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An Assessment of Nitrogen Leaching from Watersheds included in ICP on Waters

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Abstract:

The importance of nitrate in acidification has been evaluated for 163 sites included in ICP on Waters in 13 countries in Europe and North America. At 63 % of these sites yearly average nitrate concentrations amounted to more than 10% of the acid non-marine acid anions. This shows that nitrate leakage contributes significantly to acidification at a majority of the ICP sites. High leakage of nitrogen occur only at sites with high nitrogen concentrations in precipitation and high total deposition of nitrogen (wet +dry). 144 ICP sites were classified according to Stoddard's system for stages of nitrogen saturation. Approximately one half of the sites had a high degree of nitrogen saturation (Stage 2 or 3). There was a clear coherence between stage classification and total N deposition.

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4. Classification of Nitrogen saturation

Project manager

Tor S. Traaen

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For the Administration

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PREFACE

This report has been prepared at the Norwegian Institute for Water Research. A draft issue was discussed at the 10th Task Force meeting of the International Cooperative Programme on Assessment and Monitoring of Rivers and Lakes in Budapest 12.-14. october 1994. Comments and contributions from the participants at the meeting are highly appreciated. In particular, the Programme Centre appreciate John L. Stoddard's contribution to the final report. The authors appreciate valuable comments and suggestions from Dean Jeffries and Arne Henriksen

Thanks are due to the Programme members for providing water chemistry data and to Norwegian Institute for Air Research and Norwegian Meteorological Institute for providing EMEP data on precipitation chemistry and deposition used in this report.

The long term plan for reporting from the Programme focuses on in depth reports every three year and reports on different items in the years between. This report on NITROGEN is following the in depth six year report from March 1994. The Programme Task Force (1993) gave a high priority to this item for the first special issue report to follow the six year report.

Oslo, February 1995

Merete Johannessen

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MAIN CONCLUSIONS

More than half of the ICP sites have yearly average nitrate concentrations above 10 µeq/l. These sites are situated in all countries except Finland and Russia. Nitrate concentrations greater than 50 µeq/l are found at 23% of the sites. These are mainly found in Germany (27 out of 30 German sites), but also in Austria (3 sites), Belgium (2 sites) and Denmark (2 sites). Sites in The Netherlands differ from most other sites in having ammonium as the main form of inorganic nitrogen. All Dutch sites have ammonium concentrations greater than 100 µeq/l.

Even if sulphate is still the most important acidifying anion, nitrate constitutes more than 10% of the non-marine acid anions at 63 % of the ICP-sites. This shows that nitrate leakage contributes significantly to acidification at a majority of the ICP sites. Only Canada, Finland, Sweden and Russia have no ICP sites with average nitrate contribution above 10% of the acid anions. Due to the episodic pattern of nitrate concentrations at many sites, the significance of nitrate in acidification is often greater than shown by average figures.

High leakage of nitrogen occurs only at sites with high nitrogen concentrations in precipitation and high total deposition of nitrogen (wet + dry). All European sites with N concentrations less than 0.8 mgN/l in precipitation (37 sites) have concentrations less than 0.3 mgN/l in runoff.

Onehundred forty four ICP sites were classified according to Stoddard's system for stages of nitrogen saturation. Approximately one half of the sites had a high degree of nitrogen saturation (Stage 2 or 3). These sites were situated in all participating countries except Finland and Russia. All ICP-sites in Denmark, Belgium, The Netherlands and Austria, and 29 out of 30 German sites, were in Stage 2 or 3. There is a clear coherence between nitrogen saturation stages and nitrogen deposition values.

1. INTRODUCTION

Until the last decade, nitrogen has not been considered to be an important agent in the acidification of freshwater systems. This is primarily due to the ability of the watershed to act as an effective sink for nitrogen. In pristine terrestrial environments, nitrogen is usually a limiting nutrient creating a strong demand for nitrate and ammonium on part of forest trees and soils.This demand results in only small amounts of nitrogen (primarily nitrate) ammonium being leaked from the watershed to the runoff. When deposition of nitrogen compounds and sulphate increase, increased sulphate concentrations are readily detected in the runoff, while nitrate concentrations may be unaltered, at least for some time.

Reports of increased nitrate concentrations in the runoff first appeared in the 1980s. The Norwegian 1000 lake survey in 1986 revealed that nitrate concentrations in some areas in southern Norway had almost doubled since investigations in 1974-75 (Henriksen et al. 1988). This increase could only partly be explained by an increased nitrogen deposition (approximately 10%). Further, the increases in nitrate concentrations were largest in those lakes that had the highest nitrate concentrations in 1974-75, and where N deposition was highest (approx. 2 g N m^{-2} yr^{-1} , roughly equally distributed between NO_3^- and NH_4^+). This led to the suggestion that the capacities of the watersheds to retain nitrogen were exceeded. When the excess nitrogen leaves the watershed as the mobile anion nitrate, it will contibute to the acidification in the same way as sulphate.

Nitrate will contribute to acidification of the watershed by removing base cations from the soil and by mobilizing aluminium and hydrogen ions. Nitrate in the runoff, when accompanied by hydrogen, will reduce the acid neutralizing capacity (ANC). But a high nitrate concentration does not necessarily mean that the runoff will be acid. Whether the runoff will actually be acid depends upon the concentrations of other components, particularly the base cations and sulphate. This report will focus on the absolute and relative contribution of nitrate to acidification (defined as loss of ANC) and not acidity per se.

Increasing trends in runoff nitrate concentrations were also revealed in the U.S. EPA's Long-term Monitoring Project. Nine of 15 drainage lakes monitored in the Adirondack area showed increases in nitrate concentrations, ranging from 0.5 to 2.0 μeq l^{-1} yr^{-1} in the period 1982 - 1991 (Driscoll et al. 1993). Further, 5 of 8 streams in the Catskill area exhibited significant upward trends in nitrate, ranging from 1.3 to almost 3 μeq l^{-1} yr^{-1} in the period 1983 -1989 (Murdoch & Stoddard 1992). In both areas, sulphate concentrations decreased in the same periods, enhancing the relative importance of nitrate leakage in the acidification process. Similar to the situation in Southern Norway, the decrease in sulphate concentrations could be explained by reduced sulphur deposition, while increase in nitrate concentrations could not be explained by increased deposition of nitrogen compounds or other changes in the catchment (point sources, agriculture, clearcutting, forest fire, etc.). Hence, dose / response relationships are much more complicated for nitrogen than for sulphur.

The aims of the programme ICP on Waters are: (1) to establish the degree and geographic extent of acidification of surface water; (2) evaluate dose/response relationships; and (3) define long-term trends and variations in aquatic chemistry and biota due to atmospheric pollution, particularly acid deposition. Twenty countries in Europe and North America participate in the programme. Fourteen countries have contributed data. The selection of monitoring sites is the responibility of the participating countries. The sites vary from small

ponds and brooks to large lakes and rivers. The geographic coverages vary between countries. The number of sites in each participating country range from 2 to more than 30,with a typical number around 10 sites/country.

The data from 146 sites in the ICP on Water (Skjelkvåle et al. 1994) clearly show that elevated nitrate concentrations in runnoff water are common in all participating countries. In the following chapters, the ICP nitrogen data will be further evaluated, particularly with respect to nitrogen saturation.

2. NITRATE IN THE RUNOFF AT ICP SITES.

The frequency distribution for 5 intervals of yearly average nitrate concentrations is shown in Figure 2.1 for sites from each of the participating countries. Values for the last year of available data are used, usually 1992, but occasionally as far back as 1989. Data from all 150 sites (146 sites from the 12 countries in Appendix B of Skjelkvåle et al. 1994, plus 2 new Russian sites and 2 new finnish sites) are combined in Figure 2.2. We know that unweighted mean values underestimate actual annual mean values, particularly in catchments with heavy snowmelt in spring. The mean values used in this report should therefore be considered conservative estimates of mean NO_3^- concentrations.

Thirty prcent of the ICP sites have yearly average concentrations of nitrate below 5 μeq/l. Most of these sites are situated in the Nordic countries (except Denmark), Ireland, Canada, U.S. and Russia. At these sites nitrate has a low influence on acidification. More than half of the sites have nitrate concentrations above 10 μeq/l. At these sites nitrate is a relatively important acidifying agent. Due to the episodic pattern of nitrate at many sites, the significance of nitrate in acidification is often greater than shown by average figures. This will be discussed in more detail in following chapters. Nitrate concentrations greater than 50 μeq/l are found at 23% of the sites, mainly in Germany (27 out of 30 German sites), but also in Austria (3 sites), Belgium (2 sites) and Denmark (2 sites). Sites in The Netherlands differ from most other sites in having ammonium as the main form of inorganic nitrogen. All Dutch sites have ammonium concentrations greater than 100 μeq/l. If conditions for nitrification should improve, the ammomium content of these sites has a great acidification potential.

In total, the results suggest that many sites (>50%) have nitrate concentrations above those expected from sites with no impact from N deposition (Stoddard 1994). The effects of N deposition on ICP on Waters catchments therefore warrant further examination.

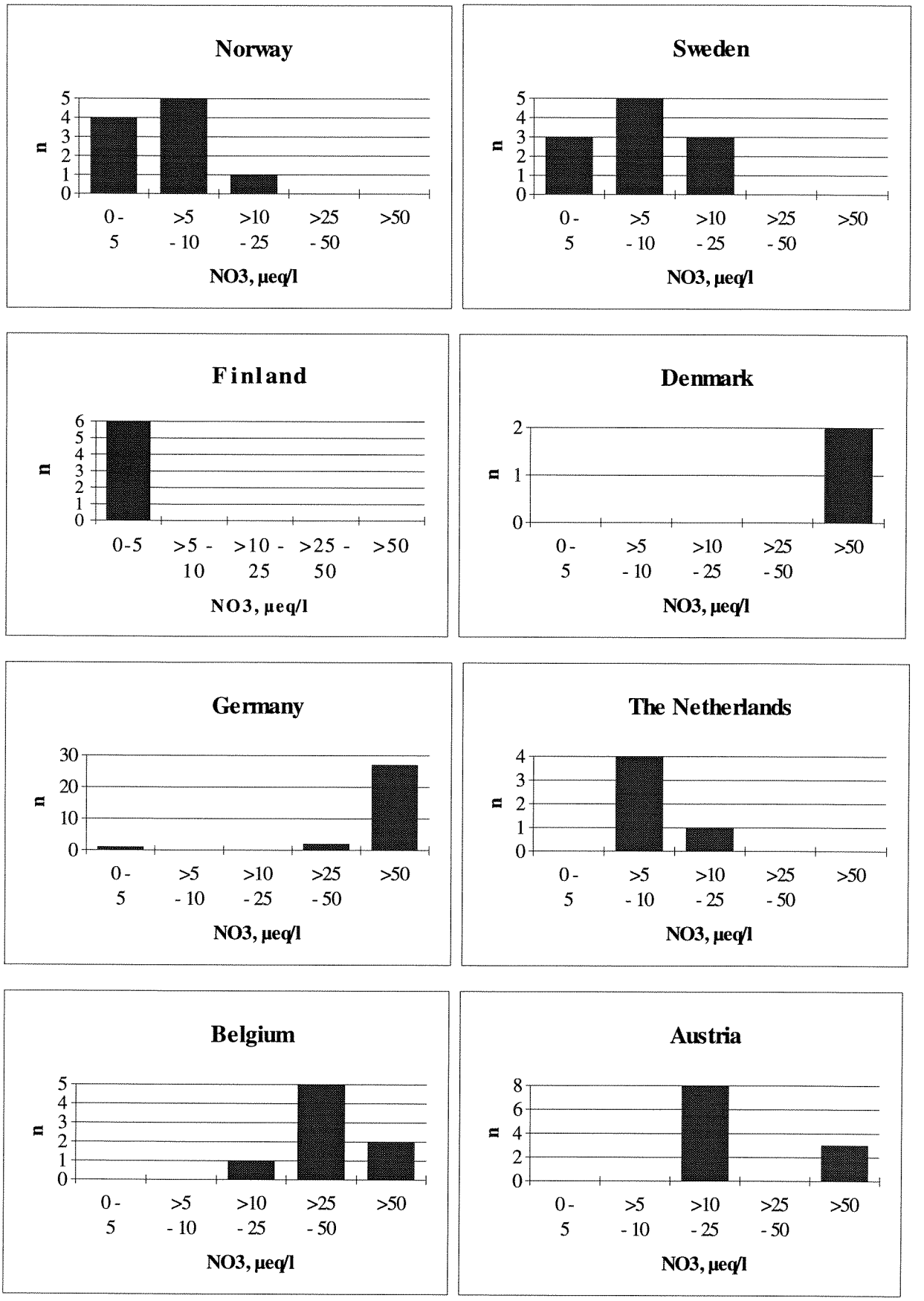

Figure 2.1 Frequency distribution of yearly average nitrate concentrations at ICP sites.

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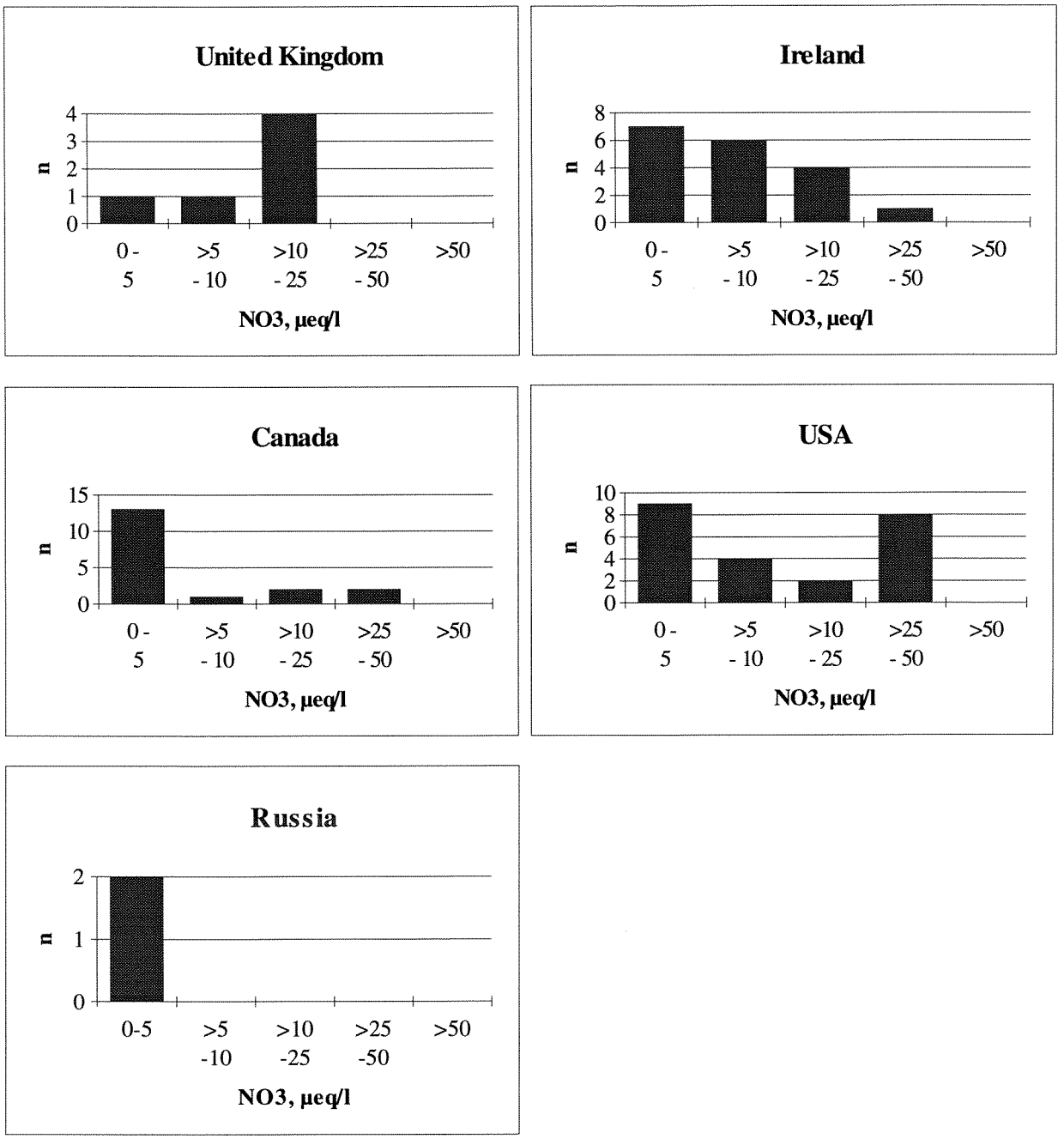

Figure 2.1. Frequency distribution of yearly average nitrate concentrations at ICP sites.

