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Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters:
May the methodologies of and the synergies between the two approaches be improved?

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Norwegian Institute for Water Research

REPORT

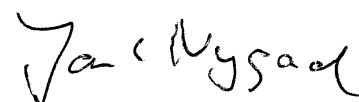| Title Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters. May the methodologies of and the synergies between the two approaches be improved?	NIVA Project No. O-25800-15	Date December 2006
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Abstract

The report is linked to the work within the OSPAR Convention, on quantifying nutrient losses from rivers to the sea. Since 1990, reporting on discharges/losses and inputs of nitrogen and phosphorus have been high on the international arena. There are, however, different practices among countries in terms of quantification and reporting on riverine inputs into marine waters. Nutrient inputs from land to sea may basically be estimated through two different approaches – the load orientated approach and the source orientated approach. In this report, these two approaches are studied in more detail, through comparisons of the results obtained by using the two approaches, and through an analysis of the sources of errors in each approach. The potential sources of errors treated here include frequency of sampling and choice of interpolation methodology for the load orientated approach; and improvements of statistical areas, improvement of coefficients, retention in lakes, and more complete datasets on sources for the source orientated approach.

4 keywords, Norwegian	4 keywords, English
1. Kilde- og tilførselstilnærming – ulike metoder 2. Næringssalttilførsel til hav 3. Overvåking 4. Direkte tilførsler	1. Load and Source Orientated Approaches 2. Nutrient inputs to the sea 3. Monitoring 4. Direct discharges

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Preface

Year 2007 will require operational monitoring programmes within the scope of the EC Water Framework Directive. It seems particularly appropriate to address the issue of targeted and harmonised Norwegian monitoring programmes in order to achieve a consolidated management of Norwegian water resources. In this context it is paramount to success to be able to optimise purely scientific issues, bridge the gap between the scientific and management communities, and show the societal advantages of a consolidated monitoring of our water bodies.

This report claims to make one step towards such optimisation and 'gap bridging'. In this context it is important to give due honours to the Norwegian Pollution Control Authorities (SFT) and the officer in charge, Jon L. Fuglestad, who is always ready to discuss new ideas from the scientific communities. This becomes even more important with regard to the main issue of this report, namely Load and Source Orientated Approaches to quantify nutrient losses (discharges/inputs), as Norway is presently in charge of the OSPAR INPUT Working Group which deals with riverine inputs' issues, i.e. Load Orientated Approach.

Oslo December 2006

Stig A. Borgvang
NIVA

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General definitions

Load Orientated Approach (LOA): *Approach to quantify nutrient loads through direct measurements of concentrations and transport values in rivers.*

Source Orientated Approach (SOA): *Approach to quantify nutrient loads through modelling, using loss coefficients and data on discharges from point sources.*

RID Programme: *Riverine inputs and direct discharges to Norwegian coastal waters. Programme monitoring rivers in Norway according to the requirements of the OSPAR Commission.*

TEOTIL: *The TEOTIL nutrient load model, as set up for Norway, produces a pollution load compilation of nitrogen and phosphorus in catchments or groups of catchments. The model compile annual loads of phosphorus and nitrogen from point and diffuse sources in each sub-catchment and accumulate these loads downstream encompassing any transformation that might be introduced along the discharge route (e.g. lake retention etc.) in order to obtain the nutrient load for the whole area under investigation.*

REGINE: *Norwegian river basin register system "REGINE". The system is developed by the Norwegian Water Resources and Energy Directorate (NVE; www.nve.no), and classifies the Norwegian river basins into 20 000 units, or 262 main catchment areas. According to this system, 247 of the 262 Norwegian rivers are draining into coastal areas. These range from Haldenvassdraget in the south east (River no. 001) to Grense Jakobselv in the north east (River no. 247).*

Nitrogen and phosphorus *means phosphorus (tot-P) and nitrogen (tot-N), except where specified differently.* Nitrogen *includes both inorganic and organic fractions of nitrogen.* Phosphorus *includes both inorganic and organic fractions of phosphorus.*

Point sources of nitrogen and phosphorus *are defined as a clearly identified, individual discharge (or a number of discharges in close proximity) to a watercourse or a body of water, such as effluent discharged from a sewage collecting and treatment system via an outfall pipe or channel. Aquaculture should be considered as a point source.*

Diffuse sources of nitrogen and phosphorus *are defined as any source of nitrogen and phosphorus that is not accounted for as a point source. Small, dispersed point discharges (e.g. from scattered dwellings or from point sources in agriculture, e.g. farmyards) should be dealt with as diffuse sources. Based on this definition, losses from scattered dwellings are included as diffuse sources.*

Nitrogen and phosphorus inputs into the Maritime Area *are defined as nitrogen and phosphorus loads to the Maritime Area via rivers and direct discharges and losses of nitrogen and phosphorus, including groundwater, to the Maritime Area.*

Catchment *means the whole of an area having a common outlet for its drainage waters.*

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Coastal areas *means the areas between main river catchments. When reporting, discharges and losses from these areas and discharges and losses from sources located in marine waters are added to a total.*

Unmonitored areas *include both sub-catchment(s) of river systems downstream monitoring points, with losses and discharges to the river downstream of monitoring points and direct losses and discharges to the Maritime Area (coastal area). Quantification of losses/discharges of nitrogen and phosphorus from unmonitored areas can be achieved by:*

- *The application of draft Guideline 6 in respect of diffuse losses of nitrogen and phosphorus or the extrapolation of diffuse losses monitored in a neighbouring area with similar physical conditions (soil, climate, topography) and land-use conditions; and*

Adding all monitored or estimated discharges from point sources in an unmonitored area, using a retention coefficient where appropriate

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1.   Summary

This report is linked to the work within the OSPAR Convention, on quantifying nutrient losses from rivers to the sea. Since the Third International North Sea Conference in 1990, reporting on discharges/losses and inputs of nitrogen and phosphorus have been high on the international arena. There are, however, different practices among countries in terms of quantification and reporting of riverine inputs into marine waters, as there are different "national interpretations" on how such questions as sampling frequency, calculation methods and the sources should be considered.

