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Whole-catchment Application of Dolomite to an Acidified Forest Ecosystem in Gjerstad, Southern Norway

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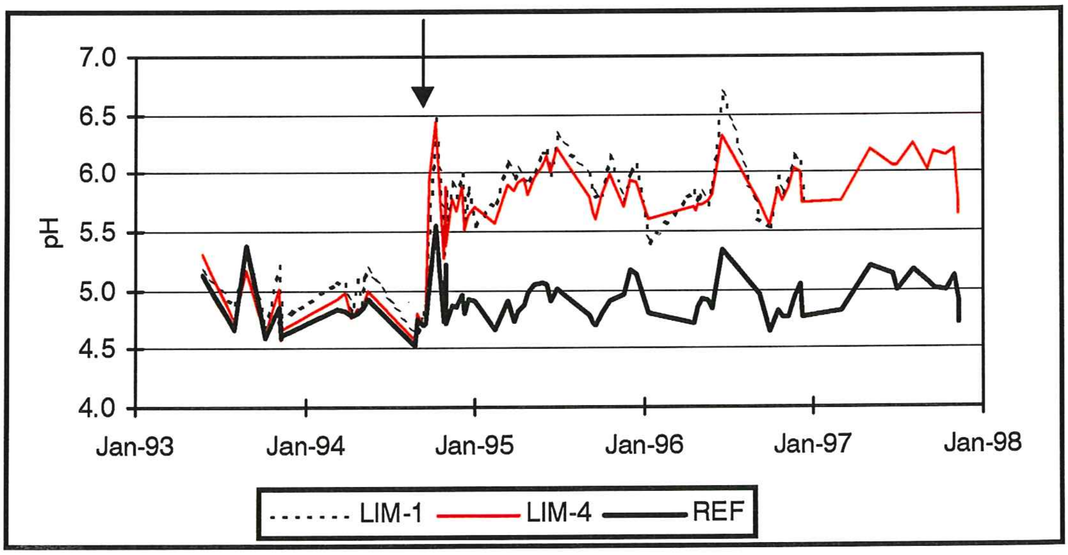

Norwegian Institute for Water Research

REPORT

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Abstract

As part of the research programme "Counteractions Against Acidification in Forest Ecosystems" (Miljøtiltak i skog), a coniferous-forested catchment was limed with dolomite in September 1994. 3 t ha^{-1} of coarse dolomite powder were spread on 0.8 km^2 by helicopter. The liming resulted in an immediate improvement in runoff water quality relative to an adjacent reference catchment. pH, Ca , Mg and ANC (acid neutralising capacity) increased and inorganic Al decreased. Favourable water quality was maintained for 3 years. NO_3-concentrations increased the second year after liming, whereas concnetrations of total N and TOC were not significantly changed. Liming did not affect concentrations of 7 trace metals (As, Cd, Cu, Fe, Ni, Pb, Zn) whereas concentrations of Mn, Co, and Zn decreased. Only minor changes in soil solution, and only at some of the lysimeters were detected. Steep slopes, thin soils, high amounts of precipitation and thus dominance of surface and subsurface flow in this catchment may explain the rapid response in runoff. During the first three years after liming there have been no significant effects on tree growth and vitality (crown density and crown colour). This experiment shows that liming of forested catchments is a viable method to obtain long-term improvement in water quality and positive effects for acid-sensitive aquatic organisms.

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Counteractions Against Acidification

in Forest Ecosystems

Whole-catchment Application of Dolomite to an Acidified Forested Ecosystem in Gjerstad, Southern Norway

Preface

The research program "Counteractions against acidification in forest ecosystems" (Miljøtiltak i skog) was initiated in 1991 as a Norwegian Forest Research Institute (NISK) program with funding from the Ministry of Agriculture. In 1993 the program was reorganised and a five-year research program led by NISK was started. Three co-operating institutes, NISK, the Norwegian Institute for Water Research (NIVA) and the Norwegian Institute for Nature Research (NINA), were main actors. Later on the Agricultural University participated.

The program was divided into an initial literature study and five separate research activities thereafter. This report gives background information and summarises the results from sub-project IV, the whole-catchment application of dolomite to an acidified forested ecosystem in Gjerstad, southern Norway.

We would like to thank the forest owner Olav Fjærbu for careful sampling and maintenance of monitoring stations during the project period and for offering his forest as a research site in an early phase of the program.

This work has been financed by the Ministry of Agriculture, the Ministry of Environment, the four counties Rogaland, Vest-Agder, Aust-Agder and Telemark and NIVA.

Grimstad, September 16, 1999

Atle Hindar

Contents

Summary

As part of the research programme "Counteractions Against Acidification in Forest Ecosystems", a forested catchment dominated by pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) was limed with dolomite in September 1994. 3 t ha^{-1} of coarse dolomite powder were spread on 80 ha by helicopter. Mean pre-liming stream water qualities (n=16 or 18) at four independent stations were in the range: pH 4.6 - 4.9; 0.85 - 1.28 mg L^{-1} Ca; 0.30 - 0.41 mg L^{-1} Mg; 194 - 275 µg L^{-1} reactive Al (Alr) and 34 - 103 µg L^{-1} inorganic monomeric Al (Ali). Dolomite application resulted in an immediate increase in runoff water quality relative to an adjacent reference catchment. For the period September 1994-December 1996 mean values at the main outlet of the limed catchment were: pH 5.86; 1.51 mg L^{-1} Ca; 0.81 mg L^{-1} Mg; 15 µg L^{-1} Ali. A small increase in NO_3 was found at the main outlet of the limed catchment the second winter after liming. Total N and TOC were not changed. Mn, Co and Zn showed significantly decreasing trends when compared to the reference stream, whereas Fe, Pb, Cd, Cu As and Ni remained relatively unaffected by the dolomite application. Cr was mostly below detection limits. Only minor changes in soil solution, most clearly for Mg, could be detected after liming. Steep slopes, thin soils, high amounts of precipitation and thus dominance of surface and subsurface flow in this catchment may explain the rapid response in runoff. During the first three years after liming there have been no significant effects on tree growth and vitality (crown density and crown colour). This experiment shows that liming of forested catchments is a viable method to obtain long-term improvement in water quality and positive effects for acid-sensitive aquatic organisms.

1. Introduction

1.1 Background

In areas in southern Norway characterised by widespread fish-death due to acidification of surface waters, so far no negative effects of acid rain on forest health can be documented (Aamlid *et al.* 1998). Forests tend to remove base cations, scavenge air pollutants and concentrate pollutants due to increased evapotranspiration (Jenkins *et al.* 1990). In the long run, acidification of forest soils may therefore be expected in vulnerable areas if the soil has a limited base cation supply. The supply of nitrogen from atmospheric deposition may stimulate forest growth and thereby also the loss of base cations from the soil. Although atmospheric deposition of sulphur in Norway has decreased during the last decade, the situation for the forest ecosystems is still uncertain, and the need to examine various counteractions against acidification of the soils has been recognised.

Episodic acidification, enhanced by sea salts, may be particularly important for sensitive aquatic organisms in forested areas (Hindar *et al.* 1994; 1995a). Afforestation may have undesired impacts on aquatic ecosystems, and the question of whether afforestation should be augmented with measures to prevent this extra acidification has been raised.

Several countermeasures against forest soil acidification are available for forest management practices, including both silvicultural measures and application of chemicals. The first group involves use of broadleaved trees, both in pure stands or mixed within conifer stands (Frank 1994).

Changes in forestry management may reduce the removal of base cations but will not prevent strong acid anions from entering soil solution and runoff. Strong acid anions, especially SO_4, are the driving force in soil acidification when balanced by base cations (BC, mainly Ca and Mg). Poorly buffered soils have a very limited capacity of base cation production because of the low weathering rate. In such soils strong acid anions may also be balanced by acid cations, especially H^+ and $Al(OH)_n^{(3-n)+}$.

A second group of countermeasures includes application of carbonates (liming), ash and various commercial fertilisers. The addition of carbonates as calcitic and dolomitic limestone increase the base saturation of the soils and thereby prevent leaching of H^+ and toxic Al-species. Liming may thus be regarded as desirable for both forest soils and aquatic systems in acidified areas, and has been practised for a long time as a compensatory or ameliorating measure in forest soils (Hüttl and Zöttl 1993; Kreutzer 1995) and in acidified lakes and rivers (Olem 1991; Henrikson *et al.* 1995). Fertilisation with the goal of revitalisation of forest stands suffering from nutrient deficiencies has also proved successful (Hüttl 1991).

The question of whether liming should be launched on a practical scale in Norwegian forestry has been raised several times during the last decade (Nilsen *et al.* 1994). The inter-institutional research program "Counteractions against acidification in forest ecosystems" (Miljøtiltak i skog) was initiated in 1991. Main goals for the program were to:

- Give a status and evaluate potential and practical measures, such as liming, vitality fertilisation, use of broad-leaved trees and other silvicultural methods, that may counteract negative effects of acid deposition in forests.
- Perform research on the effects of selected measures on trees, ground vegetation, animal life, forest soils, soil solution and the runoff water quality.
- Give necessary basis for making decisions about future activities on a practical scale.

1.2 Definitions and targets

Liming is the addition of carbonates, oxides and hydroxides of calcium and magnesium to terrestrial and aquatic ecosystems to neutralise soil or surface water. This is consistent with the definition of Olem (1991), although he included all bases. Operational liming of forest soil has gradually changed towards dolomitic materials in Germany (Feger *et al.* 1995) due to the anticipated positive effect of Mg supply to prevent Mg deficiency. Dolomite and calcite mixture was also recommended for operational liming in Sweden (Lindström *et al.* 1993). However, some of the Swedish experiments were carried out using calcitic limestone, i.e. products composed of $CaCO_3$ with only a few percent Mg.

The targets for terrestrial liming operations may be many, e.g. the soil pH, the soil (Ca+Mg)/Al ratio, tree growth, forest health, stream water pH, stream water inorganic Al, a trout population and so on. Various application strategies may be used to achieve one or more of these goals (Henrikson *et al.* 1995), and lime quality, lime dosages, and application strategies may vary. If the goals are clarified, reasonable liming strategies may be recommended, if the potential effects are adequate and acceptable.

The main targets for forest soil liming should be to avoid the negative effects on forest soils of strong acid inputs and to avoid unwanted effects on the terrestrial and aquatic ecosystems. Another target may be improved living conditions for fish in the stream water draining the limed forest. If all the potential positive effects of forest liming are achieved all the negative effects may also occur, see section 1.3. If no undesired effects can be accepted, no positive effects may occur either. The real challenge is to maximise the positive and minimise the negative effects.

1.3 Potential effects of application of dolomite

Moderate addition of dolomitic limestone to the topsoil of forest ecosystems may be intermediate in both positive and negative effects. In this report the main focus is on reduced toxicity towards aquatic organisms.

1.3.1 Soil solution and stream water

The added dolomite gradually dissolves and releases Ca and Mg that can be adsorbed in the organic layer of the top soil. Vertical movement of these base cations to deeper soils then takes place, but this is a slow process, and may occur in the range of 1 cm $year^{-1}$ (Brahmer 1994). Fast changes in the chemical composition of soil solution are therefore not likely. The first change may be increased concentration of Mg in the soil solution due to the more mobile nature of this element relative to Ca (Brahmer 1994). On the other hand dolomite often contains almost four times as much Ca on a weight basis, thereby counteracting the dominance of Mg-increase over Ca-increase in the soil solution.

Although the change in soil solution may be slow, increased amounts of base cations in the topsoil may be important for runoff water quality when hydrological events are characterised by overland or subsurface flow. Overland and subsurface flow is promoted by thin soils and steep slopes, typical of acidified areas in Norway. High amounts of precipitation increase the likelihood for a high water table and saturated soils. Dominance of a more lateral movement of the runoff and reduced residence time of rainwater in the soil may be the result. Under such circumstances runoff acidity may be exchanged with the added base cations in the top soils, thus increasing the concentration of Ca and Mg and also increasing pH.

Dolomite addition thus may result in several positive effects. Increased base saturation of the topsoil, eventually also at greater depths in the soil, and increased pH will reduce Al-mobilisation. This in turn decreases the leaching of toxic Al to soil solution and surface water. Also, increased concentrations of base cations should be expected. If no significant changes in SO_4 and NO_3 occur, liming with dolomite will therefore result in increased ANC (acid neutralising capacity).

In acidified regions low pH and high Al-concentrations in runoff may occur during episodes caused by sea salt inputs (Hindar *et al.* 1994; 1995a), snowmelt and other hydrological events. Increased base saturation in the forest soil and increased pH of the runoff after liming may reduce this Al transport, both by decreasing the preferential ion exchange with H^+ and Al in acid soils and by polymerising and precipitating ion exchanged Al in the overland flow. If forest liming in such areas reduces the Al transport and promotes terrestrial polymerisation of Al, the magnitude and frequency of episodes with toxic water will be reduced and mixing zones in streams and rivers characterised by unstable Al-chemistry (Rosseland *et al.* 1992) may be avoided.

Undesirable chemical effects of terrestrial liming include increased NO_3-leaching and mobilisation of trace metals (Matzner *et al.* 1985; Persson *et al.* 1989; Hüttl and Zöttl 1993; Kreutzer 1995). This may partly be due to increased mineralisation of the surface organic (humus) matter, and may effect soil solution and surface water.

The liming-mediated change in the top soil pH may stimulate the bacterial degradation of organically bound N in the humic material to NH_4 due to a more favourable environment for these organisms (Kreutzer 1994). Nitrification, the bacterial mediated conversion of NH_4 to NO_3, may be stimulated and lead to decreased pH. If the supply of NO_3 is already in excess due to atmospheric deposition, the result may be increased leaching of NO_3 to the soil solution (Kreutzer 1995) and probably to runoff, with subsequent increased acidification and possibilities for increased supply of N to coastal areas. N leaching may thus reduce the deacidification effect of the dolomite in runoff. In less N-polluted areas, NO_3 released will probably be stored in the soil and consumed by microorganisms and terrestrial vegetation.

Mineralisation may result in increased mobilisation of organically-complexed trace metals (especially Cu, Pb and Fe) and result in elevated concentrations in the soil solution. This may be especially so if the deposition rate of the metals is high, and they have accumulated in the surface soils, as in the Höglwald experimental area in Germany (Kreutzer 1995). Solubility of Cd and Zn (and Cu) is pH dependent and these metals will probably not be transported out after liming. On the contrary, increased pH may result in increased retention. Dissolved inorganic Mn and Cd may be oxidised and precipitated at increased pH and decrease in the soil solution after liming (Kreutzer 1995).

The deposition of Cu in Norway is mainly due to local sources and is generally low (Berg *et al.* 1996). Deposition of Zn and Pb in 1996 was an order of magnitude higher than other long-range transported metals but has decreased by 60-80 % in the period 1978-1996 (Tørseth and Manø 1997). This reduction is also true for Cd. Compared to the situation in Germany deposition of trace metals in Norway is low.

1.3.2 Aquatic organisms

Forest liming, according to the Swedish concept (Lindström *et al.* 1993) tends to result in a relatively moderate water quality change in the runoff. Exceptions may be found in areas heavily polluted with nitrogen or trace metals, as referred to above. An important question is: will these changes in any way affect aquatic organisms?

Several investigations have documented that even small water quality changes or differences may be of significance for the survival of fish (Staurnes *et al.* 1993; Dalziel *et al.* 1995; Kroglund and Staurnes 1997) and invertebrates (Raddum and Fjellheim 1984). Decreased concentration of the toxic inorganic Al-species is probably most important for sensitive aquatic organisms and increased concentration of Ca may ameliorate Al toxicity (reviewed by Wood and McDonald 1987; Rosseland *et al.* 1990). Increased concentration of dissolved organic matter will detoxify a larger fraction of Al at low pH due to complex binding. Forest soil liming may therefore represent an effective liming strategy for aquatic systems if significant changes in these parameters occur.

1.4 The whole-catchment liming project in Gjerstad

The question whether liming should be launched on a practical scale in Norwegian forestry may be answered if adequate results exist. Due to lack of integrated studies on soil, water and vegetation under Norwegian conditions, a catchment study with dolomite application was initiated in 1993. The project in Gjerstad, which is presented in this report, is one of five projects under the research program.

The purpose of the experiment was to study the effects of dolomite application to a forested area on soil solution chemistry, runoff water chemistry, soil chemistry, vegetation, tree growth and vitality. Few research programmes have focused on the effects of forest liming on both soil solution, stream water and the significance of water quality changes for aquatic organisms. One of the main purposes of the activities in the Gjerstad-project is to link these topics.

Results from this experiment have been published as part of the Acid Reign'95 Conference in Gothenburg (Hindar *et al.* 1995b) and in annual and final reports in Norwegian from the research programme. This report presents the results in more detail and covers the pre-liming and post-liming periods (until end of 1997).

2. Site description and liming

2.1 Site selection

Several possible areas were visited prior to the establishment of the project sites. The catchment was chosen to satisfy the following criteria:
- acidified due to long-range transported air-pollutants; pH in runoff in the range 4.5-5.5 and markedly elevated Al-concentrations
- mixed forest stands, typical for the moderately productive forests of the area
- mixed, but not too poor, growing conditions (nutrient and water availability) for ground vegetation
- not too close to the sea, due to possible special effects related to sea-salts
- two defined catchments with brooks suited for sampling and monitoring of runoff, one for liming operation and one as reference.

A mixed forest in Gjerstad, Aust-Agder County, southern Norway (58° 53' N, 9° 00' E) was chosen for investigations of the effects of forest soil liming. Fugleliåsen (denoted LIM and FU; 84 ha) was selected as liming area and Spjøtåsen (denoted REF and SP; 41 ha) as reference. The limed catchment was further divided in 3 by the sampling stations LIM-1 (40 ha), LIM-2 and LIM-3, whereas LIM-4 is the main sampling station (**Figure 1**).

2.2 Forest cover

The catchments are forested with a mixture of mainly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) stands. A relatively small amount of broad-leaved trees are mixed within the conifer stands. The forest consists of old mature stands and with a certain amount of newly regenerated areas (less than 15 years).

Table 1. Catchment areas (ha), standing volume (m^3), mean age (yr) and area distribution according to tree age classes and impediment.

	Size	Standing volume (m^3)			Mean	Middle aged	Regenerated	Imped.
	(ha)	Total	Spruce	Pine	age (yr)	+ old forest	areas	
LIM	84.4	9900	3400	4500	67	70 %	17 %	13 %
REF	40.8	6000	1600	3600	77	84 %	9 %	7 %

2.3 Precipitation and deposition

Mean annual precipitation is about 1200 mm and mean annual discharge about 900 mm (29 L s^{-1} km^{-2}). Mean total wet + dry deposition of S and N in the project period 1994-1996 at the Birkenes monitoring station 70 km SW of Gjerstad was 0.90 g m^{-2} and 1.52 g m^{-2}, respectively. At the Solhomfjell monitoring station 20 km NW of Gjerstad the mean wet deposition of S and N was 0.61 g m^{-2} and 0.91 g m^{-2}, respectively, in the same period. Deposition of trace metals at Solhomfjell in 1996 was as follows (numbers in mg m^{-2} yr^{-1}): 4.95 Zn; 2.01 Pb; 0.82 Cu; 0.26 Ni; 0.18 As; 0.16 Cr; 0.042 Cd; 0.02 Co (all deposition data from Tørseth and Manø 1997).

2.4 Liming

In September 1994 a total of 240 tonnes of coarse-grained dolomite was spread over the Fugleliåsen catchment, except for two small (about 1000 m^2) ponds, by helicopter. This gives a mean dose of approximately 2.9 t ha^{-1}. The grain-size distribution of the dolomite was 10 % > 1.7 mm; 90 % > 0.18 mm. The Ca, Mg and water content were 23, 12 and 1 % by weight, respectively.

3. Methods

3.1 Hydrology and water chemistry

3.1.1 Discharge

The limed catchment was divided into three sub-catchments (**Figure 1**), of which two (sampling stations LIM-1 of one of the sub-catchments and LIM-4 at the outlet of the limed catchment) have been included in the water chemistry monitoring in the whole project period. Monitoring in LIM-2 and LIM-3 of the two other sub-catchments were terminated in the summer of 1995.

Water flow was recorded beginning 26 May 1993 at 15-minute intervals at calibrated 90° (at LIM-1) and 120° (at LIM-4 and REF) V-notch weirs.

3.1.2 Runoff water sampling

Volume-weighted stream water samples were collected biweekly beginning 26 May 1993 at LIM-1, LIM-4 and REF. Point samples were collected biweekly at the other two stations in the limed catchment. Water samples were sent to NIVA by post and were analysed 2-3 days after sampling.

Samples for analysis of trace metals were taken directly in 100-ml polyethylene bottles. Before sampling the bottles were washed in 3% HNO_3 for at least 24 hours and thereafter rinsed with demineralised water. After the washing procedure the PE-bottles were refilled with demineralised water until sampling. Before sampling the PE-bottles were emptied for demineralised water and immediately filled with the sample.

3.1.3 Chemical analyses – water and soil solution

Chemical analyses of all major ions and Al-fractions were carried out at NIVA according to standard procedures (**Table 2**). Trace metal analyses were performed with ICP-MS at the Norwegian Institute for Air Research (NILU). In the event that concnetrations were reproted below the detection limit, these were set at ½ the detection limit.

3.1.4 Calculations and statistical analyses

Ali (inorganic monomeric Al) is defined as the difference between Alr (reactive Al) and Alo (organic monomeric Al). Organic N is defined as the difference: total N - (NO_3-N + NH_4-N).

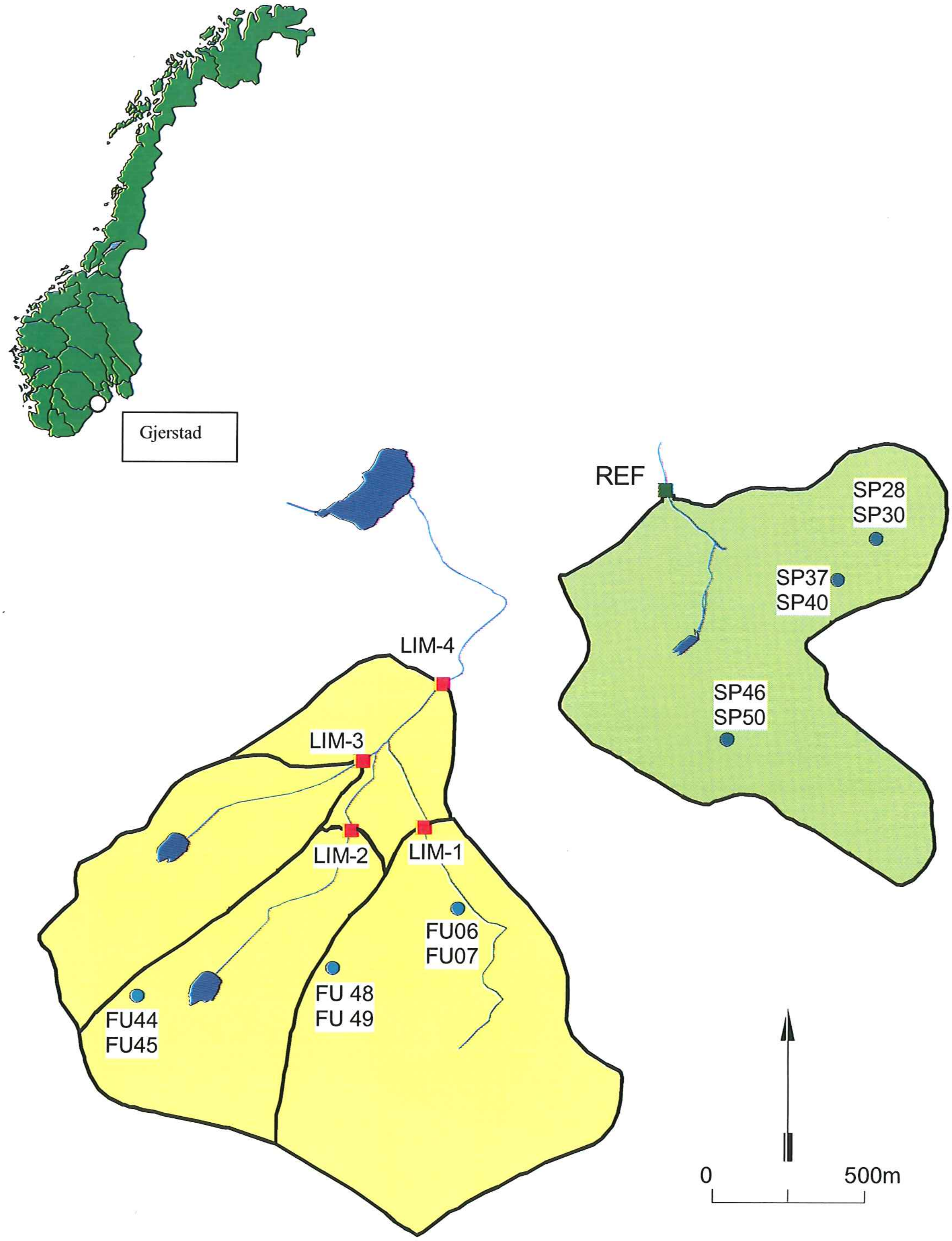


Figure 1. Situation of the limed and reference catchments in Gjerstad. Stations for surface water sampling (LIM-1, LIM-2, LIM-3, LIM-4 and REF), soil chemistry and soil solution sampling (FU and SP stations) are shown. Runoff is registered continuously at LIM-1, LIM-4 and REF.

Table 2. Chemical analysis methods used at NIVA (major components) and NILU (trace metals). ICP=Inductive coupled plasma emission spectrometry; ICP-MS= Inductive coupled plasma emission spectrometry combined with mass spectrometry; FIA=flow injection analysis.

Parameter	Parameter name	Unit	Analytical method
pH	pH	- log $[H^+]$	Potentiometric
Cond	Conductivity	mS m^{-1} at 25 °C	Electrometric
Ca	Calcium	mg L^{-1}	ICP
Mg	Magnesium	mg L^{-1}	ICP
Na	Sodium	mg L^{-1}	ICP
K	Potassium	mg L^{-1}	ICP
Cl	Chloride	mg L^{-1}	Ion chromatography
SO_4	Sulphate	mg L^{-1}	Ion chromatography
NO_3	Nitrate	µg N L^{-1}	Automatic colorimetry
NH_4	Ammonium	µg N L^{-1}	Automatic colorimetry
Alk	Alkalinity	µeq L^{-1}	Potentiometric titration to pH 4.5
TOC	Total organic carbon	mg L^{-1}	Oxidation to CO_2 and then IR detector
Alr	Reactive aluminium	µg L^{-1}	Automatic colorimetry
Alo	Non-labile aluminium	µg L^{-1}	Automatic colorimetry after ion exchange
SiO_2	Silica	mg L^{-1}	Photometry (FIA)
Tot N	Total nitrogen	µg L^{-1}	Automatic colorimetry
Tot P	Total phosphorus	µg L^{-1}	Automatic colorimetry
As	Arsenic	µg L^{-1}	ICP-MS
Cd	Cadmium	µg L^{-1}	ICP-MS
Co	Cobalt	µg L^{-1}	ICP-MS
Cu	Copper	µg L^{-1}	ICP-MS
Fe	Iron	µg L^{-1}	ICP-MS
Mn	Manganese	µg L^{-1}	ICP-MS
Ni	Nickel	µg L^{-1}	ICP-MS
Pb	Lead	µg L^{-1}	ICP-MS
Zn	Zinc	µg L^{-1}	ICP-MS

ANC (Acid neutralising capacity), in µeq L^{-1}, is defined as:
ANC = $(Ca^{2+} + Mg^{2+} + Na^+ + K^+) - (Cl^- + SO_4^{2-} + NO_3^-)$ if $NH_4^+ \approx 0$. All concentrations are in µeq L^{-1}.

Non-marine Na (Na*) in µeq L^{-1} is calculated as:
Na* = Na^+ - 0.859 * $[Cl^-]$, assuming that Cl is entirely derived from sea salts. If the Na/Cl ratio departs from the ratio in the sea (0.859), this indicates sources or sinks of Na in the catchment.

Net change in transport of Ca and Mg from the limed catchment is calculated from water flow and the difference between simultaneously taken samples from LIM-4 and REF. This difference was then corrected for the mean pre-liming difference between the two catchments. This correction was +0.14 mg L^{-1} for Ca and -0.01 mg L^{-1} for Mg.

The data material was tested statistically by different methods:

Runoff water samples;

1. Systematic pre-liming variability between sub-catchments was tested with simple ANOVA. The tests were performed on the means of calculated differences of simultaneously taken samples at independent (no autocorrelation) LIM-stations and the REF-station. This difference, which reduces the contribution of variance from seasonal variability, is referred to as e.g. Ca-diff.
2. Changes due to liming were also tested by use of this dataset and ANOVA.
3. Trends after, and due to, liming were tested by use of simple regression on the differences. General trends, as reflected in the reference catchment, were thereby eliminated.
4. Changes in water chemistry in the limed catchment (LIM4) relative to the reference catchment (REF) at the point of time of liming (September 1994) were tested by Random Intervention Analysis (RIA) (Carpenter *et al.* 1989). RIA compares differences in concentrations in paired, chronologically-ordered samples for the pre- and post-liming periods with the change obtained from 1000 randomly-ordered sets of differences.

3.2 Soil and soil solution chemistry

3.2.1 Soil sampling

Soil were sampled in summer 1994 before liming at the 6 plots (3 each in the limed and reference catchments) used for analysis of ground vegetation (**Figure 1**). At each plot 1 sample was collected from the humus horizon and 2-3 samples from the mineral soil horizon.

3.2.2 Chemical analyses – soils

Soils were extracted in water for measurement of pH and in 1 M NH_4NO_3 for determination of exchangeable cations. Bulk density, loss on ignition, and Kjeldahl N were measured on bulk soil. Contents of 31 elements was determined by ICP (Inductive coupled plasma emission spectrometry) on acid digests of the bulk soil. Analyses were performed at NISK using standard procedures.

Cation exchange capacity (CEC; NH_4NO_3 extract) was calculated as the equivalent sum of H^+, Al, Ca, Mg, Na, and K. Base saturation (%) is defined as the sum of (Ca+Mg+Na+K)/CEC.

3.2.3 Soil solution sampling

60 Prenart lysimeters were installed prior to liming (August 1994) in the 6 locations selected for vegetation analyses (**Figure 1**), at 3 sites in Fugleliåsen (FU) and 3 in Spjøtåsen (SP); two lysimeters for each sampling depth. The samples were collected following a 24-hour evacuation period. The soil solution was collected from 5 and 15 cm depth and stored in 2 litre Prenart bottles, which were covered to minimise reaction catalysed by sun light or alga growth. The soil solution samples were filtered through 2 µm membranes and stored for less than 48 hours prior to analysis at NIVA. Sampling began in September 1994. There are no pre-liming samples of soil solution.

3.3 Forest inventory

Forest inventories were carried out during summer 1994 in both limed and reference areas. The inventory was made as a systematic sample plot inventory. Lines were laid out with individual distances of 100 m in the forest and along each line sample plots were placed with 50-m distances (**Figure 2**). The plots were circular with an area of 200 m^2. Plots on mineral soil were permanently marked with a wooden pole in the centre. Plots that fell on peat-land, roads, water or barren rocks were classified as non-productive land. Plots that fell in boarder areas between stands were systematically moved 10 meters in one direction. A total of 122 (limed area) and 56 (reference area) plots were measured.

3.3.1 Tree measurement

In each sample plot all trees more than 5 cm in diameter at breast height were measured by diameter and permanently marked with tree number. Tree species were noted.

Sample trees were picked out with relascope. Relascope factor 2 was used and each third of the trees falling within the relascope were picked out for further measurements. These sample trees were measured for height above ground, height to living crown and different kinds of damages were noted according to a manual. Sample cores were taken from all sample trees and annual ring width was measured for the latest 40 years. From each sample plot, where possible, the two largest trees (by diameter) without damages were picked out for site index estimation. In addition to the variables already mentioned, bark thickness was measured and annual height growth visually estimated on these trees. All annual rings were measured for breast height age determination on these trees. The annual rings were measured in laboratory.

3.3.2 Site index, volume- and cutting class calculations

Site index for each sampling plot was estimated from age at breast height and height of the two largest trees (Tveite 1977). Curves for diameter-to-height relationship for each tree species were constructed for the two areas together. Tree height was then estimated for all trees. Volume was calculated using functions for spruce, pine and birch (all broad-leaved trees are treated as birch in this connection) (Braastad 1966, Vestjordet 1967, Brandseg 1967) with diameter and height as independent variables. Cutting class (for definition see text in **Figure 24**) is dependent on site index, species and age and the area distribution of cutting classes have been calculated from the sample plot data for the two areas.

3.4 Intensive monitoring plots

In each of the two areas, 10 sample plots (25 x 30 m) were subjectively laid out (**Figure 3**). The criteria for placing the different plots were to cover the vegetation gradient in the limed catchment, and a comparable gradient in the reference catchment. The gradient varied from dry to wet and from fertile to infertile soils. Within each sample plot an area of 5 x 10 m was used for intensive registration of vegetation (Eilertsen *et al.* 1994). On each plot steepness and exposition were measured.

3.4.1 Registration in the plots

All trees more than 5 cm in breast height were measured by diameter and permanently marked with a number. Height and crown height was measured on about half of the trees in 1994. Height increment was visually estimated on the trees and bark thickness was measured. In 1998 height was just measured on ¼ of the trees. Damages were also noted for these trees.

The 3 largest trees by diameter (spruce or pine) were cored to pith, and age and annual ring width were measured in the laboratory.

Each autumn, diameter was measured on all trees and tree vitality evaluated. The vitality evaluation is based on tree crown density and colour. The crown density (%) is defined as the amount of needles in tree crowns compared to what could be expected on a sound tree in that particular area. The crown colour is an overall impression of the colour based on a scale from 1 to 4: 1 is normal green, 2 slightly yellow, 3 average yellow and 4 strongly yellow. The result from the evaluation is based on the same trees each year and the work has been done by the same person and follows the same criteria as for the Norwegian forest monitoring programme (Groeggen 1997).

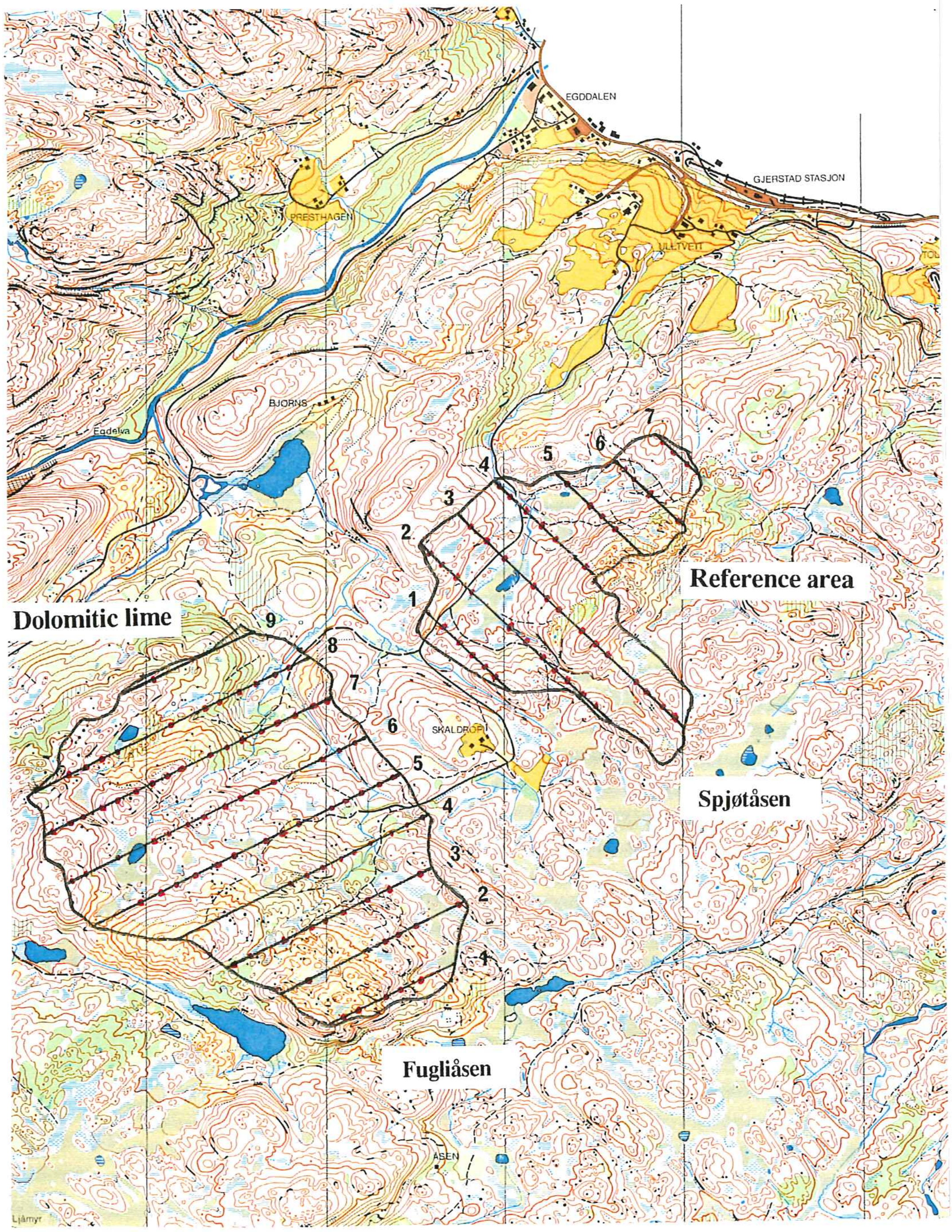


Figure 2. Map showing the two catchments and the sampling lines in each area. Red dots indicate plots where trees were measured. Scale approx. 1:20000.

