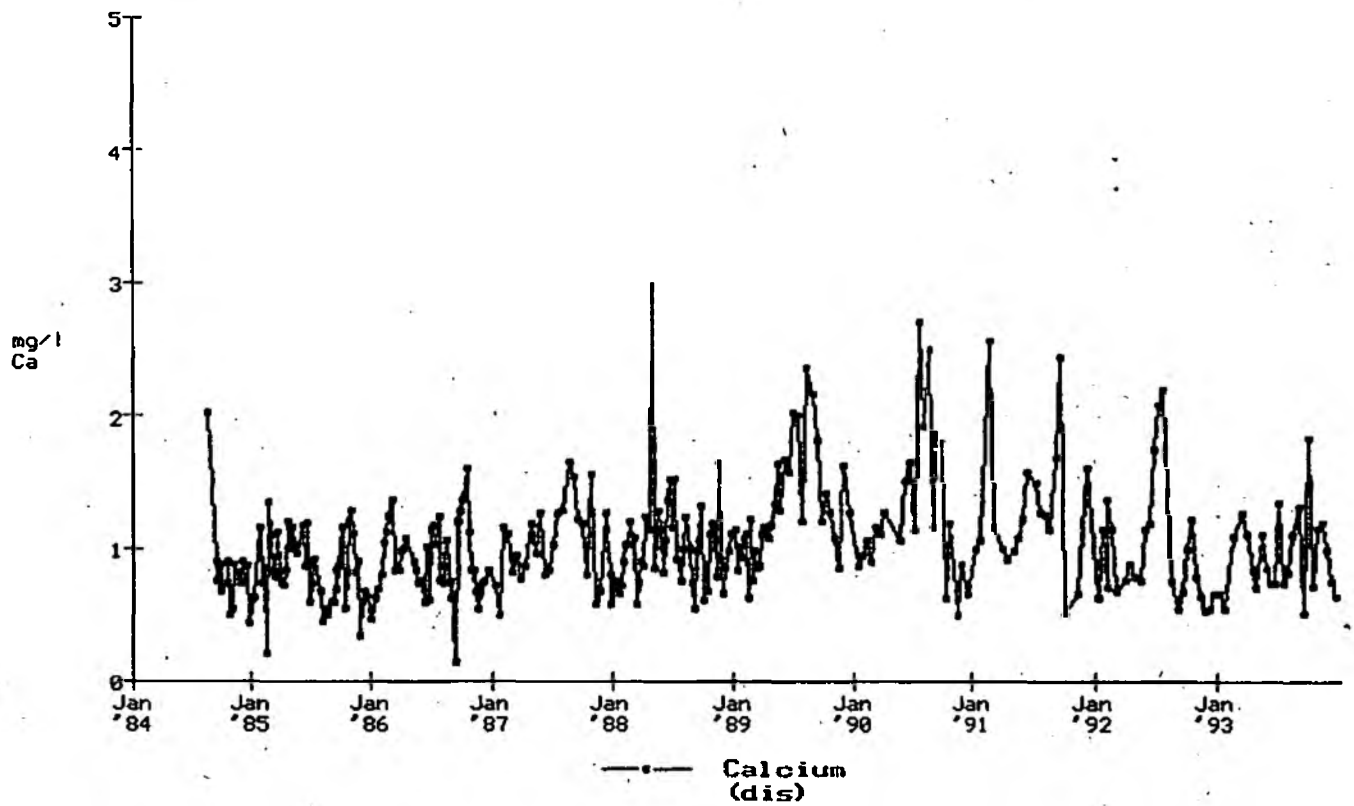


Fig 2.1.11.ii **Spot sample data for CI4 Mar'84 to Dec'93**



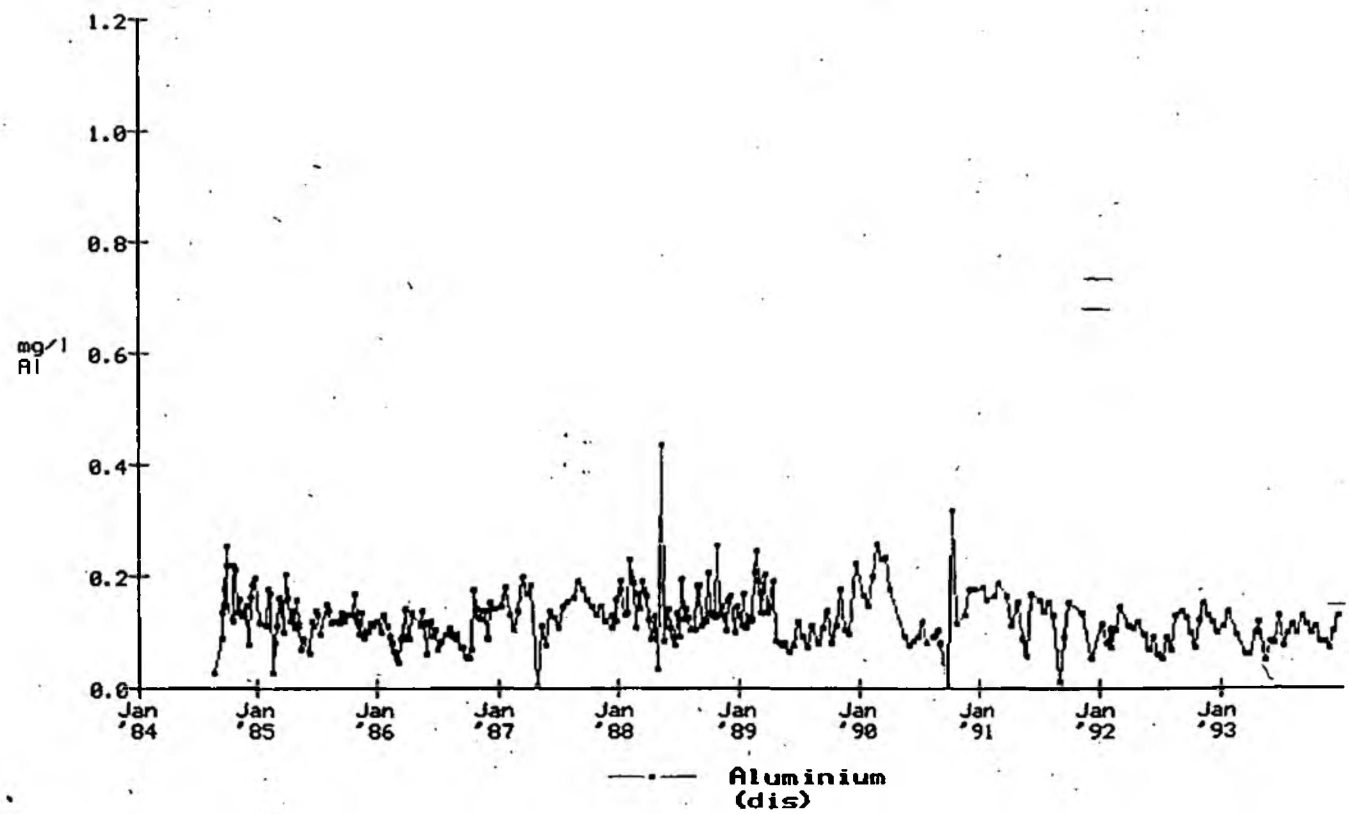
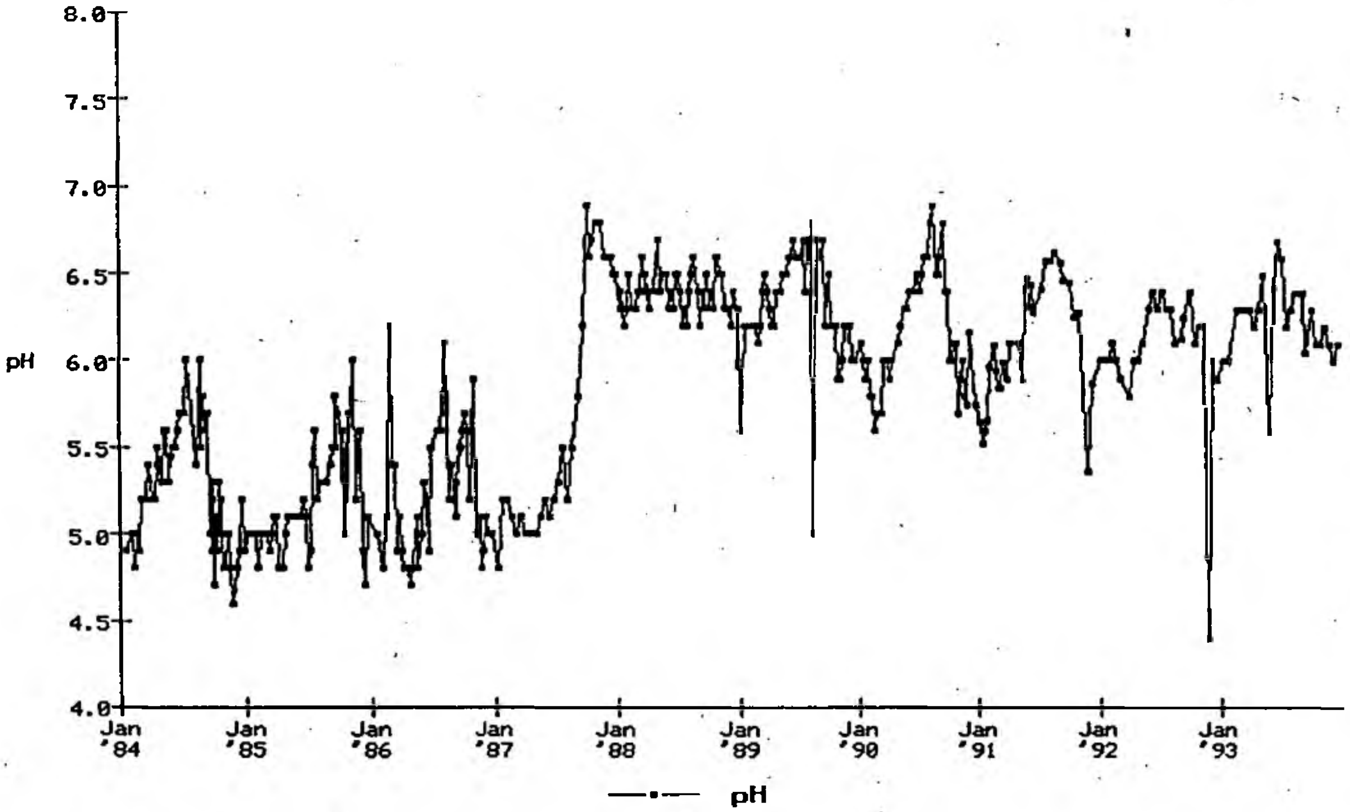


Fig 2.1.12.i **Spot sample data for CIS Jan'84 to Dec'93**



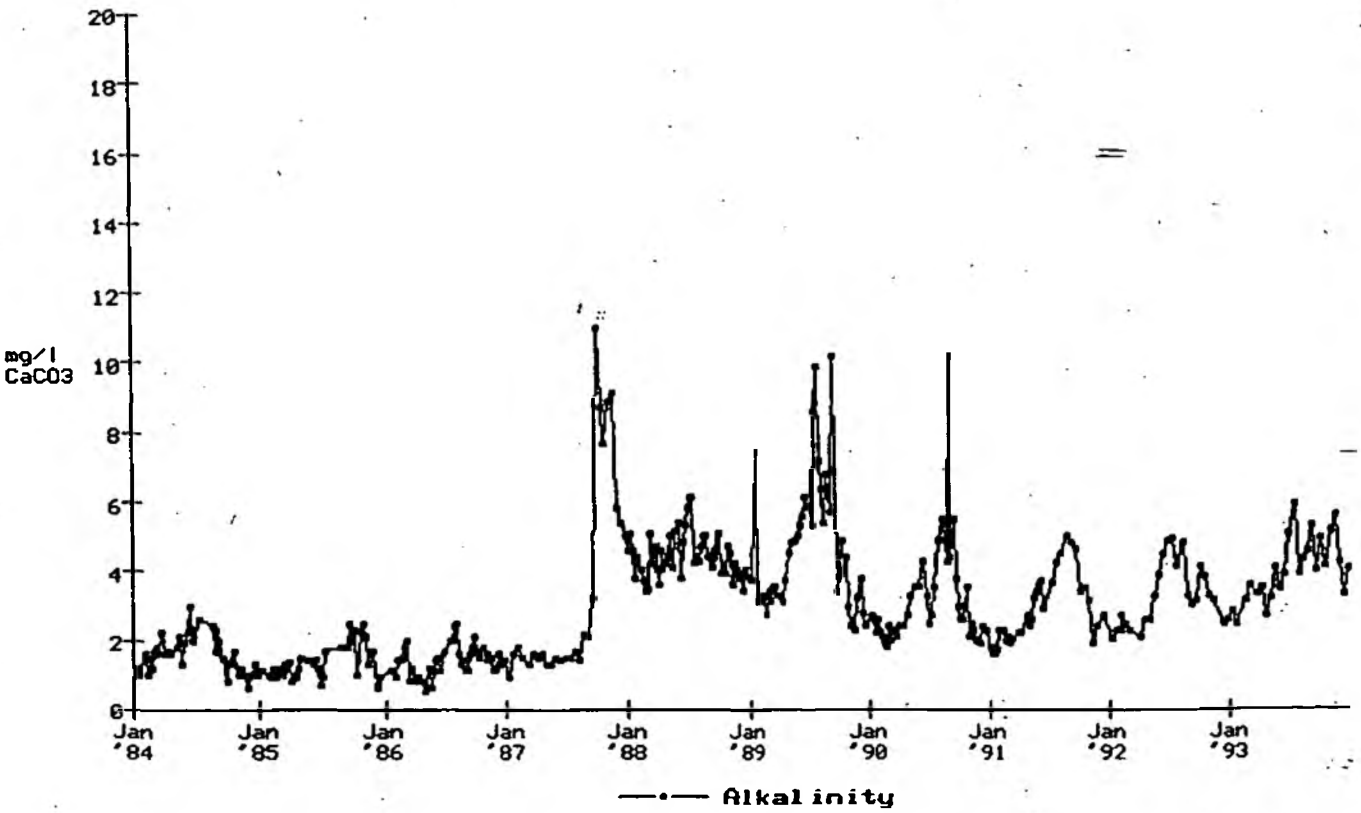
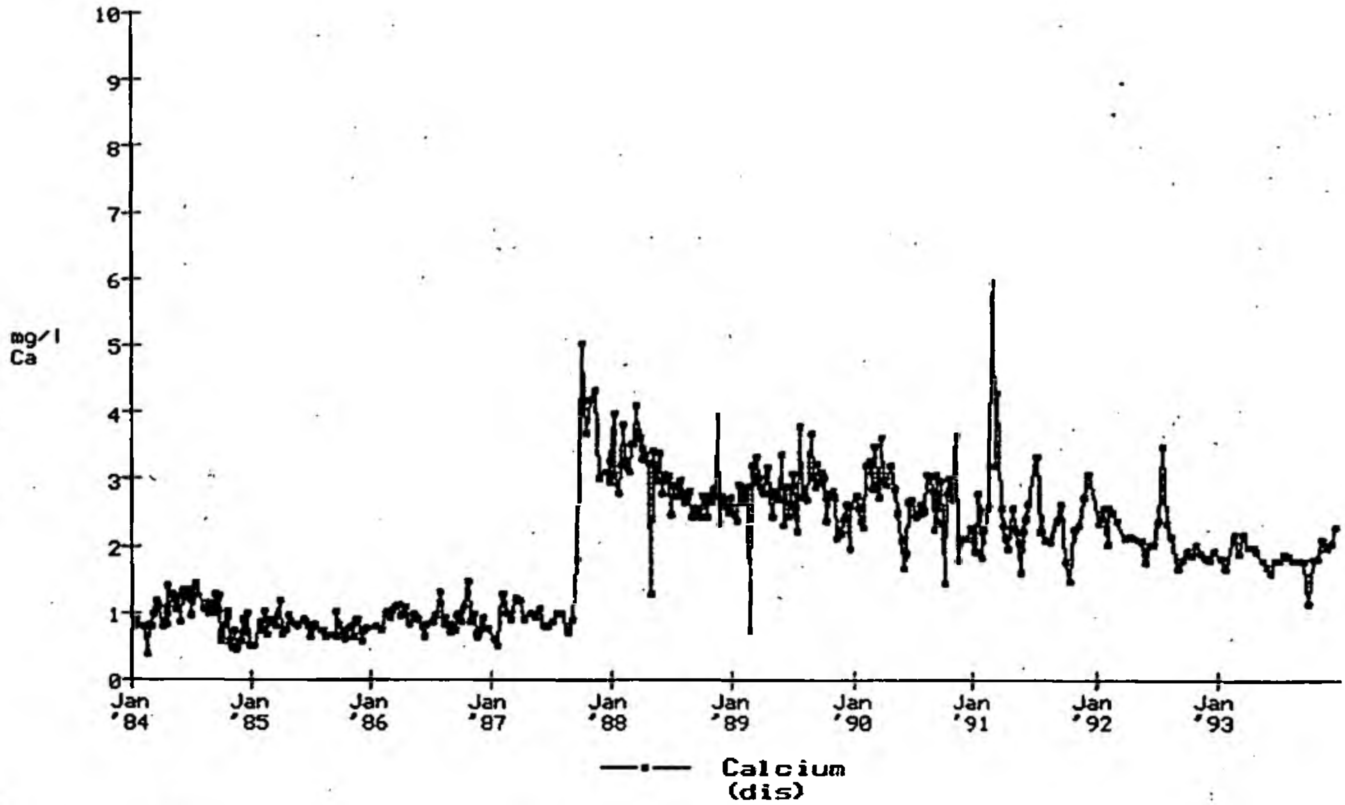


Fig 2.1.12.ii Spot sample data for CI5 Jan'84 to Dec'93



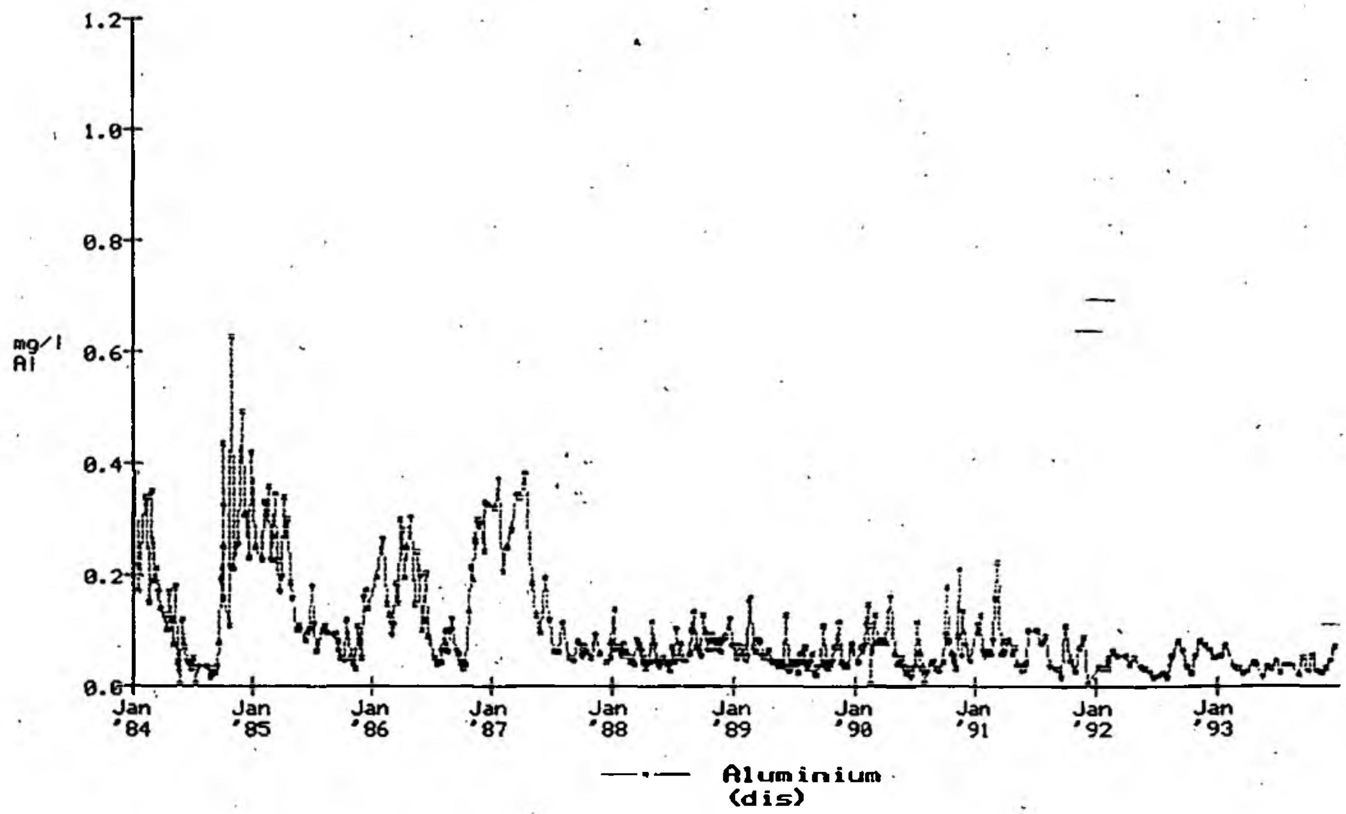
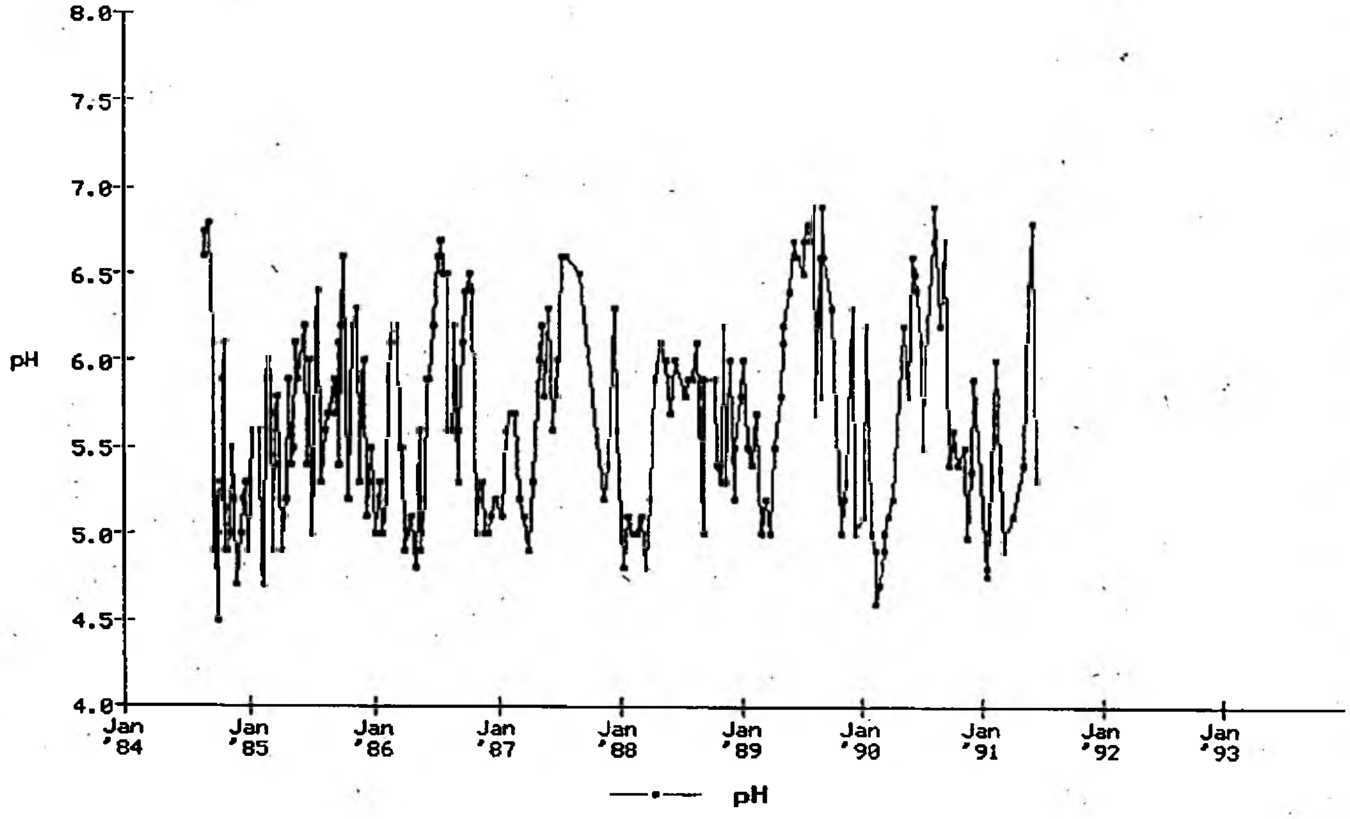


Fig 2.1.13.i **Spot sample data for CI6 Aug'84 to Jan'92**



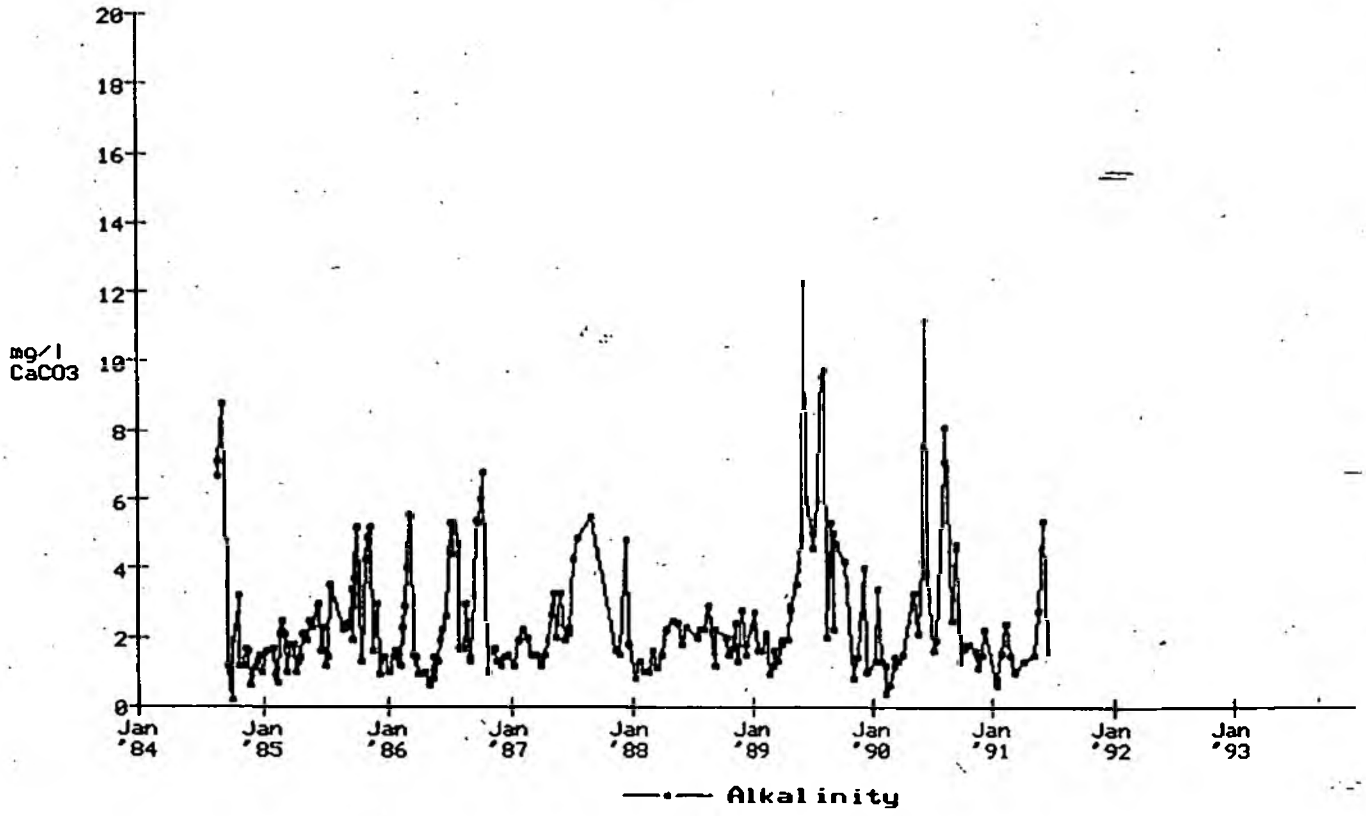
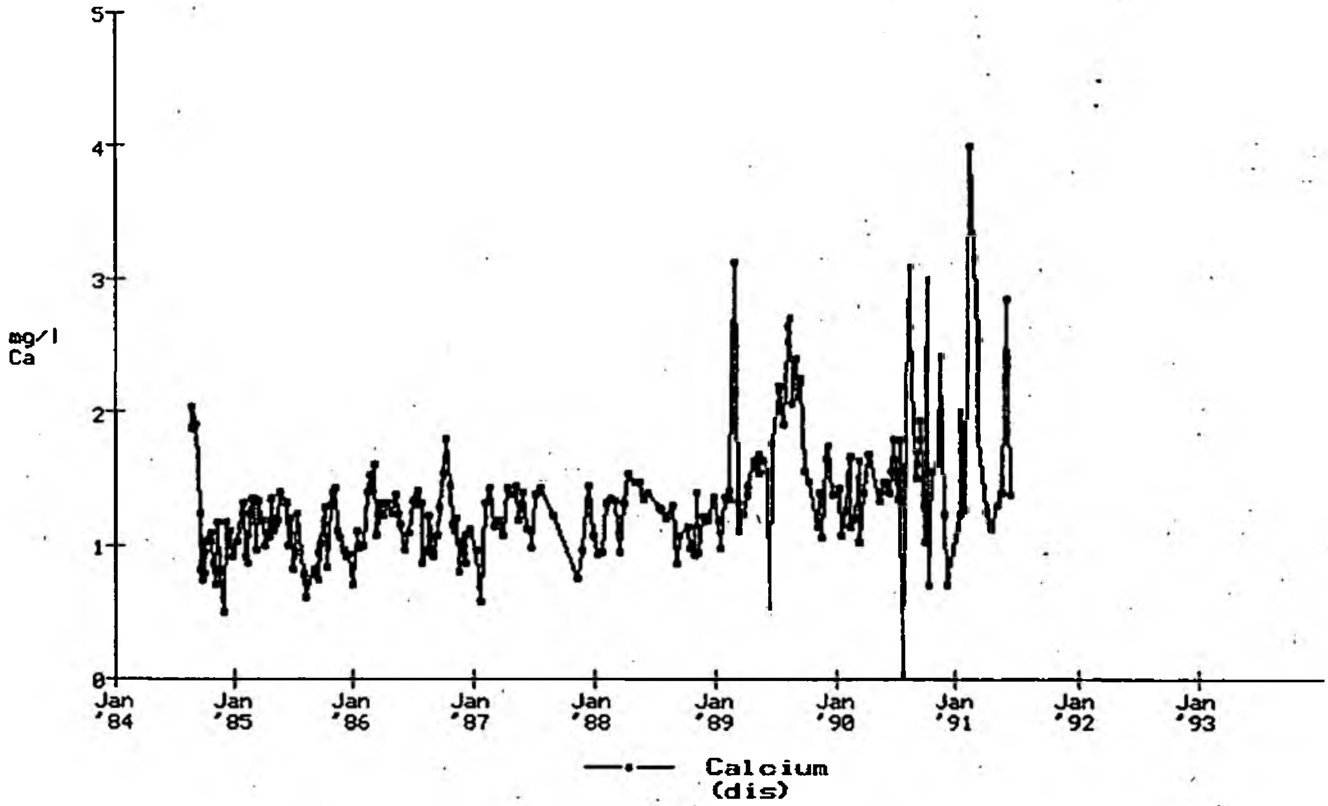


Fig 2.1.13.ii **Spot sample data for CI6 Aug'84 to Jan'92**



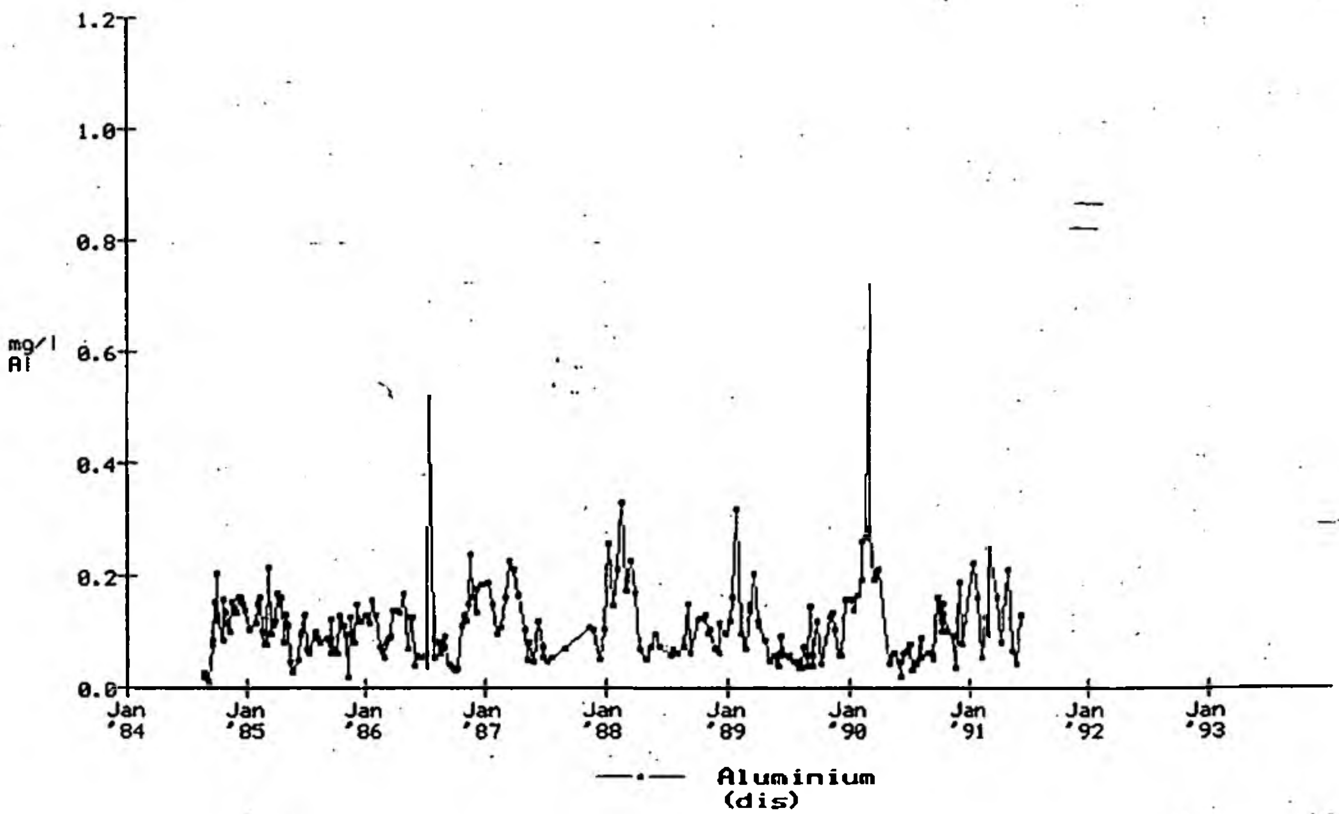
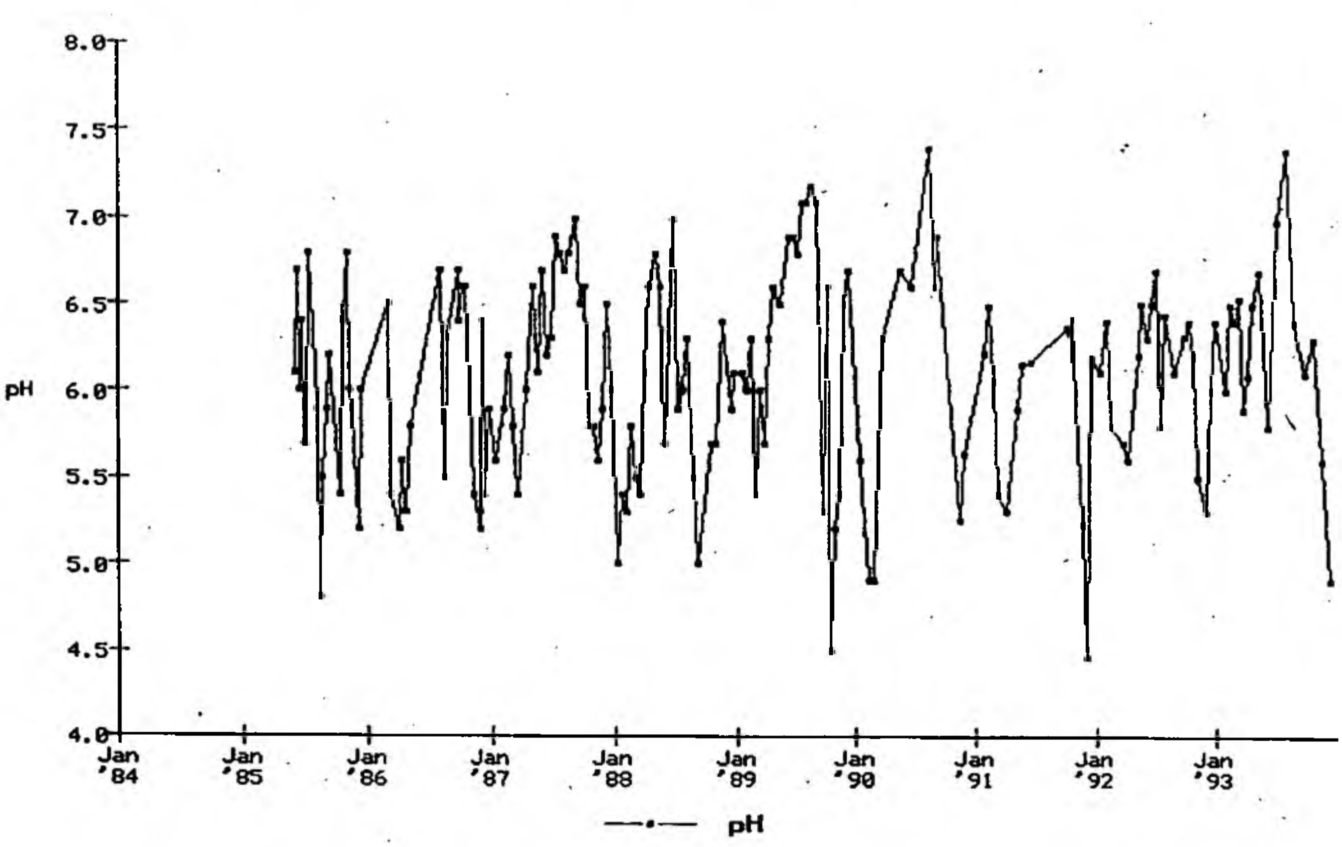