Basically, there are two main types of approaches that may be applied for the quantification of nutrient loads. These include the quantification of the discharges/losses at the source (Source Orientated Approach – SOA); and the quantification of the inputs at the river mouths, including the direct discharges/diffuse losses into the sea (Load Orientated Approach – LOA). In Norway, a model developed by NIVA called "TEOTIL" is used for the source orientated approach. The load orientated approach is based on the monitoring programme under the Riverine Discharges Programme – "RID".

The main purpose of this report is to explore these two approaches in more detail. More detailed, the objectives of the report are to provide a

- Thorough overview of the two approaches, their methods and results;
- Comparison and evaluation of the results of the two approaches,
- Assessment of the potential uncertainties of each approach,
- Detailed investigation of some of the sources of error for both approaches, including suggestions for improvement
- Recommendation for future actions that will improve the synergies of the two approaches

In Norway, the two methods are to some extent interrelated, as the source orientated approach through the TEOTIL model uses measurement data from the load orientated approach (RID) for calibration. Nevertheless, the comparison of the results of the two approaches revealed that they estimate different loads in some areas and rivers of Norway. There may be several reasons for these differences. The potential sources of differences and errors that have been treated in this report include:

➢ For the Load orientated approach:
- Frequency of sampling
- Choice of interpolation methodology
➢ For the Source orientated approach:
- Improvements of statistical areas, finer resolutions
- Improvement of coefficients, particularly for background values (forest and mountainous areas)
- Retention in lakes
- More complete datasets on sources, as all sources are not thoroughly reported

Some of the deviations between the results of the two methods are necessarily linked directly to the differences in the approaches *per se*, such as the fact that locations of the measurement stations in the RID Programme may not coincide with the statistical areas used by the TEOTIL model. Others may be explained by the change made in 2004 of the coefficients for background runoff from forests and mountainous areas, and the fact that the TEOTIL model has not yet been calibrated after this change.

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The comparisons that have been done in this report should give a good basis for evaluating the two methods in more detail. There are a number of sources of errors within each of the methods, and the goal should be to reduce these as much as possible. The fact that the source orientated model (TEOTIL) is calibrated with the data from the load approach (through the RID Programme) points to the importance of improving the results of the load estimates. Several more improvements of the load orientated approach have therefore been suggested in the latest Norwegian report on nutrient loads to marine waters (Borgvang *et al* 2006).

'Upscaling' is a challenge for both approaches. For the LOA this is related to monitoring one water body that is typical for several others, and thereby to find the right balance between number of monitoring sites (rivers and lakes), sampling frequency and resource allocation. For the SOA approach the 'upscaling' procedures are important in terms of deciding on a scientifically adequate number of sufficient types of agricultural fields throughout the country, as well as industrial plants, and thereby find the right balance between number of fields and plants, and resource allocation.

In conclusion, the reported efforts from this work have shown that a comparison of the two methods is useful inasmuch as it pinpoints the needs for improvements for each of the approaches, helps prioritise these improvements, with the ultimate goal of achieving optimal monitoring programmes as a sound scientific basis for selecting the most appropriate abatement measures within River Basin Management Plans.

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2.   Report objectives

Since 1990, at the time of the Third International North Sea Conference, issues linked to harmonised, transparent and comparable quantification and reporting on discharges/losses and inputs of nitrogen and phosphorus have been high on the international arena. With regard to e.g. the implementation of nutrient related measures within the OSPAR Commission (previously Oslo and Paris Commissions) the discussions have been linked to:

- different practices among countries concerning reporting on discharges and losses to freshwater systems and marine waters, i.e. : reports on measurements of riverine inputs and direct discharges to estuaries and coastal waters, reports on inputs to surface waters;
- "national interpretation" on how elements such as sampling frequency, calculation methods and the sources to be taken into account should be considered; and
- national criteria and the fact that no proper harmonisation process had been undertaken.

The calculation methods, the sources to be taken into account when reporting on inputs/discharges/losses of nutrients were, at various degrees, left to the discretion of each country within the relevant international organisations where quantification and reporting took place. The reporting systems and procedures amongst countries varied both with regard to calculation methods and (diffuse) sources which were taken into account; in particular, there were significant differences in the methodologies used for quantifying the losses from the agricultural sector. Some of these differences stemmed from the fact that countries have different ways of administrating the environmental issues of concern.

There are basically two main types of approaches that may be applied for the quantification of nutrient loads, viz.:

    a.   The quantification of the discharges/losses at source (Source Orientated Approach – SOA); and

    b.   The quantification of the inputs at the river mouths, including the direct discharges/diffuse losses into the sea (Load Orientated Approach – LOA).