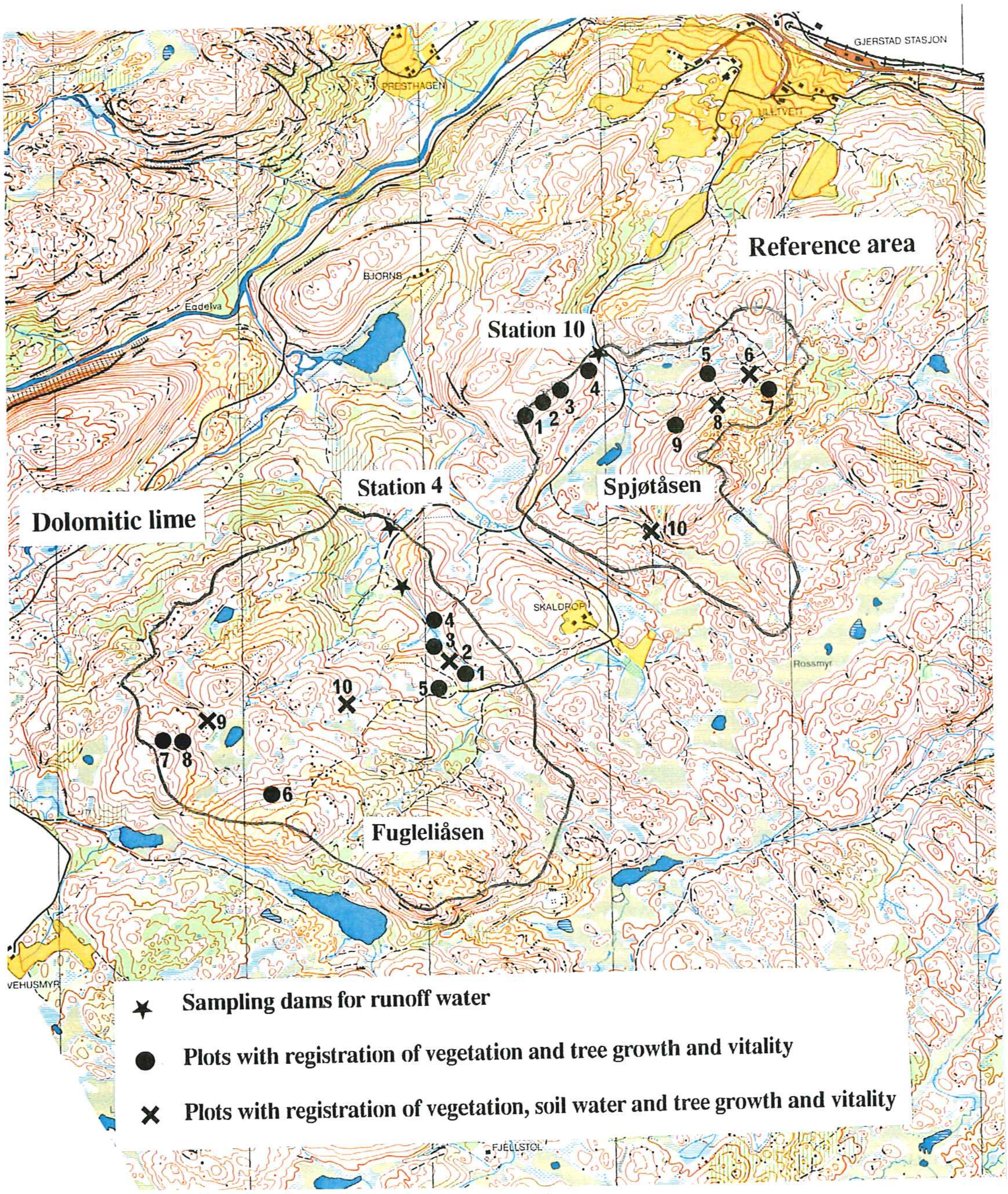


Figure 3. The location of the intensive monitoring plots. All plots were used for vegetation investigations and some for soil solution sampling. Scale approx. 1:20000.

3.4.2 Statistical analysis

Based upon height and diameter the volume of the sample trees was estimated using functions for different tree species (Braastad 1966, Vestjordet 1967, Brandseg 1967). A linear regression between diameter and volume on these trees was used to estimate volume for all trees. The function developed from the 1994 registration was also used for the 1998 data. Volume increment in the 4-year period was calculated as the difference in standing volume between the two years.

Site index (Tveite 1977) was estimated on the basis of age and height of the 3 trees per plot. Site index curves for the dominant tree species was used to determine the site index of the plots.

The increment in the 4-year period from 1994 to 1998 was compared to increment functions developed for Norwegian conditions based on increment investigations on permanent sample plots (Blingsmo 1988). The increment function has standing volume, stand age and site index as explanatory variables. Functions for pine, spruce and birch (used for all broad-leaves) were used and the increment was weighted with the tree species share of total volume.

4. Results

4.1 Precipitation and hydrology

Monthly precipitation amount at the nearby meteorological station Åsbø in Gjerstad and water discharge at the three monitoring stations are shown in **Figure 4** and **Figure 5**.

According to the runoff map of Norway average discharge in the area is 900 mm yr^{-1} (29 L s^{-1} km^{-2}). Based on the measured runoff and the subcatchment areas of stations LIM-1, LIM-4 and REF specific discharge for the four years 1994-1997 were calculated (**Table 3**).

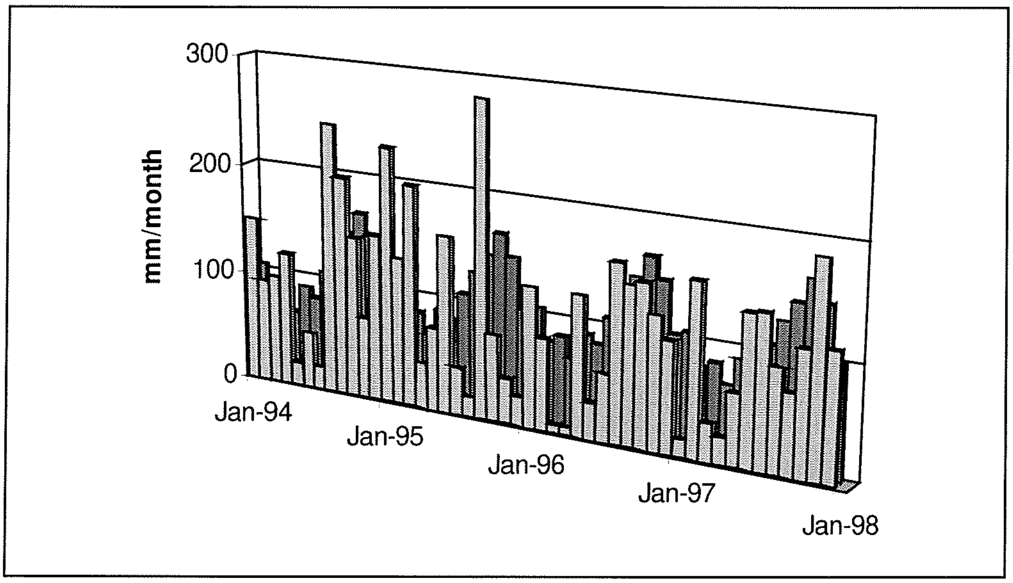


Figure 4. Monthly precipitation amount at the meteorological station (3520 Åsbø) in the monitoring period (in the front) and the 30-year monthly normal precipitation (in the back). Data from the Norwegian Meteorological Institute.

1994 and the hydrological year from summer 1994 to summer 1995 was very wet compared to the following years. Only the year 1995 was close to normal. 1996, 1997 and especially the hydrological year 1995-1996 were dry. Lower discharge in 1996 and 1997 compared with the initial period after liming is also evident when accumulated discharge is calculated (**Figure 6**).

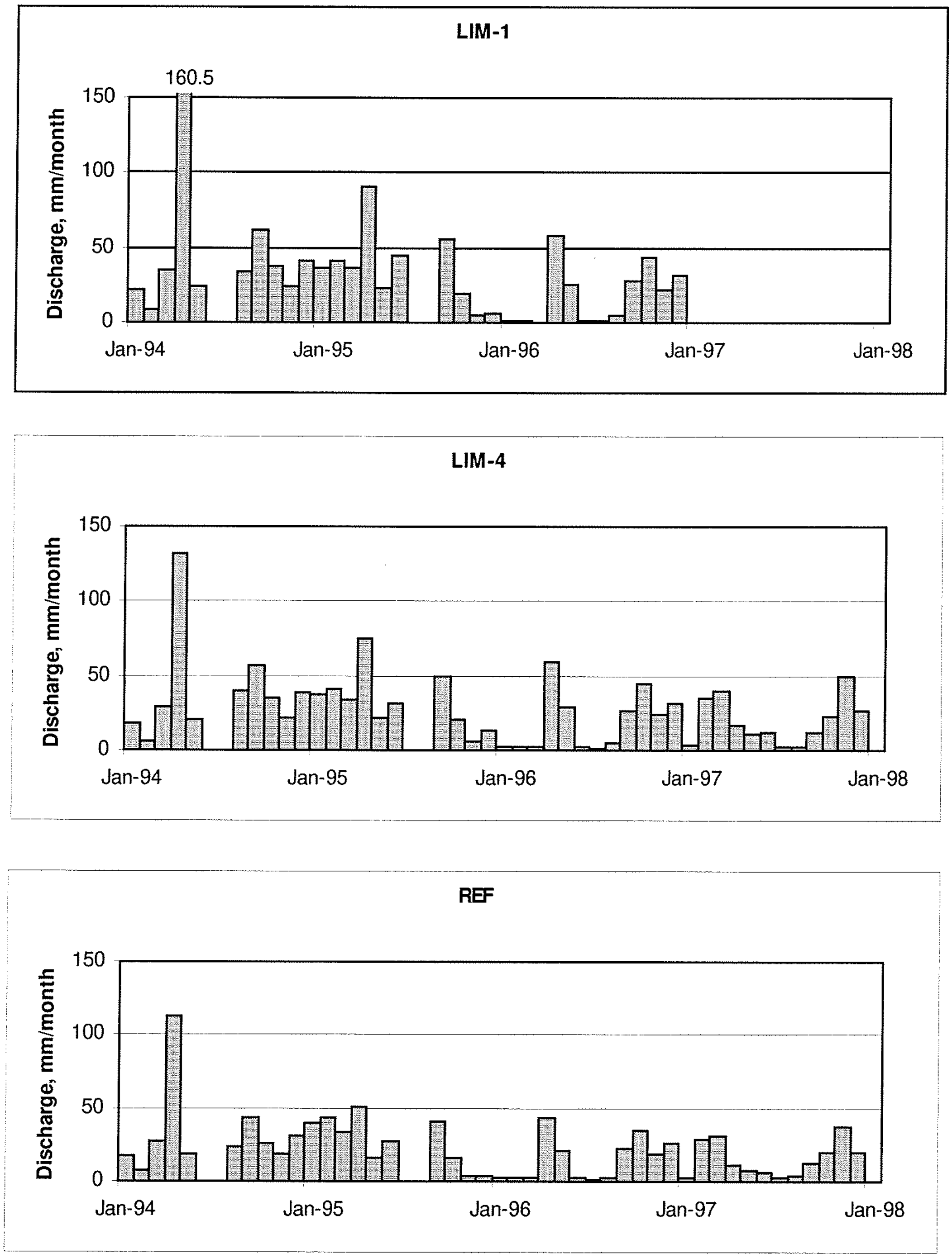


Figure 5. Monthly discharge at LIM-1, LIM-4 and REF. Discharge in 1997 was not measured at LIM-1.

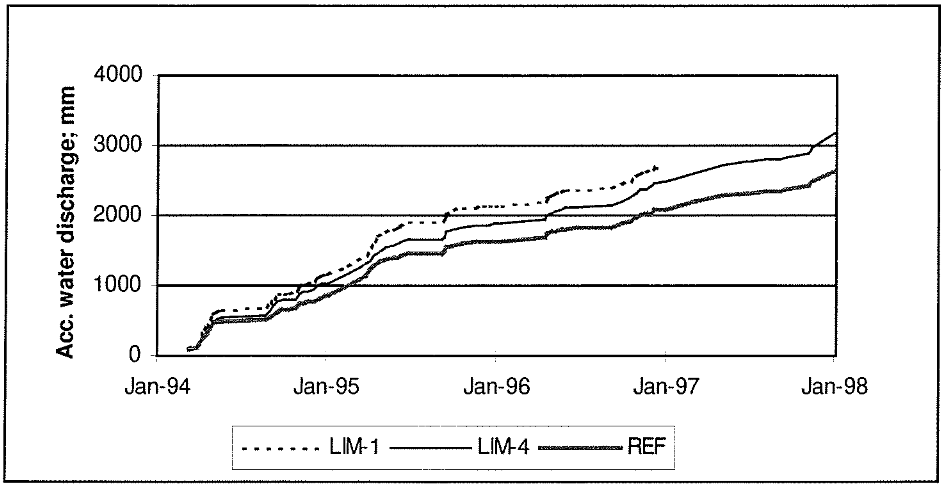


Figure 6. Accumulated water discharge (in mm) at monitoring stations LIM-1, LIM-4 and REF for the period 1994-1997.

Table 3. Calculated specific discharge (mm yr^{-1}) for catchments LIM-1, LIM-4 and REF. Results are given for calendar years and for hydrologic years (1 July to 30 June).

Calendar year		1994	1995	1996	1997
	LIM-1	1057	839	517	612
	LIM-4	1034	855	602	609
	REF	1082	918	599	
Hydrologic year		**1994-1995**	**1995-1996**	**1996-1997**	
	LIM-1	1104	410	653	
	LIM-4	1126	486	640	
	REF	1170	464		

4.2 Runoff water quality

4.2.1 Preliming characteristics

Significant pre-liming variability between subcatchments is reflected in pH, Ca, Mg, ANC, Al-fractions and TOC but not in SO_4 and NO_3 (**Table 4**). This reflects the relatively uniform response of S and N deposition on SO_4 and NO_3 in runoff within the catchment and the more non-uniform geochemical characteristics. The areas draining to LIM-2 and LIM-3 are more acid-sensitive that the LIM-1 catchment. These two areas also had the most toxic water before liming, as seen in lower pH and ANC and higher Ali.

Prior to liming the stream water in both catchments was chronically acidified (**Table 4** and **Table 5**). pH was generally between 4.5 and 5.5 (**Figure 7**), and mean concentrations of reactive aluminium (Alr) were 248 µg L^{-1} and 191 µg L^{-1} in the two catchments (**Table 5**). About 70 % of the Al was organically bound. The relatively high organic Al-fraction can be related to the generally high contents of total organic matter (TOC) in the streams (6-8 mg TOC L^{-1}).

4.2.2 Post-liming characteristics

After liming significant increases in pH, Ca, Mg and ANC were found for all LIM-stations relative to the REF-station. **Table 5** summarises this effect for LIM-4. The immediate response in pH, which increased to 5.5-6.0, is clearly seen in **Figure 7**. At the main outlet of the limed catchment (at LIM-4) the mean concentration of Ca and Mg increased by 0.35 and 0.44 mg L^{-1}, respectively. Acid

Table 4. Pre-liming mean values and st. dev. (in brackets) of 4 independent sampling stations (n=17 for LIM-2; n=19 for LIM-1, LIM-3 and REF) and of LIM-4 (n=19). Letters a-d denote significant differences ($p<0.05$) between columns based on multiple range tests.

		LIM-1	LIM-2	LIM-3	REF	LIM-4
SO_4	mg L^{-1}	4.6 (0.8)	4.2 (0.5)	4.4 (0.4)	4.3 (0.7)	4.4 (0.6)
NO_3-N	µg L^{-1}	74 (88)	67 (73)	60 (57)	50 (57)	70 (71)
H^+*	µeq L^{-1}	13 (6)a	24 (5)c	17 (6)ab	17 (6)b	16 (6)ab
pH*		4.94 (0.23)c	4.63 (0.10)a	4.82 (0.20)bc	4.79 (0.20)b	4.84 (0.19)bc
Ca*	mg L^{-1}	1.22 (0.37)b	0.85 (0.19)a	1.09 (0.23)b	1.26 (0.33)b	1.13 (0.29)b
Mg*	mg L^{-1}	0.41 (0.11)c	0.30 (0.06)a	0.32 (0.05)ab	0.36 (0.08)b	0.36 (0.08)b
ANC*	µeq L^{-1}	17 (14)cd	-6 (9)a	5 (10)b	23 (17)d	11 (11)bc
Alr*	µg L^{-1}	233 (72)ab	273 (63)b	268 (74)b	191 (56)a	248 (69)b
Alo	µg L^{-1}	175 (60)	184 (51)	164 (52)	157 (49)	176 (59)
Ali*	µg L^{-1}	58 (20)b	89 (27)c	103 (35)c	34 (14)a	72 (19)b
TOC*	mg L^{-1}	8.1 (3.4)b	6.8 (2.4)ab	6.1 (2.4)a	8.5 (2.9)b	7.0 (2.6)ab

neutralising capacity (ANC) increased from 11 to 49 µeq L^{-1}, whereas a decrease was seen in the unlimed catchment (**Table 5**. Liming did not result in significant changes in Na, K, NH_4, SO_4, Cl, Alo, tot N, organic N, TOC or organic C/N.

After the initial increase during the first 10 months after liming, no significant trends were detected for base cations, pH, ANC or aluminium species at LIM-4. There were thus no signs of re-acidification.

A significant decrease in Alr ($p<0.001$) due to liming was found for LIM-1 and LIM-4 (**Table 6** and **Figure 9**). The decrease in Alr-concentration was rather modest, however, from 42 and 47 µg L^{-1} preliming to -10 and –9 µg L^{-1} post-liming for LIM-1 and LIM-4, respectively, relative to REF. This means that the Alr-concentration in the limed catchment was only slightly lower than in the reference catchment after liming. A corresponding decrease from 24 and 38 to -22 and -21 µg L^{-1} was found for the difference in the inorganic monomeric fraction (Ali-diff). Ali is supposed to include the toxic Al-species, and the mean concentration of this fraction was 17 µeq L^{-1} after liming (**Table 5**). No significant liming-related change in Alo or TOC was found.

The Random Intervention Analysis also shows that pH, Ca, Mg, and ANC concentrations increased and Alr and Ali decreased significantly in LIM-4 relative to REF in September 1994, the point of time of liming (**Table 6**). RIA indicates no significant changes in TOC or NO_3.

A significant ($p<0.05$) increasing trend was found for TOC at LIM-1, but not at LIM-4. For sulphate and the organic C/N-ratio this was reversed; a significant increasing trend at LIM-4, but not at LIM-1.

Table 5. Mean stream water values and std. deviation (in brackets) for different variables in the limed (LIM-4) and reference (REF) catchments before and after treatment in September 1994. n=17-19 pre-liming and n=55-57 post-liming for all variables. * denotes significant change ($p<0.05$) of mean or median at LIM-4 due to liming and at REF after the time of liming. Significance of change at LIM-4 is based on differences of simultaneously taken samples according to ANOVA or the non-parametric Kruskall-Wallis test, see also **Table 6**.

		LIM-4		REF	
		Before	After	Before	After
H^+	$\mu eq\ L^{-1}$	15.9 (6.2)	1.6 (0.88)*	17.3 (6.3)	12.7 (4.5)*
pH	units	4.84 (0.19)	5.86 (0.23)*	4.79 (0.20)	4.93 (0.18)*
Ca	$mg\ L^{-1}$	1.13 (0.29)	1.51 (0.25)*	1.26 (0.33)	1.29 (0.28)
Mg	$mg\ L^{-1}$	0.36 (0.08)	0.81 (0.17)*	0.36 (0.08)	0.38 (0.08)
Na	$mg\ L^{-1}$	1.81 (0.35)	1.73 (0.20)	1.81 (0.39)	1.74 (0.25)
K	$mg\ L^{-1}$	0.21 (0.11)	0.21 (0.09)	0.17 (0.08)	0.20(0.12)
NH_4-N	$\mu g\ L^{-1}$	23 (31)	40 (56)	19 (14)	52 (58)
SO_4	$mg\ L^{-1}$	4.4 (0.6)	4.3 (0.9)	4.3 (0.7)	4.0 (0.9)
Cl	$mg\ L^{-1}$	2.2 (0.8)	2.6 (0.7)	2.2 (0.8)	2.5 (0.7)*
NO_3-N	$\mu g\ L^{-1}$	70 (71)	98 (98)**	50 (57)	59 (58)
ANC	$\mu eq\ L^{-1}$	11 (11)	54 (19)*	23 (17)	17 (14)
Alr	$\mu g\ L^{-1}$	248 (69)	167 (40)*	191 (56)	176 (38)
Alo	$\mu g\ L^{-1}$	175 (59)	152 (40)	157 (49)	140 (30)
Ali	$\mu g\ L^{-1}$	72 (19)	15 (12)*	34 (14)	37 (18)
Tot N	$\mu g\ L^{-1}$	314 (163)	355 (115)	328 (115)	358 (124)
Org N	$\mu g\ L^{-1}$	223 (116)	217 (80)	261 (106)	247 (100)
TOC	$mg\ L^{-1}$	7.0 (2.6)	7.4 (2.1)	8.5 (2.9)	8.4 (2.3)
Org C/N		34 (6)	35 (4)	34 (4)	35 (6)

Table 6. Results of random intervention analysis comparing difference in concentrations in paired samples collected from LIM-4 (limed) and REF (reference) for the periods pre- and post-liming.

			H^+	pH	Ca	Mg	Alr	Ali	TOC	ANC	NO_3-N
			$\mu eq\ L^{-1}$		$mg\ L^{-1}$	$mg\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$mg\ L^{-1}$	$\mu eq\ L^{-1}$	$\mu g\ L^{-1}$
pre-liming	average	LIM4	15.9	4.84	1.14	0.36	250	73	7.2	11	70
n=18	average	REF	17.3	4.80	1.28	0.37	194	34	8.7	24	50
	avg. diff-pre = LIM4-REF		-1.4	0.04	-0.14	0.00	56	38	-1.5	-13	20
post-liming	average	LIM4	1.6	5.86	1.51	0.81	167	15	7.4	54	98
n=57	average	REF	12.7	4.93	1.29	0.38	176	36	8.4	17	59
	avg. diff-post = LIM4-REF		-11.1	0.93	0.22	0.42	-9	-21	-1.0	36	40
change in difference between LIM4 and REF at point of time of liming, Sept. 94 = diff-post - diff-pre			-9.7	0.89	0.36	0.43	-65	-60	0.5	49	19
	RIA level of significance, p<		0.001	0.001	0.001	0.001	0.001	0.001	n.s.	0.001	n.s.

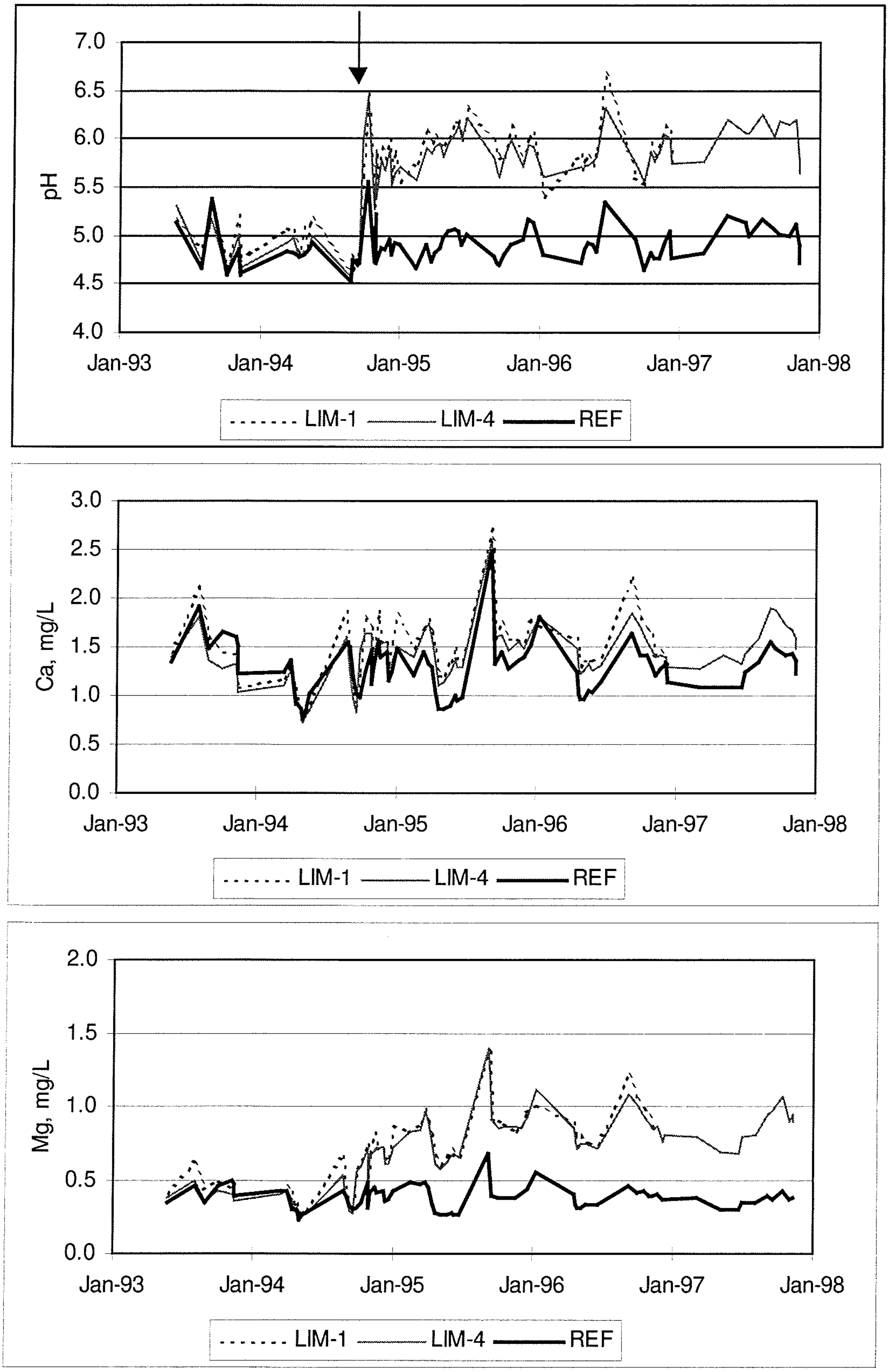
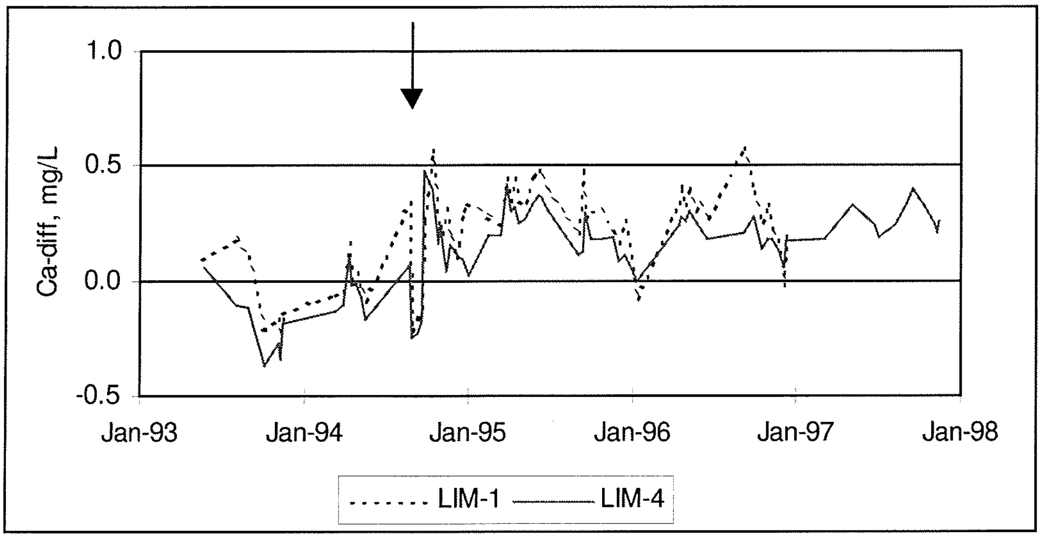


Figure 7. pH, Ca and Mg in streams of limed (LIM-1 and LIM-4) and reference (REF) catchment in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).



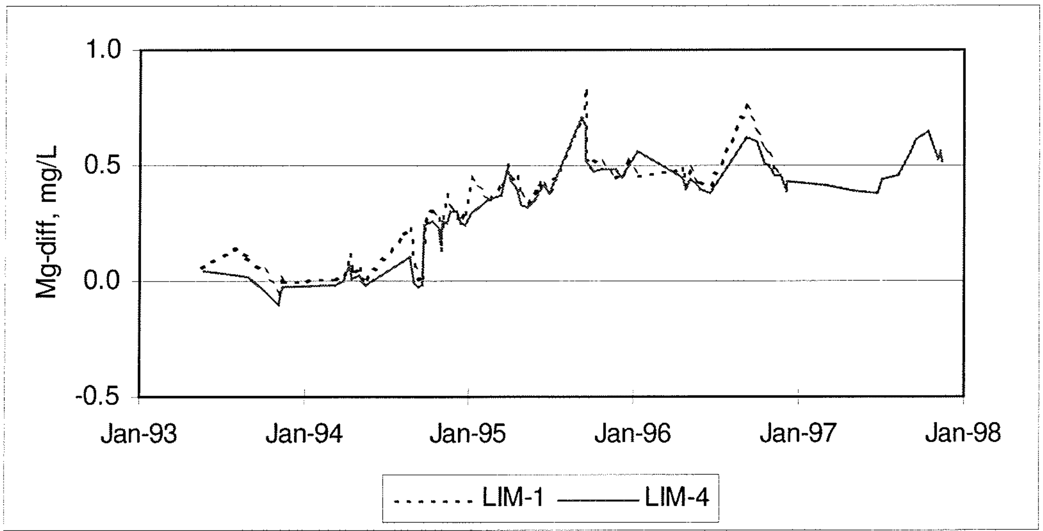


Figure 8. Differences in Ca and Mg concentrations between limed and reference streams in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).

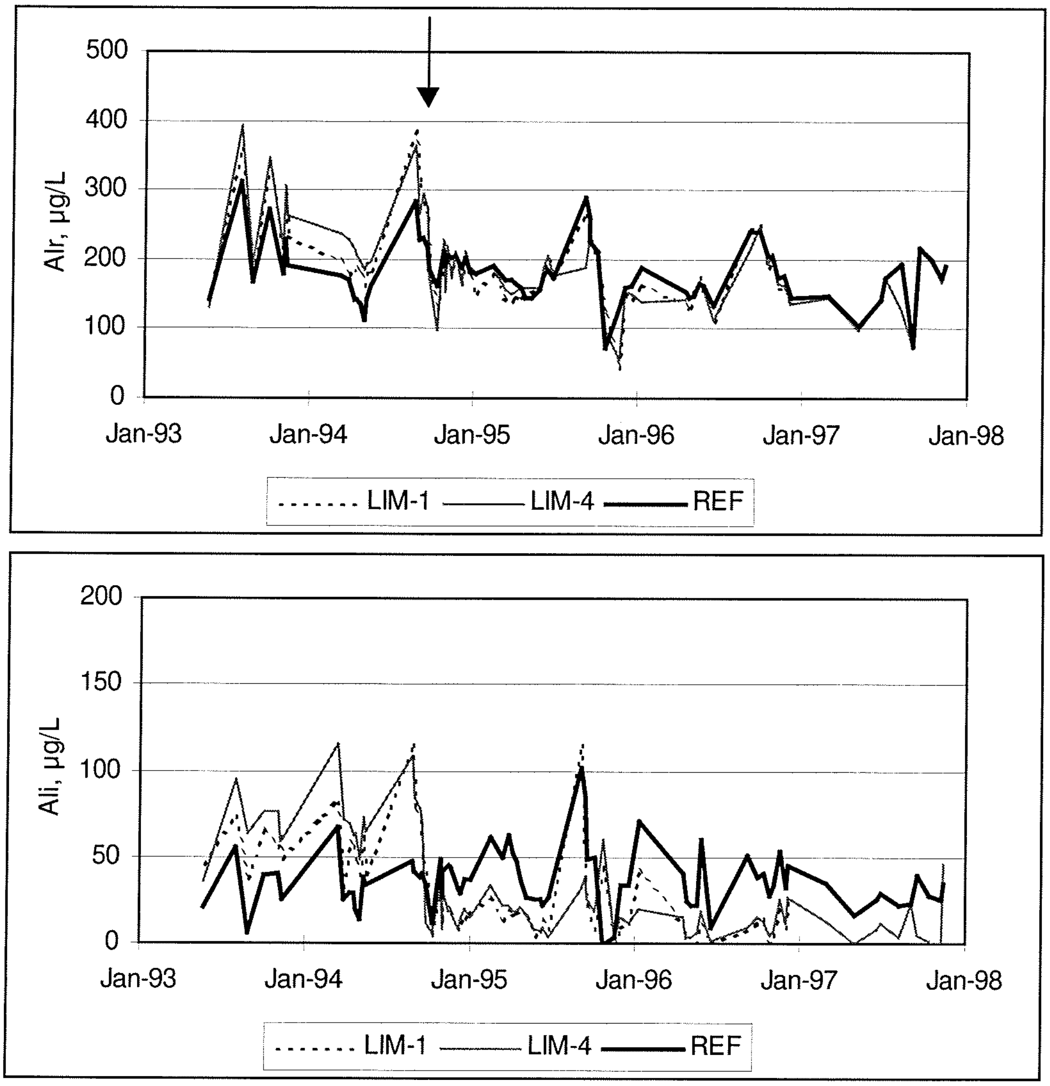


Figure 9. Reactive (Alr) and inorganic monomeric (Ali) aluminium in streams of limed (LIM-1 and LIM-4) and reference (REF) catchment in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).

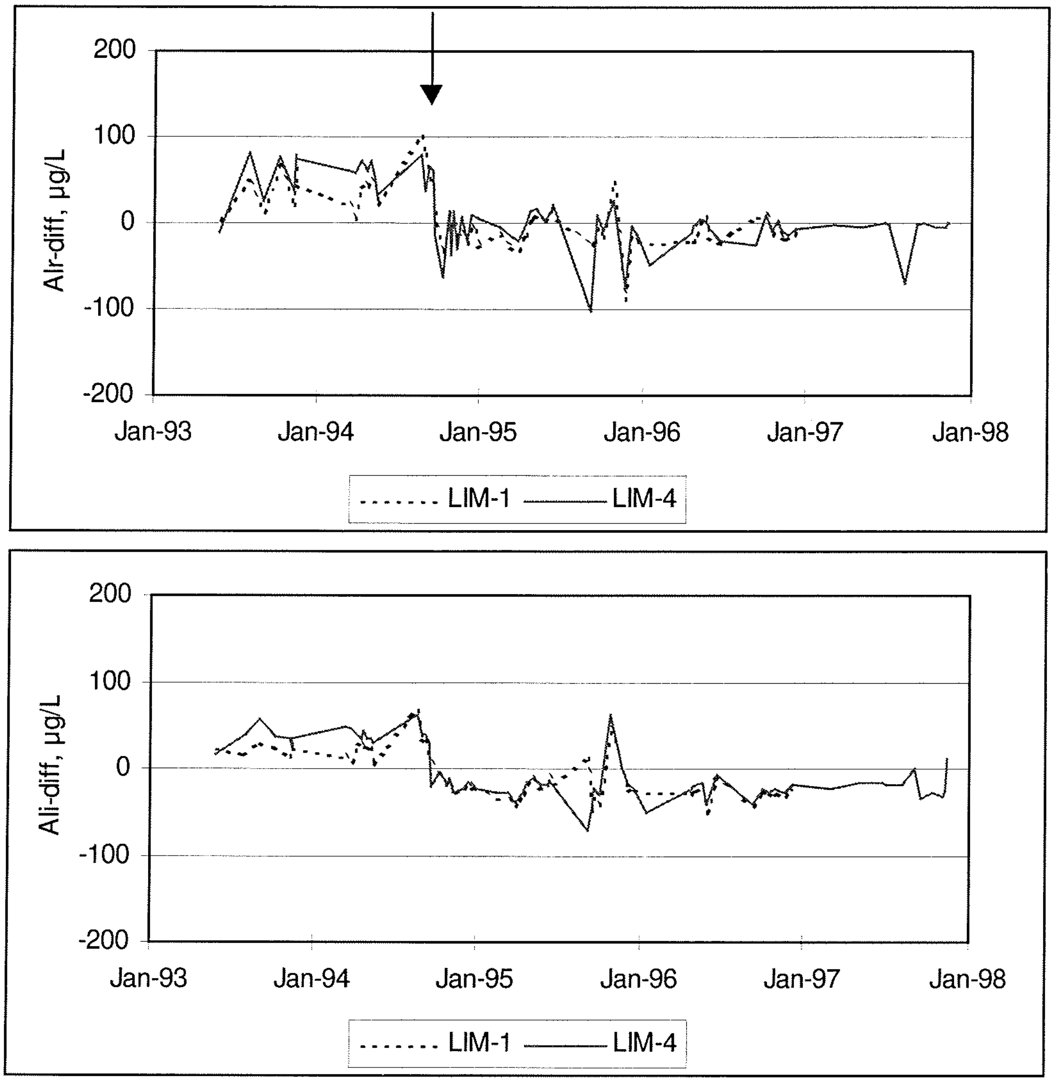


Figure 10. Differences in concentrations of reactive (Alr) and labile (Ali) aluminium between limed and reference streams in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).

Sea salts were not supposed to have significant impacts on the water chemistry, in terms of episodic acidification and Mg supply to the forest soil, due to the distance from the coast. However, in January 1995 (four months after liming) a strong increase in stream Cl concentrations indicated relatively large inputs of salts, and this resulted in negative values for non-marine Na and the lowest estimated ANC in the unlimed catchment in the project period **Figure 11**. The limed catchment also showed a drop in ANC, but not to negative values.

