NIVA IVL NISK

NITREX

Gårdsjön

Status report for 1988-90

Norwegian Institute for Water Research NIVA

NIVA – REPORT

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NITREX project - Gårdsjön

Status report for 1988-90

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At the NITREX site at Gårdsjön, Sweden, nitrogen deposition will be experimentally increased to an entire forested catchment to study the potential for nitrogen saturation. Investigations include regular sampling of precipitation, throughfall and runoff and compilation of input-output budgets. Short-term experiments of toxicity of the runoff water to fish are also underway. Studies of vegetation and soils are centered around three vegetation types characteristic of the catchments. Plots have been selected on the basis of soil and vegetation maps of the three catchments. Regular measurements include (1) volume and chemical composition of soil solution, (2) soil temperature, (3) chemical composition of needles, (4) amount and chemical composition of litterfall, and (5) soil moisture. In addition studies of mineralization, fine roots, and mycorrhiza are being conducted. Nitrogen addition will begin in April 1991.The NITREX data from Gårdsjön will be combined with similar data from the other NITREX sites throughout Europe.

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NITREX project - Gardsjön

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SUMMARY

The NITREX project addresses the role of nitrate in acidification of soil and water by means of nitrogen addition or removal to precipitation falling on entire headwater catchments and large forest stands across the gradient in nitrogen deposition in Europe. At the NITREX site at Gårdsjön, Sweden, nitrogen deposition will be experimentally increased to an entire forested catchment to study the potential for nitrogen saturation. The Gårdsjön experiment is a joint Norwegian-Swedish research project.

The Gårdsjön NITREX site (G2) is a 0.52 ha, headwater catchment in 80-year-old Norway spruce with thin and patchy podzolic soils on granitic bedrock. It lies adjacent to a similar catchment (G1) which is covered by roof beneath the canopy; here acid deposition will be removed and clean precipitation applied beneath. A third catchment (F1) serves as control. Treatment at both sites will begin April 1991. At least one year of pre-treatment data have been collected.

The Gårdsjön area receives moderately high acid deposition (25-31 kg S/ha/yr and 16-22 kg N/ha/yr). Runoff from the experimental catchments has low pH (4.0-4.3), high concentrations of sulfate (250-300 ueq/l) and inorganic aluminum (40 ueq/l), but low concentrations of both ammonium and nitrate (< 3 ueq/l). Investigations include regular sampling of precipitation, throughfall and runoff and compilation of input-output budgets. Short-term experiments of toxicity of the runoff water to fish are also underway.

Studies of vegetation and soils are centered around three vegetation types characteristic of the catchments. Plots have been selected on the basis of soil and vegetation maps of the three catchments. Regular measurements include (1) volume and chemical composition of soil solution, (2) soil temperature, (3) chemical composition of needles, (4) amount and chemical composition of litterfall, and (5) soil moisture. In addition studies of mineralization, fine roots, and mycorrhiza are being conducted.

Nitrogen addition to G2 will begin in April 1991. We plan to spike the inputs with nitrogen enriched in the stable isotope N- 15 for one year. Measurements of isotope abundances in vegetation, litterfall, soil, soil solution, and runoff will allow estimates of the fate of added nitrogen in the catchment. In subsequent years the depletion of the pool of N-15 will provide information regarding sources of nitrogen leaving the ecosystem in runoff.

The NITREX data from Gårdsjön will be combined with similar data from the other NITREX sites throughout Europe. The data will be used to evaluate and further develop process models for nitrogen. These data provide the basis for comparisons of the role of nitrogen in soil and water acidification and nutritional status of forests across the present-day gradient of nitrogen deposition in Europe.

NORSK SAMMENDRAG

NITREX prosjektet er fokusert på nitrogenets rolle i forsuring av jord og vann. Fremgangsmåte er stor-skala eksperimenter med økt eller redusert nitrogen tilførsel på hele nedbørfelt eller skogsbestand på tvers av dagens gradient i nitrogen deposisjon i Europa. Ved Gårdsjön i Sverige skal nitrogen tilførsel tredobbles til et helt skogskledd nedbørfelt for å undersøke potentiale for nitrogen metning. Gårdsjön eksperimentet er en felles norsk- svensk forskningsinnsats.

NITREX feltet ved Gårdsjön (G2) er 0.52 ha, i en 80-år gammel granskog på tynt jordsmonn og granitisk berggrunn. Nedbørfelt G2 grenser opp til G1 som skal dekkes med tak for å redusere tilførsel av sure komponenter. Et tredje felt (F1) danner felles kontroll. Behandlingen på begge felter begynner 1. april 1991. Minst ett-års bakgrunnsdata har da blitt samlet inn.

Feltene ved Gårdsjön mottar betydelige mengder sur nedbør med 25-31 kgS/ha/yr og 16-22 kgN/ha/yr. Avrenningen er sur (pH ca. 4.0-4.3) med høye konsentratsjoner av sulfat (250-300 uekv/l) og labilt aluminium (40 uekv/l), men med lave konsentrasjoner av både ammonium og nitrat (< 3uekv/l). Måleprogrammet omfatter mengde og kjemisk sammensetning av nedbør, kronedrypp, og avrenning. Avrenningsvannets toksisitet overfor ulike ørretstammer skal bestemmes.

Undersøkelser av vegetasjon og jord er konsentrert rundt tre vegetasjonstyper typisk for feltene. Prøveflater er valgt ut fra kart over vegetasjon og jordsmonn. Måleprogrammet omfatter (1) volum og kjemisk sammensetning av jordvæske, (2) jord-temperatur, (3) kjemisk sammensetning av nåler, (4) mengde og kjemisk sammensetning av strøfall, og (5) jordfuktighet. I tillegg undersøkes mineraliseringen, fin-røtter, og mykorrhiza.

Nitrogentilførsler til G2 begynner i april 1991. Vanningsvann blir anriket med den stabile isotopen, N-15 i et år. Målinger av N-15 innholdet i vegetasjon, strøfall, jord, jordvæske, og avrenningen vil gi innsikt i hvor tilført nitrogen går hen. Hvis nitrogen begynner å lekke ut av systemet, vil N-15 innholdet bidra med informasjon om hvilke deler av økosystemet nitrogenet kommer fra.

NITREX data fra Gårdsjön skal sammenliknes med tilsvarende data fra de andre NITREX eksperimenter i Europa. Den samlede datamengde skal brukes for å evaluere og videreutvikle nitrogen modeller.

PREFACE

The NITREX experiment at Gårdsjön would not be possible without the enthusiastic and conscientious efforts of support personnel at the participating institutions.

NITREX Gårdsjön receives financial support from the Norwegian National Committee for Environmental Research (NMF/NAVF), the Swedish Environmental Protection Board (SNV), the Nordic Council of Ministers (NMR), and from internal funds from the Norwegian Institute for Water Research (NIVA), the Swedish Environmental Research Institute (IVL) and the Norwegian Forest Research Institute (NISK).

1. INTRODUCTION

The NITREX project addresses the role of nitrate in acidification of soil and water by means of nitrogen addition or removal to precipitation falling on entire headwater catchments and large forest stands across the gradient in nitrogen deposition in Europe. NITREX comprises 11 experiments at 7 sites in Europe spanning the gradient in nitrogen deposition from high deposition in the Netherlands to low deposition in Norway.

Nitrogen is a key nutrient in the health and vitality of the coniferous forest ecosystems of Europe. Large-regions of Europe receive wet and dry deposition of nitrogen from the atmosphere (acid deposition) due to anthropogenic activities such as combustion of fossil fuels and intensive agriculture.

High levels of nitrogen deposition lead to "nitrogen saturation" of forest ecosystems. Increased nitrogen inputs no longer yield increased growth but instead breakdown of ecosystem structure and function. High levels of nitrogen deposition have been implicated in the recent widespread forest dieback in central Europe. Increased nitrogen leakage from forest ecosystems is commonly termed "nitrogen saturation".

In the Netherlands several decades of extremely high deposition of nitrogen and sulphur have caused severe damage to forest ecosystems and led to high concentrations of nitrate and ammonium in soil solution and groundwater. Little is known regarding the degree and rate of reversibility of nitrogen saturation.

Increased nitrogen loss from coniferous forest ecosystems has major consequences for aquatic ecosystems. Nitrogen leakage is commonly in the form of nitrate; nitrate is a strong-acid anion just as sulphate and as such is equally effective as an acidifying agent and mobilizer of toxic aluminum in soils and waters. Higher nitrate levels mean increased stream and lake acidification which can offset gains obtained by European reductions in sulfur emissions.

Increased leaching of nitrogen from terrestrial ecosystems has implications for eutrophication of coastal marine waters. Nitrogen deposited directly from the atmosphere or delivered by streams and rivers has been implicated in recent algal blooms in coastal marine waters. Increased nitrogen leaching due to "nitrogen saturation", forest disturbance or climate change will further stress these marine ecosystems. Furthermore such increased leaching will offset the ambitious plans to reduce nitrogen loadings to coastal marine ecosystems from other sources.

The NITREX site at Gårdsjön, Sweden, comprises one of the NITREX sites in Europe. At Gårdsjön nitrogen deposition will be experimentally increased to an entire forested catchment to study the potential for nitrogen saturation. The Gårdsjön experiment is a joint Norwegian-Swedish research project involving scientists from 2 Norwegian institutes (NIVA and NISK) and 2 Swedish institutes (IVL and SLU) with financing from Norwegian (NMF), Swedish (SNV) and international (NMR, CEC) organizations.
The Gårdsjön NITREX site was established in 1989 and full instrumentation completed in early 1990. Treatment will commence April 1991. Here we report the status of the Gårdsjön NITREX investigations for 1989 and 1990.

2. THE GÅRDSJÖN NITREX SITE

The NITREX site at Gårdsjön is G2, a 0.52 ha, well-defined, headwater catchment in the Gårdsjön area, western Sweden. Gårdsjön offers an ideal site for the NITREX experiment. Soils and waters here are chronically acidified due to sulfate deposition (Hultberg and Grennfelt, 1986) (Figure 2.1). Nitrogen deposition is moderately high, yet most of the incoming nitrogen is retained in the terrestrial ecosystems. Further south in Sweden at the Soderaasen site signs of nitrate saturation have already appeared (Hauhs et al. 1989).

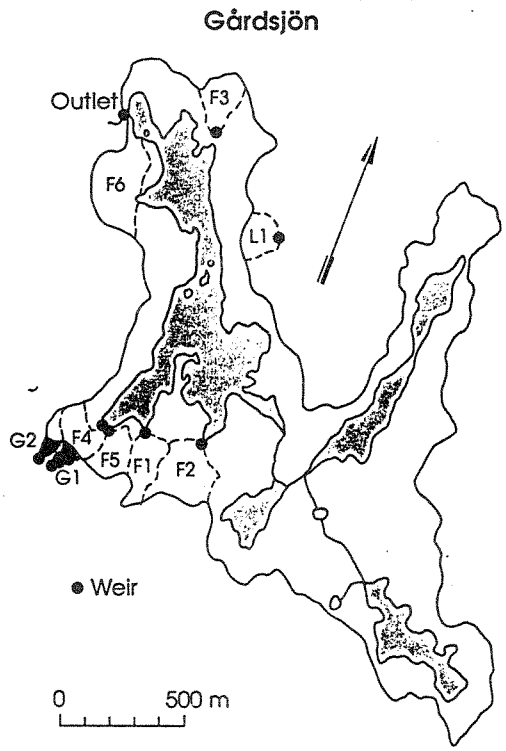


Figure 2.1. Map of Lake Gårdsjön, Sweden, at its catchment showing the location of experimental catchments. G1 is the roofed catchment, G2 NITREX and F1 control (modified from Hultberg 1985).

Gårdsjön has been a central site for acidification research in Sweden since the 1960's. The area is characteristic of acidified regions of the Swedish west coast and southeastern Norway with granitic and gneissic bedrock overlain by thin and patchy soils developed from glacial material of generally the same lithology. Vegetation is dominated by Norway spruce stands of various ages up to >80 yrs (Olsson et al. 1985).

At Gårdsjön whole-catchment manipulation experiments have been conducted since the mid-1980's (Table 1) (Hultberg and Grennfelt 1986). Manipulations have included fertilizer additions of nitrogen, liming and acidification with elemental sulfur. These experiments and the ongoing long-term background data from the Gårdsjön project provide an extensive scientific base for the proposed NITREX experiment.

Table 1. Gårdsjön project. Overview of experimental catchments and treatments conducted since 1984.

Catchment	Treatment	Area	Treatment date
F1	control	3.7 ha	- - - - - - -
F2	liming, dolomite	3.3 ha	June 1984
F3	clearfelling	3.0 ha	April 1984
F4	NH_4NO_3	2.6 ha	August 1984
F5	elemental S	3.1 ha	October 1985
L1	Na_2SO_4	2.5 ha	October 1985
BE	liming + NH_4NO_3	4.1 ha	August 1985
BW	liming	5.3 ha	October 1985
KN	liming + NH_4NO_3	3.9 ha	August 1985
G1	roof	0.6 ha	April 1991
G2	NITREX	0.5 ha	April 1991

For the NITREX experiment we have selected catchment G2, a 0.52 ha catchment with mature Norway spruce. Ammonium nitrate will be added to the incoming precipitation in amounts sufficient to increase nitrogen loadings from present-day levels of 16-23 kg N/ha/yr to about 50 kg N/ha/yr. This is the current nitrogen loading received by damaged forest ecosystems in central Europe. Addition will be accomplished by means of a sprinkling system using ion-exchanged water added during or immediately after natural precipitation events. This technique will thus avoid the shock effects of traditional nitrogen fertilizer experiments. The volume of additional water will be only about 5% of natural precipitation, so that the normal hydrologic cycle will not be greatly affected. An adjacent catchment (F1) will serve as untreated reference. The experimental design is similar to that used in the large-scale acidification experiments of the RAIN project (Wright et al. 1988).

The NITREX catchment at Gårdsjön will complement a new acid precipitation removal experiment to be conducted on a similar adjacent small headwater catchment (G1). The removal will be by means of a "roof" beneath the canopy. This removal experiment is funded independently of NITREX but will run in parallel and with many of the same procedures and personnel planned for the NITREX experiment.