Fig 2.1.14.i **Spot sample data for UC4 May '85 to Dec'93**



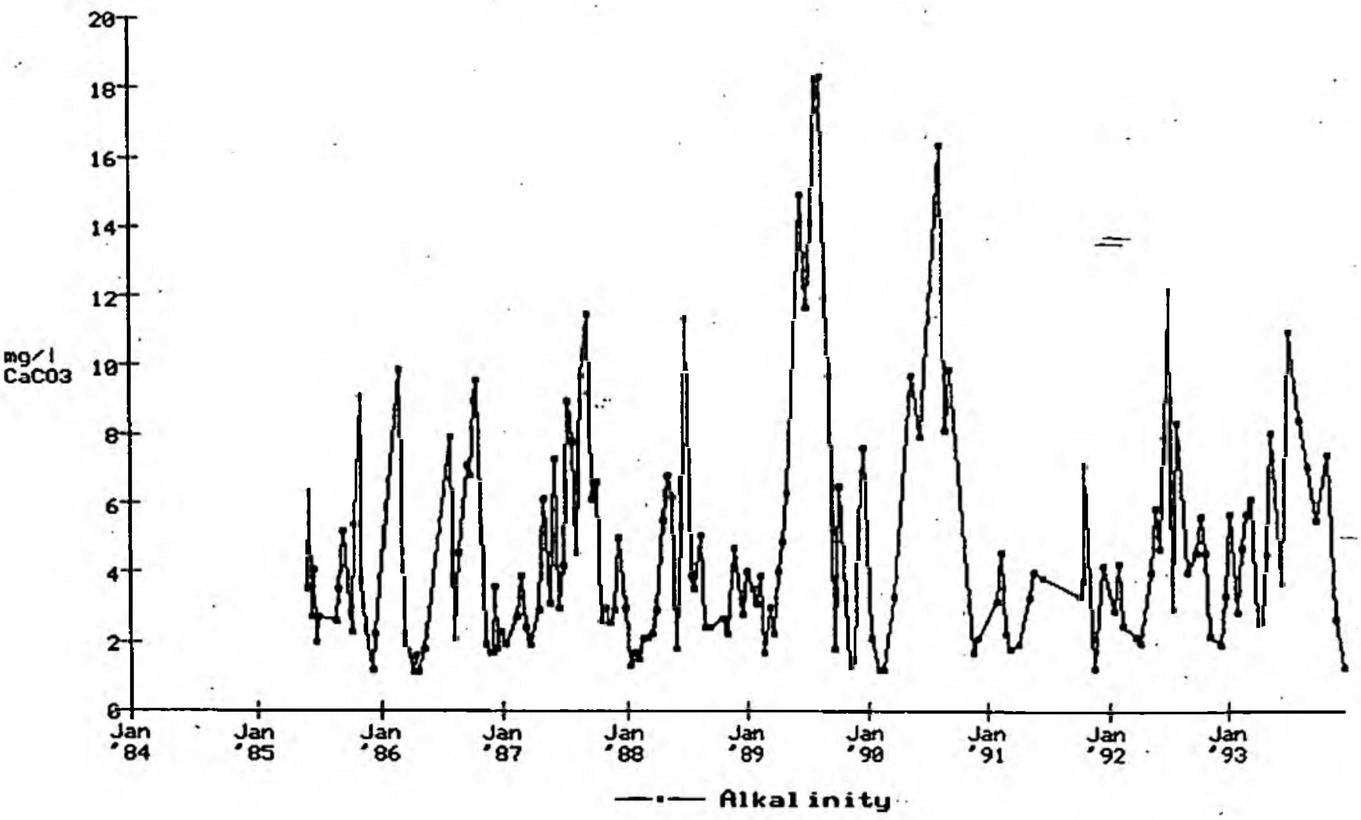
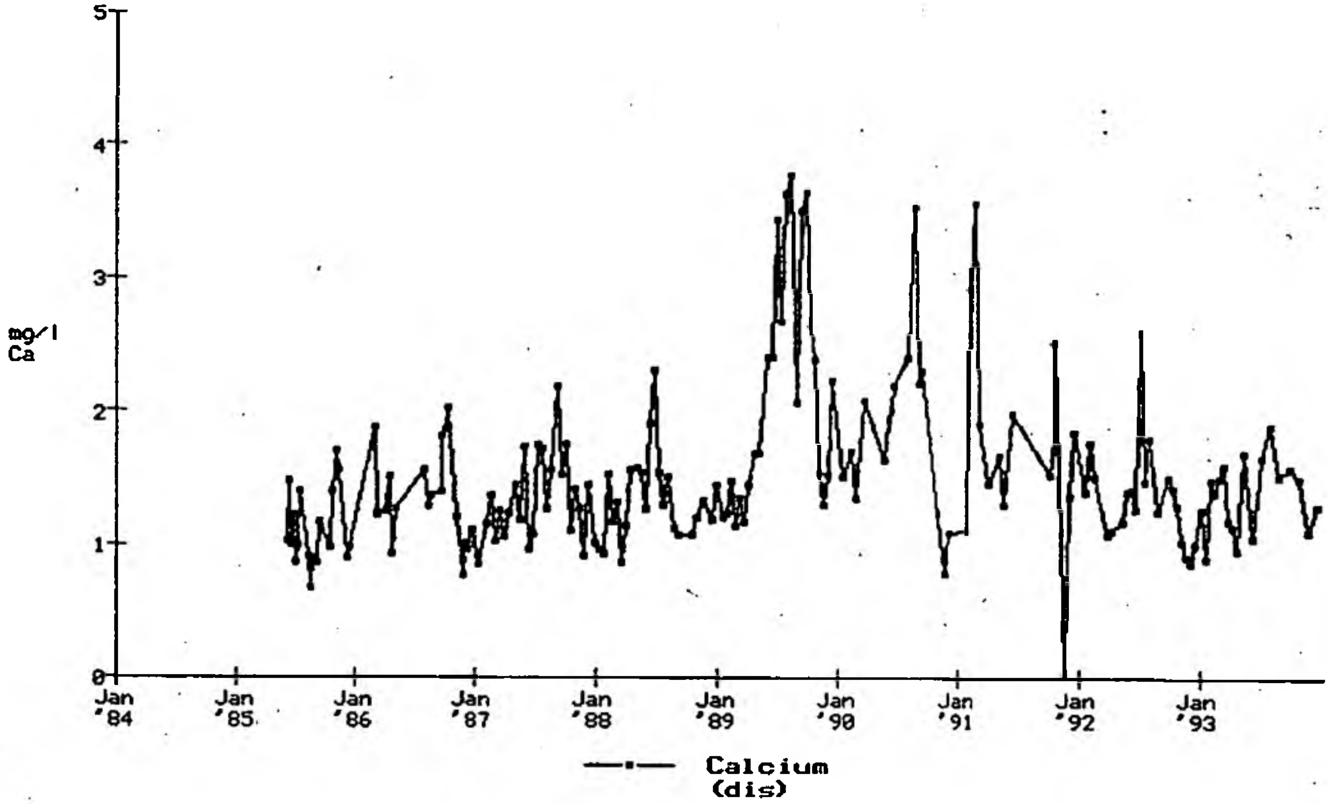


Fig 2.1.14.ii Spot sample data for UC4 May'85 to Dec'93



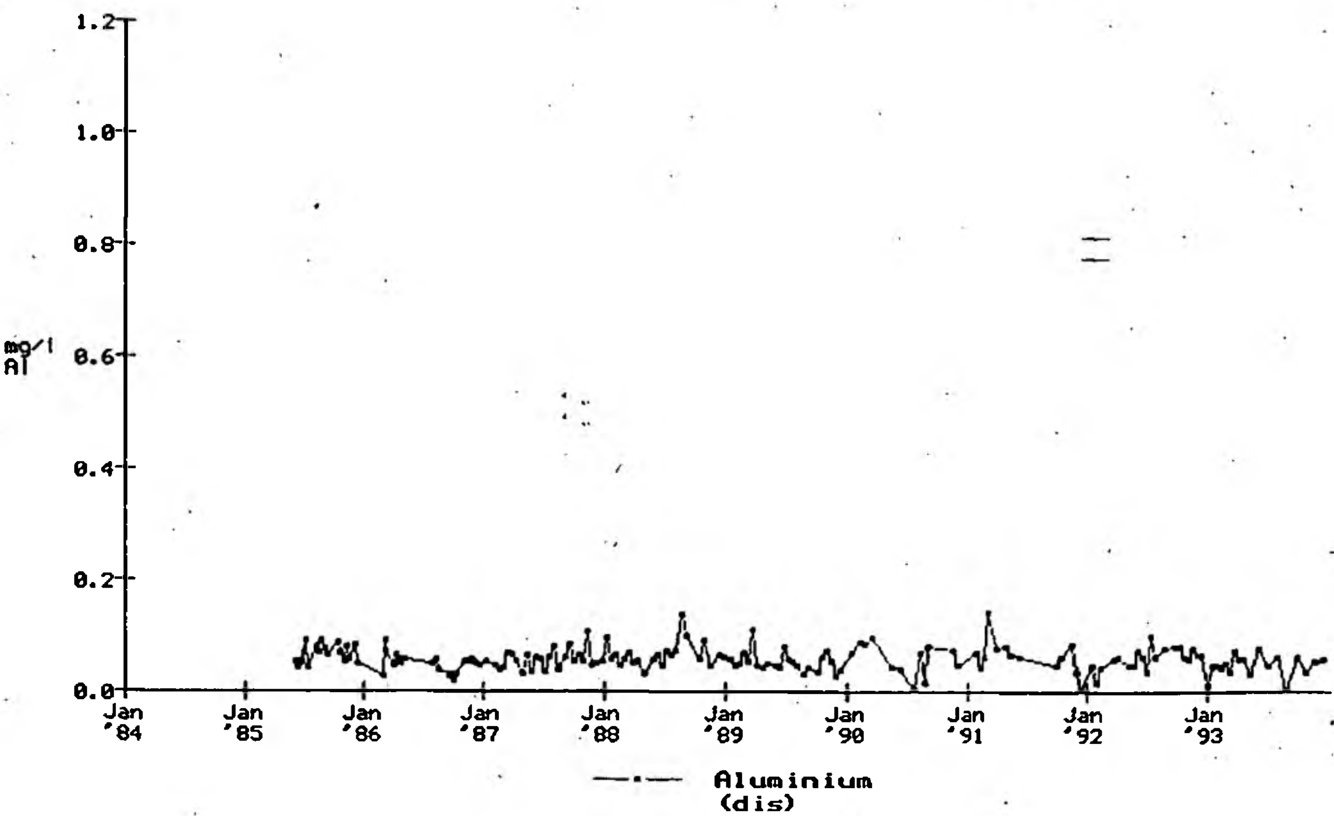
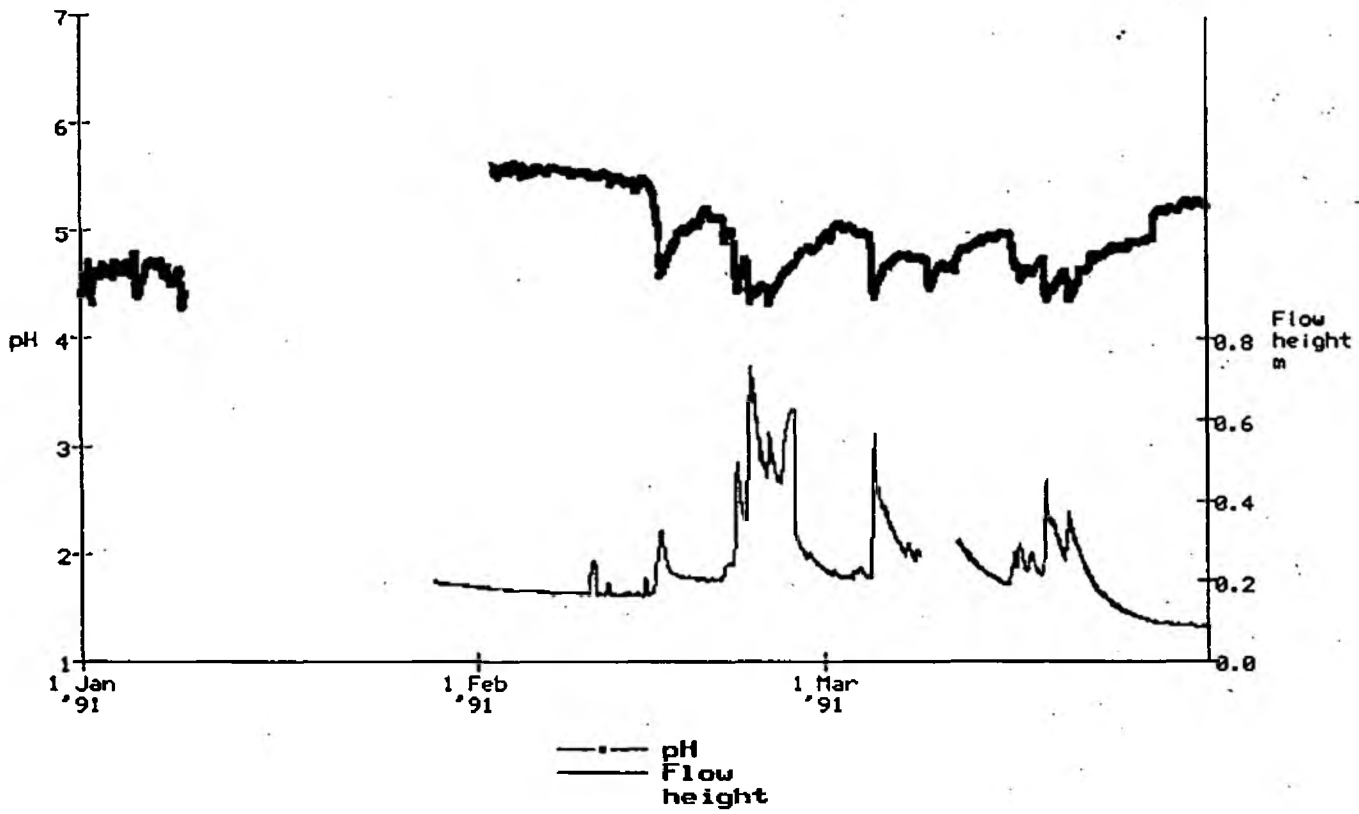
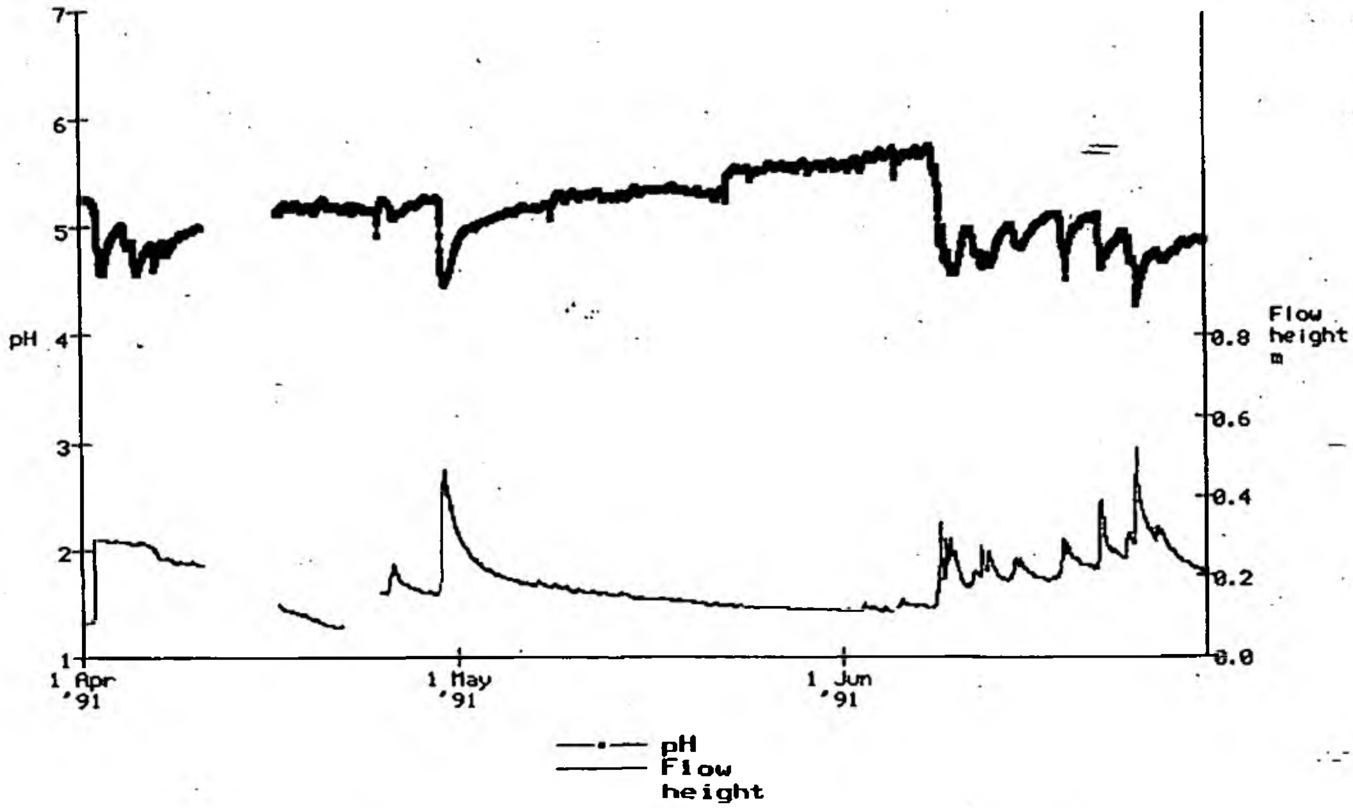
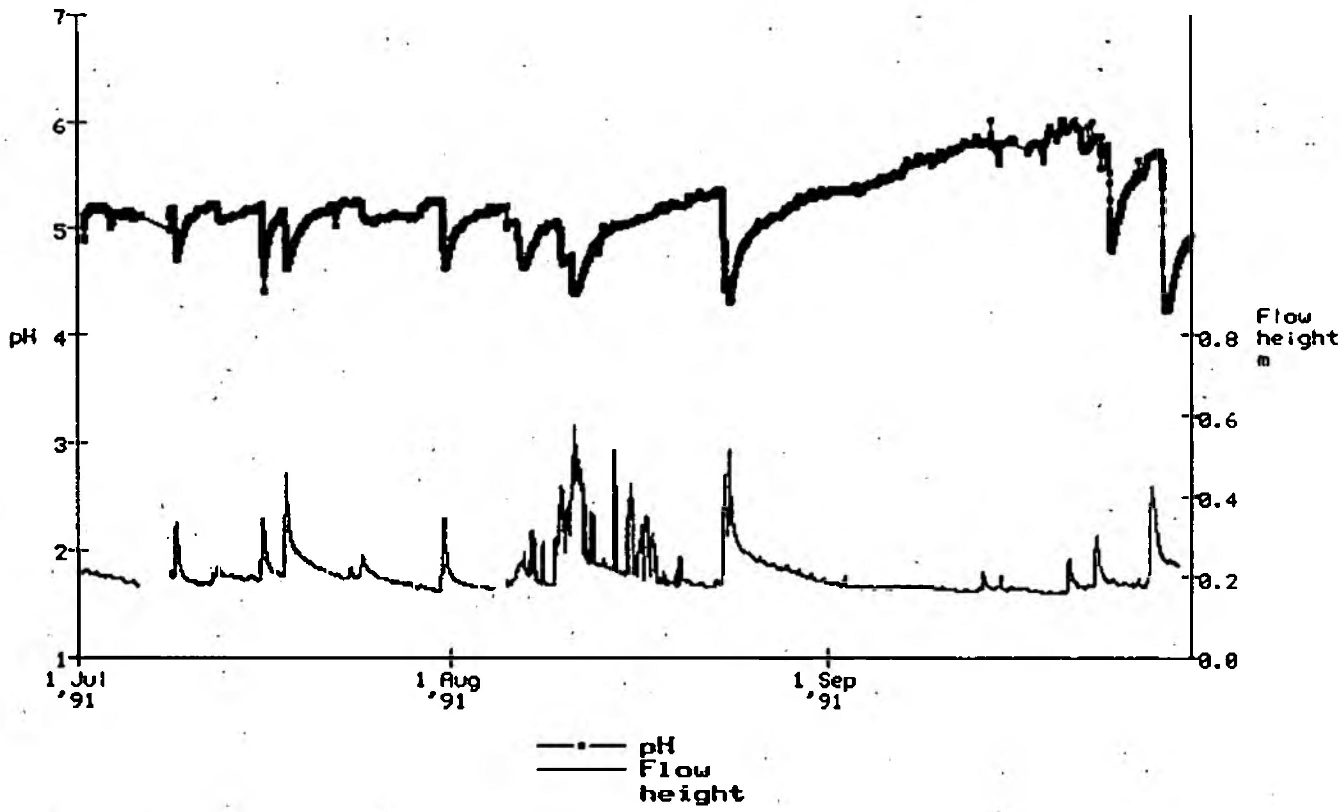


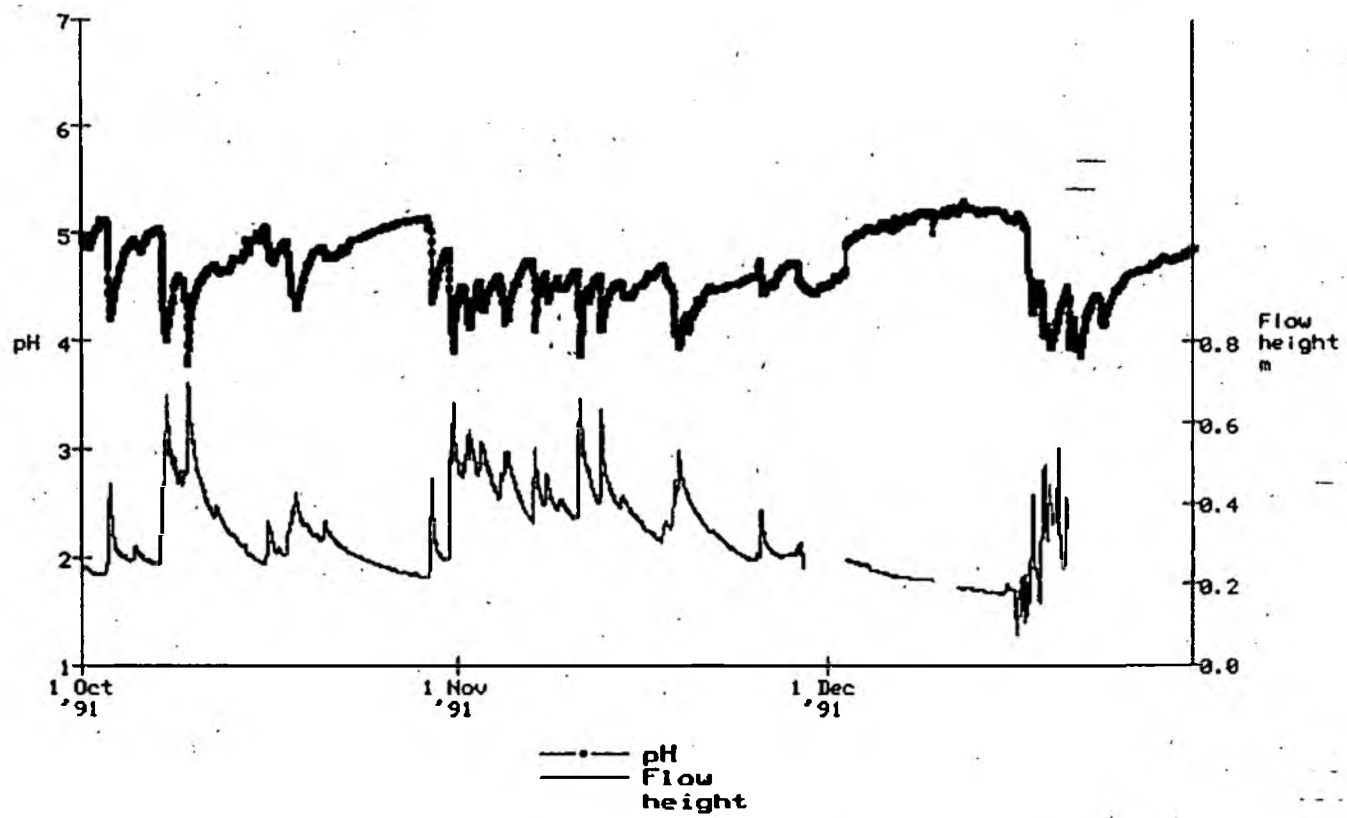
Fig 2.2.1.i Continuous Data for LI1 during 1991