Whereas
- since 1988, OSPAR (at that time PARCOM) has been concerned with adverse effects of discharges/losses of nutrients from various sources (c.f. PARCOM Recommendation 88/2, and PARCOM Recommendation 89/4);
- most OSPAR Contracting Parties (CPs) base their reports on the implementation of PARCOM Recommendation 88/2 on discharges/losses of nutrients at source;
- the OSPAR Convention is a marine Convention which is concerned with the marine environment, and inputs into the marine environment of various pollutants;
- most OSPAR CPs base their quantification of nutrient discharges/losses on the Source Orientated Approach, mainly because mitigation actions have focus;
- guidelines have been developed for the quantification of nutrient discharges from point sources (HARP Guidelines); and
- considerable attention has been paid over the most recent years to quantifying losses from diffuse sources (e.g., the EC funded project EUROHARP on diffuse losses of nutrients, www.euroharp.org);

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it is evident that if the focus is to achieve good estimates of the actual pollution loads to the sea, more attention should be paid to comparing the two approaches and to designing adequate monitoring programmes.

Figure 1 below shows the complexity of some issues linked to the 50% nutrient reduction target within OSPAR and the importance of a common understanding amongst parties of main elements in quantification and reporting.
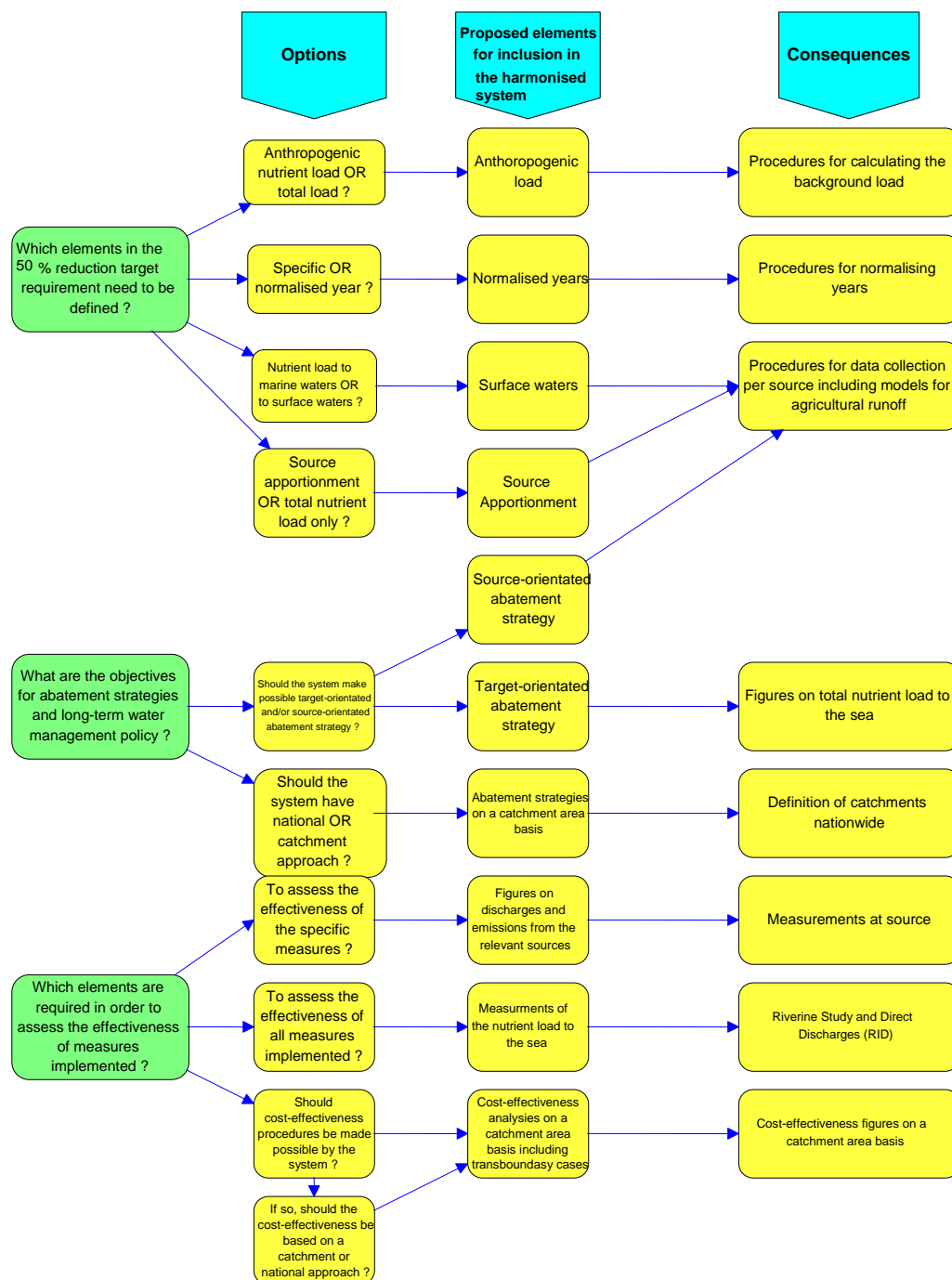

Figure 1. Selected elements and consequences of choices.

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However, it is important to have a holistic view on monitoring water bodies, as clearly expressed in the EC Water Framework Directive, where a catchment or River Basin District includes lakes, rivers, groundwater, transitional waters and coastal waters. In Norway, there are a number of monitoring programmes of water bodies at national, regional and local levels.

Presently there is no clear overriding consolidation of programmes in order to achieve harmonisation, transparency and comparability. Furthermore, the issue of scientific and financial synergies between programmes and activities has not been paid due attention. As the Norwegian Institute for Water Research (NIVA) is commissioned by the Norwegian Pollution Control Authority to carry out both the Norwegian RID Programme (Load Orientated Approach) and the yearly TEOTIL Report (Source Orientated Approach) it was considered appropriate to consider whether there are synergies to be explored between the two programmes, as well as looking into issues pointing to avenues of improvement for both of the approaches.