Technical installations at G1 (roof) and G2 (NITREX) are complete except for the ion-exchange and sprinkling systems (Figure 2.2). These will be installed in early 1991. Treatment at both catchments is scheduled to begin 1 April 1991.

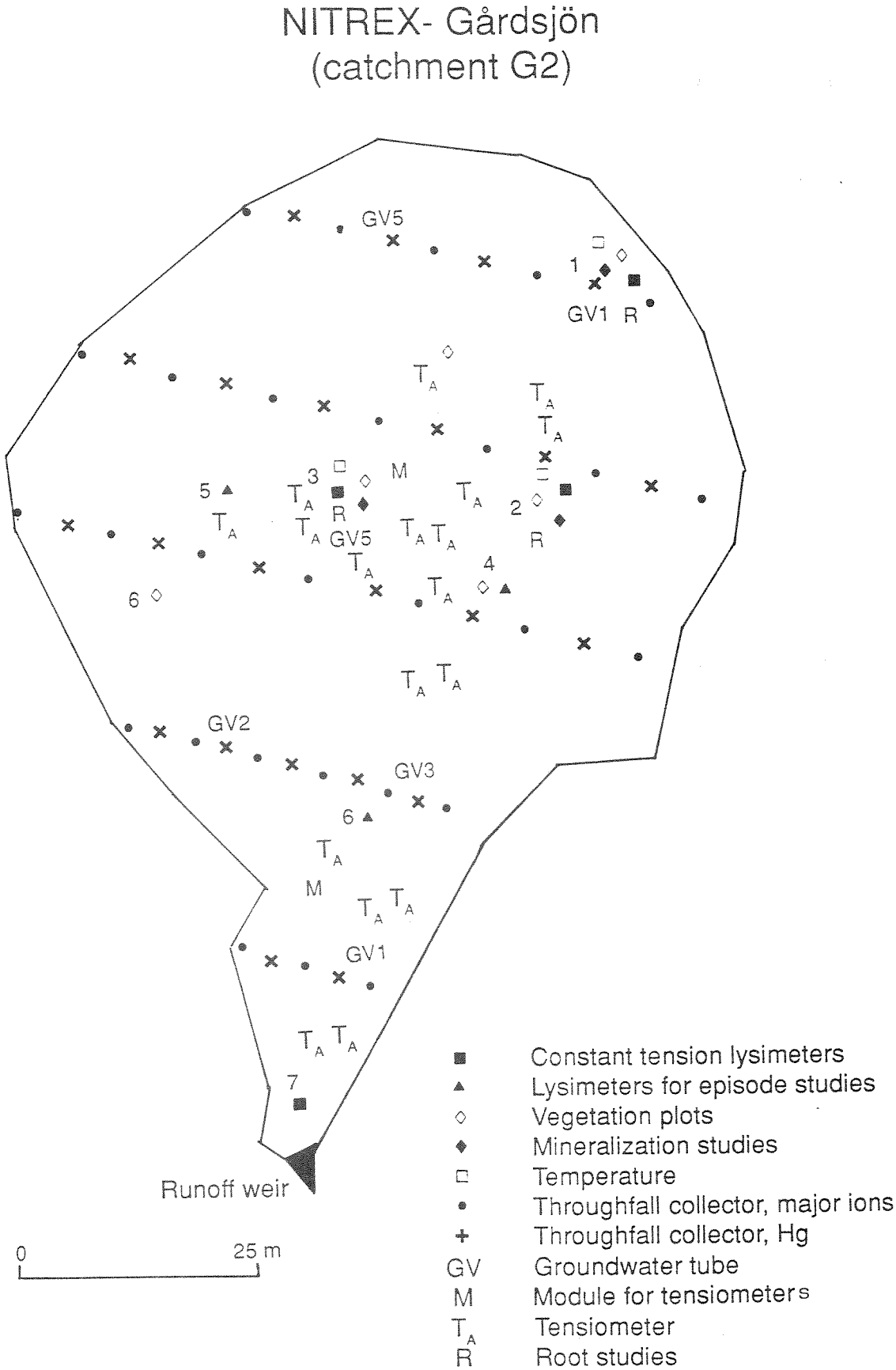


Figure 2.2. Map of the NITREX catchment G2 at Gårdsjön showing location of vegetation plots, lysimeters, tensiometers, throughfall collectors, mineralization studies, mycorrhiza transects, and groundwater tubes.

3. RESULTS AND DISCUSSION

3.1. Precipitation, throughfall and runoff.

Ulf Nyström, Ingvar Andersson and Hans Hultberg, IVL, Göteborg.

The two new experimental catchments G1 (roof) and G2 (NITREX) were selected autumn 1988. Sampling of throughfall and runoff began October 1988. Weirs and equipment for continuous gauging of runoff were brought into operation in early 1990.

Runoff volume and chemical composition at the control catchment F1 has been monitored since 1979. Precipitation is collected daily at the station near Gårdsjön outlet. Dry deposition of major constituents is estimated by one of three methods. (1) For S and Cl dry deposition is assumed equal to the difference between throughfall and open bulk precipitation fluxes. (2) For Na, K, Mg and Ca dry deposition is assumed equal to the Cl dry deposition scaled by the ionic ratios (Na/Cl, K/Cl, Mg/Cl) in seawater. (3) For NO_3 and NH_4 dry deposition is calculated from measurements of concentrations of NO_2 gas, ammonium sulfate aerosols and estimated deposition velocities (Grennfelt et al. 1985).

Input-output budgets for F1 show high deposition of S (25-31 kg S/ha/yr) and N (16-22 kg N/ha/yr) and acid, aluminium-rich runoff (Table 3.1.1) (Hultberg 1985 and Nilsson 1985).

Table 3.1.1. Fluxes and volume-weighted concentrations of major ions in precipitation (wet + dry) and runoff (control catchment F1) for the two hydrologic years 1979-81. Ranges shown for dry deposition estimates. Organic anions (A^-) are determined by difference from the ionic balance (data from Hultberg 1985 and Nilsson 1985). Flux units: meq/m^2/yr. Concentrations in ueq/l; DOC in mg C/l.

	Deposition flux			Runoff	Runoff
	wet	dry	total	flux	conc.
H_2O (mm)	1130	0	1130	666	666
H^+	50	52	102	45	68
Ca	8	10-36	18-44	44	66
Mg	10	35-40	45-50	85	127
Na	37	150	187	211	316
K	2	4-14	6-16	12	18
Al_i	0	0	0	27	40
NH_4	45	10-39	55-84	0	0
NO_3	33	29-44	62-77	2	3
SO_4	71	84-123	155-149	180	270
Cl	47	175	221	221	332
A^-	0	0	0	21	30
DOC					9.4

Preliminary data from the NITREX, the Roof, and the reference catchment include:

1) Throughfall; volume and concentrations of pH, conductivity, color, Ca, Na, K, Mg, Fe, Mn, Al, Al-inorg., SO4, Cl, NH4, NO3, Kjelldahl-N, P-tot., and DOC. Standard analytical methods at IVL are used. About 25 throughfall collectors are in each catchment. Separate vessels collect samples for Hg and methyl-Hg (Figure 2.2). The sampling frequency is monthly, except during summer, when NH4 and pH are analyzed twice a month.

2) Runoff water: the analytical program includes the same parameters as for throughfall. The sampling frequency is weekly. The water is sampled from a pipe coming from the weir at the outlet of the catchments. The water discharges from G1 and G2 are measured by automatic filling and emptyings of tanks. F1 is gauged by weir and level recorder.

3) Groundwater and stemflow: collected at lower sampling frequency. These are also analyzed for the same suite of chemical parameters..

4) Open field precipitation: collected at the SMHI-station 2 km away (at the same altitude) and from two "tipping bucket"-gauges. A meteorological mast with wind-speed, temperature, relative. humidity and global radiation is also installed. The mast-, the tipping bucket-, and the water discharge data are transferred to IVL via modem.

We show time series of runoff water data to illustrate the following:

* The state of and difference between the water chemistry in the catchments.
* The importance of a dense, long time-series of data (from F1, the reference), concerning chemistry as well as fluxes.

The data are preliminary and have not been subject to a final quality control. Every figure consists of parts (a) and (b), where (a) covers the time period 1979-1990 and (b) October 1988-September 1990.

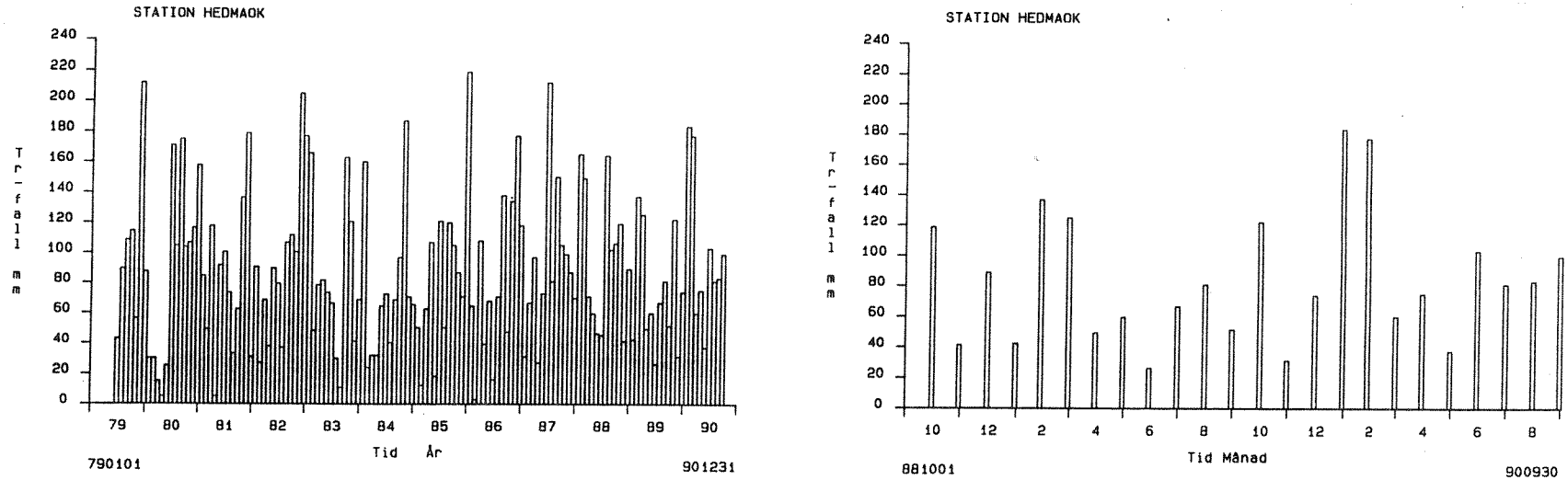


Figure 3.1.1. The monthly sums of precipitation in mm from the SMHI-station. Ordinary measured values, i.e. no correction for wind losses etc.

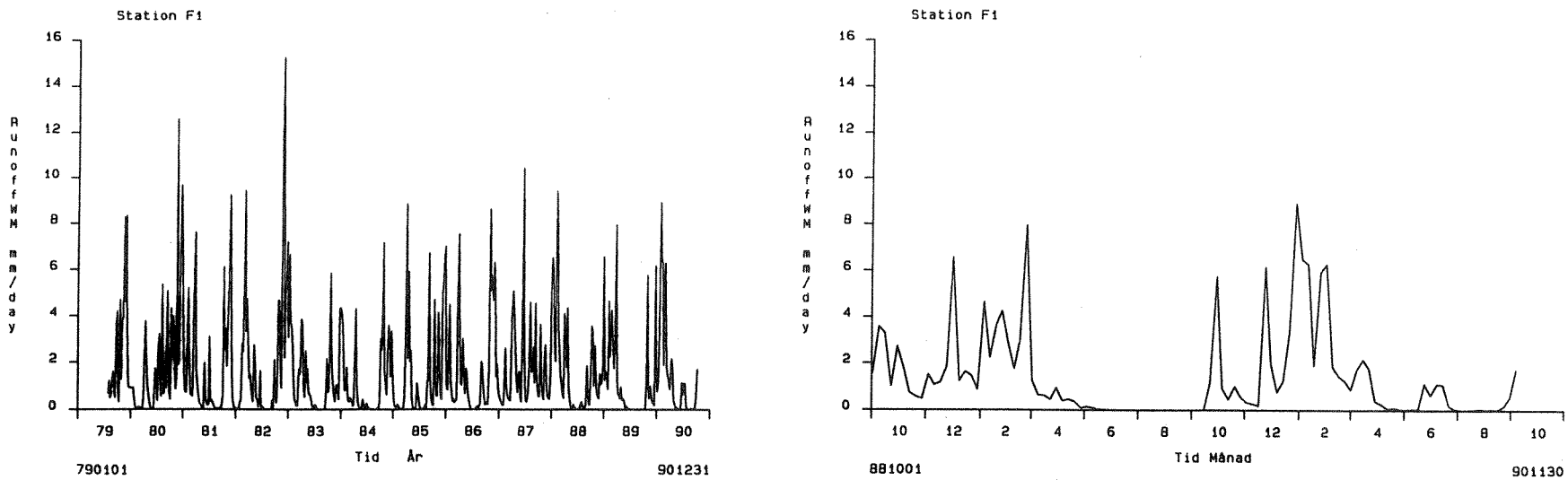


Figure 3.1.2. The runoff from F1 as weekly mean in mm/day (control catchment).