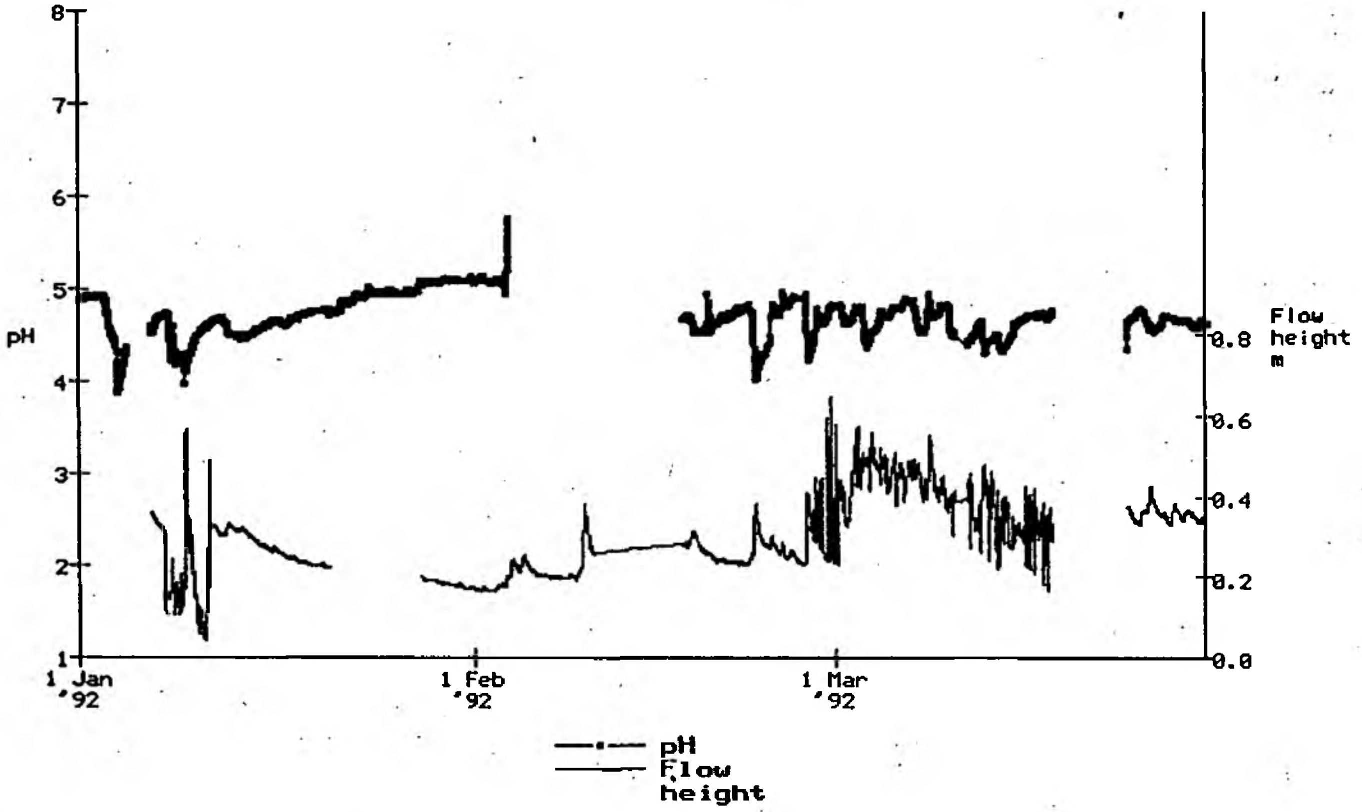


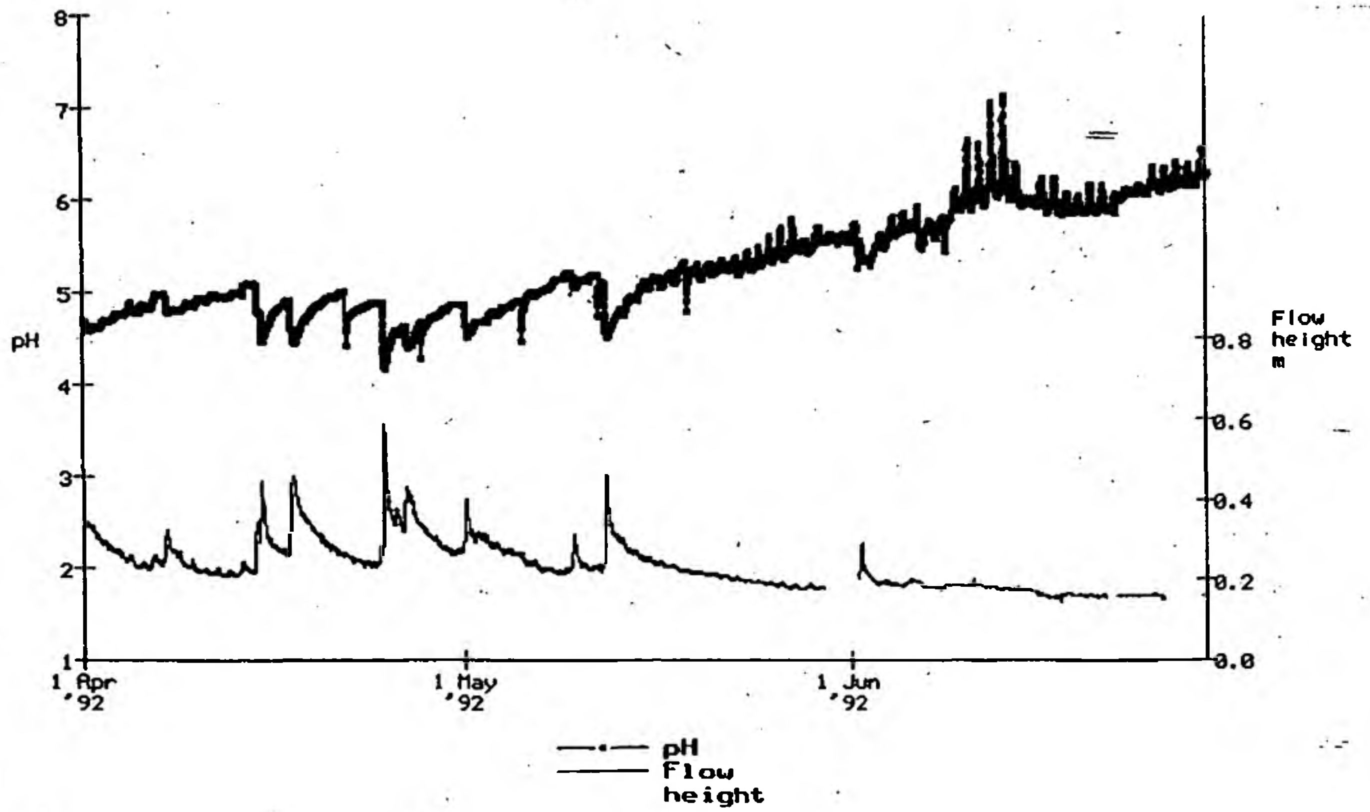
Continuous Data for LI1 during 1991



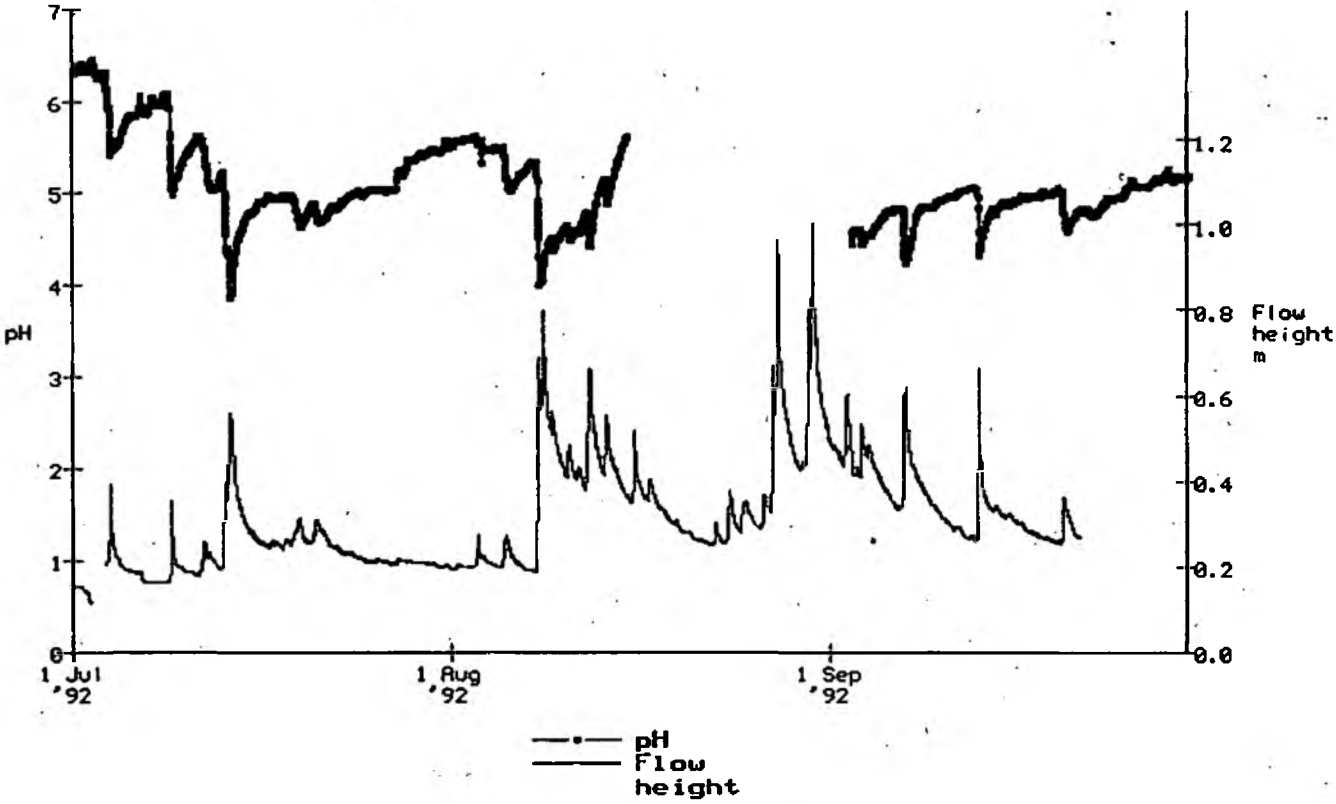


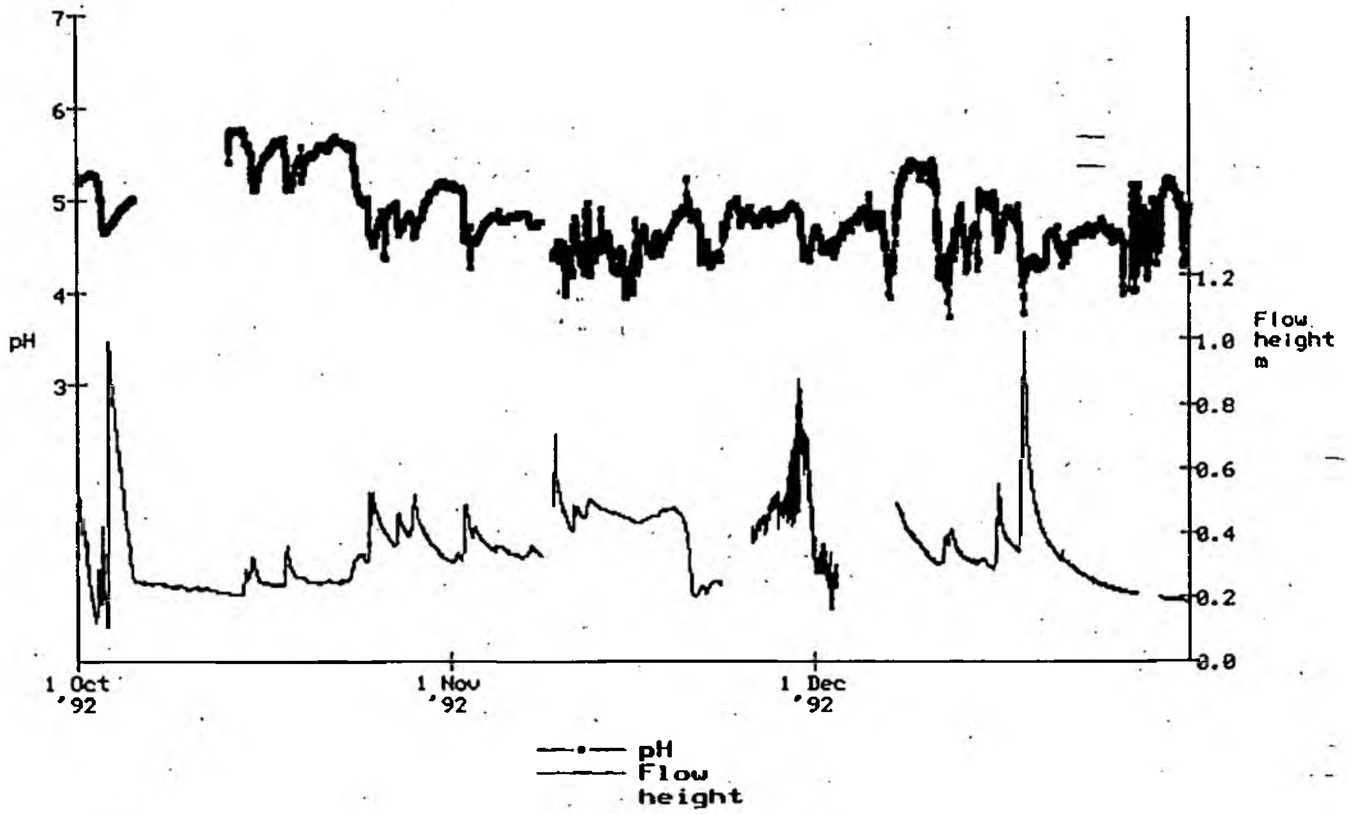
Continuous Data for LI1 during 1992



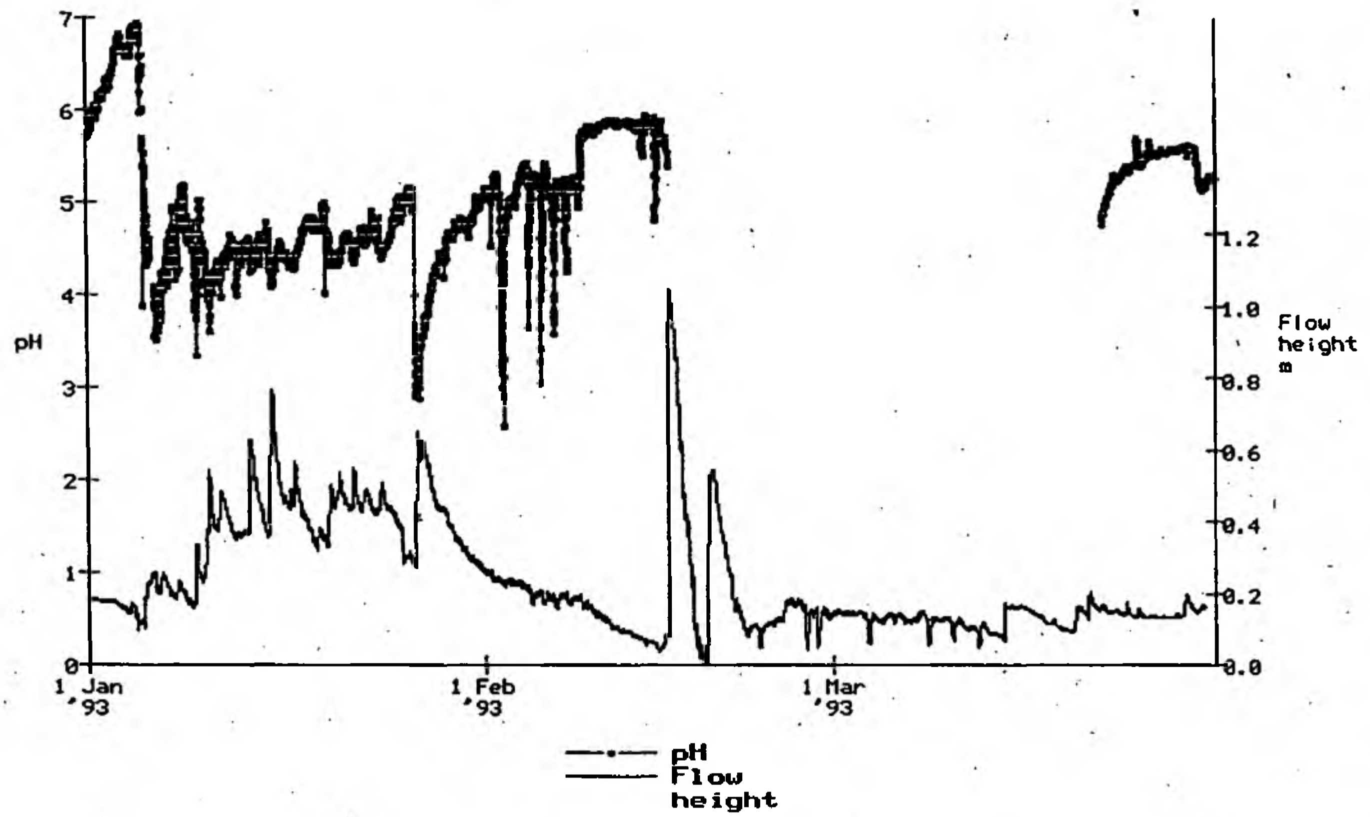


Continuous Data for LI1 during 1992





Continuous Data for LI1 during 1993



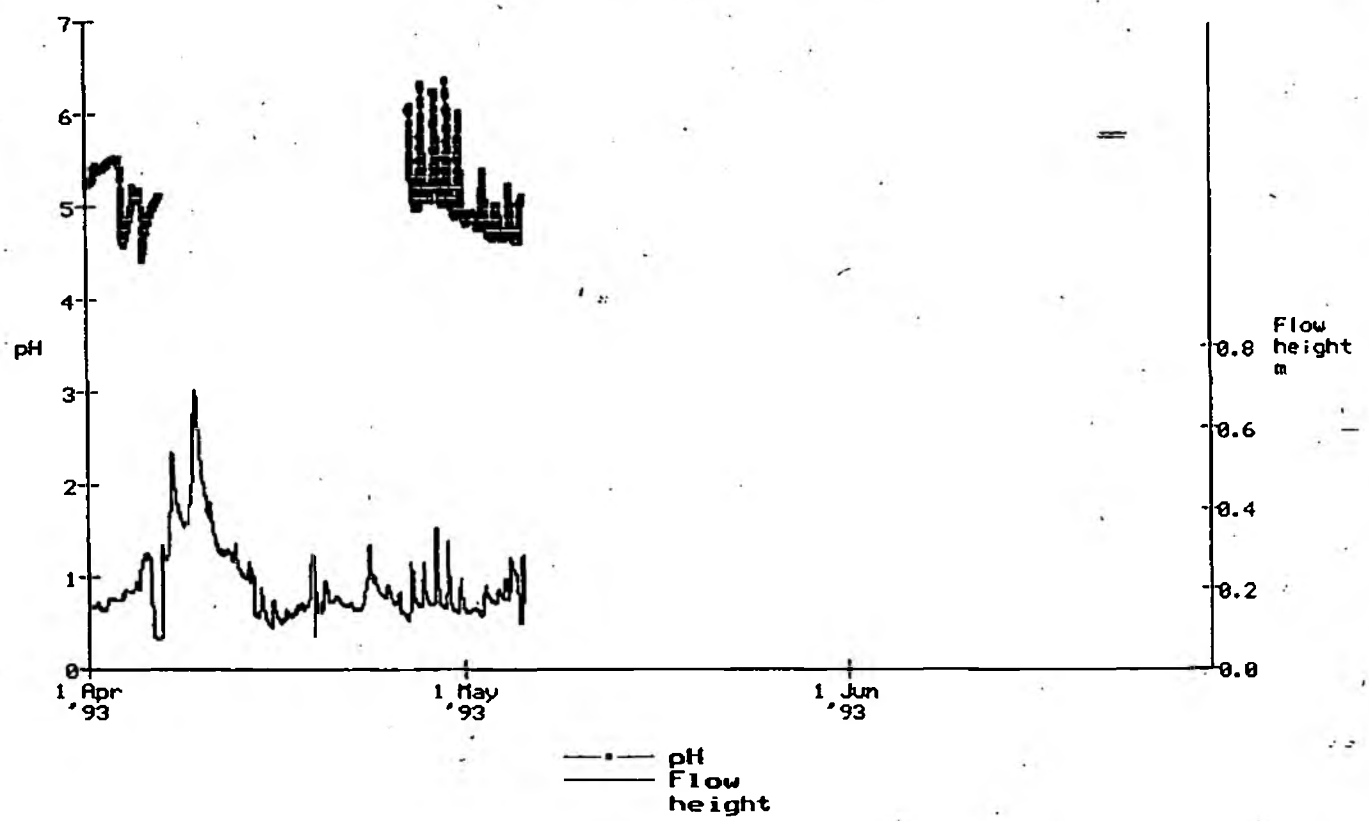
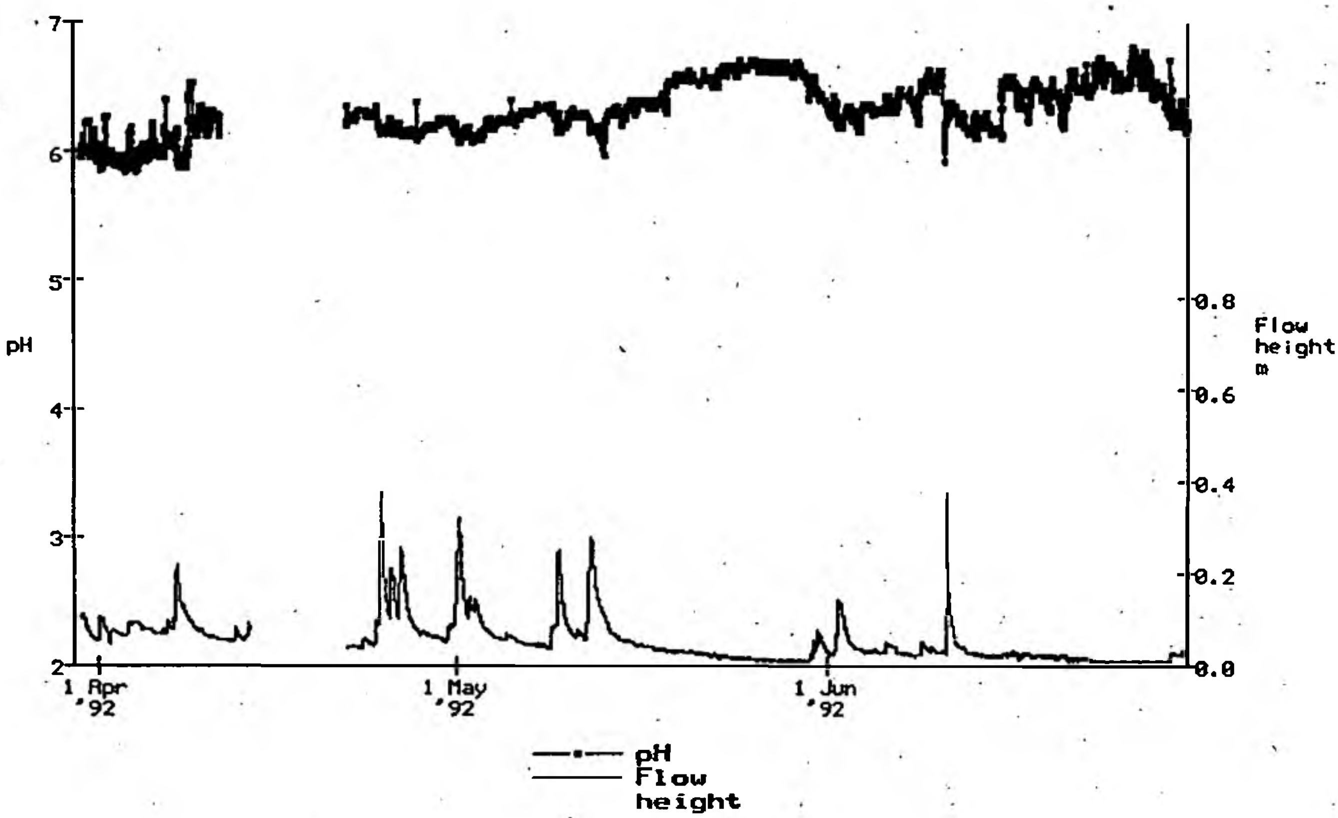
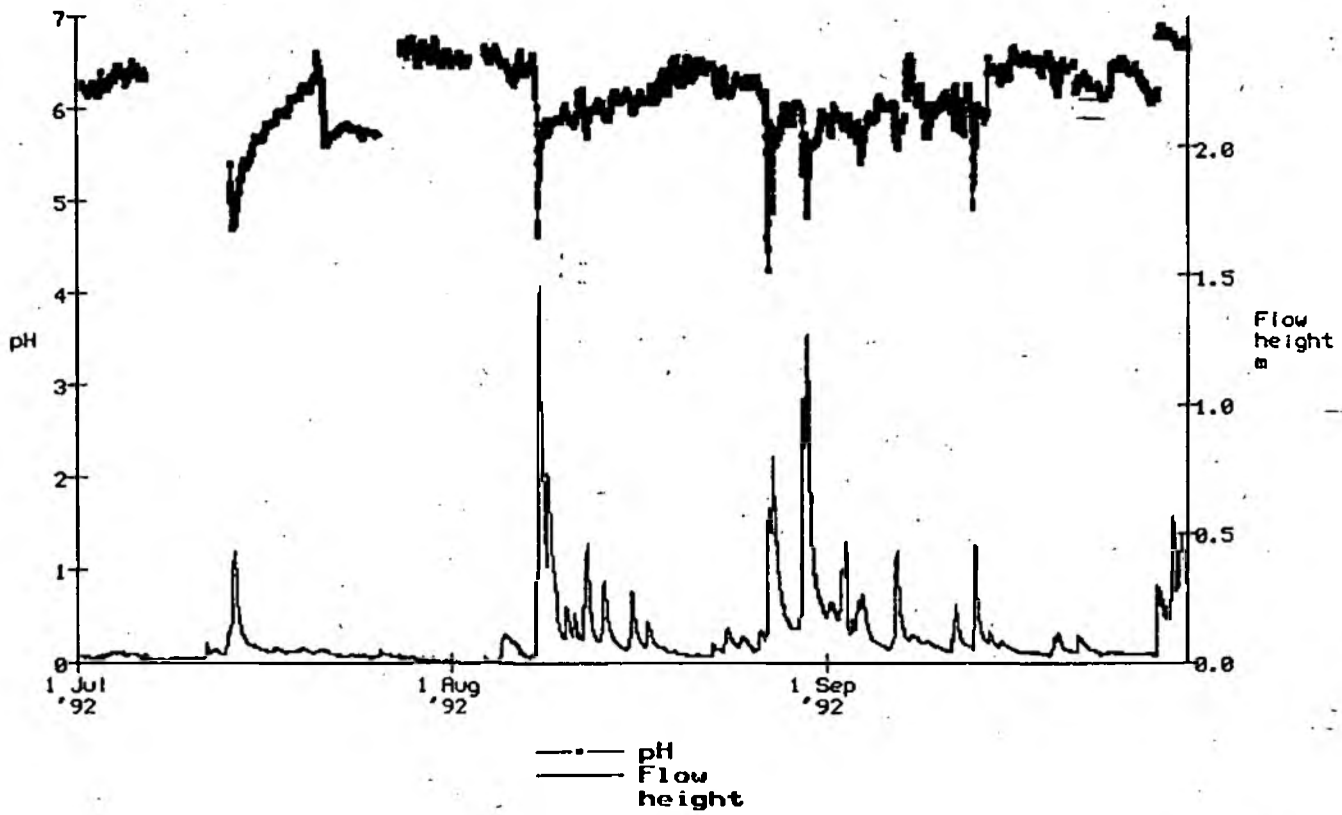


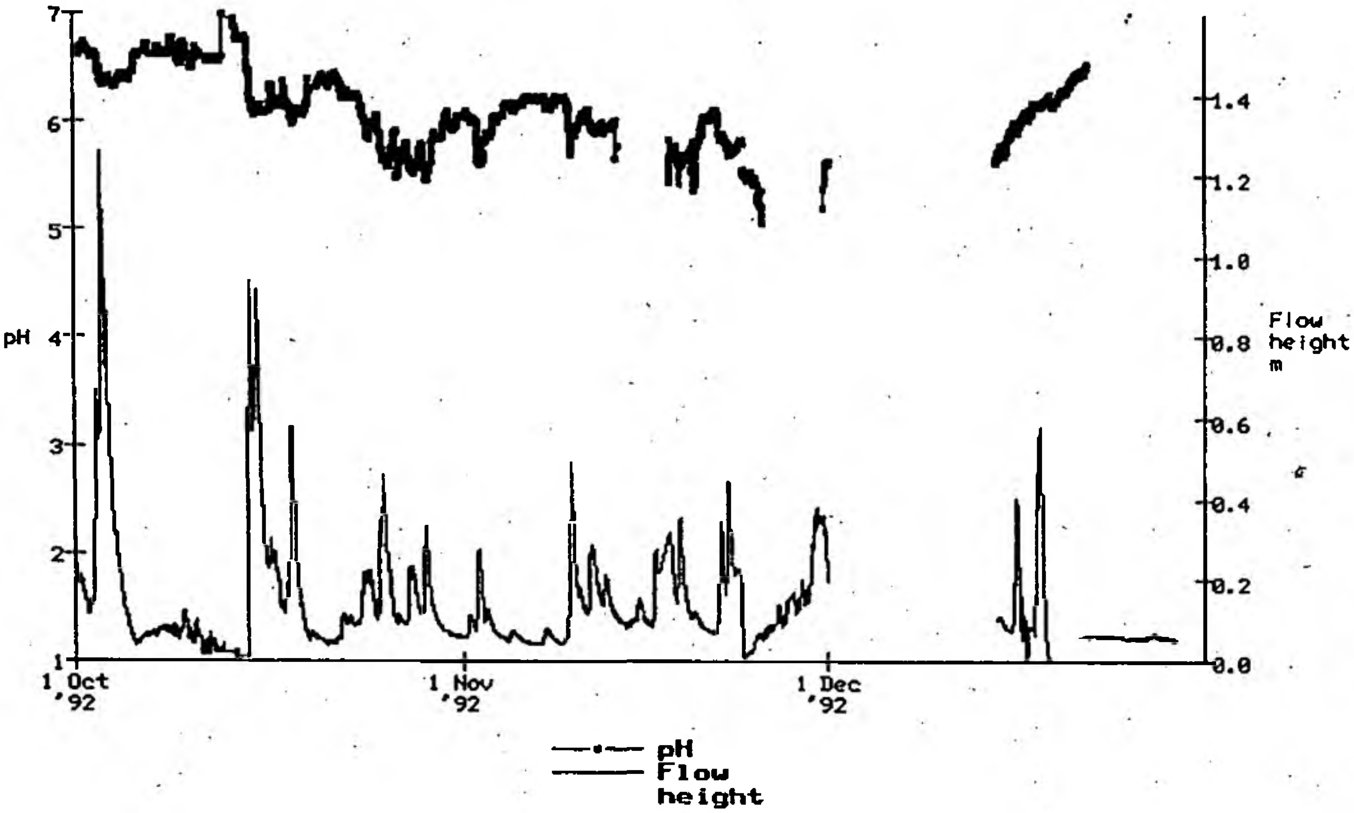
Fig 2.2.1.ii

Continuous Data for CI2 during 1992

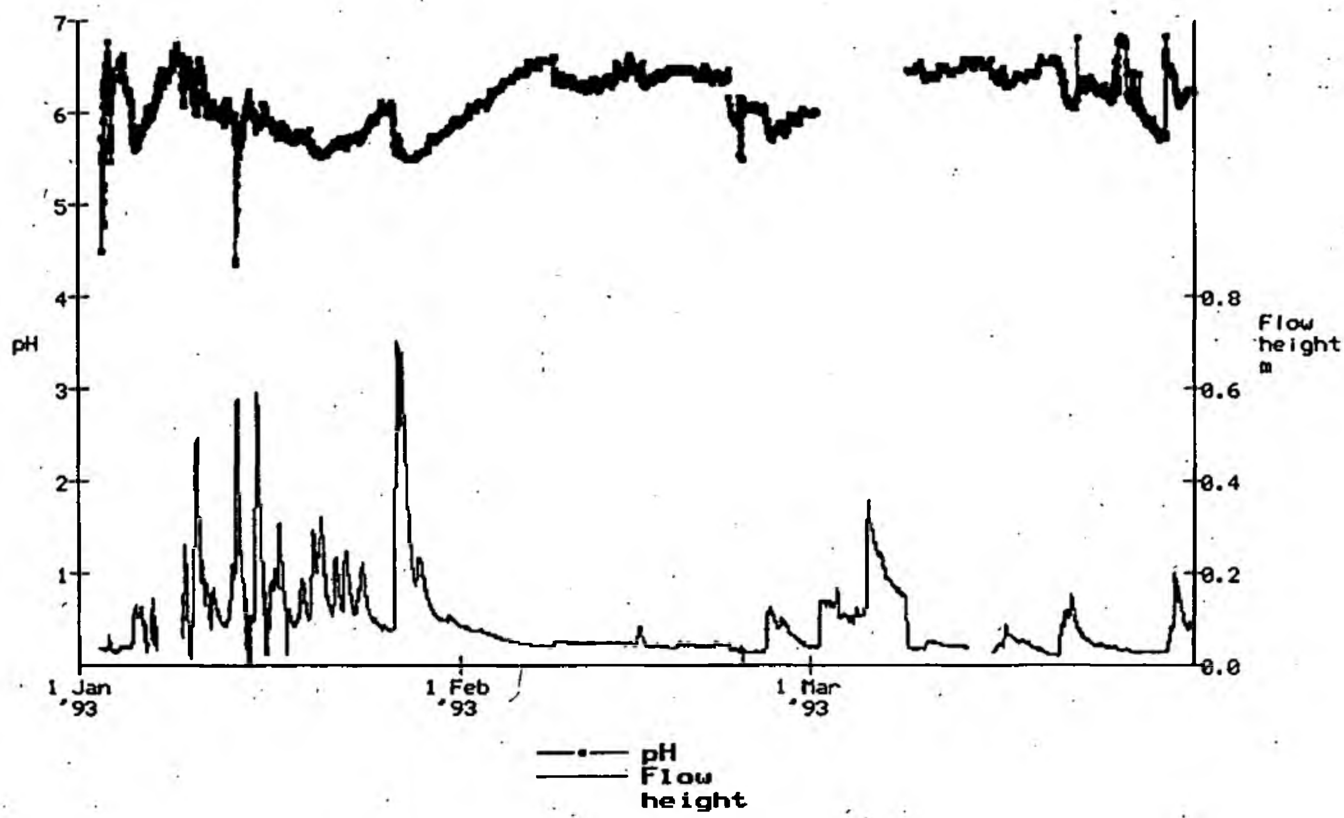




Continuous Data for CI2 during 1992



Continuous Data for CI2 during 1993



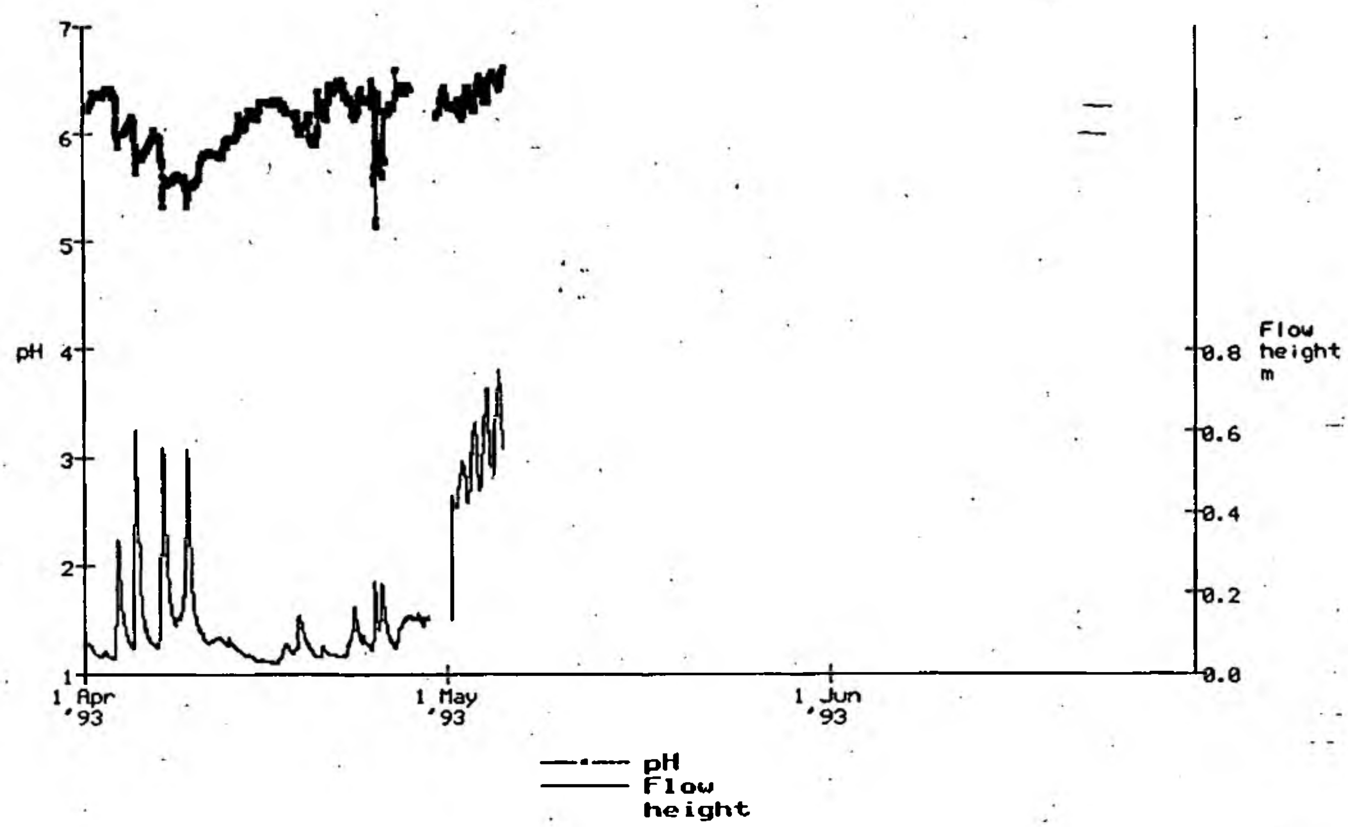
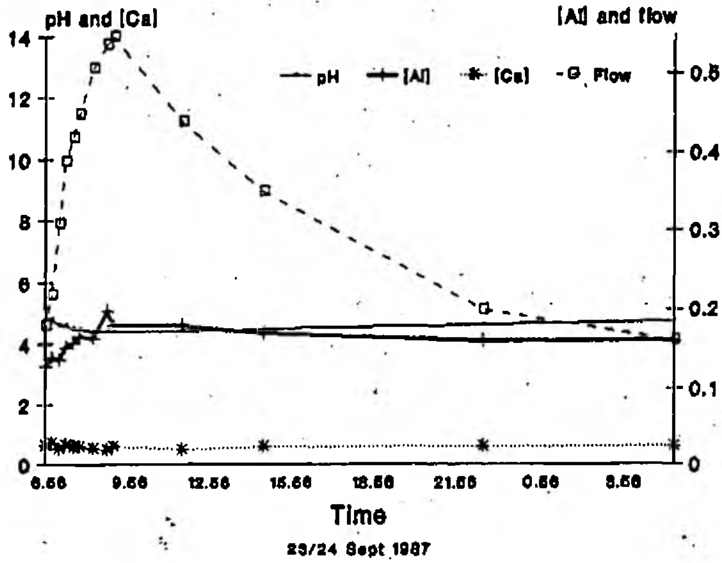
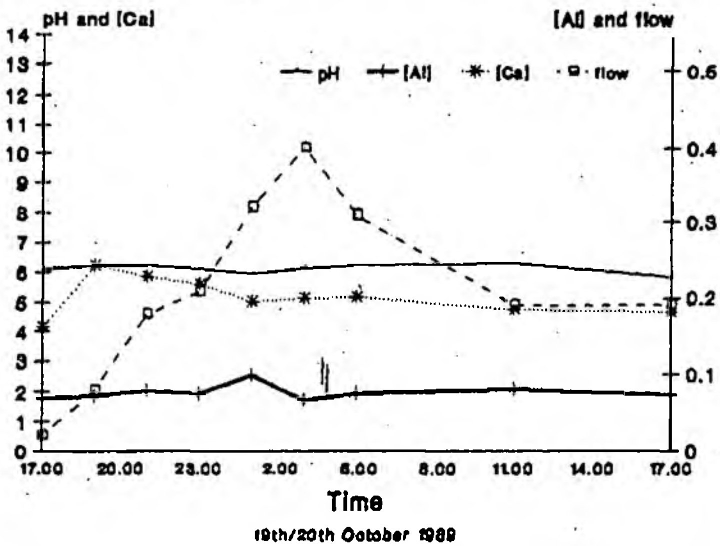


Fig 2.2.2

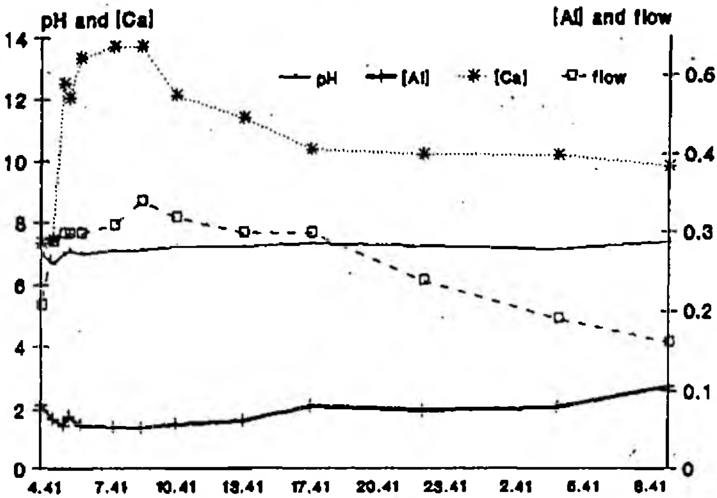
Cl2 Storm Event Pre-liming



Cl2 Storm Event 1 year Post-liming

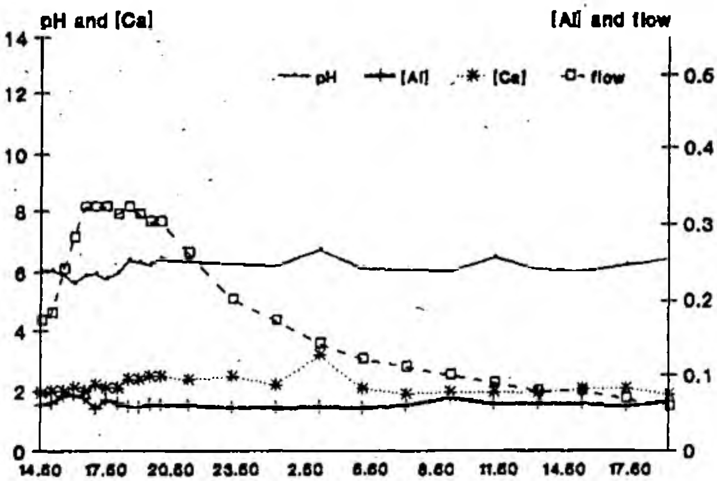


Cl2 Storm Event Immediately Post-liming



10th/11th July 1988

Cl2 Storm Event 5 years Post-liming



3rd/4th April 1993

TABLE 2.1 QUARTERLY AND ANNUAL SUMMARIES OF SPOT SAMPLE DATA

All values in mg/l except pH   Alk= Alkalinity (mg $CaCO_3$/l)

Table 2.1.1   CONIFER FOREST REFERENCE STREAM LI1

LI1 1984		pH	Alk	SO_4	Mg	Ca	Al
Q3	Mean	5.045	2.031	8.680	0.853	1.369	0.336
	Median	4.800	1.900	8.500	0.783	1.155	0.349
	S.D.	0.652	1.237	1.689	0.508	0.538	0.227
	Min	4.400					
Q4	Mean	4.730	1.018	7.402	0.757	1.423	0.487
	Median	4.800	1.050	7.000	0.763	1.170	0.499
	S.D.	0.208	0.411	1.143	0.203	0.392	0.170
	Min.	4.300					
Annual	Median	4.8	1.2	7.5	0.77	1.17	0.46
	10 pcntile	4.47	0.4	6.15	0.59	0.75	0.07
	90 pcntile	5.43	2.62	5.85	1.12	1.82	0.66
	Arth. Mean	4.87	1.39	7.92	0.80	1.24	0.42
	S.D.	0.48	0.94	1.51	0.21	0.47	0.21

LI1 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.773	1.088	8.057	0.740	1.183	0.492
	Median	4.900	1.150	7.900	0.786	1.220	0.531
	S.D.	0.261	0.236	0.837	0.129	0.319	0.205
	Min	4.300					
Q2	Mean	4.891	1.155	7.353	0.690	1.205	0.326
	Median	4.950	1.300	7.425	0.702	1.315	0.322
	S.D.	0.247	0.324	0.522	0.062	0.256	0.164
	Min	4.400					
Q3	Mean	4.764	1.060	6.086	0.529	0.975	0.333
	Median	4.700	1.000	6.015	0.535	0.995	0.325
	S.D.	0.294	0.385	0.685	0.095	0.218	0.119
	Min	4.500					
Q4	Mean	4.950	0.990	5.276	0.642	1.168	0.276
	Median	5.000	1.050	5.600	0.665	1.155	0.263
	S.D.	0.340	0.513	1.864	0.120	0.333	0.148
	Min	4.400					
Annual	Median	4.9	1.15	7.06	0.67	1.11	0.33
	10 pcntile	4.47	0.55	5.40	0.47	0.75	0.10
	90 pcntile	5.23	1.50	8.20	0.82	1.48	0.55
	Arth. Mean	4.85	1.08	6.72	0.65	1.14	0.35
	S.D.	0.31	0.37	1.53	0.13	0.29	0.18

LI1 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.855	0.975	5.433	0.654	1.135	0.365
	Median	4.800	0.900	5.500	0.710	1.140	0.440
	S.D.	0.434	0.462	1.037	0.161	0.419	0.197
	Min	4.200					
Q2	Mean	4.808	0.864	5.840	0.721	1.479	0.350
	Median	4.700	0.700	5.985	0.709	1.440	0.402
	S.D.	0.345	0.528	0.880	0.071	0.460	0.190
	Min	4.400					
Q3	Mean	5.131	1.092	5.555	0.802	1.479	0.235
	Median	5.000	1.000	5.500	0.820	1.440	0.195
	S.D.	0.528	0.579	0.376	0.084	0.460	0.172
	Min	4.500					
Q4	Mean	4.850	0.873	6.383	0.747	1.154	0.481
	Median	4.650	0.900	6.210	0.692	0.980	0.576
	S.D.	0.518	0.588	0.849	0.172	0.479	0.252
	Min	4.200					
Annual	Median	4.8	0.09	5.85	0.74	1.17	0.41
	10 pcntile	4.40	0.23	4.94	0.58	0.75	0.07
	90 pcntile	5.23	1.50	8.20	0.82	1.48	0.55
	Arth. Mean	4.91	0.95	5.81	0.73	1.25	0.36
	S.D.	0.47	0.54	0.87	0.14	0.42	0.21

LI1 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.860	1.060	6.940	0.729	1.154	0.523
	Median	4.900	1.200	6.740	0.723	1.060	0.520
	S.D.	0.152	0.378	0.818	0.102	0.334	0.063
	Min	4.600					
Q2	Mean	5.000	1.288	7.496	0.781	1.50	0.369
	Median	5.050	1.450	7.555	0.799	1.460	0.327
	S.D.	0.288	0.473	0.601	0.081	0.334	0.219
	Min	4.500					
Q3	Mean	5.357	1.671	7.313	0.735	1.580	0.187
	Median	5.200	1.600	7.140	0.712	1.630	0.185
	S.D.	0.404	0.454	0.598	0.058	0.140	0.075
	Min	5.000					
Q4	Mean	4.750	1.080	7.378	0.660	1.108	0.449
	Median	4.750	0.900	7.280	0.651	1.110	0.454
	S.D.	0.266	0.363	0.756	0.111	0.271	0.103
	Min	4.300					
Annual	Median	5.0	1.30	7.33	0.73	1.36	0.41
	10 pcntile	4.57	0.64	6.50	0.60	0.89	0.11
	90 pcntile	5.50	1.78	8.36	0.86	1.81	0.62
	Arth. Mean	5.01	1.31	7.31	0.73	1.36	0.37
	S.D.	0.37	0.47	0.67	0.09	0.33	0.18

LI1 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.617	0.680	6.282	0.762	1.092	0.658
	Median	4.650	0.600	6.325	0.757	1.090	0.679
	S.D.	0.264	0.460	0.604	0.114	0.344	0.169
	Min	4.200					
Q2	Mean	4.986	1.129	7.304	0.974	1.844	0.391
	Median	5.000	1.100	7.110	0.961	1.690	0.377
	S.D.	0.121	0.125	0.887	0.071	0.389	0.141
	Min	4.800					
Q3	Mean	4.733	0.917	7.316	0.813	1.330	0.421
	Median	4.800	1.000	7.000	0.841	1.430	0.404
	S.D.	0.274	0.343	1.240	0.128	0.349	0.138
	Min	4.400					
Q4	Mean	4.733	0.888	7.365	0.788	1.278	0.500
	Median	4.750	1.000	7.500	0.762	1.210	0.515
	S.D.	0.047	0.419	0.902	0.110	0.286	0.095
	Min	4.400					
Annual	Median	4.80	1.00	7.00	0.85	1.44	0.47
	10 pcntile	4.4	0.32	6.03	0.64	0.86	0.33
	90 pcntile	5.02	1.36	8.42	0.99	1.97	0.72
	Arth. Mean	4.77	0.92	7.10	0.84	1.40	0.48
	S.D.	0.26	0.36	1.02	0.13	0.43	0.17

LI1 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.767	0.817	6.817	0.870	1.247	0.603
	Median	4.800	0.900	6.865	0.875	1.245	0.632
	S.D.	0.105	0.306	0.478	0.089	0.238	0.082
	Min	4.600					
Q2	Mean	5.238	1.550	6.841	0.999	1.824	0.284
	Median	5.300	1.650	6.915	0.942	1.740	0.208
	S.D.	0.385	0.411	2.005	1.163	0.349	0.259
	Min	4.800					
Q3	Mean	5.530	1.750	7.917	1.057	2.176	0.098
	Median	5.600	1.750	7.730	1.057	2.270	0.084
	S.D.	0.508	0.654	1.098	0.182	0.389	0.062
	Min	4.700					
Q4	Mean	4.780	0.933	7.408	0.938	1.603	0.441
	Median	4.700	0.900	6.130	0.859	1.620	0.367
	S.D.	0.311	0.252	4.588	0.298	0.425	0.323
	Min	4.500					
Annual	Median	5.0	1.30	7.09	0.94	1.76	0.22
	10 pcntile	4.60	0.58	5.54	0.79	1.16	0.05
	90 pcntile	5.90	2.34	9.53	1.25	2.47	0.67
	Arth. Mean	5.16	1.39	7.31	0.98	1.78	0.32
	S.D.	0.50	0.61	2.29	0.20	0.49	0.27

LI1 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.617	0.775	6.043	0.809	1.092	0.759
	Median	4.650	0.700	5.975	0.797	1.015	0.761
	S.D.	0.264	0.465	1.157	0.121	0.236	0.123
	Min	4.200					
Q2	Mean	5.033	1.183	6.688	1.124	1.930	0.337
	Median	4.950	1.200	6.645	1.086	1.865	0.319
	S.D.	0.225	0.183	0.613	0.124	0.321	0.191
	Min	4.800					
Q3	Mean	5.150	1.425	5.618	1.073	1.985	0.168
	Median	5.250	1.450	6.975	1.222	2.385	0.151
	S.D.	0.480	1.169	3.094	0.392	1.058	0.072
	Min	4.500					
Q4	Mean	4.545	0.620	6.895	0.985	1.165	0.700
	Median	4.550	0.620	6.650	0.974	0.900	0.646
	S.D.	0.185	0.028	1.999	0.360	0.606	0.292
	Min	4.370					
Annual	Median	4.75	1.10	6.53	1.04	1.57	0.49
	10 pcntile	4.37	0.24	4.25	0.59	0.80	0.13
	90 pcntile	5.40	2.00	7.52	1.35	2.52	0.92
	Arth. Mean	4.83	1.07	6.32	0.99	1.54	0.50
	S.D.	0.37	0.61	1.68	0.26	0.68	0.30

LI1 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.640	0.767	6.523	1.148	1.978	0.732
	Median	4.650	0.940	6.500	1.069	1.355	0.773
	S.D.	0.272	0.541	0.691	0.094	1.500	0.159
	Min	4.320					
Q2	Mean	4.847	0.946	7.767	1.029	1.559	0.464
	Median	4.700	0.740	7.480	0.988	1.410	0.531
	S.D.	0.311	0.549	1.045	0.203	0.326	0.203
	Min	4.560					
Q3	Mean	5.052	1.128	7.949	1.047	2.036	0.270
	Median	5.050	1.300	7.700	1.020	2.240	0.317
	S.D.	0.337	0.316	0.778	0.143	0.492	0.131
	Min	4.670					
Q4	Mean	4.608	0.513	7.100	0.893	1.418	0.432
	Median	4.685	0.580	7.100	0.895	1.490	0.382
	S.D.	0.219	0.133	0.440	0.152	0.823	0.142
	Min	4.290					
Annual	Median	4.75	0.84	7.45	0.99	1.61	0.40
	10 pcntile	4.34	0.30	6.32	0.75	1.00	0.12
	90 pcntile	5.36	1.49	8.99	1.40	2.48	0.78
	Arth. Mean	4.81	0.89	7.48	1.03	1.76	0.45
	S.D.	0.32	0.46	0.94	0.39	0.77	0.22

LI1 1992		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.708	0.777	7.181	0.919	1.353	0.505
	Median	4.750	0.820	7.260	0.935	1.230	0.524
	S.D.	0.185	0.355	0.687	0.140	0.375	0.080
	Min	4.400					
Q2	Mean	5.180	1.534	7.484	0.964	1.756	0.223
	Median	5.100	1.600	7.340	0.970	1.710	0.187
	S.D.	0.396	0.314	0.871	0.033	0.391	0.131
	Min	4.800					
Q3	Mean	4.841	1.292	7.690	0.877	1.737	0.331
	Median	4.720	1.200	7.340	0.830	1.510	0.339
	S.D.	0.372	0.476	1.077	0.183	0.770	0.185
	Min	4.390					
Q4	Mean	4.698	0.928	6.750	0.712	1.025	0.497
	Median	4.650	0.865	6.900	0.680	0.875	0.560
	S.D.	0.285	0.515	0.575	0.138	0.416	0.167
	Min	4.390					
Annual	Median	4.8	1.02	7.21	0.91	1.32	0.49
	10 pcntile	4.47	0.40	6.14	0.62	0.78	0.11
	90 pcntile	5.56	1.88	8.41	1.07	2.38	0.58
	Arth. Mean	4.87	1.12	7.28	0.87	1.46	0.40
	S.D.	0.37	0.49	0.85	0.16	0.57	0.18

LI1 1993		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.157	1.464	7.557	0.883	1.543	0.282
	Median	5.200	1.670	7.500	0.910	1.640	0.220
	S.D.	0.341	0.426	0.305	0.154	0.400	0.168
	Min	4.600					
Q2	Mean	5.030	1.489	7.600	0.811	1.297	0.387
	Median	5.000	1.440	7.600	0.820	1.210	0.400
	S.D.	0.208	0.356	0.480	0.057	0.202	0.132
	Min	4.800					
Q3	Mean	5.086	1.583	7.600	0.769	1.879	0.240
	Median	5.000	1.550	7.600	0.770	1.350	0.257
	S.D.	0.498	0.397	0.480	0.134	1.452	0.105
	Min	4.300					
Q4	Mean	5.033	1.645	8.185	0.903	1.353	0.387
	Median	4.900	1.655	8.300	0.910	1.320	0.400
	S.D.	0.320	0.335	0.802	0.091	0.348	0.132
	Min	4.800					
Annual	Median	5.0	1.61	7.6	0.83	1.4	0.32
	10 pcntile	4.76	1.08	6.97	0.66	1.02	0.12
	90 pcntile	5.52	2.10	8.62	1.0	1.85	0.52
	Arth. Mean	5.08	1.54	7.7	0.84	1.52	0.31
	S.D.	0.34	0.37	0.57	0.12	0.78	0.16

Table 2.1.2 CONIFER FOREST STUDY STREAM LI2

LI2 1985		pH	Alk	SO_4	Mg	Ca	Al
Q3	Mean	4.564	0.700	6.609	0.525	1.018	0.469
	Median	4.500	0.750	6.310	0.484	1.015	0.482
	S.D.	0.180	0.392	0.853	0.096	0.241	0.085
	Min	4.300					
Q4	Mean	4.638	0.789	5.713	0.619	1.132	0.471
	Median	4.700	0.800	6.000	0.599	1.100	0.481
	S.D.	0.185	0.190	1.825	0.140	0.287	0.118
	Min.	4.400					
Annual	Median	4.6	0.8	6.28	0.55	1.07	0.5
	10 pcntile	4.36	0.32	5.20	0.45	0.76	0.32
	90 pcntile	4.80	1.10	7.60	0.72	1.46	0.59
	Arth. Mean	4.6	0.76	6.08	0.58	1.08	0.47
	S.D.	0.18	0.25	1.49	0.13	0.26	0.10

LI2 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.560	0.500	5.647	0.601	0.996	0.579
	Median	4.600	0.400	5.715	0.602	1.030	0.587
	S.D.	0.143	0.253	0.914	0.109	0.329	0.138
	Min	4.300					
Q2	Mean	4.555	0.545	6.349	0.634	1.030	0.589
	Median	4.500	0.585	6.315	0.628	1.040	0.638
	S.D.	0.157	0.271	0.493	0.079	0.179	0.204
	Min	4.300					
Q3	Mean	4.825	0.989	6.060	0.702	1.380	0.380
	Median	4.700	0.500	5.890	0.635	1.280	0.361
	S.D.	0.583	1.500	0.618	0.177	0.701	0.161
	Min	4.400					
Q4	Mean	5.050	1.192	6.971	0.878	1.435	0.499
	Median	4.800	1.050	6.940	0.871	1.300	0.596
	S.D.	0.542	0.624	0.606	0.125	0.403	0.258
	Min	4.600					
Annual	Median	4.7	0.08	6.22	0.68	1.16	0.56
	10 pcntile	4.40	0.20	5.31	0.55	0.69	0.09
	90 pcntile	4.80	1.10	7.60	0.72	1.46	0.59
	Arth. Mean	4.76	0.09	6.28	0.71	1.22	0.51
	S.D.	0.46	0.94	0.81	0.17	0.48	0.21

LI2 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.729	0.950	7.331	0.824	1.236	0.635
	Median	4.800	1.100	7.220	0.790	1.200	0.605
	S.D.	0.180	0.362	0.607	0.131	0.281	0.138
	Min	4.400					
Q2	Mean	4.880	1.220	8.144	0.892	1.466	0.514
	Median	4.900	1.200	8.280	0.916	1.420	0.583
	S.D.	0.130	0.286	0.516	0.071	0.138	0.148
	Min	4.700					
Q3	Mean	5.200	1.529	7.728	0.871	1.762	0.281
	Median	5.100	1.500	7.690	0.875	1.780	0.293
	S.D.	0.245	0.287	0.464	0.050	0.104	0.081
	Min	5.000					
Q4	Mean	4.838	0.963	7.881	0.832	1.313	0.532
	Median	4.800	1.000	7.440	0.785	1.205	0.545
	S.D.	0.297	0.331	1.558	0.182	0.267	0.085
	Min	4.500					
Annual	Median	4.90	1.20	7.65	0.84	1.43	0.53
	10 pcntile	4.58	0.52	6.81	0.72	0.97	0.27
	90 pcntile	5.34	1.72	8.58	0.97	1.82	0.68
	Arth. Mean	4.91	1.17	7.75	0.85	1.42	0.50
	S.D.	0.28	0.39	0.97	0.12	0.29	0.17