For the period 1985-2004, results from the annual TEOTIL modelling indicate a significant reduction in nitrogen and phosphorus inputs to Norwegian coastal areas for all sources except aquaculture. This reduction is particularly pronounced in the south eastern parts of Norway, where aquaculture is less widespread than in the north, as illustrated by Figure 2. The results from the RID Programme, however, give a more nuanced picture. Figures 3 and 4 show the development of phosphorus and nitrogen loads in the five main rivers draining into the same region.

The solid lines in the figures show flow-normalised loads. In terms of nitrogen, only River Skienselva showed a significant downward trend, whereas the flow-normalised loads of phosphorus show high variations from one year to the next, with no clear downward trends.

These differences in results do not necessarily imply that one of the approaches is arriving at wrong conclusions; the approaches are different in nature and thus may give different results.

The RID Programme, with its Load Orientated Approach, is reporting the loads at the mouths of a set of selected rivers, based on direct measurements, and is estimating the loads of the remaining rivers as well as discharges directly to the sea, i.e. the discharges downstream of the RID sampling stations. The TEOTIL model, on the other hand, is estimating changes in nitrogen and phosphorus discharges and losses at source.

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Figure 2. The development of phosphorus (top panel) and nitrogen (lower panel) loads to the Skagerrak area, from the Swedish border in the south east to the southernmost tip of Norway. The 50% line is showing loads caused by human activities.

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Figure 3. Observed and flow-normalised annual load of total phosphorus in five main rivers draining into the Skagerrak area – 1990 - 2004. The flow-normalisation is done according to the method proposed by Stålnacke & Grimvall (2001).

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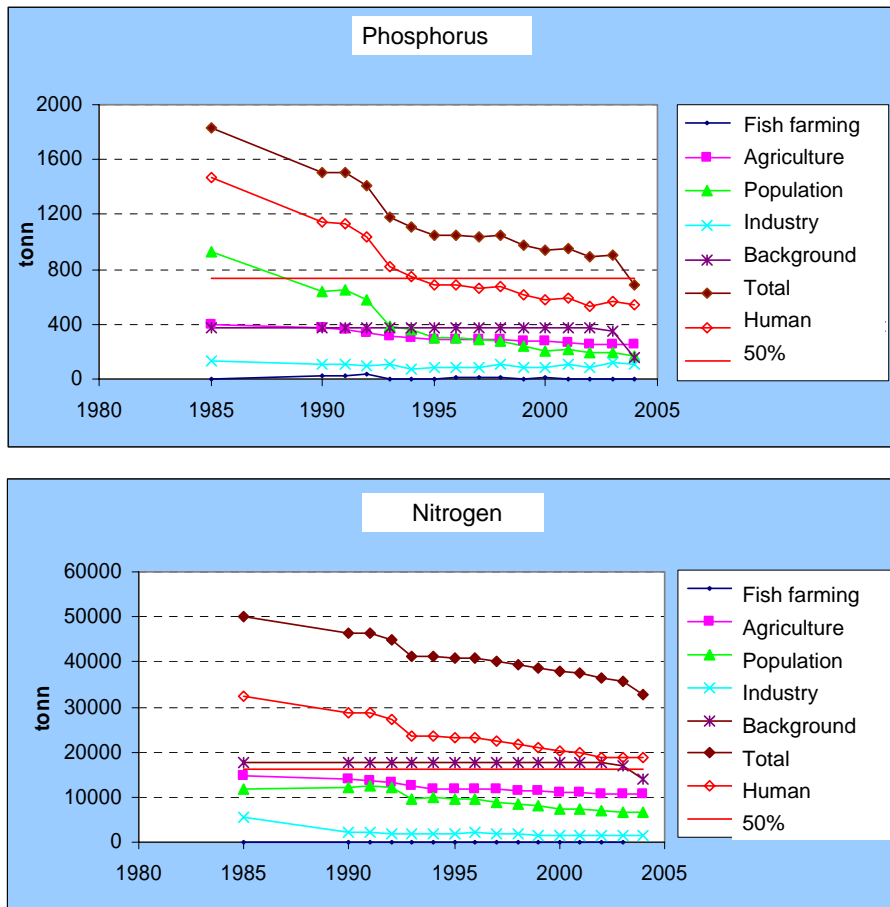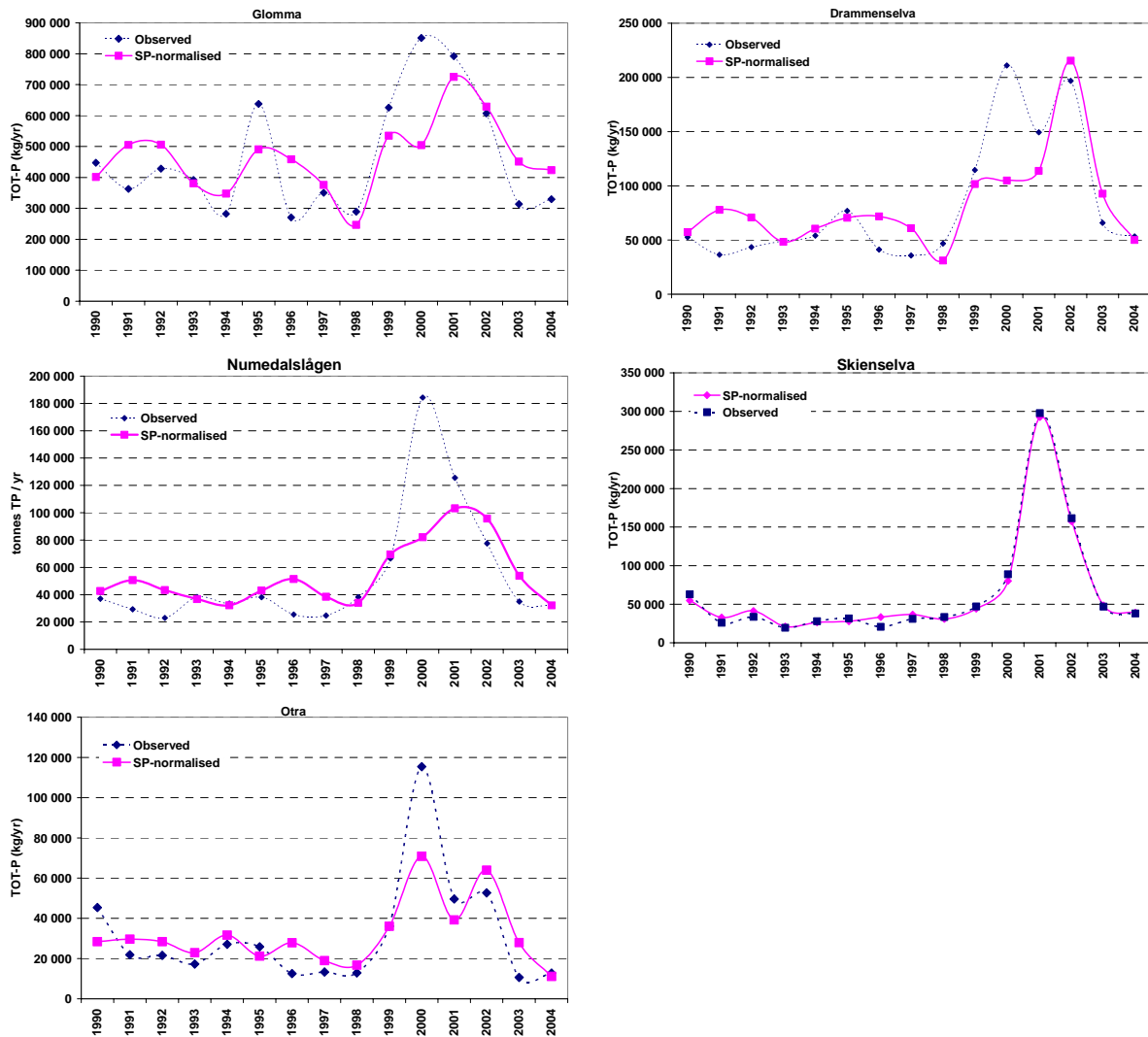(TA-2203/2006)