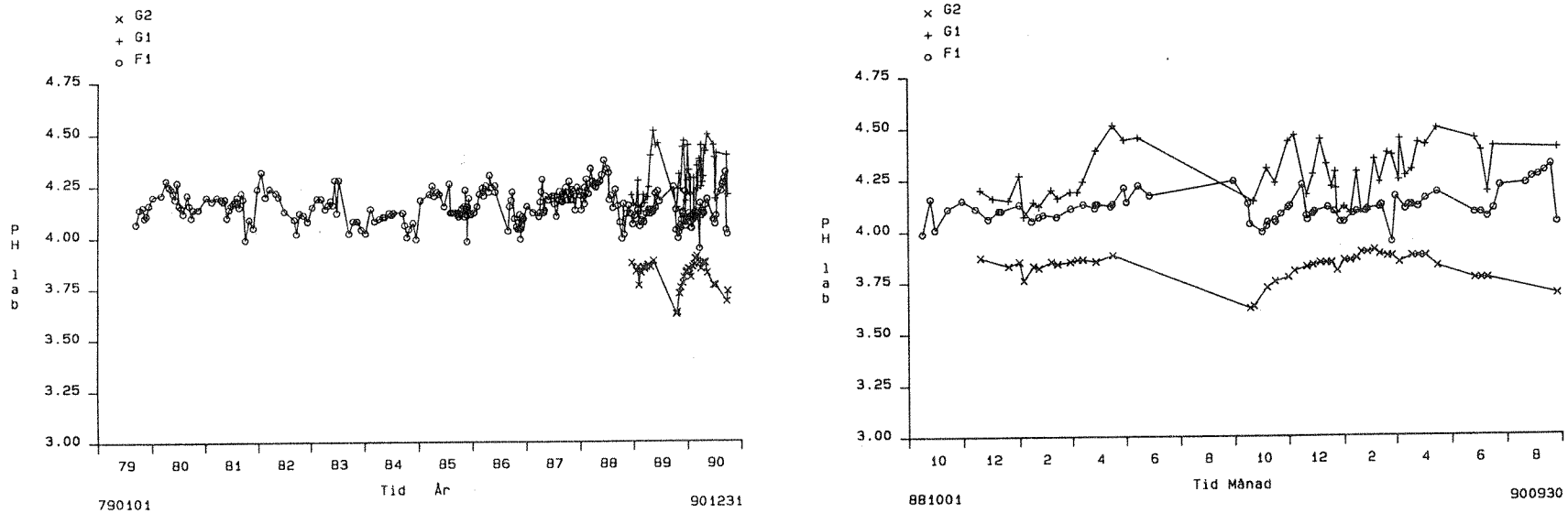


Figure 3.1.3. pH lab in runoff from F1 (control), G1 (roof) and G2 (NITREX).

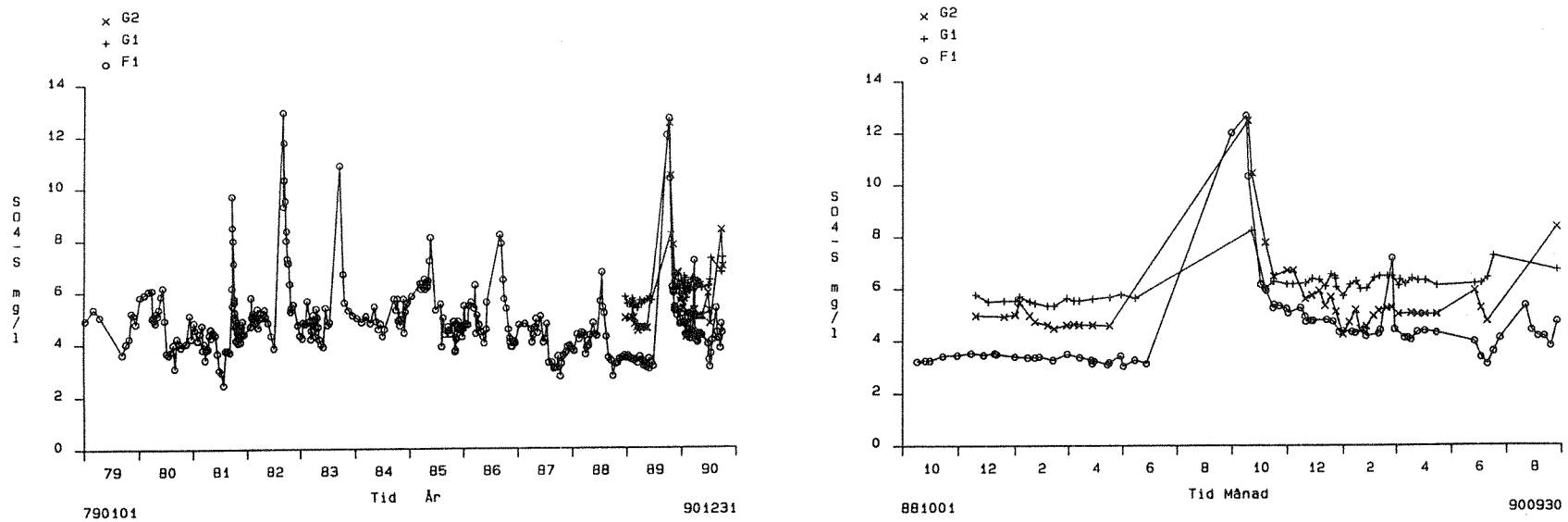


Figure 3.1.4. SO_4-S in mg/L

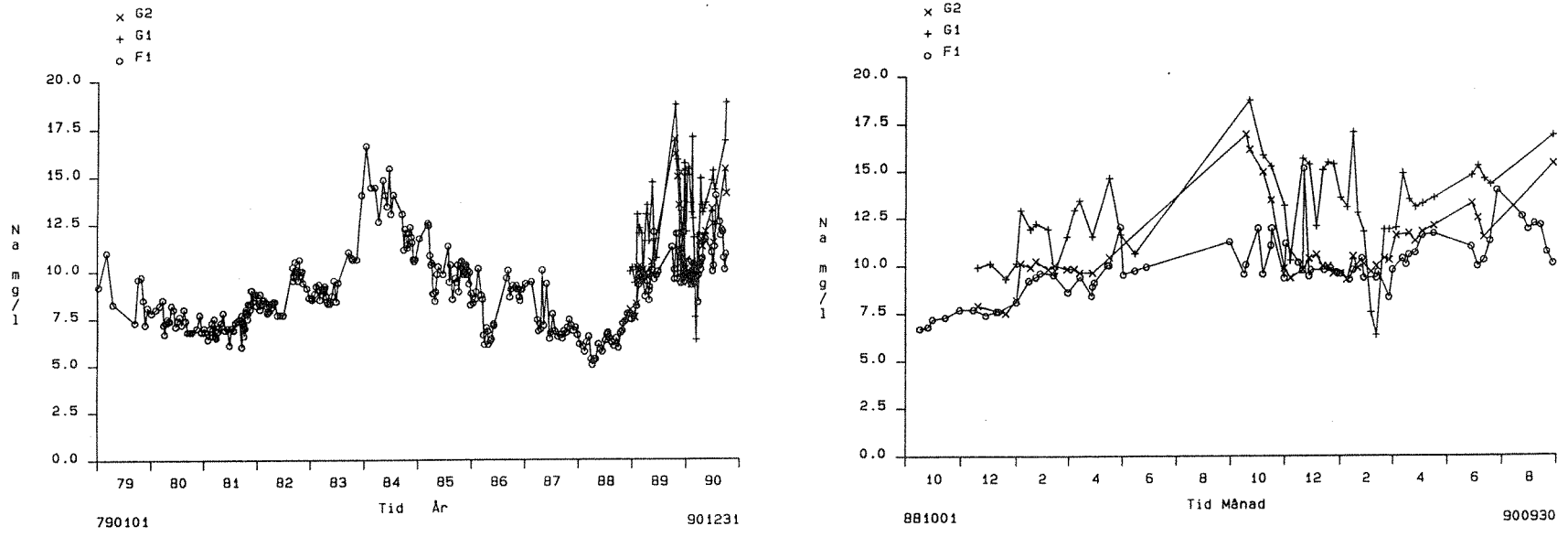


Figure 3.1.5. Na in mg/l.

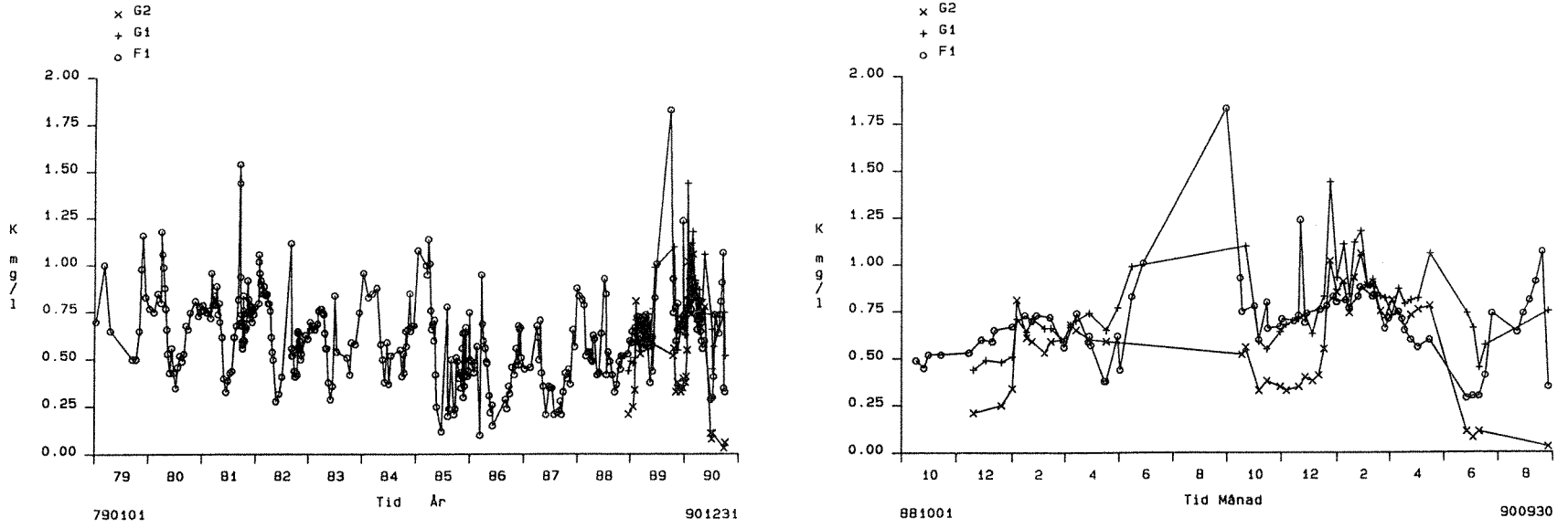


Figure 3.1.6. K in mg/l.

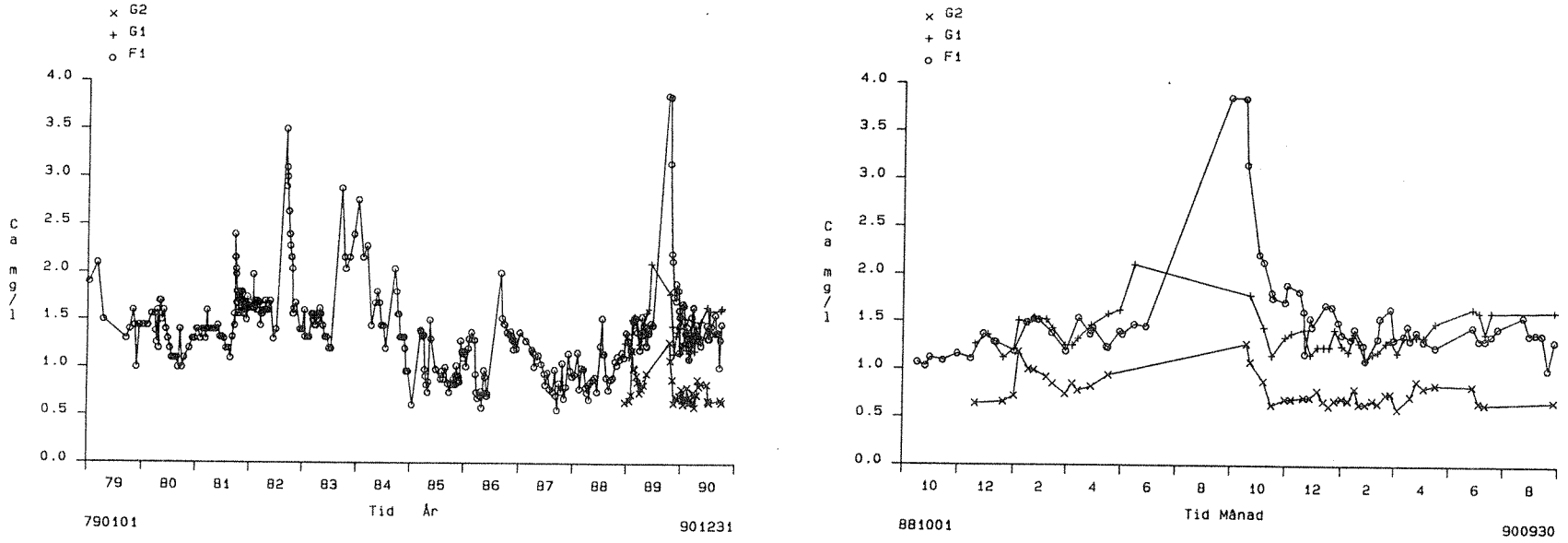


Figure 3.1.7. Ca in mg/l.