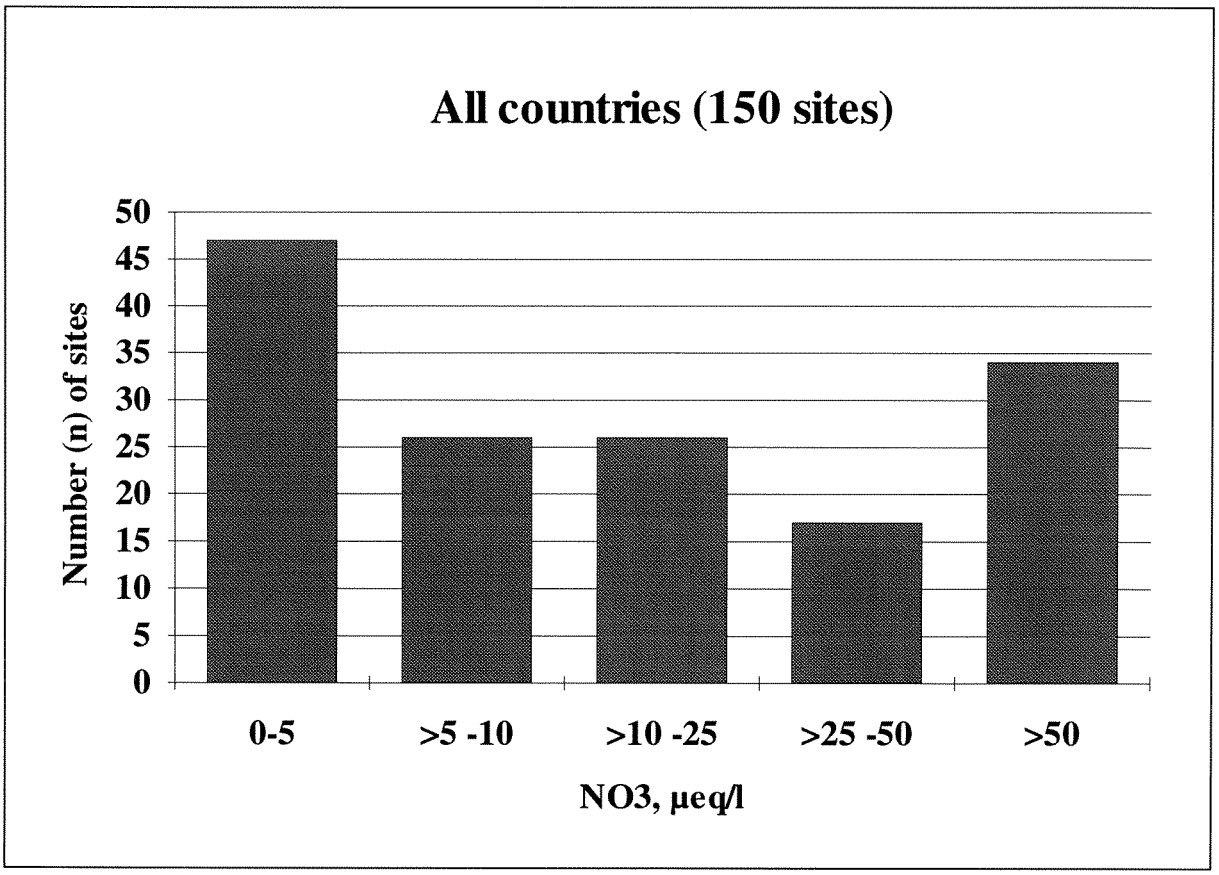

Figure 2.2. Frequency distribution of yearly average nitrate concentrations at 150 ICP sites.

3. THE RELATIVE IMPORTANCE OF NITRATE IN ACIDIFICATION.

The importance of nitrate in acidification relative to sulphate can be illustrated by the concentration of nitrate divided by the sum of non-marine sulphate and nitrate (μeq/l): KNS = NO_3^- / ($SO_4^=$ + NO_3^-), μeq/μeq. In figure 3.1 frequency diagrams for 5 intervals of KNS are shown for the latest available data for the 163 ICP sites on country-by-country basis. All sites together are shown in Figure 3.2. Some sites showed negative values for non-marine sulphate, and therefore it was not possible to calculate KNS-values.

One hundred and three sites out of 163 have KNS values greater than 0.1. In other words, nitrate constitutes more than 10% of the non-marine acid anions in 63 % of the ICP-sites. This shows that nitrate leakage contributes significantly to acidification at a majority of the ICP sites. Only Canada, Finland, Sweden and Russia have no ICP sites with KNS > 0.1. Thity-eight ICP sites have KNS > 0.25. These sites are situated in Norway , Denmark, Germany, Austria, UK and Ireland. Seven sites (4%) have KNS values > 0.5, i.e. at these sites nitrate makes a greater contribution to acidification than sulphate. These sites are situated in Germany, Austria and Ireland.

The results show that sulphate is generally the most important acid anion in acidification, but nitrate does contribute significantly at a majority of the ICP sites (Figure 3.2).

The importance of nitrate as acidifying anion may be fairly constant or vary with seasons, depending upon the degree of nitrogen saturation in the catchment and the sulphate concentration. At Birkenes, Norway, nitrate amounts to 18% of the acid non-marine anions in spring, but have no importance in the summer season (Fig.3.3). In Constable Lake, USA, the importance of nitrate varies from 38% in spring to 4% in summer. Vorderer Schactenbach, Germany, shows only minor seasonal changes. The KNS-values lies between 0.35 and 0.45 all year, suggesting a late stage of nitrogen saturation.

The seasonal changes in the relative importance of nitrate in acidification are also shown in an assessment of Canadian lakes (Jeffries 1994): mean KNS values for lakes having high concentration of nitrate (>15 μeq/l) were usually in the range 0.12 to 0.19 in the period January to May, while the values in the period June to October were usually well below 0.1.

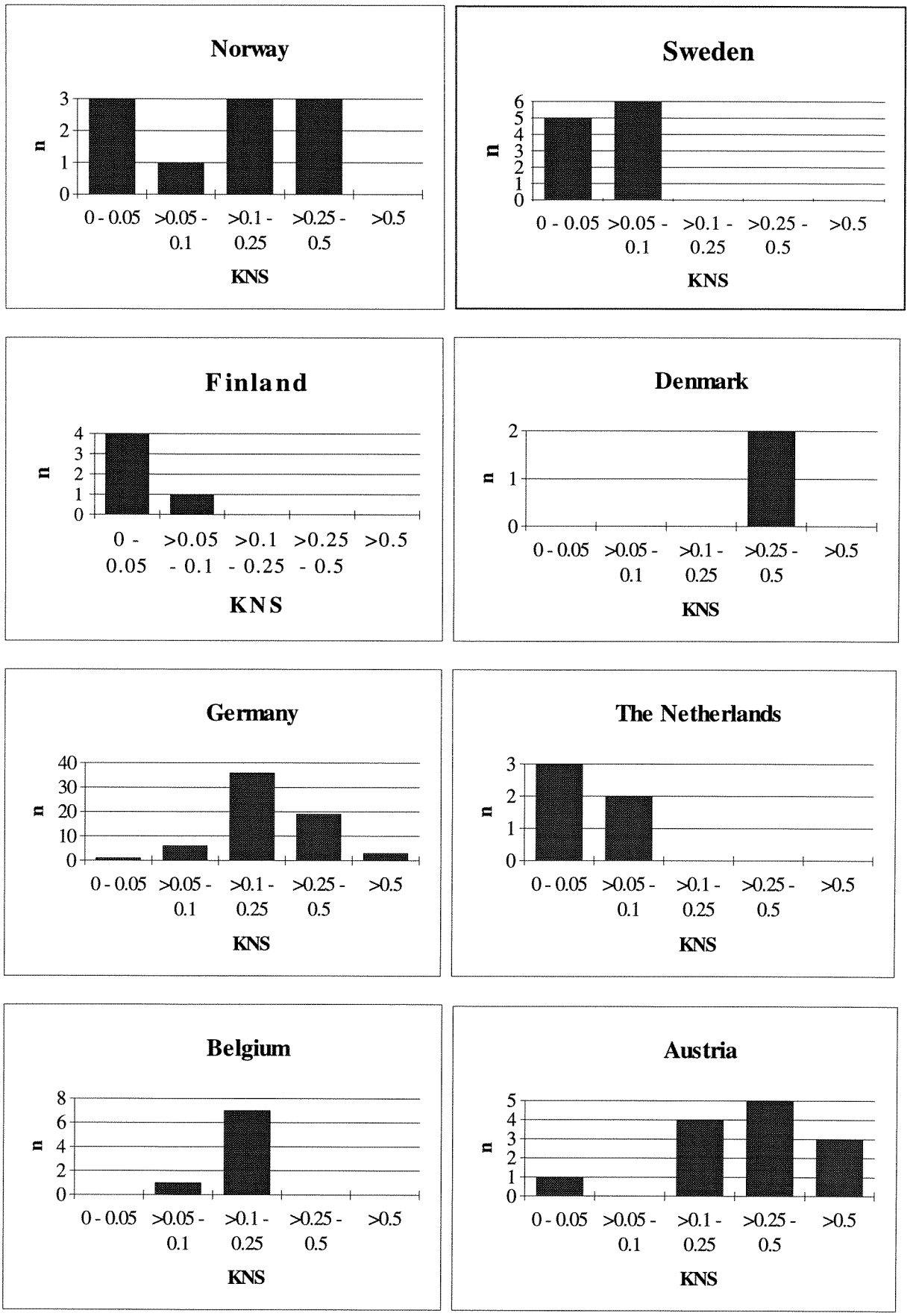

Figure 3.1. Relative importance of nitrate in acidification at ICP sites.

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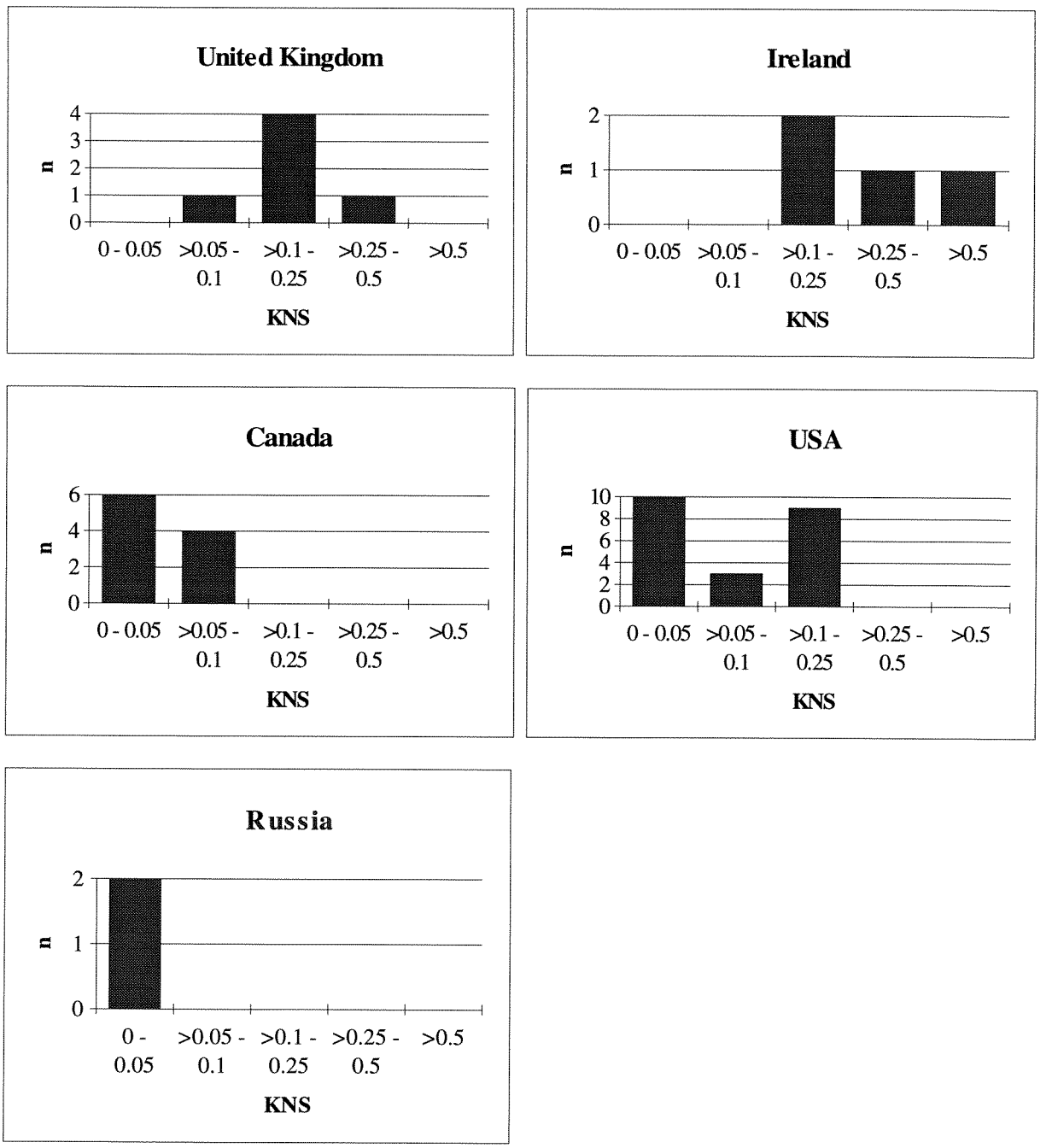

Figure 3.1. Relative importance of nitrate in acidification at ICP sites.

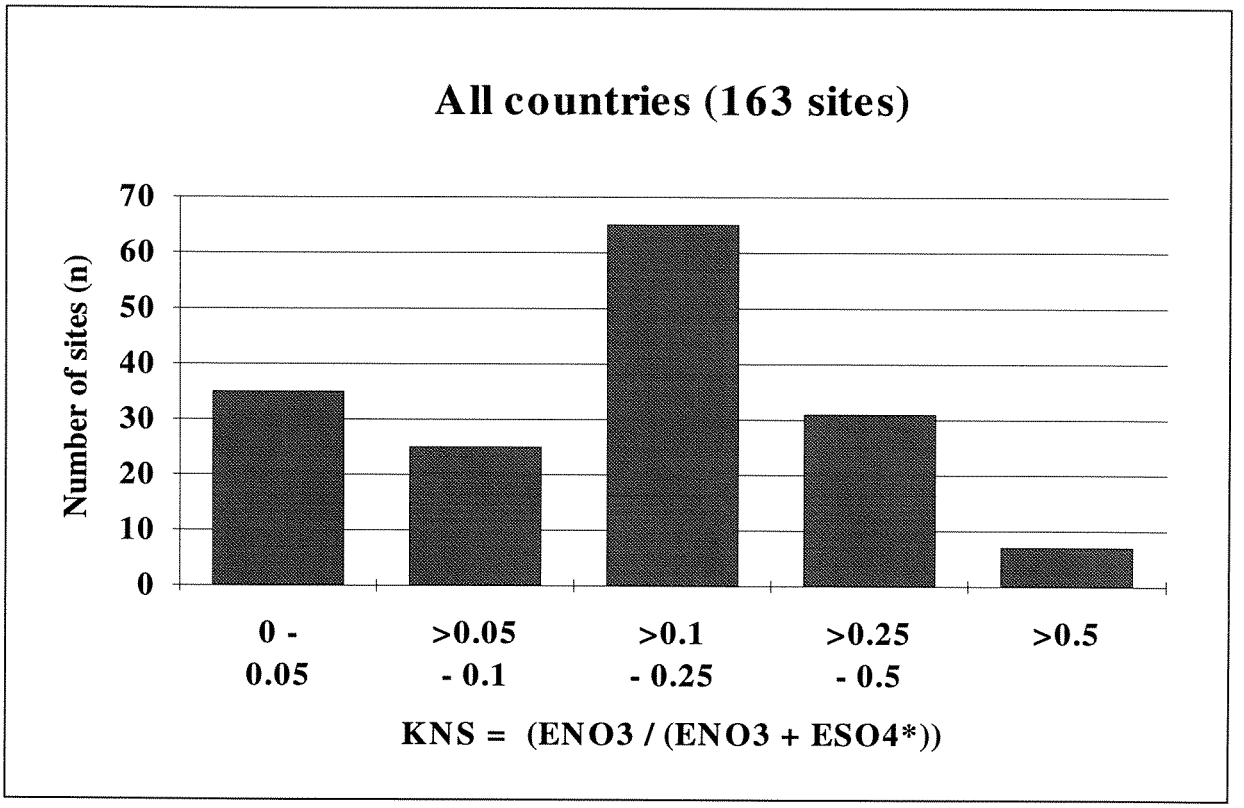

Figure 3.2. Relative importance of nitrate in acidification at 163 ICP sites.