LI2 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.683	0.643	7.021	0.897	1.268	0.698
	Median	4.650	0.650	7.050	0.910	1.200	0.715
	S.D.	0.127	0.365	0.627	0.118	0.241	0.122
	Min	4.500					
Q2	Mean	4.827	0.928	7.535	1.027	1.685	0.470
	Median	4.800	0.950	7.340	1.005	1.660	0.458
	S.D.	0.090	0.212	0.661	0.102	0.243	0.147
	Min	4.700					
Q3	Mean	4.815	0.900	7.652	0.958	1.487	0.461
	Median	4.800	0.900	7.720	0.988	1.500	0.438
	S.D.	0.134	0.242	0.617	0.092	0.231	0.146
	Min	4.600					
Q4	Mean	4.783	0.922	6.961	0.910	1.454	0.521
	Median	4.800	0.980	7.670	0.897	1.335	0.503
	S.D.	0.103	0.266	2.820	0.209	0.368	0.100
	Min	4.600					
Annual	Median	4.80	0.90	7.36	0.96	1.44	0.53
	10 pcntile	4.60	0.40	6.29	0.78	1.10	0.30
	90 pcntile	4.90	1.20	8.38	1.10	1.94	0.77
	Arth. Mean	4.78	0.85	7.31	0.95	1.48	0.53
	S.D.	0.13	0.29	1.43	0.14	0.31	0.16

LI2 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.762	0.875	6.746	1.036	1.369	0.628
	Median	4.800	0.900	7.080	0.950	1.330	0.652
	S.D.	0.096	0.234	1.488	0.295	0.268	0.106
	Min	4.600					
Q2	Mean	5.000	1.300	7.718	1.123	1.820	0.352
	Median	5.000	1.400	7.310	1.025	1.820	0.319
	S.D.	0.158	0.328	1.322	0.237	0.352	0.223
	Min	4.700					
Q3	Mean	5.300	1.600	8.552	1.234	2.405	0.217
	Median	5.350	1.600	8.645	1.157	2.315	0.154
	S.D.	0.283	0.548	2.275	0.191	0.461	0.152
	Min	4.800					
Q4	Mean	4.800	0.933	8.830	1.098	1.800	0.473
	Median	4.850	0.900	7.920	0.979	1.820	0.358
	S.D.	0.216	0.058	2.646	0.245	0.359	0.264
	Min	4.500					
Annual	Median	4.90	1.00	7.32	1.02	1.61	0.52
	10 pcntile	4.63	0.62	6.43	0.91	1.22	0.15
	90 pcntile	5.37	1.68	10.49	1.56	2.49	0.76
	Arth. Mean	4.93	1.14	7.66	1.10	1.75	0.53
	S.D.	0.26	0.43	1.91	0.26	0.50	0.50

LI2 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.750	0.920	7.332	1.002	1.365	0.854
	Median	4.650	0.700	7.095	0.990	1.380	0.885
	S.D.	0.345	0.576	1.064	0.093	1.179	0.118
	Min	4.400					
Q2	Mean	4.880	1.120	7.010	1.225	1.828	0.378
	Median	4.900	1.200	6.700	1.150	1.820	0.328
	S.D.	0.084	0.192	1.057	0.304	0.401	0.183
	Min	4.800					
Q3	Mean	4.960	1.575	7.110	1.289	1.777	0.315
	Median	5.100	1.250	7.370	1.357	1.900	0.280
	S.D.	0.378	0.685	2.873	0.464	0.742	0.109
	Min	4.300					
Q4	Mean	4.660	0.544	6.378	0.947	1.458	0.474
	Median	4.600	0.500	6.920	1.046	1.520	0.502
	S.D.	0.089	0.169	1.611	0.277	0.543	0.254
	Min	4.600					
Annual	Median	4.80	0.90	7.10	1.11	1.59	0.45
	10 pcntile	4.44	0.40	4.40	0.62	0.83	0.21
	90 pcntile	5.20	1.90	8.99	1.67	2.38	0.94
	Arth. Mean	4.81	1.01	6.98	1.12	1.60	0.51
	S.D.	0.27	0.55	1.75	0.33	0.52	0.27

LI2 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.663	0.747	6.933	1.423	2.095	0.800
	Median	4.675	0.640	6.915	1.119	1.475	0.862
	S.D.	0.174	0.257	0.605	0.645	1.406	0.161
	Min	4.440					
Q2	Mean	4.940	1.183	7.662	0.982	1.512	0.405
	Median	4.835	1.040	7.875	0.979	1.420	0.379
	S.D.	0.355	0.535	0.486	0.077	0.246	0.195
	Min	4.700					
Annual	Median	4.75	0.90	7.42	1.04	1.42	0.57
	10 pcntile	4.46	0.56	6.28	0.88	1.25	0.20
	90 pcntile	5.57	2.20	8.08	2.27	3.97	0.91
	Arth. Mean	4.83	1.04	7.37	1.16	1.74	0.56
	S.D.	0.32	0.49	0.63	0.44	0.89	0.27

Table 2.1.3 CONIFER FOREST STUDY STREAM LI3

LI3 1984		pH	Alk	SO_4	Mg	Ca	Al
Q4	Mean	4.771	0.733	7.392	0.546	1.181	0.583
	Median	4.800	0.650	7.645	0.611	1.150	0.634
	S.D.	0.170	0.423	2.787	0.229	0.741	0.294
	Min	4.600					
Annual	Median	4.8	0.65	7.65	0.61	1.15	0.63
	10 pcntile	---	----	----	----	----	----
	90 pcntile	---	----	----	----	----	----
	Arth. Mean	4.77	0.73	7.39	0.55	1.18	0.58
	S.D.	0.17	0.42	2.79	0.23	0.74	0.29

LI3 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.018	1.167	8.721	0.743	1.752	0.485
	Median	5.000	1.200	8.480	0.736	1.750	0.491
	S.D.	0.286	0.431	0.963	0.143	0.455	0.152
	Min	4.500					
Q2	Mean	5.262	1.523	7.789	0.746	1.888	0.312
	Median	5.200	1.500	7.780	0.767	1.980	0.305
	S.D.	0.517	0.648	0.529	0.080	0.429	0.197
	Min	4.600					
Q3	Mean	5.275	1.743	7.410	0.634	1.712	0.257
	Median	4.950	1.800	7.800	0.635	1.715	0.300
	S.D.	0.508	0.506	0.705	0.139	0.379	0.130
	Min	4.800					
Q4	Mean	5.317	1.475	5.500	0.723	0.723	0.228
	Median	5.200	1.250	6.100	0.700	0.700	0.195
	S.D.	0.592	0.965	1.906	0.196	0.196	0.155
	Min	4.700					
Annual	Median	5.1	1.4	7.7	0.71	1.82	0.33
	10 pcntile	4.70	0.60	5.88	0.52	1.22	0.06
	90 pcntile	6.10	2.56	8.83	0.87	2.39	0.58
	Arth. Mean	5.22	1.45	7.33	0.71	2.25	0.32
	S.D.	0.49	0.69	1.63	0.15	2.97	0.19

LI3 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	0.167	1.510	6.048	0.751	1.836	0.276
	Median	4.950	1.200	6.170	0.762	1.715	0.300
	S.D.	0.579	1.047	0.813	0.143	0.615	0.196
	Min	4.400					
Q2	Mean	4.991	1.036	6.083	0.690	1.563	0.376
	Median	4.800	0.900	6.365	0.713	1.650	0.466
	S.D.	0.493	0.679	0.758	0.070	0.557	0.201
	Min	4.600					
Q3	Mean	5.708	2.217	6.034	0.741	2.205	0.161
	Median	5.750	1.850	5.900	0.730	2.130	0.085
	S.D.	0.675	1.155	0.340	0.080	0.661	0.150
	Min	4.600					
Q4	Mean	5.158	1.875	6.934	0.737	1.740	0.443
	Median	4.800	1.100	6.820	0.730	1.520	0.576
	S.D.	0.653	1.680	0.564	0.065	0.601	0.256
	Min	4.700					
Annual	Median	5.0	1.3	6.35	0.73	1.7	0.31
	10 pcntile	4.60	0.46	5.38	0.62	1.16	0.04
	90 pcntile	6.10	2.56	8.83	0.87	2.39	0.58
	Arth. Mean	5.25	1.68	6.29	0.73	1.84	0.31
	S.D.	0.65	1.25	0.74	0.1	0.63	0.23

LI3 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.050	1.417	7.035	0.713	1.707	0.464
	Median	5.050	1.500	7.355	0.753	1.755	0.495
	S.D.	0.152	0.256	1.513	0.171	0.509	0.146
	Min	4.800					
Q2	Mean	5.371	1.800	8.231	0.818	2.200	0.320
	Median	5.300	1.700	8.020	0.824	2.030	0.278
	S.D.	0.499	0.681	0.512	0.063	0.447	0.220
	Min	4.700					
Q3	Mean	5.943	2.543	8.403	0.829	2.584	0.126
	Median	5.700	2.000	8.310	0.836	2.440	0.135
	S.D.	0.458	1.197	0.523	0.046	0.273	0.057
	Min	5.500					
Q4	Mean	5.083	1.480	7.168	0.691	1.922	0.367
	Median	5.000	1.500	6.940	0.661	1.845	0.393
	S.D.	0.331	0.361	0.634	0.091	0.347	0.127
	Min	4.700					
Annual	Median	5.20	1.60	8.01	0.81	2.09	0.31
	10 pcntile	4.77	0.89	6.62	0.62	1.46	0.08
	90 pcntile	6.23	3.11	8.90	0.89	2.83	0.58
	Arth. Mean	5.38	1.84	7.76	0.77	2.13	0.31
	S.D.	0.52	0.84	1.03	0.11	0.50	0.19

LI3 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.786	0.894	6.766	0.860	1.974	0.648
	Median	4.700	0.800	6.650	0.877	1.850	0.688
	S.D.	0.219	0.463	0.677	0.072	0.434	0.177
	Min	4.500					
Q2	Mean	5.300	1.523	7.605	1.020	2.915	0.227
	Median	5.250	1.350	7.445	1.017	2.845	0.243
	S.D.	0.494	0.886	0.714	0.089	0.319	0.123
	Min	4.600					
Q3	Mean	5.133	1.350	7.480	0.870	2.292	0.354
	Median	5.100	1.300	7.615	0.880	2.380	0.329
	S.D.	0.459	0.612	0.813	0.124	0.557	0.195
	Min	4.700					
Q4	Mean	5.225	1.538	7.516	0.855	2.415	0.325
	Median	5.100	1.400	7.440	0.818	2.365	0.382
	S.D.	0.315	0.463	0.806	0.141	0.606	0.141
	Min	4.900					
Annual	Median	5.10	1.30	7.30	0.90	2.41	0.38
	10 pcntile	4.68	0.64	6.28	0.73	1.66	0.11
	90 pcntile	5.84	2.42	8.44	1.04	3.17	0.74
	Arth. Mean	5.11	1.33	7.33	0.90	2.38	0.39
	S.D.	0.41	0.63	0.79	0.12	0.58	0.22

LI3 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.075	1.433	7.172	0.919	2.478	0.407
	Median	5.000	1.500	6.860	0.900	2.360	0.397
	S.D.	0.171	0.219	1.170	0.143	0.452	0.126
	Min	4.800					
Q2	Mean	6.192	4.092	7.669	1.031	3.534	0.159
	Median	6.400	4.600	7.320	1.017	3.610	0.126
	S.D.	0.632	1.968	1.249	0.170	0.702	0.136
	Min	5.000					
Q3	Mean	6.431	6.433	9.691	1.537	4.412	0.102
	Median	6.700	6.600	8.490	1.170	4.590	0.090
	S.D.	0.761	2.527	3.398	1.737	0.824	0.067
	Min	4.500					
Q4	Mean	5.400	2.070	7.535	0.907	2.859	0.305
	Median	5.300	1.600	7.260	0.961	2.805	0.245
	S.D.	0.680	1.167	2.023	0.178	0.826	0.256
	Min	4.500					
Annual	Median	5.80	2.60	7.35	0.99	3.20	0.15
	10 pcntile	4.80	1.10	6.00	0.74	2.22	0.05
	90 pcntile	6.80	7.12	10.59	1.26	4.71	0.52
	Arth. Mean	5.80	3.58	8.03	1.10	3.33	0.24
	S.D.	0.82	2.59	2.32	0.90	1.02	0.20

LI3 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.854	1.100	7.020	0.962	2.487	0.631
	Median	4.800	1.100	6.570	0.891	2.430	0.649
	S.D.	0.282	0.445	1.043	0.168	0.534	0.165
	Min	4.500					
Q2	Mean	6.110	3.160	7.175	1.119	3.411	0.141
	Median	6.350	3.100	7.130	1.059	3.500	0.123
	S.D.	0.495	1.160	0.529	0.113	0.481	0.112
	Min	5.300					
Q3	Mean	6.417	4.283	7.872	1.239	3.863	0.160
	Median	6.700	4.200	7.895	1.263	3.700	0.132
	S.D.	0.670	2.194	0.839	0.202	0.938	0.115
	Min	5.100					
Q4	Mean	5.090	1.345	6.333	0.927	2.331	0.378
	Median	5.040	1.300	6.550	0.846	2.220	0.391
	S.D.	0.334	0.434	0.935	0.275	0.778	0.142
	Min	4.700					
Annual	Median	5.25	1.70	6.91	1.03	3.09	0.27
	10 pcntile	4.70	0.82	5.93	0.77	1.86	0.06
	90 pcntile	6.76	5.22	8.71	1.37	4.09	0.71
	Arth. Mean	5.59	2.47	7.11	1.06	3.01	0.34
	S.D.	0.82	1.85	1.01	0.23	0.95	0.24

LI3 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.023	1.178	6.933	1.201	3.198	0.637
	Median	4.935	1.140	7.025	1.092	2.460	0.662
	S.D.	0.368	0.513	0.749	0.567	1.591	0.402
	Min	4.660					
Q2	Mean	5.724	2.510	7.903	1.039	2.812	0.220
	Median	5.650	1.800	8.020	1.037	2.565	0.131
	S.D.	0.677	1.487	0.653	0.127	0.541	0.219
	Min	4.900					
Q3	Mean	5.984	2.720	8.577	1.105	3.533	0.163
	Median	6.180	2.860	8.200	1.012	3.110	0.114
	S.D.	0.520	1.043	1.507	0.266	0.751	0.151
	Min	4.920					
Q4	Mean	5.058	1.780	8.366	1.023	2.618	0.360
	Median	5.080	1.670	8.100	1.020	2.100	0.283
	S.D.	0.865	1.045	1.641	0.215	0.858	0.326
	Min	3.740					
Annual	Median	5.28	1.60	7.73	1.03	2.77	0.25
	10 pcntile	4.71	0.70	6.61	0.81	1.99	0.04
	90 pcntile	6.50	4.20	9.16	1.70	4.74	0.75
	Arth. Mean	5.47	2.06	7.82	1.10	3.05	0.35
	S.D.	0.70	1.25	1.20	0.34	1.04	0.34

LI3 1992		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.157	1.423	7.653	0.999	2.681	0.364
	Median	5.100	1.300	7.470	1.060	2.630	0.433
	S.D.	0.310	0.356	0.505	0.122	0.478	0.131
	Min	4.900					
Q2	Mean	5.650	3.027	7.647	1.012	3.060	0.126
	Median	5.450	2.250	7.610	1.010	2.770	0.088
	S.D.	0.612	2.000	0.806	0.078	0.755	0.118
	Min	5.000					
Q3	Mean	5.687	3.166	8.169	0.924	3.059	0.232
	Median	5.900	2.400	7.700	0.860	2.770	0.131
	S.D.	0.766	2.271	1.103	0.205	1.425	0.194
	Min	4.780					
Annual	Median	5.2	1.6	7.62	0.99	2.77	0.16
	10 pcntile	4.90	1.07	6.79	0.77	1.85	0.04
	90 pcntile	6.40	6.18	9.24	1.12	4.62	0.46
	Arth. Mean	5.52	2.56	7.82	0.98	2.94	0.24
	S.D.	0.62	1.81	0.82	0.14	0.92	0.18

Table 2.1.4 CONIFER FOREST STUDY STREAM LI4

LI4 1984		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.158	1.992	6.625	1.026	2.050	0.238
	Median	5.000	1.300	6.500	1.077	2.050	0.205
	S.D.	0.608	2.447	0.711	0.191	0.521	0.145
	Min	4.700					
Q2	Mean	5.400	1.744	8.577	0.704	2.002	0.098
	Median	5.400	1.700	8.500	0.704	1.940	0.075
	S.D.	0.173	0.296	0.838	0.095	0.477	0.076
	Min	5.100					
Q3	Mean	5.225	2.050	8.750	0.942	1.944	0.171
	Median	5.300	2.050	8.500	0.901	2.060	0.142
	S.D.	0.417	0.810	1.648	0.305	0.452	0.153
	Min	4.500					
Q4	Mean	4.980	1.214	7.704	0.758	0.758	0.317
	Median	5.000	1.300	7.529	0.764	0.764	0.307
	S.D.	0.042	0.146	0.807	0.059	0.059	0.055
	Min	4.900					
Annual	Median	5.1	1.4	7.5	0.86	1.94	0.15
	10 pcntile	4.85	1.0	6.5	0.67	1.33	0.04
	90 pcntile	5.6	2.58	9.72	1.19	2.70	0.42
	Arth. Mean	5.2	1.76	7.86	0.91	1.98	0.20
	S.D.	0.4	1.52	1.29	0.25	0.48	0.14

LI4 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.780	1.050	8.309	0.752	1.844	0.266
	Median	4.900	1.050	8.343	0.765	2.020	0.258
	S.D.	0.335	0.129	0.354	0.119	0.513	0.028
	Min	4.200					
Q2	Mean	5.040	1.220	7.816	0.751	2.087	0.222
	Median	5.000	1.300	7.420	0.748	2.175	0.214
	S.D.	0.167	0.342	0.754	0.103	0.258	0.050
	Min	4.800					
Q3	Mean	5.064	2.014	9.894	0.986	1.684	0.124
	Median	5.100	1.400	7.100	0.590	1.750	0.122
	S.D.	0.121	2.177	9.376	1.240	0.216	0.026
	Min	4.800					
Q4	Mean	5.007	1.145	6.189	0.676	1.808	0.166
	Median	5.000	1.100	6.270	0.680	1.850	0.140
	S.D.	0.323	0.324	0.537	0.051	0.145	0.063
	Min	4.300					
Annual	Median	5.0	1.2	6.87	0.67	1.8	0.17
	10 pcntile	4.80	0.70	5.76	0.52	1.45	0.10
	90 pcntile	5.20	1.62	8.66	0.87	2.24	0.27
	Arth. Mean	5.0	1.37	7.88	0.79	2.41	0.18
	S.D.	0.26	1.14	5.23	0.68	3.43	0.07

LI4 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.964	1.018	5.891	0.779	1.893	0.211
	Median	4.900	1.000	6.185	0.799	1.960	0.243
	S.D.	0.211	0.357	1.555	0.117	0.237	0.119
	Min	4.700					
Q2	Mean	4.908	0.962	6.163	0.751	1.810	0.212
	Median	4.900	0.900	6.090	0.730	1.840	0.233
	S.D.	0.189	0.403	0.415	0.085	0.364	0.087
	Min	4.700					
Q3	Mean	5.108	1.325	6.211	0.760	1.805	0.140
	Median	5.100	1.350	6.065	0.736	1.980	0.135
	S.D.	0.183	0.365	0.703	0.115	0.568	0.069
	Min	4.900					
Q4	Mean	4.992	1.250	6.512	0.761	1.824	0.245
	Median	5.000	1.250	6.525	0.791	1.890	0.282
	S.D.	0.131	0.284	0.436	0.108	0.248	0.115
	Min	4.800					
Annual	Median	5.0	1.15	6.11	0.75	1.92	0.22
	10 pcntile	4.70	0.60	5.55	0.63	1.31	0.07
	90 pcntile	5.20	1.62	8.66	0.87	2.24	0.27
	Arth. Mean	4.99	1.14	6.21	0.76	1.83	0.20
	S.D.	0.19	0.38	0.86	0.10	0.36	0.10

LI4 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.000	1.317	7.587	0.780	1.900	0.305
	Median	5.000	1.400	7.730	0.811	1.925	0.314
	S.D.	0.063	0.026	0.899	0.067	0.396	0.041
	Min	4.900					
Q2	Mean	5.083	1.483	7.645	0.765	2.028	0.235
	Median	5.100	1.550	7.710	0.751	2.060	0.204
	S.D.	0.117	0.147	0.344	0.037	0.107	0.076
	Min	4.900					
Q3	Mean	5.286	1.800	8.000	0.743	2.146	0.123
	Median	5.300	1.700	7.940	0.716	2.160	0.125
	S.D.	0.107	0.451	0.431	0.070	0.178	0.029
	Min	5.200					
Q4	Mean	5.773	3.827	8.193	0.798	3.606	0.180
	Median	5.300	2.000	8.350	0.791	2.740	0.157
	S.D.	0.629	2.827	1.056	0.064	1.410	0.064
	Min	5.100					
Annual	Median	5.20	1.55	7.86	0.77	2.16	0.17
	10 pcntile	4.99	1.29	6.95	0.67	1.80	0.09
	90 pcntile	6.40	5.12	8.86	0.84	4.34	0.34
	Arth. Mean	5.29	2.04	7.88	0.77	2.44	0.20
	S.D.	0.43	1.42	0.82	0.06	0.99	0.08

LI4 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.577	8.052	7.571	0.899	5.943	0.145
	Median	6.600	8.100	7.450	0.880	5.970	0.150
	S.D.	0.201	1.804	0.758	0.098	0.756	0.088
	Min	6.200					
Q2	Mean	6.519	8.963	8.331	0.983	6.574	0.072
	Median	6.700	9.400	8.065	0.965	6.490	0.064
	S.D.	0.479	3.766	1.037	0.122	1.668	0.030
	Min	5.500					
Q3	Mean	6.600	10.986	8.016	0.850	6.824	0.076
	Median	6.700	11.550	7.965	0.843	6.990	0.057
	S.D.	0.406	3.520	0.912	0.090	1.255	0.058
	Min	5.800					
Q4	Mean	6.864	11.402	7.891	0.808	7.562	0.076
	Median	6.800	11.660	7.645	0.776	6.970	0.079
	S.D.	0.180	1.832	1.141	0.126	2.021	0.026
	Min	6.600					
Annual	Median	6.70	9.85	7.84	0.87	6.45	0.08
	10 pcntile	6.05	5.35	6.77	0.75	5.13	0.04
	90 pcntile	7.00	14.00	9.53	1.07	8.24	0.16
	Arth. Mean	6.62	11.35	7.98	0.89	6.67	0.09
	S.D.	0.37	12.30	0.98	0.13	1.53	0.06

LI4 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.646	7.646	8.106	0.934	5.962	0.091
	Median	6.600	7.500	7.710	0.943	5.450	0.089
	S.D.	0.066	1.569	1.751	0.188	1.259	0.037
	Min	6.600					
Q2	Mean	6.338	6.223	8.929	1.038	4.913	0.051
	Median	6.600	6.100	8.880	1.007	5.210	0.045
	S.D.	0.584	1.853	1.137	0.138	0.940	0.016
	Min	4.800					
Q3	Mean	6.200	5.585	10.809	1.537	4.772	0.039
	Median	6.300	5.800	10.170	1.087	4.330	0.037
	S.D.	0.436	1.684	3.513	1.845	1.349	0.012
	Min	5.200					
Q4	Mean	6.300	5.636	7.884	0.867	4.796	0.083
	Median	6.300	5.600	7.925	0.913	4.435	0.044
	S.D.	0.224	1.806	1.529	0.136	1.427	0.085
	Min	5.800					
Annual	Median	6.50	6.10	8.43	0.96	5.24	0.05
	10 pcntile	5.91	3.82	6.67	0.75	3.61	0.03
	90 pcntile	6.79	8.79	11.19	1.31	6.98	0.13
	Arth. Mean	6.37	6.30	8.95	1.10	5.12	0.07
	S.D.	0.41	1.88	2.42	0.95	1.32	0.05

LI4 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.308	4.338	7.555	1.071	5.031	0.093
	Median	6.300	3.900	7.430	1.004	5.040	0.067
	S.D.	0.206	1.510	0.622	0.211	0.651	0.079
	Min	5.900					
Q2	Mean	6.478	6.025	7.897	1.268	5.060	0.049
	Median	6.500	5.950	7.950	1.083	5.060	0.040
	S.D.	0.583	2.012	1.920	0.666	0.906	0.019
	Min	5.600					
Q3	Mean	6.625	5.957	8.478	1.233	4.781	0.068
	Median	6.600	5.050	8.585	1.217	4.670	0.059
	S.D.	0.331	3.845	0.987	0.298	1.194	0.036
	Min	6.200					
Q4	Mean	6.428	4.989	7.378	0.968	4.371	0.109
	Median	6.420	5.400	7.600	0.911	3.840	0.072
	S.D.	0.269	1.181	1.391	0.247	1.326	0.110
	Min	6.100					
Annual	Median	6.40	4.80	7.95	1.07	4.84	0.07
	10 pcntile	6.10	2.94	6.68	0.84	3.47	0.03
	90 pcntile	6.92	8.48	9.53	1.56	6.20	0.16
	Arth. Mean	6.46	5.78	7.85	1.14	4.83	0.08
	S.D.	0.37	4.17	1.27	0.38	1.03	0.07

LI4 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.288	3.258	8.083	1.494	6.095	0.078
	Median	6.300	3.400	8.080	1.201	4.685	0.063
	S.D.	0.293	0.623	1.246	0.519	2.827	0.042
	Min	5.820					
Q2	Mean	6.378	4.428	8.888	1.057	4.261	0.134
	Median	6.410	4.010	8.895	1.061	4.580	0.059
	S.D.	0.362	1.680	0.973	0.221	1.215	0.177
	Min	5.730					
Q3	Mean	6.401	5.014	8.534	1.072	4.780	0.045
	Median	6.570	5.720	9.280	1.012	4.560	0.039
	S.D.	0.351	1.553	2.142	0.199	1.356	0.030
	Min	5.780					
Q4	Mean	6.330	4.592	8.756	0.941	4.328	0.050
	Median	6.380	4.480	9.000	1.040	4.470	0.050
	S.D.	0.181	1.741	1.060	0.188	0.795	0.033
	Min	6.080					
Annual	Median	6.40	3.74	8.79	1.09	4.57	0.06
	10 pcntile	5.81	2.62	7.03	0.82	3.14	0.02
	90 pcntile	6.68	6.24	10.13	1.82	6.92	0.16
	Arth. Mean	6.35	4.26	8.56	1.17	4.92	0.09
	S.D.	0.31	1.53	1.35	0.38	1.93	0.11

LI4 1992		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.325	3.518	8.256	1.030	4.919	0.042
	Median	6.300	3.750	8.040	1.050	5.120	0.034
	S.D.	0.191	0.479	0.779	0.089	0.506	0.029
	Min	6.100					
Q2	Mean	6.250	4.220	8.910	1.087	4.175	0.056
	Median	6.200	4.205	8.825	1.040	4.295	0.052
	S.D.	0.274	0.900	1.205	0.156	0.702	0.025
	Min	5.900					
Q3	Mean	6.161	4.463	8.793	1.004	4.304	0.111
	Median	6.300	4.980	8.900	0.980	4.210	0.072
	S.D.	0.375	1.542	1.234	0.195	1.219	0.091
	Min	5.340					
Q4	Mean	6.283	4.182	8.180	0.930	4.092	0.071
	Median	6.150	3.300	8.200	0.930	3.760	0.061
	S.D.	0.337	1.549	0.936	0.049	0.600	0.046
	Min	6.000					
Annual	Median	6.3	3.9	8.3	1.01	4.49	0.05
	10 pcntile	5.98	2.82	7.27	0.85	3.45	0.03
	90 pcntile	6.70	5.97	10.23	1.22	5.29	0.15
	Arth. Mean	6.26	5.29	8.54	1.02	4.42	0.07
	S.D.	0.29	6.49	1.03	0.14	0.84	0.06

LI4 1993		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.300	4.618	9.183	0.927	4.070	0.064
	Median	6.400	4.825	9.450	0.925	4.215	0.062
	S.D.	0.303	1.544	0.788	0.216	0.588	0.021
	Min	5.700					
Q2	Mean	6.357	4.435	8.683	0.885	4.117	0.061
	Median	6.400	4.680	8.500	0.890	4.100	0.060
	S.D.	0.428	1.110	0.454	0.059	0.160	0.024
	Min	5.640					
Q3	Mean	6.349	5.906	8.504	1.000	4.110	0.063
	Median	6.400	5.770	8.430	0.890	4.070	0.067
	S.D.	0.131	1.212	0.828	0.477	0.515	0.021
	Min	6.100					
Q4	Mean	6.017	4.950	9.270	1.043	4.653	0.095
	Median	6.100	5.380	8.950	1.065	4.735	0.049
	S.D.	0.232	1.196	1.235	0.108	0.340	0.083
	Min.	5.600					
Annual	Median	6.3	4.97	8.6	0.92	4.3	0.06
	10 pcntile	5.68	3.03	7.74	0.72	3.51	0.03
	90 pcntile	6.58	6.97	10.04	1.23	4.94	0.12
	Arth. Mean	6.26	5.01	8.89	0.97	4.23	0.07
	S.D.	0.3	1.33	0.88	0.27	0.48	0.04

Table 2.1.5 CIRCUMNEUTRAL MOORLAND STREAM LI5

LI5 1984		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.517	1.825	6.042	1.062	1.350	0.045
	Median	5.500	1.650	6.000	1.055	1.400	0.050
	S.D.	0.140	0.497	0.498	0.164	0.235	0.020
	Min	5.300					
Q2	Mean	5.823	2.733	6.577	1.012	1.347	0.050
	Median	5.800	2.800	6.500	1.008	1.445	0.024
	S.D.	0.073	0.346	0.534	0.178	0.330	0.098
	Min	5.700					
Q3	Mean	6.100	3.200	7.000	1.321	1.470	0.021
	Median	5.900	3.500	7.000	1.088	1.420	0.017
	S.D.	0.541	0.728	0.612	1.006	0.161	0.010
	Min	5.600					
Q4	Mean	5.630	1.886	6.683	0.926	1.244	0.065
	Median	5.600	1.700	6.665	0.903	1.315	0.004
	S.D.	0.142	0.302	0.743	0.156	0.248	0.010
	Min	5.400					
Annual	Median	5.75	2.2	6.5	1.03	1.40	0.03
	10 pcntile	5.45	1.4	6.0	0.76	0.93	0.01
	90 pcntile	6.05	3.34	7.46	1.20	1.62	0.07
	Arth. Mean	5.75	2.29	6.54	1.08	1.57	0.04
	S.D.	0.33	0.71	0.67	0.49	1.44	0.06

LI5 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.573	1.804	7.192	1.048	1.405	0.057
	Median	5.600	1.800	7.326	1.070	1.490	0.048
	S.D.	0.079	0.222	0.695	0.163	0.208	0.015
	Min	5.400					
Q2	Mean	5.664	2.145	6.582	0.931	1.352	0.041
	Median	5.700	2.100	6.580	0.918	1.290	0.039
	S.D.	0.112	0.406	0.413	0.073	0.132	0.012
	Min	5.500					
Q3	Mean	5.755	2.643	5.578	0.805	1.203	0.035
	Median	5.700	2.700	5.650	0.795	1.190	0.037
	S.D.	0.113	0.476	0.904	0.090	0.126	0.008
	Min	5.600					
Q4	Mean	5.862	2.227	5.545	0.854	1.242	0.039
	Median	5.800	2.000	5.560	0.890	1.300	0.030
	S.D.	0.166	0.716	0.524	0.091	0.153	0.029
	Min	5.600					
Annual	Median	5.7	2.0	6.22	0.9	1.3	0.04
	10 pcntile	5.50	1.60	5.06	0.72	1.03	0.02
	90 pcntile	5.90	3.10	7.61	1.13	1.53	0.06
	Arth. Mean	5.72	2.77	6.11	.91	1.3	0.04
	S.D.	0.16	3.92	0.94	0.14	0.17	0.02

LI5 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.540	1.750	5.559	0.953	1.309	0.040
	Median	5.500	1.700	5.585	0.907	1.330	0.041
	S.D.	0.165	0.455	0.897	0.186	0.112	0.013
	Min	5.300					
Q2	Mean	5.692	2.231	5.594	0.840	1.317	0.044
	Median	5.600	1.800	5.890	0.932	1.355	0.041
	S.D.	0.340	1.377	1.001	0.289	0.243	0.020
	Min	5.300					
Q3	Mean	5.570	2.170	5.305	0.860	1.244	0.031
	Median	5.550	2.100	5.300	0.839	1.260	0.030
	S.D.	0.095	0.400	0.310	0.097	0.156	0.012
	Min	5.500					
Q4	Mean	5.517	2.173	6.083	0.992	1.348	0.040
	Median	5.600	2.000	6.375	0.994	1.335	0.044
	S.D.	0.354	0.398	0.594	0.120	0.135	0.020
	Min	4.500					
Annual	Median	5.5	1.95	5.63	0.93	1.33	0.04
	10 pcntile	5.40	1.30	4.72	0.75	1.06	0.02
	90 pcntile	5.90	3.10	7.61	1.13	1.53	0.06
	Arth. Mean	5.58	2.09	5.66	0.91	1.31	0.04
	S.D.	0.27	0.82	0.78	0.19	0.17	0.02

LI5 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.667	2.417	6.593	1.026	1.358	0.050
	Median	5.600	2.150	6.710	1.049	1.420	0.052
	S.D.	0.151	0.668	0.973	0.130	0.227	0.006
	Min	5.500					
Q2	Mean	5.686	2.443	6.996	1.035	1.477	0.049
	Median	5.700	2.500	6.950	1.039	1.450	0.037
	S.D.	0.122	0.341	0.376	0.096	0.179	0.023
	Min	5.500					
Q3	Mean	5.843	3.114	6.703	0.940	1.413	0.068
	Median	5.800	3.000	6.910	0.994	1.490	0.043
	S.D.	0.098	0.471	0.808	0.109	0.194	0.081
	Min	5.700					
Q4	Mean	5.750	2.347	6.563	0.962	1.332	0.045
	Median	5.750	2.300	6.315	0.912	1.320	0.040
	S.D.	0.055	0.229	0.713	0.837	0.160	0.012
	Min	5.700					
Annual	Median	5.80	2.50	6.85	0.99	1.36	0.04
	10 pcntile	5.57	1.97	5.59	0.84	1.11	0.03
	90 pcntile	5.90	3.39	7.58	1.15	1.62	0.08
	Arth. Mean	5.74	2.60	6.72	0.99	1.40	0.05
	S.D.	0.13	0.53	0.72	0.11	0.19	0.04

LI5 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.514	1.846	6.521	1.082	1.381	0.077
	Median	5.500	1.700	6.630	1.104	1.440	0.077
	S.D.	0.090	0.457	0.628	0.085	0.171	0.023
	Min	5.400					
Q2	Mean	5.733	2.433	6.813	1.188	1.678	0.036
	Median	5.750	2.250	6.765	1.189	1.695	0.034
	S.D.	0.082	0.484	0.380	0.053	0.073	0.010
	Min	5.600					
Q3	Mean	5.786	2.671	6.454	1.066	1.507	0.070
	Median	5.700	2.400	6.490	1.082	1.500	0.043
	S.D.	0.363	0.952	0.283	0.077	0.156	0.055
	Min	5.600					
Q4	Mean	5.883	2.537	5.922	0.998	1.834	0.034
	Median	5.850	2.360	6.135	1.058	1.560	0.034
	S.D.	0.117	0.336	1.339	0.279	0.963	0.002
	Min	5.800					
Annual	Median	5.7	2.30	6.52	1.13	1.51	0.04
	10 pcntile	5.5	1.64	5.74	0.93	1.19	0.03
	90 pcntile	5.96	3.19	7.43	1.24	2.00	0.12
	Arth. Mean	5.72	2.36	6.43	1.09	1.58	0.06
	S.D.	0.24	0.67	0.78	0.15	0.44	0.04

LI5 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.660	2.080	6.552	1.153	1.633	0.054
	Median	5.600	2.200	6.420	1.144	1.630	0.051
	S.D.	0.089	0.217	0.516	0.095	0.092	0.015
	Min	5.600					
Q2	Mean	5.871	2.886	6.750	1.263	1.990	0.038
	Median	5.800	3.100	6.750	1.315	1.990	0.038
	S.D.	0.138	0.385	0.982	0.225	0.449	0.014
	Min	5.700					
Q3	Mean	5.910	3.340	7.043	1.384	2.161	0.022
	Median	5.900	3.550	6.915	1.224	1.775	0.021
	S.D.	0.314	0.664	1.952	0.796	1.684	0.005
	Min	5.400					
Q4	Mean	5.500	1.980	7.050	1.161	1.607	0.065
	Median	5.500	2.000	7.155	1.179	1.695	0.063
	S.D.	0.071	0.559	1.073	0.179	0.335	0.021
	Min	5.400					
Annual	Median	5.80	2.90	6.74	1.22	1.72	0.04
	10 pcntile	5.48	1.68	5.28	0.86	1.24	0.02
	90 pcntile	6.10	3.72	8.24	1.50	2.15	0.08
	Arth. Mean	5.78	2.74	6.87	1.26	1.90	0.04
	S.D.	0.26	0.76	1.31	0.48	1.02	0.02

LI5 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.433	1.800	5.495	1.061	1.510	0.096
	Median	5.450	1.800	5.460	1.036	1.495	0.081
	S.D.	0.175	0.261	0.914	0.132	0.245	0.036
	Min	5.200					
Q2	Mean	5.780	2.620	5.686	1.222	1.578	0.033
	Median	5.700	2.500	5.760	1.190	1.650	0.031
	S.D.	0.179	0.239	0.484	0.100	0.337	0.011
	Min	5.700					
Q3	Mean	6.250	3.323	6.366	1.280	1.707	0.039
	Median	6.300	3.400	6.590	1.249	1.585	0.026
	S.D.	0.281	0.941	0.834	0.149	0.291	0.027
	Min	5.900					
Q4	Mean	5.640	1.983	5.227	1.092	1.502	0.065
	Median	5.530	1.850	5.315	1.083	1.405	0.052
	S.D.	0.277	0.471	0.588	0.167	0.348	0.034
	Min	5.480					
Annual	Median	5.70	2.20	5.57	1.15	1.58	0.05
	10 pcntile	5.34	1.64	4.56	0.92	1.13	0.02
	90 pcntile	6.50	3.70	6.77	1.41	1.98	0.13
	Arth. Mean	5.78	2.42	5.66	1.16	1.57	0.06
	S.D.	0.38	0.82	0.80	0.16	0.30	0.04

LI5 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.560	1.620	5.895	1.613	2.503	0.090
	Median	5.585	1.630	5.420	1.225	1.765	0.090
	S.D.	0.236	0.063	1.258	0.854	1.622	0.005
	Min	5.300					
Q2	Mean	5.482	2.125	6.154	1.148	1.542	0.063
	Median	5.600	1.900	5.980	1.145	1.460	0.065
	S.D.	0.763	0.591	0.532	0.066	0.190	0.053
	Min	4.250					
Annual	Median	5.60	1.69	5.94	1.16	1.57	0.09
	10 pcntile	4.25	----	4.99	1.07	1.39	----
	90 pcntile	6.36	----	7.75	2.89	4.92	0.14
	Arth. Mean	5.52	1.87	6.04	1.35	1.97	0.08
	S.D.	0.56	0.47	0.87	0.58	1.12	0.04

Table 2.1.6 CIRCUMNEUTRAL MOORLAND STREAM LI6

LI6 1984		pH	Alk	SO_4	Mg	Ca	Al
Q3	Mean	7.009	24.164	5.579	2.519	3.760	0.033
	Median	6.950	27.300	5.500	1.815	2.450	0.029
	S.D.	0.403	12.813	1.718	1.471	2.701	0.024
	Min	6.300					
Q4	Mean	6.874	10.350	5.231	1.522	2.363	0.079
	Median	6.900	9.500	5.000	1.439	2.450	0.067
	S.D.	0.258	3.417	0.791	0.358	0.607	0.055
	Min	6.300					
Annual	Median	6.90	10.6	5.00	1.46	2.45	0.05
	10 pcntile	6.5	6.92	4.00	1.05	1.46	0.01
	90 pcntile	7.4	35.30	7.15	4.06	6.60	0.11
	Arth. Mean	6.93	15.25	5.37	1.96	2.97	0.06
	S.D.	0.33	10.36	1.25	1.11	1.95	0.05

LI6 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.825	8.800	5.573	1.507	2.578	0.072
	Median	6.800	9,350	5.295	1.487	2.620	0.069
	S.D.	0.230	2.864	0.871	0.300	0.578	0.021
	Min	6.200					
Q2	Mean	7.067	12.150	5.130	1.632	3.018	0.030
	Median	7.100	13.100	4.857	1.896	3.280	0.046
	S.D.	0.261	5.060	0.758	0.489	0.797	0.018
	Min	6.600					
Q3	Mean	6.662	12.088	3.375	1.296	2.415	0.067
	Median	6.900	12.600	3.600	1.139	2.100	0.057
	S.D.	0.935	4.189	0.848	0.463	0.932	0.043
	Min	3.600					
Q4	Mean	6.854	12.662	3.854	1.585	2.948	0.077
	Median	6.800	11.900	3.680	1.470	2.700	0.049
	S.D.	0.285	5.473	0.812	0.576	1.129	0.122
	Min	6.300					
Annual	Median	6.9	11.4	4.48	1.46	2.7	0.06
	10 pcntile	6.60	5.76	3.10	0.92	1.60	0.03
	90 pcntile	7.29	18.50	6.24	2.15	4.05	0.10
	Arth. Mean	6.85	11.39	4.49	1.51	2.75	0.07
	S.D.	0.53	4.69	1.2	0.47	0.89	0.07