Figure 4. Observed and flow-normalised annual load of total nitrogen in five main rivers draining into the Skagerrak area – 1990 - 2004. The flow-normalisation is done according to the method proposed by Stålnacke & Grimvall (2001).

In view of these differences, the present report aims at exploring these two approaches in more detail. This will be done through a demonstration of the differences between the results arrived at by using the two approaches, and by pointing at improvements that may also increase the synergies of the two approaches.

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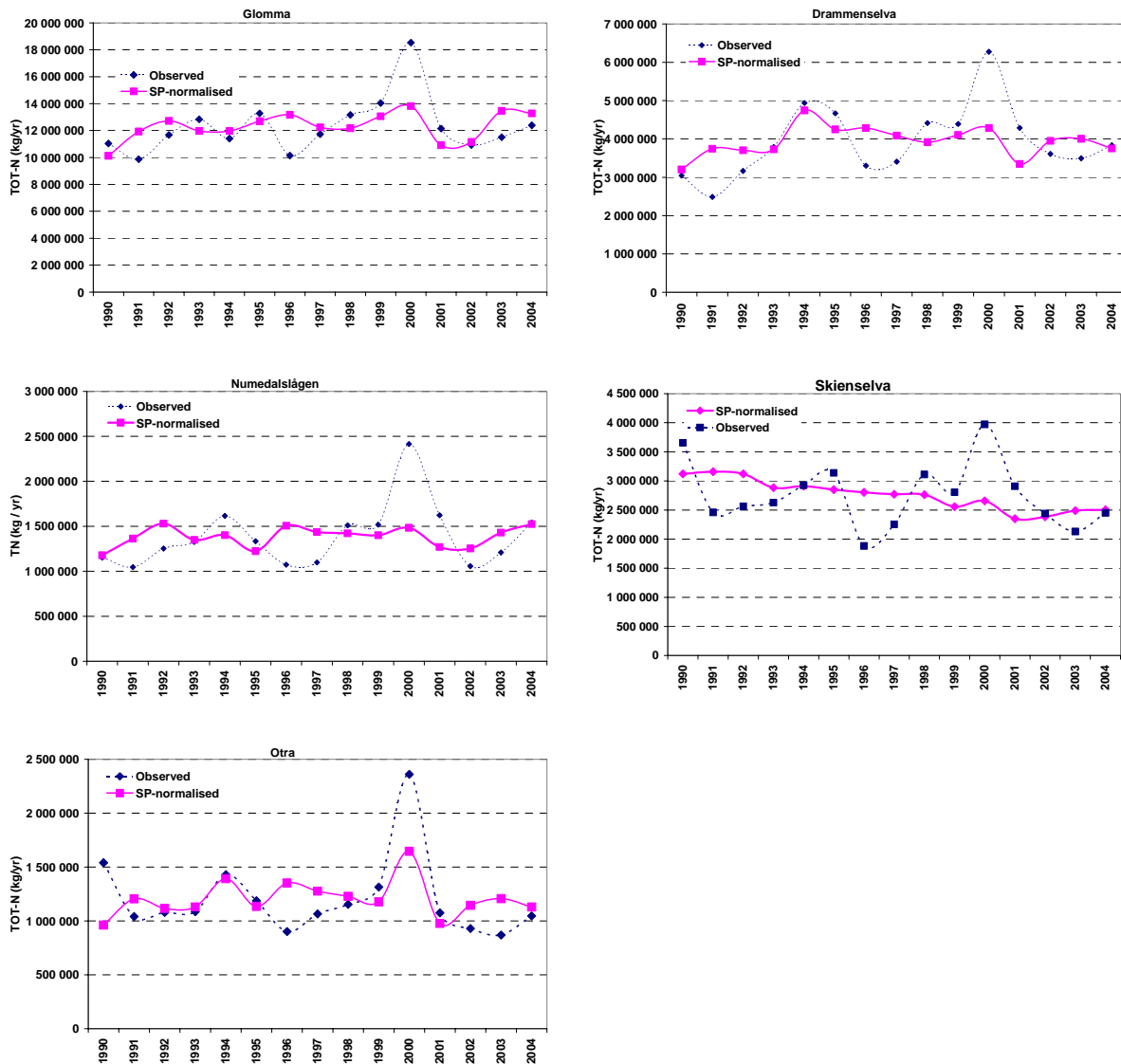(TA-2203/2006)