The seasonal variability was relatively large for concentrations of NO_3 (**Figure 12**). Some of the problems this might have on the statistical tests were eliminated by use of the differences between data-pairs of limed and reference samples. But also the differences were characterised by seasonal variability (**Figure 12**). This was found for both the preliming and post-liming period. The streams do not appear to differ until the second winter following liming. The result of the ANOVA-test of the pre-liming and post-liming NO_3-diff for LIM-1 and LIM-4 was a small but significant increase in the medians at the $p<0.05$ level in LIM-4, but not in LIM-1. Randon intervention analysis showed no significant difference (**Table 6**).

The organic N fraction, the C/N-relationship of the dissolved organic matter and total phosphorus concentration did not change significantly after liming (**Table 5** and **Figure 13**).

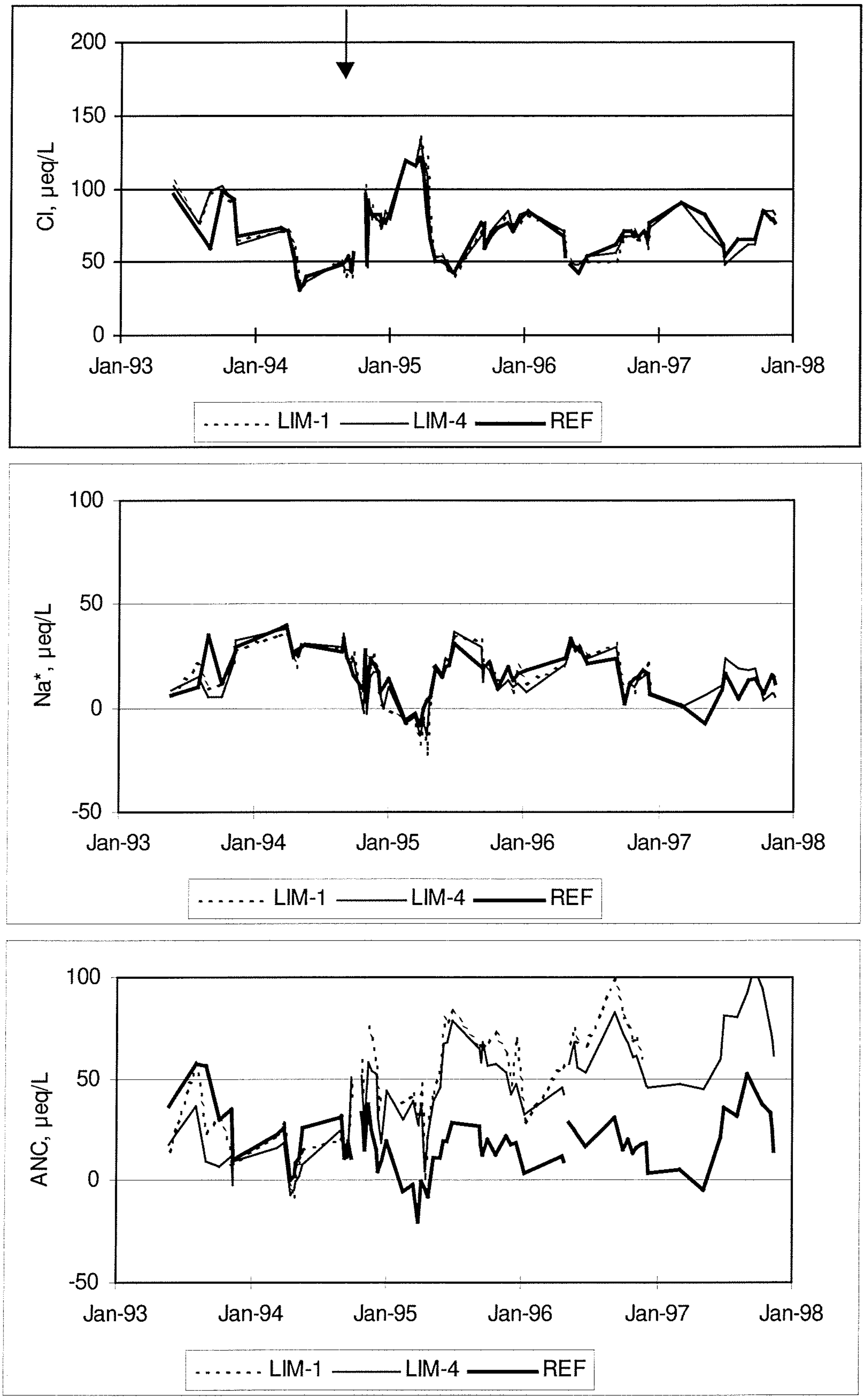


Figure 11. Chloride, non-marine Na (Na*) and ANC in streams of limed (LIM-1 and LIM-4) and reference (REF) catchment in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).

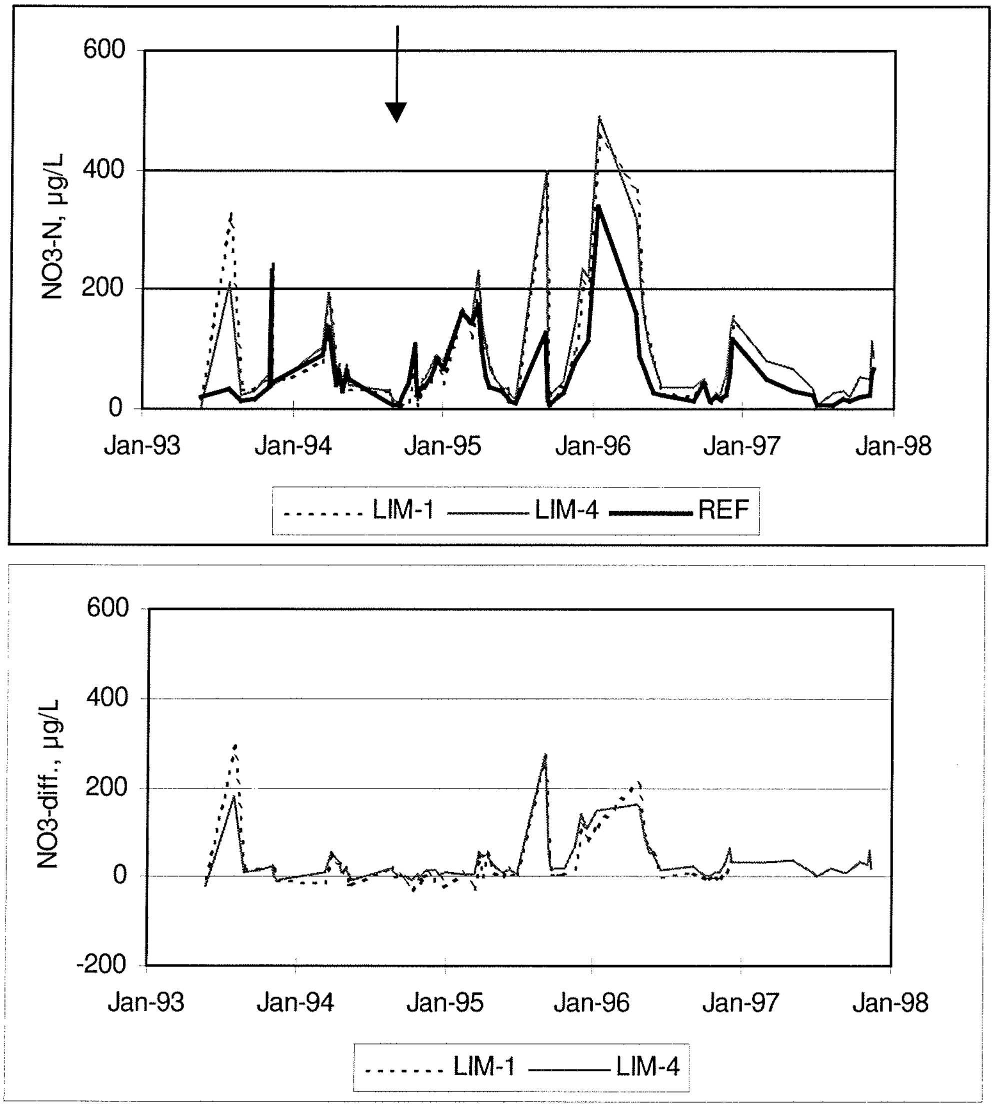


Figure 12. NO_3-N in streams of limed (LIM-1 and LIM-4) and reference (REF) catchments in the Gjerstad forest. The NO_3-N-diff. is shown in the lower panel. Dolomite was spread in September 1994 (arrow).

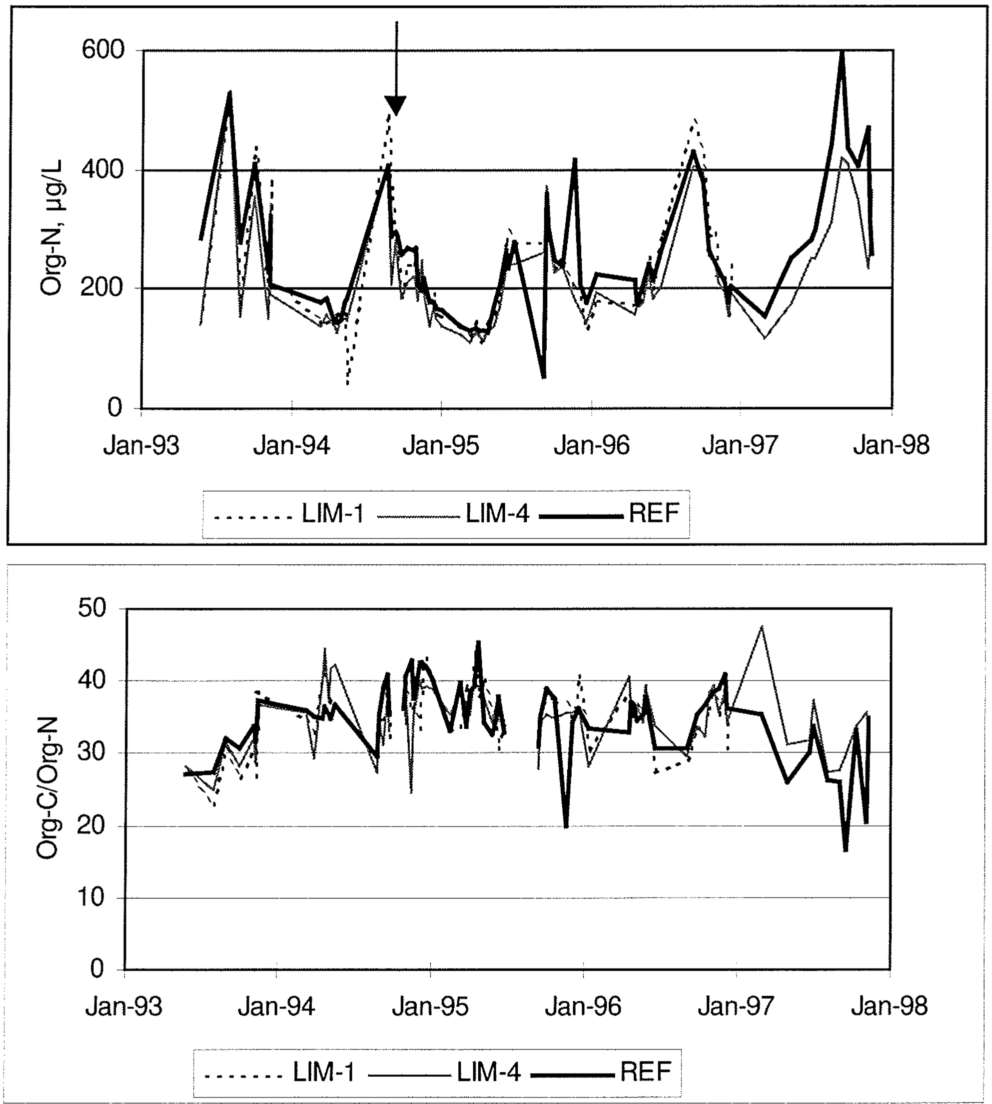


Figure 13. Dissolved organic N and the Org C/Org N ratio in streams of limed (LIM-1 and LIM-4) and reference (REF) catchment in the Gjerstad forest. Dolomite was spread in September 1994 (arrow).

4.2.3 Trace metals

No pre-liming data of trace metals are available and thus changes from pre-liming to post-liming period cannot be analysed. However, concentrations in the limed stream relative to the reference stream were analysed for differences and post-liming trends.

Relative to REF none of 10 trace metals in monthly point samples were significantly higher after liming (**Table 7**). In fact, Cd, Co, Fe, Mn, Ni, Pb and Zn were significantly lower in the stream of the limed catchment, which may be due to inherent differences between the streams or may be an effect of the liming. Only Mn, Co and Zn showed significantly decreasing trends in runoff from the limed catchment during the 3-year monitoring period (**Figure 14**). Fe, Pb, Cd, Cu, As and Ni remained relatively unaffected by the dolomite application. Cr was mostly below detection limits in both limed and unlimed catchments.

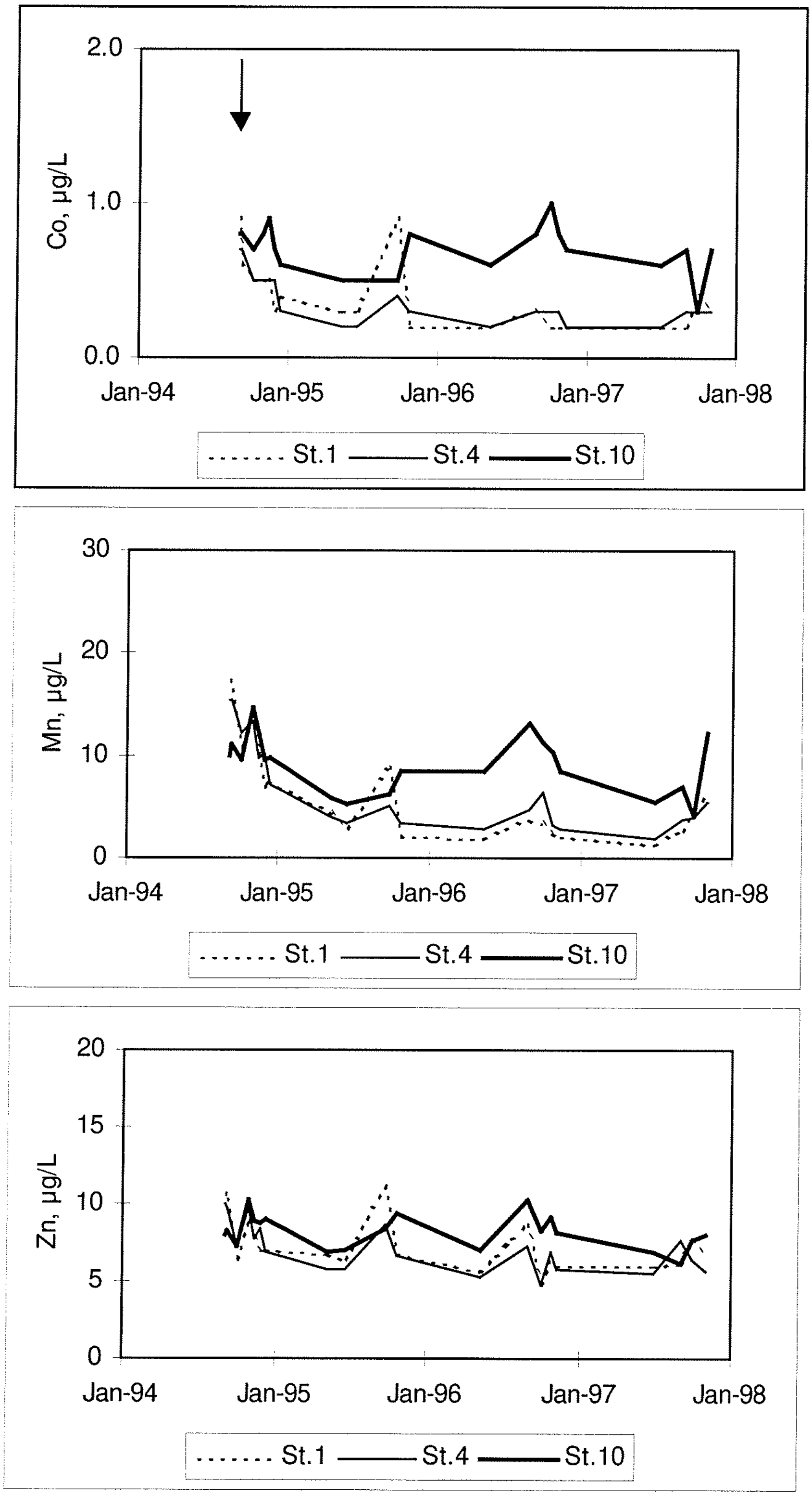


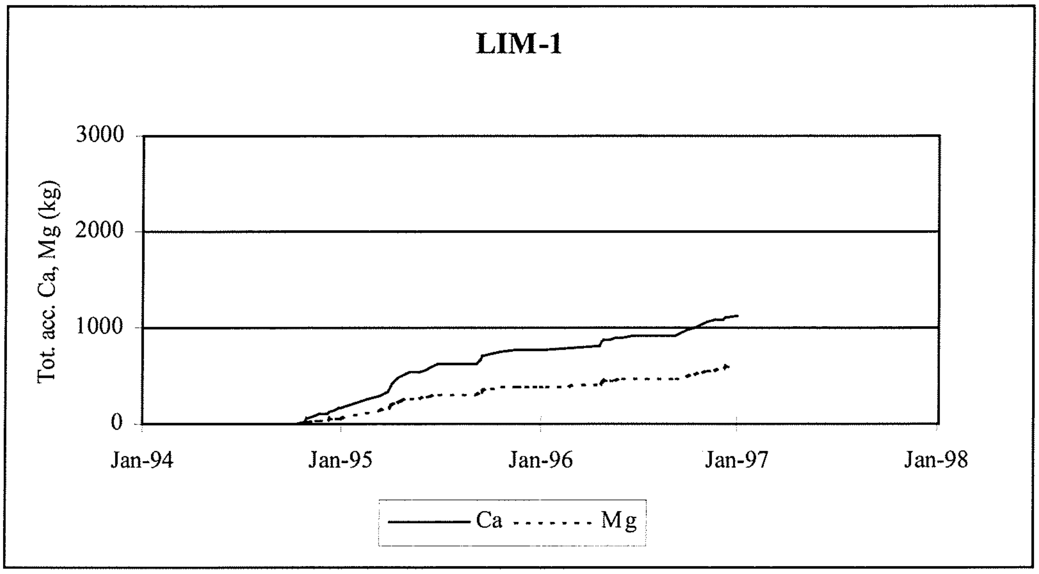
Figure 14. Cobalt (Co), manganese (Mn) and zinc (Zn) in streams of limed (LIM-1 and LIM-4) and reference (REF) catchment in the Gjerstad forest. Dolomite was spread in September 1994.

Table 7. Mean and st. dev. or median (in µg L^{-1}) of nine trace metals from point samples of streams in limed (LIM4) and unlimed (REF) catchments. All samples (n=18) are from the post-liming period. * denotes significantly ($p<0.05$) lower mean or median values for LIM-4 than for REF. Other metals are not significantly different. Concnetrations in the samples reported under the detection limit were set at ½ the detection limit.

	LIM-4		**REF**	
	Mean (st.dev.)	Median	Mean (st.dev.)	Median
As	0.27 (0.15)		0.36 (0.20)	
Cd*		0.03		0.05
Co*	0.32 (0.11)		0.68 (0.17)	
Cu	0.52 (0.17)		0.58 (0.21)	
Fe*		122		201
Mn*	5.7 (3.4)		9.0 (3.0)	
Ni*		0.8		1.05
Pb	0.64 (0.19)		0.72 (0.16)	
Zn*	6.8 (1.3)		8.2 (1.2)	

4.2.4 Ca and Mg transport

The total transport of Ca and Mg at LIM-4 during the first 3 years after liming was 2090 and 1150 kg, respectively (**Figure 15**; transport at LIM-1 is also shown). Based on the pre-liming and post-liming differences between samples from LIM-4 and REF a net transport of 518 kg Ca and 576 kg Mg from the applied dolomite was calculated for the first 3 years after liming (**Figure 16**). This corresponds to 0.9 % and 2.0 % of the added amounts of these elements. An annual transport of less than 1 % of the dose for both Ca and Mg was thus found in this experiment.



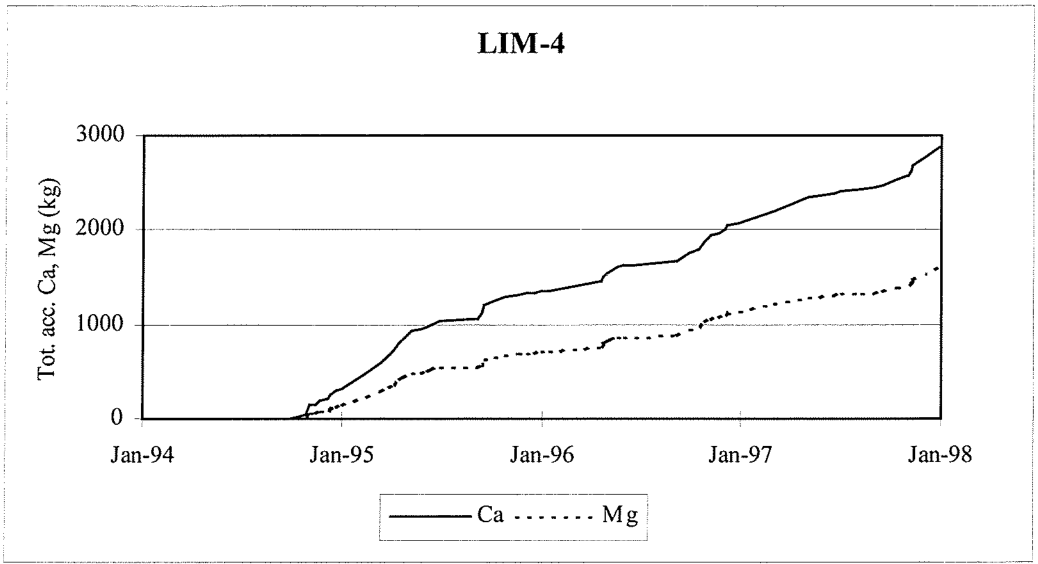
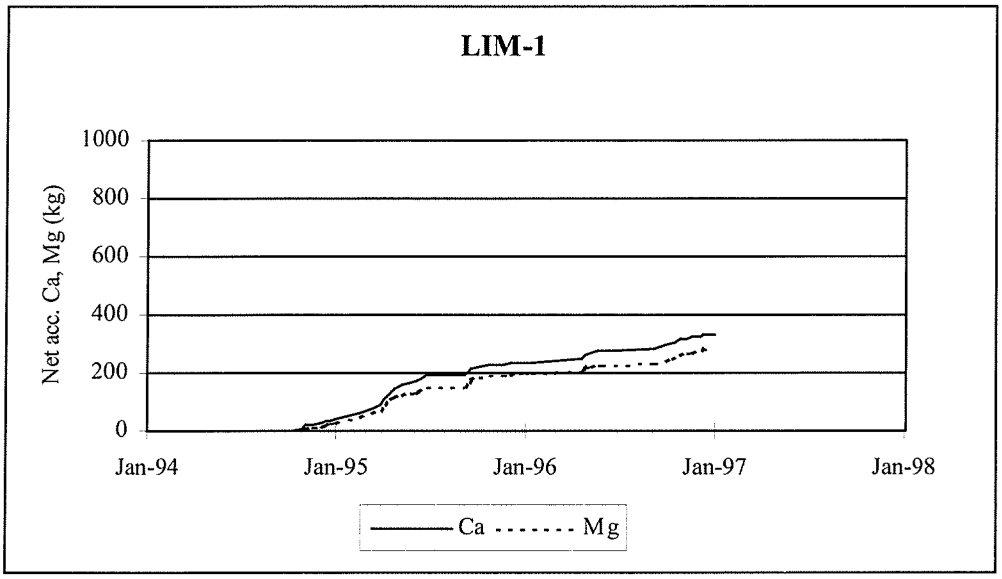


Figure 15. Accumulated total amount of Ca and Mg transported out at stations LIM-1 and LIM-4 of the limed catchment.



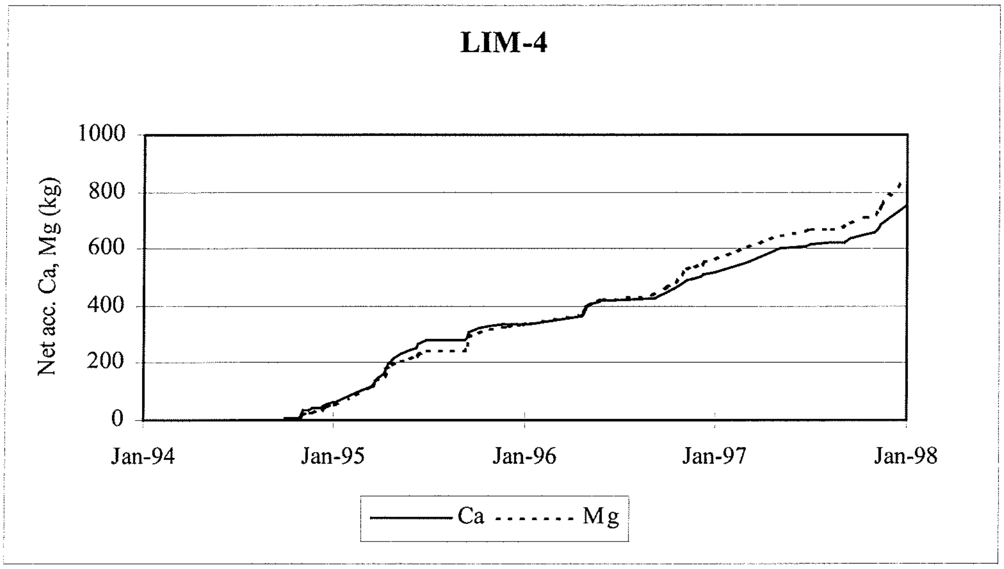


Figure 16. Accumulated net (due to liming) amount of Ca and Mg transported out at stations LIM-1 and LIM-4 of the limed catchment, relative to that expected based on transport from the reference catchment (REF).

4.3 Soil chemistry

The soil data at the lysimeter stations represent the composition of the organic (5 cm) and mineral (15 cm) soil layer before liming. Data for six locations, three located in the limed catchment and three located in the control catchment are given in **Table 8** and **Table 9**.

The results show that the soils vary widely in chemical composition. This reflects the wide range in site characteristics. The 3 sites in each catchment were intentionally chosen to cover a range in vegetation, soil and moisture conditions.

4.3.1 Soils of the control catchment

Stations SP 28 and SP 30.
This location is covered with ferns and deciduous trees. The ground water table is high, and there were never problems in filling the lysimeter bottles. The pH values in the water samples extracted from the organic and mineral soil were relatively high (4.82 and 4.9, respectively).

Stations SP 37 and SP 40
Station SP 37 is located in a hollow in the ridge hill, while SP 40 is located in a rather dry and poor slope just above SP 37. The dominating forest is coniferous. The soil solution samples normally had a vigorous yellow colour and the volume at SP 40 was usually low, especially at 15 cm.

Stations SP 46 and SP 50
These stations are located in a shady area beneath large spruce trees. The ground vegetation was poorly developed. The site is moderately dry.

4.3.2 Soils of the limed catchment

Stations FU 06 and FU 07
Stations FU 06 and FU 07 were located in poor soil in a pine forest. The soil solution samples from this location normally were low in volume and of yellow colour. The soil quality can be compared to soils at stations SP 30 and SP 40.

Stations FU 44 and FU 45
These stations are located in the bottom of a small valley with a mixed forest of coniferous and deciduous trees, among them a number of birches. The ground water level is high and the lysimeter bottles were filled up with water within a few hours.

Stations FU 48 and FU 49
Station FU 48 was placed in a boggy soil close to a stream, while FU 49 was located higher up on the ground in between the roots of a big alder. The lysimeter FU 49 seldom gave water samples at all.

Taken together the 6 soils at the 3 sites in the reference catchment are similar chemically to the 6 soils of the 3 sites in the limed catchment (**Figure 17**). The heterogeneity of the sites is reflected in the large standard deviations about the means. The soils are typical for coniferous forests in Norway, although they have rather low C/N ratios. This may reflect the long-term deposition and storage of N in the soil.

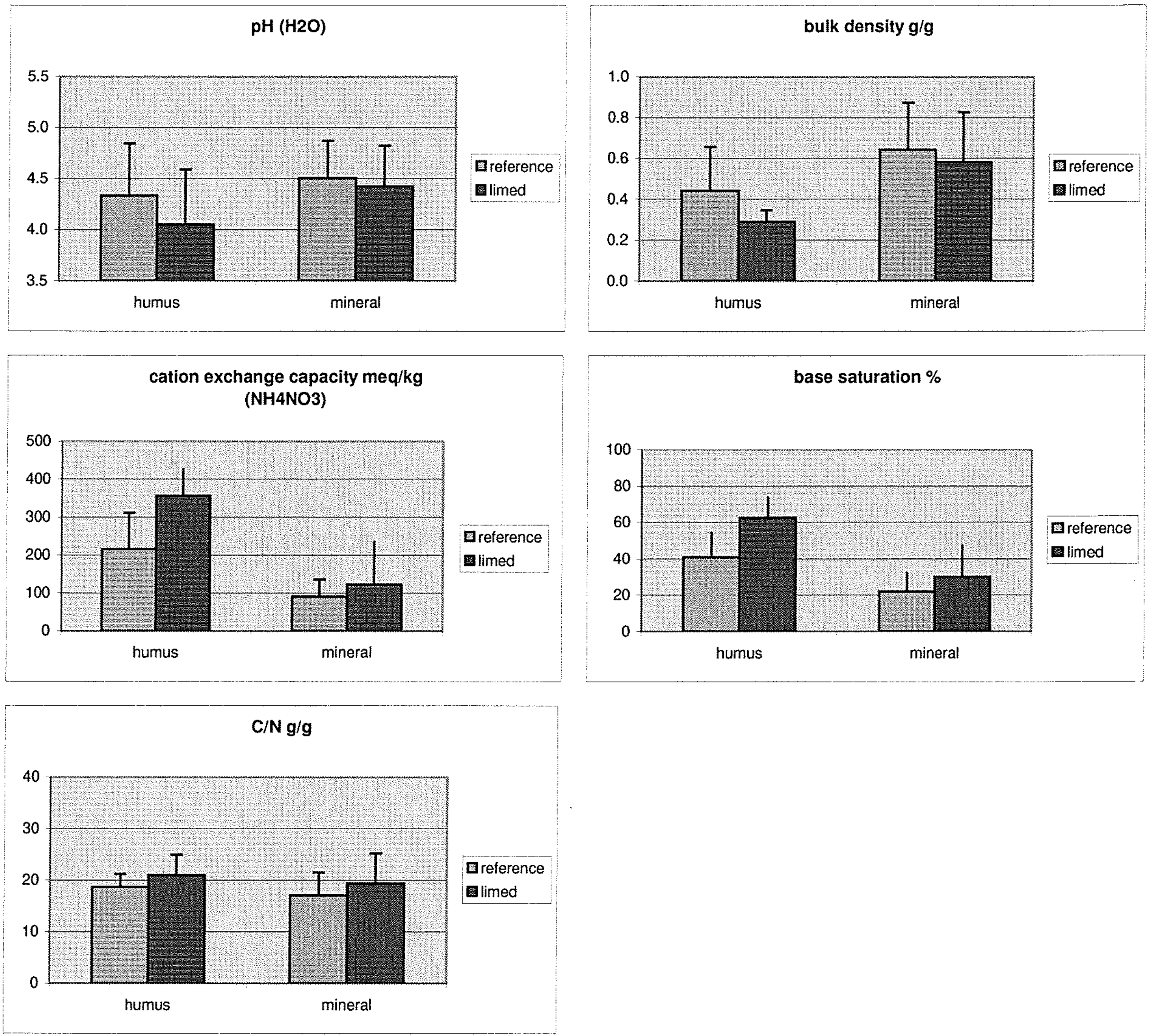


Figure 17. Soil chemistry at the 6 sites in the reference and limed catchments at Gjerstad, sampled in summer 1994 prior to liming. Mean and standard deviation of the samples (n=6 for humus; n=12-15 for mineral soil) are shown.

Table 8. a. Pre-liming composition of organic soil in three locations in the reference catchment (SP) and three locations in the limed catchment (FU). B.D. = bulk density; L.O.I. = loss on ignition; Kjel-N = Kjeldahl-N.

HUMUS GJERSTAD, 1994

									total analyses, ICP					
OBS	site		pH H_2O	B. D. $g\ g^{-1}$	Dry wt. %	L.O.I. %	Kjel-N $mmol\ kg^{-1}$	calc. C/N $g\ g^{-1}$	Al $mmol\ kg^{-1}$	Ca $mmol\ kg^{-1}$	K $mmol\ kg^{-1}$	Mg $mmol\ kg^{-1}$	Na $mmol\ kg^{-1}$	S $mmol\ kg^{-1}$
34	SP28		4.86	0.526	90.4	52.78	1167	16.15	1285	28.6	19.2	104.3	6.29	63.62
36	SP30		4.82	0.28	88.3	80.53	1717	16.75	977	20.8	16.4	15.5	6.38	81.42
44	SP37		3.87	0.236	90.1	89.95	1484	21.65	260.2	33.3	26.9	16.9	8.25	78.26
48	SP40		3.6	0.263	92.7	74.18	1009	26.26	114.2	50.5	23.8	23.6	4.93	50.28
55	SP46		4.44	0.578	94.7	29.59	616	17.16	427.7	62.6	22.4	150.8	6.14	30.53
60	SP50		4.42	0.767	97.6	15.25	386	14.11	152.9	42.1	10.8	40.6	4.86	16.53
67	FU06		3.55	0.22	90.1	89.49	1081	29.57	50.66	83.3	26.7	22.1	8.62	58.34
68	FU07		3.56	0.231	90.8	86.38	1141	27.04	61.59	79.8	20.3	21.4	7.73	62.16
113	FU44		4.51	0.293	88.9	91.72	2061	15.89	403.2	134.2	25.8	23.5	13.81	121.6
114	FU45		4.88	0.285	88.1	84.64	1559	19.39	819.1	78.4	20.7	16.6	9.12	83.99
118	FU48		3.79	0.354	92.7	68.47	1410	17.34	113.2	50.2	19.3	44.8	6.78	73.84
119	FU49		4.02	0.349	93.5	61.48	1325	16.57	91.24	111.8	18.2	49.7	7.4	68.34
count	SP	ref	6	6	6	6	6	6	6	6	6	6	6	6
average	SP	ref	4.34	0.44	92.30	57.05	1063.17	18.68	536.17	39.65	19.92	58.62	6.14	53.44
min	SP	ref	3.60	0.24	88.30	15.25	386.00	14.11	114.20	20.80	10.80	15.50	4.86	16.53
max	SP	ref	4.86	0.77	97.60	89.95	1717.00	26.26	1285.00	62.60	26.90	150.80	8.25	81.42
S.D.	SP	ref	0.51	0.22	3.42	29.82	505.34	4.46	483.31	15.29	5.76	56.10	1.24	26.08
count	FU	limed	6	6	6	6	6	6	6	6	6	6	6	6
average	FU	limed	4.05	0.29	90.68	80.36	1429.50	20.97	256.50	89.62	21.83	29.68	8.91	78.05
min	FU	limed	3.55	0.22	88.10	61.48	1081.00	15.89	50.66	50.20	18.20	16.60	6.78	58.34
max	FU	limed	4.88	0.35	93.50	91.72	2061.00	29.57	819.10	134.20	26.70	49.70	13.81	121.60
S.D.	FU	limed	0.54	0.06	2.11	12.37	355.40	5.86	305.37	29.31	3.54	13.89	2.54	23.17

Table 8. b. Pre-liming composition of organic soil (extracts in NH_4NO_3 (1M)) in three locations in the reference catchment (SP) and three locations in the limed catchment (FU). CEC = cation exchange capacity; BS = base saturation.

OBS	site		CEC µeq kg^{-1}	BS %	Al mmol kg^{-1}	Ca mmol kg^{-1}	K mmol kg^{-1} (exchangeable ions)	Mg mmol kg^{-1}	Na mmol kg^{-1}	P mmol kg^{-1}	S mmol kg^{-1}
34	SP28		150.9	31.6	34.58	13.79	8.09	4.28	3.48	0.1	4.1
36	SP30		219.3	24.7	62.94	35.64	14.27	10.48	5.47	0.1	5.03
44	SP37		356.4	32.3	65.9	29.48	24.31	12.23	7.45	0.86	6.29
48	SP40		291.5	48.7	14.12	46.21	17.53	13.96	4	2.86	3.72
55	SP46		180.5	51.4	21.12	35.08	7.41	6.86	1.56	0.19	4.14
60	SP50		96.2	57.1	9.33	20.98	3.85	4.07	0.98	0.15	1.24
67	FU06		407.6	54.7	7.16	78.6	21.95	17.53	8.54	1.88	3.81
68	FU07		395.5	52	10.7	72.99	17.61	17.43	7.26	2.11	4.07
113	FU44		446.4	73.4	36.76	127.5	22.58	18.58	12.97	0.48	6.64
114	FU45		302.5	58	47.54	67.84	14.07	8.47	8.76	0.1	5.23
118	FU48		265	57.6	15.4	40.62	15.29	25.3	5.4	1.06	5.14
119	FU49		316.9	79.4	4.16	90.25	12.28	26.76	5.2	1.35	3.55
count	SP	ref	6	6	6	6	6	6	6	6	6
average	SP	ref	215.80	40.97	34.67	30.20	12.58	8.65	3.82	0.71	4.09
min	SP	ref	96.20	24.70	9.33	13.79	3.85	4.07	0.98	0.10	1.24
max	SP	ref	356.40	57.10	65.90	46.21	24.31	13.96	7.45	2.86	6.29
S.D.	SP	ref	95.16	13.09	24.59	11.53	7.59	4.19	2.42	1.09	1.67
count	FU	limed	6	6	6	6	6	6	6	6	6
average	FU	limed	355.65	62.52	20.29	79.63	17.30	19.01	8.02	1.16	4.74
min	FU	limed	265.00	52.00	4.16	40.62	12.28	8.47	5.20	0.10	3.55
max	FU	limed	446.40	79.40	47.54	127.50	22.58	26.76	12.97	2.11	6.64
S.D.	FU	limed	70.80	11.13	17.68	28.67	4.23	6.57	2.85	0.78	1.16

Table 9. a. Preliming composition of mineral soils at three locations in the reference catchment (SP) and three locations in the limed catchment (FU). B.D. = bulk density; L.O.I. = loss on ignition; Kjel-N = Kjeldahl-N.