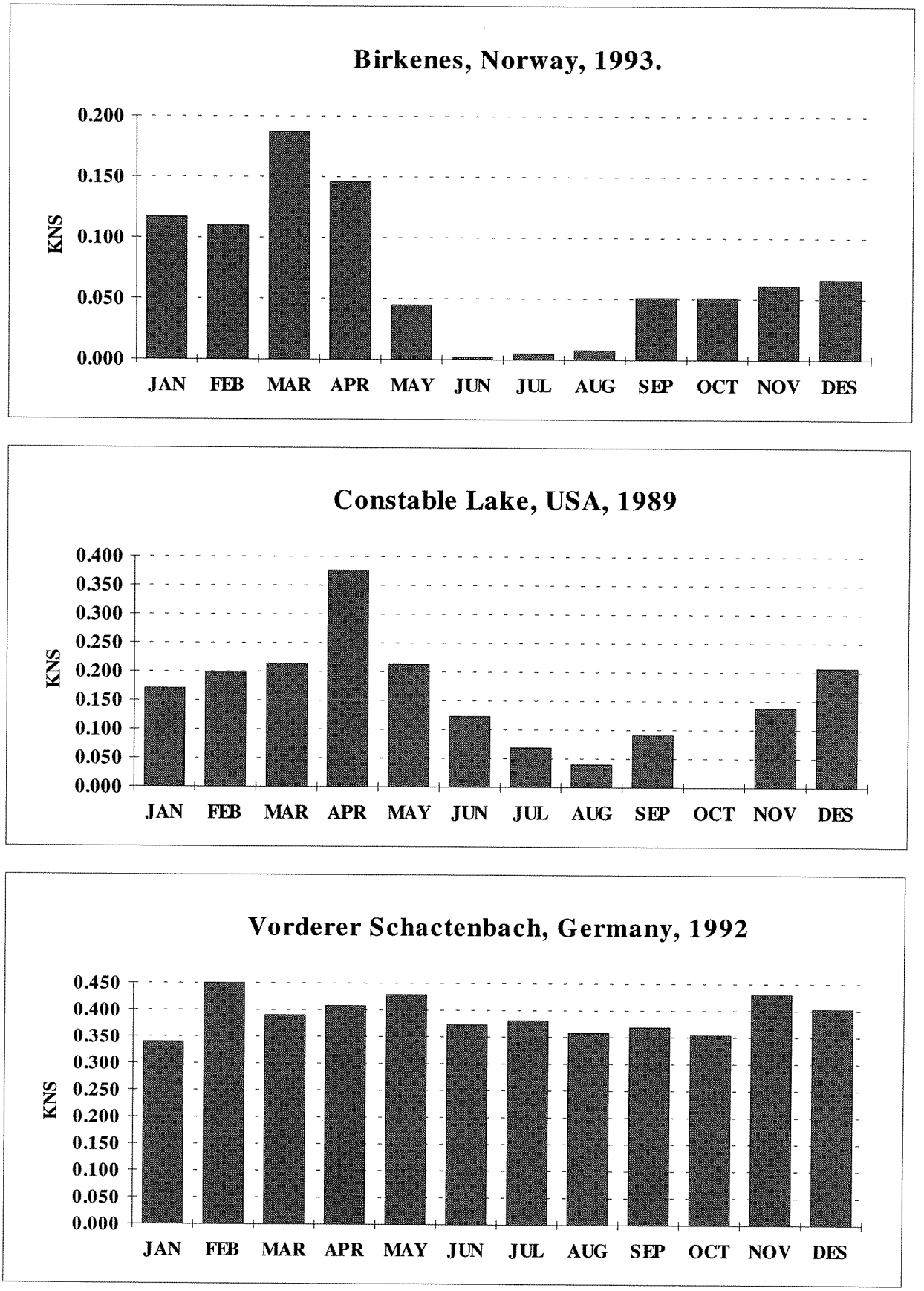

Figure 3.3. Seasonal changes in relative importance of nitrate in acidification at 3 ICP sites. KNS = ENO3 / (ENO3 + ESO4*).
ENO3: Nitrate, µeq/l. ESO4*: Non-marine sulphate, µeq/l.

4. NITROGEN IN PRECIPITATION AND RUNOFF.

It is well documented that high nitrogen loss from catchments is correlated with high nitrogen deposition (Grennfelt and Hultberg 1986, Kämäri et al. 1992). Kämäri et al. found no positive N-runoff values from lakes having a yearly wet deposition below 0.4 gN/m^2, and severe leakage started to occur above 0.8 gN/m^2. In the NITREX project, Wright et al. (1994) found that nearly all nitrogen was retained when annual N-deposition (wet+dry) was below $1gN/m^2$, and that N leakage was substantial at input above 2.5 gN/m^2.

Input / output data for nitrogen are not available for most of the ICP sites . However, one may get a general view of nitrogen leakage by comparing the concentrations in precipitation and runoff (Fig.4.1). The average N data (nitrate + ammonium) in 1990 for runoff at the ICP sites are taken from Skjelkvåle et al. 1994. Some sites with known agricultural influence (pasure land etc.) are excluded from the graph. Average concentrations in wet precipitation for 1990 are approximated from EMEP isoline maps, based on measurements at EMEP stations (Pedersen et al. 1992). Due to sharp concentration gradients in some regions, the isoline maps are considered to give better approximations for N concentration in precipitations than using direct measurements from the nearest EMEP station, which is often quite far away. Due to concentration gradients within the EMEP grids, the numbers must still be considered to be rather crude estimates.

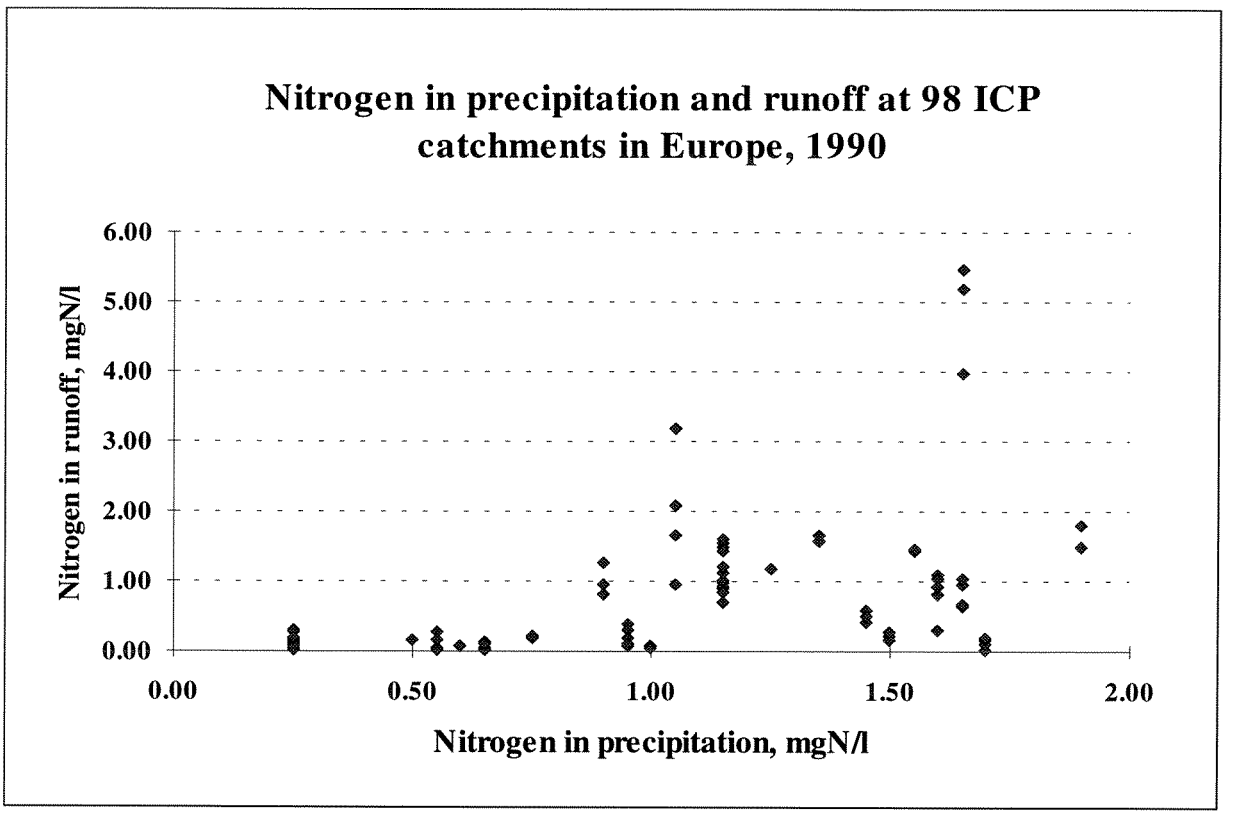

Figure 4.1. Nitrogen (NO3-N +NH4-N) concentrations in wet precipitation and runoff for 101 European ICP sites in 1990. Precipitation data from Pedersen et al. 1992.

All sites with N concentrations less than 0.8 mgN/l in the precipitation (37 sites) have concentrations less than 0.3 mgN/l in the runoff. This confirm the observations cited above that there is a treshold value below which there is only small N-leakage. A concentration of 0.8 mgN/l in precipitation corresponds to a wet deposition of 0.8 gN/m^2 at a yearly precipitation of 1000 mm.

Some sites have higher concentrations in the runoff than in the precipitation. This may be due to dry deposition, evaporation or an unknown local N-sources. Dry deposition can differ greatly between sites. In 1990 NILU found that dry deposition of N at 11 stations throughout Norway varied from 8 to 69% of total (wet + dry) N deposition, with a mean of 29% (SFT 1991). Dixon (1986) suggested an average of 50% dry deposition of N in southern Sweden. Hence, dry deposition may be a major contribution to N in the runoff.

In Figure 4.1, the 3 sites having runoff concentrations $\geq$ 4 mgN/l are all located at Achterste Goorven, the Netherlands, a small, shallow lake with low runoff and a mean residence time of 5.4 years. It is likely that evaporation is an important cause of the extreme N concentrations at these sites. At all the Dutch sites, ammonium is the dominating form of N in runoff. This is due to high ammonium deposition and slow nitrification, due to low pH.

Figure 4.2 shows the relationship between total nitrogen deposition (wet + dry) and nitrogen concentrations in the runoff for the European ICP sites in 1990. Deposition values are values for the EMEP grid where the respective ICP Water sites are situated (data from Meteorological Synthesizing Centre-West of EMEP, Norwegian Meteorological Institute). Figure 2 shows a pattern very similar to figure 4.1, confirming the general concept that watersheds have treshold values for N deposition above which increased N leakage occur. The absolute treshhold value is uncertain for several reasons: the deposition data are not site specific; the sampling frequency is low at many sites; the amount of N leaked is influenced by both deposition and the duration of the deposition; and finally, the site selection does not necessarily include the most sensitive sites with respect to N leakage. Despite these uncertainties, the data in Figure 4.2 are in reasonably good agreement with data from Dise and Wright (in press) who reported a lower treshold value (dry + wet deposition) of 1.0 $gN/m^2/yr$, above which some catchments leaked nitrogen, and an upper treshold value of 2.5 $gN/m^2/yr$, above which all ENSF (Evaluation of Nitrogen and Sulphur Fluxes) sites leaked nitrogen. All the ENSF catchments had site specific data for deposition and runoff so that input and output fluxes could be calculated.

Some of the sites in figure 4.2 with N deposition below 1.0 $gN/m^2/yr$ have very high annual precipitation (1200 -2500 mm/yr). These sites may have a pronounced outflux of N even if the concentrations are moderate. Such sites are mainly situated in Norway, Ireland and the UK. This is illustrated in Figure 4.3 where outfluxes of NO_3^-N + NH_4^+N are approximated by using the runoff concentrations in Figure 4.2 and the yearly average precipitation in the respective EMEP grids in 1990 (data from Meteorological Synthesizing Centre-West of EMEP). Yearly flow values were calculated by subtracting an estimated evopotranspiration of 300 mm/yr from the precipitation values. The results indicate that there might be N leakage even below total deposition values of 1.0 $gN/m^2/yr$. This might partly be due to short contact time between water and the soil's root zone during heavy rainfall. Stoddard (1994) observed a treshold for N-leakage at a wet deposition as low as 0.25$gN/m^2/yr$, corresponding to a wet + dry deposition of approximately 0.5$gN/m^2/yr$.

Even if there is a strong correlation between the current N deposition and N runoff, there are several other factors that may influence the N leakage, including: the duration of elevated N deposition, biomass and age of the forest stands, quality and depth of the soil, and hydrology.

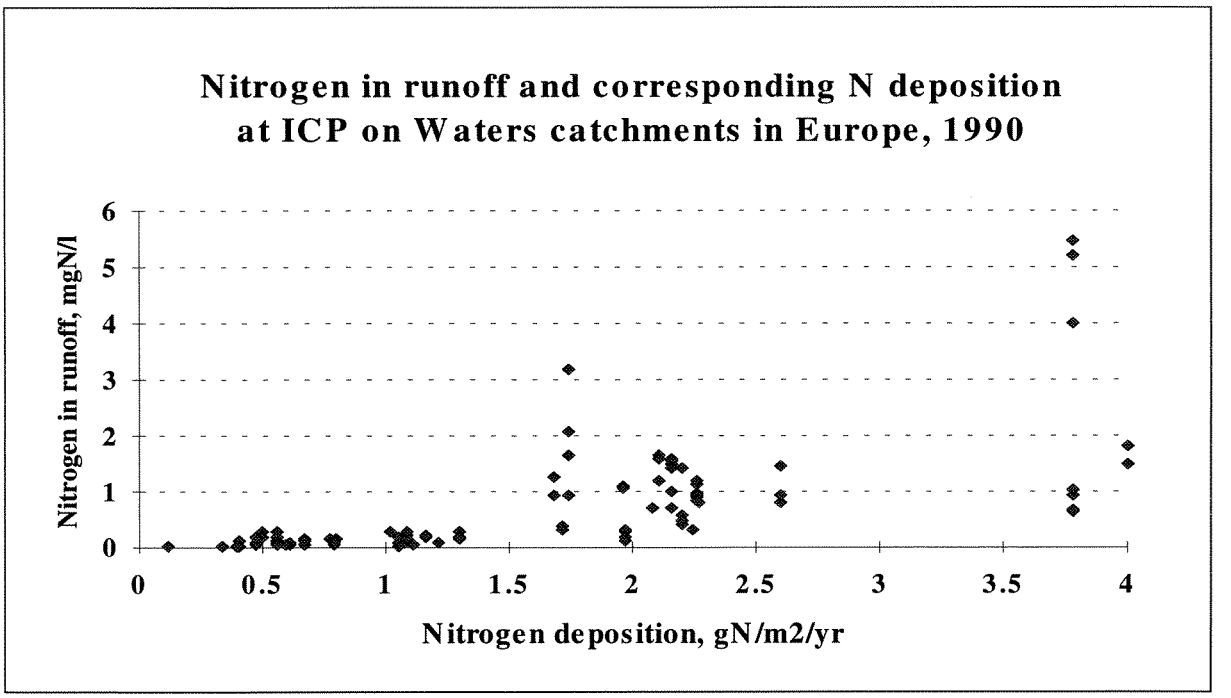

Figure 4.2. Nitrogen (NO_3^- + NH_4^+) concentration in runoff and total nitrogen deposition (wet + dry) for European ICP onWaters sites in 1990. The deposition data are values for the EMEP grids in which the respective sites are situated (data from Norwegian Meteorological Institute).

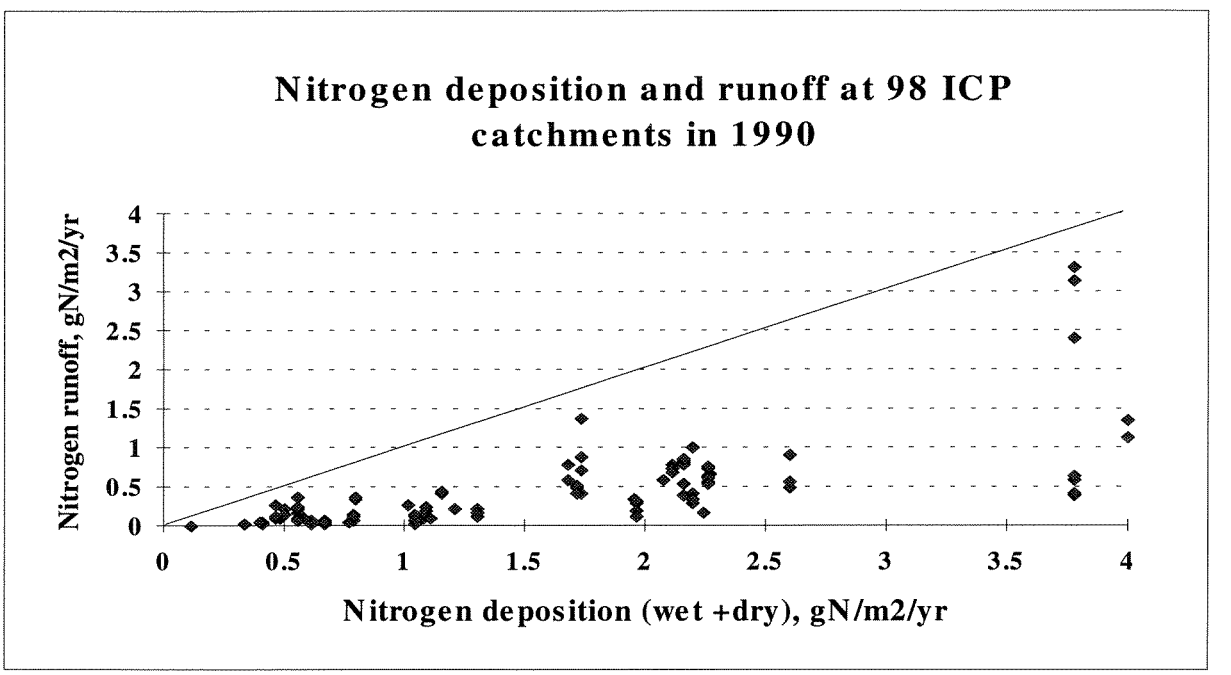

Figure 4.3. Estimates of nitrogen runoff (NO_3^--N + NH_4^+-N) from ICP on Waters catchments in Europe and corresponding total N deposition (wet + dry) in the respective EMEP grids.

High concentrations of nitrogen may also be linked to high sulphur deposition (Andersen 1986). Figure 4.4 shows nitrogen and sulphate concentrations in the runoff from 99 ICP sites in 1990. No site have N-concentrations above 0.5 mgN/l when SO_4*-concentrations are below 3 mg/l (60 µeq/l). This association may result from increased soil acidification by sulphate, or simply from an intercorrelation between nitrogen and sulphur deposition, as shown in Figure 4.5.