LI6 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.600	9.880	3.992	1.549	2.711	0.046
	Median	6.600	10.750	4.180	1.626	2.620	0.045
	S.D.	0.359	4.991	0.634	0.473	0.979	0.022
	Min	6.000					
Q2	Mean	6.710	10.250	4.221	1.501	2.548	0.054
	Median	6.750	8.800	4.090	1.494	2.640	0.051
	S.D.	0.360	4.649	0.485	0.290	0.716	0.015
	Min	6.200					
Q3	Mean	7.008	16.992	4.042	2.100	3.334	0.033
	Median	6.900	14.300	3.720	1.808	3.195	0.029
	S.D.	0.287	7.425	1.082	0.707	1.596	0.010
	Min	6.600					
Q4	Mean	6.825	12.950	4.293	1.779	3.133	0.050
	Median	6.800	7.550	4.340	1.483	2.345	0.056
	S.D.	0.239	10.321	0.586	0.762	1.757	0.020
	Min	6.400					
Annual	Median	6.8	10.6	4.08	1.61	2.62	0.04
	10 pcntile	6.3	5.52	3.47	1.09	1.62	0.02
	90 pcntile	7.29	18.50	6.24	2.15	4.05	0.10
	Arth. Mean	6.8	12.84	4.14	1.76	2.98	0.05
	S.D.	0.34	7.73	0.75	0.64	1.38	0.02

LI6 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.950	9.917	5.120	1.591	2.513	0.055
	Median	6.950	10.100	5.270	1.651	2.425	0.055
	S.D.	0.138	1.810	0.637	0.230	0.618	0.013
	Min	6.800					
Q2	Mean	7.283	15.233	4.803	1.958	3.647	0.044
	Median	7.250	14.500	4.870	1.813	3.305	0.044
	S.D.	0.147	5.192	0.240	0.470	1.055	0.012
	Min	7.100					
Q3	Mean	7.371	20.571	4.211	2.330	4.613	0.041
	Median	7.400	17.900	4.190	2.162	4.120	0.032
	S.D.	0.138	6.247	0.467	0.492	1.083	0.018
	Min	7.200					
Q4	Mean	6.729	9.043	4.711	1.386	2.377	0.068
	Median	6.800	9.600	4.720	1.381	2.330	0.050
	S.D.	0.330	4.281	0.629	0.508	0.927	0.050
	Min	6.200					
Annual	Median	7.15	11.60	4.72	1.76	3.16	0.05
	10 pcntile	6.68	6.13	3.81	1.14	1.81	0.03
	90 pcntile	7.50	24.88	5.51	2.54	5.21	0.07
	Arth. Mean	7.08	13.78	4.69	1.82	3.30	0.05
	S.D.	0.33	6.56	0.59	0.56	1.30	0.03

LI6 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.629	6.583	4.344	1.473	2.279	0.073
	Median	6.600	6.100	4.280	1.504	2.110	0.072
	S.D.	0.320	3.492	0.375	0.387	0.777	0.019
	Min	6.100					
Q2	Mean	7.200	16.483	4.572	2.321	4.212	0.041
	Median	7.200	14.350	4.410	2.127	3.805	0.038
	S.D.	0.110	5.297	0.316	0.479	1.006	0.014
	Min	7.000					
Q3	Mean	6.971	12.486	4.121	1.192	3.286	0.070
	Median	7.100	12.100	4.310	1.971	3.170	0.050
	S.D.	0.198	5.018	0.537	0.534	0.984	0.037
	Min	6.700					
Q4	Mean	6.933	10.037	4.468	1.718	3.542	0.066
	Median	6.950	8.150	4.450	1.507	2.420	0.057
	S.D.	0.121	4.127	0.739	0.503	2.108	0.024
	Min	6.800					
Annual	Median	7.0	11.85	4.39	1.84	3.13	0.06
	10 pcntile	6.54	4.04	3.46	1.21	1.86	0.03
	90 pcntile	7.23	18.62	4.98	2.62	5.15	0.11
	Arth. Mean	6.92	11.25	4.37	1.86	3.29	0.06
	S.D.	0.29	5.61	0.52	0.55	1.41	0.03

LI6 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.850	8.550	4.537	1.586	2.550	0.073
	Median	6.800	7.750	4.510	1.582	2.430	0.073
	S.D.	0.084	2.563	0.365	0.365	0.386	0.011
	Min	6.800					
Q2	Mean	7.357	22.714	4.871	2.964	5.427	0.034
	Median	7.500	21.900	4.510	2.874	5.320	0.035
	S.D.	0.223	9.696	0.877	1.047	2.071	0.017
	Min	7.000					
Q3	Mean	7.480	28.390	5.410	3.823	7.268	0.042
	Median	7.550	29.750	5.410	4.100	7.395	0.030
	S.D.	0.270	9.134	0.932	1.095	2.237	0.030
	Min	6.900					
Q4	Mean	6.750	15.500	4.927	2.107	3.445	0.054
	Median	6.750	14.200	4.710	2.287	3.225	0.047
	S.D.	0.373	10.143	1.566	0.629	1.076	0.028
	Min	6.300					
Annual	Median	7.20	21.00	4.64	2.60	4.37	0.05
	10 pcntile	6.60	6.70	3.98	1.30	2.38	0.02
	90 pcntile	7.70	36.40	6.64	4.40	8.86	0.09
	Arth. Mean	7.17	20.25	5.00	2.80	5.06	0.05
	S.D.	0.40	11.22	1.01	1.23	2.54	0.03

LI6 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.467	6.050	4.613	1.485	2.390	0.102
	Median	6.500	5.800	4.620	1.355	2.415	0.087
	S.D.	0.480	3.010	0.960	0.502	0.872	0.049
	Min	5.600					
Q2	Mean	7.143	16.614	4.854	2.338	4.099	0.052
	Median	7.200	16.600	4.400	2.068	3.860	0.045
	S.D.	0.439	7.614	1.385	0.804	1.183	0.029
	Min	6.200					
Q3	Mean	7.600	23.825	3.990	3.429	5.992	0.057
	Median	7.550	24.050	3.780	3.670	6.220	0.029
	S.D.	0.210	9.739	0.602	0.828	1.665	0.063
	Min	7.400					
Q4	Mean	6.778	9.300	3.885	1.633	2.718	0.073
	Median	6.705	8.900	3.775	1.548	2.495	0.072
	S.D.	0.222	3.061	0.403	0.291	0.739	0.024
	Min	6.600					
Annual	Median	7.10	12.75	4.07	2.01	3.62	0.06
	10 pcntile	6.28	3.88	3.49	1.13	1.84	0.02
	90 pcntile	7.60	33.51	5.74	3.81	6.57	0.15
	Arth. Mean	7.02	19.28	4.42	2.23	3.81	0.07
	S.D.	0.56	28.13	1.02	0.98	1.78	0.05

LI6 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.748	6.535	4.638	2.214	3.810	0.103
	Median	6.825	6.940	4.325	1.821	3.045	0.086
	S.D.	0.263	2.684	1.252	1.176	2.297	0.049
	Min	6.390					
Q2	Mean	7.147	13.831	4.823	2.003	3.231	0.056
	Median	7.100	12.800	4.890	1.874	2.910	0.053
	S.D.	0.294	7.390	0.924	0.593	0.836	0.034
	Min	6.800					
Q3	Mean	7.312	19.333	4.060	2.636	4.759	0.049
	Median	7.350	19.100	3.930	2.334	4.800	0.040
	S.D.	0.138	4.465	0.495	0.615	1.022	0.034
	Min	7.090					
Q4	Mean	6.715	10.620	4.150	1.460	2.665	0.037
	Median	6.715	10.620	4.150	1.460	2.665	0.037
	S.D.	0.163	7.835	1.061	0.339	0.785	0.040
	Min	6.600					
Annual	Median	7.09	13.10	4.24	1.97	3.53	0.06
	10 pcntile	6.60	5.08	3.35	1.29	2.09	0.01
	90 pcntile	7.44	26.40	5.87	3.70	6.46	0.10
	Arth. Mean	7.07	13.69	4.45	2.21	3.83	0.06
	S.D.	0.33	7.17	0.88	0.77	1.42	0.04

LI6 1992		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.666	8.288	4.381	1.735	2.891	0.045
	Median	6.850	8.590	4.410	1.655	2.950	0.046
	S.D.	0.674	4.015	0.475	0.366	0.491	0.010
	Min	5.030					
Q2	Mean	6.757	23.114	4.853	1.849	3.250	0.058
	Median	7.000	22.800	4.400	1.700	2.660	0.055
	S.D.	0.472	13.588	1.068	0.784	1.395	0.024
	Min	5.800					
Q3	Mean	6.813	12.919	4.537	2.229	4.510	0.050
	Median	6.810	8.500	4.300	1.980	3.950	0.058
	S.D.	0.215	9.084	0.713	1.101	2.414	0.023
	Min	6.500					
Q4	Mean	6.617	8.717	4.733	1.457	2.432	0.053
	Median	6.550	6.955	4.100	1.295	2.090	0.055
	S.D.	0.194	5.144	1.708	0.511	1.097	0.026
	Min	6.400					
Annual	Median	6.8	9.5	4.3	1.55	2.72	0.05
	10 pcntile	6.34	5.88	3.78	1.08	1.88	0.02
	90 pcntile	7.10	37.33	6.37	2.87	5.53	0.08
	Arth. Mean	6.72	14.14	4.61	1.83	3.29	0.05
	S.D.	0.44	10.66	1.00	0.75	1.62	0.02

LI6 1993		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	6.983	14.763	5.167	2.070	3.575	0.032
	Median	7.000	15.970	5.150	2.150	3.895	0.028
	S.D.	0.204	5.979	0.301	0.663	1.207	0.012
	Min	6.700					
Q2	Mean	6.863	12.708	4.767	1.663	2.880	0.037
	Median	7.000	13.265	4.800	1.580	2.685	0.039
	S.D.	0.485	3.740	0.266	0.293	0.607	0.010
	Min	5.910					
Q3	Mean	6.807	17.234	4.031	1.836	3.516	0.031
	Median	6.700	15.400	4.100	1.720	3.000	0.033
	S.D.	0.276	6.242	0.561	0.692	1.419	0.009
	Min	6.500					
Q4	Mean	6.550	14.093	4.827	1.953	3.328	0.035
	Median	6.550	12.815	4.930	1.870	3.135	0.033
	S.D.	0.105	6.417	0.306	0.581	1.256	0.017
	Min	6.400					
Annual	Median	6.8	13.76	4.8	1.72	3.0	0.03
	10 pcntile	6.46	7.57	3.64	1.21	1.72	0.02
	90 pcntile	7.20	24.02	5.20	2.88	5.27	0.05
	Arth. Mean	6.8	14.8	4.67	1.88	3.33	0.03
	S.D.	0.32	5.62	0.57	0.57	1.13	0.01

Table 2.1.7 YOUNG FOREST STUDY STREAM LI8

LI8 1984		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.105	1.530	5.591	0.923	1.427	0.265
	Median	4.800	1.600	5.500	0.920	1.400	0.290
	S.D.	0.480	0.673	0.539	0.179	0.516	0.154
	Min	4.500					
Q2	Mean	6.123	3.122	6.577	0.944	1.633	0.058
	Median	6.200	2.800	6.500	0.977	1.780	0.054
	S.D.	0.342	1.081	0.641	0.236	0.495	0.033
	Min	5.200					
Q3	Mean	5.614	4.787	7.904	1.091	1.889	0.137
	Median	5.200	4.500	8.000	1.008	1.910	0.098
	S.D.	0.775	3.657	2.302	0.344	0.654	0.094
	Min	4.500					
Q4	Mean	5.110	1.410	6.981	0.797	1.353	0.292
	Median	5.100	1.450	6.500	0.857	1.340	0.276
	S.D.	0.457	0.316	1.302	0.132	0.315	0.137
	Min	4.700					
Annual	Median	5.2	1.6	6.5	0.9	1.59	0.18
	10 pcntile	4.7	0.85	5.5	0.61	1.01	0.04
	90 pcntile	6.47	5.8	9.0	1.37	2.44	0.40
	Arth. Mean	5.45	2.66	7.02	0.94	1.6	0.19
	S.D.	0.68	2.44	1.73	0.27	0.56	0.14

LI8 1985		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.130	1.326	6.826	0.865	1.516	0.295
	Median	5.150	1.350	6.636	0.841	1.520	0.282
	S.D.	0.250	0.380	0.784	0.139	0.208	0.064
	Min	4.700					
Q2	Mean	5.317	1.600	6.092	0.784	1.376	0.217
	Median	5.400	1.650	6.045	0.773	1.410	0.188
	S.D.	0.343	0.451	0.535	0.098	0.179	0.088
	Min	4.800					
Q3	Mean	5.258	1.580	5.128	0.627	1.125	0.195
	Median	5.300	1.700	4.900	0.580	1.100	0.214
	S.D.	0.446	0.563	0.865	0.111	0.169	0.046
	Min	4.400					
Q4	Mean	5.336	1.500	5.052	0.821	1.557	0.158
	Median	5.400	1.500	4.700	0.685	1.190	0.150
	S.D.	0.383	0.621	1.181	0.334	0.821	0.068
	Min	4.800					
Annual	Median	5.3	1.5	5.74	0.73	1.28	0.22
	10 pcntile	4.80	0.90	4.27	0.57	1.03	0.12
	90 pcntile	5.74	2.20	7.49	1.01	1.77	0.33
	Arth. Mean	5.26	4.24	5.76	0.77	1.39	0.21
	S.D.	0.36	17.17	1.11	0.2	0.44	0.08

LI8 1986		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.046	1.152	4.901	0.816	1.382	0.233
	Median	5.000	1.200	4.460	0.800	1.310	0.267
	S.D.	0.331	0.573	0.920	0.171	0.328	0.116
	Min	4.500					
Q2	Mean	4.960	1.020	4.537	0.725	1.194	0.257
	Median	4.950	1.000	4.810	0.741	1.230	0.253
	S.D.	0.280	0.498	0.605	0.144	0.279	0.074
	Min	4.500					
Q3	Mean	5.608	1.850	4.376	0.677	1.268	0.133
	Median	5.600	1.750	4.315	0.689	1.255	0.117
	S.D.	0.399	0.542	0.312	0.052	0.133	0.05
	Min	4.900					
Q4	Mean	5.320	2.040	5.063	0.807	1.290	0.236
	Median	5.050	1.350	5.040	0.764	1.215	0.258
	S.D.	0.594	1.604	0.518	0.136	0.328	0.134
	Min	4.800					
Annual	Median	5.1	1.3	4.58	0.72	1.26	0.21
	10 pcntile	4.76	0.56	3.98	0.59	0.97	0.07
	90 pcntile	5.74	2.20	7.49	1.01	1.77	0.33
	Arth. Mean	5.24	1.51	4.72	0.76	1.54	0.21
	S.D.	0.47	0.96	0.68	0.14	1.62	0.11

LI8 1987		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.217	1.533	6.014	0.837	1.254	0.302
	Median	5.250	1.600	6.210	0.814	1.260	0.313
	S.D.	0.172	0.234	0.887	0.131	0.372	0.068
	Min	4.900					
Q2	Mean	5.486	1.843	6.120	0.864	1.491	0.233
	Median	5.500	1.700	5.970	0.823	1.370	0.167
	S.D.	0.485	0.535	0.500	0.089	0.283	0.147
	Min	4.800					
Q3	Mean	5.986	3.014	5.613	0.814	1.543	0.286
	Median	6.000	2.700	5.890	0.819	1.570	0.182
	S.D.	0.291	1.239	0.553	0.072	0.156	0.364
	Min	5.600					
Q4	Mean	5.067	1.343	5.695	0.748	1.250	0.261
	Median	5.000	1.350	5.640	0.722	1.180	0.275
	S.D.	0.398	0.559	0.525	0.113	0.255	0.043
	Min	4.600					
Annual	Median	5.35	1.70	5.91	0.81	1.42	0.22
	10 pcntile	4.87	1.10	4.95	0.66	0.99	0.10
	90 pcntile	6.23	3.40	6.78	0.97	1.71	0.44
	Arth. Mean	5.46	1.97	5.85	0.82	1.40	0.27
	S.D.	0.49	0.98	0.61	0.10	0.28	0.20

LI8 1988		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.814	1.192	4.957	0.932	1.384	0.370
	Median	4.900	1.100	4.810	0.874	1.250	0.400
	S.D.	0.393	0.699	0.271	0.182	0.327	0.106
	Min	4.300					
Q2	Mean	5.483	1.750	5.678	0.980	1.614	0.172
	Median	5.350	1.600	5.465	0.983	1.560	0.181
	S.D.	0.279	0.404	0.541	0.044	0.117	0.034
	Min	5.300					
Q3	Mean	5.271	1.423	5.570	0.886	1.446	0.250
	Median	5.100	1.300	5.720	0.903	1.400	0.238
	S.D.	0.496	0.573	0.660	0.129	0.367	0.100
	Min	4.800					
Q4	Mean	5.050	1.237	5.765	0.921	1.698	0.270
	Median	4.900	1.110	5.815	0.881	1.375	0.296
	S.D.	0.333	0.490	0.965	0.170	0.677	0.067
	Min	4.800					
Annual	Median	5.10	1.35	5.36	0.90	1.42	0.26
	10 pcntile	4.68	0.80	4.62	0.76	1.11	0.14
	90 pcntile	5.86	2.40	6.62	1.18	2.39	0.45
	Arth. Mean	5.15	1.41	5.48	0.93	7.0	0.27
	S.D.	0.45	0.55	0.69	0.14	----	0.11

LI8 1989		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.933	1.167	5.340	0.947	1.347	0.387
	Median	4.900	1.100	5.340	0.960	1.370	0.408
	S.D.	0.151	0.234	0.390	0.074	0.108	0.053
	Min	4.700					
Q2	Mean	5.850	2.663	5.595	1.087	1.886	0.171
	Median	5.950	2.750	5.355	1.051	1.905	0.134
	S.D.	0.595	1.034	0.820	0.193	0.339	0.106
	Min	5.200					
Q3	Mean	6.333	4.133	6.327	1.212	2.150	0.166
	Median	6.550	4.050	6.425	1.241	2.275	0.114
	S.D.	0.723	2.113	0.966	0.200	0.477	0.130
	Min	4.900					
Q4	Mean	5.083	1.600	6.063	0.989	1.521	0.275
	Median	4.750	0.900	5.150	1.009	1.650	0.308
	S.D.	0.821	1.247	2.799	0.197	0.332	0.122
	Min	4.200					
Annual	Median	5.20	1.60	5.34	1.04	1.66	0.26
	10 pcntile	4.60	0.86	4.81	0.82	1.21	0.10
	90 pcntile	6.63	4.50	7.53	1.38	2.53	0.43
	Arth. Mean	5.57	2.44	5.82	1.06	1.73	0.24
	S.D.	0.81	1.67	1.53	0.19	0.44	0.14

LI8 1990		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.667	0.995	5.563	0.967	1.422	0.511
	Median	4.700	1.040	5.665	0.855	1.310	0.500
	S.D.	0.273	0.248	1.174	0.283	0.530	0.075
	Min	4.300					
Q2	Mean	5.840	2.460	4.754	1.102	1.796	0.107
	Median	5.900	2.500	4.990	1.105	1.960	0.114
	S.D.	0.483	0.924	0.561	0.149	0.391	0.060
	Min	5.300					
Q3	Mean	6.100	2.870	5.350	1.367	2.210	0.210
	Median	6.200	2.950	5.020	1.387	2.330	0.237
	S.D.	0.616	1.196	0.855	0.180	0.348	0.090
	Min	5.000					
Q4	Mean	4.893	1.070	5.725	1.054	1.363	0.445
	Median	4.785	0.840	5.380	0.996	1.345	0.415
	S.D.	0.283	0.641	1.692	0.340	0.473	0.222
	Min	4.700					
Annual	Median	5.30	1.70	5.02	1.10	1.63	0.29
	10 pcntile	4.46	0.70	4.05	0.71	0.87	0.09
	90 pcntile	6.56	3.90	7.00	1.51	2.37	0.63
	Arth. Mean	5.40	1.99	5.34	1.12	1.70	0.32
	S.D.	0.76	1.18	1.08	0.27	0.53	0.20

LI8 1991		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.763	1.000	5.298	1.351	2.158	0.481
	Median	4.820	1.020	5.235	1.186	1.820	0.509
	S.D.	0.298	0.291	0.339	0.472	0.946	0.151
	Min	4.370					
Q2	Mean	5.150	1.460	6.273	1.019	1.586	0.274
	Median	5.200	1.400	5.820	0.949	1.660	0.272
	S.D.	0.246	0.527	1.271	0.197	0.294	0.195
	Min	4.900					
Q3	Mean	5.482	1.827	6.393	1.085	1.884	0.171
	Median	5.410	1.770	6.220	0.971	1.880	0.157
	S.D.	0.163	0.236	0.862	0.241	0.481	0.083
	Min	5.340					
Q4	Mean	5.155	1.520	5.950	0.750	1.315	0.251
	Median	5.155	1.520	5.950	0.750	1.315	0.251
	S.D.	0.629	1.245	0.778	0.085	0.092	0.192
	Min	4.710					
Annual	Median	5.31	1.63	5.86	0.98	1.70	0.27
	10 pcntile	4.70	0.64	5.17	0.80	1.26	0.08
	90 pcntile	5.61	2.27	8.11	1.59	2.66	0.61
	Arth. Mean	5.17	1.51	6.09	1.08	1.78	0.28
	S.D.	0.37	0.55	0.99	0.31	0.56	0.18

LI8 1992		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	4.984	1.214	5.915	0.961	1.716	0.315
	Median	4.950	1.125	5.820	1.020	1.715	0.339
	S.D.	0.178	0.328	0.480	0.393	0.361	0.074
	Min	4.770					
Q2	Mean	5.333	1.962	5.813	1.452	1.560	0.169
	Median	5.400	2.020	5.795	0.940	1.470	0.159
	S.D.	0.234	0.306	0.560	1.254	0.174	0.111
	Min	5.000					
Q3	Mean	5.324	1.894	6.523	0.899	1.751	0.195
	Median	5.300	1.740	6.540	0.850	1.560	0.138
	S.D.	0.449	0.848	0.820	0.163	0.723	0.098
	Min	4.800					
Q4	Mean	5.067	1.580	8.967	0.775	1.265	0.241
	Median	5.100	1.565	6.200	0.760	1.240	0.250
	S.D.	0.250	0.636	6.926	0.083	0.183	0.082
	Min	4.700					
Annual	Median	5.1	1.6	6.0	0.93	1.47	0.25
	10 pcntile	4.79	0.93	5.48	0.68	1.09	0.11
	90 pcntile	5.72	2.47	7.14	1.20	2.48	0.37
	Arth. Mean	5.17	1.64	6.73	1.01	1.92	0.23
	S.D.	0.32	0.62	3.33	0.64	1.75	0.10

LI8 1993		pH	Alk	SO_4	Mg	Ca	Al
Q1	Mean	5.630	2.255	6.600	0.945	1.558	0.173
	Median	5.800	2.410	6.350	0.965	1.635	0.137
	S.D.	0.442	0.608	0.610	0.134	0.265	0.102
	Min	4.900					
Q2	Mean	5.413	2.060	6.733	0.882	1.447	0.186
	Median	5.335	1.970	6.750	0.865	1.485	0.140
	S.D.	0.328	0.506	0.242	0.057	0.082	0.085
	Min	5.100					
Q3	Mean	5.713	2.737	6.250	0.790	1.909	0.123
	Median	5.700	2.590	6.300	0.770	1.500	0.111
	S.D.	0.262	0.802	0.671	0.148	1.150	0.036
	Min	5.300					
Q4	Mean	5.500	2.733	7.500	0.975	1.615	0.186
	Median	5.550	2.430	7.650	1.010	1.635	0.146
	S.D.	0.390	0.957	0.320	0.079	0.139	0.127
	Min	5.000					
Annual	Median	5.7	2.38	6.08	0.88	1.51	0.14
	10 pcntile	5.06	1.60	5.88	0.72	1.31	0.09
	90 pcntile	6.00	3.74	7.70	1.04	1.80	0.32
	Arth. Mean	5.57	2.46	6.75	0.89	1.64	0.16
	S.D.	0.36	0.76	0.67	0.13	0.62	0.09

Table 2.1.8 GRAZED MOORLAND REFERENCE STREAM CI1

CI1 1984		pH	Alk	SO_4	Ca	Mg	Al
Q3	Mean	4.900	1.480	4.188	0.965	0.720	0.096
	S.D.	0.255	0.415	0.458	0.202	0.088	0.040
	Median	4.800	1.500	4.000	0.610	0.729	0.096
	Min	4.50					
Q4	Mean	4.89	1.00	4.048	0.726	0.542	0.124
	S.D.	0.083	0.158	0.651	0.205	0.110	0.028
	Median	4.90	1.000	4.234	0.785	0.572	0.125
	Min	4.70					
Annual	Median	4.90	1.10	4.00	0.85	0.62	0.11
	10 pcntile	4.70	0.75	3.00	0.49	0.43	0.06
	90 pcntile	5.19	1.85	5.0	1.14	0.82	0.16
	Arth. Mean	4.9	1.17	4.11	0.83	0.62	0.11
	S.D.	0.18	0.35	0.57	0.23	0.13	0.04

CI1 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.99	1.038	5.362	0.869	0.601	0.124
	S.D.	0.120	0.230	0.473	0.225	0.116	0.018
	Median	5.00	1.050	5.440	0.910	0.605	0.121
	Min	4.80					
Q2	Mean	4.992	1.133	4.896	0.836	0.575	0.103
	S.D.	0.116	0.227	0.604	0.150	0.065	0.024
	Median	5.0	1.10	4.888	0.810	0.586	0.103
	Min	4.800					
Q3	Mean	5.300	1.833	3.008	0.654	0.403	0.093
	S.D.	0.241	0.409	0.659	0.111	0.070	0.015
	Median	5.250	1.80	2.80	0.660	0.410	0.090
	Min	4.900					
Q4	Mean	5.390	1.833	3.334	0.811	0.513	0.072
	S.D.	0.448	0.409	0.525	0.136	0.080	0.011
	Median	5.300	1.800	3.600	0.780	0.497	0.070
	Min	4.90					
Annual	Median	5.10	1.24	4.10	0.79	0.52	0.09
	10 pcntile	4.86	0.80	2.69	0.57	0.38	0.07
	90 pcntile	5.68	2.17	5.58	0.99	0.66	0.13
	Arth. Mean	5.17	1.36	4.14	0.79	0.52	0.10
	S.D.	0.32	0.50	1.14	0.18	0.11	0.03

CI1 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.920	0.976	3.677	0.963	0.627	0.081
	S.D.	0.274	0.279	0.520	0.161	0.072	0.008
	Median	4.950	1.000	3.57	0.920	0.605	0.081
	Min	4.30					
Q2	Mean	4.936	0.927	3.785	0.913	0.612	0.080
	S.D.	0.220	0.398	0.814	0.176	0.134	0.021
	Median	4.90	0.80	3.880	0.940	0.626	0.086
	Min	4.600					
Q3	Mean	5.292	1.354	2.940	0.755	0.500	0.066
	S.D.	0.335	0.433	0.238	0.057	0.044	0.021
	Median	5.300	1.40	2.910	0.760	0.497	0.058
	Min	4.600					
Q4	Mean	5.091	1.245	3.991	0.912	0.650	0.083
	S.D.	0.342	0.383	0.897	0.182	0.112	0.026
	Median	5.000	1.200	3.810	0.855	0.632	0.087
	Min	4.80					
Annual	Median	5.00	1.10	3.49	0.83	0.59	0.08
	10 pcntile	4.70	0.55	2.73	0.70	0.46	0.05
	90 pcntile	5.68	2.17	5.58	0.99	0.66	0.13
	Arth. Mean	5.07	1.14	3.56	0.88	0.59	0.08
	S.D.	0.33	0.41	0.76	0.16	0.11	0.02

CI1 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.167	1.483	4.637	1.000	0.699	0.096
	S.D.	0.513	0.662	0.769	0.155	0.109	0.036
	Median	5.00	1.250	4.685	1.005	0.727	0.104
	Min	4.80					
Q2	Mean	5.029	1.257	4.217	0.904	0.616	0.096
	S.D.	0.125	0.223	0.592	0.118	0.104	0.022
	Median	5.10	1.30	4.080	0.890	0.585	0.091
	Min	4.800					
Q3	Mean	5.486	1.986	3.227	0.827	0.474	0.078
	S.D.	0.204	0.291	0.386	0.138	0.045	0.014
	Median	5.500	2.10	3.120	0.820	0.493	0.077
	Min	5.200					
Q4	Mean	5.183	1.527	4.110	0.820	0.558	0.086
	S.D.	0.172	0.145	0.799	0.135	0.096	0.017
	Median	5.150	1.500	3.850	0.775	0.509	0.083
	Min	5.00					
Annual	Median	5.10	1.50	3.93	0.91	0.54	0.09
	10 pcntile	4.87	0.97	3.03	0.68	0.45	0.06
	90 pcntile	5.66	2.26	5.13	1.10	0.77	0.12
	Arth. Mean	5.22	1.57	4.02	0.89	0.58	0.09
	S.D.	0.32	0.45	0.80	0.15	0.12	0.02

CI1 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.871	0.986	3.930	1.054	0.828	0.116
	S.D.	0.111	0.234	0.516	0.198	0.168	0.019
	Median	4.900	0.900	3.900	1.030	0.848	0.116
	Min	4.70					
Q2	Mean	5.067	1.200	4.107	1.078	0.748	0.092
	S.D.	0.052	0.110	0.682	0.110	0.091	0.016
	Median	5.100	1.20	3.930	1.045	0.734	0.099
	Min	5.000					
Q3	Mean	5.086	1.257	3.493	0.880	0.616	0.103
	S.D.	0.157	0.244	0.767	0.079	0.061	0.029
	Median	5.100	1.200	0.363	0.860	0.598	0.094
	Min	4.900					
Q4	Mean	5.133	1.390	4.262	0.960	0.669	0.090
	S.D.	0.103	0.229	0.649	0.207	0.126	0.013
	Median	5.100	1.400	4.365	0.945	0.643	0.090
	Min	5.00					
Annual	Median	5.05	1.20	3.90	0.98	0.67	0.10
	10 pcntile	4.80	0.87	3.01	0.78	0.55	0.07
	90 pcntile	5.23	1.53	4.84	1.29	0.96	0.14
	Arth. Mean	5.03	1.20	3.93	0.99	0.72	0.10
	S.D.	0.15	0.25	0.69	0.17	0.14	0.02

CI1 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.050	1.250	4.447	1.010	0.768	0.194
	S.D.	0.122	0.187	1.036	0.147	0.050	0.206
	Median	5.00	1.250	4.085	1.050	0.769	0.108
	Min	4.90					
Q2	Mean	5.243	1.571	4.111	1.151	0.742	0.068
	S.D.	0.151	0.214	0.999	0.186	0.146	0.020
	Median	5.30	1.60	4.020	1.160	0.723	0.064
	Min	5.00					
Q3	Mean	5.233	1.650	4.557	1.192	0.766	0.065
	S.D.	0.186	0.521	1.457	0.200	0.146	0.012
	Median	5.250	1.70	4.525	1.220	0.732	0.068
	Min	4.900					
Q4	Mean	4.860	0.925	4.252	1.095	0.714	0.097
	S.D.	0.336	0.377	2.196	0.191	0.178	0.039
	Median	4.900	1.050	4.235	1.070	0.688	0.087
	Min	4.40					
Annual	Median	5.20	1.40	4.18	1.13	0.74	0.08
	10 pcntile	4.80	0.90	2.51	0.87	0.58	0.05
	90 pcntile	5.40	1.80	6.32	1.41	1.02	0.17
	Arth. Mean	5.11	1.40	4.33	1.72	0.75	0.10
	S.D.	0.25	0.42	1.40	0.18	0.13	0.11

CI1 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.817	0.950	4.242	1.140	0.839	0.136
	S.D.	0.160	0.373	0,523	0.206	0.193	0.037
	Median	4.800	1.050	4.280	1.130	0.771	0.135
	Min	4.60					
Q2	Mean	4.941	1.029	3.663	1.191	0.902	0.107
	S.D.	0.053	0.125	0.702	0.233	0.166	0.031
	Median	4.900	1.00	3.650	1.320	0.870	0.090
	Min	4.900					
Q3	Mean	4.940	0.960	4.035	1.223	0.923	0.125
	S.D.	0.167	0.230	1.881	0.489	0.282	0.152
	Median	4.900	0.800	4.195	1.310	0.939	0.080
	Min	4.800					
Q4	Mean	4.825	0.805	3.220	0.770	0.586	0.113
	S.D.	0.097	0.204	1.254	0.388	0.251	0.051
	Median	4.840	0.900	3.540	0.775	0.620	0.122
	Min	4.700					
Annual	Median	4.90	0.96	4.02	1.20	0.84	0.11
	10 pcntile	4.70	0.59	1.88	0.42	0.50	0.05
	90 pcntile	5.00	1.27	6.31	1.48	1.13	0.19
	Arth. Mean	4.89	0.95	5.65	1.11	0.84	0.12
	S.D.	0.13	0.24	8.84	0.36	0.24	0.08

CI1 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.843	0.860	4.728	1.625	1.142	0.139
	S.D.	0.165	0.311	0.448	0.860	0.438	0.021
	Median	4.825	0.870	4.665	1.290	0.976	0.137
	Min	4.670					
Q2	Mean	5.057	1.271	4.651	1.253	0.700	0.098
	S.D.	0.136	0.198	0.566	0.420	0.092	0.022
	Median	5.070	1.30	4.450	1.090	0.723	0.103
	Min	4.890					
Q3	Mean	5.655	2.146	3.430	1.087	0.679	0.126
	S.D.	0.309	0.444	0.557	0.356	0.120	0.039
	Median	5.700	2.320	3.560	1.100	0.625	0.124
	Min	5.110					
Q4	Mean	5.133	1.260	3.800	0.770	0.608	0.102
	S.D.	0.343	0.733	0.392	0.45	0.126	0.056
	Median	5.255	1.330	3.750	0.68	0.590	0.080
	Min	4.630					
Annual	Median	5.11	1.30	4.15	1.09	0.70	0.11
	10 pcntile	4.69	0.54	3.05	0.57	0.52	0.07
	90 pcntile	5.89	2.42	5.23	2.00	1.00	0.18
	Arth. Mean	5.20	1.44	4.09	1.18	0.76	0.12
	S.D.	0.38	0.62	0.74	0.54	0.27	0.04

CI1 1992		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.025	1.121	4.363	0.949	0.763	0.069
	S.D.	0.104	0.221	0.631	0.206	0.107	0.007
	Median	5.000	1.105	4.520	0.910	0.720	0.069
	Min	4.90					
Q2	Mean	5.450	1.958	3.793	0.813	0.627	0.069
	S.D.	0.315	0.228	0.215	0.091	0.078	0.006
	Median	5.450	1.920	3.720	0.795	0.605	0.067
	Min	5.100					
Q3	Mean	5.305	1.717	3.390	0.931	0.557	0.067
	S.D.	0.328	0.382	0.657	0.366	0.075	0.013
	Median	5.305	1.700	3.100	0.920	0.590	0.074
	Min	4.820					
Q4	Mean	5.200	1.563	3.717	0.712	0.530	0.071
	S.D.	0.303	0.421	0.436	0.102	0.038	0.009
	Median	5.100	1.420	3.850	0.685	0.525	0.073
	Min	5.00					
Annual	Median	5.10	1.45	3.90	0.81	0.59	0.07
	10 pcntile	4.90	1.04	2.99	0.64	0.49	0.06
	90 pcntile	5.73	2.28	4.68	1.25	0.81	0.08
	Arth. Mean	5.23	1.55	3.84	0.86	0.62	0.07
	S.D.	0.30	0.44	0.63	0.24	0.11	0.01

CI1 1993		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.217	1.558	4.300	0.825	0.657	0.064
	S.D.	0.147	0.154	0.322	0.128	0.096	0.008
	Median	5.250	1.570	4.350	0.820	0.670	0.063
	Min	5.00					
Q2	Mean	5.452	1.922	4.050	0.742	0.540	0.065
	S.D.	0.439	0.631	0.367	0.134	0.076	0.013
	Median	5.300	1.735	4.050	0.740	0.555	0.066
	Min	5.140					
Q3	Mean	5.706	2.389	2.940	0.844	0.499	0.052
	S.D.	0.255	0.535	0.398	0.429	0.134	0.022
	Median	5.700	2.360	3.000	0.670	0.510	0.060
	Min	5.340					
Q4	Mean	5.583	2.423	4.430	0.803	0.625	0.056
	S.D.	0.337	0.536	0.548	0.080	0.088	0.014
	Median	5.600	2.450	4.550	0.825	0.645	0.053
	Min	5.200					
Annual	Median	5.4	1.81	4.00	0.78	0.58	0.06
	10 pcntile	5.12	1.41	2.74	0.60	0.41	0.05
	90 pcntile	6.04	3.09	4.78	0.96	0.72	0.08
	Arth. Mean	5.5	2.09	3.89	0.81	0.58	0.06
	S.D.	0.35	0.59	0.73	0.24	0.12	0.02

Table 2.1.9 TREATED GRAZED MOORLAND STREAM CI2

CI2 1984		pH	Alk	SO_4	Ca	Mg	Al
Q3	Mean	4.978	3.100	6.250	1.128	0.727	0.125
	S.D.	0.833	2.334	1.363	0.525	0.131	0.075
	Median	4.500	2.350	5.750	1.025	0.712	0.127
	Min	4.10					
Q4	Mean	4.720	0.989	4.611	0.768	0.592	0.171
	S.D.	0.300	0.518	0.451	0.187	0.087	0.031
	Median	4.700	0.900	4.660	0.755	0.597	0.169
	Min	4.400					
Annual	Median	4.65	1.100	5.000	0.820	0.630	0.16
	10 pcntile	4.400	0.360	4.000	0.540	0.520	0.06
	90 pcntile	5.850	4.900	7.400	1.440	0.880	0.24
	Arth. Mean	4.820	1.64	5.18	0.91	0.65	0.15
	S.D.	0.56	1.60	1.16	0.39	0.12	0.06

CI2 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.989	0.990	5.649	0.804	0.656	0.179
	S.D.	0.404	0.406	0.703	0.127	0.106	0.055
	Median	5.000	1.100	5.351	0.790	0.625	0.167
	Min	4.400					
Q2	Mean	4.807	1.027	5.022	0.788	0.587	0.15
	S.D.	0.284	0.400	0.681	0.140	0.087	0.04
	Median	4.800	1.20	4.906	0.765	0.580	0.16
	Min	4.400					
Q3	Mean	5.023	1.778	3.043	0.652	0.409	0.15
	S.D.	0.314	1.117	0.590	0.223	0.112	0.02
	Median	5.100	1.600	2.850	0.570	0.375	0.14
	Min	4.600					
Q4	Mean	5.209	1.645	3.143	0.815	0.550	0.16
	S.D.	0.559	1.367	0.378	0.255	0.086	0.04
	Median	5.30	1.400	3.200	0.770	0.535	0.169
	Min	4.50					
Annual	Median	5.00	1.20	4.00	0.75	0.56	0.16
	10 pcntile	4.50	0.40	2.68	0.49	0.34	0.10
	90 pcntile	5.60	2.90	5.93	1.04	0.68	0.23
	Arth. Mean	5.00	1.37	4.21	0.76	0.55	0.16
	S.D.	0.41	0.98	1.27	0.20	0.13	0.04

CI2 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.04	1.111	3.338	0.813	0.575	0.120
	S.D.	0.420	0.556	0.323	0.134	0.061	0.044
	Median	5.000	1.000	3.180	0.825	0.564	0.110
	Min	4.50					
Q2	Mean	4.927	0.945	3.515	0.801	0.562	0.124
	S.D.	0.332	0.596	0.769	0.169	0.147	0.039
	Median	4.900	0.900	3.615	0.845	0.529	0.112
	Min	4.500					
Q3	Mean	5.436	1.900	2.693	0.873	0.543	0.125
	S.D.	0.478	0.924	0.272	0.241	0.104	0.042
	Median	5.600	2.000	2.690	0.830	0.493	0.109
	Min	4.800					
Q4	Mean	5.05	1.520	4.060	0.840	0.660	0.137
	S.D.	0.708	1.518	1.071	0.283	0.132	0.049
	Median	4.700	0.800	3.795	0.720	0.633	0.147
	Min	4.40					
Annual	Median	5.00	1.00	3.21	0.82	0.57	0.12
	10 pcntile	4.50	0.40	2.56	0.59	0.45	0.08
	90 pcntile	5.60	2.90	5.93	1.04	0.68	0.23
	Arth. Mean	5.11	1.38	3.42	0.83	0.59	0.13
	S.D.	0.53	1.01	0.85	0.21	0.12	0.04