More specifically, the objectives are to provide a
- Thorough overview of the two approaches, their methods and results;
- Comparison and evaluation of the results of the two approaches;
- Assessment of the potential uncertainties of each approach;
- Detailed investigation of some of the sources of error for both approaches, including suggestions for improvement; and
- Recommendation for future actions that will improve the synergies of the two approaches.

Thus, and as illustrated in Figure 5, the report first gives a short overview of each of the methods used for the two approaches in Norway. Secondly, a comparison is given of the results, together with an overview of potential errors in each approach. Finally, two chapters are delving more detailed into such potential errors: For the LOA the uncertainties connected to sampling frequency and choice of interpolation methods are dealt with; and for the SOA the uncertainties of coefficients for background losses are studied.
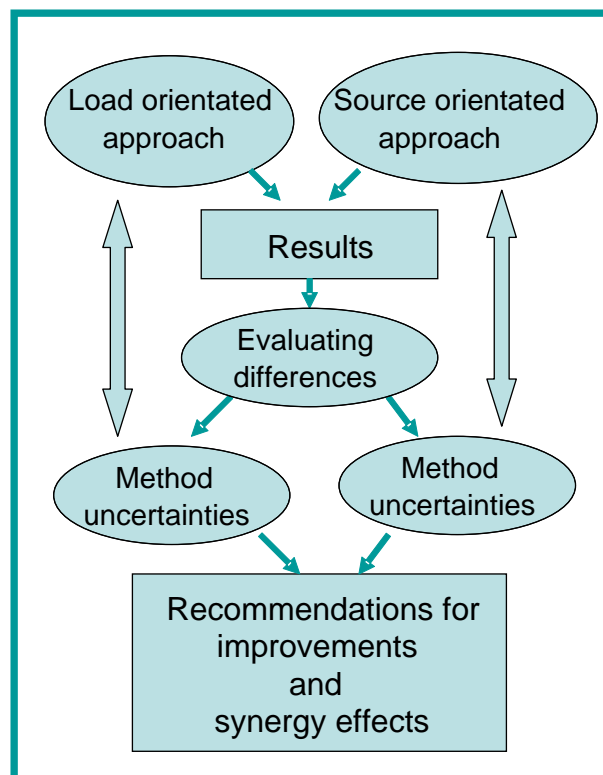

Figure 5. Structure of the report.

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3. The Methodology of the Two Approaches

This chapter provides a condensed overview of the methods applied for the two approaches for determining nutrient loads. It includes the LOA for estimating riverine inputs in the Programme Riverine Inputs and Direct Discharges to Norwegian Coastal Waters (RID); as well as a description of the SOA by means of the Norwegian TEOTIL model.

3.1 The Load Orientated Approach – RID Programme

3.1.1 Water Sampling Methodology

A riverine input is a mass of a substance carried to the sea by a watercourse (natural river or man-made watercourse) per unit of time. The objective of the water sampling is to obtain as accurate as possible an estimate of the input load to Norwegian coastal waters, and to obtain information on the long-term trends in inputs.

As noted above, monthly sampling has been performed in ten rivers, but the rivers Glomma and Drammenselva are also sampled weekly or fortnightly in the period with the highest anticipated flow (May – June/July). In the 36 rivers of quarterly sampling, the sampling was designed to cover four main meteorological and hydrological conditions in the Norwegian climate, viz. winter season with low temperatures, snowmelt during spring, summer low flow season, and autumn floods/high discharges.

The sampling sites are indicated on the map of Figure 6. The sites are located in regions of unidirectional flow (no back eddies). In order to ensure as uniform water quality as possible, sites where the water is well mixed was chosen, such as at or immediately downstream a weir, in waterfalls, rapids or in channels in connection with hydroelectric power stations. Sampling sites were located as close to the freshwater limit as possible, without being influenced by seawater.

Several of the most significant discharges from the industry and the municipal wastewater system are located downstream the sampling sites. These supplies are therefore not included in the riverine inputs, but are included in the direct discharge estimates.