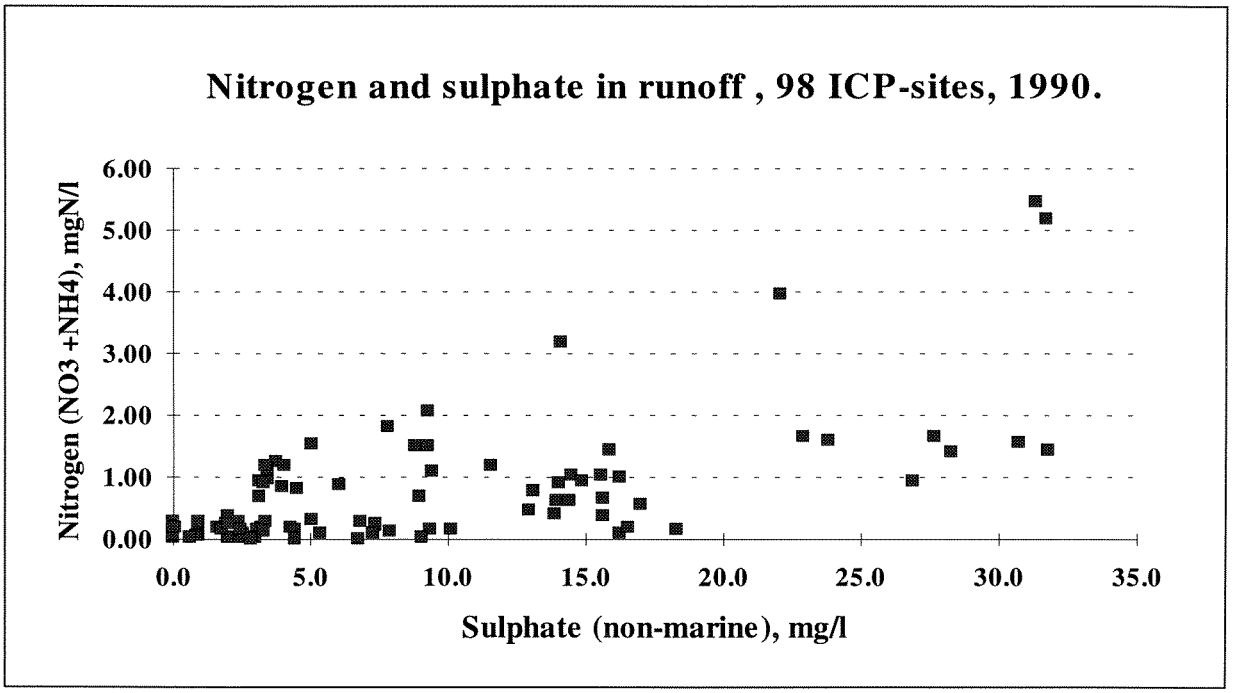

Figure 4.4. Nitrogen and sulphate in runoff at 99 ICP on Waters sites in 1990.

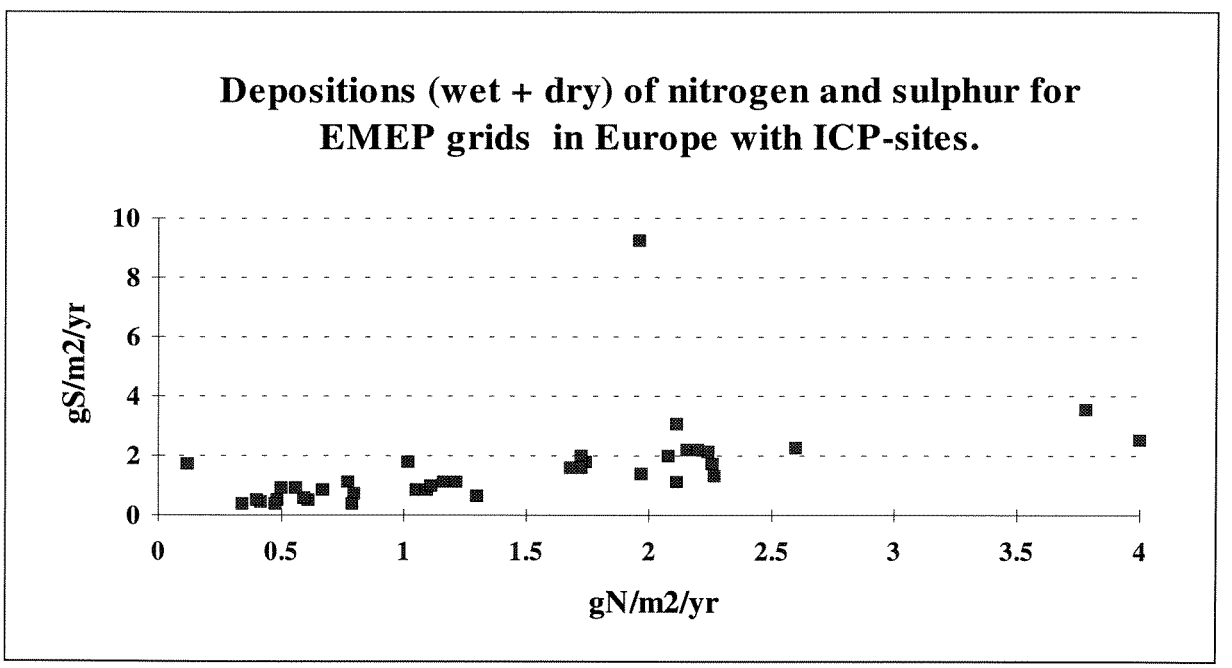

Figure 4.5. Nitrogen and sulphur deposition in 1990 for European EMEP-grids with ICP Water sites. Data from Norwegian Meteorological Institute.

5. CLASSIFICATION OF NITROGEN SATURATION

The leaching of N to surface waters can be seen to occur in stages (described in detail in Stoddard, 1994), which correspond to the stages of terrestrial N saturation described by Aber et al. (Aber et al., 1989). The most obvious characteristics of these stages of N loss are changes in the seasonal and long-term patterns of surface water NO_3^- concentrations, which reflect the changes in N cycling that are occurring in the watershed.

The N cycle at **Stage 0** is dominated by forest and microbial uptake, and the demand for N has a strong influence on the seasonal NO_3^- pattern of receiving waters (Figure 5.1a). The "normal" seasonal NO_3^- pattern in a stream draining a watershed at Stage 0 would be one of very low, or immeasurable, concentrations during most of the year, and of measurable concentrations only during snowmelt (in areas where snow packs accumulate over the winter months), or during spring rain storms. The small loss of NO_3^- during the dormant season is a transient phenomenon, and results because snowmelt and spring rains commonly occur in these environments before substantial forest and microbial growth begin in the spring.

At **Stage 1**, the seasonal pattern typical of Stage 0 watersheds is amplified. It has been suggested that this amplification of the seasonal NO_3^- signal may be the first sign that watersheds are proceeding toward the more chronic stages of N saturation (Driscoll and Schaefer 1989; Murdoch and Stoddard 1992), and this suggestion is consistent with the changes in N cycling that are thought to occur at Stage 1 (Figure 5.1b; Aber et al. 1989). Overall limitation of forest growth (in the early stages of N saturation) is characterized by a seasonal cycle of limitation by physical factors (e.g., cold and diminished light), during late fall and winter, and nutrients (primarily N) during the growing season. The effect of increasing the N supply is to postpone the seasonal switch from physical limitation to nutrient limitation during the breaking of dormancy in the spring, and to prolong the seasonal N saturation that is characteristic of watersheds at this stage (Stoddard 1994). The key characteristics of Stage 1 watersheds are episodes of surface water NO_3^- that exceed concentrations typical of deposition.

In **Stage 2** of watershed N loss, the seasonal onset of N limitation is even further delayed, with the effect that biological demand exerts no control over winter and spring N concentrations, and the period of N limitation during the growing season is much reduced (Figure 5.1c). The annual N cycle, which was dominated by uptake at Stages 0 and 1, is instead dominated by N loss (through leaching and denitrification) at Stage 2; sources of N (deposition and mineralization) outweigh N sinks (uptake). The same mechanisms that produce episodes of high NO_3^- during extreme hydrologic events at Stage 1 also operate at Stage 2. But more importantly, the increased N sufficiency of the forest and soils creates a situation where NO_3^- can leach below the rooting zone, and elevated groundwater concentrations of NO_3^- result. This creates elevated NO_3^- concentrations during baseflow periods when deeper hydrologic flowpaths are contributing most to streamflow.

In **Stage 3**, the watershed becomes a net source of N rather than a sink (Figure 5.1d). Nitrogen retention mechanisms (e.g., uptake by vegetation and microbes) are much reduced, and mineralization of stored N may add substantially to N leaving the watershed through leaching or in gaseous forms. As in Stage 2, nitrification rates are substantial. Deposition, mineralization, and nitrification all contribute NO_3^- to leaching waters, and surface water NO_3^- concentrations can exceed inputs from deposition alone. The key characteristics of Stage 3

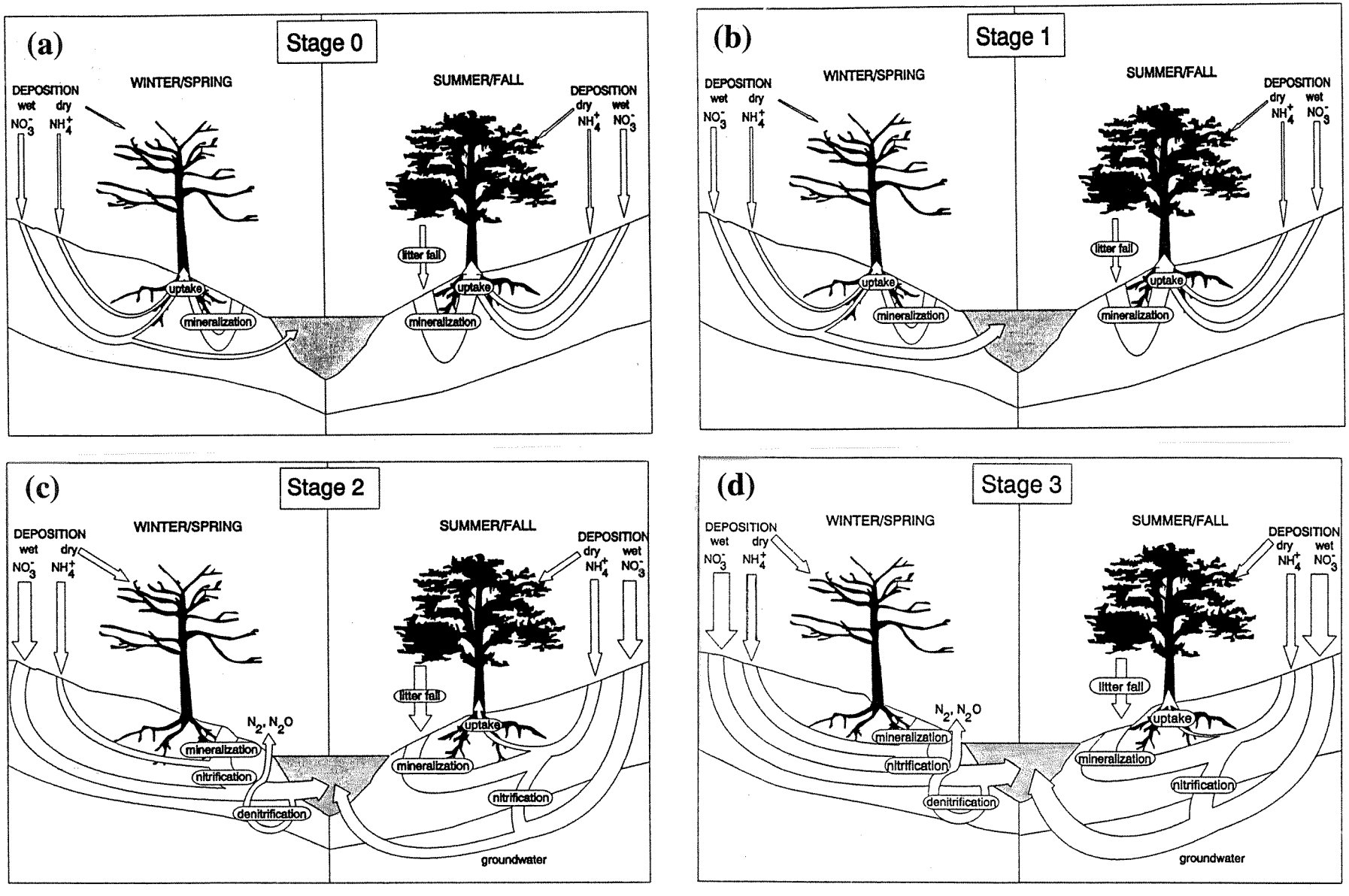

Figure 5.1. Schematic representation of the watershed nitrogen cycle at 4 Stages of nitrogen saturation. (a): Stage 0; (b): Stage 1; (c): Stage 2; and (d): Stage 3. The size of arrows is roughly equivalent to the sizes of fluxes for each process, and cycles are divided into winter/spring (dormant) and summer/fall (growing) seasons.

watersheds are these extremely high NO_3^- concentrations, and the lack of any coherent seasonal pattern in NO_3^- concentrations.

The NITREX project (Wright et al., in press; Moldan et al., in press) and the Watershed Manipulation Project (Kahl et al., 1993) have shown that it is possible to move forest ecosystems (and the runoff of nitrogen) through different stages of nitrogen saturation by experimentally changing the deposition of nitrogen, thus confirming the conceptual basis for N saturation stages.

In this chapter an attempt will be made to classify the ICP on Waters sites according to the N saturation scheme described above. The first step in such an assessment is establishing clear criteria to define each N saturation stage. The original criteria of Stoddard (1994) have been adapted here for the range of sampling frequencies that have been used to collect the ICP data. For sites with abundant data, the criteria to establish a site's N saturation stage were based on monthly average NO_3^- concentrations (Table 5.1).

Table 5.1. N saturation stage criteria for sites with frequent samples. The criteria are based on monthly average NO_3^- concentrations.

Stage	Criteria
Stage 0	≥ 3 months in the growing season with $NO_3 \leq 3$ μeq/l and peak value < 20 μeq/l.
Stage 1	1-2 months in the growing season with $NO_3 \leq 3$ μeq/l, or ≥ 3 months in the growing season with $NO_3 \leq 3$ μeq/l and peak value ≥ 20 μeq/l.
Stage 2	No month with $NO_3 \leq 3$ μeq/l and ≥ 3 months in the growing season with $NO_3 < 50$ μeq/l.
Stage 3	< 3 months with $NO_3 < 50$ μeq/l.

Many of the ICP sites have only 3 or 4 measurements during the year, usually at different seasons. It is, however, still possible to make an approximate classification of these sites, even if it will usually be impossible to distinguish between Stages 0 and 1, and 2 and 3. If the summer and/or fall values are below 3 μeq/l, the site belongs to either Stage 0 or Stage 1, and will be denoted Stage 0/1. If 3 measurement at different seasons all show values of nitrate lower than 3 μeq/l, it is reasonable to assume that the concentrations have been low also in months between measurements, and the site will be classified as Stage 0. If all measurements show nitrate concentrations above 3 μeq/l, but well below 50 μeq/l, the site will be classified as Stage 2. Sites with one or more measurements above 50 μeq/l will be classified as Stage 2/3.

In order to include as many sites as possible in this assessment of the ICP data, a second set of criteria were developed for sites with infrequent data. If insufficient data are available to distinguish between Stages 0 and 1, or between Stages 2 and 3, then the criteria designate the sites as either Stage 0/1 or Stage 2/3 (Table 5.2).

The criteria for sites with infrequent samples were tested on data from 25 sites with frequent samples, selecting 2 sets of 3 values from each site (March, June, and September, or April,

July, and October). The 2 sets gave identical classifications to the frequent sample criteria in 18 and 20 cases, respectively. In all of the remaining cases the infrequent sample classification included the frequent sample classification (e.g., Stage 0 and Stage 1 sites were classified as Stage 0/1, etc.).

Table 5.2. N saturation stage criteria for sites with infrequent samples (equally spaced in time, at least 2 samples in the growing season).

Stage	Criteria
Stage 0:	At least ≥2 values in the growing season ≤ 3 μeq/l NO_3 and peak value ≤ 10μeq/l.
Stage 0/1:	1 value in the growing season ≤3 μeq/l and peak value ≤10μeq/l or ≥1 value in the growing season ≤3μeq/l and peak value >10, but ≤20 μeq/l.
Stage 1:	≤1 value in the growing season ≤3 μeq/l and peak value >20 μeq/l.
Stage 1/2:	≥ 1 value in the growing season ≤5 μeq/l, but >3μeq/l.
Stage 2:	≥ 2 values in the growing season >5μeq/l, but ≤50μeq/l.
Stage2/3:	At least 1 value in the growing season >50μeq/l and at least 1 value ≤50μeq/l.
Stage 3:	All values in the growing season > 50 μeq/l.

Figures 5.2 to 5.15 show examples from each country of seasonal variation of nitrate concentration and suggested classification of nitrogen saturation.