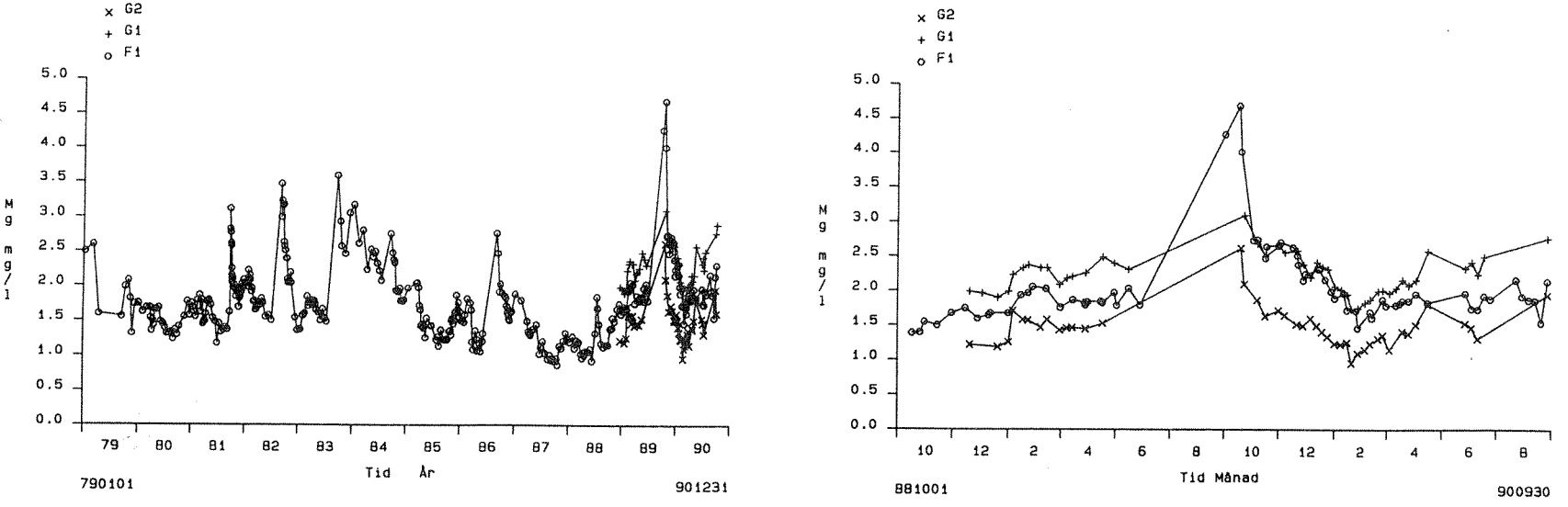
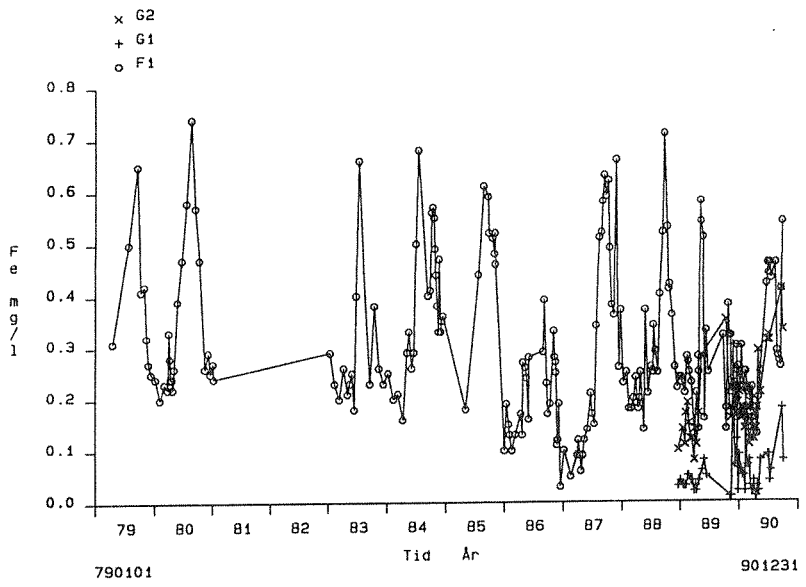


Figure 3.1.8. Mg in mg/l.



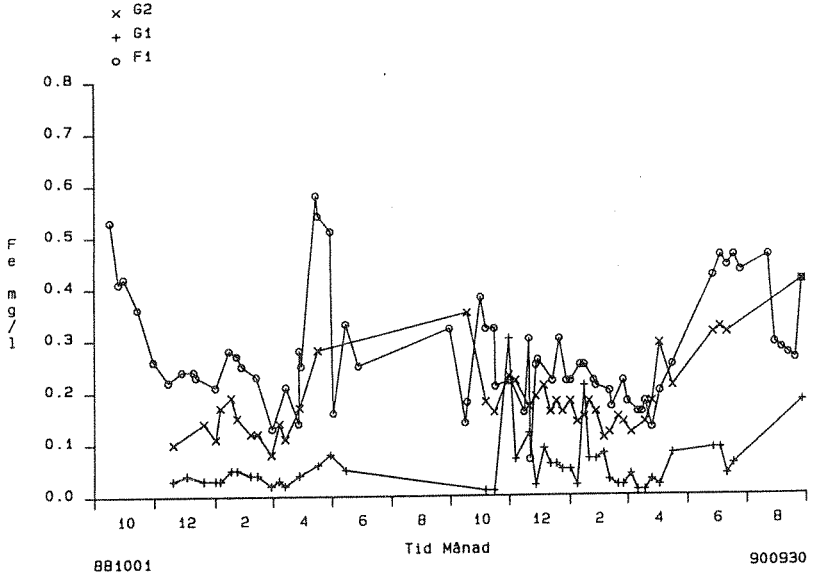
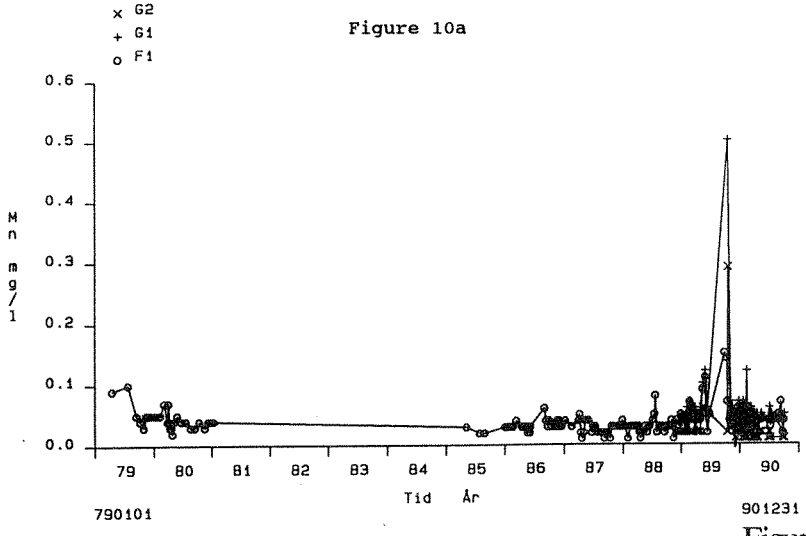


Figure 3.1.9. Fe in mg/l.



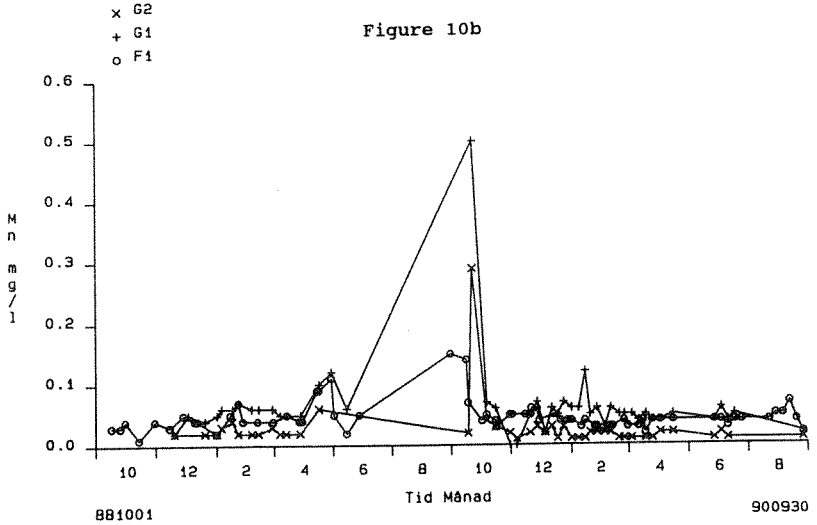


Figure 3.1.10. Mn in mg/l.

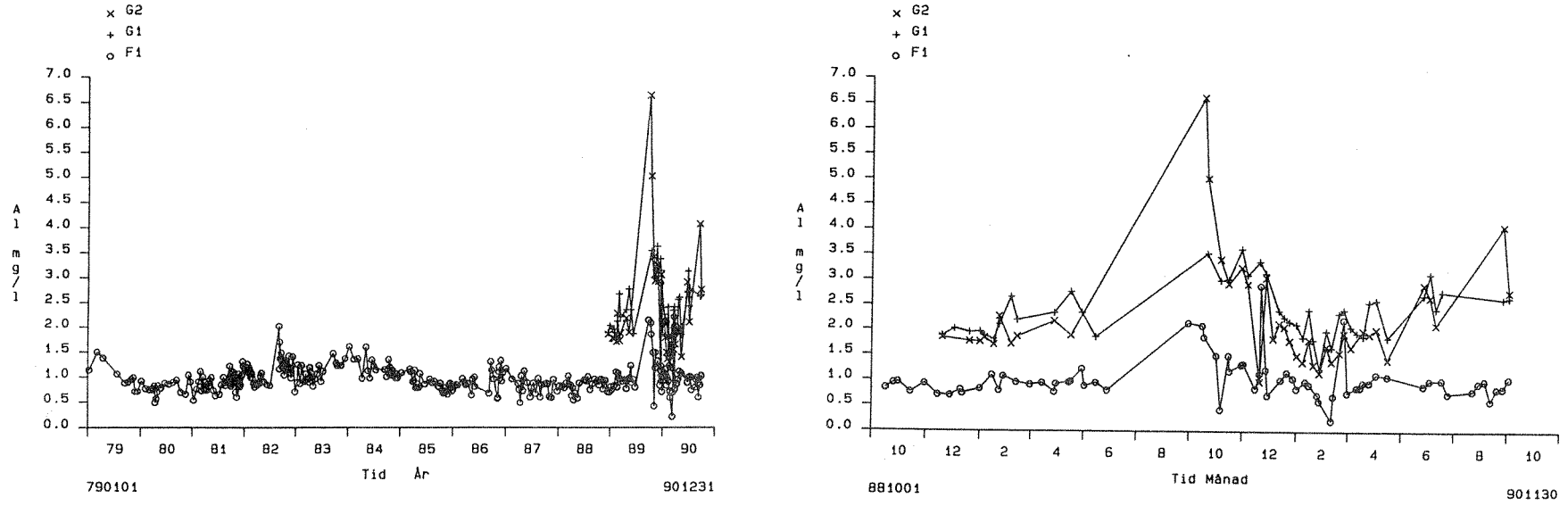


Figure 3.1.11. Al in mg/l.

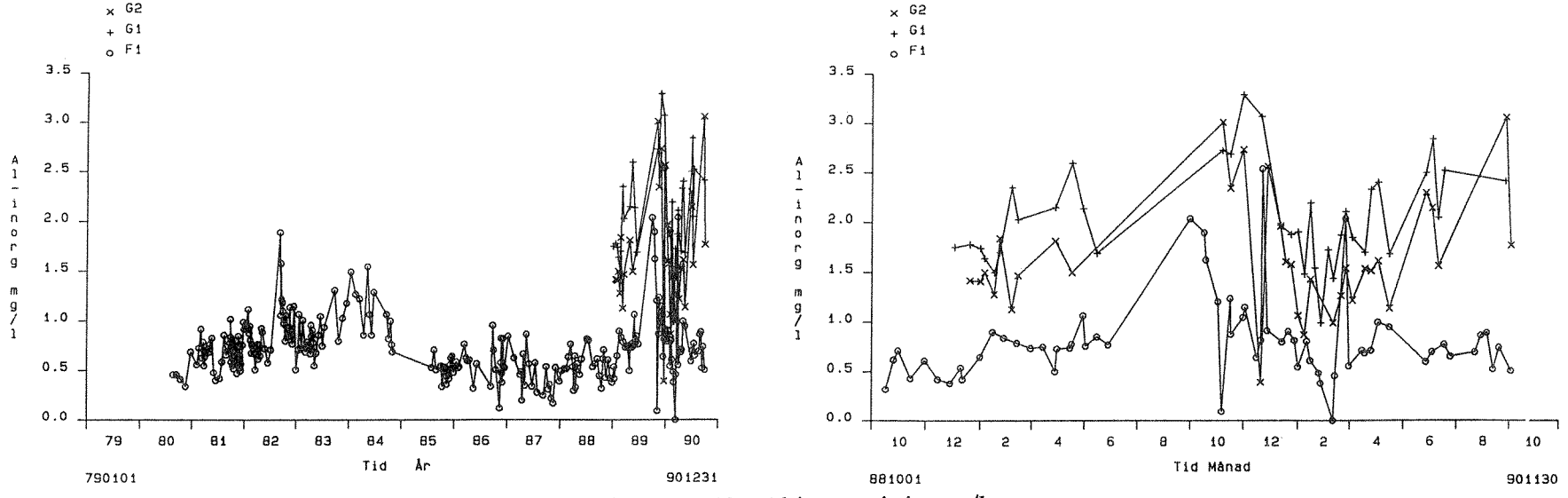


Figure 3.1.12. Al-inorganic in mg/l.

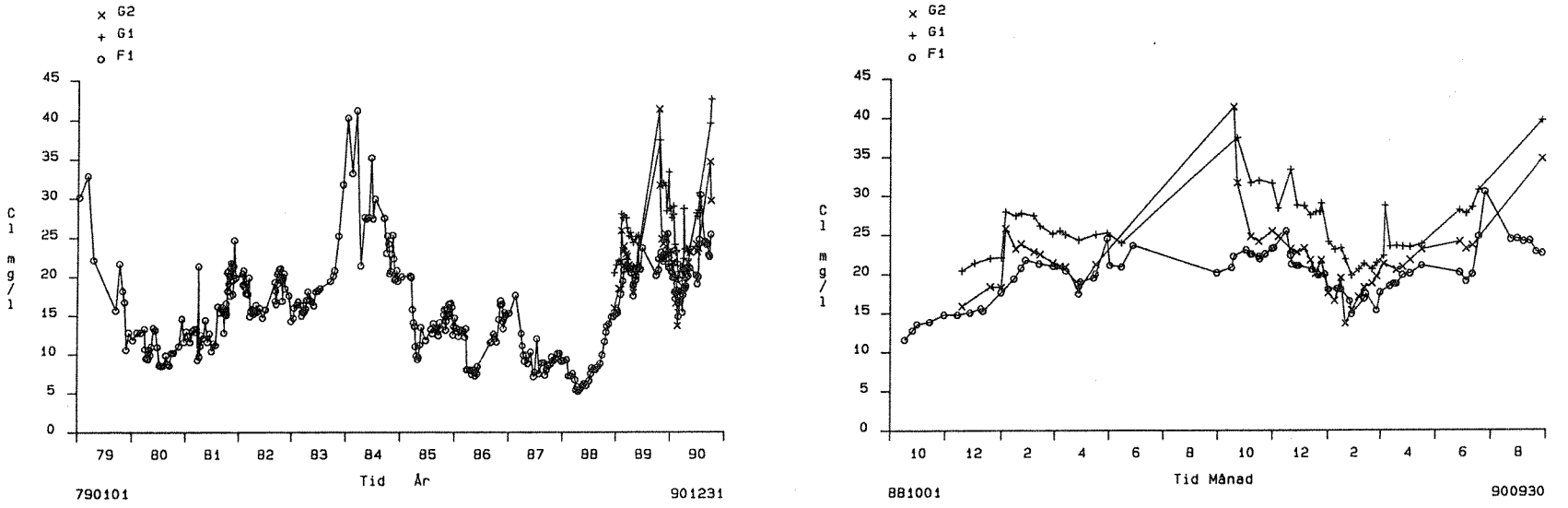


Figure 3.1.13. Cl in mg/l.