MIINERAL horizon GJERSTAD, 1994

OBS	site		pH H_2O	B. D. g g^{-1}	Dry wt. %	L.O.I. %	Kjel-N mmol kg^{-1}	calc. C/N g g^{-1}	total analyses, ICP Al	Ca	K	Mg	Na (mmol kg^{-1})	P	S
1	FU06	1	3.80	0.68	98.2	15.76	231	24.366	49.24	19.5	7.6	9	2.93	4	11.38
2	FU06	2	4.32	0.995	98.6	5.94	84	25.255	153.2	12.1	8.8	21.2	2.22	2.9	4.57
3	FU07	1	3.78	0.518	97.2	22.95	404	20.288	98.24	28.5	11.2	13.8	2.55	6.7	22.71
4	FU07	2		0.533	96.8	28.02	409	24.467	97.95	27	9.6	13.4	2.91	5.8	20.52
5	FU07	3	4.44	0.843	97	11.1	159	24.933	391.2	18.8	12.1	54.2	2.42	7.6	10.07
6	FU44	1	4.19	0.203	90.1	90.35	1884	17.127	293.7	136.4	14.8	28.2	4.22	26.9	103.5
7	FU44	2	4.67	0.719	97.3	14.74	373	14.113	270.1	18.9	4.4	10.6	2.51	8.5	19.91
8	FU45	1	4.81	0.229	88	84.34	1543	19.521	1120	45.7	8.6	12.3	2.55	47.3	97.54
9	FU45	2	5.16	0.305	89.1	59.7	1182	18.038	1976	50.1	7.8	22.9	3.18	52	89.77
10	FU45	3		0.334	88.8	59.06	1128	18.699	1970	49.6	8.6	22.5	3.5	54.3	88.18
11	FU48	1	4.28	0.543	96.9	20.1	482	14.893	295.7	29	11.3	85.9	4.43	11.6	25.48
12	FU48	2	4.64	0.811	97.6	8.58	175	17.51	399.9	24.7	11.3	128	4.86	7.6	11.95
13	FU49	1	4.36	0.627	97.6	15.44	413	13.352	293.1	31.6	8.3	104	5.19	10.4	22.28
14	FU49	2	4.65	0.795	97.7	8.37	160	18.683	551.6	32.3	10.2	209.1	6.44	6.8	13.92
15	SP28	1	4.90	0.343	89.3	57.21	1432	14.268	1411	31.7	15.5	104.8	3.07	46.1	76.39
16	SP28	2		0.35	89	58.33	1436	14.507	1445	31.2	18.2	108.5	3.25	44.7	81.15
17	SP28	3	4.91	0.519	92.5	31.51	703	16.008	1367	28.3	13.5	121.9	3.75	29.1	34.66
18	SP30	1	4.83	0.272	87.3	73.05	1650	15.812	1506	24.1	9.3	36.4	2.59	52.3	87.22
19	SP30	2	4.88	0.623	94.8	20.63	478	15.414	1285	26.4	12.9	141.2	3.61	22.7	25.55
20	SP37	1	4.11	0.498	97.1	18.59	344	19.3	193.6	10.3	6.4	10.9	2.45	10	13.34
21	SP37	2	4.33	0.953	98.8	4.71	106	15.869	166.9	7.4	4.7	9.2	1.86	4	4.5
22	SP37	3		0.981	98.8	4.74	103	16.436	168.5	8.7	9.2	9.3	1.84	3.7	4.38
23	SP40	1	3.89	0.581	98.1	13.28	201	23.596	189.2	12.4	21.1	48.5	2.25	6.7	10.04
24	SP40	2	3.97	0.932	98.9	5.4	99	19.481	149.6	8.6	15	41.7	2.18	3.8	3.89
25	SP46	1	4.53	0.62	95.8	21.58	394	19.561	547.7	50	15.4	135.6	5.76	41.9	26.95
26	SP46	2	4.75	0.698	96	13.15	249	18.861	649.5	47.9	10.1	146.3	5.99	37	16.13
27	SP50	1	4.47	0.611	98.1	10.98	252	15.561	146.4	29.7	7.5	31.7	4.66	16.4	12.19
28	SP50	2		0.718	98.2	10.63	246	15.433	150.1	31.9	8	32.7	4.26	17	12.58
29	SP50	3	4.49	0.93	98.2	8.08	181	15.943	222.2	25.1	6.6	50.9	4.3	14.7	10.29

MIINERAL horizon GJERSTAD, 1994

OBS	site		pH H_2O	B. D. $g\ g^{-1}$	Dry wt. %	L.O.I. %	Kjel-N $mmol\ kg^{-1}$	calc. C/N $g\ g^{-1}$	total analyses, ICP Al	Ca	K	$mmol\ kg^{-1}$ Mg	Na	P	S
count	FU	limed	12	14	14	14	14	14	14	14	14	14	14	14	14
average	FU		4.43	0.58	95.1	31.7	616.2	19.4	568.6	37.4	9.6	52.5	3.6	18.0	38.7
min	FU		3.78	0.20	88.0	5.9	84.0	13.4	49.2	12.1	4.4	9.0	2.2	2.9	4.6
max	FU		5.16	1.00	98.6	90.4	1884.0	25.3	1976.0	136.4	14.8	209.1	6.4	54.3	103.5
S.D.			0.40	0.25	4.03	29.01	575.00	4.04	650.98	30.77	2.49	59.25	1.27	18.90	37.38
count	SP	ref	12	15	15	15	15	15	15	15	15	15	15	15	15
average	SP		4.51	0.64	95.4	23.5	524.9	17.1	639.8	24.9	11.6	68.6	3.5	23.3	28.0
min	SP		3.89	0.27	87.3	4.7	99.0	14.3	146.4	7.4	4.7	9.2	1.8	3.7	3.9
max	SP		4.91	0.98	98.9	73.1	1650.0	23.6	1506.0	50.0	21.1	146.3	6.0	52.3	87.2
S.D.			0.37	0.23	3.98	21.89	533.79	2.55	578.97	13.46	4.80	51.44	1.33	17.19	29.15

Table 9. b. Preliming composition of mineral soils (extracts in NH_4NO_3 (1M)) at three locations in the reference catchment (SP) and three locations in the limed catchment (FU). CEC = cation exchange capacity; BS = base saturation.

OBS	site	sample	CEC µeq/kg	BS %	exchangeable ions Al mmol/kg	Ca mmol/kg	K mmol/kg	Mg mmol/kg	Na mmol/kg	P mmol/kg	S mmol/kg
1	FU06	1	62.2	37.5	5.15	6.97	4.24	2.3	0.57	0.16	0.49
2	FU06	2	46.7	5.3	15.54	0.5	0.68	0.29	0.22	0.1	0.37
3	FU07	1	126.4	34.8	18.82	15.95	3.55	3.9	0.73	0.1	0.72
4	FU07	2	126.8	33.3	18.9	15.57	2.53	3.89	0.77	0.1	0.68
5	FU07	3	59.1	7.3	19.31	1.11	1.15	0.37	0.22	0.1	0.9
6	FU44	1	467.3	63	43.72	116	16.73	21.08	3.56	0.97	3.94
7	FU44	2	58.6	23.4	15.94	4.65	2.31	0.84	0.42	0.1	0.66
8	FU45	1	242.6	35.8	55	33.38	9.37	4.47	1.9	0.1	2.95
9	FU45	2	133.5	50	24.88	27.11	5.5	2.69	1.66	0.1	2.06
10	FU45	3	133.9	48.5	25.42	26.46	4.91	2.71	1.72	0.1	2.21
11	FU48	1	89.8	28.7	19.35	5.86	5.44	4.01	0.58	0.1	1.7
12	FU48	2	45.8	16.1	13.2	1.62	2.09	0.85	0.35	0.1	0.95
13	FU49	1	73.3	30.3	15.79	6.04	3.17	3.1	0.77	0.1	1.5
14	FU49	2	44.5	8.4	14.98	0.41	1.32	0.63	0.34	0.1	1.8
15	SP28	1	159.4	32.3	36.32	15.39	9.18	5.06	1.48	0.1	4.28
16	SP28	2	158.6	32.1	35.62	15.2	8.89	5.1	1.48	0.1	4.05
17	SP28	3	83.8	25.8	22.39	7.46	2.56	1.65	0.87	0.1	2.51
18	SP30	1	180.9	25.2	48.18	13.85	7.74	4.24	1.71	0.1	4.62
19	SP30	2	60.6	23.1	17.62	4.54	2.26	0.97	0.72	0.1	1.58
20	SP37	1	129.5	15.7	34.53	5.51	4.1	2.28	0.65	0.1	0.9
21	SP37	2	46.7	6.5	14.94	0.77	0.68	0.29	0.23	0.1	0.22
22	SP37	3	48.6	6.3	15.75	0.8	0.63	0.29	0.26	0.1	0.23
23	SP40	1	93.9	24.5	16.57	7.29	3.19	2.42	0.38	0.22	0.64
24	SP40	2	55	9.5	14.63	1.41	0.84	0.64	0.28	0.1	0.26
25	SP46	1	94.6	31.7	19.02	10.26	3.83	2.58	0.51	0.1	1.93
26	SP46	2	64.8	14.6	18.51	2.79	1.67	0.89	0.41	0.1	1.45
27	SP50	1	66.7	34.7	10.89	7.85	2.94	2.05	0.41	0.1	1.11
28	SP50	2	64.2	32.9	10.71	7.2	2.63	1.87	0.37	0.14	1.12
29	SP50	3	46.9	16	12.47	2.31	1.01	0.81	0.27	0.1	0.69

OBS	site		CEC µeq/kg	BS %	exchangeable ions Al mmol/kg	Ca mmol/kg	K mmol/kg	Mg mmol/kg	Na mmol/kg	P mmol/kg	S mmol/kg
count	FU	limed	14	14	14	14	14	14	14	14	14
average	FU	limed	122.18	30.2	21.9	18.7	4.5	3.7	1.0	0.2	1.5
min	FU	limed	44.50	5.3	5.2	0.4	0.7	0.3	0.2	0.1	0.4
max	FU	limed	467.30	63.0	55.0	116.0	16.7	21.1	3.6	1.0	3.9
S.D.	FU	limed	113.18	17.06	12.84	30.07	4.19	5.23	0.93	0.23	1.04
count	SP	ref	15	15	15	15	15	15	15	15	15
average	SP	ref	90.28	22.1	21.9	6.8	3.5	2.1	0.7	0.1	1.7
min	SP	ref	46.70	6.3	10.7	0.8	0.6	0.3	0.2	0.1	0.2
max	SP	ref	180.90	34.7	48.2	15.4	9.2	5.1	1.7	0.2	4.6
S.D.	SP	ref	45.35	9.96	11.30	5.02	2.88	1.60	0.50	0.03	1.50

4.4 Soil solution

The lysimeters were installed in September 1994. Samples collected through 31 October 1994 were disregard here due to possible effects of disturbance caused by the installation.

The chemical composition of soil solution varies widely between the sites, in part reflecting the heterogeneity of soil and site properties. For example, pH in the humus layer was about 4 at site SP40, FU 06 and FU 07, but 5.5-6.0 at site SP28, FU 44 and FU 45 (**Figure 18** and **Figure 19**). There were no trends over time in pH at any of the lysimeters in either the limed or reference catchments.

Mg concentrations in soil solution also varied from site-to-site (**Figure 20** and **Figure 21**). At 5 of the lysimeters in the limed catchment the Mg concentrations show a statistically significant ($p < 0.05$) increase during the 3 years following liming. There were no significant trends in Ca concentrations (**Figure 22** and **Figure 23**).

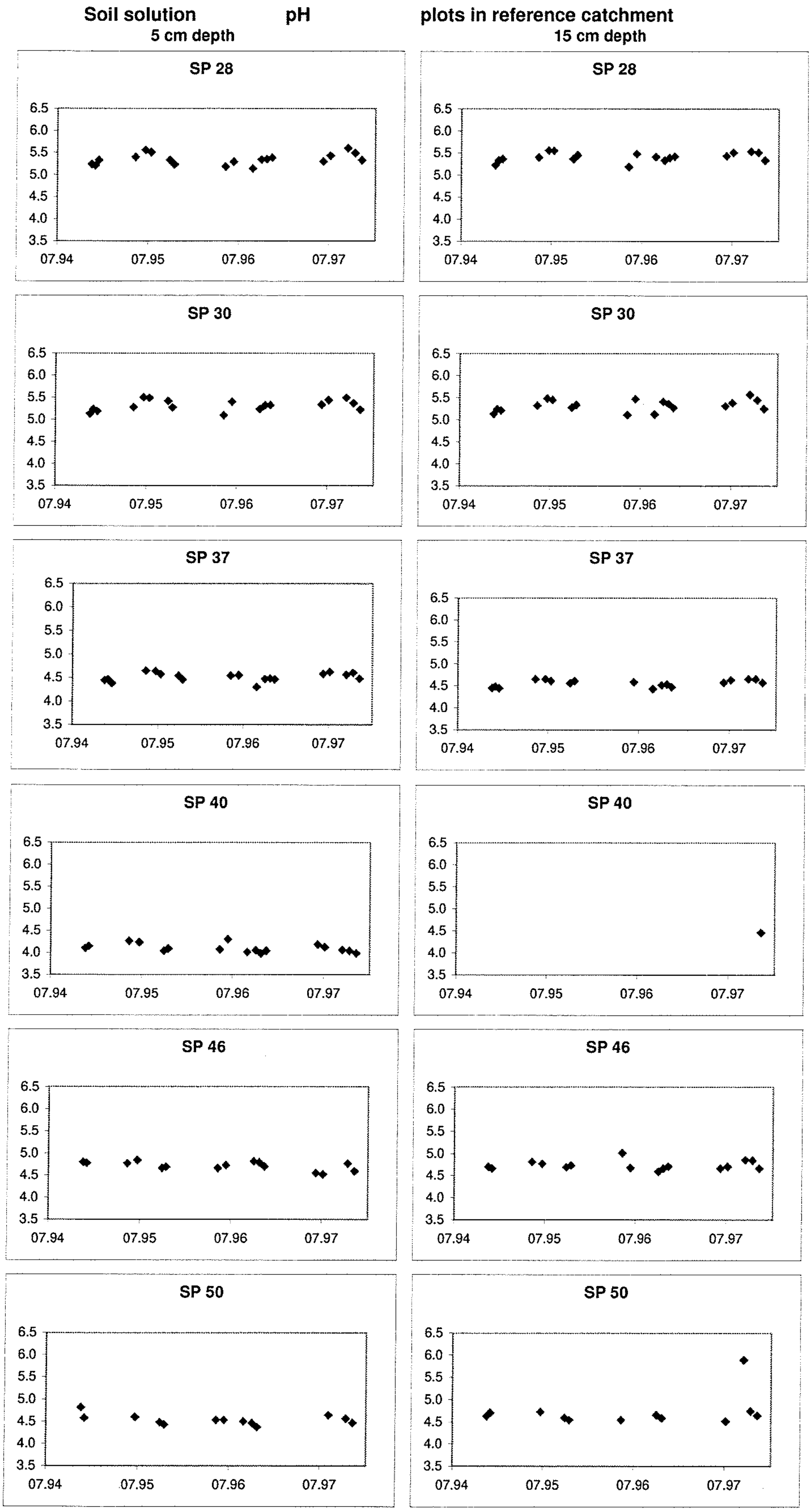


Figure 18. pH in soil solution in plots in the reference catchment.

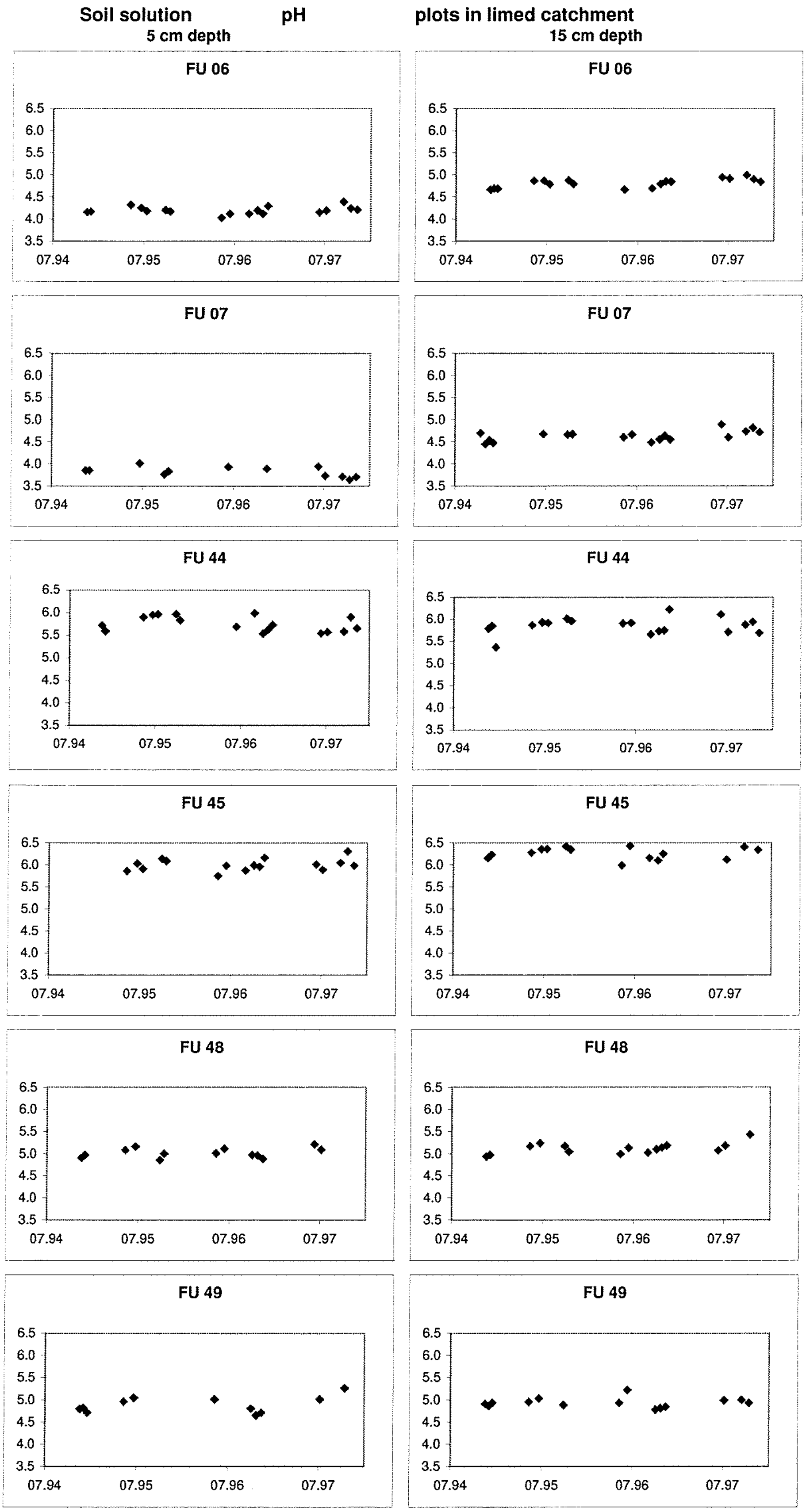


Figure 19. pH in soil solution in plots in the limed catchment.

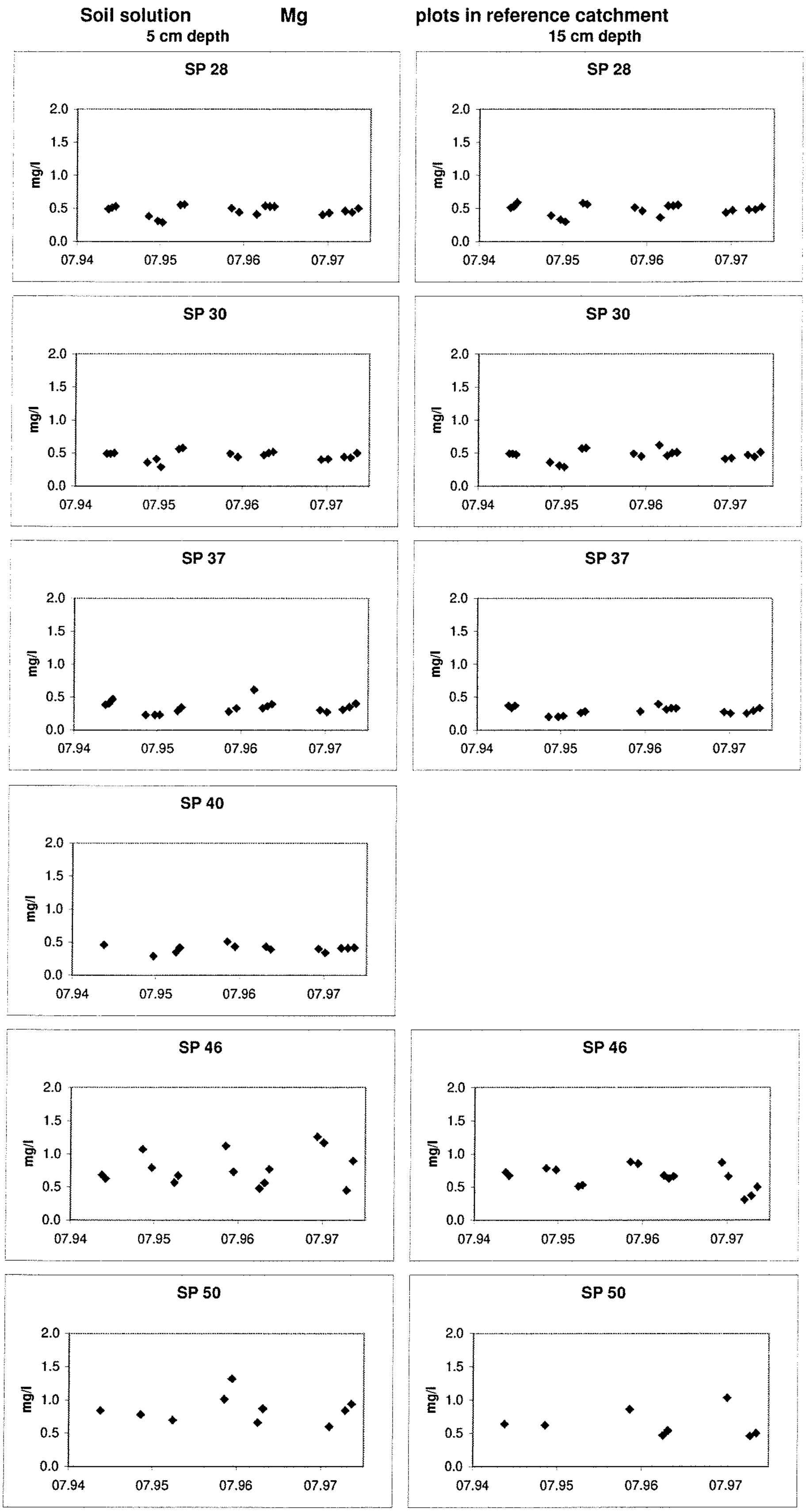


Figure 20. Mg concentrations in soil solution in plots in the reference catchment.

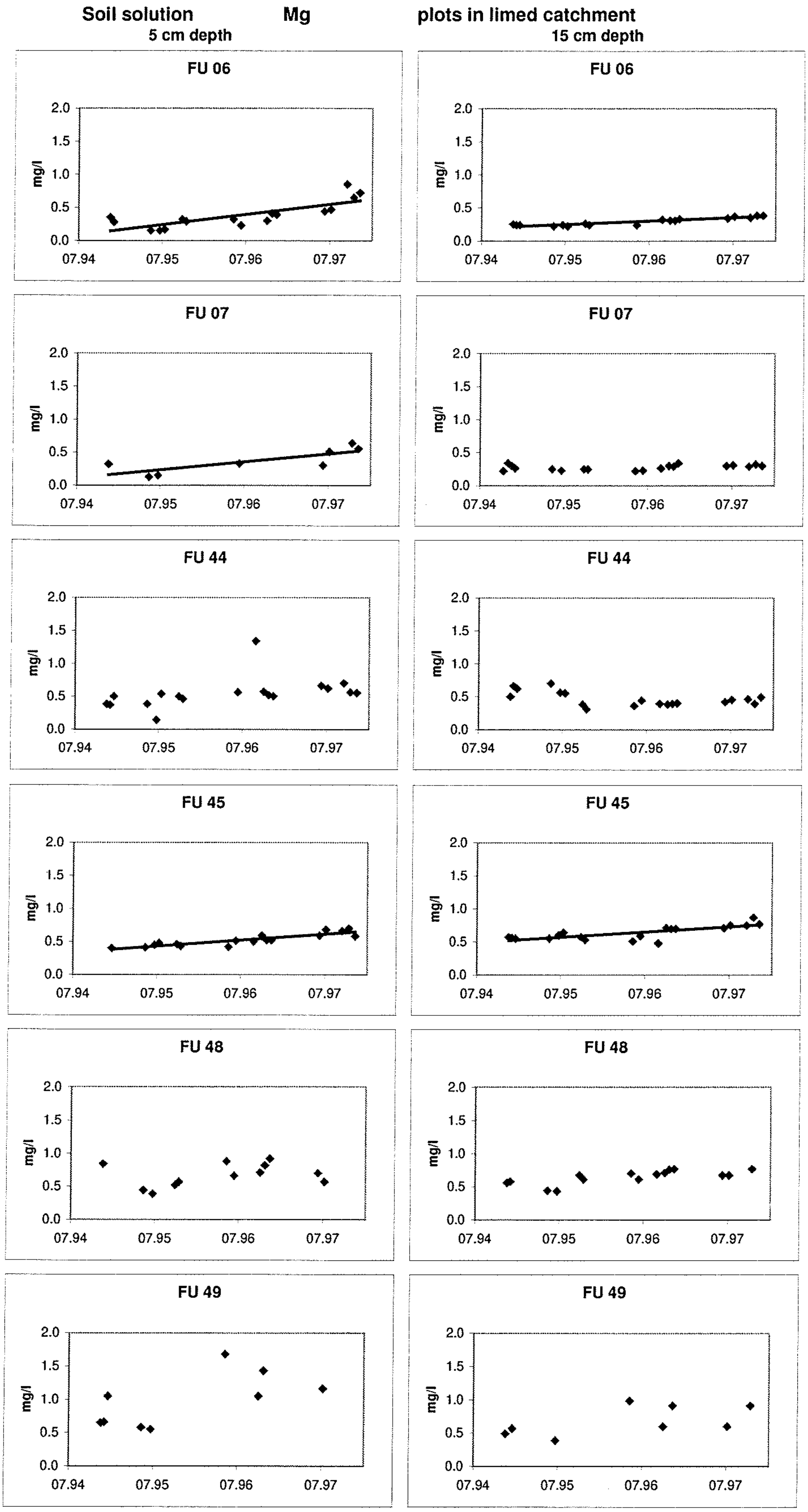


Figure 21. Mg concentrations in soil solution in plots in the limed catchment. Significant linear trends indicated by regression lines.

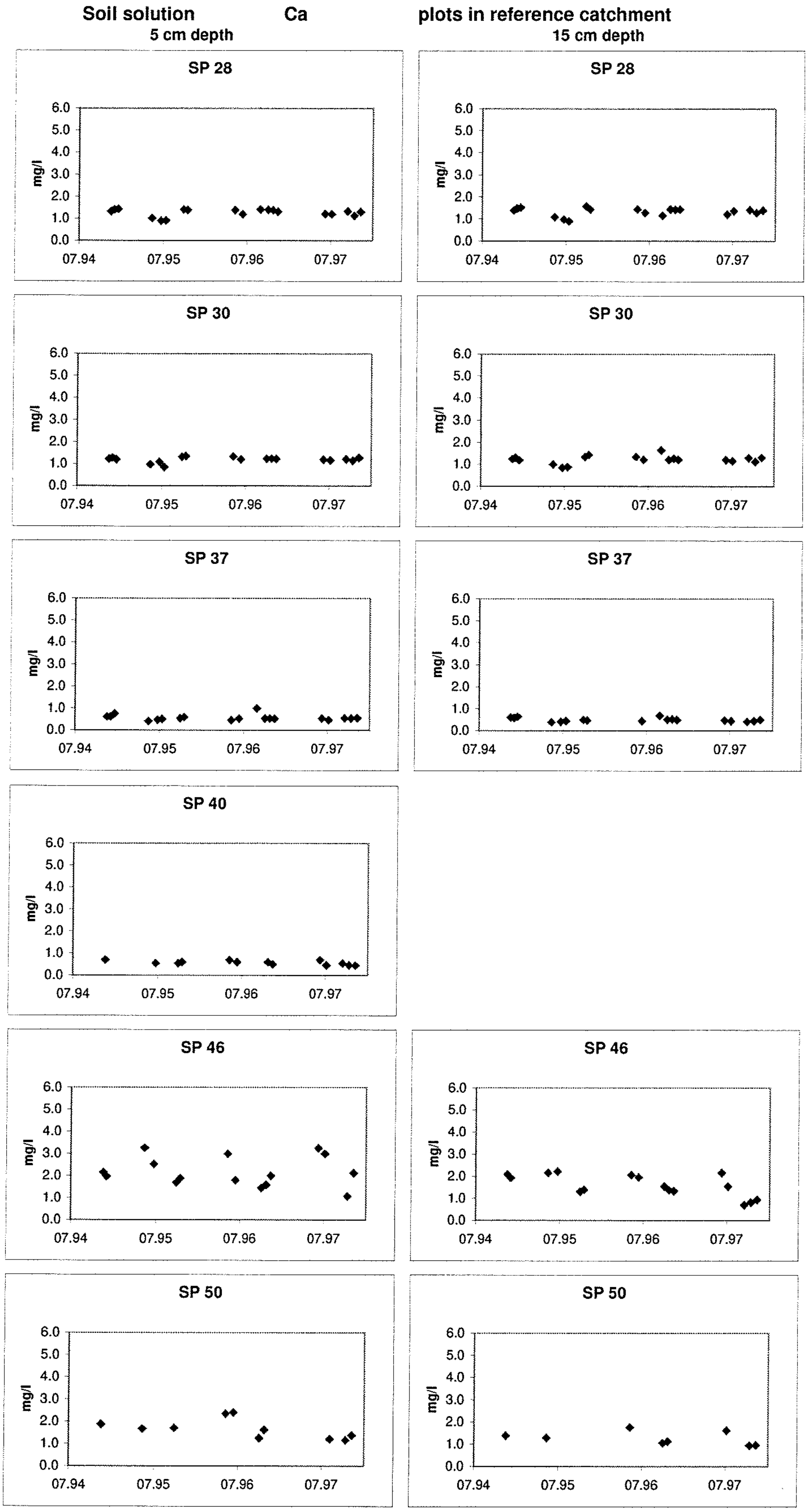


Figure 22. Ca concentrations in soil solution in plots in the reference catchment.

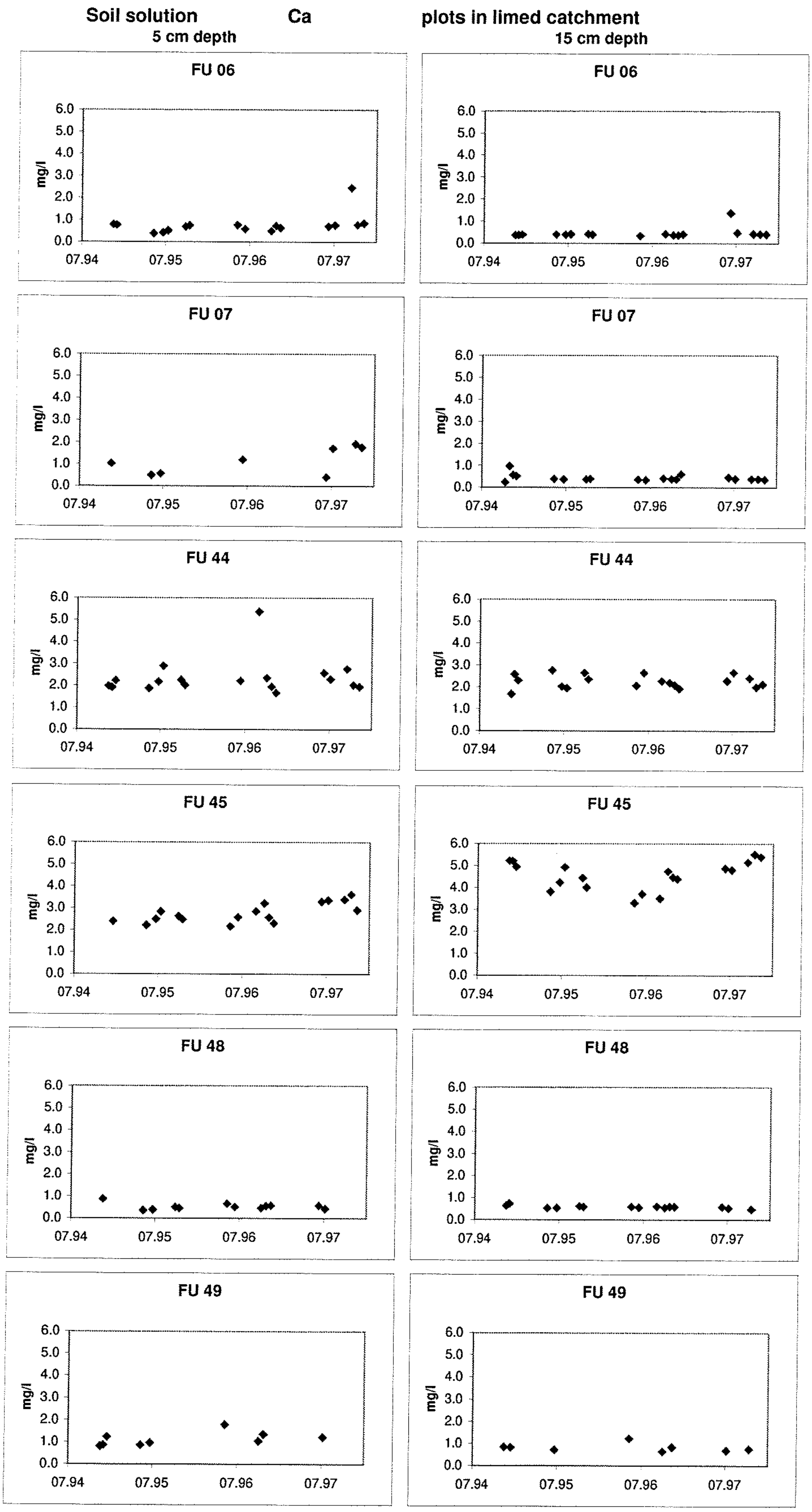


Figure 23. Ca concentrations in soil solution in plots in the limed catchment.

4.5 Forest investigations

4.5.1 Forest condition

In **Figure 24** the distribution of different cutting classes is shown in the two catchments. The sampling intensity is approximately 3% for both areas, and the stand composition is fairly alike. In the reference area there is less young and middle-aged forest. Here, about 70% of the forest area is classified as old production forest or old forest, while in the limed catchment this proportion is 50%.

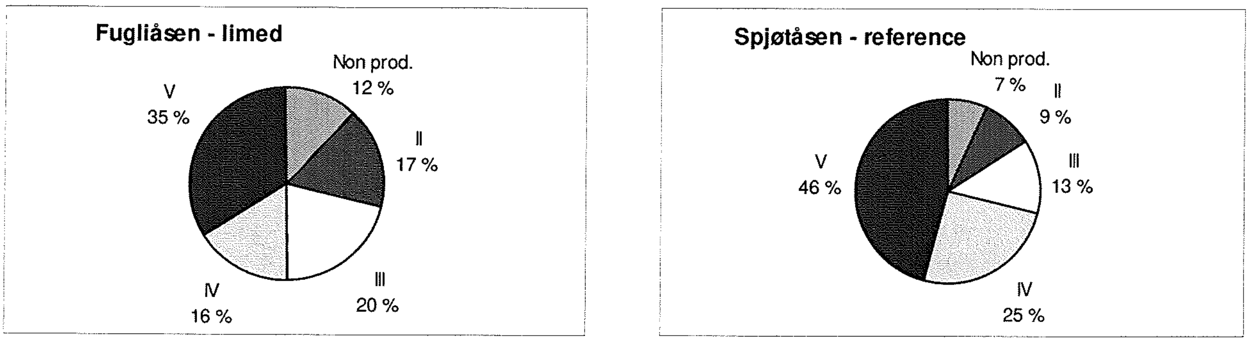


Figure 24. Area distribution of different cutting classes in the two catchments. Cutting classes according to following definition: I- Forest under regeneration, II - Regenerated areas and young forest, III - Young production forest, IV - old production forest, V - old forest.

Table 10 and **Table 11** show aggregated figures for forest condition in the two catchments. The share of Scots pine to Norway spruce is higher in the reference area (70/30) compared to the limed area (56/44). A small fraction of broad-leaved trees in the middle aged and old stands is typical for this region. The clear-cut areas in the catchments are mainly dominated by birch or trembling aspen.

Table 10. Some key figures for the forest stands in the two catchments.