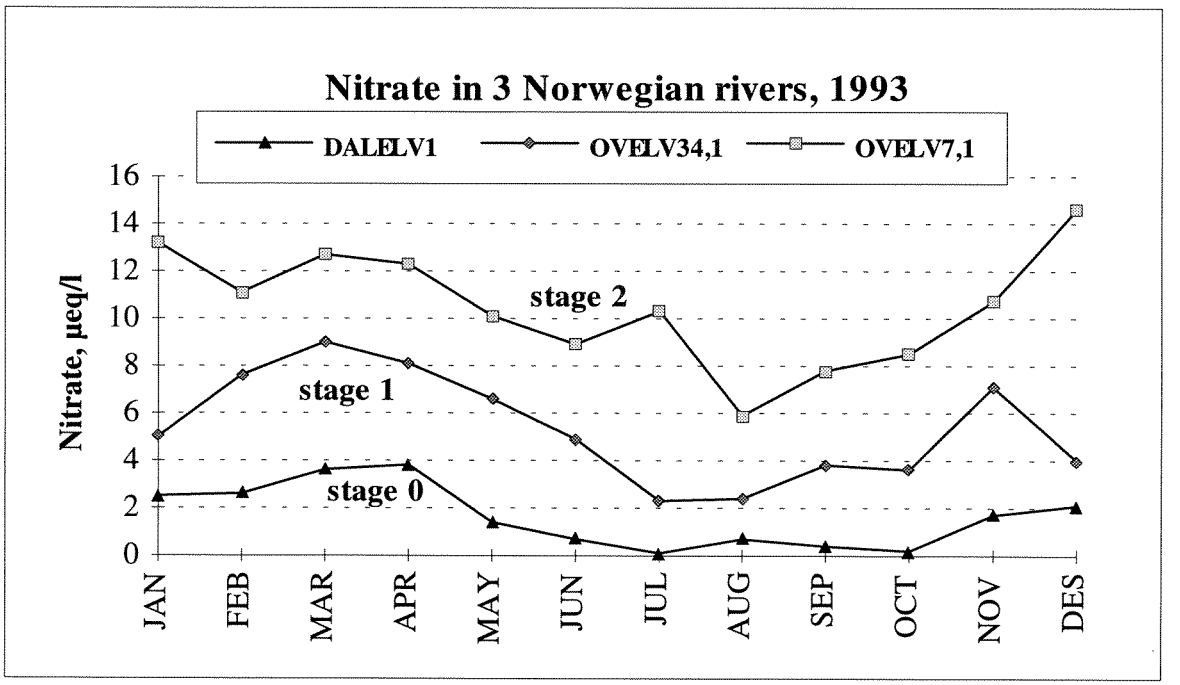

Figure 5.2. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
DALELV1: Dalelva River, Northern Norway. OVELV34,1: Nausta River, Western Norway. OVELV7,1: Tovdalselva River, Southern Norway.

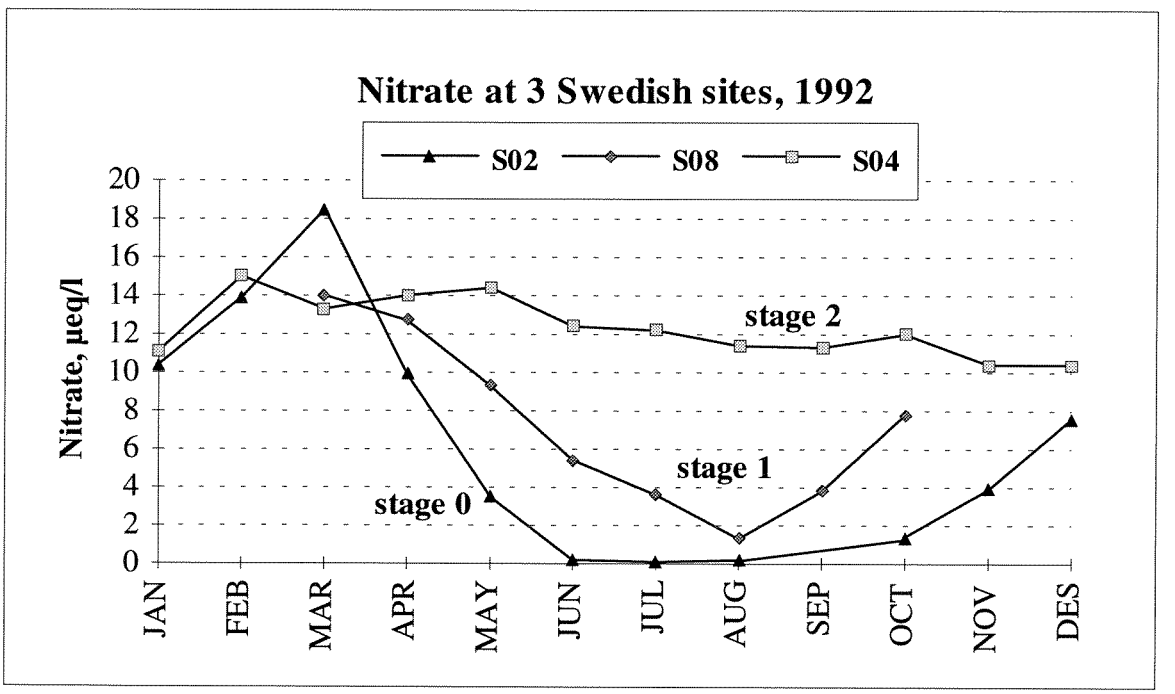

Figure 5.3. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
S02: Alsteraan River, Getebro. S08: Brunnsjøen Lake. S04: Haersvatn Lake.

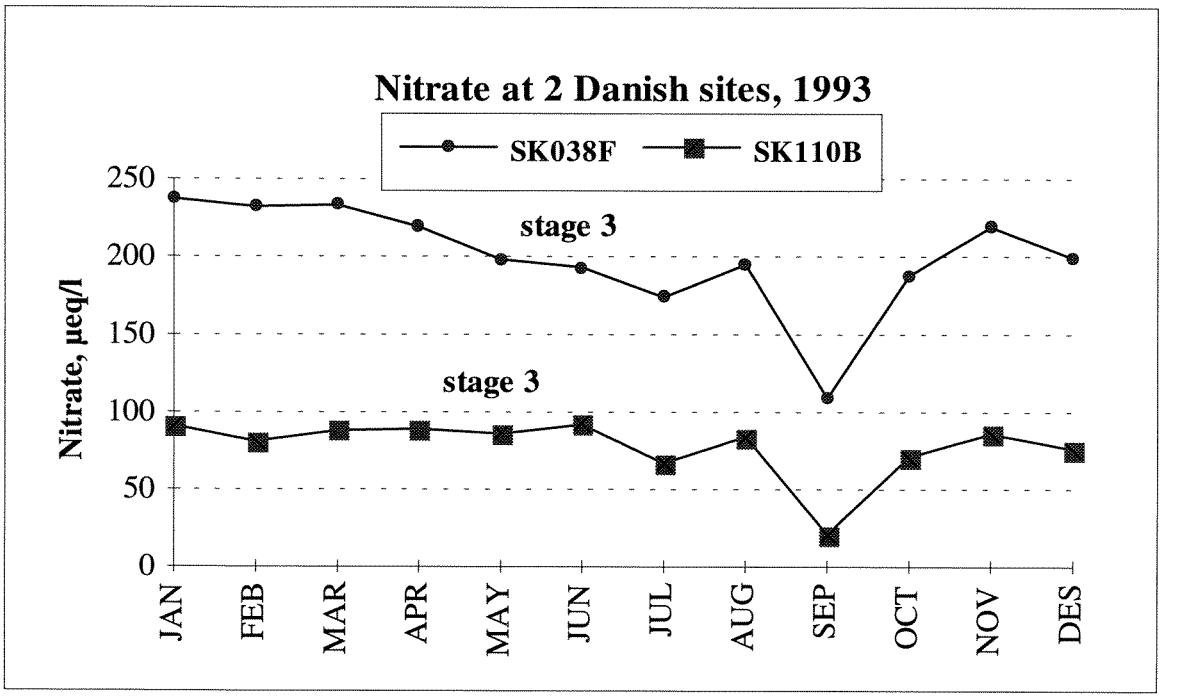

Figure 5.4. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
SK038F: Skaerbaek River, st.F, Sestrup Sande. SK110B Skaerbaek River, st.B.

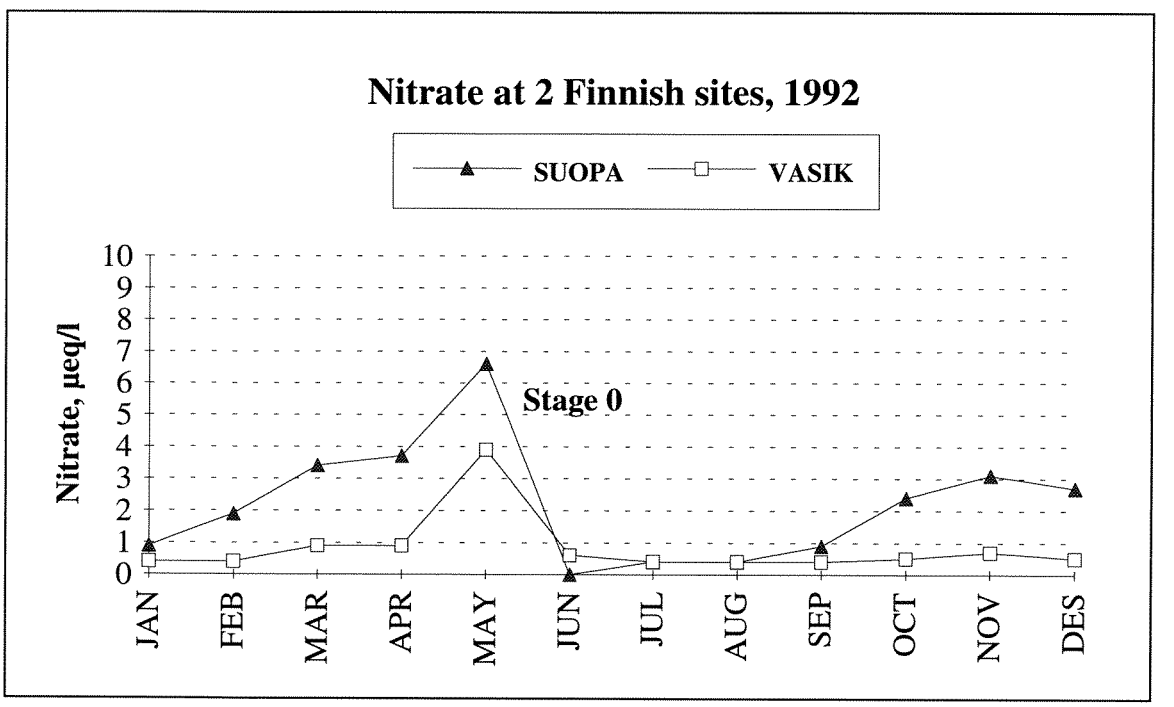

Figure 5.5. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
SUOPA:Suopalampi. VASIK: Vasikkajärvi.

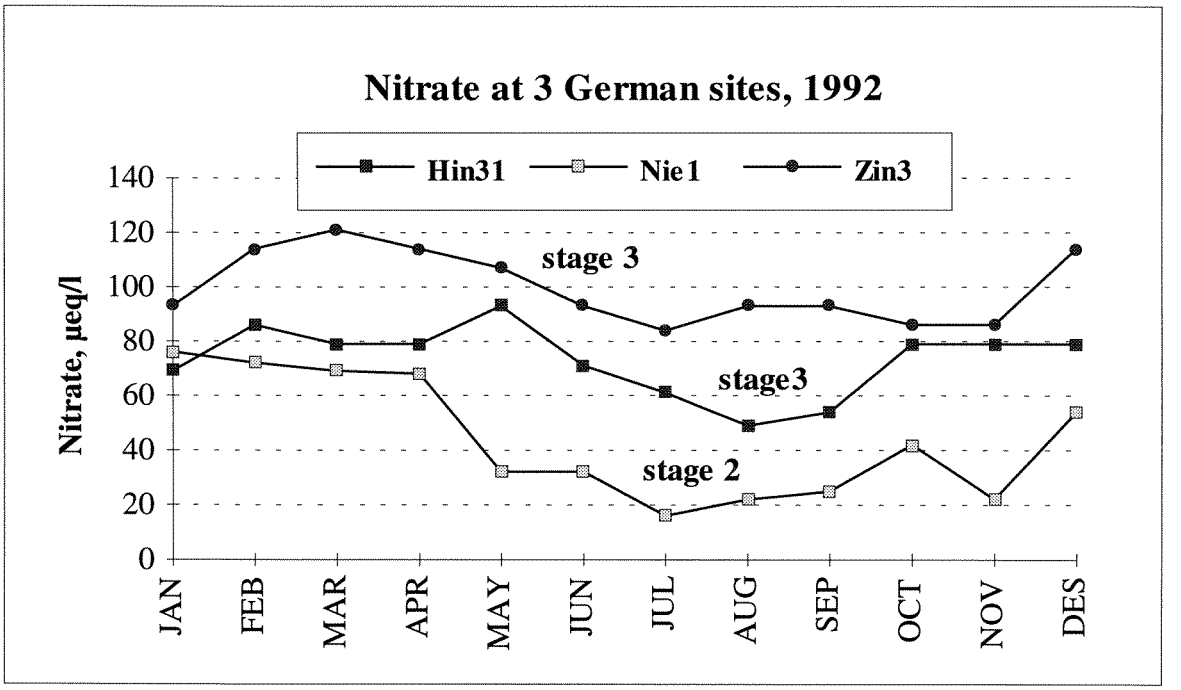

Figure 5.6. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
Hin31: Hinterer Schactenbach, East Bavaria. Nie1: Nieste, Kaufunger Wald. Zin3: Zinnbach, Fichtelsgebirge.

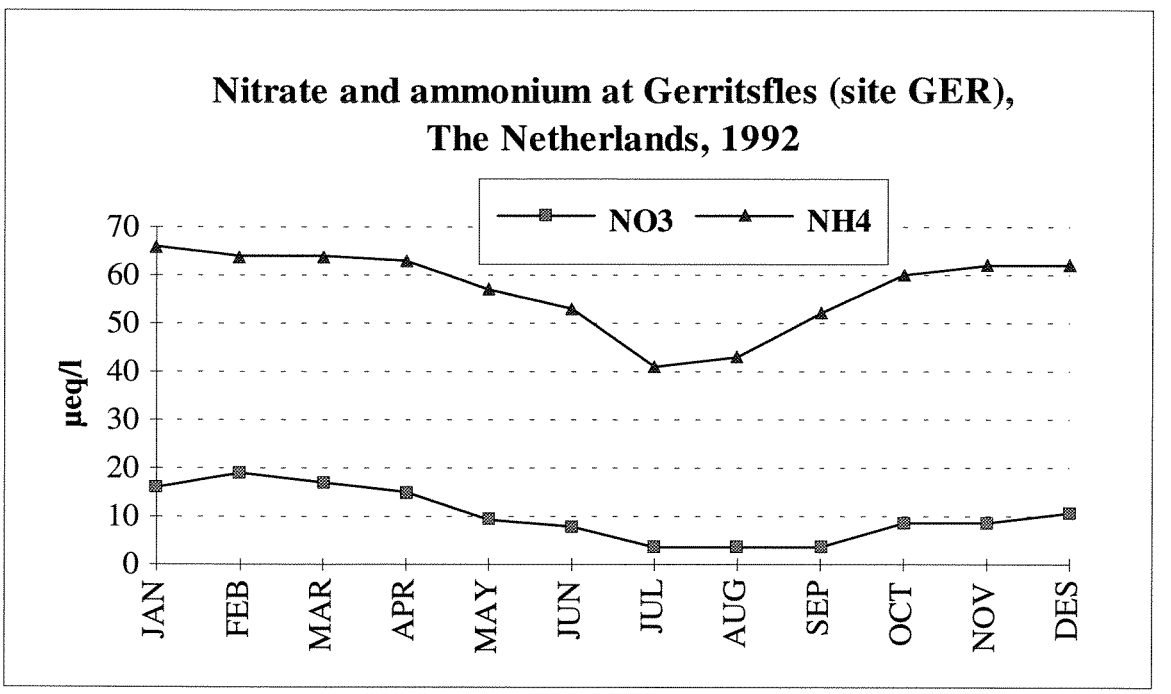

Figure 5.7. Annual pattern of nitrate and ammonium concentrations (monthly averages) at Gerritsfles, The Netherlands.
Due to extremely high ammonium concentrations, the site is considered to be in Stage 3 of nitrogen saturation.