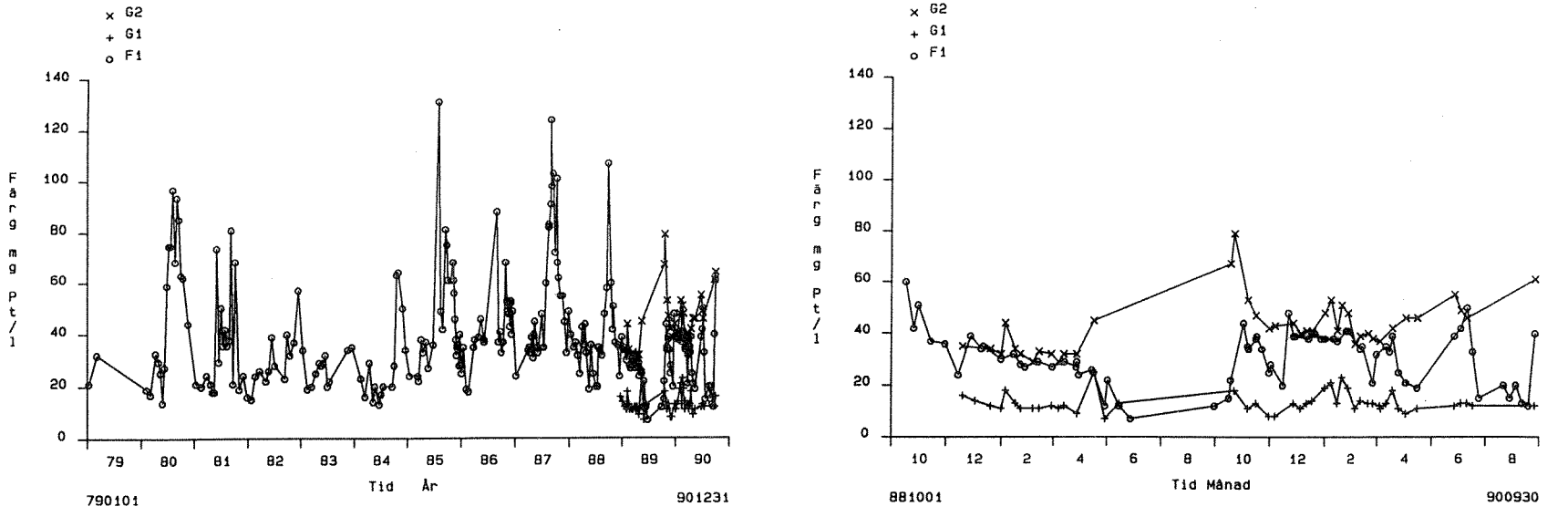


Figure 3.1.14. Colour in mg Pt/l.

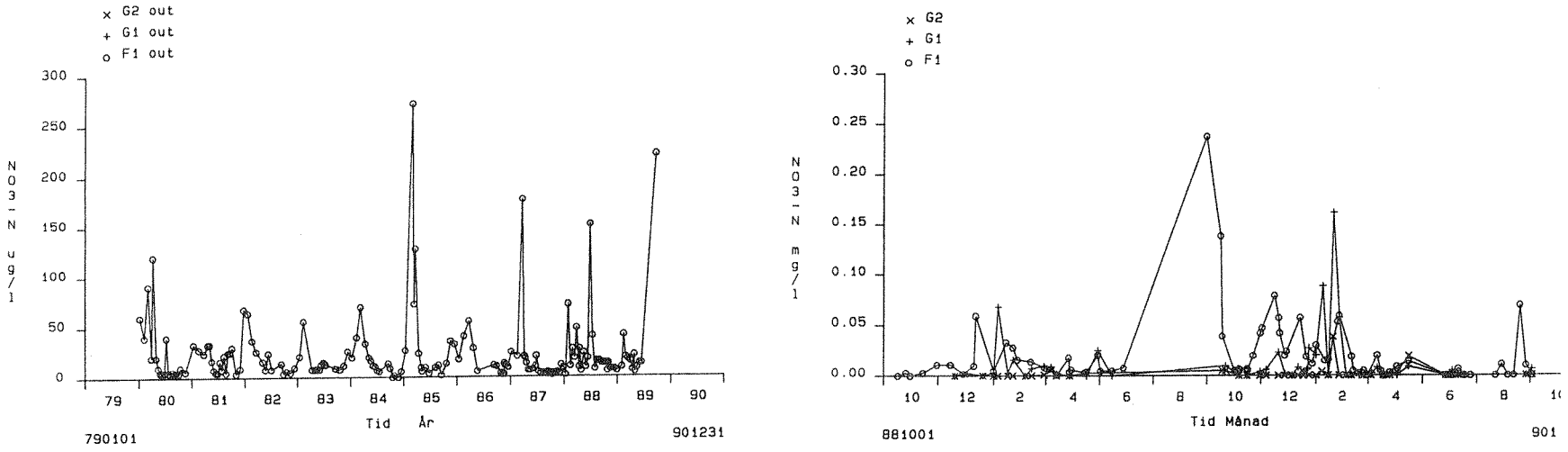


Figure 3.1.15. NO3-N in a) ug/l and in b) mg/l.

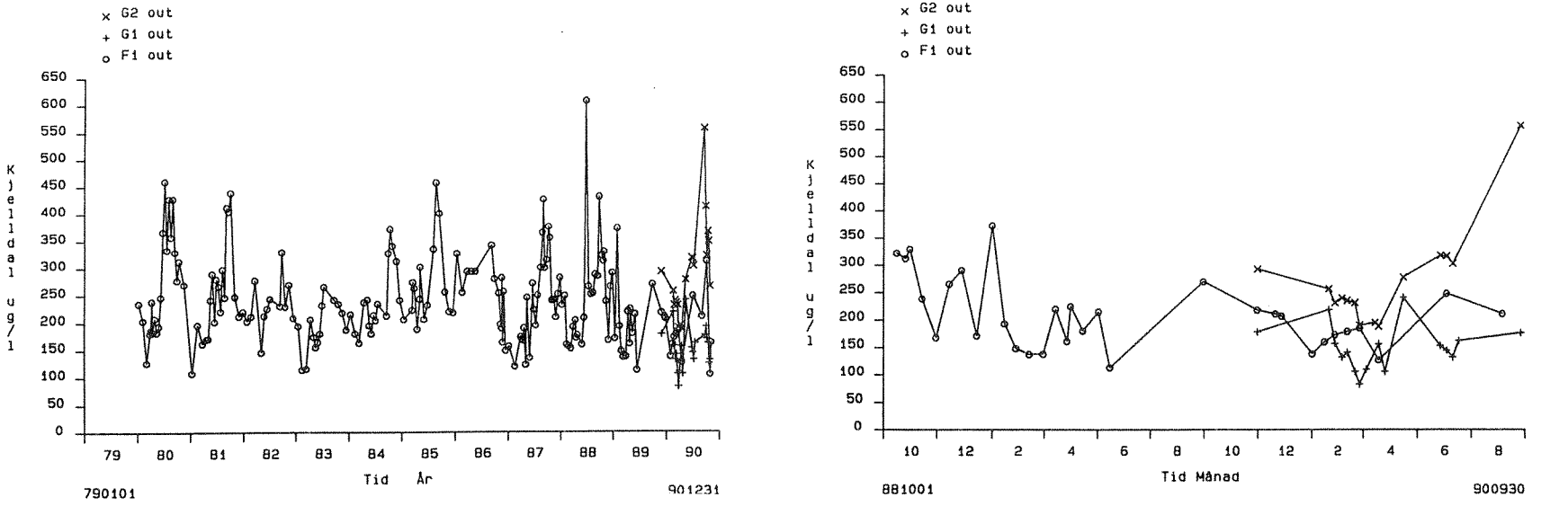


Figure 3.1.16. Kjelldahl-N i ug/l.

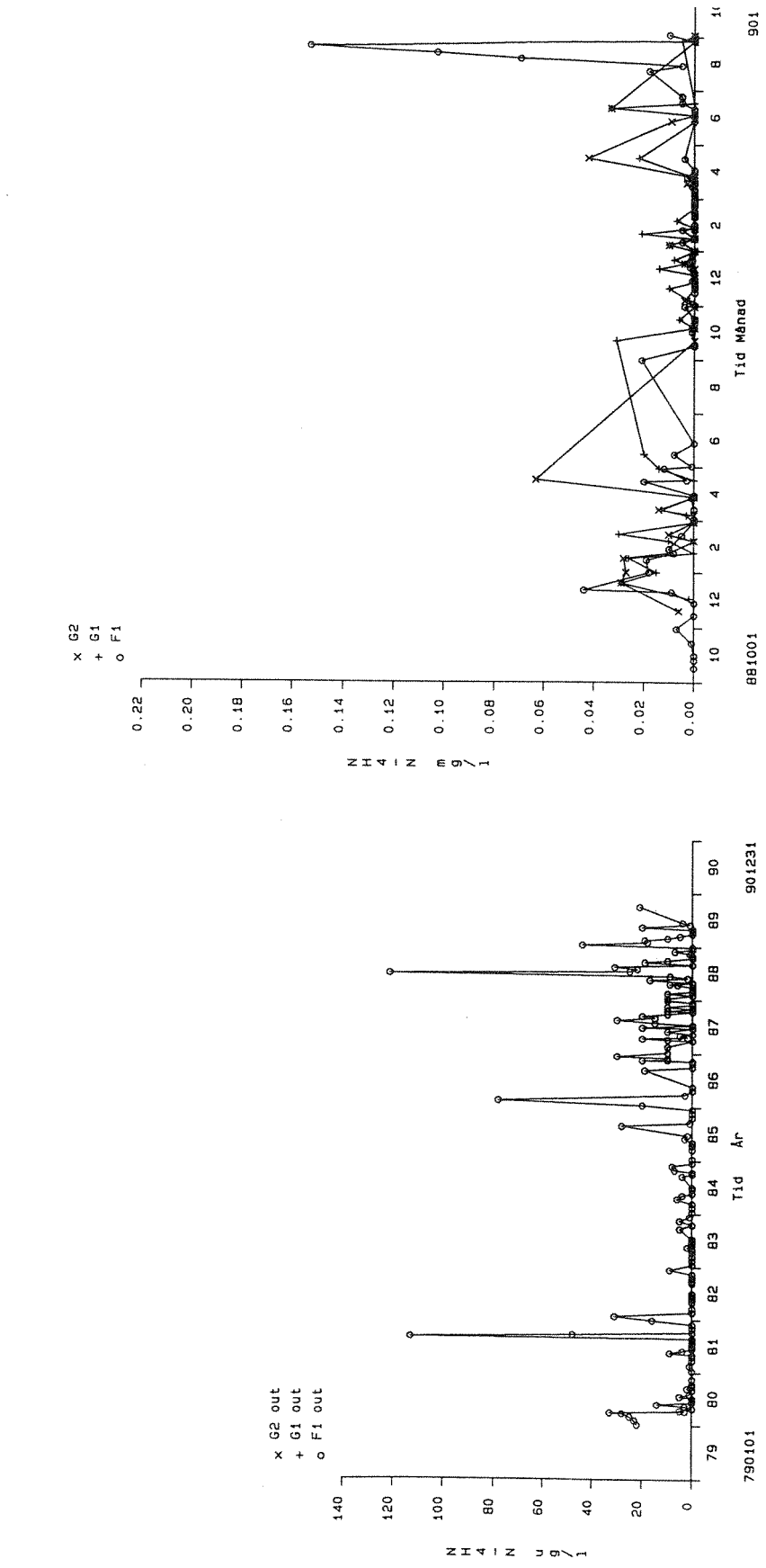
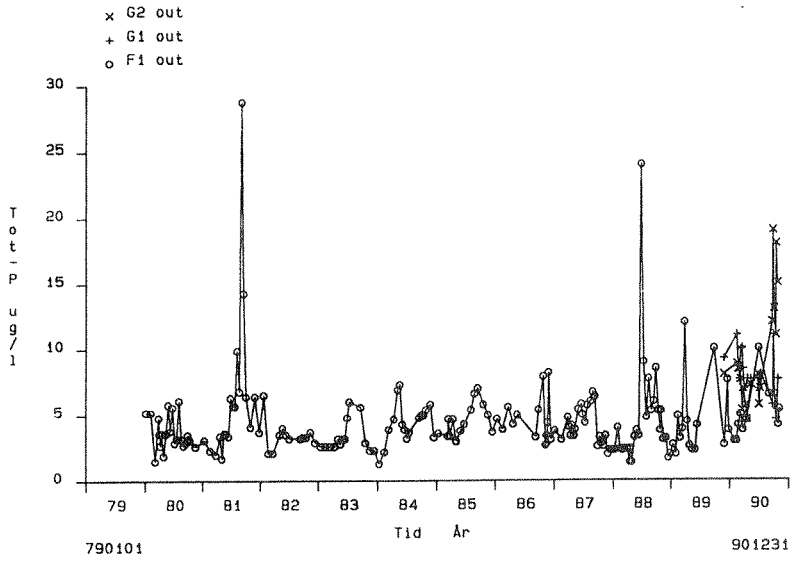


Figure 3.1.17. NH4-N in a) ug/l and in b) mg/l.