CI2 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.767	0.750	4.978	0.723	0.650	0.162
	S.D.	0.163	0.414	1.046	0.148	0.095	0.048
	Median	4.750	0.750	4.940	0.730	0.665	0.155
	Min	4.60					
Q2	Mean	4.929	1.057	4.036	0.754	0.562	0.137
	S.D.	0.275	0.522	0.681	0.122	0.083	0.046
	Median	4.900	1.100	3.840	0.690	0.540	0.117
	Min	4.500					
Q3	Mean	5.657	2.729	3.000	0.931	0.520	0.163
	S.D.	0.251	0.976	0.351	0.153	0.093	0.056
	Median	5.700	2.400	3.050	0.900	0.514	0.148
	Min	5.200					
Q4	Mean	4.917	1.030	3.905	0.675	0.508	0.129
	S.D.	0.407	0.589	0.744	0.146	0.080	0.026
	Median	4.850	1.000	3.760	0.665	0.480	0.131
	Min	4.600					
Annual	Median	4.90	1.15	3.61	0.77	0.54	0.14
	10 pcntile	4.60	0.30	2.91	0.56	0.44	0.10
	90 pcntile	5.73	2.96	5.25	0.97	0.69	0.21
	Arth. Mean	5.08	1.43	3.94	0.78	0.56	0.15
	S.D.	0.45	1.03	0.99	0.17	0.10	0.05

CI2 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.586	0.407	4.093	0.734	0.780	0.245
	S.D.	0.121	0.247	0.801	0.191	0.217	0.089
	Median	4.600	0.400	4.310	0.770	0.817	0.194
	Min	4.400					
Q2	Mean	5.350	2.412	3.595	1.478	0.644	0.118
	S.D.	0.689	2.990	0.530	1.399	0.031	0.021
	Median	5.100	1.20	3.420	0.940	0.647	0.122
	Min	4.800					
Q3	Mean	6.882	14.518	3.766	7.084	0.636	0.152
	S.D.	0.098	2.822	0.767	1.269	0.125	0.032
	Median	6.900	13.600	3.590	6.570	0.660	0.153
	Min	6.700					
Q4	Mean	6.850	6.850	4.323	5.998	0.610	0.103
	S.D.	0.157	0.157	0.570	1.179	0.099	0.022
	Median	6.800	6.800	4.400	5.990	0.590	0.106
	Min	6.70					
Annual	Median	6.75	10.88	3.79	5.25	0.65	0.13
	10 pcntile	7.00	0.42	3.17	0.72	0.51	0.08
	90 pcntile	4.57	14.98	5.06	7.73	0.85	0.21
	Arth. Mean	6.17	9.00	3.95	4.45	0.66	0.15
	S.D.	1.01	6.10	0.70	2.91	0.14	0.07

CI2 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.815	9.108	3.735	4.228	0.654	0.096
	S.D.	0.069	1.126	0.414	1.079	0.092	0.020
	Median	6.800	9.600	3.740	4.580	0.667	0.095
	Min	6.70					
Q2	Mean	6.80	10.062	3.663	4.402	0.861	0.121
	S.D.	0.158	1.994	0.699	0.667	0.179	0.039
	Median	6.80	10.10	3.705	4.415	0.799	0.105
	Min	6.600					
Q3	Mean	6.731	9.762	5.177	4.731	0.909	0.119
	S.D.	0.155	2.60	2.254	0.694	0.133	0.025
	Median	6.700	9.100	5.100	4.600	0.956	0.122
	Min	6.500					
Q4	Mean	6.364	5.609	4.778	3.520	0.672	0.120
	S.D.	0.220	1.841	1.563	0.744	0.103	0.092
	Median	6.400	5.300	4.735	3.495	0.685	0.098
	Min	6.10					
	Median	6.70	8.85	4.22	4.34	0.74	0.10
	10 pcntile	6.31	4.67	3.04	2.86	0.57	0.07
	90 pcntile	7.00	10.95	6.07	5.14	1.02	0.15
	Arth. Mean	6.69	8.76	4.34	4.23	0.78	0.11
	S.D.	0.23	2.57	1.54	0.90	0.17	0.05

CI2 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.992	3.338	4.360	2.811	0.789	0.127
	S.D.	0.359	0.801	0.686	0.569	0.186	0.034
	Median	6.100	3.100	4.260	2.840	0.801	0.129
	Min	5.10					
Q2	Mean	6.313	7.313	3.640	2.578	0.884	0.114
	S.D.	0.196	8.178	0.933	0.467	0.164	0.040
	Median	6.30	4.950	3.415	2.740	0.878	0.104
	Min	6.100					
Q3	Mean	6.550	5.133	5.293	3.099	1.037	0.163
	S.D.	0.198	1.346	2.595	0.628	0.178	0.176
	Median	6.550	5.250	4.675	3.185	1.067	0.118
	Min	6.200					
Q4	Mean	5.876	2.856	4.381	2.178	0.634	0.116
	S.D.	0.371	0.942	0.520	0.687	0.126	0.048
	Median	5.955	2.950	4.530	2.095	0.641	0.095
	Min	4.920					
Annual	Median	6.20	3.60	4.38	2.82	0.86	0.12
	10 pcntile	5.70	2.34	2.79	1.81	0.52	0.08
	90 pcntile	6.70	5.86	6.40	3.54	1.14	0.18
	Arth. Mean	6.18	4.47	4.49	2.70	0.84	0.13
	S.D.	0.40	3.83	1.56	0.67	0.22	0.10

CI2 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.942	2.302	4.694	2.898	0.946	0.121
	S.D.	0.238	0.452	0.480	1.303	0.319	0.041
	Median	5.890	2.400	4.620	2.350	0.853	0.124
	Min	5.590					
Q2	Mean	6.023	3.436	4.415	2.025	0.707	0.141
	S.D.	0.657	0.941	1.065	0.512	0.118	0.125
	Median	6.30	3.450	4.455	2.115	0.714	0.110
	Min	4.340					
Q3	Mean	6.609	6.057	3.577	2.831	0.784	0.187
	S.D.	0.178	1.334	0.778	0.487	0.147	0.088
	Median	6.670	6.360	3.290	2.760	0.725	0.157
	Min	6.350					
Q4	Mean	6.006	2.890	4.118	0.874	0.655	0.098
	S.D.	0.447	1.060	0.888	0.498	0.127	0.040
	Median	6.290	3.420	3.900	0.810	0.700	0.093
	Min	5.450					
	Median	6.28	3.30	4.43	2.20	0.73	0.12
	10 pcntile	5.52	1.64	3.12	1.52	0.55	0.08
	90 pcntile	6.68	6.61	5.66	3.56	1.06	0.21
	Arth. Mean	6.11	3.53	4.30	2.44	0.79	0.14
	S.D.	0.49	1.66	0.89	0.93	0.23	0.09

CI2 1992		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.875	2.275	4.293	1.778	0.591	0.085
	S.D.	0.175	0.319	0.611	0.236	0.225	0.017
	Median	5.900	2.300	4.495	1.805	0.665	0.083
	Min	5.60					
Q2	Mean	6.160	3.848	3.762	1.818	0.654	0.100
	S.D.	0.230	1.406	0.267	0.250	0.061	0.012
	Median	6.10	3.20	3.700	1.760	0.640	0.101
	Min	5.900					
Q3	Mean	6.360	4.429	3.690	2.067	0.664	0.103
	S.D.	0.372	1.309	0.928	0.377	0.211	0.010
	Median	6.300	4.810	3.290	2.160	0.620	0.103
	Min	5.990					
Q4	Mean	5.883	2.933	3.800	1.495	0.495	0.101
	S.D.	0.299	1.294	0.738	0.335	0.91	0.012
	Median	5.850	2.440	3.650	1.530	0.470	0.098
	Min	5.60					
Annual	Median	6.00	2.80	3.81	1.78	0.62	0.01
	10 pcntile	5.60	1.95	3.07	1.28	0.41	0.07
	90 pcntile	6.43	5.79	5.05	2.29	0.79	0.11
	Arth. Mean	6.06	3.31	3.91	1.80	0.60	0.1
	S.D.	0.34	1.37	0.71	0.35	0.18	0.01

CI2 1993		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.183	3.228	4.067	1.535	0.598	0.078
	S.D.	0.293	0.633	0.225	0.155	0.120	0.011
	Median	6.300	3.410	4.050	1.550	0.610	0.075
	Min	5.60					
Q2	Mean	6.169	3.474	3.943	1.500	0.544	0.093
	S.D.	0.366	1.025	0.447	0.259	0.058	0.049
	Median	6.00	3.230	4.000	1.460	0.540	0.092
	Min	5.630					
Q3	Mean	6.317	4.913	2.723	1.596	0.583	0.099
	S.D.	0.268	1.331	0.375	0.491	0.259	0.017
	Median	6.300	4.970	2.800	1.570	0.530	0.100
	Min	5.920					
Q4	Mean	6.00	4.362	4.087	1.658	0.607	0.091
	S.D.	0.219	1.223	0.497	0.145	0.069	0.016
	Median	6.100	4.275	3.900	1.625	0.595	0.090
	Min	5.60					
Annual	Median	6.2	3.60	3.85	1.57	0.57	0.09
	10 pcntile	5.62	2.55	2.54	1.26	0.42	0.06
	90 pcntile	6.60	6.04	4.53	1.98	0.73	0.13
	Arth. Mean	6.17	4.01	3.68	1.57	0.58	0.09
	S.D.	0.30	1.24	0.70	0.29	0.15	0.03

Table 2.1.10 PLOUGHED MOORLAND STUDY STREAM CI3

CI3 1984		pH	Alk	SO_4	Ca	Mg	Al
Q3	Mean	5.117	1.40	5.200	0.850	0.828	0.171
	S.D.	0.652	1.472	0.570	0.226	0.142	0.123
	Median	4.950	1.250	5.000	0.790	0.768	0.231
	Min	4.500					
Q4	Mean	5.227	1.692	4.472	0.887	0.712	0.122
	S.D.	0.440	0.812	0.597	0.159	0.110	0.061
	Median	5.000	1.600	4.500	0.820	0.713	0.154
	Min	4.50					
	Median	5.00	1.6	4.59	0.79	0.73	0.16
	10 pcntile	4.50	0.10	3.54	0.67	0.59	0.04
	90 pcntile	5.98	2.86	5.50	1.13	0.99	0.25
	Arth. Mean	5.20	1.62	4.65	0.88	0.75	0.14
	S.D.	0.49	0.97	0.66	0.17	0.13	0.08

CI3 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.378	1.793	5.609	1.100	0.867	0.160
	S.D.	0.447	0.897	0.564	0.190	0.154	0.108
	Median	5.200	1.440	5.700	1.100	0.833	0.176
	Min	4.80					
Q2	Mean	5.008	1.380	5.044	0.943	0.684	0.139
	S.D.	0.578	0.424	0.452	0.151	0.105	0.063
	Median	5.150	1.450	4.987	0.920	0.675	0.125
	Min	3.400					
Q3	Mean	5.383	1.700	3.941	0.674	0.477	0.087
	S.D.	0.237	0.30	0.423	0.070	0.049	0.020
	Median	5.300	1.700	3.980	0.660	0.460	0.093
	Min	5.100					
Q4	Mean	5.273	1.409	3.725	0.778	0.568	0.105
	S.D.	0.429	0.695	0.229	0.092	0.072	0.049
	Median	5.000	1.100	3.800	0.790	0.568	0.100
	Min	4.80					
	Median	5.20	1.50	4.21	0.82	0.60	0.10
	10 pcntile	4.85	0.79	3.50	0.61	0.45	0.06
	90 pcntile	5.80	2.34	5.82	1.14	0.85	0.22
	Arth. Mean	5.25	1.55	4.53	0.86	0.64	0.12
	S.D.	0.45	0.63	0.87	0.20	0.17	0.07

CI3 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.109	1.145	3.889	0.964	0.681	0.141
	S.D.	0.314	0.425	0.337	0.214	0.085	0.057
	Median	5.000	1.100	3.910	0.930	0.670	0.148
	Min	4.70					
Q2	Mean	5.00	0.992	4.255	0.926	0.702	0.157
	S.D.	0.305	0.493	0.407	0.181	0.112	0.063
	Median	4.90	0.900	4.190	0.940	0.717	0.161
	Min	4.600					
Q3	Mean	5.531	1.662	3.751	0.854	0.591	0.071
	S.D.	0.335	0.405	0.297	0.069	0.068	0.025
	Median	5.600	1.600	3.755	0.875	0.571	0.067
	Min	5.100					
Q4	Mean	5.245	1.582	4.175	1.045	0.789	0.138
	S.D.	0.408	0.502	0.391	0.117	0.102	0.074
	Median	5.100	1.300	4.240	1.015	0.804	0.153
	Min	4.900	1.100				
Annual	Median	5.10	1.30	3.99	0.93	0.68	0.12
	10 pcntile	4.80	0.68	3.53	0.75	0.55	0.05
	90 pcntile	5.80	2.34	5.82	1.14	0.85	0.22
	Arth. Mean	5.23	1.35	4.01	0.94	0.69	0.13
	S.D.	0.39	0.53	0.41	0.16	0.12	0.06

CI3 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.017	1.300	4.803	1.100	0.930	0.246
	S.D.	0.098	0.237	0.658	0.201	0.070	0.053
	Median	5.050	1.350	4.880	1.155	0.933	0.240
	Min	4.90					
Q2	Mean	5.183	1.483	4.723	1.123	0.551	0.174
	S.D.	0.214	0.223	0.338	0.097	0.087	0.090
	Median	5.200	1.600	4.730	1.105	0.846	0.144
	Min	4.900					
Q3	Mean	5.843	2.300	4.446	1.043	0.684	0.079
	S.D.	0.162	0.311	0.352	0.096	0.066	0.015
	Median	5.800	2.300	4.520	1.070	0.684	0.076
	Min	5.700					
Q4	Mean	5.400	1.833	4.593	1.082	0.748	0.111
	S.D.	0.155	0.197	0.692	0.196	0.107	0.026
	Median	5.350	1.800	4.365	1.045	0.693	0.113
	Min	5.300					
Annual	Median	5.30	1.70	4.56	1.08	0.80	0.12
	10 pcntile	4.90	1.20	3.98	0.86	0.65	0.07
	90 pcntile	5.80	2.44	5.45	1.27	0.99	0.28
	Arth. Mean	5.38	1.75	4.63	1.09	0.80	0.15
	S.D.	0.36	0.46	0.51	0.15	0.12	0.08

CI3 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.000	1.197	4.378	1.132	0.952	0.243
	S.D.	0.063	0.188	0.425	0.132	0.128	0.046
	Median	5.000	1.200	4.400	1.135	0.979	0.257
	Min	4.900					
Q2	Mean	5.450	1.617	4.690	1.325	0.898	0.100
	S.D.	0.281	0.496	0.477	0.258	0.040	0.024
	Median	5.400	1.500	4.525	1.220	0.904	0.098
	Min	5.200					
Q3	Mean	5.414	1.557	4.541	1.017	0.791	0.110
	S.D.	0.267	0.374	0.667	0.152	0.084	0.046
	Median	5.500	1.800	4.570	1.000	0.792	0.092
	Min	5.000					
Q4	Mean	5.320	1.560	4.434	1.082	0.834	0.115
	S.D.	0.130	0.195	0.516	0.174	0.101	0.018
	Median	5.300	1.500	4.560	1.040	0.807	0.115
	Min	5.200					
Annual	Median	5.30	1.50	4.53	1.09	0.87	0.11
	10 pcntile	5.00	1.05	3.73	0.90	0.71	0.08
	90 pcntile	5.65	1.90	5.26	1.35	1.04	0.27
	Arth. Mean	5.30	1.48	4.52	1.14	0.87	0.14
	S.D.	0.27	0.36	0.52	0.21	0.11	0.07

CI3 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.133	1.283	4.372	1.166	0.935	0.180
	S.D.	0.294	0.422	0.461	0.114	0.156	0.073
	Median	5.200	1.400	4.395	1.230	0.982	0.197
	Min	4.700					
Q2	Mean	5.471	2.700	4.293	1.210	0.888	0.098
	S.D.	0.415	1.883	1.597	0.364	0.197	0.066
	Median	5.600	2.200	4.690	1.290	0.927	0.075
	Min	4.800					
Q3	Mean	5.900	3.350	5.683	1.580	0.956	0.081
	S.D.	0.460	2.321	1.163	0.367	0.200	0.048
	Median	5.950	2.700	5.480	1.470	0.907	0.069
	Min	5.100					
Q4	Mean	5.220	1.280	5.323	1.200	0.862	0.108
	S.D.	0.390	0.545	1.066	0.152	0.138	0.060
	Median	5.100	1.200	5.275	1.190	0.856	0.091
	Min	4.800					
Annual	Median	5.35	1.65	4.71	1.26	0.93	0.09
	10 pcntile	4.80	0.85	3.85	1.00	0.64	0.04
	90 pcntile	6.05	5.20	6.54	1.96	1.10	0.21
	Arth. Mean	5.44	2.21	4.89	1.45	0.91	0.12
	S.D.	0.48	1.74	1.26	0.86	0.17	0.07

CI3 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.920	1.160	4.464	1.328	1.050	0.304
	S.D.	0.130	0.207	0.597	0.119	0.114	0.143
	Median	5.000	1.200	4.340	1.400	1.062	0.223
	Min	4.70					
Q2	Mean	5.380	1.620	4.054	1.278	1.022	0.127
	S.D.	0.349	0.415	0.531	0.215	0.173	0.104
	Median	5.200	1.500	3.970	1.160	0.990	0.082
	Min	5.000					
Q3	Mean	5.580	1.620	4.533	1.330	1.072	0.070
	S.D.	0.482	0.507	0.817	0.232	0.135	0.032
	Median	5.300	1.500	4.465	1.310	1.117	0.061
	Min	5.100					
Q4	Mean	4.984	1.120	4.556	1.230	1.019	0.185
	S.D.	0.113	0.045	1.157	0.208	0.266	0.086
	Median	5.000	1.100	4.000	1.270	0.881	0.167
	Min	4.800					
Annual	Median	5.07	1.25	4.33	1.30	1.04	0.12
	10 pcntile	4.81	1.10	3.49	1.04	0.84	0.05
	90 pcntile	6.07	2.19	5.48	1.54	1.29	0.35
	Arth. Mean	5.22	1.38	4.41	1.29	1.04	0.17
	S.D.	0.40	0.40	0.78	0.19	0.17	0.13

CI3 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.925	1.060	4.495	1.910	1.520	0.283
	S.D.	0.053	0.149	0.428	1.074	0.704	0.024
	Median	4.925	1.090	4.510	1.515	1.248	0.286
	Min	4.870					
Q2	Mean	5.398	1.770	4.618	1.402	0.981	0.133
	S.D.	0.441	0.603	0.553	0.289	0.132	0.063
	Median	5.365	1.630	4.480	1.350	0.940	0.120
	Min	4.900					
Annual	Median	4.99	1.20	4.51	1.37	1.00	0.20
	10 pcntile	4.87	0.88	4.01	1.11	0.89	0.05
	90 pcntile	6.00	2.54	5.46	3.31	2.43	0.30
	Arth. Mean	5.21	1.49	4.57	1.60	1.20	0.19
	S.D.	0.41	0.59	0.48	0.71	0.50	0.09

Table 2.1.11 PLOUGHED MOORLAND STUDY STREAM CI4

CI4 1984		pH	Alk	SO_4	Ca	Mg	Al
Q3	Mean	4.986	3.400	5.583	1.008	0.897	0.150
	S.D.	1.012	3.732	1.021	0.501	0.292	0.085
	Median	4.500	2.500	5.750	0.840	0.795	0.156
	Min	4.200					
Q4	Mean	4.867	1.000	4.576	0.792	0.614	0.156
	S.D.	0.335	0.656	0.499	0.159	0.113	0.041
	Median	4.800	0.950	4.500	0.740	0.631	0.153
	Min	4.500					
Annual	Median	4.80	1.10	4.97	0.80	0.66	0.15
	10 pcntile	4.44	0.10	3.97	0.50	0.51	0.08
	90 pcntile	5.70	4.00	6.70	1.02	1.10	0.22
	Arth. Mean	4.91	1.50	4.96	0.83	0.71	0.15
	S.D.	0.60	1.76	0.91	0.32	0.22	0.06

CI4 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.345	1.491	5.402	0.868	0.638	0.128
	S.D.	0.491	0.741	0.748	0.308	0.238	0.051
	Median	5.400	1.600	5.300	0.830	0.641	0.116
	Min	4.70					
Q2	Mean	5.285	1.546	4.732	0.959	0.671	0.115
	S.D.	0.503	0.733	0.620	0.198	0.107	0.030
	Median	5.200	1.600	4.690	1.000	0.698	0.115
	Min						
Q3	Mean	5.300	2.344	2.960	0.713	0.488	0.125
	S.D.	0.478	1.218	0.398	0.201	0.111	0.014
	Median	5.000	2.000	2.860	0.685	0.450	0.122
	Min	4.800					
Q4	Mean	5.375	2.242	3.028	0.780	0.613	0.118
	S.D.	0.574	1.823	0.438	0.297	0.131	0.022
	Median	5.350	1.650	2.850	0.745	0.620	0.118
	Min	4.700					
Annual	Median	5.20	1.60	3.87	0.83	0.61	0.12
	10 pcntile	4.70	0.50	2.73	0.54	0.40	0.09
	90 pcntile	6.00	3.70	5.46	1.19	0.80	0.16
	Arth. Mean	5.31	1.86	4.03	0.84	0.60	0.12
	S.D.	0.49	1.24	1.20	0.26	0.17	0.03

CI4 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.427	2.036	3.421	0.943	0.716	0.091
	S.D.	0.535	1.536	0.487	0.241	0.103	0.030
	Median	5.300	1.300	3.340	0.855	0.750	0.092
	Min	4.60					
Q2	Mean	5.200	1.355	3.944	0.847	0.684	0.106
	S.D.	0.480	0.766	0.664	0.169	0.138	0.023
	Median	5.000	1.100	3.915	0.870	0.678	0.112
	Min	4.600					
Q3	Mean	5.685	2.808	3.056	0.921	0.642	0.085
	S.D.	0.620	1.393	0.304	0.318	0.104	0.015
	Median	5.900	2.700	3.095	1.020	0.640	0.087
	Min	4.600					
Q4	Mean	5.200	2.042	3.910	0.908	0.746	0.118
	S.D.	0.706	2.073	0.920	0.321	0.141	0.041
	Median	4.900	1.150	3.705	0.830	0.727	0.132
	Min	4.500					
Annual	Median	5.20	1.30	3.34	0.84	0.69	0.10
	10 pcntile	4.68	0.70	2.91	0.62	0.53	0.06
	90 pcntile	6.00	3.70	5.46	1.19	0.80	0.16
	Arth. Mean	5.39	2.09	3.57	3.35	0.70	0.10
	S.D.	0.61	1.57	0.72		0.12	0.03

CI4 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.167	1.417	4.595	0.870	0.747	0.150
	S.D.	0.344	0.475	0.814	0.245	0.138	0.035
	Median	5.100	1.450	4.460	0.875	0.779	0.144
	Min	4.800					
Q2	Mean	5.343	1.757	4.192	0.956	0.715	0.116
	S.D.	0.503	0.752	0.369	0.194	0.064	0.061
	Median	5.400	1.800	4.230	0.870	0.710	0.126
	Min	4.600					
Q3	Mean	6.183	4.183	3.781	1.310	0.845	0.157
	S.D.	0.232	0.933	0.882	0.214	0.243	0.027
	Median	6.150	3.900	3.790	1.270	0.768	0.157
	Min	5.900					
Q4	Mean	5.013	1.543	4.560	0.923	0.682	0.132
	S.D.	0.546	1.013	1.423	0.356	0.173	0.017
	Median	5.000	1.300	4.090	0.800	0.619	0.132
	Min	4.200					
Annual	Median	5.30	1.80	4.12	1.00	0.73	0.14
	10 pcntile	4.60	0.78	3.28	0.58	0.54	0.10
	90 pcntile	6.20	4.14	5.54	1.54	0.93	0.19
	Arth. Mean	5.39	2.18	4.28	1.02	0.74	0.14
	S.D.	0.61	1.37	0.98	0.31	0.17	0.04

CI4 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.846	0.988	3.875	0.868	0.808	0.170
	S.D.	0.254	0.387	0.415	0.193	0.172	0.034
	Median	4.800	0.900	4.110	0.900	0.799	0.176
	Min	4.50					
Q2	Mean	5.708	2.666	4.305	1.272	0.862	0.136
	S.D.	0.606	1.594	0.813	0.553	0.088	0.098
	Median	6.000	2.400	4.130	1.130	0.850	0.122
	Min	4.600					
Q3	Mean	5.415	1.962	3.761	0.966	0.747	0.139
	S.D.	0.657	1.371	0.973	0.276	0.147	0.039
	Median	5.700	2.200	3.340	0.970	0.714	0.124
	Min	4.500					
Q4	Mean	5.242	1.645	4.124	0.994	0.772	0.144
	S.D.	0.538	0.727	0.635	0.268	0.149	0.041
	Median	5.250	1.800	4.110	0.940	0.720	0.134
	Min	4.300					
Annual	Median	5.10	1.50	3.99	1.00	0.80	0.13
	10 pcntile	4.60	0.60	3.16	0.66	0.60	0.09
	90 pcntile	6.20	3.76	5.21	1.36	1.00	0.20
	Arth. Mean	5.30	1.84	4.01	1.03	0.80	0.15
	S.D.	0.61	1.28	0.75	0.37	0.14	0.06

CI4 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.077	1.262	3.815	0.962	0.816	0.158
	S.D.	0.383	0.623	0.284	0.170	0.077	0.044
	Median	5.100	1.400	3.750	0.980	0.804	0.136
	Min	4.600					
Q2	Mean	5.944	3.544	4.382	1.433	0.982	0.102
	S.D.	0.588	2.042	1.425	0.308	0.201	0.043
	Median	6.100	3.400	4.030	1.330	0.904	0.080
	Min	4.700					
Q3	Mean	6.033	4.633	5.852	1.790	1.145	0.101
	S.D.	0.619	2.565	1.666	0.492	0.308	0.024
	Median	6.150	4.900	5.555	1.905	1.134	0.101
	Min	4.900					
Q4	Mean	5.200	1.700	5.240	1.250	0.885	0.132
	S.D.	0.682	1.483	1.897	0.265	0.192	0.055
	Median	4.900	1.200	4.810	1.270	0.941	0.107
	Min	4.600					
Annual	Median	5.50	1.90	4.08	1.18	0.89	0.12
	10 pcntile	4.64	0.48	3.38	0.84	0.74	0.08
	90 pcntile	6.46	5.96	7.62	2.01	1.37	0.20
	Arth. Mean	5.51	2.56	4.58	1.28	0.93	0.13
	S.D.	0.67	2.09	1.45	0.42	0.22	0.05

CI4 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.600	0.725	3.820	1.00	0.848	0.205
	S.D.	0.190	0.377	0.377	0.121	0.172	0.043
	Median	4.600	0.800	3.850	0.995	0.822	0.215
	Min	4.400					
Q2	Mean	5.920	3.080	3.632	1.322	1.027	0.105
	S.D.	0.531	1.425	0.347	0.247	0.168	0.042
	Median	6.100	3.200	3.500	1.260	1.124	0.093
	Min	5.100					
Q3	Mean	5.520	2.820	3.748	1.990	1.234	0.081
	S.D.	0.920	3.132	2.338	0.555	0.246	0.040
	Median	5.400	1.800	3.400	1.890	1.310	0.088
	Min	4.600					
Q4	Mean	4.696	0.720	3.870	0.768	0.750	0.184
	S.D.	0.235	0.337	0.830	0.273	0.201	0.081
	Median	4.650	0.700	3.760	0.650	0.823	0.177
	Min	4.400					
Annual	Median	4.80	1.10	3.66	1.14	0.93	0.12
	10 pcntile	4.40	.20	2.86	0.63	0.63	0.08
	90 pcntile	6.38	5.20	4.85	2.33	1.35	0.25
	Arth. Mean	5.16	1.96	3.77	1.29	0.97	0.14
	S.D.	0.76	2.03	1.22	0.58	0.27	0.07

CI4 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.740	0.947	4.193	1.445	1.180	0.174
	S.D.	0.284	0.349	0.517	0.753	0.493	0.014
	Median	4.790	1.040	4.070	1.110	0.956	0.175
	Min	4.380					
Q2	Mean	5.516	2.264	4.343	1.127	0.817	0.125
	S.D.	0.759	1.662	0.897	0.242	0.068	0.046
	Median	5.200	1.400	4.430	1.040	0.840	0.133
	Min	4.800					
Q3	Mean	6.362	4.183	3.457	1.394	0.908	0.119
	S.D.	0.343	1.153	0.799	0.585	0.178	0.052
	Median	6.480	4.230	3.630	1.270	0.810	0.138
	Min	5.700					
Q4	Mean	5.630	4.060	3.750	1.130	0.760	0.096
	S.D.	0.566	3.903	0.354	0.665	0.255	0.057
	Median	5.630	4.060	3.750	1.130	0.760	0.096
	Min	5.230					
Annual	Median	5.70	2.51	4.00	1.16	0.87	0.15
	10 pcntile	4.60	0.87	2.99	0.66	0.71	0.06
	90 pcntile	6.60	5.88	4.90	2.43	1.16	0.18
	Arth. Mean	5.65	2.96	3.92	1.29	0.92	0.13
	S.D.	0.79	1.99	0.81	0.52	0.28	0.05

CI4 1992		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.129	1.294	4.073	0.914	0.777	0.105
	S.D.	0.427	0.629	0.639	0.294	0.132	0.024
	Median	5.000	1.200	4.100	0.760	0.750	0.107
	Min	4.70					
Q2	Mean	5.867	3.628	3.693	1.082	0.798	0.091
	S.D.	0.609	2.100	0.281	0.373	0.091	0.022
	Median	5.950	3.330	3.730	1.010	0.765	0.095
	Min	5.100					
Q3	Mean	5.652	2.740	4.283	1.240	0.784	0.102
	S.D.	0.708	1.921	1.221	0.679	0.234	0.033
	Median	5.865	2.585	3.800	1.000	0.760	0.100
	Min	4.780					
Q4	Mean	5.133	1.648	1.648	0.732	0.605	0.116
	S.D.	0.543	1.340	1.340	0.257	0.113	0.027
	Median	4.900	1.100	1.100	0.650	0.565	0.122
	Min	4.800					
Annual	Median	5.20	1.60	3.80	0.79	0.75	0.11
	10 pcntile	4.79	0.77	3.17	0.55	0.52	0.07
	90 pcntile	6.44	5.28	5.10	1.85	0.96	0.14
	Arth. Mean	5.43	2.29	4.00	1.00	0.74	0.10
	S.D.	0.63	1.75	0.78	0.46	0.17	0.03

CI4 1993		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.480	2.475	4.060	0.934	0.744	0.094
	S.D.	0.901	1.167	0.251	0.311	0.187	0.034
	Median	5.700	2.770	4.000	1.090	0.750	0.096
	Min	4.30					
Q2	Mean	5.817	2.790	4.150	0.825	0.672	0.094
	S.D.	0.639	1.243	0.321	0.148	0.070	0.029
	Median	5.790	2.560	4.200	0.785	0.680	0.093
	Min	5.100					
Q3	Mean	5.966	3.960	3.061	1.094	0.624	0.105
	S.D.	0.526	2.107	0.369	0.454	0.135	0.017
	Median	5.900	3.790	3.000	1.100	0.610	0.100
	Min	5.160					
Q4	Mean	5.633	3.238	4.163	0.912	0.745	0.098
	S.D.	0.513	1.483	0.371	0.237	0.095	0.021
	Median	5.750	3.000	4.300	0.880	0.755	0.096
	Min	4.900					
Annual	Median	5.90	2.79	4.00	0.85	0.68	0.01
	10 pcntile	4.85	1.54	2.80	0.60	0.52	0.06
	90 pcntile	6.50	5.71	4.45	1.33	0.87	0.13
	Arth. Mean	5.74	3.21	3.82	0.95	0.69	0.10
	S.D.	0.63	1.60	0.59	0.13	0.13	0.02

Table 2.1.12 TREATED GRAZED MOORLAND STREAM CI5

CI5 1984		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.050	1.458	4.583	0.860	0.785	0.232
	S.D.	0.183	0.365	0.417	0.197	0.106	0.094
	Median	5.000	1.550	4.500	0.810	0.795	0.200
	Min	4.80					
Q2	Mean	5.488	1.956	5.962	1.148	0.863	0.081
	S.D.	0.156	0.477	0.660	0.206	0.120	0.054
	Median	5.500	1.900	6.000	1.210	0.892	0.068
	Min	5.200					
Q3	Mean	5.373	1.825	5.214	1.040	0.821	0.120
	S.D.	0.427	0.614	0.699	0.244	0.114	0.136
	Median	5.400	1.850	5.000	1.080	0.854	0.036
	Min	4.700					
Q4	Mean	4.959	1.150	4.604	0.711	0.613	0.299
	S.D.	0.180	0.278	0.951	0.210	0.130	0.147
	Median	4.900	1.100	4.500	0.645	0.579	0.256
	Min	4.600					
Annual	Median	5.20	1.50	5.00	0.95	0.79	0.17
	10 pcntile	4.80	1.00	4.00	0.57	0.55	0.03
	90 pcntile	5.70	2.28	6.42	1.29	0.97	0.37
	Arth. Mean	5.21	1.55	5.07	0.95	0.77	0.18
	S.D.	0.34	0.52	0.91	0.27	0.15	0.14

CI5 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	4.991	1.115	5.619	0.857	0.662	0.264
	S.D.	0.083	0.153	0.624	0.177	0.099	0.062
	Median	5.000	1.100	5.450	0.880	0.671	0.251
	Min	4.80					
Q2	Mean	4.991	1.164	5.133	0.801	0.623	0.174
	S.D.	0.158	0.273	0.319	0.101	0.056	0.090
	Median	5.100	1.200	4.979	0.800	0.620	0.157
	Min	4.800					
Q3	Mean	5.423	1.844	4.247	0.754	0.468	0.083
	S.D.	0.235	0.445	0.434	0.104	0.048	0.023
	Median	5.400	1.800	4.200	0.730	0.465	0.093
	Min	4.900					
Q4	Mean	5.340	1.470	3.718	0.743	0.513	0.095
	S.D.	0.420	0.668	0.367	0.122	0.072	0.052
	Median	5.350	1.500	3.840	0.760	0.520	0.093
	Min	4.700					
Annual	Median	5.10	1.30	4.80	0.79	0.56	0.11
	10 pcntile	4.80	0.82	3.63	0.64	0.42	0.05
	90 pcntile	5.70	2.18	5.80	0.97	0.72	0.32
	Arth. Mean	5.19	1.37	4.70	0.79	0.57	0.16
	S.D.	0.32	0.50	0.86	0.13	0.11	0.09

CI5 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.190	1.290	4.158	0.982	0.672	0.175
	S.D.	0.407	0.409	0.437	0.132	0.080	0.070
	Median	5.100	1.300	4.090	1.010	0.683	0.150
	Min	4.800					
Q2	Mean	4.991	1.055	4.343	0.896	0.678	0.194
	S.D.	0.255	0.378	0.302	0.124	0.072	0.073
	Median	4.900	1.100	4.290	0.920	0.694	0.199
	Min	4.700					
Q3	Mean	5.533	1.742	3.846	0.935	0.574	0.068
	S.D.	0.284	0.472	0.289	0.165	0.055	0.027
	Median	5.550	1.700	3.845	0.930	0.554	0.064
	Min						
Q4	Mean	5.133	1.442	4.418	0.893	0.671	0.223
	S.D.	0.314	0.215	0.550	0.228	0.105	0.105
	Median	5.050	1.450	4.260	0.865	0.642	0.251
	Min						
Annual	Median	5.10	1.40	4.11	0.94	0.64	0.15
	10 pcntile	4.80	0.80	3.68	0.70	0.55	0.04
	90 pcntile	5.70	2.18	5.80	0.97	0.72	0.32
	Arth. Mean	5.22	1.39	4.19	0.92	0.65	0.16
	S.D.	0.37	0.45	0.46	0.17	0.09	0.09

CI5 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.067	1.450	4.722	0.918	0.706	0.296
	S.D.	0.151	0.315	0.627	0.306	0.142	0.061
	Median	5.100	1.550	4.715	0.940	0.738	0.299
	Min	4.800					
Q2	Mean	5.086	1.443	5.096	0.957	0.756	0.207
	S.D.	0.090	0.113	0.831	0.139	0.156	0.112
	Median	5.100	1.500	5.000	0.930	0.733	0.184
	Min	5.000					
Q3	Mean	5.771	3.294	4.644	1.610	0.597	0.068
	S.D.	0.599	3.451	0.461	1.548	0.015	0.025
	Median	5.500	2.100	4.560	0.990	0.596	0.062
	Min	5.200					
Q4	Mean	6.600	5.988	5.008	3.332	0.602	0.064
	S.D.	0.122	1.818	0.521	0.572	0.096	0.021
	Median	6.60	5.400	4.950	3.100	0.551	0.058
	Min	6.500					
Annual	Median	5.10	1.60	4.76	1.20	0.71	0.28
	10 pcntile	4.84	0.98	3.91	0.54	0.53	0.05
	90 pcntile	6.78	8.86	6.57	4.19	1.04	0.38
	Arth. Mean	5.50	3.37	4.91	1.79	0.70	0.24
	S.D.	0.78	3.27	0.79	1.45	0.18	0.13

CI5 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.379	4.196	4.745	3.468	0.742	0.068
	S.D.	0.105	0.581	0.498	0.375	0.090	0.025
	Median	6.400	4.100	4.795	3.525	0.767	0.066
	Min	6.200					
Q2	Mean	6.436	4.774	4.927	3.016	0.816	0.049
	S.D.	0.108	0.707	0.456	0.548	0.049	0.022
	Median	6.400	4.700	4.830	3.130	0.820	0.043
	Min	6.300					
Q3	Mean	6.362	4.631	4.674	2.694	0.712	0.075
	S.D.	0.126	0.572	0.540	0.196	0.091	0.031
	Median	6.400	4.400	4.420	2.750	0.707	0.065
	Min	6.200					
Q4	Mean	6.392	3.992	5.095	2.758	0.714	0.083
	S.D.	0.131	0.358	1.013	0.402	0.146	0.017
	Median	6.350	3.950	4.950	2.705	0.684	0.083
	Min	6.200					
Annual	Median	6.40	4.30	4.73	2.95	0.76	0.07
	10 pcntile	6.24	3.64	4.15	2.44	0.63	0.04
	90 pcntile	6.56	5.24	5.49	3.69	0.87	0.11
	Arth. Mean	6.39	4.41	4.85	3.00	0.75	0.07
	S.D.	0.12	0.64	0.64	0.50	0.10	0.03

CI5 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.208	3.569	4.798	2.697	0.762	0.078
	S.D.	0.214	1.178	0.604	0.641	0.048	0.038
	Median	6.200	3.300	4.800	2.870	0.764	0.068
	Min	5.600					
Q2	Mean	6.492	4.623	5.116	2.782	0.836	0.048
	S.D.	0.155	1.009	0.658	0.302	0.131	0.026
	Median	6.500	4.800	5.040	2.790	0.832	0.042
	Min	6.200					
Q3	Mean	6.462	6.585	5.828	2.974	1.116	0.044
	S.D.	0.468	2.048	2.014	0.427	0.592	0.024
	Median	6.600	6.400	5.820	2.940	1.018	0.041
	Min	5.000					
Q4	Mean	6.118	3.245	5.150	2.465	0.687	0.056
	S.D.	0.178	0.899	1.195	0.293	0.121	0.025
	Median	6.200	3.000	5.230	2.495	0.687	0.046
	Min	5.900					
Annual	Median	6.40	3.85	5.16	2.79	0.80	0.05
	10 pcntile	6.00	2.71	4.09	2.21	0.60	0.03
	90 pcntile	6.70	7.17	6.95	3.23	1.04	0.10
	Arth. Mean	6.33	4.56	5.22	2.73	0.86	0.06
	S.D.	0.32	1.88	1.28	0.47	0.34	0.03

CI5 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.869	2.246	4.514	2.938	0.777	0.081
	S.D.	0.160	0.276	1.445	0.407	0.161	0.031
	Median	5.900	2.200	4.540	2.910	0.713	0.075
	Min	5.600					
Q2	Mean	6.250	3.211	4.536	2.498	0.927	0.052
	S.D.	0.196	0.615	0.833	0.483	0.108	0.042
	Median	6.300	3.300	4.495	2.585	0.924	0.037
	Min	5.900					
Q3	Mean	6.583	4.600	4.666	2.582	1.036	0.056
	S.D.	0.170	2.039	1.538	0.451	0.299	0.046
	Median	6.550	4.350	4.330	2.520	1.019	0.041
	Min	6.400					
Q4	Mean	5.934	2.473	4.918	2.616	0.812	0.127
	S.D.	0.163	0.461	1.110	0.591	0.186	0.155
	Median	6.000	2.400	4.580	2.700	0.779	0.073
	Min	5.700					
Annual	Median	6.10	2.60	4.43	2.70	0.87	0.06
	10 pcntile	5.70	2.00	3.76	2.02	0.64	0.03
	90 pcntile	6.60	5.08	6.02	3.28	1.13	0.15
	Arth. Mean	6.15	3.51	4.66	2.67	0.89	0.08
	S.D.	0.34	3.01	1.26	0.50	0.23	0.09

CI5 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.818	1.973	5.306	3.235	1.017	0.100
	S.D.	0.184	0.250	0.627	1.436	0.364	0.053
	Median	5.840	2.000	5.440	2.590	0.892	0.083
	Min	5.520					
Q2	Mean	6.227	2.978	5.317	2.212	0.752	0.057
	S.D.	0.209	0.544	0.630	0.288	0.126	0.024
	Median	6.280	2.940	5.230	2.220	0.738	0.058
	Min	5.900					
Q3	Mean	6.526	4.331	4.753	2.346	0.751	0.064
	S.D.	0.078	0.590	1.001	0.512	0.142	0.037
	Median	6.560	4.540	4.670	2.200	0.687	0.077
	Min	6.420					
Q4	Mean	5.916	2.772	5.254	2.362	0.666	0.047
	S.D.	0.376	0.631	0.675	0.604	0.130	0.034
	Median	5.870	2.740	5.100	2.310	0.700	0.045
	Min	5.360					
Annual	Median	6.09	2.65	5.19	2.29	0.76	0.06
	10 pcntile	5.62	1.77	4.20	1.80	0.60	0.03
	90 pcntile	6.57	4.60	6.40	3.81	1.19	0.12
	Arth. Mean	6.10	2.90	5.21	2.58	0.82	0.07
	S.D.	0.35	0.99	0.73	0.98	0.26	0.04