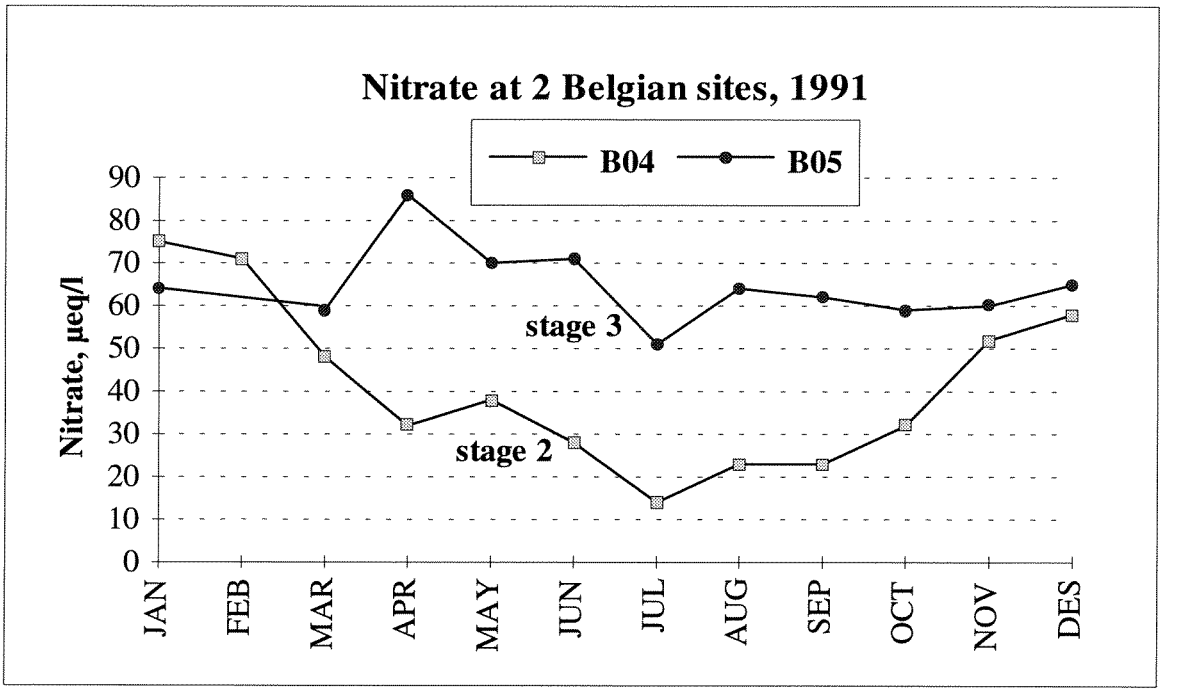

Figure 5.8. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
B04: Helle River, Jalhay, Schornstein. B05: Gileppe Lake, Jalhay.

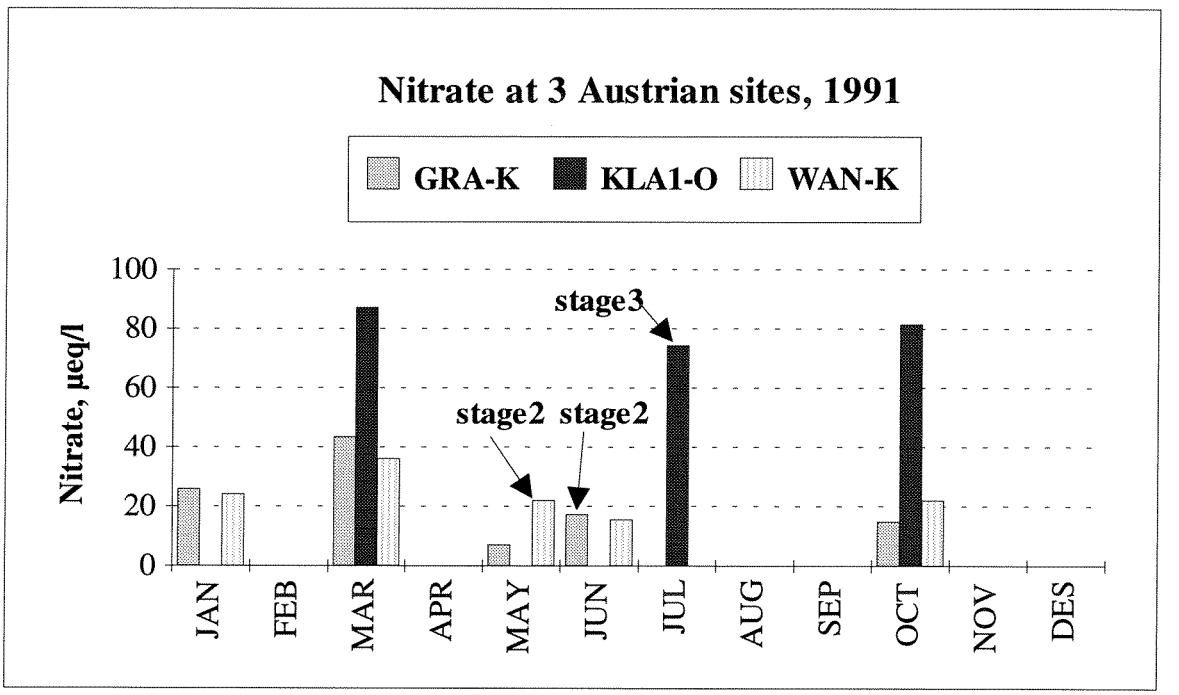

Figure 5.9. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
GRA-K: Gradenbach, Kaernten. KLA1-O: Klafferbach, Rehberg, Upper-Austria, WAN-K: Wangenitzbach, Kaernten.

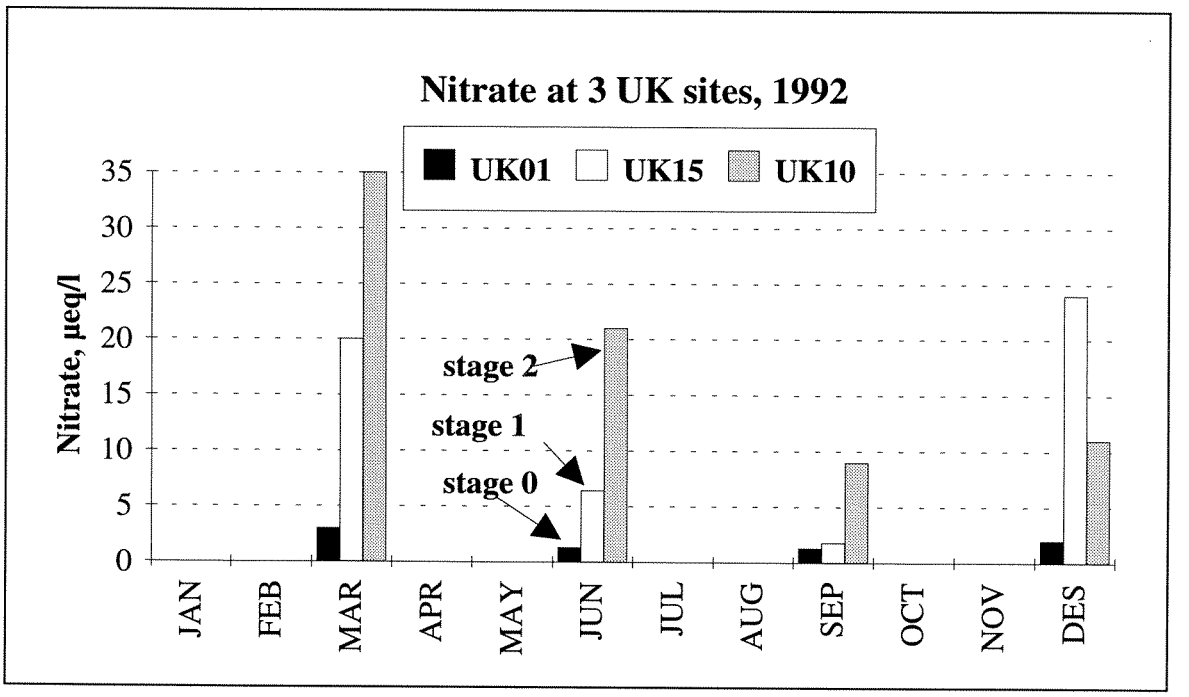

Figure 5.10. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
UK01: Loch Coire nan Arr, Scotland. UK15: Llyn Llagi, Wales.
UK10: Scoat Tarn, England.

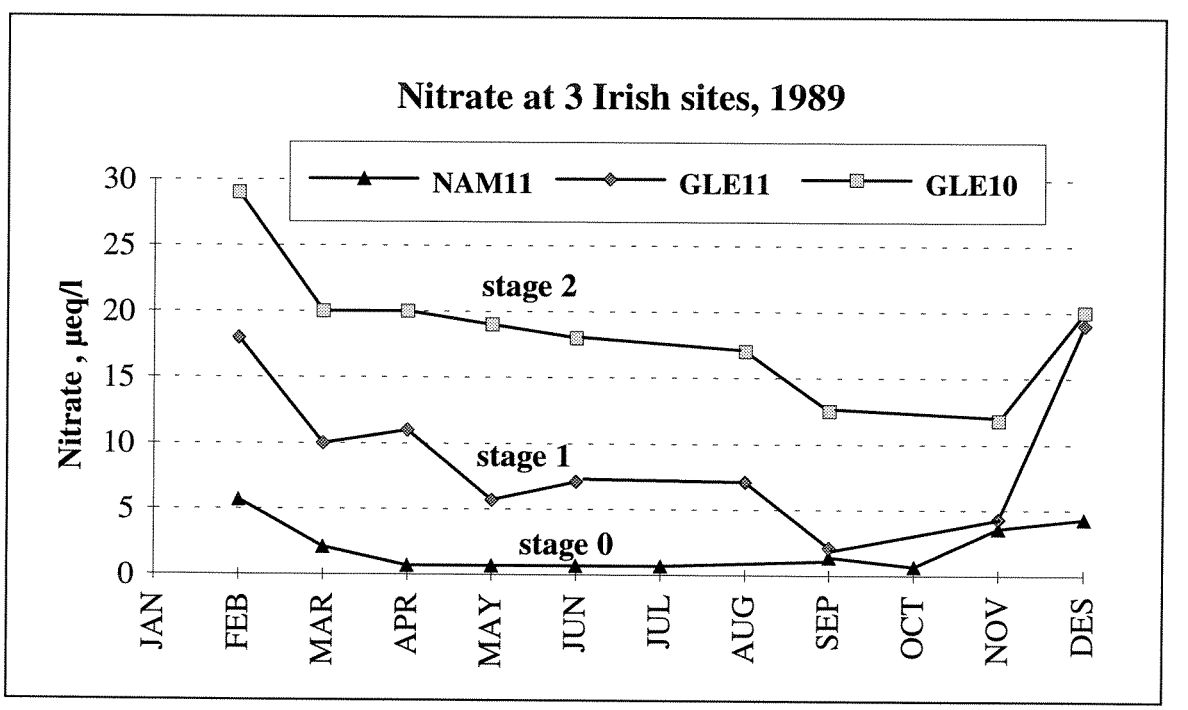

Figure 5.11. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
NAM11:Lough Naminna, Inflow 1. GLE11: Glendalough, Lake Upper, Inflow 1.
GLE10: Glendalough, Lake Upper, Mid Lake.

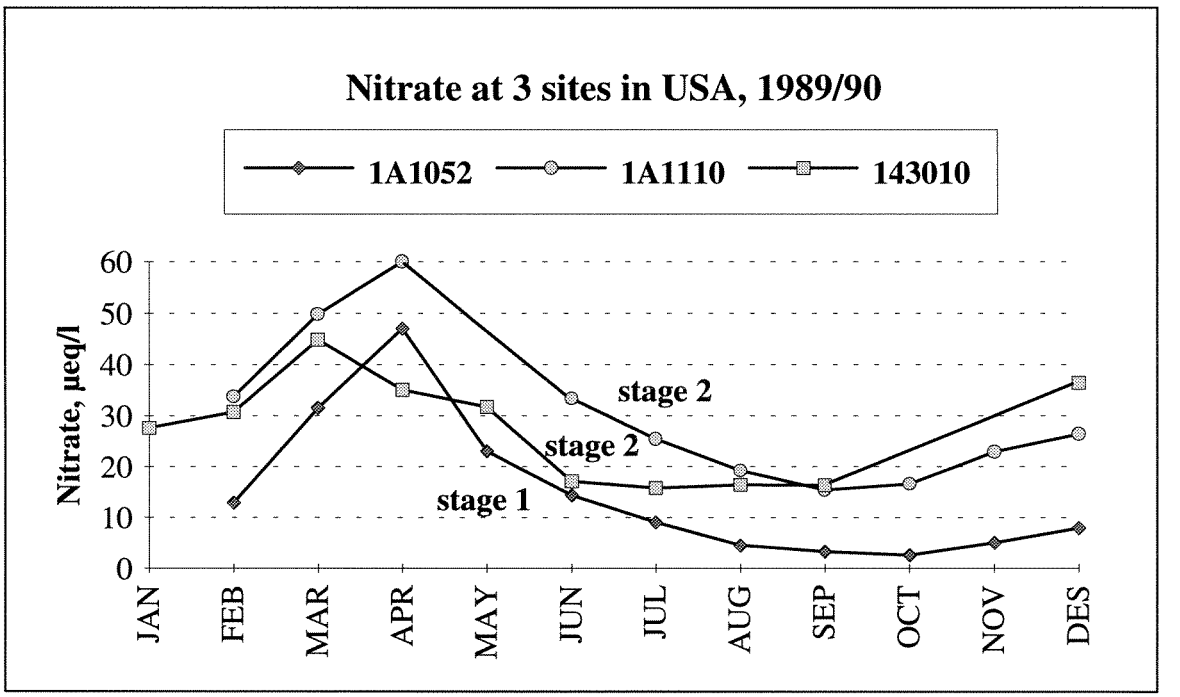

Figure 5.12. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
1A1052: Arbutus Lake, Adirondack, New York. 1A1110: Lake Rondaxe, Adirondack. 143010: East Branch Neversink, Catskill Mountain.

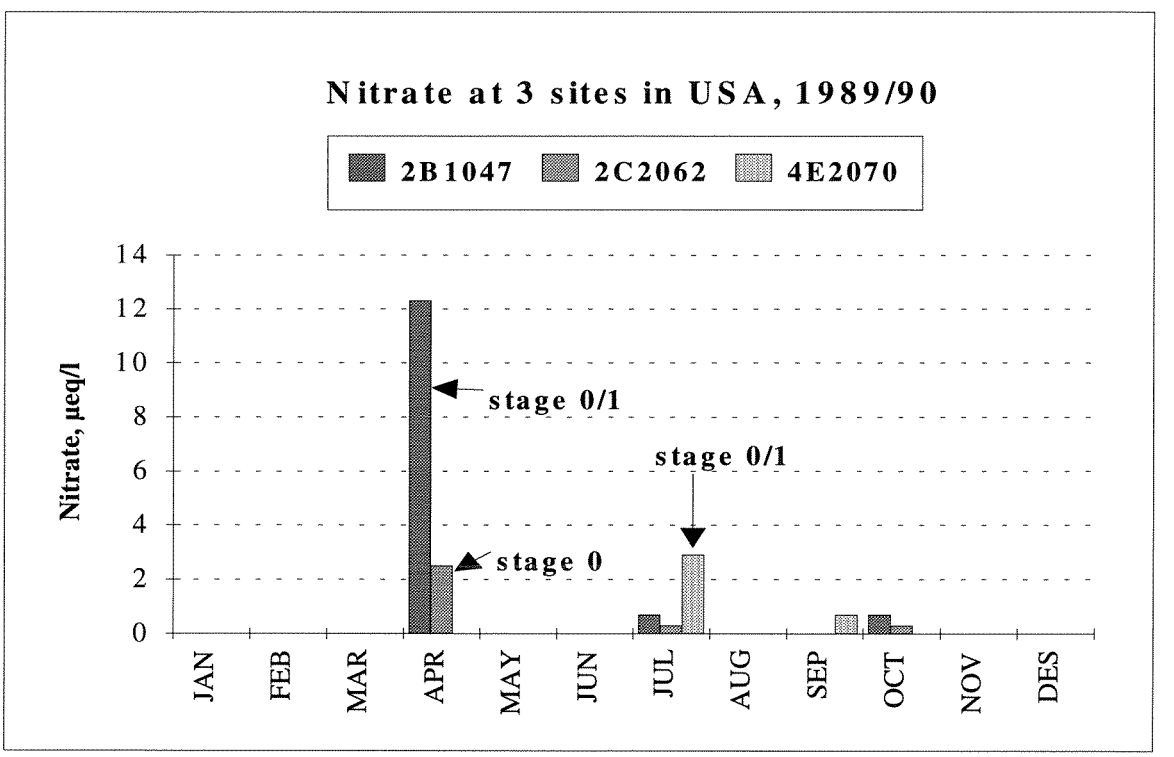

Figure 5.13. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
2B1047: Johnson Lake, Michigan. 2C2062: Luna Lake, Wisconsion. 4E2070: Upper Sunlight Lake, Colorado.