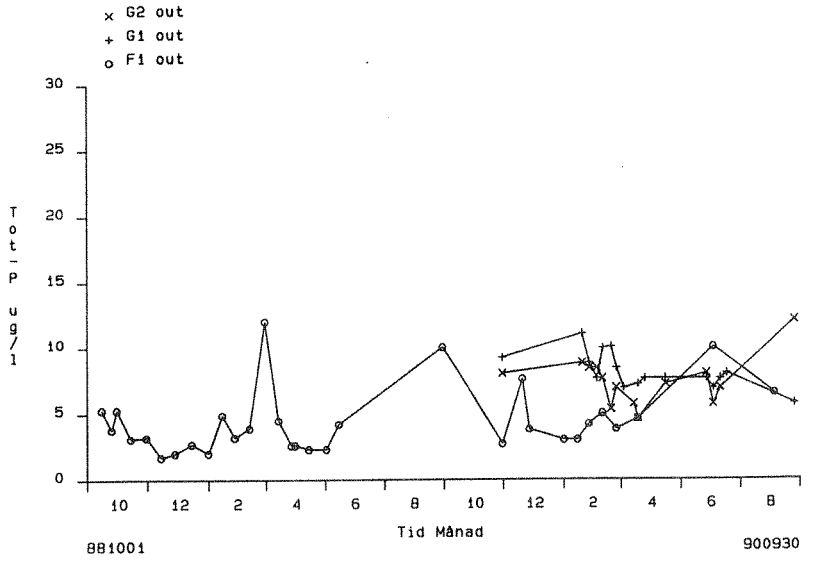
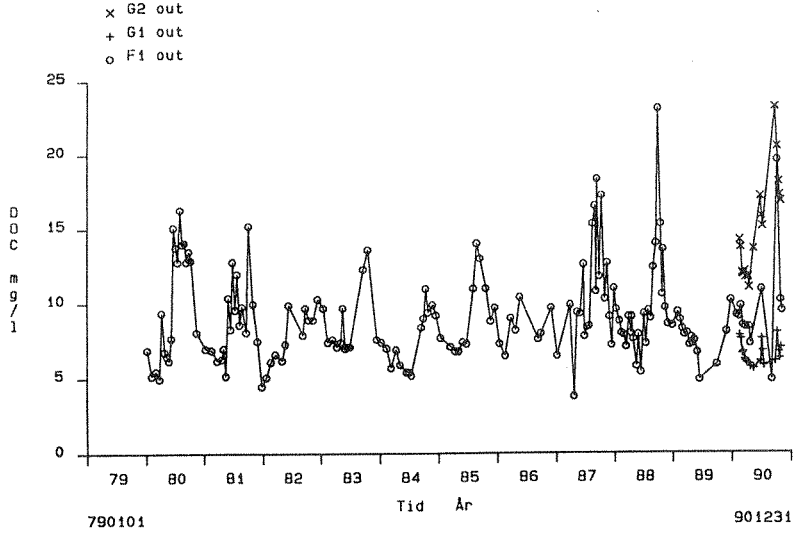


Figure 3.1.18. P-total in ug/l.



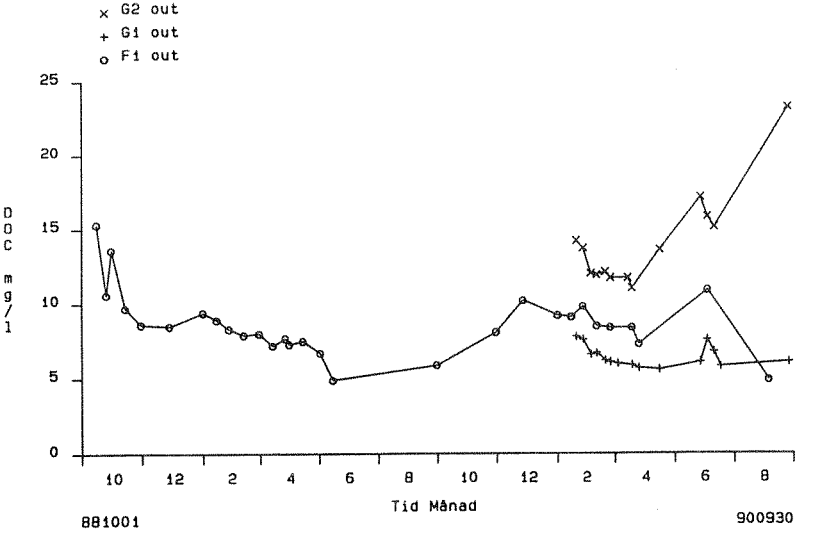


Figure 3.1.19. DOC in mg/l.

3.2. Vegetation, soil and soil solution.

Janne Kjønaas and Arne O. Stuanes, NISK

Work began in 1989 at all three catchments (G2-NITREX, G1-roof and F1-control). Sampling of each component began in 1990 such that at least 1 year of background data will be available prior to beginning of treatment in April 1991. Our investigations encompass: soil, soil water, vegetation, trees, needles, litter and mineralization. (Figures 3.2.1, 3.2.2).

Soil mapping: Soil samples were collected from a grid system, every 5 x 10 m for the humus layer and 10 x 10 m for the mineral soil. A preliminary survey has been conducted to prepare a rough soil map, with thorough profile descriptions made for each soil type. The samples are now being analyzed.

Soil water: Lysimeters were installed in February1990 in each of 3 different vegetation types in G2, G1 and F1 (Figure 2.2).

In G2 90 lysimeters are located in seven lysimeter plots, four with constant suction and three for episodic studies. The lysimeters are mainly at 5, 10, 20, 40 and 70 cm depth, with 2-3 lysimeters at each depth. For control of two of the vegetation types two lysimeter plots were established in both G1 and F1. Water samples for chemical analysis are collected twice a month.

Ground vegetation: Vegetation analysis is carried out at several locations spanning the natural moisture gradient. The analysis will be repeated regularly to record vegetation changes due to treatments.

Trees: The diameter and height of all trees in G2 and G1 have been measured. Standard forest decline parameters such as crown density and color were assessed for about 100 trees in G1 and G2 and 10 trees in F1.

Needles: Needles were collected in March 1990 by gathering the 7th and 15th branch from 6 trees per vegetation type. Altogether 42 trees in G2, G1 and F1 were sampled. The needles were sorted into current-year needles, previous-year needles, and "rest" for every branch, and the samples are ready for analysis.

Litterfall: Litter is collected every month by IVL and sorted by NISK. The samples of G2 will be sorted according to vegetation and soil type; analysis will begin when the results from the soil sampling are available.

Mineralization: Temperature measurements for air and several soil depths began in February 1990. In situ mineralization experiments began 1 July 1990 using soil cores and resin bags installed at approximatly 2-month intervals. The mineralization plots, lysimeters, and the fine-root plots (studied by SLU) have been coordinated to ensure optimal data compatibility.

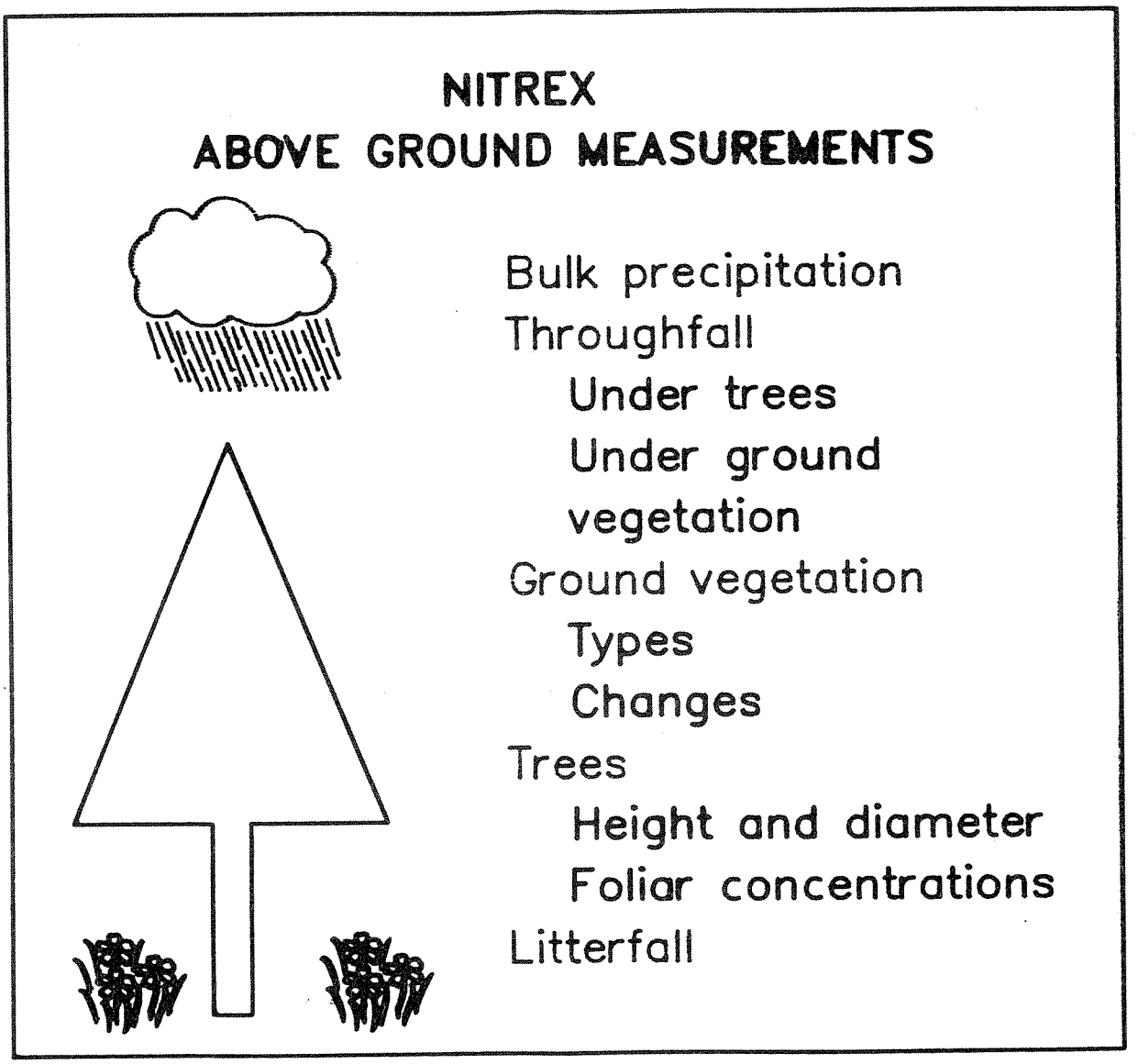

NITREX
ABOVE GROUND MEASUREMENTS
Bulk precipitation
Throughfall
Under trees
Under ground vegetation
Ground vegetation
Types
Changes
Trees
Height and diameter
Foliar concentrations
Litterfall

Figure 3.2.1.

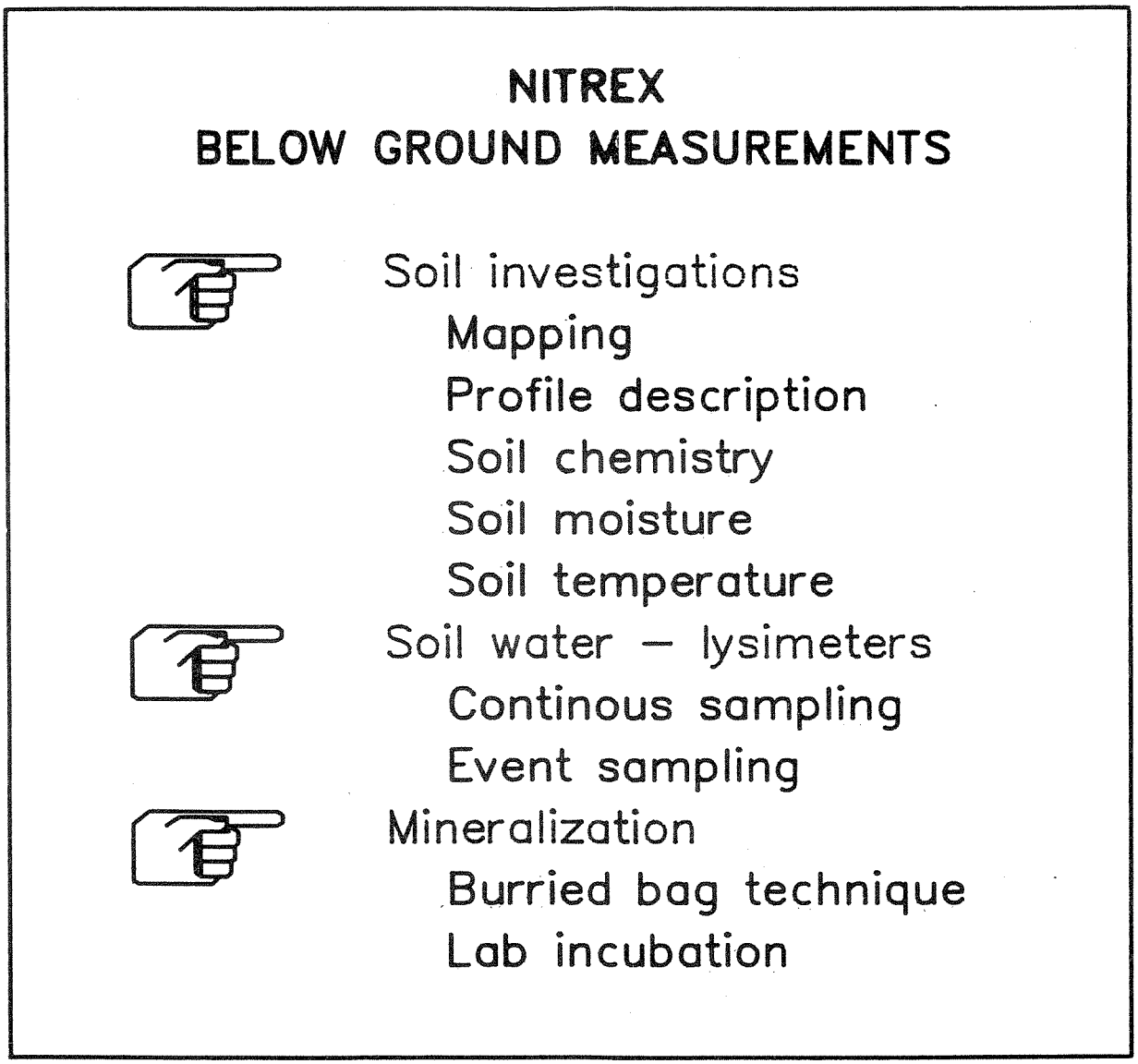

NITREX
BELOW GROUND MEASUREMENTS
Soil investigations
Mapping
Profile description
Soil chemistry
Soil moisture
Soil temperature
Soil water – lysimeters
Continous sampling
Event sampling
Mineralization
Burried bag technique
Lab incubation

Figure 3.2.2.