CI5 1992		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.971	2.324	5.053	2.351	0.680	0.128
	S.D.	0.095	0.221	0.463	0.211	0.105	0.226
	Median	6.000	2.300	5.100	2.370	0.640	0.050
	Min	5.80					
Q2	Mean	6.183	3.625	4.988	2.025	0.673	0.033
	S.D.	0.172	0.960	0.378	0.144	0.029	0.011
	Median	6.200	3.850	4.890	2.060	0.680	0.033
	Min	6.000					
Q3	Mean	6.270	3.934	5.260	2.251	0.657	0.042
	S.D.	0.118	0.792	0.666	0.611	0.130	0.025
	Median	6.300	4.150	5.200	2.160	0.660	0.036
	Min	6.100					
Q4	Mean	5.800	3.064	5.283	1.887	0.545	0.058
	S.D.	0.696	0.549	0.700	0.073	0.051	0.020
	Median	6.050	3.150	5.200	1.865	0.545	0.061
	Min	4.400					
Annual	Median	6.10	3.15	5.17	2.06	0.64	0.04
	10 pcntile	5.87	2.22	4.57	1.78	0.50	0.02
	90 pcntile	6.40	4.84	6.04	2.56	0.80	0.08
	Arth. Mean	6.06	3.24	5.15	2.14	0.64	0.07
	S.D.	0.38	0.92	0.55	0.37	0.10	0.12

CI5 1993		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.200	3.152	5.417	1.955	0.670	0.040
	S.D.	0.155	0.431	0.688	0.198	0.149	0.019
	Median	6.300	3.270	5.600	1.950	0.675	0.033
	Min	0.155					
Q2	Mean	6.290	3.743	5.433	1.807	0.585	0.035
	S.D.	0.378	0.825	0.207	0.146	0.048	0.010
	Median	6.365	3.670	5.400	1.805	0.600	0.038
	Min	5.600					
Q3	Mean	6.323	4.723	4.954	1.727	0.541	0.033
	S.D.	0.170	0.727	0.505	0.253	0.105	0.011
	Median	6.300	4.570	5.000	1.800	0.560	0.035
	Min	6.060					
Q4	Mean	6.100	4.450	5.903	2.020	0.663	0.042
	S.D.	0.063	0.818	0.541	0.179	0.067	0.019
	Median	6.100	4.235	5.835	2.020	0.680	0.039
	Min	6.000					
Annual	Median	6.30	4.08	5.40	1.86	0.62	0.04
	10 pcntile	6.02	3.19	4.68	1.64	0.46	0.02
	90 pcntile	6.56	5.50	6.10	2.17	0.74	0.05
	Arth. Mean	6.25	4.17	5.48	1.88	0.62	0.04
	S.D.	0.22	0.85	0.56	0.23	0.11	0.01

Table 2.1.13 ACIDIC MOORLAND REFERENCE STREAM CI6

CI6 1984		pH	Alk	SO_4	Ca	Mg	Al
Q3	Mean	5.479	3.391	4.406	1.158	0.768	0.101
	S.D.	0.738	2.864	0.688	0.473	0.215	0.058
	Median	5.200	2.300	4.500	1.030	0.702	0.117
	Min	4.500					
Q4	Mean	5.114	1.257	4.077	0.950	0.628	0.142
	S.D.	0.267	0.387	1.061	0.242	0.119	0.022
	Median	5.200	1.300	4.506	0.990	0.630	0.149
	Min	4.700					
Annual	Median	5.20	1.55	4.50	1.01	0.67	0.13
	10 pcntile	4.75	0.56	3.50	0.71	0.53	0.02
	90 pcntile	6.67	7.27	5.31	1.91	1.12	0.16
	Arth. Mean	5.37	2.56	4.31	1.09	0.72	0.12
	S.D.	0.65	2.45	0.81	0.41	0.20	0.05

CI6 1985		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.482	1.638	5.411	1.154	0.749	0.120
	S.D.	0.471	0.556	0.534	0.182	0.075	0.042
	Median	5.600	1.800	5.570	1.190	0.762	0.110
	Min	4.700					
Q2	Mean	5.550	1.883	4.831	1.139	0.661	0.104
	S.D.	0.454	0.598	1.106	0.167	0.131	0.049
	Median	5.450	1.950	4.960	1.125	0.706	0.110
	Min	4.900					
Q3	Mean	5.862	2.889	3.563	0.897	0.509	0.080
	S.D.	0.409	1.167	0.595	0.213	0.105	0.020
	Median	5.700	2.400	3.500	0.820	0.490	0.080
	Min	5.300					
Q4	Mean	5.636	2.491	3.387	1.065	0.633	0.107
	S.D.	0.490	1.613	0.367	0.242	0.094	0.035
	Median	5.500	1.600	3.420	1.010	0.635	0.120
	Min	5.000					
Annual	Median	5.70	1.90	4.60	1.06	0.67	0.10
	10 pcntile	4.98	1.00	2.96	0.75	0.42	0.06
	90 pcntile	6.20	4.06	5.81	1.35	0.79	0.16
	Arth. Mean	5.64	2.19	4.31	1.07	0.66	0.10
	S.D.	0.46	1.13	1.10	0.22	0.13	0.04

CI6 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.636	2.573	4.013	1.259	0.785	0.100
	S.D.	0.503	1.717	0.642	0.222	0.138	0.035
	Median	5.500	1.600	3.850	1.260	0.796	0.091
	Min	4.900					
Q2	Mean	5.400	1.411	4.516	1.198	0.760	0.102
	S.D.	0.510	0.685	0.506	0.131	0.104	0.047
	Median	5.200	1.300	4.470	1.225	0.801	0.127
	Min	4.800					
Q3	Mean	6.136	3.557	3.190	1.146	0.646	0.094
	S.D.	0.467	1.688	0.271	0.199	0.082	0.124
	Median	6.300	3.800	3.190	1.210	0.659	0.062
	Min	5.300					
Q4	Mean	5.364	2.309	4.182	1.192	0.779	0.134
	S.D.	0.550	2.040	0.690	0.293	0.116	0.061
	Median	5.200	1.500	4.000	1.120	0.770	0.135
	Min	5.000					
Annual	Median	5.60	1.70	3.81	1.20	0.72	0.09
	10 pcntile	5.00	0.96	3.10	0.92	0.57	0.04
	90 pcntile	6.20	4.06	5.81	1.35	0.79	0.16
	Arth. Mean	5.68	2.58	3.88	1.19	0.73	0.11
	S.D.	0.59	1.77	0.73	0.22	0.12	0.08

CI6 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.400	1.717	4.870	1.100	0.773	0.155
	S.D.	0.297	0.376	0.581	0.300	0.136	0.049
	Median	5.400	1.700	4.970	1.160	0.802	0.155
	Min	5.100					
Q2	Mean	5.767	2.249	4.700	1.233	0.752	0.100
	S.D.	0.444	0.727	0.408	0.180	0.097	0.056
	Median	5.800	2.100	4.670	1.180	0.732	0.080
	Min	4.900					
Q3	Mean	6.567	4.900	3.350	1.340	0.668	0.092
	S.D.	0.058	0.600	0.481	0.115	0.030	0.028
	Median	6.600	4.900	3.560	1.380	0.653	0.105
	Min	6.500					
Q4	Mean	5.625	2.425	4.603	1.058	0.700	0.092
	S.D.	0.479	1.588	0.571	0.289	0.138	0.028
	Median	5.500	1.700	4.570	1.020	0.735	0.105
	Min	5.200					
Annual	Median	5.70	2.00	4.64	0.10	0.72	1.18
	10 pcntile	5.10	1.29	3.60	0.81	0.59	0.05
	90 pcntile	6.57	4.87	5.39	1.44	0.89	0.20
	Arth. Mean	5.75	2.50	4.54	0.11	0.74	1.18
	S.D.	0.51	1.29	0.68	0.05	0.11	0.24

CI6 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.000	1.186	4.197	1.164	0.894	0.216
	S.D.	0.153	0.291	0.426	0.207	0.140	0.063
	Median	5.000	1.100	4.150	1.320	0.920	0.210
	Min	4.800					
Q2	Mean	5.940	2.240	4.548	1.446	0.893	0.072
	S.D.	0.152	0.270	0.420	0.076	0.046	0.016
	Median	6.000	2.300	4.340	1.470	0.874	0.073
	Min	5.700					
Q3	Mean	5.767	2.117	4.085	1.163	0.743	0.079
	S.D.	0.388	0.546	0.374	0.171	0.073	0.036
	Median	5.900	2.200	4.120	1.230	0.749	0.065
	Min	5.000					
Q4	Mean	5.622	1.922	4.383	1.152	0.791	0.101
	S.D.	0.360	0.494	0.518	0.171	0.118	0.025
	Median	5.500	1.800	4.390	1.180	0.787	0.103
	Min	5.200					
Annual	Median	5.70	1.80	4.33	1.26	0.84	0.10
	10 pcntile	4.96	1.00	3.60	0.93	0.67	0.06
	90 pcntile	6.10	2.56	4.94	1.47	1.01	0.23
	Arth. Mean	5.55	1.83	4.30	1.21	0.83	0.12
	S.D.	0.45	0.57	0.45	0.20	0.12	0.07

CI6 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.411	1.656	4.264	1.452	0.877	0.151
	S.D.	0.344	0.532	0.265	0.644	0.071	0.075
	Median	5.400	1.600	4.260	1.320	0.834	0.138
	Min	5.000					
Q2	Mean	6.156	4.222	4.306	1.464	0.920	0.073
	S.D.	0.467	3.351	0.392	0.363	0.054	0.030
	Median	6.200	2.900	4.430	1.550	0.919	0.057
	Min	5.500					
Q3	Mean	6.545	5.718	5.981	2.233	1.183	0.063
	S.D.	0.413	2.653	1.362	0.322	0.190	0.035
	Median	6.700	5.000	6.380	2.205	1.226	0.051
	Min	5.700					
Q4	Mean	5.517	2.133	4.900	1.406	0.823	0.097
	S.D.	0.618	1.542	1.109	0.249	0.130	0.045
	Median	5.250	1.400	4.920	1.390	0.870	0.105
	Min	5.000					
Annual	Median	6.000	2.700	4.550	1.550	0.920	0.070
	10 pcntile	5.000	1.120	3.840	1.100	0.810	0.040
	90 pcntile	6.800	9.060	6.950	2.560	1.290	0.160
	Arth. Mean	5.980	3.670	4.950	1.700	0.980	0.090
	S.D.	0.650	2.840	1.180	0.550	0.190	0.060

CI6 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.056	1.344	4.308	1.314	0.943	0.265
	S.D.	0.461	0.846	0.494	0.233	0.177	0.179
	Median	5.000	1.300	4.420	1.260	0.900	0.194
	Min	4.600					
Q2	Mean	6.114	4.071	3.511	1.513	0.926	0.073
	S.D.	0.485	3.294	0.719	0.178	0.142	0.062
	Median	6.200	3.300	3.600	1.480	0.944	0.061
	Min	5.200					
Q3	Mean	6.263	3.975	4.356	1.774	1.157	0.069
	S.D.	0.583	2.591	1.313	0.893	0.500	0.039
	Median	6.450	3.550	4.220	1.800	1.248	0.057
	Min	5.400					
Q4	Mean	5.463	1.671	4.157	1.604	0.928	0.106
	S.D.	0.277	0.335	0.456	0.855	0.154	0.050
	Median	5.500	1.700	4.050	1.560	0.910	0.099
	Min	4.980					
Annual	Median	5.50	1.80	4.03	1.49	0.97	0.09
	10 pcntile	4.90	1.12	3.01	0.80	0.72	0.04
	90 pcntile	6.70	6.62	5.66	2.58	1.28	0.27
	Arth. Mean	5.70	2.71	5.32	1.55	1.00	0.13
	S.D.	0.68	2.37	6.93	0.63	0.30	0.13

CI6 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.161	1.276	4.196	2.287	1.265	0.162
	S.D.	0.442	0.600	0.563	1.017	0.398	0.073
	Median	4.960	1.070	4.140	2.000	1.051	0.161
	Min	4.760					
Q2	Mean	5.790	2.508	4.988	1.548	0.955	0.115
	S.D.	0.738	1.715	0.386	0.645	0.267	0.063
	Median	5.400	1.580	4.895	1.340	0.879	0.105
	Min	5.100					
Annual	Median	5.32	1.50	4.60	1.39	1.01	0.13
	10 pcntile	4.77	0.67	3.52	1.16	0.77	0.05
	90 pcntile	6.66	4.61	5.46	3.66	1.85	0.24
	Arth. Mean	5.42	1.79	4.56	1.95	1.12	0.14
	S.D.	0.64	1.29	0.62	0.92	0.37	0.07

Table 2.1.14 MOORLAND/YOUNG FOREST STUDY STREAM UC4

UC4 1985		pH	Alk	SO_4	Ca	Mg	Al
Q2	Mean	6.180	3.720	4.118	1.114	0.837	0.054
	S.D.	0.383	1.647	0.488	0.240	0.141	0.010
	Median	6.100	3.500	4.140	1.030	0.809	0.053
	Min	5.700					
Q3	Mean	5.829	3.500	2.601	0.990	0.698	0.074
	S.D.	0.616	1.203	0.539	0.232	0.140	0.018
	Median	5.900	3.100	2.500	0.920	0.690	0.078
	Min	4.800					
Q4	Mean	5.957	3.771	3.216	1.248	0.899	0.070
	S.D.	0.547	2.713	0.509	0.346	0.198	0.016
	Median	6.000	2.400	3.300	1.185	0.817	0.070
	Min	5.200					
Annual	Median	6.00	3.10	3.30	0.99	0.77	0.07
	10 pcntile	5.20	1.76	2.30	0.84	0.58	0.04
	90 pcntile	6.80	7.14	4.60	1.57	1.11	0.09
	Arth. Mean	5.97	3.69	3.23	1.11	0.80	0.07
	S.D.	0.53	1.99	0.78	0.28	0.18	0.02

UC4 1986		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.766	4.667	8.623	1.447	1.184	0.064
	S.D.	0.635	4.535	4.294	0.375	0.087	0.033
	Median	5.400	2.200	10.500	1.240	1.206	0.074
	Min	5.400					
Q2	Mean	5.440	1.400	6.018	1.258	1.018	0.055
	S.D.	0.251	0.356	1.087	0.209	0.169	0.008
	Median	5.300	1.350	5.590	1.260	1.016	0.056
	Min	5.200					
Q3	Mean	6.320	5.700	4.054	1.482	1.098	0.041
	S.D.	0.492	2.355	1.523	0.206	0.130	0.013
	Median	6.400	6.800	3.220	1.390	1.076	0.040
	Min	5.500					
Q4	Mean	5.850	3.950	3.983	1.226	0.894	0.045
	S.D.	0.605	3.364	0.641	0.462	0.232	0.014
	Median	5.650	2.100	3.925	1.060	0.810	0.052
	Min	5.200					
Annual	Median	5.60	2.15	4.24	1.26	1.01	0.05
	10 pcntile	5.22	1.15	3.01	0.89	0.74	0.03
	90 pcntile	6.80	7.14	4.60	1.57	1.11	0.09
	Arth. Mean	5.85	3.99	5.15	1.33	1.02	0.05
	S.D.	0.57	3.13	2.35	0.35	0.20	0.02

UC4 1987		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.780	2.560	5.198	1.126	0.918	0.050
	S.D.	0.303	0.823	0.947	0.199	0.139	0.012
	Median	5.800	2.400	5.590	1.150	0.949	0.046
	Min	5.400					
Q2	Mean	6.317	4.433	3.903	1.241	0.917	0.053
	S.D.	0.279	1.857	0.509	0.267	0.131	0.014
	Median	6.250	3.630	3.870	1.190	0.908	0.057
	Min	6.000					
Q3	Mean	6.757	7.900	2.901	1.679	1.075	0.059
	S.D.	0.172	2.354	0.421	0.280	0.171	0.018
	Median	6.800	7.800	2.920	1.720	1.010	0.061
	Min	6.500					
Q4	Mean	5.933	3.170	4.148	1.192	0.873	0.063
	S.D.	0.308	0.919	0.775	0.213	0.146	0.022
	Median	5.850	2.950	4.070	1.185	0.803	0.055
	Min	5.600					
Annual	Median	6.20	3.50	3.81	1.26	0.95	0.06
	10 pcntile	5.60	2.15	2.71	0.94	0.72	0.04
	90 pcntile	6.85	9.35	5.59	1.75	1.15	0.08
	Arth. Mean	6.24	4.74	3.94	1.33	0.94	0.06
	S.D.	0.46	2.69	1.02	0.32	0.17	0.02

UC4 1988		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.500	1.977	4.251	1.129	1.013	0.063
	S.D.	0.356	0.543	0.498	0.233	0.230	0.017
	Median	5.400	2.100	4.570	1.130	1.111	0.057
	Min	5.000					
Q2	Mean	6.500	6.167	4.000	1.688	1.178	0.050
	S.D.	0.456	3.100	0.725	0.364	0.244	0.013
	Median	6.600	5.850	3.730	1.560	1.125	0.052
	Min	5.700					
Q3	Mean	5.740	3.468	4.206	1.306	0.981	0.091
	S.D.	0.503	1.123	2.443	0.214	0.125	0.030
	Median	5.900	3.500	3.400	1.300	0.930	0.074
	Min	5.000					
Q4	Mean	5.960	3.272	3.944	1.250	0.999	0.066
	S.D.	0.297	1.039	0.836	0.143	0.093	0.017
	Median	5.900	2.800	3.910	1.200	1.030	0.062
	Min	5.700					
Annual	Median	5.90	2.80	3.80	1.30	1.03	0.07
	10 pcntile	5.12	1.58	2.72	0.94	0.79	0.05
	90 pcntile	6.72	6.56	5.21	1.77	1.25	0.12
	Arth. Mean	5.91	3.68	4.11	1.34	1.05	0.08
	S.D.	0.55	2.31	1.19	0.33	0.20	0.08

UC4 1989		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.917	2.900	3.905	1.262	1.026	0.065
	S.D.	0.319	0.817	0.237	0.125	0.113	0.023
	Median	6.000	3.050	3.890	1.220	0.982	0.055
	Min	5.400					
Q2	Mean	6.667	9.000	4.800	2.178	1.597	0.052
	S.D.	0.242	4.517	2.214	0.736	0.585	0.014
	Median	6.700	9.000	4.290	2.045	1.400	0.048
	Min	6.300					
Q3	Mean	6.733	12.400	8.038	3.217	2.151	0.046
	S.D.	0.734	6.227	4.939	0.693	0.475	0.011
	Median	7.100	13.100	5.615	3.570	2.282	0.046
	Min	5.300					
Q4	Mean	5.817	4.250	7.010	1.937	1.426	0.048
	S.D.	0.911	2.629	2.985	0.553	0.468	0.018
	Median	5.950	4.300	6.635	1.885	1.313	0.046
	Min	4.500					
Annual	Median	6.50	5.10	4.39	1.87	1.31	0.05
	10 pcntile	5.25	1.60	3.39	1.18	0.94	0.03
	90 pcntile	7.10	16.65	11.54	3.64	2.57	0.09
	Arth. Mean	6.28	7.14	5.94	2.15	1.55	0.07
	S.D.	0.72	5.43	3.34	0.90	0.59	0.09

UC4 1990		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	5.425	1.950	4.980	1.658	1.273	0.084
	S.D.	0.670	0.995	0.531	0.316	0.219	0.010
	Median	5.250	1.650	5.165	1.600	1.279	0.086
	Min	4.900					
Q2	Mean	6.650	8.800	3.805	1.910	1.540	0.041
	S.D.	0.071	1.273	0.658	0.396	0.022	0.001
	Median	6.650	8.800	3.805	1.910	1.540	0.041
	Min	6.600					
Q3	Mean	6.967	11.460	5.385	2.618	2.199	0.043
	S.D.	0.404	4.370	2.841	0.620	0.173	0.038
	Median	6.900	9.880	4.205	2.360	2.238	0.042
	Min	6.600					
Q4	Mean	5.440	1.900	3.615	0.940	0.877	0.060
	S.D.	0.269	0.283	0.134	0.212	0.098	0.018
	Median	5.440	1.900	3.615	0.940	0.877	0.060
	Min	5.250					
Annual	Median	6.30	3.30	4.24	1.89	1.49	0.07
	10 pcntile	4.90	1.20	3.39	0.88	0.85	0.01
	90 pcntile	7.30	15.10	8.31	3.20	2.34	0.09
	Arth. Mean	6.07	5.78	4.69	1.90	1.56	0.06
	S.D.	0.85	4.97	1.70	0.73	0.53	0.03

UC4 1991		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.043	2.940	4.510	2.380	1.804	0.078
	S.D.	0.464	1.238	0.590	1.091	0.701	0.044
	Median	6.140	2.690	4.670	2.420	1.832	0.065
	Min	5.400					
Q2	Mean	5.883	3.275	5.253	1.603	1.243	0.071
	S.D.	0.408	0.969	1.017	0.294	0.135	0.010
	Median	6.030	3.580	5.54	1.565	1.208	0.071
	Min	5.300					
Q3	NO DATA						
Q4	Mean	5.808	3.932	3.917	1.498	1.243	0.048
	S.D.	0.790	2.119	0.515	0.821	0.348	0.028
	Median	6.190	3.780	4.000	1.620	1.210	0.053
	Min	4.460					
Annual	Median	6.16	3.34	4.39	1.69	1.28	0.06
	10 pcntile	4.84	1.45	3.35	0.57	0.94	0.02
	90 pcntile	6.45	6.10	5.92	3.25	2.40	0.11
	Arth. Mean	5.90	3.42	4.47	1.78	1.40	0.06
	S.D.	0.58	1.52	0.87	0.84	0.48	0.03

UC4 1992		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.000	2.960	4.445	1.433	1.095	0.040
	S.D.	0.316	0.946	0.471	0.282	0.175	0.016
	Median	5.950	2.700	4.350	1.445	1.115	0.044
	Min	5.700					
Q2	Mean	6.300	6.112	3.573	1.488	1.150	0.055
	S.D.	0.385	3.558	0.501	0.552	0.167	0.015
	Median	6.400	5.300	3.725	1.325	1.110	0.055
	Min	5.600					
Q3	Mean	6.163	4.988	4.098	1.505	1.115	0.079
	S.D.	0.279	2.354	1.455	0.221	0.163	0.016
	Median	6.205	4.305	3.590	1.490	1.055	0.079
	Min	5.800					
Q4	Mean	5.967	3.878	3.537	1.116	0.860	0.060
	S.D.	0.468	1.662	0.388	0.210	0.220	0.023
	Median	6.100	3.940	3.700	1.030	0.800	0.065
	Min	5.300					
Annual	Median	6.20	4.15	3.80	1.30	1.06	0.06
	10 pcntile	5.51	2.01	2.92	0.94	0.68	0.02
	90 pcntile	6.50	8.32	4.96	1.78	1.33	0.08
	Arth. Mean	6.11	4.59	3.83	1.36	1.04	0.06
	S.D.	0.38	2.56	0.77	0.37	0.22	0.02

UC4 1993		pH	Alk	SO_4	Ca	Mg	Al
Q1	Mean	6.268	4.370	4.150	1.348	1.082	0.049
	S.D.	0.297	1.632	0.468	0.260	0.149	0.013
	Median	6.400	4.680	4.050	1.445	1.100	0.046
	Min	5.900					
Q2	Mean	6.418	5.974	4.080	1.300	1.104	0.053
	S.D.	0.478	3.470	0.798	0.352	0.194	0.016
	Median	6.500	4.530	4.100	1.130	1.070	0.056
	Min	5.800					
Q3	Mean	6.633	6.993	2.857	1.667	1.263	0.042
	S.D.	0.681	1.486	0.311	0.204	0.116	0.033
	Median	6.400	7.050	3.000	1.580	1.320	0.060
	Min	6.100					
Q4	Mean	5.600	3.793	4.237	1.300	1.067	0.050
	S.D.	0.700	3.249	0.346	0.200	0.153	0.012
	Median	5.600	2.690	4.200	1.300	1.100	0.055
	Min	4.900					
Annual	Median	6.35	5.08	4.00	1.49	1.10	0.05
	10 pcntile	5.39	2.14	2.90	0.95	0.86	0.03
	90 pcntile	7.12	9.21	5.04	1.74	1.32	0.07
	Arth. Mean	6.26	5.25	3.92	1.38	1.12	0.05
	S.D.	0.58	2.66	0.72	0.29	0.16	0.02

3. LONG-TERM TRENDS IN WATER QUALITY

3.1 Introduction

Streams at Llyn Brianne have been monitored for up to ten years as part of analytical and experimental studies of acidification. The unmanipulated sites provide comparisons between different land uses, principally moorland and conifer forestry, and reference data against which to assess changes in the treated catchments. Responses to liming have been sufficiently marked to render statistical comparisons of the main acidity-related variables largely unnecessary, but long-term chemical trends in relation to land use and deposition remain of international importance. The nature, rate and extent of recovery from acidification, as sulphur emissions are cut according to the second United Nations Economic Commission for Europe (UNECE) protocol, will guide future revisions of the agreement. Any continued need for liming and restrictions on land use will be determined by observed recovery.

Current critical loads exceedance maps indicate that sulphur deposition in 2010 will have been reduced below the critical load of many of the presently exceeded areas in the UK and elsewhere (CLAG, 1994). However, this is based on equilibrium models which do not predict the rate of deacidification. Dynamic models such as MAGIC, indicate that recovery may take several decades, but predictions remain uncertain. Observations of actual long-term trends in surface water chemistry provide the best test of model forecasts and hard evidence of effects.

An additional major uncertainty in acidification is the effect of nitrogen (UKRGIAN, 1994). Transport and agriculture are principal sources of nitrogen emissions and future emissions rates are difficult to predict. Catchment responses to nitrogen inputs are also more difficult to model than sulphur due to the complexities of the nitrogen cycle (Jenkins & Renshaw, 1993). The monitoring of long-term trends in chemistry is therefore central to model development and to the demonstration of effects on acidification.

3.2 Trend analysis results for untreated catchments

A modified seasonal Kendall test (Hirsch & James, 1984) was used to investigate stream water quality for trends in pH, sulphate, dissolved calcium, dissolved aluminium and alkalinity at all reference catchments. This non-parametric technique for trend detection is unaffected by the complicating characteristics associated with time-series data, such as non-normal distribution, seasonality and missing values. While ten years of data is recommended when using the modified form it was felt that the presence of serial correlation favoured its use in preference to the original Kendall test (A. Jenkins, pers. comm.).

Results from the trend analysis indicate a position of relative constancy in streamwater chemistry over the monitoring period, with very little long-term change occurring in the

Table 3.1 **Absolute change (mg l^{-1} or pH units year $^{-1}$) in selected determinands in untreated streams assessed by a seasonal Kendall Test**

Catchment	Data years	pH	Alk	SO_4	Ca	Al
LI1	10	0.0021	0.1690	0.0910	0.0339	0.0009
LI2	6	0.0167	-0.0150	0.1983	0.1050	0.0107
LI5	8	0.0000	0.0125	-0.0425	0.0575**	0.0028*
LI6	10	-0.0095	0.0619	0.0025	0.0468	-0.0011
LI7	8	0.0325	0.2708	0.0011	0.1500	0.0004
LI8	10	-0.0092	0.0117	0.0780	0.0292	0.0011
CI1	9	0.0250	0.0550	0.0025	0.0134	-0.0024
CI4	9	0.0300	0.0500	-0.0296	0.0183	-0.0011
CI6	7	0.0008	-0.0327	0.0394	0.0842**	0.0000
UC4	9	0.0250	0.2024	0.0083	0.0475	-0.0003

* Significant at the $p < 0.05$ level
** Significant at the $p < 0.01$ level

reference catchments (Table 3.2). The test fails to highlight any significant trends in pH or sulphate values at the catchments under consideration. Calcium concentrations increased in all catchments with significant long-term trends being apparent at LI5 and CI6. Aluminium concentrations also showed a significant increase at LI5, all other catchments showing little or no change. Alkalinity concentrations showed no significant changes, though the general trend was upwards.

3.3 Application of MAGIC to LI8

Simulation of the impact of afforestation on surface water acidification was attempted by modelling the predicted response of surface water chemistry to plantation growth and canopy closure at LI8, and comparing this to observed patterns (Llyn Brianne Final Report, 1992). 94% of the catchment of LI8 was planted between 1971 and 1977.

The MAGIC model was applied using seven years of deposition data, estimates of base cation uptake patterns and estimates of dry deposition to the forest canopy. Observed changes in surface water chemistry were studied by fortnightly spot sampling. Figure 3.3 shows the predicted and observed pH at LI8 for the period 1982-1993. The relationship over this period appears variable.

3.4 Discussion

Trends in stream chemistry analysed here for seven to ten years up to 1993, at Llyn Brianne, have been small and generally non-significant. By contrast, a previous analysis of data up to 1990 showed a number of changes in the same determinands as statistically significant (Llyn Brianne Final Report, 1992). This points to the need for caution in identifying long-term trends, as noted by Robson & Neal (in press), who found long-term cycles or variations in water chemistry which confounded linear analysis. The present analysis is therefore regarded as preliminary and could be enhanced by the use of alternative techniques, inclusion of a wider range of sites, and modelling of the interactions of catchment variables and deposition.

The MAGIC model simulation for the juvenile conifer plantation catchment has had limited success to date in matching observed pH change over 11 years (Figure 3.3). This may be attributable to inadequacy of the model, poor estimation of enhanced deposition by scavenging of the forest canopy, the lack of updates of deposition rates to drive the model, or the effects of climatic variability on long-term trends as suggested by the data for other sites. These aspects will be further addressed in the Welsh Acid Waters Survey to be reported in 1996.

The preliminary conclusions here are that a single decade is likely to be too short for the description of acidification related trends in water quality. However, the Llyn Brianne data showed no clear evidence of recovery in stream chemistry or differences in trends related to land use. Robson & Neal (in press) also found no indication of changes in acid deposition corresponding with known reductions in UK sulphur emissions. Caution is required in interpreting such data, and increases in the spatial and temporal components of data sets may be needed to detect the apparently gradual changes.

Trend analysis requires regular sampling over a period of several years (UKAWRG, 1986). In a review of the effect of sampling frequency on the statistical analysis of acid waters chemistry, Stevens et al. (1994) concluded that sampling at monthly intervals would provide a balance between cost and adequacy of data. Mean values would be obtained, with precision as great or greater than from weekly sampling and at this frequency, chance events would not disproportionately affect results.

At Brianne there is a need for continued monitoring of both the biology and chemistry of treated and reference streams, to establish the ultimate duration of the effectiveness of liming and to monitor long-term trends in acidification. It is recommended therefore that monthly spot sampling is continued for the limed streams CI2, CI5 and LI4, the maturing forest stream LI8, plus reference streams CI4 and LI1.

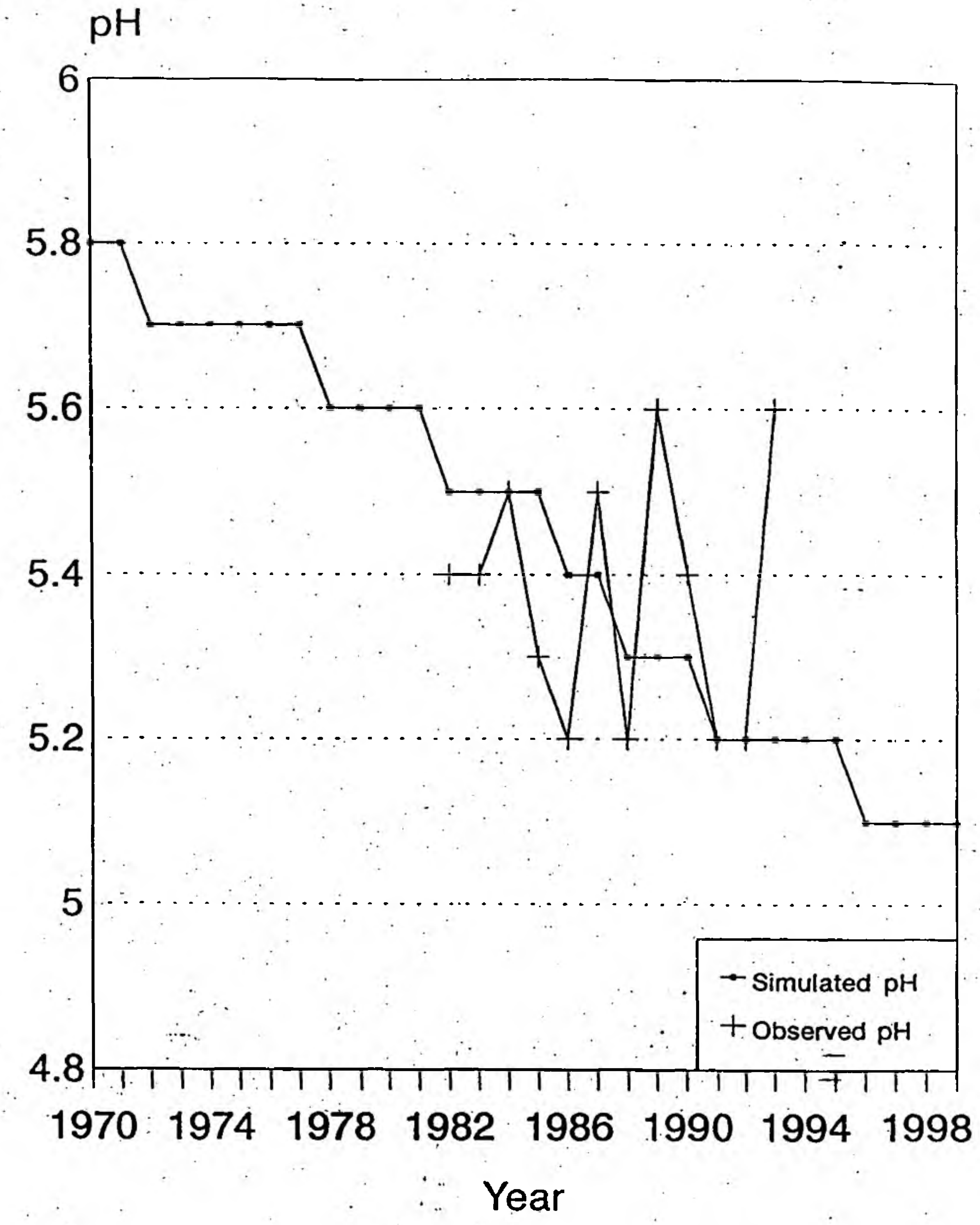


Figure 3.3 Observed and MAGIC simulated stream pH for LI8

4. COST BENEFIT ANALYSIS OF LIMING STRATEGIES

4.1 Introduction

The process of assessing acidification impacts and the options for their amelioration can be represented in the form of a decision tree, as described by Merrett (1992, Figure 4.1). In the case of the River Tywi, the poor biological and fisheries status of the upper main river are consistent with the acidic water chemistry. The catchment characteristics indicate that the cause is diffuse acidification due to atmospheric deposition, enhanced in some sub-catchments by afforestation. The next stage, addressed in this section, is the analysis of the financial and other costs and benefits, of alternative management options.

Possible strategies for the restoration and protection of sensitive surface waters include management of the causes, by reducing sulphur and nitrogen emissions and controlling intermediary factors such as forestry, and management of the symptoms, for example by liming. Substantial deposition reductions are anticipated under the UNECE protocol on sulphur emissions, however these are not expected to be sufficient to protect many waters and any recovery is likely to be slow (Jenkins et al., 1991; CLAG, 1994). New conifer planting and replanting may be restricted to a certain extent in sensitive areas (Forestry Authority, 1993), but existing forests are likely to delay the recovery of surface waters from acidification.

This context justifies work, such as that presented here, into identifying management techniques capable of achieving rapid restoration or protection of fisheries. Various alkaline materials can be used to neutralize acidic surface waters, for example limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$), quick lime (CaO), sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). Calcium compounds in solution increase the tolerance of fish to aluminium as well as correcting pH, and have therefore tended to be preferred to sodium compounds. Quicklime and hydrated lime are very reactive, thus too high a dose can result in toxicity to fish through high pH and the formation of metal hydroxides. Powdered limestone has been the preferred material, as it is easily handled, readily available and will not increase pH to harmful levels. Calcium content and particle size are the two critical factors, a high proportion of $CaCO_3$ being most effective ($\geq$90%), with particle size dependent on treatment method. Although finer limestone powder dissolves more efficiently, it is also more expensive, so a balance needs to be struck between particle size, treatment effectiveness and cost.