	Fugleliåsen - limed area	Spjøtåsen - reference area
Area	84.4 ha	40.8 ha
Total standing volume	9920 m^3	6027 m^3
Mean diameter	140 mm	157 mm
Mean height	10.4 m	11.4 m
Average volume per tree	0.157 m^3	0.187 m^3
Mean age	67 yr	77 yr
Number of sample plots	122	56
Sample intensity	2.9%	2.7%
Site index (H_{40})	12.4	11.8

Table 11. Volume in different cutting classes and by tree species in the two catchments.

Fugleliåsen - limed catchment

	Volume (m^3)						
Cutting class	Spruce	Pine	Birch	Aspen	Oak	Other broadleaves	Sum
III	230	445	177	177	124	18	1171
IV	703	990	92	144	101	3	2033
V	2516	3025	192	502	306	51	6592
Sum	3449	4460	461	823	531	72	9796

Spjøtåsen - reference catchment

	Volume (m^3)						
Cutting classes	Spruce	Pine	Birch	Aspen	Oak	Other broadleaves	Sum
III	48	231	8	108	16	2	413
IV	467	1015	36	114	1	1	1631
V	1050	2318	117	214	57	47	3803
Sum	1565	3564	161	433	74	50	5847

4.5.2 Intensive monitoring plots

The increment in the 4-year period 1994-1998 is compared to the estimated increment based on increment function (**Figure 25**) The overall level of estimated increment is 70% for the reference catchment and 77% for the limed catchment. This difference is not significant. As seen from **Figure 25** the variation in residuals is rather large. One plot, no 6 in the reference catchment, has a very low increment compared to that expected from the function. This is probably caused by low vitality and declining trees. The reason for this has not been investigated further.

The average crown density and crown colour are shown in **Figure 26** and **Figure 27**. The crown density is also relatively low, with many of the stands with less than 85% crown density for most of the period. The level varies little from year-to-year; no effect of liming can be extracted. The same holds for the crown colour. The year-to-year variation is more pronounced for crown colour. An increase in colour value (more yellow trees) was found in 1995. Then a steady decrease in value (more green trees) has been noted in both catchments.

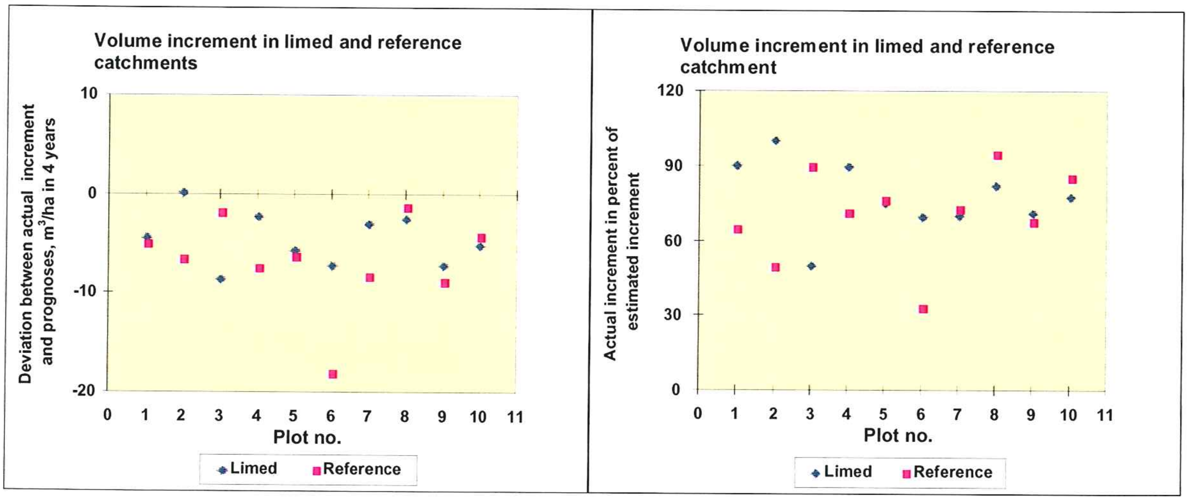


Figure 25. Differences between measured and estimated increment on the intensive monitoring plots. Residuals ($m^3 ha^{-1}$ in 4 years) (left) and measured increment in percent of estimated (right).

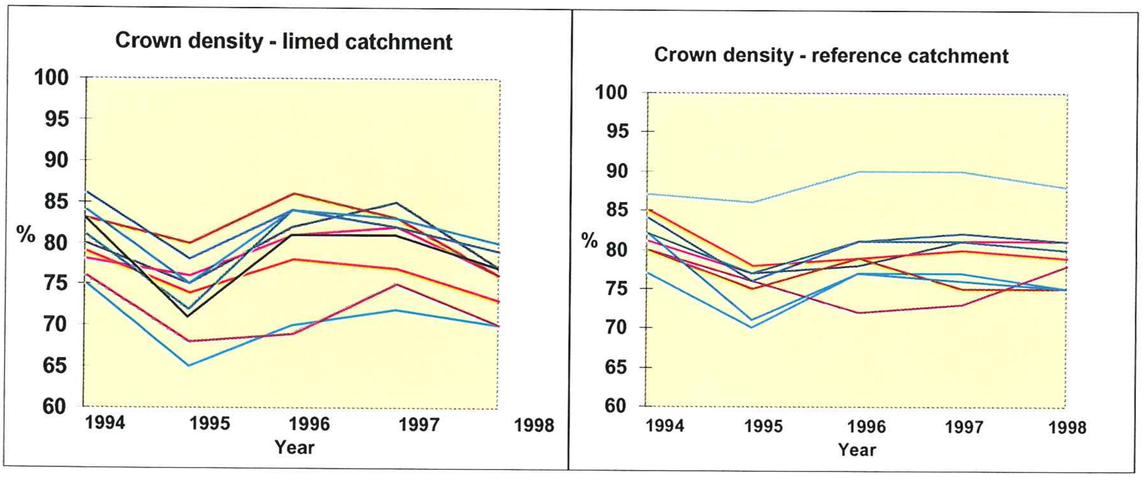


Figure 26. Average crown density on intensive monitoring plots in the period in the two areas.

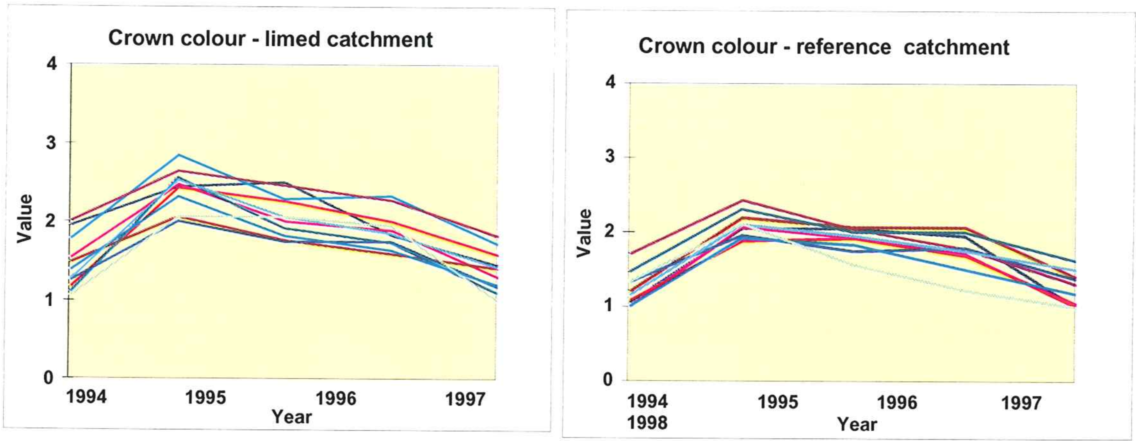


Figure 27. Average crown colour in the intensive monitoring plots during the period in the two catchments.

In **Figure 28** the percentage amount of green trees in each plot can be seen. For most of the plots an almost complete recovery in crown colour compared to 1994 has occurred. Still some stands have low proportions of green trees.

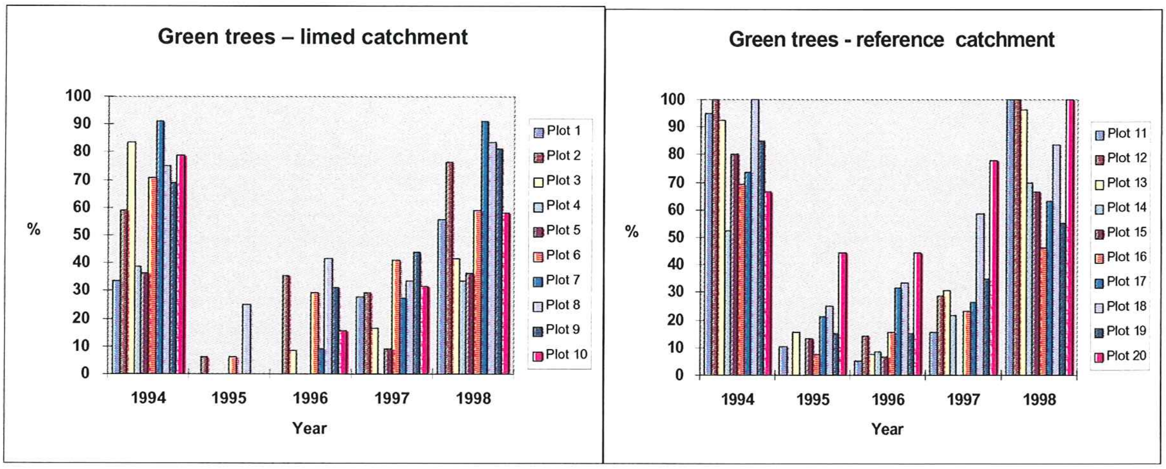


Figure 28. The amount of green trees on the intensive monitoring plots in the limed catchment and reference catchment in the different years.

5. Discussion

The choice of coarse dolomite and the dose of 3 t ha^{-1} for liming the 80 ha forested ecosystem in Gjerstad was partly based on recommendations for forest soil liming in Sweden, as summarised by Nihlgård *et al.* (1996). Results from the whole-catchment liming at Tjønnstrond (Traaen *et al.* 1997) with the same dose of more fine-powdered calcite indicated that significant improvement of the water quality was likely. Higher doses may change the soil pH too much, whereas ion exchange of accumulated Al and H^+ in the soil with the added Ca and Mg and production of organic acids from decomposition of organic matter may increase the acidity of the soil solution if lower doses are used.

Due to the anticipated variability of many important factors for acidity and liming effects within heterogeneous catchments, mixed forests and climatic regions, we chose a fixed dose and a paired catchment experiment in a forest ecosystem that might be regarded as typical for large acidified areas in Norway. An initial split in the limed catchment for stream water analyses and parallel sampling of soil solution at different stations were included to study in-catchment variability.

5.1 Soil chemistry

Sites for soil chemistry was selected mainly for vegetation purposes. Large gradients in nutrient status and water supply were two central criteria for this selection. As a result large variability in most of the soil chemical compounds was expected, and this is indeed what was found.

The chemistry of the soils at the two Gjerstad catchments is typical for soils in southern Norway in coniferous forests on nutrient-poor, siliceous moraine. Soils on well-drained sites are acidic and exhibit podsolic character, while those on adjacent wetter areas are typically organic-rich and humified. Both the cation exchange capacity (CEC) and the base saturation, two key parameters with respect to acidification of soil and mitigation by liming, are well within the ranges expected for coniferous forest soils of southern Norway.

Whether liming has resulted in changes in soil chemistry such as increase base saturation remains to be seen. A resampling of soils is scheduled for 1999. Liming at Tjønnstrond, for example, resulted in significant increase in base saturation (Traaen *et al.* 1997).

5.2 Soil solution chemistry

In principal one should expect a close relation between chemistry of soil and chemistry of soil solution at each individual site. The wide range in soil chemistry should be reflected in a corresponding wide range of soil solution chemistry. This is in part the case for pH in the humus layer. In both catchments soils with low pH (water) yield soil solution with low pH (**Figure 29**). This is the case for the humus layer. The mineral soil horizons do not show this relationship, however. Similarly for both Mg and Ca there is a tendency for the humus layers with higher contents of exchangeable base cations to have higher concentrations in soil solution (**Figure 30**). Again there is no such relationship for the mineral horizons.

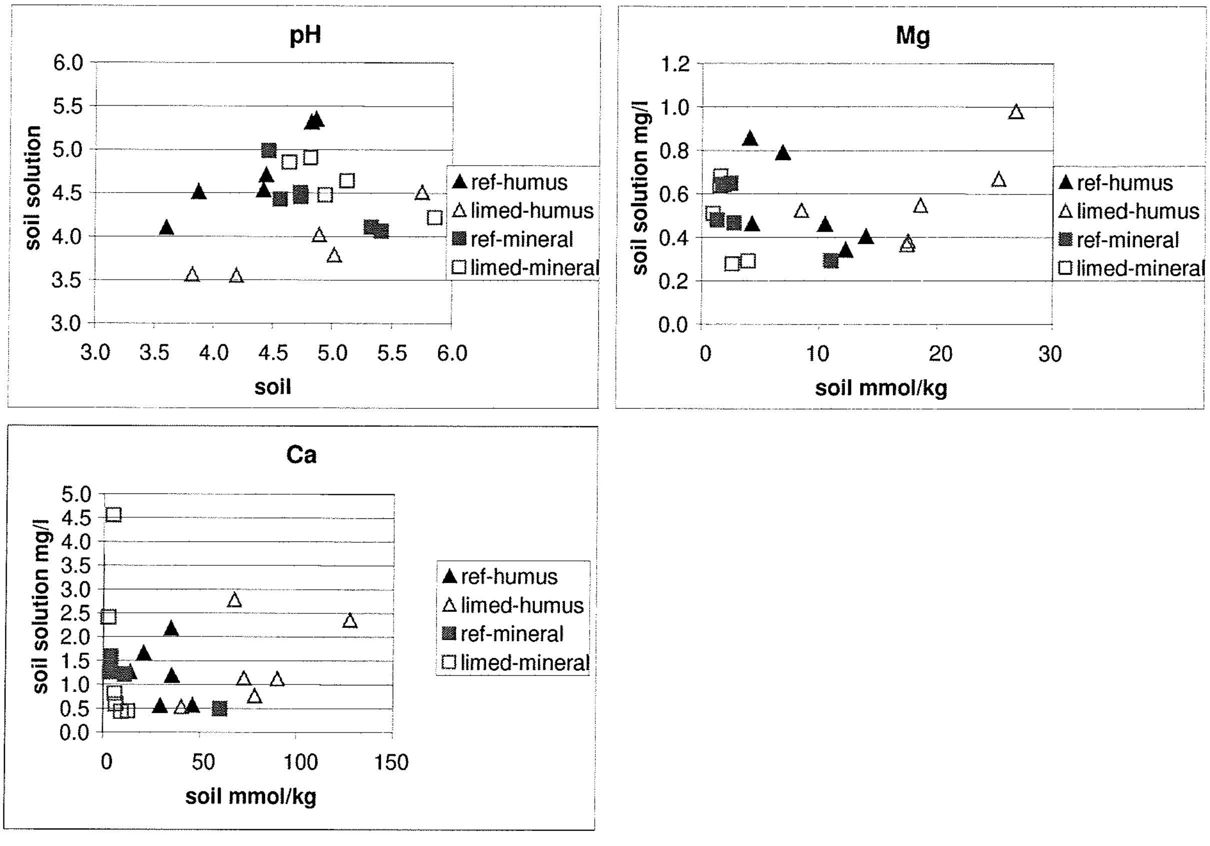


Figure 29. A comparison of soil and soil solution chemistry in the humus and mineral soil horizons at two catchments at Gjerstad. The soils were sampled in summer 1994. The soil solution data are means for samples from each lysimeter collected November 1994 through November 1997.

During the first 2.5 years following liming there have been very few indications of changes in soil solution chemistry. A small increase in Mg at only some of the locations has taken place. This was expected due to the slow movement of the dissolved base cations in other experiments (Brahmer 1994; Nohrstedt 1992). This contrasts with the rapid change of runoff water chemistry.

The most striking result from the Gjerstad experiment is the relatively uniform, acid and Al-rich runoff in the sub-catchments and the great variability in soil solution (**Figure 30**). This indicates that soil solution collected by the Prenart tension lysimeters is not representative of runoff. Similar observations on the lack of similarity between soil solution and runoff comes from other whole-catchment experiments such as the RAIN (Hauhs 1998) and CLIMEX (Jenkins *et al.* 1996) projects at Risdalsheia near Grimstad, about 60 km SW of Gjerstad and the NITREX project at Gårdsjön, near Gothenburg Sweden (Stuanes and Kjønaas 1998). In both these cases runoff responded more rapidly and consistently to changes in the chemical composition of deposition, while lysimeter data showed wide variations ranging from little or no response over many years, to immediate and persistent response. As at Gjerstad the lysimeter samples show great heterogeneity spatially.

There are several possible explanations for the lack of similarity between soil solution and runoff. First, the sampling technique for soil solution probably does not collect water in volumes proportional to that in runoff. Soil solution is comprised of water in pore spaces over a continuum of sizes, from macropores that have water only during saturated conditions, to micropores that retain water by capillary tension. The Prenart lysimeters under tension will collect water from a fraction of these pore sizes, but most probably some will be over-represented. The macropore flow will be underrepresented in volume. And since the lysimeters at Gjerstad were only evacuated 1 day each 14 days, the samples represent only a small time fraction as well.

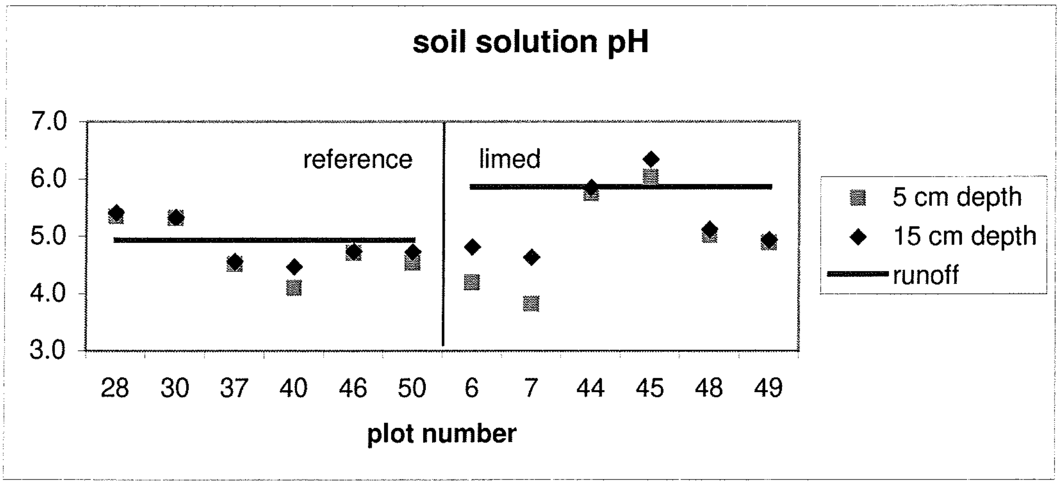
Second, water movement varies greatly in time and space though heterogeneous uneven terrain such as is characteristic of the forested catchments at Gjerstad, and also Risdalsheia and Gårdsjön. The dominant pathway from soil surface to the stream is horizontal, not vertical. Incoming precipitation (or throughfall) percolates down through the soil undergoing chemical change underway until an impermeable surface is reached – either bedrock or a water-saturated zone. The water then moves horizontally towards the stream channel, and may alter chemical composition further, especially in the discharge regions near the stream. The runoff in the stream is a composite sample of water "packages" that have moved vertically and horizontally through the soil at a wide variety of distances and contact times.

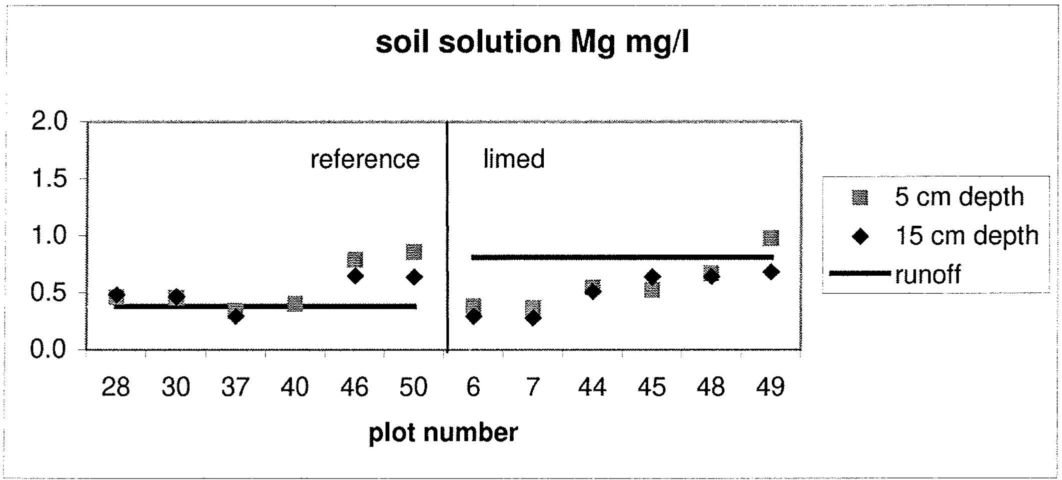
Although lysimeter water is not representative for runoff, it may, however, give a good picture of the water quality available for uptake by roots. Thus the response of trees and ground vegetation to the liming treatment may first occur when the chemical composition of soil solution changes. At the NITREX experiment at Gårdsjön the runoff began to respond to N additions already during the first year of treatment, while the soil solution responded after 2-3 years and the vegetation yet later (Kjønaas *et al.* 1998).

5.3 Runoff chemistry

In runoff, the most striking effects of the dolomite treatment at Gjerstad were increased pH and concentrations of base cations, slightly reduced Al transport and change of Al species from highly toxic to non-toxic species. These effects are probably due to dissolution of dolomite in the topsoil and subsequent ion exchange of base cations in the humic layer. Lateral surface and sub-surface flow transport excess and ion-exchanged Ca and Mg to the stream.

Rapid, almost immediate, improvements in the stream water quality were found. This occurred even though the finest fraction of the dolomite was removed before spreading, in contrast to the liming material used in e.g. the Gårdsjön liming experiment, where the particles were in the range 0-30 μm, a particle size fraction that was almost completely removed from the Gjerstad dolomite.





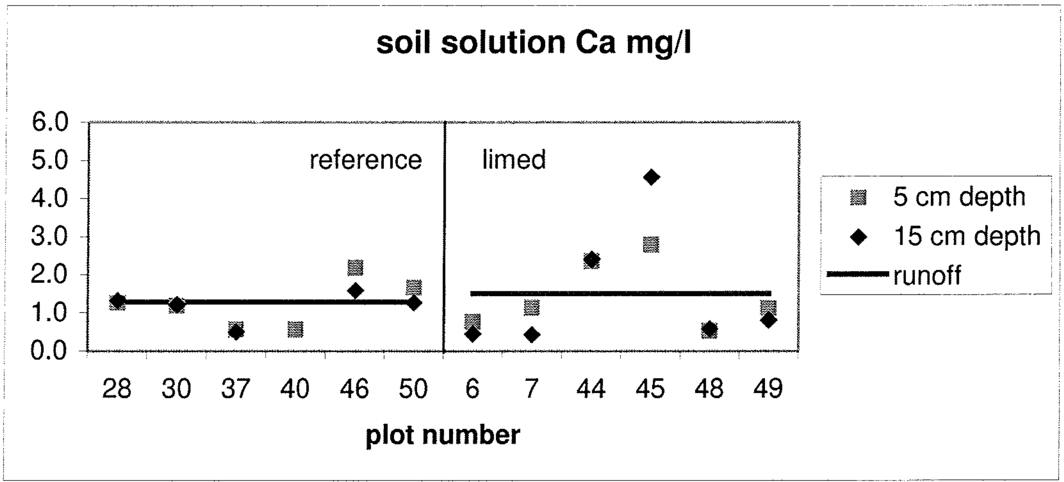


Figure 30. Comparison of mean concentrations in soil solution (6 sites at each catchment) and in runoff for samples collected during the post-liming period November 1994 through November 1997.

The post-liming increase in runoff concentrations of Ca and Mg was not significantly different in the Gjerstad experiment. Higher mobility of Mg relative to Ca was reflected in the relative increase. Whereas 0.5 % of the added Ca was transported out, 2.0 % of the added Mg was transported out of the limed catchment during the first 2.5 years.

Although the annual net transport of Ca and Mg was less than 1 % of the amount added, this was sufficient to cause a rapid response in runoff water quality after liming. The increase in water quality persisted throughout the period. No decreasing trends were documented after the initial increase in pH, base cations or ANC, and a longer monitoring period is needed to draw conclusions regarding duration and thereby mean annual liming costs.

These changes due to liming have turned the potentially toxic runoff into a water quality adequate for survival of acid sensitive organisms such as trout.

The results from Gjerstad generally agree with other comparable experiments with liming terrestrial areas. Hultberg *et al.* (1995) reported similar effects on runoff after application of 6 t ha^{-1} of extremely fine-ground dolomite (particle size range: 0-30 µm) to a small catchment at the Gårdsjön research site, Sweden. A significant reduction of inorganic Al and Mn of 40-50 % was found. As in Gjerstad the mean annual flux of Mg was less than 1 % (7 % in 9 years). Fransman and Nihlgård (1995) also found increased pH, Ca and Mg and reduced Al, Fe and Mn after forest soil liming. Other experiments from Sweden with moderate lime doses (3-4 t ha^{-1}) showed only minor effects on pH and Al-concentration in stream water during a 3-year period (Westling and Skärby 1993).

In Schluchsee, Black Forest in Germany a minor increase in stream-water Ca was registered one year after liming with 4 t ha^{-1} of pelleted dolomitic limestone, but the increase in Mg was as rapid as in Gjerstad (Brahmer 1994). Marked increases (after an initial peak) in both Ca and Mg in the soil solution at 30-cm depth were seen the year following liming. Increased Al-mobilisation at 30 cm was ascribed to the initial ion exchange processes after liming. Al did not increase in the stream water the first year after liming.

Kreutzer (1995) reported increased pH in the humic layer and in drainage water from this layer in the 6-year period after liming. No pH change in soil solution at 20-cm depth or drainage water from this layer was found. Drastic deprotonation of functional groups of the humic matrix was reported and both the cation exchange capacity and the base saturation increased. This stored buffer capacity in the topsoil. Six years after liming, dissolution of the added dolomite was regarded as 100 % and 70 % of the added Ca and 30 % of the Mg were still present in the humic layer. The low number for Mg reflects the more mobile nature of this element compared to Ca. Dissolution of lime was described by the equation: $m(t) = A*e^{-0.643*t}$, where A is the mass of carbonate added in tonnes, m is mass of carbonates remaining in tonnes, and t is time in years. According to this equation 80 % of the added dolomite in Gjerstad should be dissolved at the end of 1996.

Liming of the heathland Tjønnstrond-catchment in Norway with a 3 t ha^{-1} dose of calcite powder resulted in a rapid and long-lasting increase in both pH and Ca and a more than 50 % reduction in reactive Al (Traaen *et al.* 1997). Liming of an upland, forested catchment (subcatchment IV) at Woods Lake, Adirondack Mountains, New York, USA, also resulted in improvement in water quality (Cirmo and Driscoll 1996). Liming of wetlands may increase the water quality of runoff, although the duration may be significantly shorter due to the more favourable dissolution properties of flushed bog surfaces and effective draining of dissolved liming material (Hindar *et al.* 1996).

Although the results from some of these experiments indicate only minor changes in pH, base cations and Al, even small water quality changes or differences may be of significance for the survival of acid-sensitive fish and invertebrates. The significance of minor water quality changes may also be important for the duration of adequate liming effects on streamwater, tending to increase duration and thereby reducing costs if being part of a liming programme for aquatic systems.

Potential undesirable effects, such as increased NO_3 leaching and mobility of organically-complexed trace metals (Fe, Cu and Pb), may be expected after forest soil liming. So far, a significant but minor increase in the median concentration of NO_3 due to liming was found after 2.5 years of liming in Gjerstad. The seasonal variability was large and concentrations in the limed catchment were within the concentration range in the reference most of the year. A clear increase in concentration was found the second winter after liming. This "winter/spring" trend was also found at Tjønnstrond (Traaen *et al.* 1997). A possible explanation may be that liming in general stimulates decomposition of organic matter and that the result of this change is insignificant or masked during the first period after liming due to a delay in the build-up of the microflora and uptake of the produced NO_3 by the soil and vegetation during summer. Nitrification may still be significant in the snow-covered soil during winter, however, and the accumulated NO_3 from the dormant season may be flushed out with meltwater during spring melt, thus increasing the concentrations in late winter/spring. A longer data record is needed to draw any conclusion on the course of NO_3 in this experiment.

Warfvinge *et al.* (1996) summarised liming effects on runoff from several forested catchments in Sweden and found no increased N leaching during periods of 9-10 years. An alternative hypothesis to increased N leaching after liming was pointed out; increased N leaching due to shortage of base cations after several years of acidification was regarded as relevant for areas in Sweden that receive high amounts of atmospheric N. If liming would counteract this was not commented on, however.

At Schluchsee, increased NO_3 in soil seepage from the humus layer and both 30 and 80 cm soil depth were recorded (Brahmer 1994). As a consequence of the pH increase of two units in the O-horizon a shift in the population of nitrifiers from heterotrophic to autotrophic organisms took place (Feger *et al.* 1995). All mineralised N was converted to NO_3 in the limed topsoil, whereas NH_4 dominated the inorganic N fraction in the reference. However, no change in streamwater was found the following 3 years after liming (Brahmer 1994; Feger *et al.* 1995).

Kreutzer (1995) reported loss of N from the humus layer after 7 years of liming and also an increase of about 1 meq L^{-1} in the NO_3 concentration in the drainage water leaving the root zone at 40-cm soil depth. The data record indicates a doubling of the NO_3 concentration at this depth due to liming already after one year. This is explained by a transformation of organically-bound N from the humus layer to dissolved organic N which was translocated to deeper soil depth and converted to NO_3 by stimulated nitrification in the mineral soil. No data for streamwater was presented, but increased concentrations of drainage-water NO_3 was calculated from soil solution data and a flux model. N deposition in Höglwald (12 kg N ha^{-1}) is of the same order of magnitude as in the Birkenes area but higher than at Solhomfjell closer to the Gjerstad site.

Increased mobility of potentially harmful trace metals complexed in the humic layer, especially Cu and Pb, may be expected after forest soil liming, if liming results in increased decomposition of organic matter (Kreutzer 1995). However, mobility of trace metals also depends on soil pH and increasing pH may stop leaching of metals related to accelerated soil acidification (Hüttl 1988). No increasing trends or elevated concentrations of the 10 trace metals relative to the reference stream were documented after the forest soil liming with dolomite in Gjerstad. This was probably due to the pH increase in runoff water, the moderate dose (3 t ha^{-1}) and low or moderate deposition of some of the trace metals in the area relative to e.g. German sites. Deposition of Cd, Cu and Pb in 1992-1993 at the Deuselbach monitoring station 200 km north of the Black Forest in Germany was higher than at Solhomfjell in Norway (Berg *et al.* 1996) by factors of 6.8, 4.6 and 1.5, respectively. Increased pH will increase the retention of some metals, whereas organically-complexed metals not will be mobilised if decomposition of organic matter is insignificant for this to occur. Hüttl (1988), in a review of forest soil liming, concluded that the risk of trace metal mobilisation for limed soils is probably not more pronounced than for acidified soils.

The decrease in Mn, Zn and Co may or may not be desirable, depending on the resulting concentrations. Both Mn and Co are elements of importance for flora and fauna and increased retention, e.g. as the result of oxidation of inorganic monomeric Mn to MnO_2 at pH>5 and subsequent precipitation, may result in shortage. Mn limitation in lime-rich soils has been reported and appears to be common (Pearson and Adams 1967). In some acidified areas in Sweden large concentrations of dissolved inorganic Mn (> 1 mg L^{-1}) have been reported and a reduction is probably desirable. In Gjerstad, however, the concentrations are very low (5-15 µg L^{-1}) and a reduction to < 5 µg L^{-1} after liming signals less availability of Mn for vegetation and forests and might be considered as a potential problem. For 985 Norwegian lakes the median Mn concentration was 2.5 µg L^{-1} (Skjelkvåle *et al.* 1999), about the same level as measured at LIM-1 and LIM-4 the last 1.5 years. Higher concentrations should be expected in streams with higher concentrations of organic matter such as is characteristic of forested ecosystems.

The liming effects on soil solution and stream water depend on hydrology, soil permeability and topography, i.e. the contact between runoff and limestone material. Steep slopes, thin soils and high precipitation, as in the Gjerstad area, was expected to promote rapid response in stream water due to anticipated dominance of overland and subsurface flow. Soil stratification in hillslope profiles is characterised by compact basal layers (Feger 1994), which also may promote lateral flow. Poorly mineralised humus, forming hydrophobic layers in the organic top layer of the coniferous forest may act in the same way. Less clear-cut effects in stream water in other forested ecosystems may be due to different topography, soil properties and climatic conditions. Possibilities of undesirable effects, like increased leaching of N and trace metals, is dependent on the deposition history of these elements in the actual sites. As deposition may vary to a great extent, e.g. between German and Norwegian sites, different results should be expected and this is indeed also what has been found. This confirms the rationale in selecting Norwegian sites for research activities before drawing conclusions on possible effects of forest soil liming in Norway.

Terrestrial liming, as the forest soil liming in Gjerstad and the alternative strategies represented by whole-catchment liming of non-forested catchments (Traaen *et al.* 1997) and wetland liming (Hindar *et al.* 1996), has certain advantages compared to more traditional (in Norway) lake liming and lime dosing methods. The Al-transport from the acidified catchment to watercourses will be reduced, and a more stable water quality is achieved throughout the year. Low doses of coarse-grained dolomite will probably minimise the undesirable effects on water quality. Terrestrial liming, also the forest soil liming concept, may therefore represent an interesting supplement to other liming methods for aquatic systems. A longer data record is needed, however, to draw conclusions on NO_3 leaching and costs.

5.4 Forest condition

An overall conclusion from the tree stand investigations is that the liming has so far shown no significant effects on tree growth and tree vitality (crown density and crown colour).

The causes for the general low level of increment could be several. In specific periods deviation from the function may occur due to e.g. climatic factors. The increment function can be said to represent the average climate for a long period. Another explanation could be that the function is based on forest stands that have been treated regularly with thinning and therefor represent high vitality and high «class» stands.

From other investigations we know that increment in old pine and spruce forests will be little or even negatively effected for more than 20 years after liming (Staaf *et al.* 1996). To evaluate the forest growth more detailed increment analyses should be performed 10 years after liming. Then increment cores should be taken and a calibration to pre-liming increment could be done. Then more information on long-term effects of this low dose dolomite application can be extracted.