3.3. Soil Hydrology

Isabel Wohlfeil, NIVA, and Dirk Müller, SI

The objective of soil hydrology investigations at the NITREX site at Gårdsjön is to identify which soil solution fractions (as sampled by the lysimeters) potentially contribute to runoff under different hydrologic conditions. To this end early summer 1989 18 tensiometers were installed at various depths between 20 and 75 cm by the Institute of Soil Science and Forest Nutrition, University of Göttingen (IFBW). (Figure 2.2). The tensiometers contain a transducer system for the measurement of matrix potential. The system is connected to a portable computer and records at a frequency of every 15 minutes. Under unsaturated conditions the tensiometers show a negative potential, whereas under saturated conditions the signal is positive (Figure 3.3.1.).

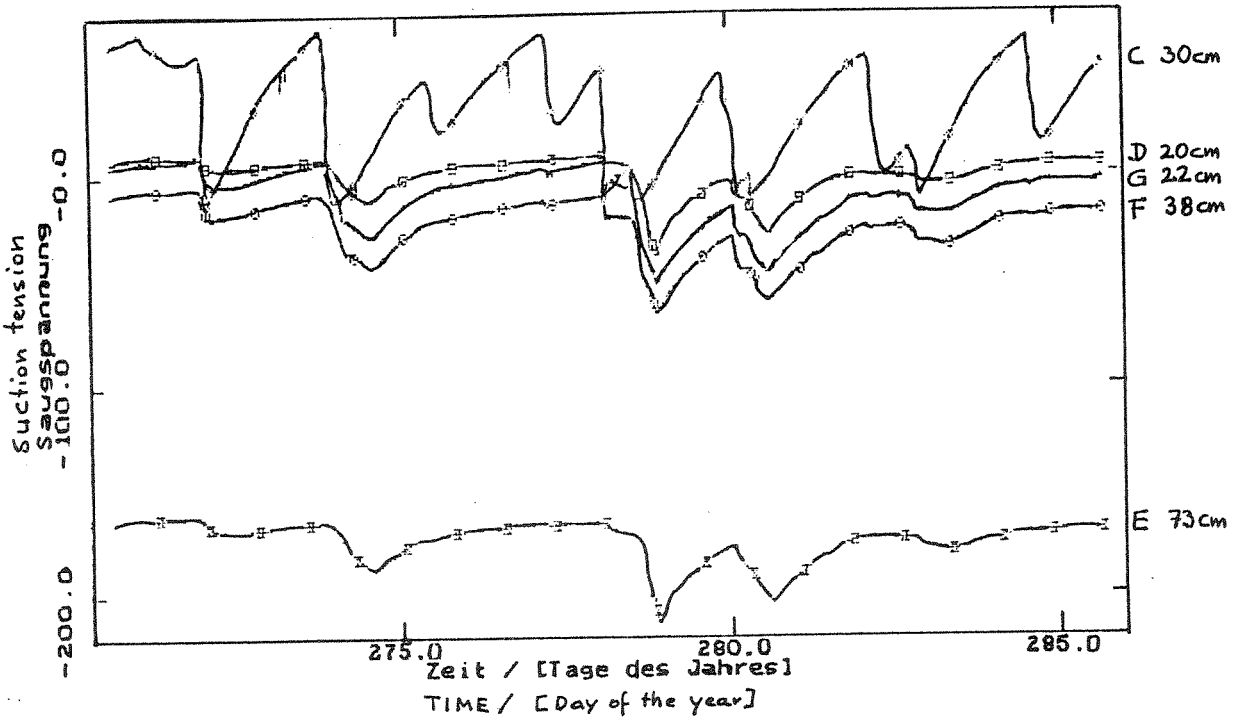


Figure 3.3.1. Absolute soil moisture tension recorded 28 September to 13. October at the NITREX site Gårdsjøn.

The Swedish Environmental Research Institute (IVL) is in charge of the maintenance of the whole system. From October 1990 on the IFBW Göttingen (Isabel Wohlfeil and Dirk Müller) have taken responsibility to assess the recorded output. So far the recording system is not connected to the modem system that is available for the whole catchment.

The data for several episodes will be used to calibrate a two-dimensional hydrologic model (Hauhs, 1986). Decisions will then be made regarding placement of the tensiometers within the catchment.

The hydrologic model requires knowledge about topography, soil thickness, discharge, precipitation rates, pF- and conductivity curves and evapotranspiration. Evapotranspiration is calculated from climatic data for windspeed, global radiation, precipitation and fine-root biomass. The model is based on a numerical solution of the instationary flow equation that is derived from a finite-element approach. The application enables the calculation of saturated and unsaturated flow through the rooting zone.

3.4. Root and Rhizosphere Studies

Anna Clemensson-Lindell and Hans Persson, SLU

The objective of the fine root studies is to document changes in fine root growth and abundance due to increased deposition of nitrogen.

Work started March 1990 in the NITREX-project at Gårdsjön. Soils were sampled and the first ingrowth cores were installed into the soil. The soil cores were taken close to the NISK lysimeters, in order to enable a comparison between results. These are located in each of the 3 vegetation types (Figure 2.2).

In each area 20 4.5-cm diameter soil cores were taken to a depth of about 30 cm, with sufficient space left between the holes for subsequent sampling. An ingrowth core, viz. a nylon net filled with perlite, was installed in each hole.

The second sampling was carried out in October 1990. Soil coring and installation of ingrowth cores were repeated in the same way as before. This time, however, only the dry and the medium moisture gradients were sampled, since in the wet area the soil consists mainly of organic material. This made a total of 40 soil cores and 40 ingrowth cores in the NITREX catchment on each sampling occasion.

We have started sorting and processing the soil cores. In the field each soil core is divided into the different horizon layers, A_0 and B; the LH-layer was divided into 5-cm slices. The roots are picked out from each layer, and the rhizosphere soil separated from the roots by gentle brushing (from the mineral soil layers). The rhizosphere soil and the bulk soil is collected for further extraction and analyses. A soil sample is also taken from each horizon for measurement of the moisture content.

The roots are sorted into live and dead in different diameter classes. The length and the dry weight is measured. A stereo microscope (x4-x40) is used to separate the roots into different damage classes.

There will be a new round of soil core sampling in October 1991. Again 40 soil cores will be taken and 40 ingrowth cores installed in the holes from soil coring. A first resampling of ingrowth cores will be carried out, viz. of those which have been into the ground for two growing seasons. The holes left after the retrival of ingrowth cores will be filled with soil from the experimental area in order to avoid disturbance of the mineralization measurements.

3.5. Ectomycorrhizal Fungi

Tor Erik Brandrud, NIVA

The objective of the studies of mycorrhiza at the NITREX site at Gårdsjön is to investigate changes in abundance and vitality resulting from the experimental change in nitrogen deposition. Studies conducted in 1990 represent the pre-treatment year.

The mycorrhizal fungus flora was investigated during site visits in 1990 (ultimo July, September and primo October). The above-ground fruitbody production was recorded in 3 transects (52 5 x 5 m relevees) throughout the season (except August, due to severe drought). For the below-ground study 25 soils samples with mycorrhizal roots were collected ultimo September and primo October. The sampling is coordinated with NISK's vegetation studies and SLU's fine-root studies.

Below-ground study of mycorrhizal roots: A high density of well-developed, living mycorrhizal roots was found in the raw humus (mor) layer, normally ranging from ca. 100 to 225 ectomycorrhizal root tips per cm^3 at the surface (0-1 cm depth) and ca. 60 to ca. 180 mycorrhizae just below (1-2 cm depth) (Table 3.5.1). The two sampled plots with dominance of Vaccinium myrtillus- and Dicranum majus vegetation, respectively, did not differ significantly.

The frequency of inactive/dead mycorrhizal roots showed a much higher degree of variation, from near absence to as many as160 root tips per cm^3. A clear vertical gradient was found in the material; while the mycorrhizal roots at surface often were nearly 100 % live and healthy, at 1-2 cm depth the inactive/death mycorrhiza normally increased by a factor of 2-5.

The numbers of dead/inactive mycorrhizae were considerably higher in the moss-dominated than in the blueberry-dominated area (Table 3.5.1), and this may indicate some root damages in this area due to drought or acidification. Generally, the gradient in mycorrhizal vitality from surface and down in the humus layer seems not to be typical (at least not so pronounced) in normal raw humus (Mikola & Laiho 1962), and may be an indication of unhealthy conditions. On the other hand, the total number of vital mycorrhizae in the humus of the NITREX site was very high, even higher than most other published counts from raw humus. Generally, this soil type possesses a higher density of mycorrhizae than normally found in other kinds of forest soil.

The ratio between well-developed and dead/inactive mycorrhizae is often used as an indication of the vitality of the symbiotic system. At Gårdsjön this ratio varies from 7.5 in the root mat at surface to 1.4 in the subsurface layer. The latter is probably most representative for the humus layer as a whole, and is also comparable with the values obtained from raw humus at Åmli, southernmost Norway, where this ratio is 2.0; the value decreased to 0. 9 after treatment with acid rain (Olsen 1986).

The vital mycorrhizae were classified into four broad categories, based on color and development of external mycelium. Mycorrhizae with well-developed external mycelium increased the root surface considerably, and are regarded as the most efficient type for nutrient uptake by the roots. The major category of mycorrhizae with external mycelium (white, cottony) includes a wide range of fruitbody producing species (such as species of the genus Cortinarius), and is also frequently accepted as an

indicator group of healthy, undisturbed conditions (Olsen 1986). At Gårdsjön the white external mycelium mycorrhizae constituted on the average ca. 25% of the living mycorrhizal roots both in the moss-dominated and blueberry-dominated area (Table 3.5.1). However, these numbers are for the thin root mat at humus surface; below this the portion of the white external mycelium mycorrhiza was considerably lower (on the average ca. 5%).

The black Cenococcum mycorrhiza, a monotypic category (includes solely one species), is often regarded as an indicator of stress, and is particularly adapted to temporarly drought. This species is also, according to literature, less dependent on symbiosis, and often occupies older and less vital short roots. It may thus be regarded as an indication of less vital and less efficient mycorrhiza. Cenococcum constituted about one third of the living mycorrhizae at Gårdsjön, and was fairly similarly developed in the moss-dominated and blue-berry-dominated area. This percentage is somewhat higher than normal for raw humus acccording to the standards from Finland (Mikola & Laiho 1962), which may indicate that the investigated surface layer of the humus is subject to some periodical drought.

Above ground study of fruitbody production: The fungus season was estimated to be slightly less than average yield in 1990, due to the extensive drought in August. The results from the above-ground study can to some extent be used to evaluate the richness and composition of the mycorrhizal fungus flora, but not so much its productivity potential. A total of 67 species were recorded (Table 3.5.2), of which especially three species (complexes) dominated; Cortinarius obtusus coll. (859 fruitbodies recorded), Cantharellus tubaeformis (471 frb.) and Lactarius camphoratus (206 frb.), the latter mainly in moister areas. Of these species, the C. obtusus-complex (especially the most frequent variety acutus) is regarded to be favoured by acidification (Høiland 1986); this applies possibly also for L. camphoratus.

At the genus level, the following groups were the most abundant in the plots; Cortinarius (22 species), Russula (11) and Lactarius (6). The genus Cortinarius comprised as much as 37% of the species recorded. However, this huge genus and major contributor to the mycorrhizal category having white, cottony external mycelium, normally comprises 50-60% of the mycorrhizal flora in oligotrophic spruce forests (Brandrud 1988). Thirty-seven percent is thus a remarkably low number. This low number may be explained by the abnormal, periodically very dry season of 1990, or by climatic gradients in this particular forest type, but may also be used as an indication of acidification. A high diversity of Cortinarius is, although some species may be acid-tolerant, regarded as a typical trait of undisturbed, virgin systems (Brandrud 1988). A high percentage of genera with smooth surface mycorrhiza (Lactarius + Russula; at Gårdsjön 28 %, normally ca. 20 %) may be an indication of a less healthy system.

The total species diversity, as a measure of the vitality of the system, may be compared with a series of studies which recently have been carried out along an acidification gradient from Høylandet, central Norway (undisturbed), Gjerstad, southernmost Norway (moderately polluted), to Schwarzwald, Germany (heavily polluted) (Gulden et al. in press). When the results from each year in these studies are compared, the diversity at Gårdsjön scores higher than that of a moderately good/fairly good season in Schwarzwald, and the Gårdsjön numbers seem most comparable with a moderate season at Gjerstad (Figure 3.5.1).