Liming of acid waters has been proceeding since the late 1970's with Sweden at the forefront. A national liming programme has been in operation there since 1982 (Nyberg & Thornelof, 1988), and much of the current technology is of Scandinavian origin. A variety of methods exist to distribute lime into aquatic systems including application directly to lakes and streams, or indirectly via wetland areas within the catchment (Weatherley et al., in press). Three methods have been assessed using the River Tywi as a case study:-

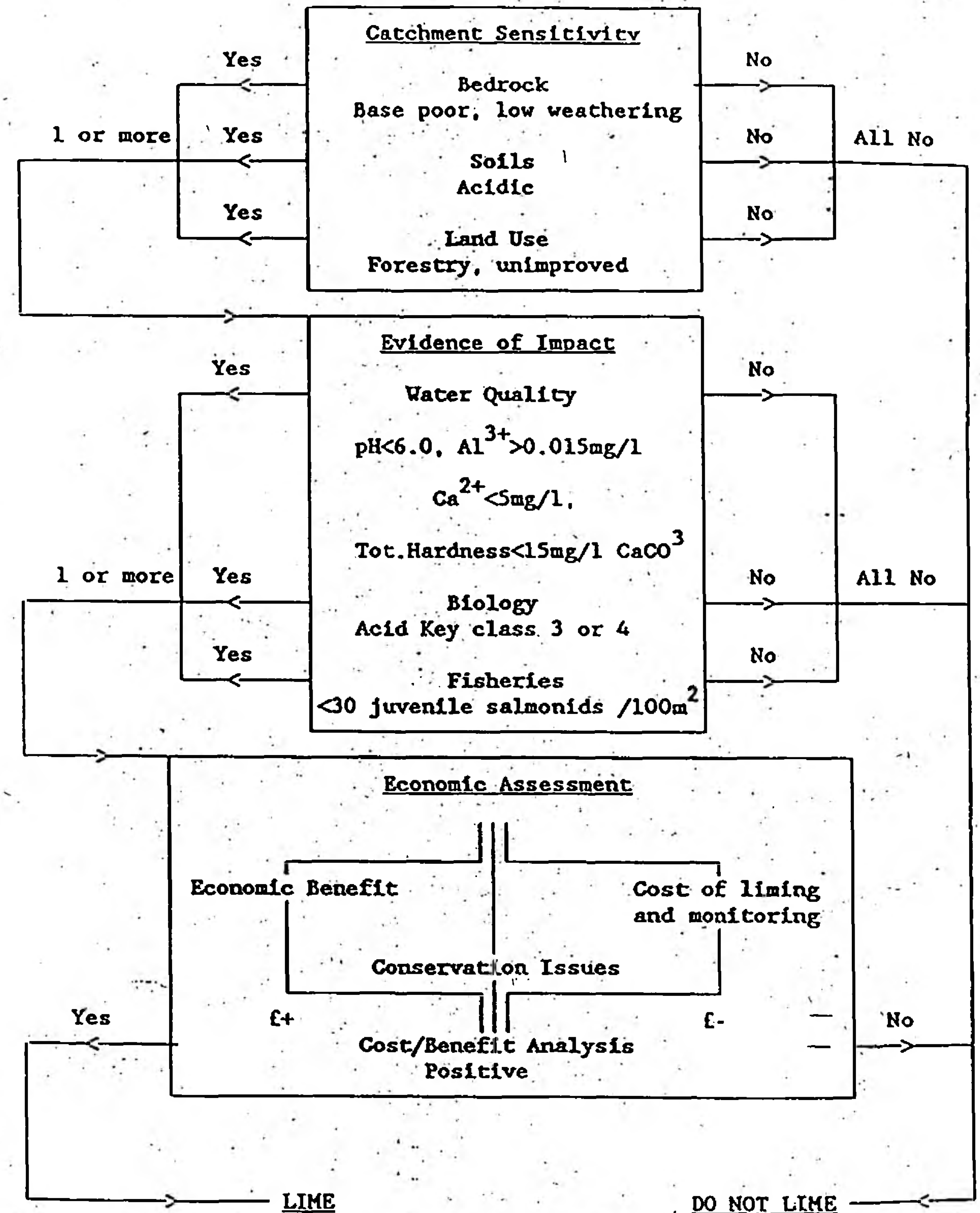


Figure 4.1 Protocol for assessment of catchment suitability for liming

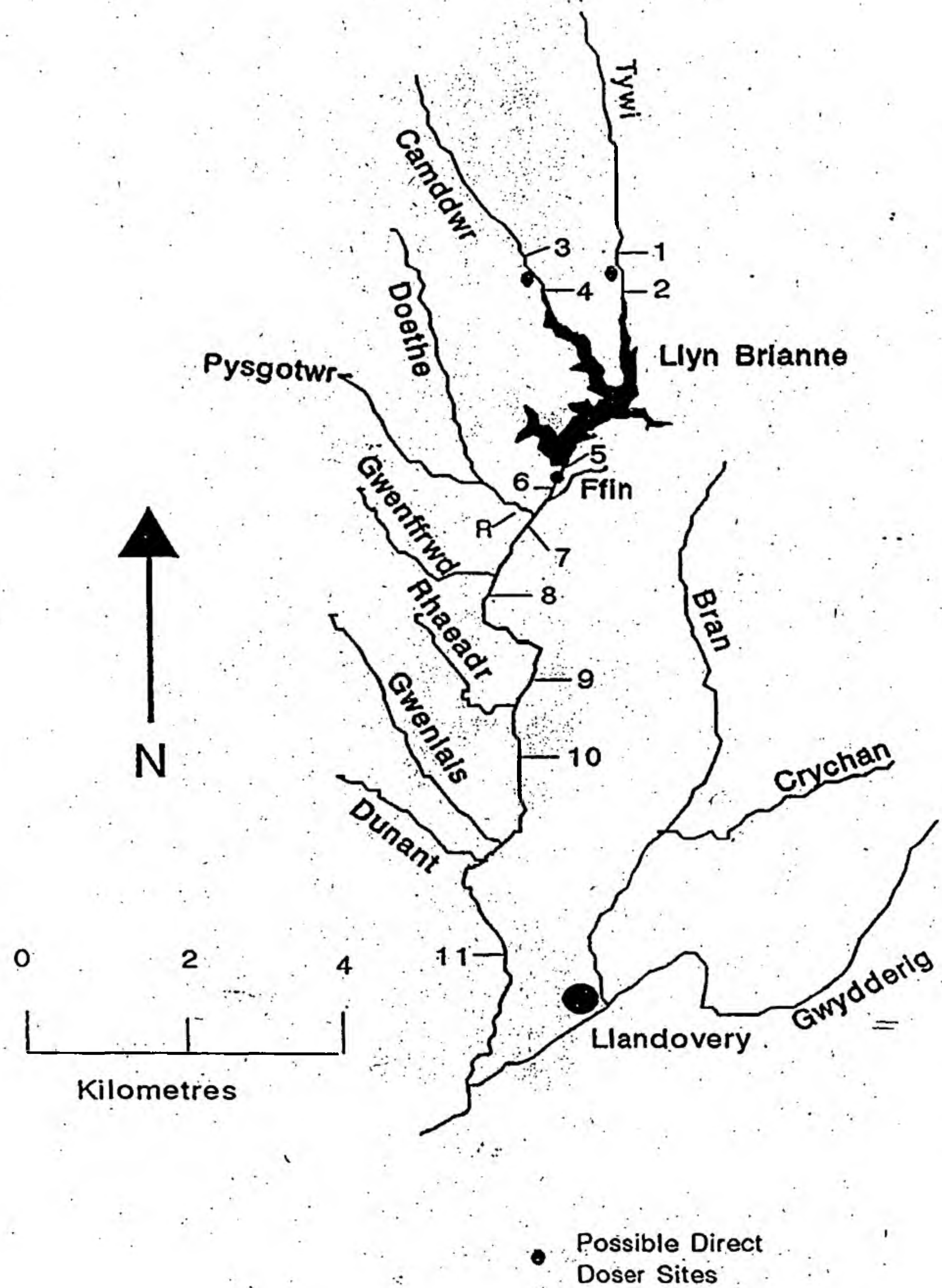


Figure 4.2 Sampling sites on the upper Tywi

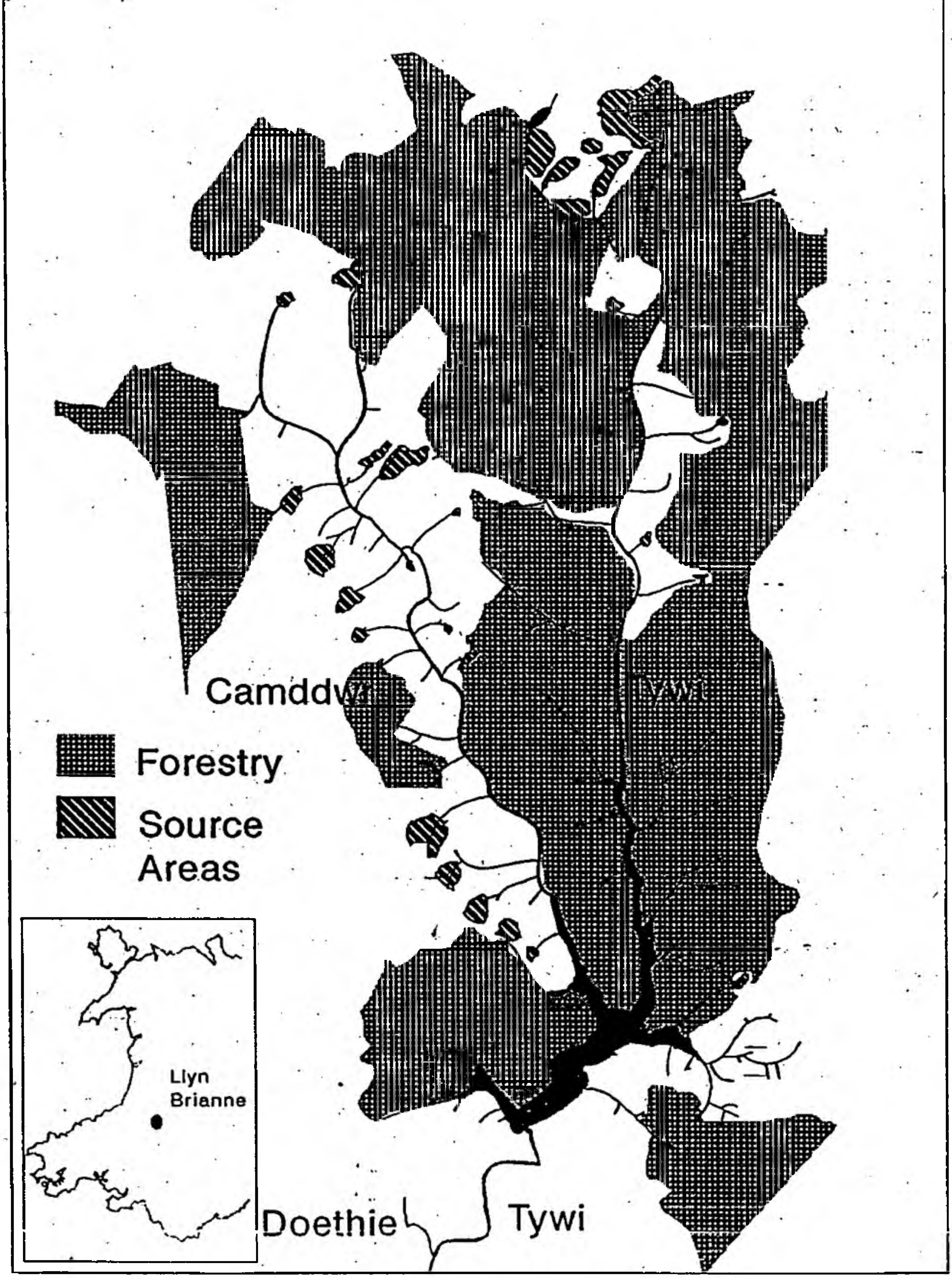


Figure 4.3 Hydrological source areas within the upper Tywi catchment

1. Direct liming of Llyn Brianne reservoir to treat the River Tywi downstream.
2. Liming of hydrological source areas (HSA's) within the upper Tywi catchment.
3. Direct dosing of input streams to Llyn Brianne, or the Tywi immediately below the reservoir.

A direct reservoir liming programme is currently in operation at Llyn Brianne. This section provides a review, in the form of a desk study, focusing on the costs and benefits of the three liming techniques in relation to the benefits to the fishery of the River Tywi. Data from the present and previous studies at Llyn Brianne are utilized. It may be noted that costing restoration also provides an estimate of the environmental costs of acid emissions as an alternative to attempting to cost ecological damage directly.

4.2 Techniques

4.2.1 Lake Liming

Direct lake liming has been used effectively to ameliorate acidification at a small number of sites in Wales, including Llyn Brianne which is the largest and most effectively studied example. Longevity of treatment is largely dependent upon lake retention time, the method being feasible for lakes with a retention time greater than about six months (Simonin, 1990; Olem, 1991). Two basic techniques for applying limestone to lakes are boat/barge or fixed-wing aircraft/helicopter. Dosing by boat is the least expensive method for accessible lakes, and is now the most commonly used.

The NRA Welsh Region commenced an experimental liming programme at Llyn Brianne in 1991. Required dose rates were estimated using an empirical model (Underwood et al., 1987) and a Swedish dynamic lake-liming model (Sverdrup & Warfvinge, 1985). During February 1991, 850 tonnes of powdered limestone were spread depth proportionately over the reservoir by boat. This was followed by 500 tonnes in October of that year, and further doses of 500 tonnes in the March and October of 1992, 1993 and 1994. The applications were carried out using a specially designed liming boat imported from Sweden.

The liming operation is currently contracted out annually at a cost of approximately £40,000 per year inclusive of all costs other than contract management and environmental monitoring. Limestone is transported to the lake in bulk tankers each carrying 24 tonnes of material, which is pumped into the lime boat in four tonne loads. Water is mixed with the limestone as it is sprayed out, using a Venturi effect.

Particle size has a critical effect on the dissolution rate of the limestone, small particles dissolving more rapidly and therefore more completely (Warfvinge et al., 1984). Large particles tend to sink to the bed where they quickly become coated in humic substances and inorganic manganese, iron and aluminium compounds, thus inhibiting their dissolution (Bengtsson et al., 1984). As Llyn Brianne is relatively deep, average 28 metres, this factor may be less critical. The current operation uses particle size 100% <

212um, and the cost of the limestone accounts for approximately 50% of the total liming cost.

Costs

Capital, boat £70 000

Operation p.a. £40 000 (inclusive of limestone, transport and labour costs)

Monitoring p.a. Includes water quality, macroinvertebrate and fish surveys £13 720

Project management p.a. £4000

Advantages and disadvantages of lake liming

Direct application of powdered limestone to lakes neutralizes pH and decreases concentrations of toxic metals due to the precipitation of metal hydroxides. However, it uses limestone inefficiently as high calcium concentrations must be attained initially to allow for dilution by acidic input streams. This results in high losses of calcium via the outlet during the early part of the liming cycle (Underwood et al., 1985), and some loss to the bed. A rapid change in water quality as a consequence of the initial liming treatment, or mixing of limed streams with those that are still acidic, has been observed to result in toxic conditions (Dickson, 1983; Wright & Skogheim, 1983). During the pH change following liming, or as metalliferous acid streamwater mixes with the limed lake water, metals are precipitated out of solution (Wright & Skogheim, 1983). The formation of aluminate ions, polymeric hydrolysis products of precipitating aluminium are possible causes of the fish toxicity occasionally observed in these circumstances (Weatherley et al., 1991).

Dissolved organic carbon (DOC) can be an important source of alkalinity, and also reduces the toxicity of aluminium through complexation. In some lakes reacidifying after liming has ceased, concentrations of toxic metals have increased, but DOC has remained low thus leaving conditions more toxic than pre-liming (Weatherley, 1988).

Whilst improving conditions in the lake and the river downstream, lake liming offers no protection to the spawning streams entering the lake. At Llyn Brianne these streams are inaccessible to migratory salmonids at present, however they do provide spawning sites for the resident brown trout population. This lack of protection may therefore be of more importance in other lakes and reservoirs.

An important advantage of reservoir or lake liming is that it avoids damage or change to ecologically sensitive wetland areas and their associated wildlife which is often of high conservation value and ecological importance (section 4.2.2). Other advantages include the low manpower requirement and no need for remote power supplies, continuous maintenance or security. The reservoir itself will provide a temporary buffer against failure of the lake liming operation, though this is limited and there is the risk of bad weather delaying re-treatment.

4.2.2 Catchment Liming

Catchment liming neutralizes acidic inputs before they enter surface waters, thereby reducing the mobilization of toxic metals and their precipitation on the river or lake bed. The treatment may remain active for up to ten years, though its effectiveness during reacidification from less than five years onwards remains uncertain (section 2.1.4). In this study, hydrological source area (HSA) liming would be required in the Tywi and Camddwr upstream of Llyn Brianne. Much of the Tywi catchment is conifer afforested, while most of the Camddwr is open moorland.

The protocol adopted follows Merrett (1992). The flow and chemical data reference point for the main river Tywi is 1.5km below the reservoir (site 6, Figure 4.2). HSAs were identified from Ordnance Survey 1:10,000 maps as areas with low gradients draining relatively large sub-catchments (Waters et al., 1991) and sites marked as marshes. The total area of HSAs available and accessibility to transport were estimated.

The amount of limestone required to raise the calcium concentration to 5mg l^{-1}, taken as a working target to provide long-term fishery protection, was calculated from the main river flow and calcium concentrations before treatment. Calcium concentration below the reservoir was found to be independent of flow, rendering flow weighting unnecessary. An initial annual loss rate of calcium of 11.8% of the initial dose, an empirical figure (Llyn Brianne Final Report, 1992), was assumed in calculating the total tonnage required for treating the entire catchment.

Costings for limestone, transport and manpower were based on figures for a previous operation in Wales in 1991.

Cost of Limestone Addition

The selected HSAs are shown in Figure 4.3. Much of the Tywi catchment of Llyn Brianne is afforested and so source areas here were assumed inaccessible.

Calcium requirements

Loss Ca	=	(Ca add x annual river flow) tonnes $year^{-1}$
where Ca add	=	[Ca] target (mg l^{-1}) - [Ca] mean (mg l^{-1}) x 10^{-6} tonnes m^{3-1}
([Ca] target	=	5mg l^{-1}
[Ca] mean	=	long-term concentration pre-treatment, 1.85mg l^{-1}
annual flow	=	1.27 x $10^{8}m^{2}$ $year^{-1}$)
Thus, Loss Ca	=	400 tonnes $year^{-1}$

Table 4.1 Hydrological source areas in the upper Tywi catchment

Map No.	Stream	NGR	Area (ha)	Access	Distance to land site (km)
SA1	Tywi Source	SN 804 631	34.00	Helicopter	1.5
SA2	Nant Gorast	SN 792 625	29.75	Track/ATV	
SA3	Nant Gwinau	SN 796 624	8.25	Track/ATV	
SA4	trib	SN 798 625	4.25	Helicopter	1.0
SA5	Boggy area	SN 803 605	19.75	Helicopter	1.5
SA6	Nant Gwinau	SN 819 587	12.50	Track/ATV	
SA7	trib	SN 798 570	2.75	Helicopter	1.5
SA8	Boggy area	SN 818 564	1.75	Forestry Road	
SA9	Nant Gwyn	SN 823 506	1.25	Forestry Road	
SA10	Nant Tadarn	SN 756 602	1.00	Road	
SA11	Unnamed trib	SN 823 506	1.75	Forestry Road	
SA12	Maesnant	SN 756 602	2.25	Helicopter	3.0
SA13	Nant Cwm-bys	SN 764 606	6.50	Forestry Road	
SA14	Camddwr source	SN 754 573	5.00	Road/ATV	
SA15	Nant y Maen	SN 766 582	6.00	Helicopter	1.0
SA16	Nant y Ffrwd	SN 773 585	16.25	Helicopter	1.0
SA17	Nant y Cwr	SN 759 566	16.50	Helicopter	1.5
SA18	Nant Tyhelyg	SN 763 560	12.50	Heli/ATV	2.0
SA19	Nant Bryn-glas	SN 779 576	1.00	Road	
SA20	Nant Gruffydd	SN 764 555	5.50	Helicopter	2.0
SA21	Nant y Gelli	SN 778 558	1.25	Helicopter	2.5
SA22	Nant y Gronwen	SN 784 253	1.25	ATV	
SA23	Nant y Coeleth	SN 777 537	2.50	Helicopter	2.0
SA24	Nant y Ceseg	SN 776 529	18.50	Track	
SA25	Nant Grufydd	SN 776 522	6.25	Track	
SA26	Nant y Brithdir	SN 784 517	10.25	Forestry Road	
SA27	Nant Llwyd	SN 791 511	2.25	Track	—
SA28	Nant Rhytalog	SN 789 513	4.75	Forestry Road	—
	Unnamed trib		235.50		
	Nant Hendredail				

ATV = All Terrain Vehicle

Assuming that 11.8% of the initial doses is lost annually, the initial dose required is 8500 tonnes of limestone.

Total area of available HSA's (Table 4.1)	=	235.5ha
Application rate	=	36 tonnes ha^{-1}

Transport

Where possible, transport costs were based on use of All Terrain Vehicles (ATV's) since helicopter costs are very high. However, the major HSA's within the Tywi and Camddwr source areas are inaccessible to ATV's, and therefore helicopter costs were calculated for 12 of the 28 HSAs.

Costs

a. Liming

Cost of limestone	£340 000	
Helicopter costs	£275 000	
Manual spreading costs	£127 500	
ATV costs	£ 23 300	
Total cost	£765 800	(detailed in Table 4.2)

Note that this figure is likely to be an upper estimate as economics of scale have not been allowed for.

b. Annual monitoring

Water quality , invertebrate and fisheries monitoring is assumed, including sampling of streams draining each HSA to determine treatment effects.

Monitoring cost p.a.	£28 000
Project Management	£ 4 000

Advantages and disadvantages of Catchment liming

Catchment liming has the advantage of being relatively long-lasting. Retreatment is only necessary at about five to possibly ten year intervals, with no need for the maintenance of equipment during the intervening period. The soil retains the lime as calcium carbonate and adsorbed calcium ions, and supplies base cations to the stream at a rate dictated by the volume and rate of water passing through the catchment (Jenkins et al., 1991), and is effective at the majority of high flows. Acidic inputs are neutralized before they enter the water body, thereby avoiding the creation of sharp pH gradients and the mobilization of toxic metals. The reduction in soil output of toxic metals such as aluminium creates conditions suitable for fish to spawn in the tributaries, as demonstrated by Norrgren & Degerman (1993).

Table 4.2 Liming costs for the upper Tywi catchment

	Limestone Costs		Helicopter Costs			
Map Code	Limestone (Tonnes)	Cost of Limest. (£)	No. of loads	Time per load (min)	Total time (h)	Cost of Transfer (£)
SA1	1 224	48 960	2 448	2.5	102.00	67 320
SA2	1 071	42 840				
SA3	297	11 880				
SA4	153	6 120	306	2.0	10.20	6 732
SA5	711	24 440	1 422	2.5	59.25	29 105
SA6	450	18 000				
SA7	99	3 960	198	2.5	8.25	5 445
SA8	63	2 520				
SA9	45	1 800				
SA10	36	1 440				
SA11	63	2 520				
SA12	81	3 240	162	4.0	10.80	7 128
SA13	234	9 360				
SA14	180	7 200				
SA15	216	8 640	432	2.0	14.40	9 504
SA16	585	23 400	1 170	2.0	39.00	25 740
SA17	594	23 760	1 188	2.5	49.50	32 670
SA18	450	18 000	900	3.0	45.00	29 700
SA19	36	1 440				
SA20	198	7 920	396	3.0	19.80	13 068
SA21	45	1 800	90	3.5	5.25	3 465
SA22	45	1 800				
SA23	90	3 600	180	3.0	9.00	5 940
SA24	666	26 640				
SA25	225	9 000				
SA26	369	14 760				
SA27	81	3 240				
SA28	171	6 840				
		340 000			372.45	245 817

Flying time assumed: 1km per minute, 1 minute per trip loading/unloading a 0.5 tonne load

Cost of limestone in 25kg bags, inc. delivery	: £40 per tonne
Total limestone costs	: £340 000
Manual spreading rate	: 2 tonnes per day/person
Spreading costs (30 people for 142 days)	: £127 500
Helicopter	: £660 per hour
Helicopter overheads	: £470 per day
Flying costs	: £245 817

Overheads (based on 62 days, 6 hours/day)	: £ 29 140
ATV purchase (6 vehicles)	: £ 19 800
ATV running costs	: £ 3 500
Total overall costs	: £765 757

The present unpredictability of catchment treatments and their aquatic effects remains a disadvantage, as discussed in previous sections of this report.

Terrestrial liming strategies have also been criticized for their adverse effect on plant and animal ecology. Limestone use on catchments is likely to have significant consequences for terrestrial ecosystems such as ombrogenous mires and blanket bogs, for which Britain is internationally important in conservation terms. There is some evidence for detrimental effects on Sphagnum and invertebrate populations (Ormerod & Buckton, 1994). However, Ormerod & Buckton (1994) found that the most prevalent National Vegetation Classification type in HSAs was not rare. They recommended that the conservation value of such areas should be assessed on a site specific basis and provided a protocol for this approach in liming schemes.

4.2.3 Direct Dosing

Surface water dosing systems are in widespread use in Scandinavia for the treatment of flowing waters (Hindar, 1985; Lessmark & Thornelof, 1986). Systems for small streams can be water powered, while electrically powered dosers have been used to dose rivers with flows of up to $100m^3s^{-1}$. Material may be dosed as a dry powder or a slurry. Dry powder dosers use a lime particle size of <0.1mm, giving 50% instantaneous dissolution, the rest sedimenting out and dissolving more slowly. Slurry dosers use fine suspensions of 0-15um material giving 90-100% instantaneous dissolution (Tideston & Moberg. 1984).

Episodicity of river pH requires that liming equipment must dose according to flow and water chemistry, and be able to cope with peak flows. Control of dosing rate can be manual or automatic. Automatic dosing is achieved electronically or mechanically by water flow (Turnpenny, 1992).

Two scenarios were assessed for Llyn Brianne:

a. One large doser delivering lime to the river below the reservoir.
b. Two dosers sited on the two major input streams (Tywi & Camddwr), upstream of the reservoir.

Calcium requirements

Calculation using:

Loss Ca	=	(Ca add x annual river flow) tonnes $year^{-1}$
where Ca add	=	[Ca] target (mg l^{-1}) - [Ca] mean (mg l^{-1}) x 10^{-6} tonnes m^{3-1}
([Ca] target	=	2.5mg l^{-1}
[Ca]mean	=	long-term concentration pre-treatment, 1.85mg l^{-1}

annual flow = 1.27 x 10^8 m^3 $year^{-1}$)

For option b, calculations allow for 'overdosing' at the two stations upstream of the reservoir to compensate for other acidic inputs to the reservoir.

Table 4.3 Annual calcium requirements for the three direct dosing sites under consideration

Site	Mean [Ca] (mg l^{-1} $CaCO^3$)	ADF (m^3s^{-1})	Lime dose (tonnes) 80%	50% dissolution
1. Tywi d/s reservoir	1.820	4.300	270	432
2. Tywi u/s reservoir	1.154	1.798	173	277
3. Camddwr u/s reservoir	1.132	1.020	98	157

Costs

The costings in Table 4.4 are based on 40 tonne storage capacity dosers, excluding the more costly solar/wind power option. The single doser option would require refilling on a monthly basis whereas the option b dosers (Tywi and Camddwr) would need replenishing on five and ten weekly programmes respectively.

Table 4.4 Operational costs (£) for a single direct doser downstream of Llyn Brianne (option a) and two dosers upstream of the reservoir (option b) (Maintenance costs apply after year 6)

Option	Cost/Unit	Lime costs p.a. 80% - 50% dissolution	Maintenance costs p.a.	Energy costs p.a.	Total
a. Water	18 450	5670-9216	7000	-	31 120-34 666
Electric	18 200	5670-9216	7000	2000	32 870-36 416
b. Water	36 900	5670-9216	14 000	-	56 570-60 116
Electric	36 400	5670-9216	14 000	4000	60 070-63 616

While the costs incurred for option a will be lower, acidification of the reservoir upstream could lead to problems in the event of a failure in the dosing mechanism. In option b, the reservoir provides a buffer for any major acid episodes and a zone for possible precipitation of metals caused by liming.

Annual Monitoring Costs

Monitoring requirements are similar to those for reservoir liming, but include water quality samples upstream and downstream of the dosers and reservoir samples for the first year (option b).

Monitoring costs	year 1 option a	£18 760	
	year 1 option b	£33 960	
	year >1 options a, b	£17 720	
Project Management			£ 4 000

Advantages and disadvantages of Direct Dosing

A recent modelling study of the feasibility of direct dosing at Llyn Brianne confirmed approximate limestone requirements at 250 - 370 tonnes year $^{-1}$ (Comber et al., 1995).

The main concern with direct dosing systems is reliability, particularly in winter at remote sites. Freezing conditions can result in the failure of both pH and flow monitoring systems. Winter access may be restricted so the equipment must function unattended for up to a month in freezing conditions. Even a brief failure is likely to lead to fish mortalities, though here the reservoir offers a short-term safety mechanism (option b). For electric dosers reliable mains electricity may not be available on site and the use of batteries is reliant on frequent servicing. Consideration must also be given to the risk of vandalism to the dosing structure, constant management of maintenance and limestone delivery.

Direct dosing, like lake liming, avoids damage to ecologically sensitive wetland areas, but will only restore the tributaries the dosers are sited on. Lime dosing directly into running waters has been shown to have detrimental effects immediately downstream of the liming site, some metals (eg. aluminium) precipitating out as toxic hydroxides. Therefore the doser must be sited to avoid important habitat for fish or other biota.

4.3 Economic Benefit

For any programme to be justifiable in the long-term, there should be a demonstratable benefit. Economic factors are one component of any assessment, which will also take into account a range of other factors, such as the protection of species of conservation interest. In this instance, economic benefit is measured in terms of the fishery, ie. the potential increase in rod catch of migratory salmonids. Gains or losses on conservation grounds are harder to quantify. Populations of salmonid species are genetically distinct and adapted to specific local conditions, it is therefore important to protect particular stocks.

Methods

a. Liming Costs

The current estimated liming cost for each technique was converted to capital equivalents (Table 4.5). The estimated present day value (Cv) of liming costs over a 20 and 30 year timespan for a range of discount rates, was calculated by the formula:-

$$C_{pv} = C_0 + C_1 / (1 + r) + C_2 / (1+r) \ldots\ldots\ldots\ldots\ldots\ldots C_n/(1+r)$$

where r = discount rate, n = number of years, C = cost.
Discount rates were taken at 3%, 6% & 9%.

Table 4.5 Estimated present day values for three liming methods costs (capital and capitalized) according to a range of discount rates and time horizons. Direct river liming is assumed to be water powered

	Time (years)	Discount rate (%) 3	6	9
Lake liming	20	£ 954 490	£ 771 766	£ 586 601
	30	£1 235 278	£ 912 176	£ 658 645
Catchment liming	20	£2 930 999	£2 438 094	£2 087 283
	30	£3 855 181	£2 921 948	£2 345 603
Direct liming				
a. d/s reservoir	20	£ 551 127	£ 438 736	£ 360 693
	30	£ 726 546	£ 526 456	£ 405 702
b. u/s reservoir	20	£ 646 943	£ 514 157	£ 422 236
	30	£ 856 415	£ 618 905	£ 475 982

b. Fisheries

The increased economic benefit to the fishery has been estimated by Evans (1994). The benefit was derived from the increased economic rent due to the increased capture of salmon and seatrout, plus the consumer surplus, assumed to be 50% of the increased economic rent. The economic rent is related to the market value of the fishery, whilst the consumer surplus is the additional amount anglers would be prepared to pay to avoid loss of the resource. Radford et al., (1991) give a capital value of each salmon for the Tywi of £2182, though recent trends suggest this may have increased substantially (Shearer, 1992). The value of one salmon was assumed equivalent to 2.5 seatrout. A linear increase in fishery value with increased catch was assumed. The estimated increase in rod catch of salmon and seatrout was based on the potential juvenile production following liming, a modest density of five 1+ parr/100m^2 was used for each species. In modelling the increased catch and mortality rates of the various life stages were given mean and standard deviation values from the literature or expert advice. Each variable was assumed to be normally distributed and 50 random values were generated from each distribution thus giving 50 estimates of the increase in rod catch.

The mean estimated increase in rod catch was 61 salmon and 163 seatrout (range 14-205 salmon, 54-336 seatrout). This gave an increase in economic value of £413 053 (£116 519-£110 857).

The costs of achieving the average estimated fishery enhancement by smolt stocking, assuming four hatchery smolts to be equivalent to one wild smolt, were approximately £40 000 per year each for salmon and sea trout, total £80 000 p.a.

4.4 Discussion

It should be noted that many assumptions underly the simplistic economic evaluation of the Tywi fishery. The estimate of increased rod catches spans nearly an order of magnitude and wide annual variations in economic rent are also typical. Comparing projected benefits to the fishery with the preliminary estimates of costs for the various liming techniques suggests that both the lake liming and direct dosing options may be economically justifiable whereas catchment liming appears too costly in this case. The catchment liming option offers protection to spawning grounds in the headwaters and also to river and reservoir or lake trout fisheries where they occur. However, benefits to these are likely to be generally small, or zero in comparison to those for the migratory fishery. In favour of catchment liming are possible conservation benefits from the protection of genetically distinct populations of wild brown trout. However the conservation ramifications for wetland areas would require careful appraisal, could limit the scope of the proposed treatment and may offset any conservation benefits.

The costs of the smolt stocking option are provided for comparison, though its feasibility is considered low. Moreover, the revenue costs exceed those of liming by boat, and only catchment liming is more expensive.

This case study demonstrates a number of options available for the maintenance of water quality within the River Tywi downstream of Llyn Brianne. Catchment liming may be the least feasible option on the grounds of economic and environmental cost. Both the use of direct dosers and the continuation of the lake liming programme appear viable techniques, with management judgement on costs, benefits and risks required. Many features of the cost-benefit appraisal are catchment-specific and therefore it is likely that the relative merits of the alternative techniques will differ elsewhere. The quantitative aspects of the assessment will also vary locally making it difficult to extrapolate the conclusions of this study to other areas.

5. CONCLUSIONS AND RECOMMENDATIONS

1. This project has demonstrated that catchment liming of acidified streams can create mean chemical conditions suitable for the protection of acid sensitive biota, including brown trout, for a duration of greater than six years. Acid episodes recur from early in this period though their impact is uncertain as it is dependent on the timing, severity, duration and frequency. Unmanipulated streams of similar mean pH are episodically acidic yet support moderate trout populations, suggesting that temporary failures in buffering may be damaging but not necessarily eliminate fish populations. Whole catchment liming, though more costly, may slightly reduce the risks of acid episodes compared with liming hydrological source areas. These conclusions must be qualified according to 2 and 3 below.

2. The experimental design lacked replication for the practical reason that the treatment units were catchments. Coupled with the site specific catchment characteristics this makes generalization from individual treatment responses uncertain.

3. The parallel biological project showed limited change of macroinvertebrate, macrofloral and fish populations and communities towards unimpacted status. This may be explained by the lack of replication, relatively short-term study duration, constraints on colonization and recovery related to dispersal abilities, or by water chemistry effects. Colonization processes appear important, as increases in invertebrate populations downstream of Llyn Brianne after liming have occurred rapidly from source populations in unacidified tributaries. However, reacidification and the return of acid episodes whilst biological recovery was being monitored, may also have inhibited population increases. Overall, the weakness of biological restoration casts some doubt on the effectiveness of the treatments.

4. In combination with recent information from other NRA projects, this study has set out the key management options for acidified surface waters. Active remedial measures include catchment liming, direct river liming and reservoir/lake liming. Promoting in-lake generation of alkalinity by artificial nutrient additions is another option under research (George et al., in prep.). Estimated monetary costs for the upper River Tywi case study are presented. Catchment liming is the most expensive in this example and implications for wetland conservation interests would add qualitative costs. River and reservoir/lake liming are cheaper and closer to the estimated monetary benefits of the improved fishery. All options require appraisal on a case by case basis.

5. The need for liming must be set in the context of controlling acidification by emissions reductions and adjusting catchment sensitivity by controlling land use. Emissions of sulphur dioxide have fallen since 1980 and further reductions are

planned to the year 2010. Oxidized nitrogen emissions increased to around 1990 but are expected to decline towards 2000, whilst for reduced nitrogen emissions, which are primarily from agriculture, the pattern is less clear (UKRGIAN, 1994). The recovery of surface waters with reductions in acidic emissions and deposition is uncertain but will probably be slow (CLAG, 1994). Long-term trend analysis of stream chemistry in this study demonstrated minor changes over the past decade. Recovery is predicted to be retarded further in afforested and restocked catchments as the 'forest effect' tends to counteract deposition reductions, though this is not well quantified.

6. The control of acidifying emissions is the essential primary target to promote long-term protection and recovery of acid sensitive freshwaters. Continued monitoring studies and research into the relationships between emissions, deposition and surface water chemistry and ecology are important to guide the management of emissions (CLAG, 1994; Patrick et al., 1995).

7. The control of conifer forestry is also a key factor in mitigating acid deposition effects and work on the impacts and suitable management techniques is continuing (Neal et al., 1992; Stevens & Reynolds, 1993). However, though land use controls may be important in limiting impacts, the majority of sensitive catchments will probably remain impacted for decades.

8. Liming therefore offers the main option for rapid recovery of water quality and fisheries, if this is required and appropriate funding is available. The feasibility, effectiveness and costs of catchment liming are site dependent. Sufficient information is now available to design treatments though the complexity of catchment hydrochemistry means there is some uncertainty in predicting the chemical effects, particularly on a large scale. There is also some uncertainty in the biological response, so that any future studies or operational schemes should be monitored accordingly.

9. Continued monitoring of the upper Tywi treated and reference streams is recommended. Significant effects on water quality were apparent to the end of the current project and the duration of effects should be established. The moorland and forest reference streams and developing forest stream have important long-term data which should be continued to monitor trends in chemistry in relation to changes in atmospheric deposition and forest growth. There are few data sets of comparable length and of the quality needed to provide evidence of long-term impacts and recovery. The minimum requirement is monthly water samples from each stream.

REFERENCES

Bengtsson, B, Bagalius, A and Thornelof, E (1984) Kalkning av sjoar och vattendrag. Statens naturvardsverk rapport, SNV PM 1786, 140pp.

CNS Scientific and Engineering Services (1992) Economic value of changes to the water environment. NRA R&D Note 37. NRA Bristol.

Comber, S D W, Whitehead, P G and Gardner, M J (1995) Water quality modelling of Llyn Brianne and its input streams. Report to NRA. Water Research Centre, Medmenham.

Critical Loads Advisory Group (CLAG) (1994) Critical loads of acidity in the United Kingdom. Summary report to DOE. Institute of Terrestrial Ecology, Edinburgh.

Dickson, W (1983) Liming Toxicity of Aluminium to Fish. Vatten 39: 400-404.

Edwards, R W, Gee, A S and Stoner, J H (1990) Acid Waters in Wales. Dordrecht: Kluwer.

Evans, D (1994) Sea trout (Salmo trutta L.) studies of the River Tywi, South Wales. PhD Thesis, University of Hull.

Forestry Authority (1993) Forests & Water Guidelines. London, HMSO.

George, G et al. (in prep.) Management of acid lakes by regulating the supply of nutrients. NRA R&D Note. NRA Bristol.

Hindar, A (1985) Lime Treatment as a countermeasure. pp23-39. In: Liming of Acid Waters. Final Technical Report on the Liming Project (Ed. K. Baalsrud) Department of the Environment and the Directorate of Nature Management. Trondheim, Norway, 147pp.

Hirsch, R M and James, J R (1984) A Nonparametric Trend Test for Seasonal Data with Serial Dependence. Water Resources Research 20(6): 727-732.

Jenkins, A and Renshaw, C (1993) Comparison of empirical and dynamic model approaches for surface waters. In: Critical loads: concept and applications. ITE Symposium no.28 (Eds. M Hornung and R A Skeffington), London, HMSO, pp.109-114.

Jenkins, A, Waters, D and Donald, A (1991) An assessment of terrestrial liming strategies in upland Wales. Journal of Hydrology 124: 243-261.

Lessmark, O and Thornelof, E (1986) Liming in Sweden. Water, Air and Soil Pollution 30: 809-816.

Llyn Brianne Acid Waters Project. Final Report (1992) NRA ref EAR/91/7. DOE.

Merrett, W J (1992) Liming of Hydrological Source Areas to Ameliorate Acidification: A Provisionsl Protocol and Cost-Benefit Analysis. NRA internal report.

Neal, C, Robson, A J, Leeks, G J L, Hudson, J A and Smith, C J (1992) Forestry Impact on Upland Water Quality. NRA R&D Note 77. NRA Bristol.

Nisbet, T R (1991) Effects of pelletized limestone on drainage water quality, tree growth and nutrition. In: Forest Soils Group 1991, report of the Forestry Commission Research Division.

Norrgren, L and Degerman, E (1993) Effects of Different Water Qualities on the Early Development of Atlantic Salmon and Brown Trout Exposed in situ. Ambio 22(4): 213-218.

Nyberg, P and Thornelof, E (1988) Operational liming of surface waters in Sweden. Water Air & Soil Pollution 41: 3-16.

Olem, H (1991) Liming Acidic Surface Waters. Lewis Publ., Chelsea, Mi.

Ormerod, S J and Buckton, S T (1994) Catchment source areas and the ecological effects of catchment liming - Phase I and II. NRA R&D Note 281. NRA Bristol.

Patrick, S, Monteith, D T and Jenkins, A (1995) UK Acid Waters Monitoring Network: The First Five Years. Analysis and Interpretation of Results, April 1988 - March 1993. DOE & DOE (NI).

ENSIS Publ., London.
Radford, A F, Hatcher, A C and Whitmarsh, D J (1991) An Economic Evaluation of Salmon Fisheries in Great Britain Volume 1: Principles, Methodology and Results for England and Wales. Portsmouth Polytechnic.
Robson, A J and Neal, C (in press) Water quality trends at an upland Welsh site, 1983-93. Hydrological Processes.
Rundle, S D, Weatherley, N S and Ormerod, S J (1995) The effects of catchment liming on the chemistry and biology of upland Welsh streams: testing model predictions. Freshwater Biology 34: 165-175.
Shearer, W M (1992) The Atlantic Salmon: Natural History, Exploitation and Future Management. Fishing News Books, Oxford.
Simonin, H A (1990) Final Generic Environmental Impact Statement of the New York Department of Environmental Conservation Program for Liming Selected Acidified Waters. New York State Dep. Environ. Conserv. Albany.
Stevens, P A, Ormerod, S J, Reynolds, B, Radford, G L, Norris, D A and Sparks, T H (1994) Project definition study for re-survey of Acid Waters in Wales. Project T07072P5. ITE.
Stevens, P A and Reynolds, B (1993) A review of water quality implications of conifer harvesting in the UK. 1. Literature review and recommendations for research. NRA R&D Note 156. NRA Bristol.
Sverdrup, H and Warfvinge, P (1985) A reacidification model for acidified lakes neutralized with calcite. Water Resources Research 21: 1374-1380.
Tideston, H and Moberg, P O (1984) Liming Running Waters. Machine Characteristics Assessed. SNV PM 1873 Board of Fisheries No. 2.
Turnpenny, A W H (1992) Alternatives to Catchment Liming. pp.173-196. In: Restoring Acid Waters: Loch Fleet 1984-1990 (ed. G. Howells & T.R.K Dalziel) Elsevier Applied Science, London. 421pp.
Underwood, J, Donald, A P and Stoner, J H (1985) Liming to Combat Surface Water Acidification in West Wales. Welsh Water Authority Internal Report.
Underwood, J, Donald, A P and Stoner, J H (1987) Investigations into the use of limestone to combat acidification in two lakes in West Wales. J.Environmental Management 24: 29-40.
United Kingdom Acid Waters Review Group (UKAWRG) (1986) Acidity in United Kingdom Fresh Waters. Report to DOE. DOE, London.
United Kingdom Review Group on Acid Rain (UKRGAR) (1990) Acid deposition in the United Kingdom 1986-1988. Third report of the UK Review Group on Acid Rain, Warren Spring Laboratory, Stevenage.
United Kingdom Review Group on Impacts of Atmospheric Nitrogen (UKRGIAN) (1994) Impacts of Terrestrial Nitrogen Deposition on Terrestrial Ecosystems. Report to DOE. DOE, London.
Warfvinge, P, Sverdrup, H and Bjerle, I (1984) Dissolution of Calcite powder Sinking in a Column of Acid Water in relation to a Theoretical Lake Liming Model. Chemica Scripta 24(4): 67-72.
Waters, D, Jenkins, A, Staples, T and Donald, A P (1991) The Importance of Hydrological Source Areas in Terrestrial Liming. J. IWEM 5: 336-341.
Weatherley, N S (1988) Liming to Mitigate Acidification in Freshwater Ecosystems: A Review of the Biological Consequences. Water Air and Soil Pollution 39: 421-437.

Weatherley, N S and Ormerod, S J (1991) The importance of acid episodes for faunal distributions in Welsh streams. Freshwater Biology 25: 71-84.
Weatherley, N S, Jenkins, M J, Evans, D M, Rogers, A P and Gee, A S (in press) Options for liming rivers to ameliorate acidity - a UK perspective. Acid Reign '95? conference, Gothenburg, June 1995. Water, Air and Soil Pollution.
Weatherley, N S , Rutt, G P , Thomas, S P and Ormerod, S J (1991) Liming acid streams: toxicity to fish in mixing zones. Water, Air and Soil Pollution 55: 345-353.
Wright, R F and Skogheim, O K (1983) Aluminium Speciation at the Interface of an acid Stream and a Limed Lake. Vatten 39: 301-304.