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Appendix A. Water and soil chemistry

Abbreviation and references for sampling stations:

LIM-1: Stream outlet of catchment 1 in the limed catchment Fugleliåsen
LIM-2: Stream outlet of catchment 2 in the limed catchment Fugleliåsen
LIM-3: Stream outlet of catchment 3 in the limed catchment Fugleliåsen
LIM-4: Main stream outlet of the limed catchment Fugleliåsen
REF: Stream outlet of reference catchment Spjøtåsen

Limed: 1=unlimed; 2=limed

FU-06 to FU-xx: Sampling stations for soil solution in the limed catchment Fugleliåsen
SP-28 to SP-xx: Sampling stations for soil solution in the limed catchment Spjøtåsen

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	26-May-93	1	5.2	1.4	0.4	145	100	4	2.2	0.2	3.7	4.1	15	16	165		2
LIM-3	26-May-93	1	5.4	1.5	0.4	123	86	3	2.3	0.2	3.4	4.3	22	6	120		2
LIM-4	26-May-93	1	5.3	1.4	0.4	130	94	4	2.2	0.2	3.6	4.0	18	1	143		2
REF	26-May-93	1	5.1	1.3	0.3	142	121	8	2.0	0.2	3.4	2.6	37	20	305		3
LIM-1	3-Aug-93	1	4.9	2.1	0.6	358	285	12	2.0	0.4	2.7	4.5	57	325	870	15	17
LIM-2	3-Aug-93	1	4.5	1.2	0.4	433	292	11	1.8	0.1	2.6	4.0	10	79	550	13	13
LIM-3	3-Aug-93	1	4.7	1.7	0.4	458	265	12	1.5	0.4	2.7	4.4	15	160	725	18	25
LIM-4	3-Aug-93	1	4.7	1.8	0.5	394	299	13	1.9	0.3	2.7	4.4	37	210	755	15	18
REF	3-Aug-93	1	4.7	1.9	0.5	312	256	14	1.6	0.2	2.5	3.8	58	32	575	18	17
LIM-1	31-Aug-93	1	5.4	1.6	0.4	180	143	5	2.2	0.1	3.5	4.2	24	33	215	5	3
LIM-2	31-Aug-93	1	4.7	1.0	0.3	260	156	5	2.1	0.0	3.4	4.0	-10	11	190	5	2
LIM-3	31-Aug-93	1	5.2	1.3	0.3	180	107	4	1.9	0.1	3.3	3.8	5	13	160	5	2
LIM-4	31-Aug-93	1	5.2	1.4	0.4	193	129	5	2.1	0.1	3.5	3.9	10	22	180	5	3
REF	31-Aug-93	1	5.4	1.5	0.3	168	162	9	2.0	0.1	2.1	3.6	56	13	295	5	4
LIM-1	6-Oct-93	1	4.7	1.4	0.5	337	272	12	2.2	0.5	3.4	4.4	30	34	480	11	13
LIM-2	6-Oct-93	1	4.6	1.1	0.4	356	266	10	2.3	0.3	3.7	4.0	4	12	370	9	6
LIM-3	6-Oct-93	1	4.7	1.0	0.3	335	238	9	1.9	0.4	3.0	3.8	3	25	325	9	8
LIM-4	6-Oct-93	1	4.6	1.3	0.4	348	272	10	2.1	0.5	3.6	4.4	7	29	395	11	11
REF	6-Oct-93	1	4.6	1.7	0.5	271	232	13	2.2	0.4	3.5	4.6	30	16	445	20	8
LIM-1	7-Nov-93	1	5.2	1.4	0.5	201	146	5	2.3	0.2	3.2	5.0	14	55	240	6	2
LIM-2	7-Nov-93	1	4.8	1.0	0.4	275	164	5	2.4	0.1	3.3	4.5	-7	60	240	5	2
LIM-3	7-Nov-93	1	5.0	1.2	0.4	227	115	4	2.3	0.1	3.2	4.5	7	60	205	6	2
LIM-4	7-Nov-93	1	5.0	1.3	0.4	217	141	5	2.3	0.1	3.2	4.6	12	60	215	5	2
REF	7-Nov-93	1	4.9	1.6	0.5	180	139	8	2.4	0.1	3.3	4.7	35	38	275	9	3
LIM-1	11-Nov-93	1	4.6	1.2	0.5	291	230	10	2.0	0.5	2.4	5.0	14	245	640	15	12
LIM-2	11-Nov-93	1	4.5	1.0	0.4	305	230	9	2.1	0.4	2.5	5.2	-12	235	565	27	7
LIM-3	11-Nov-93	1	4.6	1.1	0.4	329	212	9	2.1	0.4	2.7	5.0	-3	170	490	21	9
LIM-4	11-Nov-93	1	4.6	1.2	0.4	307	248	10	2.0	0.5	2.5	5.2	-2	230	590	18	10
REF	11-Nov-93	1	4.6	1.5	0.5	227	193	10	2.2	0.3	2.8	5.3	11	230	590	39	7
LIM-1	14-Nov-93	1	4.7	1.1	0.4	235	186	8	1.9	0.2	2.3	4.8	8	38	260	5	3
LIM-3	14-Nov-93	1	4.6	1.1	0.3	316	227	7	2.0	0.1	2.3	4.6	8	37	235	6	2
LIM-4	14-Nov-93	1	4.7	1.0	0.4	264	204	7	2.0	0.2	2.2	4.7	9	38	235	6	2
REF	14-Nov-93	1	4.6	1.2	0.4	190	165	8	2.0	0.2	2.4	5.0	10	44	265	12	3

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	13-Mar-94	1	5.1	1.2	0.4	197	116	5	2.2	0.3	2.5	4.7	22	81	235	6	2
LIM-2	13-Mar-94	1	4.7	0.9	0.4	287	137	6	2.4	0.2	2.7	4.8	-2	160	320	15	2
LIM-3	13-Mar-94	1	4.9	1.1	0.4	270	106	5	2.3	0.2	2.6	4.9	8	108	250	9	2
LIM-4	13-Mar-94	1	4.9	1.1	0.4	237	121	5	2.3	0.2	2.5	4.7	16	103	250	9	2
REF	13-Mar-94	1	4.8	1.2	0.4	176	109	6	2.3	0.3	2.6	4.9	22	92	300	32	2
LIM-1	29-Mar-94	1	5.1	1.3	0.5	175	143	5	2.2	0.3	2.5	4.6	28	185	370	42	3
LIM-2	29-Mar-94	1	4.7	1.0	0.4	271	178	5	2.4	0.3	2.6	4.8	4	210	400	45	2
LIM-3	29-Mar-94	1	4.8	1.1	0.4	280	158	5	2.6	0.2	2.5	4.8	23	175	360	42	2
LIM-4	29-Mar-94	1	5.0	1.3	0.4	229	157	5	2.3	0.3	2.5	4.8	18	195	400	48	2
REF	29-Mar-94	1	4.8	1.4	0.4	171	145	7	2.3	0.3	2.5	5.0	26	139	385	60	3
LIM-1	11-Apr-94	1	4.8	1.1	0.4	185	127	5	1.9	0.6	2.4	4.8	3	165	330	16	3
LIM-2	11-Apr-94	1	4.6	0.9	0.3	239	153	5	1.9	0.3	2.5	5.1	-32	205	385	39	1
LIM-3	11-Apr-94	1	4.7	1.0	0.3	271	162	5	1.9	0.2	2.4	5.0	-18	160	330	7	2
LIM-4	11-Apr-94	1	4.8	1.0	0.4	214	145	5	1.9	0.3	2.4	4.9	-13	170	355	14	2
LIM-1	18-Apr-94	1	4.9	0.9	0.4	186	130	6	1.7	0.3	2.1	4.6	-6	68	230	12	2
LIM-2	18-Apr-94	1	4.7	0.7	0.3	224	151	5	1.6	0.2	1.9	4.6	-20	64	200	9	2
LIM-3	18-Apr-94	1	4.8	0.9	0.3	255	156	5	1.7	0.2	1.9	4.7	-9	75	210	6	2
LIM-4	18-Apr-94	1	4.8	0.9	0.3	206	143	6	1.7	0.2	2.0	4.5	-7	72	215	7	3
REF	18-Apr-94	1	4.8	0.9	0.3	142	113	5	1.6	0.2	1.8	4.4	0	39	195	12	2
LIM-1	25-Apr-94	1	5.1	0.9	0.3	177	131	6	1.5	0.3	1.8	4.4	-8	73	240	10	2
LIM-2	25-Apr-94	1	4.7	0.7	0.3	200	142	5	1.4	0.2	1.4	4.4	-18	79	220	13	3
LIM-3	25-Apr-94	1	4.8	0.8	0.3	234	161	5	1.5	0.1	1.4	4.7	-10	72	215	5	2
LIM-4	25-Apr-94	1	4.8	0.9	0.3	197	133	6	1.5	0.2	1.6	4.5	-5	74	210	10	2
REF	25-Apr-94	1	4.8	0.9	0.3	136	116	5	1.4	0.2	1.4	4.2	2	64	230	21	2
LIM-1	2-May-94	1	4.9	0.8	0.3	162	123	6	1.3	0.2	1.2	3.9	8	49	220	9	3
LIM-2	2-May-94	1	4.7	0.6	0.2	187	135	5	1.2	0.2	1.0	3.8	-7	40	185	6	2
LIM-3	2-May-94	1	4.8	0.8	0.2	211	147	5	1.3	0.1	1.1	4.0	0	45	195	5	2
LIM-4	2-May-94	1	4.8	0.7	0.3	186	138	6	1.3	0.2	1.2	4.0	0	51	205	7	2
REF	2-May-94	1	4.8	0.8	0.2	113	99	5	1.2	0.2	1.1	3.4	9	31	190	12	2
LIM-1	10-May-94	1	5.1	0.8	0.3	183	122	7	1.3	0.2	1.2	4.0	9	48	240	14	6
LIM-2	10-May-94	1	4.7	0.6	0.2	204	123	5	1.2	0.2	1.1	3.9	-11	67	201	8	2
LIM-3	10-May-94	1	4.8	0.8	0.3	225	129	5	1.4	0.1	1.2	4.2	3	69	235	12	2
LIM-4	10-May-94	1	4.9	0.8	0.3	193	120	6	1.4	0.2	1.2	4.1	2	74	245	20	2
REF	10-May-94	1	4.9	0.9	0.3	141	103	6	1.4	0.2	1.2	3.8	11	65	260	17	2

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	18-May-94	1	5.2	0.9	0.3	183	144	8	1.4	0.2	1.3	4.0	15	35	270	193	4
LIM-2	18-May-94	1	4.7	0.7	0.2	222	149	5	1.4	0.1	1.3	4.0	-5	35	160	5	2
LIM-3	18-May-94	1	5.0	1.0	0.3	203	120	4	1.6	0.1	1.6	4.4	9	20	137	5	2
LIM-4	18-May-94	1	5.0	0.8	0.3	196	131	6	1.4	0.2	1.3	4.0	8	40	285	96	2
REF	18-May-94	1	4.9	1.0	0.3	163	129	7	1.5	0.2	1.4	3.5	26	50	245	12	3
LIM-1	25-Aug-94	1	4.6	1.9	0.7	383	269	17	1.7	0.2	1.8	7.3	20	29	640	120	17
LIM-2	25-Aug-94	1	4.4	0.9	0.3	348	263	12	1.5	0.1	1.8	4.1	-1	7	370	13	7
LIM-3	25-Aug-94	1	4.6	1.1	0.3	364	246	10	1.4	0.1	1.7	4.4	1	16	330	5	9
LIM-4	25-Aug-94	1	4.6	1.6	0.5	363	254	11	1.7	0.2	1.8	5.9	24	30	540	102	12
REF	25-Aug-94	1	4.5	1.5	0.4	284	237	12	1.6	0.1	1.7	4.9	31	9	425	10	8
LIM-1	31-Aug-94	1	4.6	1.3	0.5	307	231	12	1.5	0.1	1.4	5.1	22	6	370	11	7
LIM-2	31-Aug-94	1	4.6	0.9	0.3	288	199	8	1.6	0.0	1.7	4.1	3	1	210	5	2
LIM-3	31-Aug-94	1	4.8	1.2	0.3	256	144	6	1.7	0.0	1.6	4.5	21	9	225	5	3
LIM-4	31-Aug-94	1	4.8	1.3	0.4	266	182	7	1.7	0.1	1.6	4.8	23	18	230	5	3
REF	31-Aug-94	1	4.8	1.5	0.4	228	186	10	1.8	0.1	1.8	4.9	32	6	300	5	4
LIM-1	12-Sep-94	1	4.8	1.0	0.3	280	210	10	1.4	0.1	1.6	4.1	13	6	310	23	5
LIM-2	12-Sep-94	1	4.6	0.7	0.2	278	198	7	1.5	0.1	1.9	4.3	-23	9	210	8	2
LIM-3	12-Sep-94	1	4.8	1.0	0.3	281	174	6	1.6	0.1	1.9	4.8	-12	12	200	10	2
LIM-4	12-Sep-94	1	4.7	1.0	0.3	295	217	9	1.5	0.1	1.6	3.9	11	9	300	10	5
REF	12-Sep-94	1	4.7	1.2	0.3	231	193	12	1.6	0.1	1.9	4.5	11	6	325	23	4
LIM-1	19-Sep-94	1	4.9	0.9	0.3	256	209	10	1.3	0.2	1.4	3.4	22	3	270	15	4
LIM-2	19-Sep-94	1	4.6	0.7	0.2	257	185	7	1.3	0.1	1.6	3.4	-5	4	190	5	2
LIM-3	19-Sep-94	1	4.8	0.9	0.3	267	167	7	1.4	0.1	1.6	3.9	4	15	185	5	2
LIM-4	19-Sep-94	1	4.7	0.8	0.3	276	207	9	1.3	0.1	1.5	3.4	11	7	265	13	4
REF	19-Sep-94	1	4.7	1.0	0.3	216	176	12	1.4	0.1	1.6	3.5	20	6	305	12	4
LIM-1	26-Sep-94	2	5.6	1.3	0.6	184	143	6	1.5	0.1	1.6	4.1	46	8	205	9	3
LIM-2	26-Sep-94	2	5.3	0.9	0.5	223	152	7	1.3	0.0	2.0	3.6	9	6	215	9	3
LIM-3	26-Sep-94	2	5.9	1.3	0.5	173	139	5	1.5	0.1	1.7	4.2	33	31	210	9	2
LIM-4	26-Sep-94	2	6.0	1.5	0.6	173	161	6	1.5	0.1	1.7	4.1	51	25	220	11	4
REF	26-Sep-94	1	5.1	1.0	0.3	186	153	9	1.5	0.1	2.0	3.5	11	24	290	9	3
LIM-2	29-Sep-94	2	5.4	1.1	0.5	216	178	7	1.4	0.1	1.8	3.6	27	10	205	14	2
LIM-3	29-Sep-94	2	5.6	1.5	0.5	162	133	5	1.5	0.1	1.8	4.3	41	45	205	12	2

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	12-Oct-94	2	6.5	1.8	0.6	128	123		1.6					13	470	214	
LIM-2	12-Oct-94	2	5.5	1.1	0.6	194	173	6	1.5	0.1	2.1	4.4	18	27	200	12	2
LIM-3	12-Oct-94	2	5.8	1.7	0.6	134	112	4	1.7	0.1	2.1	4.9	43	83	235	19	5
LIM-4	12-Oct-94	2	6.4	1.6	0.6	98	92		1.6					36	580	332	
REF	12-Oct-94	1	5.6	1.2	0.3	161	150		1.6					43	580	268	
LIM-1	27-Oct-94	2	5.3	1.7	0.8	223	194	9	2.0	0.5	3.6	3.7	59	97	370	31	6
LIM-2	27-Oct-94	2	5.0	1.3	0.7	239	189	8	1.8	0.3	3.3	3.4	34	78	300	19	3
LIM-3	27-Oct-94	2	5.2	1.6	0.7	251	206	8	1.9	0.3	3.3	3.5	49	66	285	21	4
LIM-4	27-Oct-94	2	5.3	1.6	0.7	227	193	8	1.9	0.4	3.5	3.7	51	112	370	37	5
REF	27-Oct-94	1	4.7	1.5	0.5	212	164	10	2.1	0.4	3.4	3.7	33	106	395	23	4
LIM-1	31-Oct-94	2	5.8	1.4	0.5	181	169	8	1.5	0.1	1.6	4.0	42	7	355	126	4
LIM-2	31-Oct-94	2	5.4	1.1	0.5	216	178	7	1.4	0.1	1.8	3.6	27	10	205	14	2
LIM-3	31-Oct-94	2	5.6	1.5	0.5	162	133	5	1.5	0.1	1.8	4.3	41	45	205	12	2
LIM-4	31-Oct-94	2	5.9	1.4	0.5	154	146	7	1.5	0.1	1.7	4.0	39	25	370	137	3
REF	31-Oct-94	1	5.2	1.1	0.3	192	165	11	1.6	0.1	1.7	3.6	28	22	455	164	4
LIM-1	3-Nov-94	2	5.5	1.5	0.7	206	182	8	1.8	0.3				19	230	8	3
LIM-2	3-Nov-94	2	5.2	1.2	0.7	227	182	6	1.8	0.2	2.9	3.8	30	33	205	5	2
LIM-3	3-Nov-94	2	5.4	1.4	0.6	224	177	6	1.8	0.1	2.8	3.9	38	82	200	5	3
LIM-4	3-Nov-94	2	5.4	1.5	0.7	220	189	7	1.8	0.2	3.3	4.2	28	28	220	10	3
REF	3-Nov-94	1	4.7	1.3	0.4	206	164	8	1.9	0.2	3.1	3.8	15	30	250	13	3
LIM-1	14-Nov-94	2	5.9	1.9	0.8	187	167	7	2.2	0.2	3.1	4.6	75	37	265	27	3
LIM-2	14-Nov-94	2	5.2	1.3	0.7	226	184	6	1.9	0.1	2.7	3.7	47	100	265	6	2
LIM-3	14-Nov-94	2	5.5	1.5	0.7	219	175	6	1.9	0.1	3.0	4.4	30	80	220	5	2
LIM-4	14-Nov-94	2	5.8	1.6	0.7	172	154	6	1.9	0.2	2.8	4.0	58	49	315	19	2
REF	14-Nov-94	1	4.9	1.6	0.5	202	157	9	2.2	0.1	2.9	4.3	38	37	265	30	3
LIM-1	21-Nov-94	2	5.8	1.6	0.7	193	176	7	2.1	0.2	2.8	4.0	70	41	250	19	3
LIM-2	21-Nov-94	2	5.3	1.2	0.7	217	178	6	1.9	0.1	2.7	4.0	33	58	230	6	2
LIM-3	21-Nov-94	2	5.5	1.4	0.6	210	166	5	1.9	0.1	2.7	4.0	39	59	205	5	1
LIM-4	21-Nov-94	2	5.7	1.5	0.7	212	193	7	2.0	0.1	2.9	4.2	54	51	265	19	2
REF	21-Nov-94	1	4.9	1.4	0.4	205	161	8	2.1	0.1	2.9	4.2	25	37	275	19	2
LIM-1	6-Dec-94	2	6.0	1.5	0.7	164	156	6	1.8	0.2	2.6	4.1	55	47	290	66	3
LIM-2	6-Dec-94	2	5.5	1.2	0.7	219	180	6	1.8	0.1	2.5	3.9	30	120	265	8	2
LIM-3	6-Dec-94	2	5.5	1.3	0.6	200	177	5	1.8	0.1	2.7	4.2	26	104	235	7	2
LIM-4	6-Dec-94	2	5.9	1.6	0.7	166	158	6	1.9	0.1	2.7	4.3	53	69	255	49	2
REF	6-Dec-94	1	5.0	1.4	0.4	187	156	8	2.0	0.1	2.9	4.6	15	55	295	61	2

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	12-Dec-94	2	5.6	1.3	0.6	197	186	8	1.6	0.2	2.7	3.7	35	77	290	21	4
LIM-2	12-Dec-94	2	5.3	1.2	0.6	216	191	6	1.7	0.1	2.6	4.0	25	73	225	5	1
LIM-3	12-Dec-94	2	5.5	1.3	0.6	220	183	5	1.7	0.1	2.6	4.0	27	73	205	5	1
LIM-4	12-Dec-94	2	5.5	1.3	0.6	211	197	7	1.6	0.2	2.6	3.7	30	87	280	21	2
REF	12-Dec-94	1	4.8	1.2	0.4	201	172	8	1.7	0.2	2.7	3.8	5	71	270	23	3
LIM-1	21-Dec-94	2	5.9	1.6	0.7	174	160	7	1.6	0.2	2.8	3.8	43	81	260	19	3
LIM-2	21-Dec-94	2	5.4	1.3	0.7	207	176	6	1.7	0.1	2.8	4.0	24	89	225	5	1
LIM-3	21-Dec-94	2	5.5	1.4	0.6	216	176	5	1.7	0.1	2.8	4.1	23	77	210	5	1
LIM-4	21-Dec-94	2	5.6	1.3	0.6	189	169	6	1.7	0.1	3.0	4.0	19	92	270	28	2
REF	21-Dec-94	1	4.9	1.3	0.4	183	146	7	1.7	0.2	2.7	3.9	9	85	295	41	3
LIM-1	3-Jan-95	2	5.6	1.8	0.9	151	134	6	2.2	0.3				44	230	29	3
LIM-2	3-Jan-95	2	5.3	1.3	0.7	209	166	6	1.8	0.1	3.0	4.3	21	109	245	5	1
LIM-3	3-Jan-95	2	5.5	1.4	0.7	207	156	5	1.8	0.1	2.9	4.4	28	99	225	5	1
LIM-4	3-Jan-95	2	5.7	1.5	0.7	183	168	5	1.8	0.2	2.8	4.2	44	79	250	32	1
REF	3-Jan-95	1	4.9	1.5	0.4	179	142	7	2.0	0.2	3.0	4.4	20	67	255	24	2
LIM-1	15-Feb-95	2	5.8	1.5	0.8	177	151	5	2.2	0.3	4.2	3.6	38	165	315	14	2
LIM-2	15-Feb-95	2	5.4	1.4	0.9	200	151	5	2.4	0.2	4.7	3.7	30	175	325	32	2
LIM-3	15-Feb-95	2	5.4	1.4	0.8	216	161	5	2.2	0.2	4.0	3.8	29	160	295	10	2
LIM-4	15-Feb-95	2	5.6	1.4	0.8	188	154	4	2.2	0.2	4.2	3.7	30	165	305	16	2
REF	15-Feb-95	1	4.7	1.2	0.5	192	131	5	2.2	0.2	4.2	3.7	-5	160	340	41	2
LIM-1	14-Mar-95	2	6.1	1.7	0.9	144	131	4	2.1	0.2	4.2	4.1	43	119	245	7	2
LIM-2	14-Mar-95	2	5.4	1.4	0.9	182	149	5	2.2	0.2	4.4	4.0	23	180	305	8	1
LIM-3	14-Mar-95	2	5.6	1.5	0.8	181	136	4	2.2	0.1	4.0	4.3	22	170	285	12	1
LIM-4	14-Mar-95	2	5.9	1.7	0.8	155	133	4	2.2	0.2	4.1	4.1	39	150	270	11	1
REF	14-Mar-95	1	4.9	1.5	0.5	171	121	5	2.2	0.2	4.1	4.3	-2	145	310	34	2
LIM-1	27-Mar-95	2	6.0	1.8	1.0	138	119	6	2.3	0.3	4.8	4.6	28	220	415	52	2
LIM-2	27-Mar-95	2	5.5	1.5	1.0	172	135	4	2.5	0.2	4.9	4.7	15	260	430	38	1
LIM-3	27-Mar-95	2	5.5	1.6	0.8	190	138	4	2.3	0.1	4.5	4.5	16	185	305	8	1
LIM-4	27-Mar-95	2	5.9	1.8	1.0	151	129	5	2.3	0.2	4.7	4.6	28	230	415	59	2
REF	27-Mar-95	1	4.7	1.3	0.5	171	109	5	2.2	0.2	4.3	4.5	-20	175	375	67	2
LIM-1	5-Apr-95	2	6.0	1.6	0.9	146	130	4	2.2	0.4	4.1	4.2	48	103	220	5	1
LIM-2	5-Apr-95	2	5.6	1.4	0.9	175	144	4	2.3	0.3	4.2	4.2	33	149	285	8	1
LIM-3	5-Apr-95	2	5.5	1.5	0.8	190	144	4	2.2	0.2	3.9	4.3	30	155	270	5	1
LIM-4	5-Apr-95	2	5.9	1.6	0.9	153	135	4	2.2	0.3	4.2	4.2	38	149	290	22	1
REF	5-Apr-95	1	4.8	1.3	0.5	165	113	5	2.2	0.3	3.9	4.2	-1	101	265	32	1

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	16-Apr-95	2	6.0	1.5	0.8	145	128	5	1.9	0.3	4.3	4.8	1	104	235	10	2
LIM-2	16-Apr-95	2	5.7	1.1	0.7	169	142	5	1.8	0.2	2.7	4.0	27	78	205	11	1
LIM-3	16-Apr-95	2	5.5	1.2	0.6	198	157	5	1.8	0.2	2.8	4.2	21	88	210	5	1
LIM-4	16-Apr-95	2	6.0	1.4	0.8	158	139	5	1.9	0.3	3.9	4.6	4	105	235	15	2
REF	16-Apr-95	1	4.9	1.0	0.4	158	111	5	1.7	0.3	2.9	3.8	-4	54	205	21	2
LIM-1	25-Apr-95	2	5.9	1.2	0.7	147	129	6	1.5	0.3	2.5	3.9	31	66	225	11	3
LIM-2	25-Apr-95	2	5.7	0.9	0.6	166	139	5	1.3	0.3	2.0	3.9	15	57	190	8	1
LIM-3	25-Apr-95	2	5.5	1.0	0.5	203	171	6	1.5	0.2	2.2	4.1	12	64	200	5	2
LIM-4	25-Apr-95	2	5.8	1.1	0.6	160	139	5	1.5	0.3	2.4	4.0	23	70	210	10	2
REF	25-Apr-95	1	5.0	0.9	0.3	145	108	6	1.4	0.3	2.3	3.6	-8	38	185	21	2
LIM-1	8-May-95	2	6.0	1.2	0.6	153	138	6	1.5	0.3	1.9	4.0	43	44	230	29	3
LIM-2	8-May-95	2	5.8	1.0	0.6	182	158	6	1.4	0.2	1.6	3.1	42	75	260	5	3
LIM-3	8-May-95	2	5.7	1.2	0.6	195	167	6	1.6	0.1	1.9	3.7	44	51	220	5	3
LIM-4	8-May-95	2	6.0	1.1	0.6	160	144	5	1.5	0.2	1.9	3.9	39	51	210	21	2
REF	8-May-95	1	5.1	0.9	0.3	144	117	6	1.4	0.2	1.8	3.3	11	34	265	59	2
LIM-1	26-May-95	2	6.2	1.4	0.7	160	156	7	1.5	0.2	1.9	3.8	56	29	325	105	4
LIM-2	26-May-95	2	5.8	1.1	0.6	167	150	5	1.5	0.1	2.0	4.2	30	64	215	5	2
LIM-3	26-May-95	2	6.0	1.5	0.6	137	111	4	1.7	0.2	2.3	4.6	41	43	180	5	2
LIM-4	26-May-95	2	6.1	1.2	0.6	160	152	6	1.4	0.2	1.9	3.8	45	38	260	52	3
REF	26-May-95	1	5.1	0.9	0.3	157	131	7	1.3	0.2	1.8	3.2	11	29	325	87	3
LIM-1	6-Jun-95	2	6.2	1.5	0.7	188	181	10	1.6	0.2	1.8	3.4	80	33	355	40	7
LIM-2	6-Jun-95	2	5.8	1.2	0.6	191	174	7	1.6	0.1	1.9	3.9	45	34	225	5	2
LIM-3	6-Jun-95	2	5.9	1.3	0.6	175	155	6	1.7	0.1	2.1	4.2	48	19	175	6	3
LIM-4	6-Jun-95	2	6.1	1.4	0.7	188	181	9	1.6	0.2	1.8	3.6	67	35	320	53	5
REF	6-Jun-95	1	5.1	1.0	0.3	175	149	9	1.4	0.1	1.7	3.3	19	19	375	91	6
LIM-1	13-Jun-95	2	6.0	1.4	0.7	198	185	9	1.4	0.1	1.6	3.2	78	18	345	31	6
LIM-2	13-Jun-95	2	5.9	1.1	0.7	195	182	8	1.4	0.1	1.7	3.4	52	30	225	5	3
LIM-3	13-Jun-95	2	5.9	1.2	0.6	200	180	7	1.5	0.1	1.9	3.7	46	28	210	5	3
LIM-4	13-Jun-95	2	6.0	1.3	0.7	206	197	8	1.5	0.1	1.7	3.3	68	26	290	23	5
REF	13-Jun-95	1	4.9	0.9	0.3	184	162	9	1.4	0.1	1.6	3.1	19	13	275	27	4
LIM-1	27-Jun-95	2	6.3	1.4	0.7	178	170	9	1.6	0.1	1.4	3.4	83	14	325	34	7
LIM-2	27-Jun-95	2	6.1	1.2	0.7	185	173	8	1.6	0.0	1.6	4.0	60	36	260	5	4
LIM-3	27-Jun-95	2	6.0	1.5	0.7	162	145	6	1.9	0.1	1.9	4.2	72	24	215	5	4
LIM-4	27-Jun-95	2	6.2	1.3	0.7	177	174	8	1.7	0.1	1.5	3.4	79	16	305	48	5
REF	27-Jun-95	1	5.0	1.0	0.3	174	147	9	1.6	0.1	1.5	3.3	28	10	355	68	5

St. no.	DATO	Limed	pH	Ca	Mg	Alr	Alo	TOC	Na	K	Cl	SULF	ANC1	NO3-N	Tot N	NH4-N	Tot P
			-log (H+)	mg L-1	mg L-1	µg L-1	µg L-1	mg L-1	mg L-1	mg L-1	mg L-1	mg L-1	µeq L-1	µg L-1	µg L-1	µg L-1	µg L-1
LIM-1	7-Sep-95	2	6.0	2.7	1.4	264	150	9	2.1	0.3	2.5	8.9	66	395	680	7	9
LIM-2	7-Sep-95	2	5.4	2.3	1.5	231	182	10	1.9	0.3	2.3	9.4	39	340	670	9	9
LIM-3	7-Sep-95	2	5.6	2.3	1.3	194	147	7	1.9	0.3	2.7	7.4	42	560	780	7	8
LIM-4	7-Sep-95	2	5.8	2.6	1.4	187	156	8	2.0	0.3	2.4	8.6	64	400	670	10	9
REF	7-Sep-95	1	4.8	2.5	0.7	290	188	11	2.0	0.7	2.7	8.2	26	126	190	10	9
LIM-1	14-Sep-95	2	5.8	2.5	1.4	239	203	11	1.9	0.4	2.7	8.9	63	67	425	17	6
LIM-2	14-Sep-95	2	5.5	1.4	0.9	240	203	10	1.7	0.3	2.6	5.2	45	24	305	7	3
LIM-3	14-Sep-95	2	5.5	1.6	1.0	228	191	8	1.7	0.2	2.6	5.7	42	61	300	5	3
LIM-4	14-Sep-95	2	5.7	2.1	1.2	232	194	10	1.8	0.3	2.7	7.4	58	73	450	5	6
REF	14-Sep-95	1	4.7	2.0	0.5	259	175	11	1.9	0.4	2.6	7.0	17	21	410	31	6
LIM-1	18-Sep-95	2	5.8	1.6	0.9	228	207	11	1.6	0.4	2.1	5.3	65	15	320	5	5
LIM-2	18-Sep-95	2	5.6	1.2	0.8	225	211	9	1.7	0.3	2.1	4.6	54	16	265	5	3
LIM-3	18-Sep-95	2	5.6	1.5	0.9	225	191	8	1.7	0.2	2.2	5.2	49	37	260	5	3
LIM-4	18-Sep-95	2	5.6	1.6	0.9	236	210	10	1.7	0.3	2.2	5.1	68	21	320	7	4
REF	18-Sep-95	1	4.7	1.3	0.4	226	178	11	1.6	0.3	2.1	5.0	12	8	320	10	4
LIM-1	4-Oct-95	2	5.8	1.7	0.9	196	188	9	1.9	0.3	2.5	5.3	68	21	270	19	4
LIM-2	4-Oct-95	2	5.6	1.3	0.8	204	180	8	1.8	0.2	2.6	4.2	49	103	310	5	4
LIM-3	4-Oct-95	2	5.6	1.5	0.8	184	162	6	1.8	0.2	2.5	4.9	44	97	265	7	3
LIM-4	4-Oct-95	2	5.8	1.6	0.9	202	183	8	1.8	0.2	2.5	5.1	56	34	280	17	11
REF	4-Oct-95	1	4.8	1.4	0.4	212	162	10	1.9	0.2	2.4	4.8	20	17	290	26	4
LIM-1	23-Oct-95	2	6.1	1.6	0.9	119	75	9	1.8	0.3	2.6	4.3	72	33	300	23	5
LIM-4	23-Oct-95	2	6.0	1.5	0.9	97	37	8	1.7	0.3	2.7	4.2	57	46	305	21	6
REF	23-Oct-95	1	4.9	1.3	0.4	72	73	9	1.7	0.2	2.6	4.1	13	27	315	49	3
LIM-1	20-Nov-95	2	5.8	1.6	0.8	42	43	7	1.9	0.3	2.9	4.1	62	101	375	72	4
LIM-4	20-Nov-95	2	5.7	1.6	0.9	56	52	7	2.0	0.2	3.0	4.4	53	149	385	51	2
REF	20-Nov-95	1	5.0	1.4	0.4	131	128	8	2.0	0.2	2.7	4.1	22	80	640	144	7
LIM-1	4-Dec-95	2	6.0	1.6	0.9	151	142	6	1.7	0.2	2.7	4.3	47	210	400	5	2
LIM-4	4-Dec-95	2	5.9	1.5	0.9	154	139	6	1.7	0.2	2.6	4.3	42	235	405	5	2
REF	4-Dec-95	1	5.2	1.4	0.4	159	125	7	1.7	0.1	2.5	4.1	18	96	310	7	2
LIM-1	19-Dec-95	2	6.1	1.8	1.0	141	129	6	2.0	0.2	2.7	4.7	70	195	335	5	1
LIM-4	19-Dec-95	2	5.9	1.6	0.9	149	137	5	1.9	0.2	2.9	4.8	47	220	370	5	1
REF	19-Dec-95	1	5.1	1.5	0.4	163	129	6	1.9	0.1	2.8	4.5	19	113	300	10	2

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	12-Jan-96	2	5.4	1.7	1.0	165	123	6	1.9	0.5	2.9	5.8	28	455	660	24	4
LIM-4	12-Jan-96	2	5.6	1.8	1.1	140	120	6	1.9	0.4	3.0	5.8	33	490	730	45	5
REF	12-Jan-96	1	4.8	1.8	0.6	189	119	8	2.1	0.4	3.0	6.0	4	340	630	65	4
LIM-1	18-Apr-96	2	5.8	1.6	0.9	132	119	7	1.9	0.4	2.5	4.4	56	365	560	22	3
LIM-4	18-Apr-96	2	5.7	1.5	0.9	141	126	6	1.9	0.4	2.5	4.6	46	320	500	22	3
REF	18-Apr-96	1	4.7	1.3	0.4	153	113	7	1.9	0.4	2.4	4.6	12	160	410	37	13
LIM-1	22-Apr-96	2	5.8	1.4	0.8	129	126	6	1.7	0.4	2.0	4.0	57	325	520	15	5
LIM-4	22-Apr-96	2	5.7	1.3	0.8	147	141	6	1.7	0.4	2.1	4.2	42	280	465	15	3
REF	22-Apr-96	1	4.8	1.0	0.3	149	117	7	1.6	0.3	1.9	4.1	10	121	320	24	3
LIM-1	28-Apr-96	2	5.8	1.3	0.7	131	133	6	1.6	0.4				235	430	18	3
LIM-4	28-Apr-96	2	5.7	1.2	0.7	142	138	6	1.6	0.4				220	405	15	3
REF	28-Apr-96	1	4.9	1.0	0.3	145	121	7	1.5	0.3				88	315	42	3
LIM-1	7-May-96	2	5.8	1.4	0.8	148	152	7	1.7	0.4	1.8	4.3	67	148	355	12	3
LIM-4	7-May-96	2	5.7	1.3	0.8	153	149	6	1.7	0.3	1.8	4.2	57	155	340	9	3
REF	7-May-96	1	4.9	1.0	0.3	148	126	7	1.7	0.3	1.7	3.9	29	70	315	36	3
LIM-1	20-May-96	2	5.7	1.4	0.8	172	172	9	1.6	0.3	1.6	3.9	74	106	400	42	5
LIM-4	20-May-96	2	5.8	1.3	0.8	167	161	8	1.6	0.3	1.7	4.0	68	101	360	35	4
REF	20-May-96	1	4.9	1.1	0.3	164	142	9	1.5	0.2	1.6	3.8	25	45	350	62	5
LIM-1	29-May-96	2	5.9	1.4	0.8	145	135	8	1.6	0.3	1.6	4.2	68	77	310	32	3
LIM-4	29-May-96	2	5.8	1.3	0.7	155	137	7	1.6	0.3	1.7	4.3	55	77	290	27	2
REF	29-May-96	1	4.8	1.0	0.3	161	101	8	1.5	0.2	1.5	3.9	23	28	275	33	3
LIM-1	20-Jun-96	2	6.7	1.4	0.7	110	110	8	1.6	0.3	1.8	4.2	66	27	595	275	15
LIM-4	20-Jun-96	2	6.3	1.3	0.7	112	111	7	1.6	0.2	1.9	4.3	53	38	405	163	5
REF	20-Jun-96	1	5.4	1.1	0.3	133	124	8	1.6	0.2	1.9	4.0	16	25	500	210	7
LIM-1	7-Sep-96	2	5.6	2.2	1.2	247	240	14	1.7	0.2	1.8	6.6	99	24	665	160	11
LIM-4	7-Sep-96	2	5.8	1.9	1.1	215	206	12	1.8	0.1	2.0	5.8	83	36	590	147	9
REF	7-Sep-96	1	5.0	1.6	0.5	241	190	13	1.8	0.1	2.2	5.1	30	12	700	258	10
LIM-1	30-Sep-96	2	5.5	1.8	1.1	249	237	14	1.4	0.3	2.4	4.5	80	45	495	26	12
LIM-4	30-Sep-96	2	5.6	1.7	1.0	248	233	13	1.4	0.2	2.4	4.4	72	49	465	17	11
REF	30-Sep-96	1	4.7	1.4	0.4	239	201	13	1.4	0.3	2.5	4.1	15	43	445	23	9
LIM-1	16-Oct-96	2	6.0	1.7	1.0	189	175	10	1.6	0.1	2.4	4.5	76	9	320	23	4
LIM-4	16-Oct-96	2	5.9	1.6	0.9	195	182	8	1.6	0.1	2.4	4.4	67	13	280	11	4
REF	16-Oct-96	1	4.8	1.4	0.4	204	163	10	1.7	0.1	2.5	4.3	20	12	290	12	3
LIM-1	28-Oct-96	2	5.8	1.6	0.9	204	205	11	1.6	0.3	2.5	4.4	69	19	325	13	9
LIM-4	28-Oct-96	2	5.8	1.5	0.9	207	202	9	1.6	0.2	2.5	4.3	60	28	280	7	4
REF	28-Oct-96	1	4.8	1.3	0.4	204	176	9	1.7	0.1	2.4	4.3	14	19	275	12	4