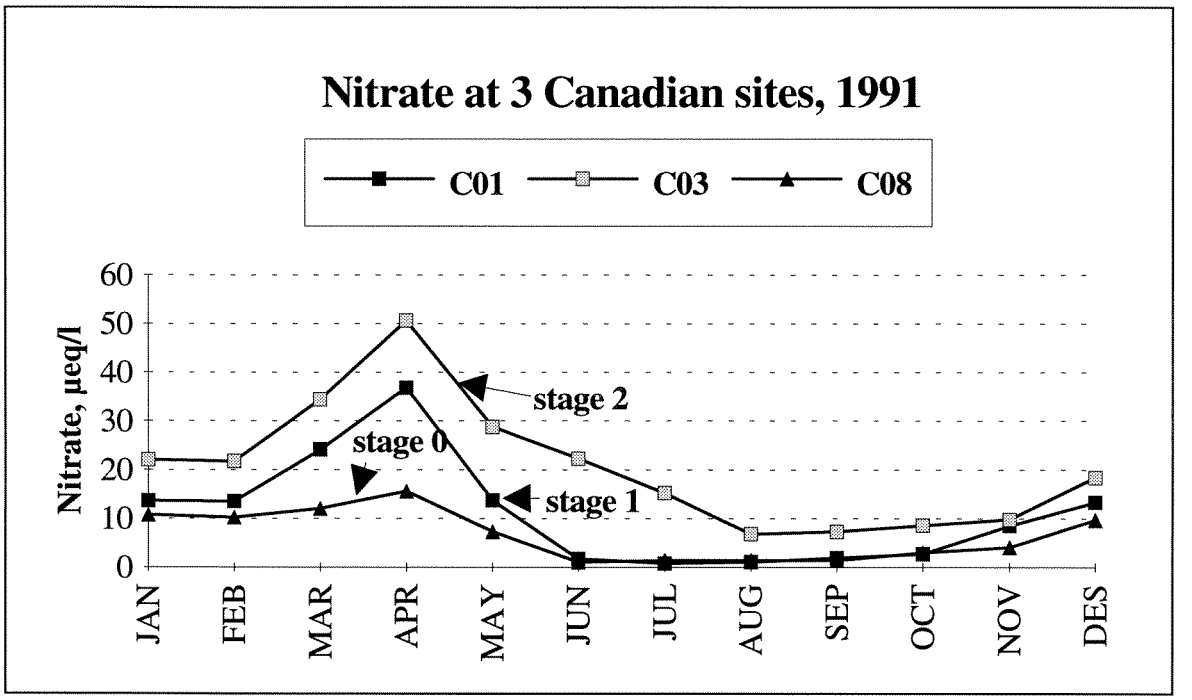

Figure 5.14. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages).
C01: Batchawana Lake, Algoma Region, Ontario. C03: Little Turkey Lake, Algoma Region, Ontario. C08: Laflamme Lake, Quebec.

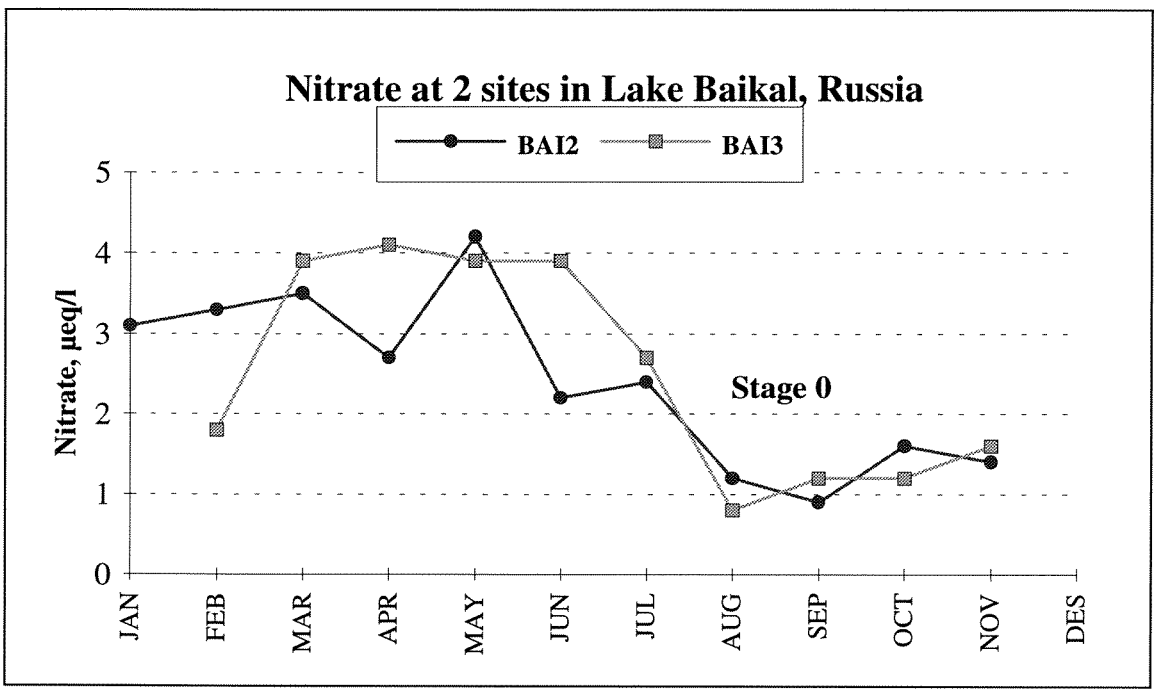

Figure 5.15. Stages of nitrogen saturation based on the annual pattern of nitrate concentrations (monthly averages, 1993).
BAI2: Lake Baikal, shallow site. BAI3: Lake Baikal, pelagic site.

A summary of the N saturation status of ICP on Waters catchmets is shown in Table 5.3. Included in this analysis are 146 sites listed in the ICP on Waters Six Year Report (Skjelkvåle et al., 1994), plus 2 new Russian and 2 new Finnish sites. Due to insufficient data, it was not possible to determine stages for 6 of these sites, leaving 144 catchments in Table 3. In the case of the Dutch sites, the seasonal patterns in NH_4^+ are used, rather than patterns of NO_3^-, because NH_4^+ is the dominant form of nitrogen in the runoff.

Table 5.3. Number of ICP catchments within each stage of nitrogen saturation.
For explanation see text.

Country	Stage 0	Stage 0/1	Stage 1	Stage 2	Stage 2/3	Stage 3	Total
Norway	4		4	2			**10**
Sweden	6		3	2			**11**
Finland	4	2					**6**
Denmark						2	**2**
Germany		1		8	1	20	**30**
Netherlands						5	**5**
Belgium				7		1	**8**
Austria				3		3	**6**
UK	1	2		3			**6**
Ireland	10		5	3			**18**
Canada	9	6		3			**18**
USA	8	4	3	7			**22**
Russia	2						**2**
Total	**44**	**15**	**15**	**38**	**1**	**31**	**144**

Some comments will be made for catchments in each of the countries listed in table 5.3.

Norway.
Stage 0 sites are found mainly in Central and Northern Norway. Sites in western Norway belong to Stage 1. Sites in Stage 2 are found in Southern and Southwestern Norway. As a whole, 80% of the sites are classified as either Stage 0 or 1.

Sweden.
Stage 0 sites are found in Eastern and Southeastern Sweden. Stage 2 sites are only found in Southwestern Sweden. 82% of the sites belong to Stage 0 or 1.

Finland.
4 Finnish sites are situated in Southeastern Finland and 2 sites in Northern Finland. All sites are classified as Stage 0 or 0/1.

Denmark.
The 2 Danish sites have very high concentrations of nitrate, and are both classified as Stage 3.

Germany.
Only one out of 30 sites is classified as Stage 0 or 1. This site (Pinnsee) is situated in Lauenburg, Northern Germany. All the other sites, situated from Hartz in Cental Germany to Black Forest in the South, belong to Stage 2 or 3, with a majority in Stage 3. Some sites also have relative high concentrations of ammonium.

The Netherlands.
The Dutch sites are particular in having ammonium as the dominant form of nitrogen in the runoff. The ammonium concentrations are very high (averge values from 0.8 to 2.6 mgN/l in 1992). The nitrate concentrations are moderate. In Table 5.1 the Dutch sites are classified according to ammonium concentrations. All sites belong to Stage 3 of nitrogen saturation.

Belgium.
7 out of 8 Belgian sites are classified as Stage 2. One belongs to Stage 3.

Austria.
All the classified Austrian sites (n=6) belong to Stage 2 or 3. The Stage 2 sites are situated in the south (Kaernten and Tirol), while the Stage 3 sites are in the north (Upper Austria). Six sites could not be classified due to lack of sufficient data.

United Kingdom.
Three of the 6 sites are classified as Stage 0 or 1. These sites are situated in Scotland and Wales. The three Stage 2 sites are situated in Scotland, England and North Ireland.

Ireland.
All the sites in the west and north (15 sites out of 18) belong to Stage 0 or 1. Stage 2 (n=3) sites are situated in the west (Glendalough).

Canada.
All the sites in Nova Scotia (n=5), Quebec (n=5) and Ontario outside Algoma Region (n=4) are classified as Stage 0 or 0/1. The three Stage 2 sites are situated in Algoma Region. As a whole 83% of the 18 Canadian sites are classified as Stage 0 or 1.

USA.
All classified sites (n=13) in Maine, Michigan, Minnesota, Wisconsin and Colorado (except one) belong to Stage 0 or 1. Stage 2 sites are situated in the Adirondack Mts., New York (4 out of 7 sites), Catskill Mts., New York (both sites) and 1 site in Colorado. As a whole 68% of the US sites are classified as Stage 0, 0/1 or 1. The remaining sites are in Stage 2.

Russia.
The 2 sites in Lake Baikal are both typical Stage 0 sites.

Nearly half (70 of 144) of the ICP catchments exhibit a high degree of nitrogen saturation (Stage 2 or 3). Such sites are found in all participating countries except Finland and Russia. All ICP on Waters sites in Denmark, Belgium, the Netherlands and Austria, and 29 out of 30 German sites, exhibited Stage 2 or Stage 3 patterns.

The relationship between rates of nitrogen deposition (estimated from EMEP grid data) and nitrogen saturation stages in European ICP on Waters sites is shown in Figure 5.16. The mixed classifications (e.g. Stages 0/1 and 2/3) are not included. There is a clear connection between N deposition values and stage classification. At Stage 0 and 1 catchments only 7 out of 35 have N deposition values above 0.8 gN $m^{-2}yr^{-1}$, while at Stage 2 only 2 out of 25 have deposition values below 1.0 g $m^{-2}yr^{-1}$. All Stage 3 sites have deposition values above 1.5 gN $m^{-2}yr^{-1}$·. While these results suggest that a threshold value of N deposition, above which significant N saturation can exist, occurs at approximately 1 g $m^{-2}yr^{-1}$, it should be reiterated that deposition is only one factor influencing NO_3^- leaching from catchments. Nitrogen demands on the part of vegetation (controlled largely by forest age and health) and on the part of soils (controlled largely by pool sizes for nitrogen and carbon) must be satisfied before N saturation can occur. Some consideration should be given to these factors when identifying critical levels of N deposition. Because information on forest status and soil chemistry is unavailable for most ICP on Waters catchments, the data in Figure 5.16 indicate only a strong influence of rates of N deposition on the stage of N saturation, but cannot precisely identify what an appropriate threshold value of N deposition is.

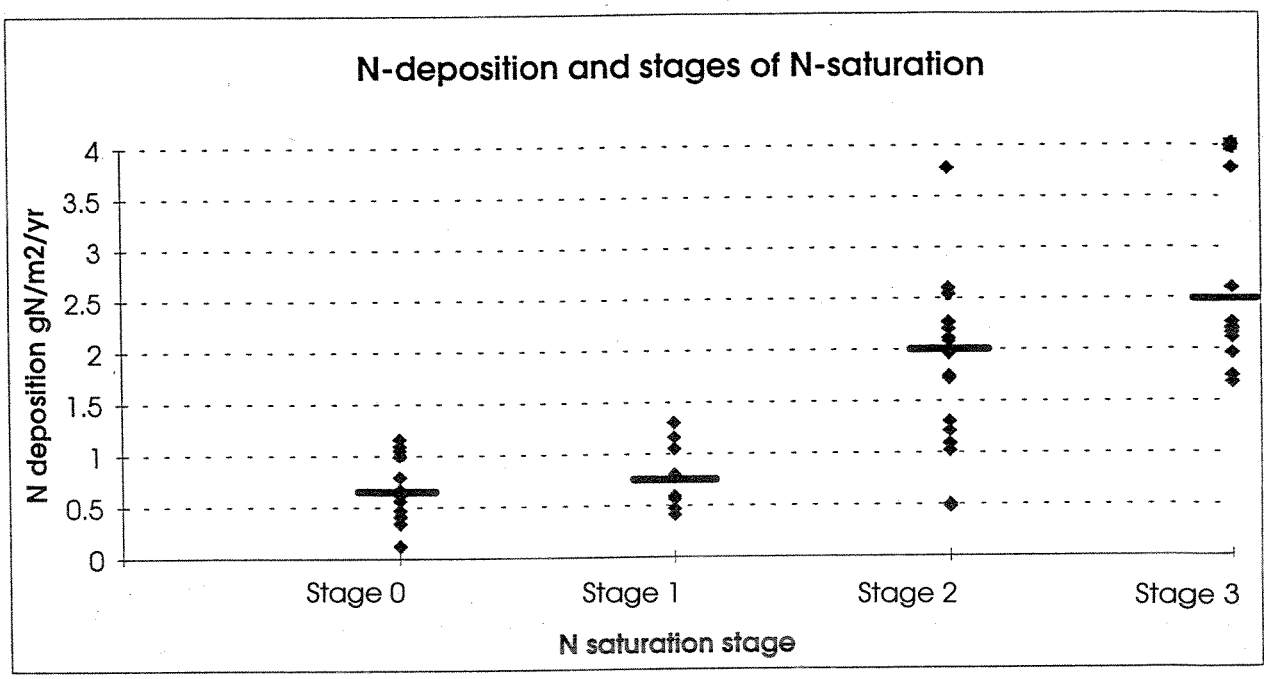

Figure 5.16. Relationship between nitrogen deposition (wet + dry, estimated from EMEP grid data) and stages of nitrogen saturation for European ICP on Waters sites.
Average values are indicated by horizontal bars.

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APPENDIX

ICP Water sites and current database status (October 1994).

ICP Water sites and current database status (October 1994).

Station name	file	Chemistry code	year	Site data	Biology code	Biology year
Austria, Kaernten, Doesener See	IA-AU	DOS-K	1989-1991	x		
Austria, Kaernten, Gradenbach	IA-AU	GRA-K	1989-1991	x		
Austria, Kaernten, Hairlacher See	IA-AU	HAI-T	1988-1991	x		
Austria, Kaernten, Melniksee	IA-AU	MEL-K	1988-1991	x		
Austria, Kaernten, Wangenitzbach	IA-AU	WAN-K	1990-1991	x		
Austria, Tirol, Gossenkoelle See	IA-AU	GKS-T	1988-1991	x		
Austria, Tirol, Mutterberger See	IA-AU	MUT-T	1988-1991	x		
Austria, Tirol, Piburger Bach	IA-AU	PIB-T	1988-1990			
Austria, Tirol, Schwarzee ob Soelden	IA-AU	SOS-T	1989-1991	x		
Austria, Upperaustria, Klafferbach, Rehberg	IA-AU	KLA1-0	1989-1991	x	15 1-5	1989
Austria, Upperaustria, Stingbach vor Klafferbach	IA-AU	KLA2-0	1989-1991	x	16 1-3	1989
Austria, Upperasutria, Klafferbach, Brucke, Freundorf	IA-AU	KLA3-0	1989-1991	x	14 1-3	1989
Austria, Upperaustria, Ramenbach, Brucke Hinterberg	IA-AU	KLA4-0	1989-1991			
Belgium, Eupen, Getz river, Small dam	IA-BE	B03	1987-1991	x	1 2	1988
Belgium, Eupen, Vesdre river, Bellesfort	IA-BE	B02	1987-1991	x	1 1	1988
Belgium, Eupen, Vesdre, Dam	IA-BE	B01	1987-1991	x		
Belgium, Jalhay, Gileppe river, Chemin des charbonniers	IA-BE	B06	1987-1991	x	1 4	1988
Belgium, Jalhay, Helle river, Schornstein	IA-BE	B04	1987-1991	x	1 3	1988
Belgium, Jalhay, Lake Gileppe	IA-BE	B05	1987-1991	x		
Belgium, Jalhay, Louba river, Les Hes	IA-BE	B07	1987-1991	x	1 5	1988
Belgium, Jalhay, Soor river, Small dam	IA-BE	B08	1987-1991	x	1 6	1988
Belgium, Raeren, Steinbach						1990
Canada, Nova Scotia, Beaverskin Lake	IA-CA	C14	1970-1992	x		
Canada, Nova Scotia, Kejimkujik Lake	IA-CA	C13	1970-1982	x		
Canada, Nova Scotia, Little Red Lake	IA-CA	C12	1979-1982	x		
Canada, Nova Scotia, Mount Tom Lake	IA-CA	C10	1980-1982	x		
Canada, Nova Scotia, Mountain Lake	IA-CA	C11	1970-1982	x		
Canada, Ontario, Algoma Region. Batchawana Lake	IA-CA	C01	1980-1991	x		
Canada, Ontario, Algoma Region, Little Turkey Lake	IA-CA	C03	1980-1991	x		
Canada, Ontario, Algoma Region, Turkey Lake	IA-CA	C04	1980-1991	x		
Canada, Ontario, Algoma Region, Wishart Lake	IA-CA	C02	1980-1991	x		
Canada, Ontario, Lake 111	IA-CA	CA111	1987-1990		1 1-5	1990
Canada, Ontario, Lake 224	IA-CA	CA224	1987-1990		2 1-5	1990
Canada, Ontario, Lake 239	IA-CA	CA239	1987-1990		3 1-5	1990
Canada, Ontario, Lake 262	IA-CA	CA262	1987-1990		4 1-5	1990
Canada, Ontario, Lake 305	IA-CA	CA305	1987-1990			
Canada, Ontario, Lake 373	IA-CA	CA373	1987-1990		5 1-5	1990
Canada, Quebec, Laflamme Lake	IA-CA	C08	1981-1991	x		
Canada, Quebec, Parc de la Jacques-Cart., Lac Bonnevlle	IA-CA	C07	1981-1991	x		
Canada, Quebec, Reserve faunique des Laur., Lac MacCeod	IA-CA	C09	1982-1991	x		
Canada, Quebec, Reserve faunique des laur., Lac Josselin	IA-CA	C06	1982-1991	x		
Canada, Quebec, Reserve faunique des Laur., Lac Veilleux	IA-CA	C05	1982-1991	x		
Denmark, Sepstrup Sande, Skaerbaek, Station A	IA-DA	SK297A	1989-1990	x		
Denmark, Sepstrup Sande, Skaerbaek, Station B	IA-DA	SK110B	1976-1993	x		
Denmark, Sepstrup Sande, Skaerbaek, Station C	IA-DA	SK298C	1989-1990	x		
Denmark, Sestrup Sande, Skaerbaek, Station D	IA-DA	SK299D	1989-1991	x		
Denmark, Sepstrup Sande, Skaerbaek, Station E	IA-DA	SK037E	1987-1990	x		
Denmark, Sepstrup Sande, Skaerbaek, Station F	IA-DA	SK038F	1987-1993	x		
Finland, Hirvilampi	IA-SF	SF01	1978-1993	x	2 3	1988
Finland, Kivijaervi	IA-SF	SF04	1962-1993	X		
Finland, Maekilampi	IA-SF	SF03	1978-1993	x	2 1	1988
Finland, Vuorilampi	IA-SF	SF02	1978-1993	x	2 2	1988
FRG, Black Forest, Duerreychblach	IA-FRG	Due6	1987-1992	x	7 6	1985-1988
FRG, Black Forest, Goldersbach	IA-FRG	Go17	1986-1992	x	7 7	1985-1988
FRG, Black Forest, Huettenbaechle	IA-FRG	Hue2	1986-1991	x	7 2	1985-1988
FRG, Black Forest, Kaltenbach	IA-FRG	Kal4	1988-1991			
FRG, Balck Forest, Kaltenbach	IA-FRG	Kal5	1986-1989	x	7 5	1985-1988
FRG, Black Forest, Kinzigtalsperre	IA-FRG	Kin3	1988-1989			