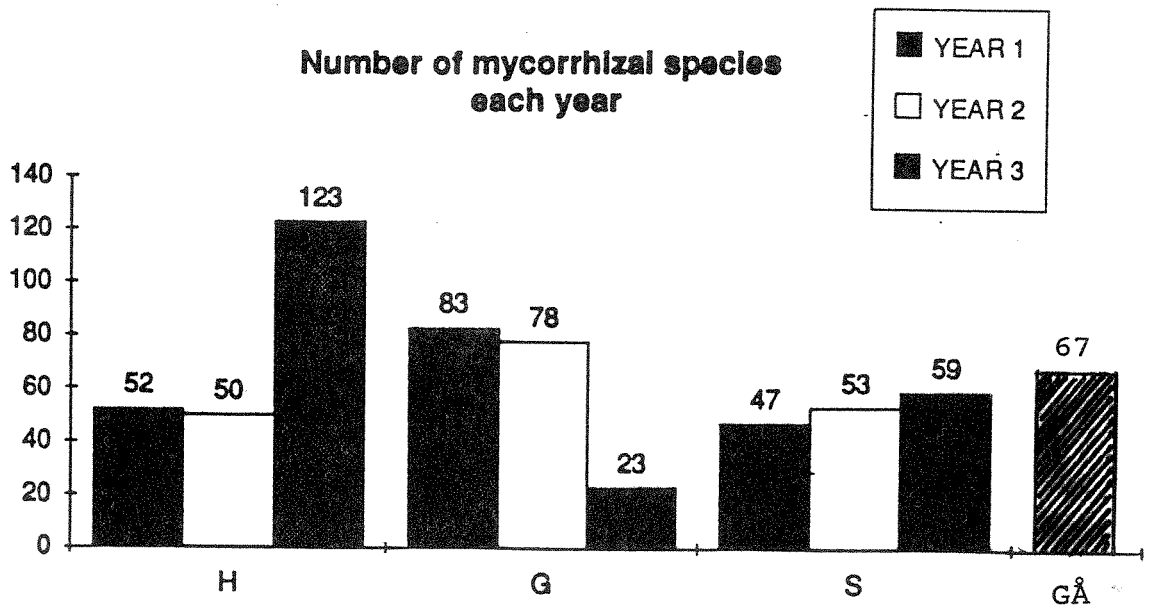


Figure 3.5.1. Number of mycorrhizal species in three different years at Høylandet, central Norway (H); Gjerstad, southernmost Norway (G) and Schwarzwald, Germany (S), compared with the numbers from Gårdsjön (Gå) 1990. The Høylandet-Gjerstad-Schwarzwald results are from Gulden et al. (in press)

Table 3.5.1. Numbers of active and inactive mycorrhizal root tips per 3 cm^3, in raw humus at the NITREX site, Gårdsjön Sept./Oct. 1990.
A = surface layer (0-1 cm depth). B = subsurface layer (1-2 cm).
Y80-Y95/X55-X75 = Dicranum majus-dominated plots
Y55-Y80/X20-X30 = Vacinium myrtillus-dominated plots

		Y80 X60	Y80 X65	Y85 X60	Y85 X65	Y85 X70	Y90 X55	Y90 X60	Y90 X65	Y90 X70	Y90 X75	Y95 X70	Y55 X20	Y65 X25	Y65 X30	Y70 X25	Y70 X30	Y75 X25	Y75 X30	Y80 X25	Y80 X30	AVERAGE	AVERAGE Per cm^3
external mycelium	A	205	43	22	111	158	128	100	145	287	126	91	36	68	171	210	145	35	243	48	96	123,4	41,1
mycorrhiza, white	B	8	2		35	39				21			11	0	46							20,3	6,8
Piloderma	A	0	0	0	0	12	48	0	0	0	7	0	0	0	0	0	0	0	0	104	0	8,6	2,9
(yellow)	B	36	2		9	1				5			4	0	0							7,1	2,4
Cenococcum	A	187	121	235	341	258	107	149	196	143	82	159	196	90	470	50	108	87	51	0	154	159,2	53,1
(black)	B	145	97		224	136				284			144	45	240							164,4	54,8
mycorrhiza with	A	86	375	40	223	182	137	119	186	245	278	156	199	190	429	81	101	564	165	391	409	227,8	75,9
smooth surface	B	51	86		104	65				223			292	513	411							218,1	72,7
TOTAL vital myc.	A	478	538	296	675	610	420	368	527	675	493	406	431	348	1020	341	354	686	459	543	659	516,5	172,2
TOTAL v.m.per cm3	A	159	180	99	225	203	160	123	176	225	164	135	144	116	340	114	118	229	153	181	220	172,2	172,2
TOTAL v.m.	B	240	187		372	241				533			451	558	651							404,1	134,7
TOTAL v.m.per cm3	B	80	62		124	80				178			150	186	217							134,7	134,7
inactiv/dead myc.	A	84	98	161	84	167	130	77	179	82	219	61	18	0	0	8	0	55	5	53	3	69,2	23,1
inactiv/dead myc.	B	387	475		289	316				490			99	158	64							284,8	94,9

Table 3.5.2. Mycorrhizal species recorded at the NITREX site, Gårdsjön 1990. The total number of fruitbodies recorded is indicated in the right column. The left column indicates the frequency, given as percent occurence in the 52 plots.

	FREKV.	MIDDEL	MAKS.	MIN.	SD	SUM
Amanita erubescens	5,77	2	3	1	1	6
Amanita fulva	7,69	1,5	2	1	0,58	6
Amanita porphyria	7,69	1,25	2	1	0,5	5
Amanita virosa	11,54	2,17	3	1	0,75	13
Boletus edulis	1,92	1	1	1	****	1
Boletus pinicola	1,92	2	2	2	****	2
Cantharellus tubaeformis	25	36,23	145	1	46,68	471
Chalciporus piperatus	1,92	1	1	1	****	1
Cortinarius albovariegatus	3,85	22,5	42	3	27,58	45
Cortinarius biformis	11,54	1,67	3	1	0,82	10
Cortinarius cinnamomeus	1,92	1	1	1	****	1
Cortinarius croceus	7,69	1,25	2	1	0,5	5
Cortinarius evernius	1,92	2	2	2	****	2
Cortinarius flos-paludis	1,92	1	1	1	****	1
Cortinarius gentilis	3,85	2	3	1	1,41	4
Cortinarius limonius	3,85	4,5	6	3	2,12	9
Cortinarius mucifluus coll	13,46	1,57	2	1	0,53	11
Cortinarius obtusus	50	6	39	1	7,65	156
Cortinarius obtusus v. acutus	69,23	19,53	94	1	22,86	703
Cortinarius orellanoides	1,92	1	1	1	****	1
Cortinarius paleaceus	32,69	3,41	9	1	2,62	58
Cortinarius paleifer	1,92	2	2	2	****	2
Cortinarius pluviorum	1,92	3	3	3	****	3
Cortinarius sanguineus	5,77	2,33	4	1	1,53	7
Cortinarius scaurus	1,92	2	2	2	****	2
Cortinarius semisanguineus	3,85	1	1	1	0	2
Cortinarius stillatitius	3,85	1	1	1	0	2
Cortinarius strobilaceus	23,08	2,75	9	1	2,3	33
Cortinarius tortuosus	1,92	1	1	1	****	1
Cortinarius vibratilis coll	7,69	1,75	3	1	0,96	7
Elaphomyces sp	1,92	2	2	2	****	2
Entoloma cetratum	19,23	1,7	4	1	1,16	17
Entoloma conferendum	3,85	1	1	1	0	2
Entoloma turbidum	17,31	1,78	5	1	1,39	16
Hebeloma longicaudum	13,46	2,86	8	1	2,67	20
Hygrophorus camarophyllus	3,85	5	9	1	5,66	10
Hygrophorus olivaceoalbus	32,69	2,18	5	1	1,47	37
Inocybe lanuginosa coll	1,92	2	2	2	****	2
Inocybe napipes	1,92	1	1	1	****	1
Inocybe relicina	5,77	5,67	7	3	2,31	17
Laccaria amethystea	9,62	3,2	7	2	2,17	16
Laccaria laccata coll	7,69	18	54	1	24,29	72
Lactarius camphoratus	11,54	34,33	78	1	30,43	206
Lactarius glyciosmus	1,92	1	1	1	****	1
Lactarius helvus	34,62	3,56	8	1	2,64	64
Lactarius rufus	26,92	3,29	14	1	3,79	46
Lactarius sphagneti	3,85	2,5	3	2	0,71	5
Lactarius theiogalus	1,92	42	42	42	****	42
Leccinum scabrum	1,92	2	2	2	****	2
Paxillus involutus	11,54	2,67	5	1	1,63	16
Rozites caperatus	3,85	1,5	2	1	0,71	3
Russula aquosa	5,77	1,33	2	1	0,58	4
Russula atrorubens	5,77	1,33	2	1	0,58	4
Russula betularum	3,85	8	12	4	5,66	16
Russula decolorans	19,23	1,8	4	1	0,92	18
Russula emetica	13,46	1,57	2	1	0,53	11
Russula fragilis	9,62	4,6	7	1	2,19	23
Russula ochroleuca	3,85	4,5	5	4	0,71	9
Russula paludosa	3,85	1	1	1	0	2
Russula puellaris	1,92	1	1	1	****	1
Russula vinosa	1,92	1	1	1	****	1
Russula violacea	1,92	3	3	3	****	3
Tricholoma virgatum	1,92	1	1	1	****	1
Tylopilus felleus	15,38	1,25	3	1	0,71	10
Xerocomus badius	11,54	1,5	2	1	0,55	9

3.6 Fish Toxicity Studies

Frode Kroglund (NIVA-Sørlandet) and Ulf Carlsson (IVL)

The objective of the fish toxicity studies at the two experimental catchments G1 (roof) and G2 (NITREX) at Gårdsjön is to document changes in biological response resulting from the changed chemistry of runoff due to the treatments. Fish give an integrated response to water chemistry, and may be more sensitive to changes in water quality than straight measurements of individual chemical parameters.

Runoff from each of the two catchments is led to a series of tanks for the fish experiments (Figure 3.6.1). Each rig consists of 5 tanks and a circulation pump. Water is pumped from holding tanks which are directly connected to the outlets of the runoff tanks at the two catchments. The setup is similar to that used at the RAIN catchments at Risdalsheia, Norway. Five strains of brown trout will be used in the tests. This will eliminate vagaries of strain-dependent response. Water quality will be measured at frequent intervals during the tests. Initially tests will last for several days.

The experimental plan calls for one or more tests prior to the beginning of treatment in April 1991, and then periodic tests as the runoff chemistry begins to change as a result of nitrogen addition at the NITREX catchment and acid removal at the roofed catchment.

Preliminary results from the first test conducted in January 1991 indicate that the mortality rate was higher in runoff from the NITREX catchment than from the roofed catchment. This difference is probably due to the lower concentrations of calcium, lower pH, and higher concentrations of inorganic aluminum in runoff from the NITREX catchment.

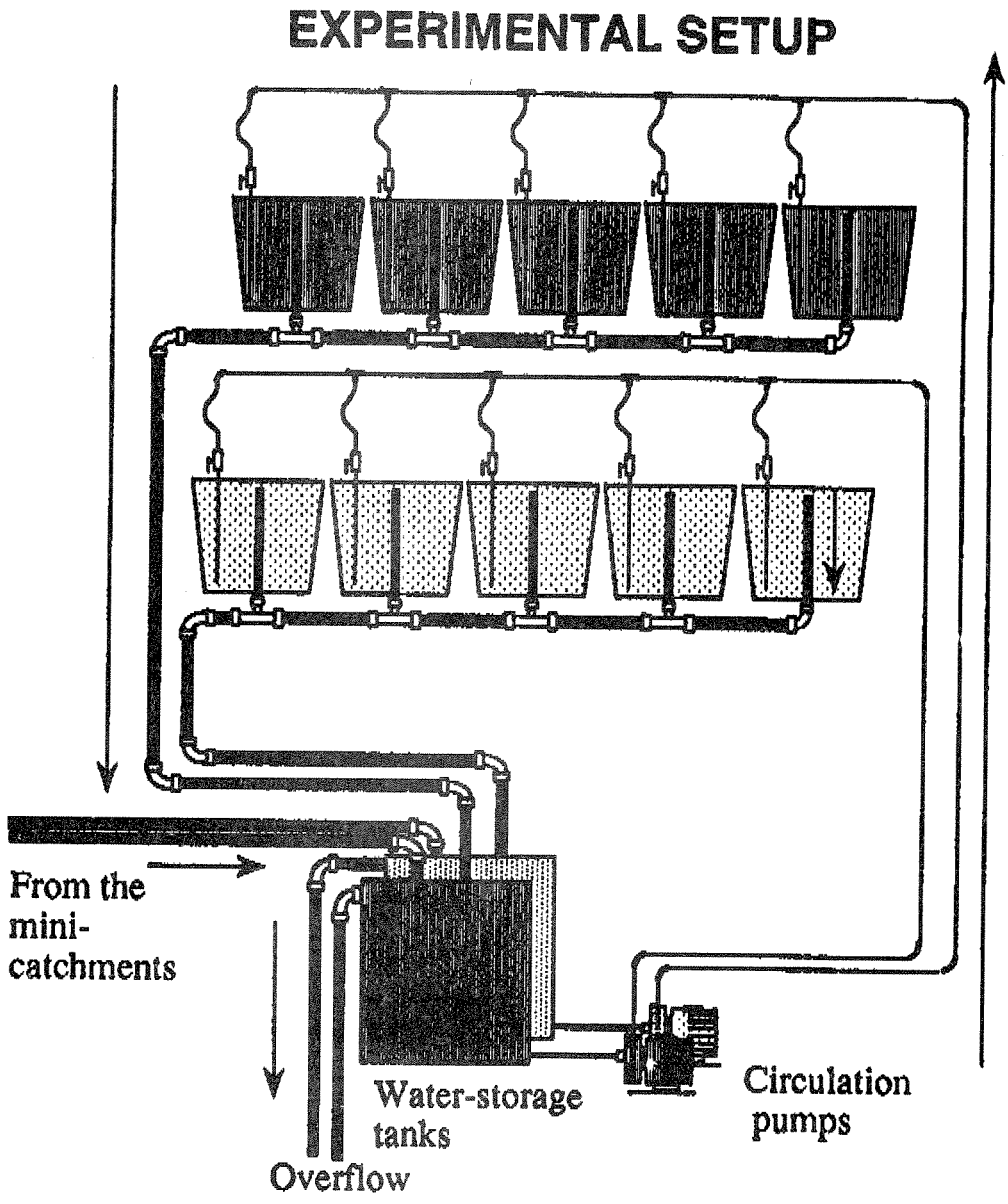


Figure 3.6.1 Schematic diagram of the fish toxicity test setup at Gårdsjön.

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