St. no.	DATO	Limed	pH -log (H+)	Ca mg L-1	Mg mg L-1	Alr µg L-1	Alo µg L-1	TOC mg L-1	Na mg L-1	K mg L-1	Cl mg L-1	SULF mg L-1	ANC1 µeq L-1	NO3-N µg L-1	Tot N µg L-1	NH4-N µg L-1	Tot P µg L-1
LIM-1	7-Nov-96	2	5.9	1.4	0.9	158	153	9	1.6	0.2	2.3	3.9	70	14	250	12	3
LIM-4	7-Nov-96	2	5.9	1.4	0.9	165	158	8	1.6	0.1	2.4	4.0	61	24	245	10	3
REF	7-Nov-96	1	4.8	1.2	0.4	174	141	9	1.7	0.1	2.4	4.0	16	16	260	12	3
LIM-1	21-Nov-96	2	6.1	1.4	0.9	158	137	8	1.7	0.2	2.4	4.3	60	37	285	31	4
LIM-4	21-Nov-96	2	6.0	1.4	0.9	162	136	7	1.7	0.1	2.5	4.4	54	57	270	20	3
REF	21-Nov-96	1	4.9	1.3	0.4	176	123	8	1.8	0.1	2.5	4.2	17	25	255	19	3
LIM-1	4-Dec-96	2	6.1	1.3		136	127	6	1.7	0.2	2.1	4.1		96	260	5	2
LIM-4	4-Dec-96	2	6.0	1.4	0.8	141	129	6	1.6	0.1	2.2	4.2	47	126	285	6	2
REF	4-Dec-96	1	5.0	1.3	0.4	151	119	7	1.7	0.1	2.3	4.0	19	61	255	15	2
LIM-1	8-Dec-96	2	5.8	1.3	0.9	135	112	7	1.6	0.3	2.6	3.4	60	155	410	13	6
LIM-4	8-Dec-96	2	5.7	1.3	0.8	137	110	7	1.6	0.2	2.6	3.6	46	150	360	15	4
REF	8-Dec-96	1	4.8	1.1	0.4	145	100	7	1.7	0.2	2.7	3.6	4	118	340	17	4
LIM-4	3-Mar-97	2	5.8	1.3	0.8	144	131	6	1.8	0.2	3.2	3.3	47	82	255	55	4
REF	3-Mar-97	1	4.8	1.1	0.4	147	112	5	1.8	0.2	3.2	3.4	5	49	230	28	2
LIM-4	5-May-97	2	6.2	1.4	0.7	99	99	5	1.5	0.2	2.5	3.8	45	68	325	84	4
REF	5-May-97	1	5.2	1.1	0.3	103	87	7	1.5	0.2	2.9	3.3	-5	30	375	92	12
LIM-4	23-Jun-97	2	6.1	1.3	0.7	144	136	8	1.4	0.1	2.1	3.2	59	34	340	55	7
REF	23-Jun-97	1	5.1	1.1	0.3	143	118	8	1.4	0.2	2.2	2.9	21	25	380	75	9
LIM-4	2-Jul-97	2	6.1	1.4	0.8	172	161	9	1.5	0.1	1.7	3.5	81	8	270	12	5
REF	2-Jul-97	1	5.0	1.2	0.4	174	145	10	1.4	0.1	1.9	3.1	36	6	325	22	7
LIM-4	7-Aug-97	2	6.3	1.6	0.8	126	123	9	1.6	0.1	2.0	3.7	80	26	540	202	9
REF	7-Aug-97	1	5.2	1.3	0.4	195	173	12	1.4	0.1	2.3	2.9	32	8	610	158	17
LIM-4	4-Sep-97	2	6.0	1.9	0.9	71	48	12	1.6	0.1	2.2	4.3	93	29	530	82	12
REF	4-Sep-97	1	5.1	1.6	0.4	74	51	15	1.6	0.1	2.3	3.0	52	17	715	102	33
LIM-4	18-Sep-97	2	6.2	1.9	1.0	217	212	12	1.7	0.1	2.2	3.9	105	21	455	26	7
REF	18-Sep-97	1	5.0	1.5	0.4	218	179	7	1.6	0.1	2.3	3.1	46	13	490	42	16
LIM-4	14-Oct-97	2	6.2	1.7	1.1	196	195	12	1.8	0.3	3.0	3.6	94	55	425	20	8
REF	14-Oct-97	1	5.0	1.4	0.4	200	172	13	1.8	0.3	3.0	3.3	37	21	450	25	12
LIM-4	4-Nov-97	2	6.2	1.7	0.9	169	176	8	1.8	0.2	3.0	3.8	74	51	310	24	5
REF	4-Nov-97	1	5.1	1.4	0.4	173	148	10	1.9	0.1	2.8	3.6	33	25	515	20	7
LIM-4	10-Nov-97	2	5.8	1.6	0.9	183	183	9	1.8	0.2	3.0	3.8	69	114	390	9	6
REF	10-Nov-97	1	4.9	1.4	0.4	182	156	10	1.9	0.1	2.8	3.7	26	57	390	18	9
LIM-4	13-Nov-97	2	5.6	1.5	0.9	192	146	9	1.7	0.2	2.9	3.8	61	86	460	9	4
REF	13-Nov-97	1	4.7	1.2	0.4	191	156	9	1.8	0.1	2.7	3.7	14	68	340	14	5

Loc.	no.	Date	Depth cm	Limed	pH -log (H+)	kond. mS/m	ALK mmol/L	Cl mg/L	SO4 mg/L	Si mg/L	NH4-N µg/L	NO3-N µg/L	Tot-N µg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Alr µg/L	Alo µg/L	TOC mg/L
FU	06	8-Sep-94	5	1										1.23	0.35	1.77			0	
FU	06	11-Sep-94	5	1										1.37						
FU	06	19-Sep-94	5	1	4.6							4		0.68						
FU	06	11-Oct-94	5	1														282	271	
FU	06	31-Oct-94	5	1	4.13	4.58		4	4.4	4.2	23	19	280	0.79	0.35	1.78	0.73	294	229	12.2
FU	06	16-Nov-94	5	2	4.16	4.61		3.3	4.6	2.7	54	102	490	0.78	0.35	1.63	1.36	362	293	15.1
FU	06	30-Nov-94	5	2	4.17	4.31						3		0.76	0.28	1.78		481	414	
FU	06	11-May-95	5	2	4.32	3.36						66		0.38	0.15	1.65		395	367	25.4
FU	06	21-Jun-95	5	2	4.25	3.71								0.41	0.15	1.89		479	450	
FU	06	13-Jul-95	5	2	4.18									0.51	0.17					
FU	06	28-Sep-95	5	2	4.2							0.5		0.68	0.32	3.11		402	372	
FU	06	15-Oct-95	5	2	4.17									0.74	0.29	2.27		435	414	
FU	06	10-May-96	5	2	4.03									0.76	0.32			480	454	30.1
FU	06	12-Jun-96	5	2	4.12									0.58	0.23			624	566	
FU	06	29-Aug-96	5	2	4.12													722	712	
FU	06	3-Oct-96	5	2	4.19	4.52						0.05		0.49	0.3	2.05		432	350	20.1
FU	06	24-Oct-96	5	2	4.12									0.72	0.41			762	752	
FU	06	13-Nov-96	5	2	4.29									0.64	0.39	1.68				
FU	06	10-Jun-97	5	2	4.15									0.7	0.44			782	702	43.6
FU	06	8-Jul-97	5	2	4.19									0.76	0.47			650	612	
FU	06	17-Sep-97	5	2	4.39									2.46	0.85	2.76		810	853	
FU	06	16-Oct-97	5	2	4.24	5.08						0.05		0.77	0.65	2.36		497	463	40.4
FU	06	12-Nov-97	5	2	4.21									0.84	0.72			429	389	29.5
FU	06	8-Sep-94	15	1	4.59	2.68	0.012	1.8	4.6	5	8	0.5	116	0.49	0.25	1.66	0.18	411	165	3.9
FU	06	11-Sep-94	15	1	4.56	2.56	0.012	1.7	4.5	4.8	7	0.5	117	0.33	0.2	1.55	0.18	439	157	3.7
FU	06	19-Sep-94	15	1	4.62	2.3	0.015	1.4	4.2	4.6	3	2	105	0.37	0.19	1.3	0.21	444	135	3.2
FU	06	11-Oct-94	15	1	4.73	2.05	0.018	1.3	4.4	4.8	12	0.5	102	0.16	0.25	1.31	0.19	445	147	3.5
FU	06	31-Oct-94	15	1	4.58	2.92	0.01	3.5	4	4.8	3	5	99	0.4	0.27	1.8	0.18	596	136	3.2
FU	06	16-Nov-94	15	2	4.66	2.73	0.014	3.3	3.9	4.8	3	3	99	0.36	0.25	1.95	0.23	792	144	3.1
FU	06	30-Nov-94	15	2	4.69	2.6	0.014	3	4.1	4.5	3	4	78	0.37	0.24	1.96	0.22	552	121	2.7
FU	06	15-Dec-94	15	2	4.68	2.65	0.018	3	4.7	5.5	3	4	84	0.39	0.24	1.8	0.32	670	152	3.5
FU	06	11-May-95	15	2	4.86	2.36	0.025	1.4	5.3	4.4	6	3	92	0.39	0.22	1.66	0.43	461	138	3
FU	06	21-Jun-95	15	2	4.86	2.24	0.029	1.4	5	5.4	3	3	92	0.39	0.24	1.54	0.28	428	142	3
FU	06	13-Jul-95	15	2	4.78	2.36	0.019	1.7	5.3	5.4	3	9	113	0.4	0.22	1.69	0.24	416	127	3.4
FU	06	28-Sep-95	15	2	4.87	2.42	0.026	1.9	4.8	6.3	3	4	120	0.41	0.26	1.97	0.28	458	136	3.7
FU	06	15-Oct-95	15	2	4.79	2.53	0.024	2.8	4.6	6.1	3	4	99	0.38	0.24	1.8	0.26	468	142	3.4

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
FU	06	10-May-96	15	2	4.66	2.49	0.029	1.5	5.4	7.3	3	2	108	0.34	0.24	1.77	0.45	403	152	3.3
FU	06	29-Aug-96	15	2	4.69	3.24	0.016	4.3	4.4	6	3	3	117	0.42	0.32	2.42	0.41	498	177	4
FU	06	3-Oct-96	15	2	4.79	2.58	0.024	2.3	4.8	7	3	0.5	96	0.37	0.31	1.92	0.11	486	152	3.7
FU	06	24-Oct-96	15	2	4.85	2.54	0.028	2.4	4.8	7.3	10	5	78	0.36	0.31	1.87	0.15	494	178	3.5
FU	06	13-Nov-96	15	2	4.84	2.49	0.027					4		0.4	0.33	1.88		483	177	3.6
FU	06	10-Jun-97	15	2	4.94	2.4	0.028	2.2	5	6.1	6	5	96	1.37	0.34	2.92	0.13	405	116	3
FU	06	9-Jul-97	15	2	4.91	2.37	0.026	2.6	4.4	6.6	3	0.5	92	0.47	0.37	1.62	0.08	389	128	3.1
FU	06	17-Sep-97	15	2	4.99	2.31	0.033	1.7	4.8	7	9	0.5	138	0.42	0.35	1.86	0.12	364	155	3.9
FU	06	16-Oct-97	15	2	4.9	2.9	0.03	2.7	4.4	7.6	6	0.5	110	0.41	0.38	1.85	0.08	457	152	3.8
FU	06	12-Nov-97	15	2	4.84	2.57	0.023	2.9	4.4	6.9	3	12	111	0.4	0.38	2.04	0.08	448	153	3.6
FU	07	8-Sep-94	5	1								3		1.11	0.29	1.78				
FU	07	11-Sep-94	5	1								3		1.05						
FU	07	19-Sep-94	5	1	4.03															
FU	07	11-Oct-94	5	1														92	14	
FU	07	16-Nov-94	5	2	3.85									1.02	0.32	1.87		37	45	
FU	07	30-Nov-94	5	2	3.85															
FU	07	11-May-95	5	2								35		0.49	0.13	1.33				
FU	07	21-Jun-95	5	2	4.01									0.56	0.15	1.59				
FU	07	28-Sep-95	5	2	3.76															
FU	07	15-Oct-95	5	2	3.83															
FU	07	12-Jun-96	5	2	3.93	2.62								1.2	0.33	2.06	2.6			
FU	07	13-Nov-96	5	2	3.89															
FU	07	10-Jun-97	5	2	3.94									0.4	0.3	1.73				
FU	07	8-Jul-97	5	2	3.73									1.72	0.51					
FU	07	17-Sep-97	5	2	3.71															
FU	07	16-Oct-97	5	2	3.64									1.92	0.64	2.92		41	51	
FU	07	12-Nov-97	5	2	3.7									1.76	0.55			63	66	
FU	07	8-Sep-94	15	1	4.62							4		0.79	0.3	1.66				
FU	07	11-Sep-94	15	1	4.58							2		0.71				244	163	
FU	07	19-Sep-94	15	1	4.56							1		0.5				273	191	6.5
FU	07	11-Oct-94	15	1	4.69	2.12	0.013					4		0.23	0.22	1.32		274	197	
FU	07	31-Oct-94	15	1	4.44	3.42		4.2	3.7	5.2	8	8	160	0.96	0.34	1.94	0.43	460	213	5.9
FU	07	16-Nov-94	15	2	4.53									0.55	0.3	2.06		446	218	
FU	07	30-Nov-94	15	2	4.47							0.5		0.51	0.26	2.04		443	246	6.6
FU	07	11-May-95	15	2								8		0.38	0.25	1.46				5.7
FU	07	21-Jun-95	15	2	4.67	2.44	0.015							0.36	0.23	1.38		460	231	
FU	07	28-Sep-95	15	2	4.66	2.71	0.012							0.37	0.25	1.84		464	267	7.3
FU	07	15-Oct-95	15	2	4.67	2.83	0.013							0.38	0.25	2.04		465	256	

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
FU	07	10-May-96	15	2	4.6									0.35	0.22			418	254	6.3
FU	07	12-Jun-96	15	2	4.66									0.34	0.23			437	224	
FU	07	29-Aug-96	15	2	4.48									0.41	0.26			501	260	6.8
FU	07	3-Oct-96	15	2	4.55	2.83	0.005					0.5		0.38	0.3			544	248	6.6
FU	07	24-Oct-96	15	2	4.63	2.92	0.012					0.5		0.37	0.29			572	277	6.7
FU	07	13-Nov-96	15	2	4.55									0.6	0.34	1.73		578	247	
FU	07	10-Jun-97	15	2	4.89									0.45	0.3	2.14		409	205	
FU	07	8-Jul-97	15	2	4.6									0.39	0.31			479	194	
FU	07	17-Sep-97	15	2	4.73									0.38	0.29	1.92		418	220	
FU	07	16-Oct-97	15	2	4.81	2.69	0.025	2.3	4.3	9	35	0.5	230	0.38	0.32	1.91	0.17	446	323	6.8
FU	07	12-Nov-97	15	2	4.71	2.59	0.015	2.4	4.3	7.8	7	21	160	0.35	0.3	2.05	0.16	459	213	5.6
FU	44	8-Sep-94	5	1	5.39	3.1	0.089	2.6	6.3	4.6	3	0.5	210	2.64	0.42		0.13	162	151	7.2
FU	44	11-Sep-94	5	1	5.3	2.8	0.079	2.2	5.4	4.5	8	0.5	175	2.22	0.31	1.82	0.12	139	130	5.5
FU	44	19-Sep-94	5	1	5.39	2.33	0.08	1.4	4.2	4.4	3	0.5	122	1.92	0.32	1.44	0.15	82	74	3.1
FU	44	11-Oct-94	5	1	5.61	2.6	0.06	2.6	5.2	4	6	0.5	205	1.86	0.37	1.62	0.39	194	193	6.8
FU	44	31-Oct-94	5	1	5.46	2.8	0.068	3.5	4.2	4.1	3	0.5	121	2.32	0.42	1.79	0.28	113	106	3.4
FU	44	16-Nov-94	5	2	5.72	2.41	0.067	2.8	3.7	4.3	3	0.5	99	1.97	0.38	1.96	0.15	112	103	2.8
FU	44	30-Nov-94	5	2	5.59	2.41	0.051	2.7	4	4.4	3	0.5	108	1.91	0.37	1.98	0.11	153	134	4.2
FU	44	15-Dec-94	5	2										2.22	0.5	1.93				
FU	44	11-May-95	5	2	5.9	2.44	0.07	2	5.1	3.7	8	3	59	1.86	0.38	1.59	0.14	67	52	1.9
FU	44	21-Jun-95	5	2	5.95	2.63	0.087	1.7	5.2	4.3	3	2	90	2.16	0.14	1.65	0.16	77	69	2.4
FU	44	13-Jul-95	5	2	5.96	3.48	0.06	3.3	7.4	3.8	5	0.5	200	2.88	0.54	2.02	0.46	127	104	4.2
FU	44	28-Sep-95	5	2	5.96	3.02	0.072	2.7	5.6	5	5	0.5	185	2.24	0.5	2.1	0.54	174	174	6.1
FU	44	15-Oct-95	5	2	5.83	2.86	0.067	2.7	5.2	4.3	5	0.5	185	2.01	0.46	2.1	0.51	188	180	6.6
FU	44	12-Jun-96	5	2	5.69	2.94	0.05	2.3	7	4.1	14	0.5	165	2.21	0.56	1.81	0.04	127	103	4.6
FU	44	29-Aug-96	5	2	5.99	6.8	0.08					3		5.37	1.34			250	216	8.9
FU	44	3-Oct-96	5	2	5.53	2.98	0.058	2.4	5.8	4.8	3	0.5	126	2.34	0.57	1.84	0.05	161	128	4
FU	44	24-Oct-96	5	2	5.62	2.64	0.07	2.3	5.2	5.1	13	0.5	128	1.94	0.52	1.76	0.05	150	135	3.6
FU	44	13-Nov-96	5	2	5.73	2.44	0.052	2.4	5.3	5.2	3	0.5	138	1.67	0.5	1.65	0.08	127	97	3.6
FU	44	10-Jun-97	5	2	5.54	3.39	0.046	3.4	7	3.8	5	5	113	2.58	0.66	1.83	0.05	136	107	3.4
FU	44	8-Jul-97	5	2	5.57	3.03	0.056	2.9	5.7	4.7	3	0.5	125	2.29	0.62	1.54	0.02	140	118	3.8
FU	44	17-Sep-97	5	2	5.58	3.6	0.058	3.6	6.6	4.9	9	0.5	210	2.75	0.7	2.03	0.18	192	171	6.1
FU	44	16-Oct-97	5	2	5.9	2.83	0.073	2.8	5	5.3	6	0.5	135	2.02	0.56	1.75	0.17	140	113	3.7
FU	44	12-Nov-97	5	2	5.65	2.72	0.059	3.1	4.6	4.6	3	4	141	1.94	0.55	1.92	0.09	154	121	4

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
FU	44	8-Sep-94	15	1	5.51	3.08	0.137	2.3	4.4	5.1	3	0.5	128	2.64	0.38	2.04	0.17	78	48	2.5
FU	44	11-Sep-94	15	1	5.44	2.83	0.115	1.8	4.1	4.7	3	0.5	102	2.34	0.31	1.83	0.14	85	45	2.6
FU	44	11-Oct-94	15	1	5.91	2.51	0.088	1.9	5.1	4.5	3	3	96	2.06	0.36	1.61	0.12	79	65	2.3
FU	44	31-Oct-94	15	1	5.48	2.98	0.081	3.3	4.5	4.3	3	0.5	87	2.64	0.44	1.75	0.07	97	63	2.1
FU	44	16-Nov-94	15	2	5.79	2.24	0.09	2.9	3.5	4.5	13	0.5	75	2.26	0.39	1.94	0.05	94	74	1.8
FU	44	30-Nov-94	15	2	5.85	2.47	0.08	2.7	3.7	4.6	3	0.5	60	2.18	0.38	2.01	0.04	81	66	1.6
FU	44	15-Dec-94	15	2	5.37	2.59	0.079					4		2.08	0.39	1.62		63	51	1.8
FU	44	11-May-95	15	2	5.87	2.53	0.073	1.9	5.3	3.7	3	2	59	1.91	0.4	1.56	0.15	65	52	1.6
FU	44	21-Jun-95	15	2	5.93	2.7	0.09	1.9	5.4	4.4	3	2	69	2.27	0.42	1.62	0.07	47	38	1.8
FU	44	13-Jul-95	15	2	5.92	3.13	0.064	2.4	7.5	4.5	3	0.5	77	2.65	0.45	1.86	0.04	69	45	1.7
FU	44	28-Sep-95	15	2	6.01	2.99	0.091	2.5	5.6	5.3	5	4	99	2.39	0.46	2.04	0.18	93	71	2.3
FU	44	15-Oct-95	15	2	5.96	2.61	0.09	2.5	4.3	4.9	3	4	90	1.98	0.39	2.09	0.06	90	68	2.5
FU	44	10-May-96	15	2	5.91	2.82	0.084	2	5.6	4.7	3	4	78	2.12	0.49	1.72	0.14	42	45	1.9
FU	44	12-Jun-96	15	2	5.92	2.92	0.068	2.2	6.6	4.6	5	4	72	2.36	0.54	1.78	0.04	75	47	1.6
FU	44	29-Aug-96	15	2	5.66	5.07	0.048	3.8	13.4	5.1	3	4	93	3.99	0.88	2.66	0.17	129	67	2.1
FU	44	3-Oct-96	15	2	5.73	3.21	0.083	2.5	6.3	5	3	0.5	83	2.78	0.6	1.86	0.03	115	77	2.2
FU	44	24-Oct-96	15	2	5.75	2.81	0.098	2.3	5.1	5.2	9	0.5	71	2.3	0.54	1.74	0.03	100	70	2.1
FU	44	13-Nov-96	15	2	6.22									2.05	0.53	1.69		80	59	2.2
FU	44	10-Jun-97	15	2	6.11	3.09	0.06	2.8	6.7	4.6	5	5	71	2.48	0.47	1.71	0.03	57	42	1.5
FU	44	8-Jul-97	15	2	5.71	3.22	0.083	2.8	5.9	5.1	3	0.5	74	2.66	0.64	1.54	0.02	76	50	3.8
FU	44	17-Sep-97	15	2	5.88	3.51	0.083	3.2	6.4	5.3	8	0.5	125	2.86	0.63	1.99	0.07	80	59	2.2
FU	44	16-Oct-97	15	2	5.94	2.99	0.086	2.7	5.3	5.3	3	0.5	104	2.41	0.57	1.73	0.03	108	67	2.5
FU	44	12-Nov-97	15	2	5.69	2.73	0.071	2.9	4.7	4.8	3	4	89	2.05	0.51	1.92	0.01	98	62	2.3
FU	45	8-Sep-94	5	1	5.65	3.33	0.166	1.8	4.1	4.7	3	0.5	72	3.45	0.42	1.68	0.14	74	41	1.9
FU	45	11-Sep-94	5	1	5.62	3.21	0.17	1.8	3.6	4.7	8	0.5	92	3.3	0.38	1.65	0.13	88	55	2
FU	45	19-Sep-94	5	1	5.81	2.61	0.161	1.5	2.8	4.5	3	4	83	2.76	0.36	1.37	0.18	68	45	2.2
FU	45	11-Oct-94	5	1	6.81	2.24	0.146					3		2.34	0.35	1.47		35	25	
FU	45	31-Oct-94	5	1	5.73	3.02	0.13	2.4	4.8	4.4	3	1	74	3.25	0.44	1.76	0.06	78	52	1.9
FU	45	15-Dec-94	5	2	6.53	2.53	0.11					4		2.4	0.4	1.51		80	72	1.9
FU	45	11-May-95	5	2	5.86	2.62	0.097	1.9	4.7	3.6	3	3	48	2.22	0.41	1.5	0.1	86	60	1.6
FU	45	21-Jun-95	5	2	6.03	2.69	0.121	1.7	4.4	4.3	3	2	81	2.5	0.45	1.5	0.1	61	40	1.5
FU	45	13-Jul-95	5	2	5.91	3.26	0.073	2	7.9	4.4	3	0.5	68	2.83	0.48	1.88	0.03	66	34	1.5
FU	45	28-Sep-95	5	2	6.14	2.88	0.104	2.1	5.4	5	3	2	81	2.62	0.46	1.75	0.08	93	68	2.1
FU	45	15-Oct-95	5	2	6.09	2.8	0.115	2.5	4.4	5	3	0.5	66	2.48	0.43	1.87	0.05	90	59	1.9

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
FU	45	10-May-96	5	2	5.75	2.63	0.102	1.6	4.8	4.5	3	3	74	2.16	0.42	1.55	0.11	64	60	1.8
FU	45	12-Jun-96	5	2	5.98	2.9	0.098	2	5.6	5	3	4	68	2.59	0.51	1.7	0.06	81	51	1.9
FU	45	29-Aug-96	5	2	5.87	3.53	0.056	2.9	8.4	4.7	8	4	84	2.85	0.5	1.91	0.11	81	53	1.9
FU	45	3-Oct-96	5	2	5.99	3.22	0.12	2.1	5.7	5	3	0.5	87	3.22	0.59	1.57	0.04	76	61	2
FU	45	24-Oct-96	5	2	5.96	2.78	0.127	2	4.1	5.2	7	0.5	56	2.57	0.52	1.44	0.04	103	70	2.1
FU	45	13-Nov-96	5	2	6.16	2.46	0.121	2.3	3.6	5.2	12	0.5	83	2.31	0.52	1.47	0.06	91	66	2.1
FU	45	10-Jun-97	5	2	6.01	3.51	0.108	2.4	6.6	5.2	3	4	57	3.3	0.59	1.79	0.04	59	38	1.6
FU	45	8-Jul-97	5	2	5.89	3.46	0.128	2.2	6.1	5.2	5	0.5	68	3.36	0.68	1.47	0.07	63	43	2.1
FU	45	17-Sep-97	5	2	6.05	3.48	0.138	2.1	5.6	5.3	5	0.5	95	3.39	0.66	1.63	0.06	60	40	2.1
FU	45	16-Oct-97	5	2	6.31	3.56	0.158	2.5	5.4	5.4	5	0.5	84	3.62	0.7	1.68	0.06	73	48	2.3
FU	45	12-Nov-97	5	2	5.98	2.91	0.14	2.1	2.3	3.6	3	4	75	2.91	0.58	1.7	0.01	68	48	2.1
FU	45	8-Sep-94	15	1	5.79	4.77	0.269	5	5	5.2	3	0.5	77	5.69	0.62	1.93	0.26	35	18	1.9
FU	45	11-Sep-94	15	1	5.92	4.59	0.275	2.2	5	5.2	13	0.5	81	5.73	0.58	1.87	0.23	32	11	1.9
FU	45	19-Sep-94	15	1	5.86	3.91	0.281	1.7	3.2	5.1	7	2	83	4.87	0.56	1.67	0.27	25	19	1.7
FU	45	11-Oct-94	15	1	6.32	3.45	0.299	1.9	1.5	5	16	3	81	4.83	0.57	1.58	0.18	31	20	2.1
FU	45	31-Oct-94	15	1	5.96	4.01	0.278	2.1	3.2	5.2	6	0.5	69	5.24	0.63	1.88	0.12	31	20	1.7
FU	45	16-Nov-94	15	2	6.15	3.8	0.279	1.2	1	5.1	3	0.5	57	5.22	0.57	1.81	0.11	36	20	1.5
FU	45	30-Nov-94	15	2	6.23	3.7	0.274	2.3	2.2	5	3	0.5	44	5.22	0.56	1.9	0.1	19	14	1.5
FU	45	15-Dec-94	15	2	6.65	3.77	0.256					4		4.95	0.55	1.79	0.1	35	30	1.6
FU	45	11-May-95	15	2	6.28	3.62	0.195	2.2	4.5	4.3	7	4	48	3.81	0.55	1.63	0.11	31	14	1.5
FU	45	21-Jun-95	15	2	6.36	3.81	0.218	1.9	4.6	4.9	10	4	69	4.23	0.6	1.67	0.2	14		1.5
FU	45	13-Jul-95	15	2	6.36	4.4	0.136	2.1	10.1	4.9	5	0.5	68	4.92	0.64	1.87	0.05	27	11	1.4
FU	45	28-Sep-95	15	2	6.42	3.85	0.176	2.5	6.3	5.2	3	4	71	4.44	0.57	1.78	0.14	44	23	1.8
FU	45	15-Oct-95	15	2	6.35	3.5	0.196	2.4	4.4	5.1	3	0.5	66	4	0.53	1.92	0.1	37	20	1.6
FU	45	10-May-96	15	2	5.99	3.32	0.164	1.8	4.8	4.9	3	4	104	3.3	0.51	1.68	0.1	25	21	1.7
FU	45	12-Jun-96	15	2	6.43	3.46	0.161	2	5.5	5.1	3	0.5	62	3.71	0.59	1.75	0.09	45	22	1.2
FU	45	29-Aug-96	15	2	6.16	3.58	0.093	2	8.5	4	3	4	84	3.5	0.48	1.64	0.12	44	28	2.6
FU	45	3-Oct-96	15	2	6.1	4.31	0.205	2.4	6.5	5.4	6	0.5	138	4.74	0.71	1.91	0.12	50	32	1.7
FU	45	24-Oct-96	15	2	6.25	3.93	0.246	2.1	4.2	5.6	9	0.5	51	4.46	0.7	1.63	0.08	50	32	1.4
FU	45	13-Nov-96	15	2	6.67	3.5	0.251	2.1	3.3	5.5	3	0.5	74	4.39	0.7	1.57	0.1	32	21	2
FU	45	10-Jun-97	15	2	6.56	4.22	0.205	2.3	6	5.4	3	4	65	4.87	0.71	1.81	0.08	25	14	1.4
FU	45	8-Jul-97	15	2	6.12	4.2	0.212	2	5.8	5.7	3	0.5	54	4.8	0.75	1.6	0.1	27	13	1.5
FU	45	17-Sep-97	15	2	6.41	4.46	0.22	2.2	6.3	5.6	3	0.5	80	5.15	0.75	1.76	0.09	26	15	1.6
FU	45	16-Oct-97	15	2	6.6	4.65	0.281	2.6	5	6	3	0.5	66	5.51	0.87	1.9	0.08	29	15	1.7
FU	45	12-Nov-97	15	2	6.34	4.14	0.283	2.3	3.3	5.5	3	4	69	5.4	0.77	1.81	0.06	28	15	1.7

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
FU	48	8-Sep-94	5	1	5.04		0.038	2.3	7.7	4.7	3	9	425	0.94	0.89	1.63	1.57	190	162	11.4
FU	48	11-Sep-94	5	1	5.09	4.23	0.069	1.9	5.3	5	35	5	530	1.54	1.34	1.58	2.24			22.3
FU	48	16-Nov-94	5	2	4.91	2.84	0.02	4	3.7	4.2	7	30	225	0.88	0.84	1.74	0.63	185	121	4.8
FU	48	30-Nov-94	5	2	4.97															
FU	48	11-May-95	5	2	5.08	2.11	0.034	1.4	4.2	3.3	31	39	215	0.36	0.44	1.22	1.1	184	117	4.1
FU	48	21-Jun-95	5	2	5.16	2.01	0.038	1	4.4	5.2	5	6	185	0.39	0.39	1.52	0.52	194	109	4.7
FU	48	28-Sep-95	5	2	4.85							117		0.5	0.52	1.86		239	159	
FU	48	15-Oct-95	5	2	5	2.74	0.029							0.46	0.57	2.06		244	168	
FU	48	10-May-96	5	2	5.01	3.04	0.037	2.9	4.1	6.6	22	470	620	0.66	0.88	1.86	0.68	188	110	3.9
FU	48	12-Jun-96	5	2	5.11	2.52	0.027	2.4	4.5	7.1	8	12	190	0.51	0.66	1.66	0.39	190	100	4.5
FU	48	29-Aug-96	5	2																
FU	48	3-Oct-96	5	2	4.97	2.56	0.024	1.9	4.9	5.3	3	0.5	175	0.47	0.71	1.61	0.18	192	89	4.1
FU	48	24-Oct-96	5	2	4.96	2.86	0.025	3.6	4.3	5.6	13	0.5	123	0.56	0.82	1.68	0.21	196	86	3.2
FU	48	13-Nov-96	5	2	4.88									0.58	0.92	1.61		211	59	2.8
FU	48	10-Jun-97	5	2	5.21	2.62	0.03					11		0.58	0.7	2.03		181	68	2.9
FU	48	8-Jul-97	5	2	5.09	2.11	0.028	1.4	4.6	6.8	5	1	160	0.44	0.57	1.4	0.07	183	76	3.7
FU	48	17-Sep-97	5	2																
FU	48	8-Sep-94	15	1	4.97	2.47	0.033	1.8	5.6	4.8	12	4	220	0.71	0.67	1.56	0.28	117	75	5.5
FU	48	11-Sep-94	15	1	4.92	2.36	0.032	1.3	4.8	4.6	7	1	190	0.57	0.59	1.47	0.2	148	85	4.2
FU	48	19-Sep-94	15	1	5	2.13	0.032	1.2	4.6	3.7	3	4	131	0.57	0.51	1.2	0.19	136	63	3.1
FU	48	11-Oct-94	15	1	5	2.02	0.028	1.6	4.1	4	11	9	120	0.52	0.43	1.17	0.13	168	66	2.7
FU	48	31-Oct-94	15	1	4.75	3.31	0.018	5.9	2.8	4.3	3	13	130	0.86	0.76	1.86	0.43	282	67	2.4
FU	48	16-Nov-94	15	2	4.93	2.3	0.022	1.9	2.5	3.7	3	7	113	0.64	0.56	1.62	0.22	209	79	2.5
FU	48	30-Nov-94	15	2	4.97	2.36	0.024	2.9	3.7	3.9	3	7	86	0.73	0.58	1.66	0.19	196	63	2.2
FU	48	11-May-95	15	2	5.17	2.2	0.035	1.8	4.8	3.4	3	5	117	0.53	0.44	1.38	0.94	162	80	2.9
FU	48	21-Jun-95	15	2	5.24	2.03	0.041	0.9	4.6	4.7	3	6	123	0.54	0.43	1.52	0.21	153	53	2.7
FU	48	28-Sep-95	15	2	5.17	2.41	0.034	2	4.8	5.6	9	25	190	0.61	0.67	1.6	0.41	190	107	4.6
FU	48	15-Oct-95	15	2	5.04	2.41	0.03	2.6	4.2	5.4	3	8	132	0.59	0.61	1.74	0.2	191	87	3.1
FU	48	10-May-96	15	2	4.99	2.67	0.041	2.8	4.3	5.9	9	110	205	0.6	0.7	1.9	0.31	191	75	2.5
FU	48	12-Jun-96	15	2	5.13	2.29	0.03	2.1	4.4	6.5	5	9	130	0.57	0.61	1.61	0.08	166	94	3
FU	48	29-Aug-96	15	2	5.02									0.61	0.69			230	141	
FU	48	3-Oct-96	15	2	5.1	2.45	0.036	1.9	4.8	5.2	3	4	150	0.55	0.71	1.64	0.11	213	83	3.7
FU	48	24-Oct-96	15	2	5.14									0.6	0.76			213	81	3
FU	48	13-Nov-96	15	2	5.18	2.5	0.033	3.2	4.5	5.6	3	4	102	0.59	0.77	1.65	0.26	221	56	2.6
FU	48	10-Jun-97	15	2	5.07	2.52	0.03	3.1	3.8	5.9	5	5	104	0.58	0.67	1.67	0.05	209	51	2.3
FU	48	8-Jul-97	15	2	5.18	2.25	0.042	1.5	4.9	6.4	3	0.5	125	0.53	0.67	1.45	0.04	184	67	3
FU	48	16-Oct-97	15	2	5.43	2.54	0.042	3.1	4.1	5.9	3	0.5	147	0.48	0.77	1.89	0.23	190	68	3.3

Loc.	no.	Date	Depth cm	Limed	pH -log (H+)	kond. mS/m	ALK mmol/L	Cl mg/L	SO4 mg/L	Si mg/L	NH4-N µg/L	NO3-N µg/L	Tot-N µg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Alr µg/L	Alo µg/L	TOC mg/L
FU	49	8-Sep-94	5	1	4.96							415		0.92	0.59	1.53				
FU	49	11-Sep-94	5	1	4.95							455		0.86						
FU	49	19-Sep-94	5	1	5.07							106		0.55						
FU	49	31-Oct-94	5	1	4.59	5.08		4.8	6.4	2.9	74	825	1300	1.33	1.13	1.86	3.3	350	257	11.2
FU	49	16-Nov-94	5	2	4.79	3.67					0	137		0.81	0.65	1.62		390	315	10.4
FU	49	30-Nov-94	5	2	4.82									0.87	0.66	1.63				
FU	49	15-Dec-94	5	2	4.71	5.3	0.016							1.23	1.05	1.89		453	334	
FU	49	11-May-95	5	2	4.96	3.79	0.037					595		0.87	0.58	1.93		501	447	17.5
FU	49	21-Jun-95	5	2	5.05	2.76	0.046					124		0.96	0.55	1.94		598	429	17.4
FU	49	10-May-96	5	2	5.01							2840		1.79	1.68			277	189	7.7
FU	49	3-Oct-96	5	2	4.8									1.04	1.05	2.15		387	258	
FU	49	24-Oct-96	5	2	4.65									1.35	1.43			434	314	
FU	49	13-Nov-96	5	2	4.71															
FU	49	8-Jul-97	5	2	5.01									1.22	1.16	1.9				
FU	49	16-Oct-97	5	2	5.26															
FU	49	8-Sep-94	15	1	5.03							53		1.07	0.53	1.57				
FU	49	11-Sep-94	15	1								51		0.99						
FU	49	19-Sep-94	15	1	5.02							13		0.57						
FU	49	11-Oct-94	15	1										1.19						
FU	49	31-Oct-94	15	1	4.68	3.23	0.014	5	3.4	5.1	6	120	305	1.02	0.62	1.98	0.88	145	92	4.4
FU	49	16-Nov-94	15	2	4.91									0.83	0.49	1.88		163	121	
FU	49	30-Nov-94	15	2	4.86															
FU	49	15-Dec-94	15	2	4.93									0.82	0.57	1.43				
FU	49	11-May-95	15	2	4.95	2.71	0.031											184	132	
FU	49	21-Jun-95	15	2	5.03	2.27	0.034							0.71	0.39	1.58		202	133	
FU	49	28-Sep-95	15	2	4.88															
FU	49	10-May-96	15	2	4.93							1080		1.23	0.98			207	120	5.5
FU	49	12-Jun-96	15	2	5.22															
FU	49	3-Oct-96	15	2	4.78									0.64	0.6	1.6		238	134	
FU	49	24-Oct-96	15	2	4.81															
FU	49	13-Nov-96	15	2	4.84									0.83	0.91	1.83				
FU	49	8-Jul-97	15	2	4.99									0.68	0.6	1.59		234	156	7.6
FU	49	17-Sep-97	15	2	5															
FU	49	16-Oct-97	15	2	4.93	3.12	0.028					51	380	0.75	0.91	1.81		309	184	8.3