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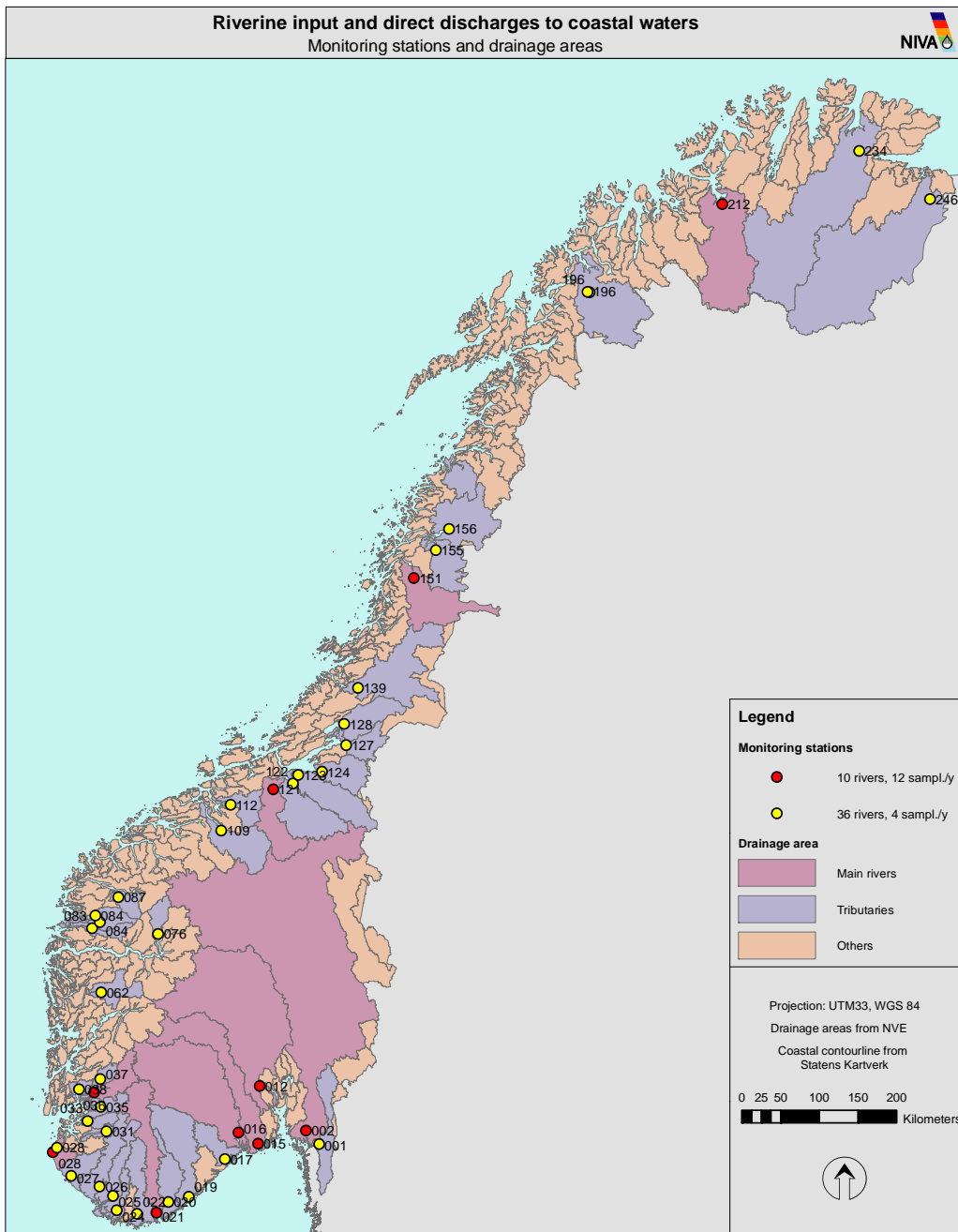
Figure 6 River sampling sites in the Norwegian RID programme. Red dots represent the ten main rivers. Yellow dots represent the 36 'tributary' rivers. Numbers next to the dots refer to the national river register (REGINE; www.nve.no).

3.1.2   Chemical parameters – detection limits and analytical methods

In 2004, the following nutrients and fractions of nutrients were monitored:
- total phosphorus
- orthophosphate
- total nitrogen
- ammonia
- nitrate + nitrite
- silicate

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In addition, several other parameters were monitored in the RID programme, but of these, only suspended particulate matter (SPM) is relevant for this Synthesis (cf. Section 4 on Reliability of riverine load estimates).

Information on methodology and obtainable limits of detection for these parameters are shown in Table 1 below.

Table 1. Analytical methods and obtainable detection limits for all parameters included in the riverine sampling programme.

Parameter	Detection limit	Analytical Methods (NS: Norwegian Standard)
Suspended particulate matter (S.P.M.) (mg/L)	0.1	NS 4733 modified
Total phosphorus (µg P/L)	1.0	NS 4725 – Peroxidisulphate oxidation method
Orthophosphate (PO$_4$-P) (µg P/L)	1.0	NS 4724 – Automated molybdate method
Total nitrogen (µg N/L)	10	NS 4743 – Peroxidisulphate oxidation method
Nitrate (µgN/L)	1	NS-EN ISO 10304-1
Ammonia (NH$_4$) (µg N/L)	5	NS-EN ISO 14911
Silicate (SiO$_2$) (Si/ICD; mg/L)	0.02	ISI/DIS 11885 + NIVA's accredited method E9-5

According to the document "Principles of the Comprehensive Study of Riverine Inputs and Direct Discharges" (PARCOM, 1988), it is necessary to choose an analytical method which gives at least 70 % of positive findings (i.e. no more than 30% of the samples below the detection limit). As shown in Table 2, this is only a problem in terms of orthophosphate, which had 38% of the samples below the detection limit.