Station name	file	Chemistry code	year	Site data	Biology code	Biology year
FRG, Black Forest, Kleine Kinzig	IA-FRG	Kle1	1986-1992	x	7 1	1985-1987
FRG, Black Forest, Kleine Kinzig	IA-FRG	Kle3	1987-1987			
FRG, Colditzer Forst, Ettelsbach	IA-FRG	Ett6	1992-1992	x		
FRG, Dahlener Heide, Heidelbach	IA-FRG	Hei7	1992-1992	x		
FRG, East Bavaria, Grosse Ohe	IA-FRG	Gro33	1979-1992	x	8 33	1985-1988
FRG, East Bavaria, Hinterer Schactenbach	IA-FRG	Hin31	1983-1992	x	8 31	1985-1988
FRG, East Bavaria, Rachelsee	IA-FRG	Rac40	1984-1993	x		
FRG, East Bavaria, Seebach	IA-FRG	See30	1983-1992	x	8 30	1985-1988
FRG, East Bavaria, Vorderer Schachtenbach	IA-FRG	Vor32	1983-1992	x	8 32	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal1	1986-1991	x	8 1	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal2	1986-1992	x	8 2	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal3	1986-1992	x	8 3	1988-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal5	1986-1987			
FRG, East Bavaria, Waldnaab	IA-FRG	Wal6	1988-1988			
FRG, East Bavaria, Waldnaab	IA-FRG	Wal8	1986-1992	x	8 8	1988-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal9	1986-1992	x	8 9	1988-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal11	1986-1988		8 1	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal12	1986-1991	x	8 11	1985-1988
FRG, East Bavaria, Wlaldnaab	IA-FRG	Wal14	1986-1992	x	8 14	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal15	1987-1987		8 15	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal16	1986-1991	x	8 16	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal17	1986-1987	x	8 17	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal18	1986-1991	x	8 18	1985-1988
FRG, East Bavaria, Waldnaab	IA-FRG	Wal15a	1987-1987			
FRG, East Bavaria, Waldnaab	IA-FRG	Wal17a	1987-1988			
FRG, East Bavaria, Waldnaab	IA-FRG	Wal17b	1988-1991			
FRG, Elbsandsteingebirge, Taubenbach	IA-FRG	Tau5				
FRG, Erzegebirge, Grosse Pyra	IA-FRG	Gro2	1992-1992	x		
FRG, Erzegebirge, Neunzehnhain	IA-FRG	Neu8	1992-1992	x		
FRG, Erzegebirge, Rote Pockan	IA-FRG	Rot3	1992-1992	x		
FRG, Erzegebirge, Sosa	IA-FRG	Sos9	1992-1992	x		
FRG, Erzegebirge, Wilde Weisseritz	IA-FRG	Wil4	1992-1992	x		
FRG, Erzegebirge, Wolfsbach	IA-FRG	Wol1	1992-1992			
FRG, Fichtelgebirge, Eger	IA-FRG	Ege1	1982-1992	x		
FRG, Fichtelgebirge, Roeslau	IA-FRG	Roe2	1982-1992	x		
FRG, Fichtelgebirge, Zinnbach	IA-FRG	Zin3	1982-1992	x		
FRG, Harz, Alte Riefensbeek	IA-FRG	AltR1	1986-1991	x	2 3	1986-1987
FRG, Harz, Alte Riefensbeek	IA-FRG	AltR2	1986-1991	x	2 4	1986-1987
FRG, Harz, Alte Riefensbeek	IA-FRG	AltR3	1986-1991	x	2 5	1986-1987
FRG, Harz, Dicke Bramke	IA-FRG	Dic	1988-1992			
FRG, Harz, Grosse Bode	IA-FRG	Gro14	1988-1992	x		
FRG, Harz, Grosse Soese	IA-FRG	GRoS1	1986-1991	x	2 6	1986-1987
FRG, Harz, Grosse Soese	IA-FRG	GroS2	1986-1992	x	2 7	1986-1987
FRG, Harz, Grosse Soese	IA-FRG	GroS3	1986-1991	x	2 8	1986-1987
FRG, Harz, Lange Bramke	IA-FRG	LanL1	1989-1989	x	2 11	1986-1987
FRG, Harz, Lange Bramke	IA-FRG	Lan12	1988-1991	x	2 12	1986-1987
FRG, Harz, Lange Bramke	IA-FRG	Lan13	1988-1991	x		
FRG, Harz, Mollentalbach	IA-FRG	Mol10	1986-1991	x	2 10	1986-1988
FRG, Harz, Grosse Schacht	IA-FRG	Sch9	1986-1991	x	2 9	1986-1987
FRG, Harz, Varleybach	IA-FRG	Var1	1986-1991	x		
FRG, Harz, Varleybach	IA-FRG	Var2	1986-1991	x		
FRG, Harz, Warme Bode	IA-FRG	War14		x		
FRG, Harz, Warme Bode	IA-FRG	War15	1988-1991	x		
FRG, Hunsrueck, Grafenbach	IA-FRG	Gra5	1982-1992	x	9 5	1985-1988
FRG, Hunsrueck, Schwollbach	IA-FRG	Sch10	1982-1991	x	9 10	1985-1988
FRG, Hunsrueck, Traunbach	IA-FRG	Tra1	1982-1992	x	9 1	1985-1988
FRG, Hunsrueck, Traunbach	IA-FRG	Tra2	1984-1991	x	9 2	1985-1988
FRG, Kaufunger Wald, Nieste	IA-FRG	Nie1	1987-1992	x	3 1	1988-1988
FRG, Kaufunger Wald, Nieste	IA-FRG	Nie2	1987-1991	x	3 2	1988-1988
FRG, Kaufunger Wald, Nieste	IA-FRG	Nie3	1987-1992	x	3 3	1988-1988
FRG, Kaufunger Wald, Nieste	IA-FRG	Nie4	1987-1991	x	3 4	1988-1988
FRG, Kaufunger Wald, Nieste	IA-FRG	Nie5	1987-1992	x	3 5	1988-1988
FRG, Lauenburg, Garrensee	IA-FRG	Gar1	1986-1991	x	1 1	1986-1988
FRG, Lauenbrug, Pinnsee	IA-FRG	Pin3	1986-1992	x	1 3	1986-1988
FRG, Lauenburg, Ploetschersee	IA-FRG	Plo2	1986-1991	x	1 2	1986-1988
FRG, Odenwald, Schmerbach	IA-FRG	Sch1	1984-1992	x	6 1	1988-1988
FRG, Odenwald, Schmerbach	IA-FRG	Sch3	1985-1992	x	6 2	1988-1988
FRG, Odenwald, Schmerbach	IA-FRG	Sch4	1988-1991	x	6 3	1988-1988
FRG, Odenwald, Schmerbach, Hiltersklinger Teich	IA-FRG	Sch2	1985-1991	x	6 4	1988-1988
FRG, Rothaargebirge, Elberndorfer Bach	IA-FRG	Elb1	1986-1992	x	4 1	1986-1988

Station name	file	Chemistry code	year	Site data	Biology code	Biology year
FRG, Rothaargebirge, Zinse	IA-FRG	Zin2	1986-1992	x	4 2	1986-1988
FRG, Taunus, Rombach	IA-FRG	Rom1	1988-1991	x	5 1	1988-1988
FRG, Taunus, Rombach	IA-FRG	Rom2	1986-1992	x	5 2	1988-1988
FRG, Taunus, Rombach	IA-FRG	Rom3	1986-1992	x	5 3	1988-1988
FRG, Taunus, Rombach	IA-FRG	Rom4	1987-1991	x	5 4	1988-1988
FRG, Taunus, Silberbach	IA-FRG	Sil5	1986-1991	x	5 5	1988-1988
Hungary, Matra Mountains, Csorret	IA-HU	CSORR	1988-1993			
Ireland, Doo Lough, Inflow 1	IA-IR	DOO11	1987-1989	x		
Ireland, Doo Lough, Inflow 2	IA-IR	DOO12	1987-1989	x		
Ireland, Doo Lough, Inflow 3	IA-IR	DOO13	1987-1989	x		
Ireland, Doo Ough, Mid Lake	IA-IR	DOO10	1984-1989	x		
Ireland, Glendalough, Lake Upper, Inflow 1	IA-IR	GLE11	1984-1993	x	1 1	1987-1988
Ireland, Glendalough, Lake Upper, Inflow 2	IA-IR	GLE12	1984-1993	x	1 3	1987-1988
Ireland, Glendalough, Lake Upper, Inflow 3	IA-IR	GLE13	1987-1993	x		
Ireland, Glendalough, Lake Upper, Mid Lake	IA-IR	GLE10	1984-1993	x		
Ireland, Lough Maumwee, Inflow 1	IA-IR	MAU11	1984-1993	x	2 1	1988-1989
Ireland, Lough Maumwee, Inflow 2	IA-IR	MAU12	1984-1993	x	2 2	1988-1989
Ireland, Lough Maumwee, Mid Lake	IA-IR	MAU10	1984-1993	x	2 3	1988-1989
Ireland, Lough Naminna, Inflow 1	IA-IR	NAM11	1987-1993	x	4 1	1988-1989
Ireland, Lough Naminna, Mid Lake	IA-IR	NAM10	1987-1993	x	4 4	1988-1989
Ireland, Lough Veagh, Mid Lake	IA-IR	VEA10	1988-1993		5 5	1988-1989
Ireland, Lough Veagh, Inflow 1	IA-IR	VEA11	1988-1993		5 1	1988-1989
Ireland, Lough Veagh, Inflow 2	IA-IR	VEA12	1988-1993		5 2	1988-1989
Ireland, Lough Veagh, Inflow 3	IA-IR	VEA13	1988-1993		5 3	1988-1989
Ireland, Lough Veagh, Inflow 4	IA-IR	VEA14	1988-1993		5 4	1988-1989
Norway, Aust-Agder, Birkenes stream, Birkenes	BIE01		1972-1993	x		
Norway, Aust-Agder, Tovdalselva, Boen bruk	OVELV	7 1	1980-1993	x		
Norway, Buskerud, Langtjern, outflow	LAE01		1972-1993	x		
Norway, Finnmark, Dalelva, Jarfjord	DALELV	1	1988-1993	x		
Norway, Oppland, Aurdoela, Aurdalsfjorden	OVELV	90 1	1986-1993	x		
Norway, Rogaland,Ogna					3 1-10	1984-1988
Norway, Rogaland, Vikedalselva, Vindafjord	OVELV	32 9	1982-1993	x	6 1-18	1987-1988
Norway, Sogn og Fjordane, Gaular, Eldalen	OVELV	57 3	1980-1993		17 1-17	1985-1988
Norway, Sogn og Fjordane, Nausta, Naustdal	OVELV	34 1	1980-1993	x	20 1-20	1985-1988
Norway, Sogn og Fjordane, Trodoela	OVELV	34 5	1984-1993	x	20 7	1986-1988
Norway, Telemark, Storgama, Outflow	STE01		1974-1993	x		
Norway, Vest-Agder, Farsund Gjaervollstadvatn and Saudlandsvatn					2 1-7	1981-1988
Russia, Baikal, shallow	IA-RU	BAI2	1991-1993	x		
Russia, Baikal, pelagic	IA-RU	BAI3	1991-1993	x		
Russia, Kola, Chibiny mountain, Lake Verchnee	IA-RU	KOLA1	1993-1993	x		
Russia, Kola, Chuna mountain, Lake Elnun	IA-RU	KOLA2	1993-1993	x		
Russia, Kola						1988-1988
Russia, Kolos-yoki						1988-1990
Russia, Kovdor						1988-1990
Russia, Lovosero						1988-1990
Russia, Lotta						1988-1990
Russia, Niva						1988-1990
Russia, Pechenga						1988-1990
Sweden, Alsteraan, Getebo	IA-SV	S02	1985-1992	x		
Sweden, Alsteraan, Stroemsborg	IA-SV	S03	1985-1992	x		
Sweden, Anraasen, Haersvatn	IA-SV	S04	1984-1992	x		
Sweden, Brunnsjoen	IA-SV	S08	1984-1992	x	1 3	1986-1988
Sweden, Delaangersaan, Iggersund	IA-SV	S01	1984-1992	x		
Sweden, Fiolen	IA-SV	S09	1984-1992	x	1 1	1986-1988
Sweden, Fraecksjoen	IA-SV	S11	1984-1992	x	1 5	1986-1988
Sweden, Haersvatn	IA-SV	S12	1984-1992	x	1 4	1986-1988
Sweden, Moecklasjoen	IA-SV	S07	1984-1987	x		
Sweden, Stensjoen	IA-SV	S06	1985-1992	x	1 6	1986-1988
Sweden, Storasjoen	IA-SV	S10	1984-1992	x	1 2	1986-1988
Sweden, Tvaeringen	IA-SV	S05	1984-1992	x		

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The Netherlands, Achterste Goorven, station A	IA-NE	AGA	1958-1992	x		
The Netherlands, Achterste Goorven, station B	IA-NE	AGB	1925-1992	x		
The Netherlands, Achterste Goorven, station E	IA-NE	AGE	1975-1992	x		
The Netherlands, Gerritsfles	IA-NE	GER	1991-1992	x		
The Netherlands, Kliplo	IA-NE	KLI	1958-1992	x		
UK, N. Ireland, Blue Loch	IA-UK	UK21	1990-1993			
UK, England, Scoat Tarn	IA-UK	UK10	1988-1993		1 1	1988-1988
UK, Scotland, Loch Coire nan Arr	IA-UK	UK01	1988-1993		5 1	1988-1988
UK, Scotland, Lochnager	IA-UK	UK04	1988-1993			
UK, Scotland, Round of Glenshead	IA-UK	UK07	1988-1993		5 1	1988-1988
UK, Wales, Wales, Llyn Llagi	IA-UK	UK15	1988-1992		7 1	1988-1988
USA, Colorado, Seven Lakes	IA-US	4E2009	1985-1991	x		
USA, Colorado, Summit Lake	IA-US	4E2060	1985-1991	x		
USA, Colorado, Sunlight Lake	IA-US	4E2070	1985-1991	x		
USA, Colorado, White Dome Lake	IA-US	4E2071	1985-1991	x		
USA, Maine, Little Long Pond	IA-US	1E1132	1982-1991	x		
USA, Maine, Tilden Pond	IA-US	1E1133	1982-1991	x		
USA, Michigan, Andrus	IA-US	2B3082	1983-1991	x		
USA, Michigan, Buckeye	IA-US	2B2102	1983-1991	x		
USA, Michigan, Johnson	IA-US	2B1047	1983-1991	x		
USA, Minnesota, Cruiser	IA-US	2A2063	1983-1991	x		
USA, New York, Adirondack Mountain, Arbutus	IA-US	1A1052	1983-1991	x		
USA, New York, Adirondack Mountain, Constable	IA-US	1A1017	1982-1991	x		
USA, New York, Adirondack Mountain, Dart Lake	IA-US	1A1106	1982-1991	x		
USA, New York, Adirondack Mountain, Heart Lake	IA-US	1A1102	1982-1991	x		
USA, New York, Adirondack Mountain, Lake Rondaxe	IA-US	1A1110	1982-1991	x		
USA, New York, Adirondack Mountain, Moss Lake	IA-US	1A1109	1982-1991	x		
USA, New York, Adirondack Mountain, Otter Lake	IA-US	1A2078	1982-1991	x		
USA, New York, Catskill M., East Branc Neversink, Mid.	IA-US	143010	1983-1989	x		
USA, New York, Catskill m., High Falls Brook	IA-US	143105	1983-1989	x		
USA, Wisconsion, Luna	IA-US	2C2062	1983-1991	x		
USA, Wisconsion, Nichols	IA-US	2C1069	1983-1991	x		
USA, Wisconsion, Sand	IA-US	2C1068	1983-1991	x		

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