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
SP	28	8-Sep-94	5	1	5.15	2.62	0.04	2	6.7	3.9	3	4	132	1.32	0.48	1.69	0.11	171	113	3.8
SP	28	11-Sep-94	5	1	5.11	2.44	0.041	1.8	6.2	3.9	3	4	146	1.17	0.42	1.51	0.09	198	122	3.9
SP	28	19-Sep-94	5	1	5.19	2.02	0.042	1.2	4.2	3.6	3	5	150	1	0.38	1.23	0.14	190	129	3.9
SP	28	11-Oct-94	5	1	5.24	2.23	0.035	1.7	5.3	3.8	11	111	270	1.03	0.39	1.46	0.14	220	141	4.5
SP	28	31-Oct-94	5	1	5.14	2.68	0.037	3.4	4.1	3.8	3	69	200	1.4	0.56	1.74	0.24	220	121	3.4
SP	28	16-Nov-94	5	1	5.24	2.54	0.035	3	4.1	3.9	3	68	185	1.32	0.49	1.86	0.22	222	135	3.2
SP	28	30-Nov-94	5	1	5.21	2.53	0.034	3	4.5	4.1	3	90	195	1.41	0.51	1.93	0.21	225	119	3.2
SP	28	15-Dec-94	5	1	5.33	2.71	0.039	5.3	6.8	4.3	3	65	205	1.43	0.53	1.88	0.27	250	153	3.9
SP	28	11-May-95	5	1	5.4	2.05	0.043	1.7	4.2	2.6	3	50	147	1.02	0.38	1.5	0.19	218	135	3.4
SP	28	21-Jun-95	5	1	5.56	1.83	0.051	1	3.9	3	3	6	138	0.9	0.31	1.33	0.07	212	148	4.5
SP	28	13-Jul-95	5	1	5.51	1.81	0.039	0.6	4.7	3	3	80	260	0.91	0.29	1.55	0.04	219	144	4.6
SP	28	28-Sep-95	5	1	5.33	2.66	0.044	2.4	5.6	4.4	9	72	195	1.41	0.55	2.01	0.2	205	133	3.8
SP	28	15-Oct-95	5	1	5.23	2.76	0.037	2.7	5.1	4.1	3	215	345	1.39	0.56	1.95	0.19	217	128	3.7
SP	28	10-May-96	5	1	5.18	2.65	0.041	1.9	4.7	4	3	415	490	1.39	0.5	1.63	0.32	191	129	3.2
SP	28	12-Jun-96	5	1	5.29	2.33	0.033	1.7	5.3	4	8	50	190	1.19	0.44	1.56	0.13	193	111	3.9
SP	28	29-Aug-96	5	1	5.14									1.41	0.41			208	133	
SP	28	3-Oct-96	5	1	5.34	2.6	0.042	2.3	5.2	3.9	3	8	145	1.4	0.54	1.61	0.06	226	124	3.7
SP	28	24-Oct-96	5	1	5.35	2.54	0.045	2.3	5.4	4.2	4	13	123	1.38	0.53	1.67	0.12	224	135	3.4
SP	28	13-Nov-96	5	1	5.39	2.4	0.043	2.6	4.8	4.2	3	36	160	1.31	0.53	1.55	0.15	231	127	3.5
SP	28	10-Jun-97	5	1	5.3	2.39	0.048	2.2	4.7	3.9	5	22	149	1.21	0.4	1.56	0.09	198	105	3.3
SP	28	8-Jul-97	5	1	5.43	2.28	0.045	2	4.4	3.9	3	0.5	125	1.2	0.43	1.49	0.03	166	110	3.4
SP	28	17-Sep-97	5	1	5.6	2.45	0.044	2.2	4.6	4.1	40	61	360	1.32	0.46	1.83	0.08	159	113	3.9
SP	28	16-Oct-97	5	1	5.49	2.24	0.047	2.4	4.1	4.4	3	0.5	1775	1.13	0.44	1.52	0.1	184	118	4
SP	28	12-Nov-97	5	1	5.33	2.5	0.04	2.8	4	4.3	3	200	325	1.3	0.5	1.79	0.06	200	110	3
SP	28	8-Sep-94	15	1	5.13	2.68	0.043	1.7	6.1	3.9	3	6	135	1.42	0.5	1.73	0.11	162	113	3.9
SP	28	11-Sep-94	15	1	5.1	2.63	0.044	1.5	5.6	4.1	3	10	144	1.36	0.46	1.62	0.08	185	114	4
SP	28	19-Sep-94	15	1	5.14	2.08	0.042	1.3	4.5	3.6	3	7	140	1.06	0.39	1.23	0.14	185	130	4
SP	28	11-Oct-94	15	1	5.39	2.3	0.046	1.6	5.4	4	9	54	180	1.15	0.42	1.67	0.1	199	125	3.7
SP	28	31-Oct-94	15	1	5.11	2.79	0.038	3.4	4.3	3.9	3	90	220	1.43	0.58	1.84	0.2	226	117	3.2
SP	28	16-Nov-94	15	1	5.22	2.59	0.036	2.6	3.8	3.9	3	76	190	1.38	0.51	1.95	0.22	233	133	3.2
SP	28	30-Nov-94	15	1	5.33	2.57	0.043	3	4.8	4.1	3	56	138	1.48	0.53	1.99	0.22	222	121	3
SP	28	15-Dec-94	15	1	5.36	2.85	0.041	3.7	4.9	4.5		65		1.52	0.59	1.96	0.28	274	162	3.8
SP	28	11-May-95	15	1	5.4	2.15	0.043	1.7	4.5	2.7	3	54	155	1.08	0.39	1.56	0.21	218	135	3.3
SP	28	21-Jun-95	15	1	5.56	1.91	0.053	1	4.3	3	3	8	138	0.97	0.33	1.35	0.08	199	145	4.1
SP	28	13-Jul-95	15	1	5.55	1.83	0.042	0.7	5	2.7	3	39	180	0.9	0.3	1.62	0.03	195	132	4.1
SP	28	28-Sep-95	15	1	5.36	2.71	0.054	2.4	5.6	4.5	3	72	185	1.57	0.58	2.09	0.19	216	127	3.6
SP	28	15-Oct-95	15	1	5.45	2.72	0.047	2.6	5.4	4.1	3	120	230	1.42	0.56	2.05	0.19	224	131	3.5

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
SP	28	10-May-96	15	1	5.18	2.74	0.049	2	4.9	4	3	410	490	1.43	0.51	1.68	0.32	204	126	3.1
SP	28	12-Jun-96	15	1	5.48	2.43	0.042	1.8	5.4	4.1	7	45	155	1.28	0.46	1.6	0.17	201	105	3.5
SP	28	29-Aug-96	15	1	5.41	2.03	0.042	1.1	4.8	2.1	3	74	195	1.16	0.36	1.29	0.07	186	106	3.3
SP	28	3-Oct-96	15	1	5.33	2.64	0.043	2.3	5.3	3.9	3	15	138	1.44	0.54	1.61	0.04	217	114	3.4
SP	28	24-Oct-96	15	1	5.39	2.65	0.048	2.3	5.5	4.2	2	13	117	1.42	0.54	1.66	0.1	233	132	3.5
SP	28	13-Nov-96	15	1	5.42	2.55	0.046	2.6	5	4.2	3	24	132	1.43	0.55	1.65	0.16	236	124	3.3
SP	28	10-Jun-97	15	1	5.43	2.47	0.041	2.3	4.8	4	5	29	122	1.21	0.43	1.67	0.11	190	108	2.8
SP	28	8-Jul-97	15	1	5.51	2.37	0.053	2	4.5	3.9	3	2	205	1.36	0.47	1.56	0.04	154	108	3.2
SP	28	17-Sep-97	15	1	5.53	2.56	0.054	2.2	4.8	4.4	5	70	205	1.41	0.48	1.87	0.02	167	123	3.4
SP	28	16-Oct-97	15	1	5.51	2.38	0.045	2.4	4.6	4.3	3	12	155	1.28	0.48	1.62	0.06	199	117	3.7
SP	28	12-Nov-97	15	1	5.33	2.61	0.04	2.8	4.6	4.3	3	195	310	1.39	0.52	1.91	0.03	214	109	3
SP	30	8-Sep-94	5	1	5.06	2.48	0.036	1.5	5.3	3.7	3	4	120	1.16	0.45	1.53	0.12	175	108	3.5
SP	30	11-Sep-94	5	1	5.06	2.52	0.039	1.6	6.1	3.9	3	5	141	1.1	0.42	1.5	0.13	199	108	3.6
SP	30	19-Sep-94	5	1	5.07	2.06	0.036	1.1	4.7	3.4	3	4	129	0.96	0.38	1.14	0.14	199	110	3.6
SP	30	11-Oct-94	5	1	5.26	2.13	0.04	1.4	4.8	3.5	8	89	205	0.96	0.4	1.25	0.14	227	112	3.2
SP	30	31-Oct-94	5	1	5.04	2.73	0.033	3.7	3.8	3.5	3	72	190	1.33	0.57	1.61	0.18	255	98	2.8
SP	30	16-Nov-94	5	1	5.13	2.46	0.032	2.8	3.7	3.6	3	76	180	1.22	0.49	1.71	0.18	260	112	3.1
SP	30	30-Nov-94	5	1	5.23	2.39	0.038	2.7	4.3	3.8	3	56	147	1.28	0.49	1.72	0.18	231	108	2.8
SP	30	15-Dec-94	5	1	5.19	2.48	0.035	3	4.3	3.8	3	85	185	1.19	0.5	1.56	0.23	271	131	3.4
SP	30	11-May-95	5	1	5.28	2.1	0.042	1.7	4.5	2.6	3	44	147	0.97	0.36	1.51	0.26	229	126	3.3
SP	30	21-Jun-95	5	1	5.5	1.88	0.052	0.9	4.2	2.9	3	4	126	1.08	0.41	1.6	0.13	212	136	3.9
SP	30	13-Jul-95	5	1	5.49	1.78	0.042	0.6	4.8	2.9	3	56	190	0.85	0.29	1.46	0.05	205	127	3.9
SP	30	28-Sep-95	5	1	5.42	2.43	0.048	2.1	5.4	4.1	5	63	190	1.31	0.56	1.58	0.23	204	122	3.3
SP	30	15-Oct-95	5	1	5.27	2.54	0.045	2.4	5.1	3.8	3	125	235	1.35	0.58	1.67	0.22	244	116	3.3
SP	30	10-May-96	5	1	5.09	2.63	0.045	1.8	4.7	3.8	3	445	535	1.33	0.49	1.59	0.35	217	117	3
SP	30	12-Jun-96	5	1	5.4	2.29	0.046	1.6	5.2	3.9	5	51	165	1.19	0.44	1.4	0.22	209	100	3.4
SP	30	3-Oct-96	5	1	5.23	2.4	0.038	1.8	5	3.6	3	4	125	1.23	0.47	1.57	0.12	223	106	3.3
SP	30	24-Oct-96	5	1	5.32	2.4	0.041	2.1	5.2	4	2	5	107	1.23	0.5	1.44	0.1	236	123	3.4
SP	30	13-Nov-96	5	1	5.33	2.23	0.04					16		1.22	0.52	1.38		231	109	3.4
SP	30	10-Jun-97	5	1	5.34	2.32	0.035	2.1	4.5	3.7	3	40	175	1.19	40	1.54	0.1	189	105	2.7
SP	30	8-Jul-97	5	1	5.44	2.19	0.048	1.6	4.5	3.7	3	1	125	1.16	0.41	1.41	0.06	176	110	3.1
SP	30	17-Sep-97	5	1	5.49	2.31	0.05	1.8	4.5	4	14	52	220	1.21	0.44	1.62	0.07	200	106	3.4
SP	30	16-Oct-97	5	1	5.37	2.28	0.042	2.4	4.3	4	3	8	144	1.14	0.43	1.6	0.07	212	106	3.3
SP	30	12-Nov-97	5	1	5.22	2.43	0.036	2.7	4	4	3	215	330	1.27	0.5	1.64	0.04	242	105	2.9

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
SP	30	8-Sep-94	15	1	5.07	2.5	0.037	1.7	6.2	3.7	3	4	126	1.19	0.45	1.53	0.11	170	101	3.4
SP	30	11-Sep-94	15	1	5.05	2.49	0.039	1.5	5.3	4	3	8	135	1.12	0.43	1.49	0.11	198	112	3.4
SP	30	19-Sep-94	15	1	5.05	2.04	0.036	1.1	4.6	3.3	3	5	128	1	0.4	1.14	0.12	200	112	3.3
SP	30	11-Oct-94	15	1	5.34	2.15	0.043	1.4	4.9	3.7	6	79	205	1.15	0.51	1.43	0.1	220	118	3.4
SP	30	16-Nov-94	15	1	5.13	2.43	0.032	3	4.1	3.7	3	76	180	1.24	0.49	1.74	0.18	251	114	3
SP	30	30-Nov-94	15	1	5.24	2.4	0.04	2.7	4.2	3.8	3	53	146	1.3	0.49	1.74	0.16	225	108	3
SP	30	15-Dec-94	15	1	5.21	2.4	0.036	2.9	4.2	3.7	3	77	170	1.18	0.48	1.49	0.21	270	128	3.3
SP	30	11-May-95	15	1	5.32	2.09	0.04	1.7	4.4	2.6	3	44	141	0.99	0.36	1.44	0.25	224	129	3.2
SP	30	21-Jun-95	15	1	5.48	1.84	0.049	0.9	4.1	2.8	3	4	129	0.84	0.31	1.27	0.11	212	133	4.1
SP	30	13-Jul-95	15	1	5.45	1.8	0.043	0.8	4.6	2.8	3	17	160	0.87	0.29	1.54	0.09	206	131	3.9
SP	30	28-Sep-95	15	1	5.28	2.53	0.049	2.2	5.4	4.1	3	67	185	1.33	0.57	1.62	0.21	217	116	3.5
SP	30	15-Oct-95	15	1	5.34	2.6	0.052	2.4	5.1	4	3	130	240	1.42	0.58	1.81	0.19	217	139	3.2
SP	30	10-May-96	15	1	5.11	2.62	0.045	1.8	4.6	3.8	3	440	535	1.33	0.49	1.51	0.36	199	114	4.6
SP	30	12-Jun-96	15	1	5.47	2.33	0.044	1.7	5.1	3.9	8	51	180	1.21	0.45	1.48	0.221	212	105	3.4
SP	30	29-Aug-96	15	1	5.12	3.17	0.033	4.8	3.9	2.8	3	285	405	1.63	0.62	1.91	0.24	239	101	2.9
SP	30	3-Oct-96	15	1	5.41									1.19	0.46	1.49		189	106	
SP	30	24-Oct-96	15	1	5.36	2.37	0.04	2.1	5.2	4	3	7	117	1.26	0.5	1.45	0.09	218	129	3.6
SP	30	13-Nov-96	15	1	5.27	2.29	0.042	2.3	4.8	4	3	20	138	1.21	0.51	1.42	0.12	253	122	3.3
SP	30	10-Jun-97	15	1	5.31	2.33	0.036	2.4	4.3	3.8	5	5	104	1.19	0.41	1.54	0.09	205	105	2.8
SP	30	8-Jul-97	15	1	5.38	2.18	0.046	1.6	4.4	3.8	3	2	117	1.15	0.42	1.41	0.07	180	112	3.3
SP	30	17-Sep-97	15	1	5.57	2.4	0.055	1.9	4.6	4.2	3	44	185	1.28	0.47	1.68	0.06	191	112	3.3
SP	30	16-Oct-97	15	1	5.44	2.27	0.043	2.4	4.3	4.1	6	12	155	1.12	0.44	1.52	0.08	200	109	3.5
SP	30	12-Nov-97	15	1	5.25	2.46	0.038	2.6	4.1	4	3	235	345	1.29	0.51	1.64	0.04	236	109	3
SP	37	8-Sep-94	5	1	4.42	2.83		1.4	3.8	4.4	3	2	250	0.54	0.27	1.38	0.18	438	343	13.8
SP	37	11-Sep-94	5	1	4.44	2.84		1.2	3.1	4.2	7	1	260	0.44	0.22	1.32	0.15	451	363	11.4
SP	37	19-Sep-94	5	1	4.5	2.54		1.1	2.9	3.4	3	1	215	0.4	0.2	1.05	0.18	418	343	11.5
SP	37	11-Oct-94	5	1	4.47	2.8		1.8	3.4	4.9	9	2	215	0.51	0.31	1.21	0.25	423	318	11
SP	37	31-Oct-94	5	1	4.34	3.51		3.6	3.6	4.7	6	5	190	0.72	0.43	1.66	0.19	428	292	9.5
SP	37	16-Nov-94	5	1	4.44	2.88		1.8	2.8	3.6	7	0.5	185	0.61	0.38	1.51	0.13	398	300	9.4
SP	37	30-Nov-94	5	1	4.46	2.79		2.1	3.6	4.6	3	2	170	0.61	0.4	1.54	0.13	431	300	9.6
SP	37	15-Dec-94	5	1	4.38	3.53						0.5		0.75	0.47	1.7	0	499	391	
SP	37	11-May-95	5	1	4.65	2.03	0.014	1.2	2.6	2	7	2	205	0.41	0.23	1.12	0.19	337	276	9.2
SP	37	21-Jun-95	5	1	4.64	2.31	0.014	0.8	3.2	3.1	7	2	215	0.47	0.23	1.35	0.13	403	308	11.8
SP	37	13-Jul-95	5	1	4.57							0.5		0.5	0.23	1.49	0	399	250	10.3
SP	37	28-Sep-95	5	1	4.54	2.69		1.8	3.1		10	0.5	285	0.54	0.29	1.54	0.21	464	360	14.2
SP	37	15-Oct-95	5	1	4.46	3.03		2.5	3.4	5.2	7	4	250	0.59	0.34	1.62	0.24	427	330	11.9

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
SP	37	10-May-96	5	1	4.54	2.41	0.019	1	3.1	3.4	5	14	220	0.45	0.28	1.25	0.2	366	293	10.8
SP	37	12-Jun-96	5	1	4.55	2.66		1.2	3.5	4.6	11	4	230	0.53	0.33	1.3	0.08	422	33	12
SP	37	29-Aug-96	5	1	4.3	4.69		3.4	5.3	8.5	32	0.05	760	0.99	0.61	1.88	0.18	1180	564	19.3
SP	37	3-Oct-96	5	1	4.47	3.05		1.6	3.5	4.7	6	0.5	245	0.53	0.33	1.43	0.08	474	356	12.1
SP	37	24-Oct-96	5	1	4.48	3.08		1.9	3.7	4.5	7	0.5	195	0.53	0.36	1.35	0.08	431	353	10.8
SP	37	13-Nov-96	5	1	4.46									0.52	0.39	1.3		353	269	
SP	37	10-Jun-97	5	1	4.58	2.77	0.005	2.3	2.8	5.4	5	0.5	175	0.53	0.3	1.44	0.06	399	264	9.6
SP	37	8-Jul-97	5	1	4.62	2.51	0.005	1.3	2.6	5.2	10	0.5	250	0.46	0.27	1.31	0.06	424	349	14.6
SP	37	17-Sep-97	5	1	4.56	2.82	0.005	1.4	3.3	6.4	9	0.5	315	0.54	0.31	1.58	0.09	462	375	16.6
SP	37	16-Oct-97	5	1	4.6	2.91	0.005	2	3.2	5.4	10	0.5	280	0.54	0.35	1.62	0.06	432	351	13.6
SP	37	12-Nov-97	5	1	4.48	3.02		2.3	3.4	5	6	0.5	235	0.55	0.4	1.69	0.04	452	342	12.9
SP	37	8-Sep-94	15	1	4.45	2.8		1.4	3.8	4.5	3	0.5	225	0.51	0.26	1.37	0.17	463	372	13.9
SP	37	19-Sep-94	15	1	4.51	2.3		1.1	2.8	3.5	3	3	215	0.35	0.18	1.02	0.18	471	363	12.6
SP	37	11-Oct-94	15	1	4.5	2.42		1.6	2.8	4.9	12	2	195	0.43	0.26	1.14	0.19	411	312	10.6
SP	37	31-Oct-94	15	1	4.36	3.47		3.6	3.4	5	3	2	180	0.69	0.42	1.64	0.19	431	275	8.5
SP	37	16-Nov-94	15	1	4.45	2.76		1.7	2.5	4.1	3	0.5	175	0.6	0.37	1.48	0.13	416	308	9.1
SP	37	30-Nov-94	15	1	4.48	2.67		2	3.4	4.6	3	0.5	165	0.58	0.33	1.43	0.11	441	287	9
SP	37	15-Dec-94	15	1	4.44	3.11						0.5		0.64	0.37	1.4		490	370	10.4
SP	37	11-May-95	15	1	4.65	1.95	0.014	1.1	2.4	1.9	6	2	170	0.38	0.2	1.09	0.22	373	309	9.6
SP	37	21-Jun-95	15	1	4.65	2.2	0.015	0.8	2.9	3.1	7	2	215	0.4	0.2	1.34	0.19	452	349	12
SP	37	13-Jul-95	15	1	4.61	2.33	0.011					0.5		0.44	0.21	1.44		453	289	11
SP	37	28-Sep-95	15	1	4.56	2.5		1.6	2.9	5.1	7	0.5	225	0.48	0.26	1.42	0.22	449	376	13
SP	37	15-Oct-95	15	1	4.61	2.59	0.015	2.2	2.8	5.4	5	0.5	200	0.47	0.28	1.52	0.22	412	346	11.1
SP	37	12-Jun-96	15	1	4.58	2.5	0.005	1	3.4	5	10	0.5	205	0.44	0.28	1.25	0.3	422	318	11.2
SP	37	29-Aug-96	15	1	4.43	4.05		2.5	4	8.7	25	0.5	710	0.68	0.39	1.75	0.61	3290	860	28.9
SP	37	3-Oct-96	15	1	4.51	2.75		1.6	3.3	5	3	0.5	220	0.5	0.31	1.36	0.25	482	358	12
SP	37	24-Oct-96	15	1	4.53	2.88		1.9	3.5	4.8	7	0.5	175	0.52	0.33	1.33	0.15	458	386	10.7
SP	37	13-Nov-96	15	1	4.47									0.49	0.33	1.22		385	290	
SP	37	10-Jun-97	15	1	4.57	2.77	0.005	2	3.3	5.8	6	0.5	170	0.47	0.27	1.47	0.13	436	268	9.8
SP	37	8-Jul-97	15	1	4.63	2.45	0.005	1.3	2.6	5.7	10	0.5	235	0.44	0.25	1.31	0.15	453	345	14.3
SP	37	17-Sep-97	15	1	4.65	2.47	0.014	1.3	2.8	7.1	11	0.5	285	0.41	0.25	1.56	0.14	452	376	14.3
SP	37	16-Oct-97	15	1	4.65	2.73	0.011	2.1	3	6.5	10	0.5	250	0.44	0.29	1.64	0.15	452	349	13.3
SP	37	12-Nov-97	15	1	4.57	2.7	0.005	2.3	3.1	6.2	3	4	220	0.49	0.33	1.71	0.12	459	344	11.3

Loc.	no.	Date	Depth cm	Limed	pH -log (H+)	kond. mS/m	ALK mmol/L	Cl mg/L	SO4 mg/L	Si mg/L	NH4-N µg/L	NO3-N µg/L	Tot-N µg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Alr µg/L	Alo µg/L	TOC mg/L
SP	40	8-Sep-94	5	1	4.12							3		0.88	0.33	1.57	0.21			
SP	40	11-Sep-94	5	1													0.12			
SP	40	19-Sep-94	5	1	4.39							3		1.38						
SP	40	11-Oct-94	5	1								3		0.58	0.32	1.18		255	254	
SP	40	31-Oct-94	5	1	4.1			3.4	4.1	3.1	13	4	300	0.63	0.39	1.85		199	193	14.5
SP	40	16-Nov-94	5	1	4.1									0.7	0.46	1.5		236	226	
SP	40	30-Nov-94	5	1	4.15												0.15			
SP	40	11-May-95	5	1	4.26	3.55														
SP	40	21-Jun-95	5	1	4.23									0.54	0.29	1.59				
SP	40	28-Sep-95	5	1	4.04									0.53	0.35	1.29		257	237	
SP	40	15-Oct-95	5	1	4.09									0.6	0.42	1.39		303	272	
SP	40	10-May-96	5	1	4.07							8		0.68	0.51			321	309	28
SP	40	12-Jun-96	5	1	4.3									0.6	0.43					
SP	40	29-Aug-96	5	1	4.01															
SP	40	3-Oct-96	5	1	4.05															
SP	40	24-Oct-96	5	1	3.98									0.59	0.43			396	363	30.9
SP	40	13-Nov-96	5	1	4.04									0.49	0.39	1.06				
SP	40	10-Jun-97	5	1	4.18									0.68	0.4	1.56		440	383	
SP	40	8-Jul-97	5	1	4.12									0.46	0.34	1.45		387	367	
SP	40	17-Sep-97	5	1	4.06									0.54	0.41	2.16		426	433	
SP	40	16-Oct-97	5	1	4.04							2		0.46	0.41	1.83		394	396	40.6
SP	40	12-Nov-97	5	1	3.98									0.44	0.42			416	394	32.4
SP	40	8-Sep-94	15	1								7								
SP	40	11-Sep-94	15	1								6								
SP	40	19-Sep-94	15	1	4.6															
SP	40	12-Nov-97	15	1	4.46															
SP	46	8-Sep-94	5	1	4.97		0.046					2		2.34	0.68	2.67	0.16	596	468	22.8
SP	46	11-Sep-94	5	1	4.99							2	630	1.74			0.15	494	380	
SP	46	19-Sep-94	5	1	4.95	2.64		1.9	4	4.4	8	2	595	1.38	0.39	1.44		477	271	16.6
SP	46	11-Oct-94	5	1	4.88	2.97	0.027	3.8	3.4	3.6	64	5	380	1.3	0.46	1.43		348	218	8.9
SP	46	31-Oct-94	5	1	4.56	8.06		16.4	4.7	4.8	166	16	730	3.62	1.15	3.59	1.21	770	309	12.3
SP	46	16-Nov-94	5	1	4.8	3.93	0.021	4.9	4.9	4.2	39	18	500	2.14	0.68	2.48	0.7	526	328	12.8
SP	46	30-Nov-94	5	1	4.78	4.01	0.022	5.1	4.7	4.4	3	28	405	1.96	0.63	2.49	3.1	451	287	10.1
SP	46	11-May-95	5	1	4.77	6.81	0.023	12	6.7	4.9	3	8	430	3.26	1.07	4.6	1.1	556	294	11
SP	46	21-Jun-95	5	1	4.84	5.07	0.029	5.5	8.4	4.4	10	4	500	2.52	0.79	3.56	0.89	544	314	12.9
SP	46	28-Sep-95	5	1	4.66									1.68	0.57	2.52	1.34	394	216	8.9
SP	46	15-Oct-95	5	1	4.69	4.83	0.016					0.5		1.88	0.67	3.27	0.77	394	157	7

Loc.	no.	Date	Depth	Limed	pH	kond.	ALK	Cl	SO4	Si	NH4-N	NO3-N	Tot-N	Ca	Mg	Na	K	Alr	Alo	TOC
			cm		-log (H+)	mS/m	mmol/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L
SP	46	10-May-96	5	1	4.66	8.4		18.7	3.4	5.8	158	205	785	2.99	1.12	5.89		510	168	9.6
SP	46	12-Jun-96	5	1	4.73	4.01	0.019					11	330	1.79	0.73			430	190	8.8
SP	46	29-Aug-96	5	1													0.81			
SP	46	3-Oct-96	5	1	4.81	3.14					18	0.5	405	1.44	0.48	1.79		340	305	26.9
SP	46	24-Oct-96	5	1	4.79	3.7	0.024	3.8	5.7	4.3	9	0.5	355	1.58	0.56	2.28	0.35	440	304	10.6
SP	46	13-Nov-96	5	1	4.7									1.99	0.77	2.66		431	247	10.3
SP	46	10-Jun-97	5	1	4.55	8.54	0.005					5		3.24	1.26	6.33		634	151	5.8
SP	46	8-Jul-97	5	1	4.52	8.22						2		2.99	1.17	5.8		756	232	10.3
SP	46	16-Oct-97	5	1	4.76									1.06	0.45	3.4				
SP	46	12-Nov-97	5	1	4.59									2.12	0.89			580	361	
SP	46	8-Sep-94	15	1	4.91		0.028	3.9	7.1	4.4	3	1	330	1.46	0.47	2.52		271	191	9.6
SP	46	11-Sep-94	15	1	4.86		0.026	3.8	7.6	4.6	3	1	330	1.38	0.44	2.56		301	205	10
SP	46	19-Sep-94	15	1	4.83	3.48	0.026	3.4	6	4.9	3	1	440	1.4	0.47	2.16	1.33	364	240	11.5
SP	46	11-Oct-94	15	1	4.82	3.14	0.022	4.8	4.4	3.6	8	0.5	215	1.2	0.45	1.85	1.3	321	157	6.1
SP	46	31-Oct-94	15	1	4.59									2.93	1.03	3.01	1.07			
SP	46	16-Nov-94	15	1	4.7									2.07	0.72	2.55	0.61	469	272	
SP	46	30-Nov-94	15	1	4.66	4.63	0.013	6.1	5.4	4.4	3	2	295	1.91	0.67	2.96		476	235	7.5
SP	46	11-May-95	15	1	4.81	5.41	0.025	8.3	6.8	4.6	13	3	280	2.15	0.78	4.11		530	237	7.7
SP	46	21-Jun-95	15	1	4.77	5.34	0.023	8.1	6.8	4.5	5	3	280	2.21	0.76	3.77	0.75	550	237	8.3
SP	46	28-Sep-95	15	1	4.69							4		1.3	0.51	2.98	0.51	423	207	7.9
SP	46	15-Oct-95	15	1	4.73	4.18	0.02					0.5		1.38	0.53	3.43	0.27	436	192	6.5
SP	46	10-May-96	15	1	5.01	6.55	0.026	9.5	8.6	5.4	81	15	385	2.05	0.88	5.01		630	240	8.1
SP	46	12-Jun-96	15	1	4.67	5.5	0.017	9.5	7.6	4.5	12	4	260	1.95	0.85	4.85		562	163	7.4
SP	46	29-Aug-96	15	1													0.65			
SP	46	3-Oct-96	15	1	4.59	4.98	0.012	7	6.9	4	12	0.5	235	1.53	0.67	3.99	0.12	636	206	7.2
SP	46	24-Oct-96	15	1	4.66	2.09	0.014	6.8	7.2	4.4	12	0.5	235	1.37	0.63	4	0.09	662	228	7.7
SP	46	13-Nov-96	15	1	4.71	4.61	0.018	7.1	6.9	4.7	13	0.5	230	1.32	0.66	3.95	0.13	579	224	6.7
SP	46	10-Jun-97	15	1	4.66	7.01	0.012	12.7	6.5	3.7	3	4	250	2.15	0.87	5.98	0.18	646	171	6
SP	46	8-Jul-97	15	1	4.7	5.71	0.014	8.5	7.2	3.2	7	0.5	275	1.53	0.66	5.14	0.04	580	184	8.3
SP	46	17-Sep-97	15	1	4.85									0.7	0.31	2.9		255	129	
SP	46	16-Oct-97	15	1	4.84	3.38	0.028	3.7	5.5	3.3	13	1	310	0.81	0.37	2.75	0.5	423	191	9.4
SP	46	12-Nov-97	15	1	4.66	3.96	0.012	6.5	4.1	2.7	3	4	245	0.93	0.5	3.3	0.35	521	195	7.9

Loc.	no.	Date	Depth cm	Limed	pH -log (H+)	kond. mS/m	ALK mmol/L	Cl mg/L	SO4 mg/L	Si mg/L	NH4-N µg/L	NO3-N µg/L	Tot-N µg/L	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Alr µg/L	Alo µg/L	TOC mg/L
SP	50	8-Sep-94	5	1	4.59							4		1.6	0.69	2.37				
SP	50	11-Sep-94	5	1	4.68							2		1.77						
SP	50	19-Sep-94	5	1	4.69															
SP	50	31-Oct-94	5	1	4.45									2.41	1.04	2.68				
SP	50	16-Nov-94	5	1	4.82									1.87	0.84	2.26		464	374	
SP	50	30-Nov-94	5	1	4.58															
SP	50	11-May-95	5	1								16		1.66	0.78	3.53				
SP	50	21-Jun-95	5	1	4.6															
SP	50	28-Sep-95	5	1	4.48									1.71	0.7	2.61				
SP	50	15-Oct-95	5	1	4.43															
SP	50	10-May-96	5	1	4.53									2.34	1.01			670	307	
SP	50	12-Jun-96	5	1	4.53									2.4	1.32					
SP	50	29-Aug-96	5	1	4.5															
SP	50	3-Oct-96	5	1	4.46									1.24	0.66	1.94		660	480	
SP	50	24-Oct-96	5	1	4.37									1.62	0.87					
SP	50	7-Aug-97	5	1	4.64									1.21	0.6	2.5				
SP	50	16-Oct-97	5	1	4.56									1.16	0.84	4.28		542	330	16.8
SP	50	12-Nov-97	5	1	4.47									1.37	0.94			508	333	
SP	50	8-Sep-94	15	1	4.68							1		1.27	0.51	2.08				
SP	50	11-Sep-94	15	1								2		1.24						
SP	50	19-Sep-94	15	1	4.78															
SP	50	31-Oct-94	15	1	4.61															
SP	50	16-Nov-94	15	1	4.62									1.38	0.64	2.8		184	86	
SP	50	30-Nov-94	15	1	4.7															
SP	50	11-May-95	15	1								4		1.28	0.62	2.77	0.21			
SP	50	21-Jun-95	15	1	4.72															
SP	50	28-Sep-95	15	1	4.59															
SP	50	15-Oct-95	15	1	4.54															
SP	50	12-May-96	15	1	4.54							1185		1.76	0.86			366	143	6.3
SP	50	3-Oct-96	15	1	4.65									1.04	0.47	1.83		258	126	
SP	50	24-Oct-96	15	1	4.58									1.12	0.54					
SP	50	8-Jul-97	15	1	4.51									1.62	1.03	3.73		624	352	
SP	50	17-Sep-97	15	1	5.89															
SP	50	16-Oct-97	15	1	4.74									0.93	0.46	2.71		278	149	7.4
SP	50	12-Nov-97	15	1	4.64									0.95	0.5			320	146	6.2
SP	50	11-Sep-94	15	1	4.77	2.84	0.023	1.8	4.9	4.8	3	0.5	295	1.16	0.34	1.75	0.25	352	262	11.3

Appendix B. Hydrology

Abbreviation and references for sampling stations:
LIM-1: Stream outlet of catchment 1 in the limed catchment Fugleliåsen
LIM-4: Main stream outlet of the limed catchment Fugleliåsen
REF: Stream outlet of reference catchment Spjøtåsen

DATO	LIM-1 m3/period	LIM-4 m3/period	REF m3/period
1-Mar-94			
13-Mar-94	42409	73455	35718
29-Mar-94	12056	20882	14520
11-Apr-94	90137	156122	60915
18-Apr-94	27255	47206	23256
25-Apr-94	28191	48829	20565
2-May-94	38872	67329	28031
9-May-94	14053	24482	12153
18-May-94	5632	9755	3450
25-Aug-94	12747	30574	9079
31-Aug-94	22617	57695	16508
11-Sep-94	29915	59405	22739
19-Sep-94	30121	58337	22593
29-Sep-94	3188	5960	372
12-Oct-94	1799	2428	1338
26-Oct-94	8774	17119	15401
31-Oct-94	22534		7212
3-Nov-94	11524	69380	8300
14-Nov-94	5331	10642	4321
21-Nov-94	9675	18438	7314
6-Dec-94	6146	11686	4907
12-Dec-94	20238	38509	14988
21-Dec-94	14412	27807	11131
31-Dec-94	6536	13172	5316
3-Jan-95	1122	2449	1095
15-Feb-95	53026	115920	63605
14-Mar-95	31353	65867	30239
27-Mar-95	25161	48771	25208
5-Apr-95	42085	29331	38208
16-Apr-95	39339	68756	23288
25-Apr-95	30706	53875	15301
8-May-95	23320	45086	13549
26-May-95	9291	19022	7794
6-Jun-95	11336	18702	7054
13-Jun-95	16064	24167	10057
27-Jun-95	22051	31656	13272
7-Sep-95	1069	1663	1052
14-Sep-95	17515	29530	11848
18-Sep-95	27845	54684	22350
4-Oct-95	13389	26732	10949
23-Oct-95	16168	36374	13771
20-Nov-95	4779	11416	3737
4-Dec-95	2715	6821	1859
19-Dec-95	4400	10787	2907
31-Dec-95	858	2307	975

DATO	LIM-1 m3/period	LIM-4 m3/period	REF m3/period
12-Jan-96	600	2070	907
18-Apr-96	25594	68129	27005
22-Apr-96	19326	42038	13419
28-Apr-96	16009	29703	11203
7-May-96	8767	20578	7690
20-May-96	10797	24244	8553
29-May-96	7424	18413	6707
20-Jun-96	2810	9437	3152
7-Sep-96	7468	18105	5167
30-Sep-96	25941	51575	21310
16-Oct-96	11639	26823	10589
28-Oct-96	28738	59484	22306
7-Nov-96	17446	37884	15207
21-Nov-96	8094	19409	7497
4-Dec-96	9081	28174	6213
8-Dec-96	19230	29127	17316
31-Dec-96	7679	18918	7382
3-Mar-97		104865	41315
5-May-97		106724	36057
23-Jun-97		32745	9340
2-Jul-97		17242	5711
7-Aug-97		5320	3937
4-Sep-97		9252	5668
18-Sep-97		19720	8800
14-Oct-97		35028	14427
4-Nov-97		18359	7886
10-Nov-97		29766	9648
13-Nov-97		39454	14800
31-Dec-97		163590	61217

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