Table 2. Proportion of analyses below detection limit for all parameters included in the sampling programme

Parameter	% samples below detection limit	Total no. of samples	No. of samples below detection limit
Suspended particulate matter (S.P.M.) (mg/L)	2	276	6
Total phosphorus (µg P/L)	3	276	9
Orthophosphate (PO4-P) (µg P/L)	38	276	106
Total nitrogen (µg N/L)	0	276	0
Nitrate (µg N/L)	2	276	5
Ammonia (NH$_4$) (µg N/L)	25	276	69
Silicate (SiO$_2$) (Si/ICD; mg/L)	0	276	0

3.1.3 Water discharge and hydrological modelling

For the 10 main rivers, daily water discharge measurements were used directly for the calculation of loads. However, for the 36 rivers monitored quarterly, as well as the remaining 109 rivers from the former RID studies, water discharge was simulated with a spatially distributed version of the HBV-model (Beldring *et al.* 2003). The use of this model was

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introduced in 2004, and a more thorough description of the model as used in the RID Programme is found in Borgvang et al. (2006). Earlier, the water discharge in 145 rivers was calculated based on the 30 year average, and adjusted with precipitation data for the actual year. The introduction of more sophisticated hydrological modelling is done to improve the water discharge estimates in the tributary rivers.

The hydrological model performs water balance calculations for square grid cell landscape elements characterised by their altitude and land use. The model is run with daily time steps, using precipitation and air temperature data as input. It has components for accumulation, sub-grid scale distribution and ablation of snow, interception storage, sub-grid scale distribution of soil moisture storage, evapotranspiration, groundwater storage and runoff response, lake evaporation and glacier mass balance. Potential evapotranspiration is a function of air temperature, however, the effects of seasonally varying vegetation characteristics are considered.
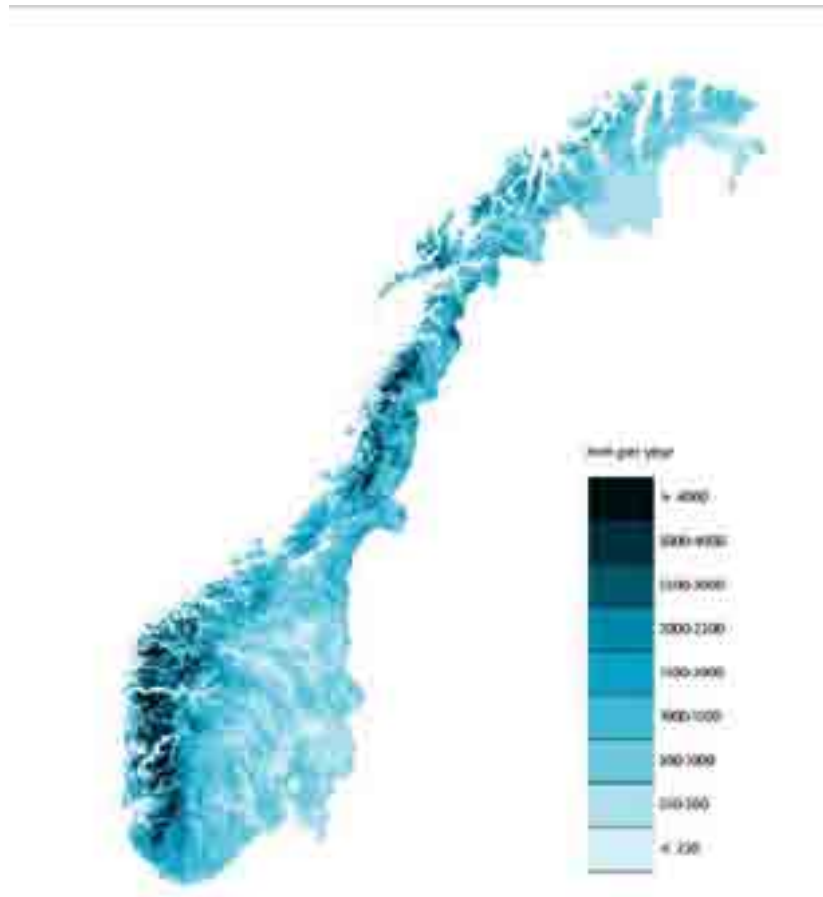
Figure 7: Annual average runoff (mm/year) for Norway for the period 1961-1990.

Differences in precipitation and temperature caused by elevation were corrected by precipitation-altitude gradients and temperature lapse rates determined by the Norwegian Meteorological Institute. There is considerable uncertainty with regard to the variations of precipitation with altitude in the mountainous terrain of Norway and this is probably the

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major source of uncertainty in the streamflow simulations. Figure 7 shows the spatial distribution of mean annual runoff (mm/year) for Norway for the period 1961-1990.

3.1.4   Calculating Riverine Loads

The formula given by the Paris Commission was used for calculating loads for all of the 46 rivers:

$$Load = Q_r \frac{\sum_{i=1}^{n}(C_i \bullet Q_i)}{\sum_{i=1}^{n} Q_i}$$

Ci = measured concentration in sample i
Qi = corresponding flow for sample i
Qr = mean flow rate for each sampling period (i.e., annual flow)
N = number of samples taken in the sampling period

Essentially the formula expresses the annual load (L) as the product of a flow-weighted estimate of annual mean concentration and annual flow (Qa).

In Section 5, this load calculation method is compared with two other methods for estimating riverine loads.

3.2   The Source Orientated Approach – and the TEOTIL Model

3.2.1   The development of the TEOTIL model

The Norwegian TEOTIL model was originally developed as a tool to quantify the input of nutrients to coastal areas of Norway and intended as a tool to control progress toward the internationally agreed North Sea declaration to reduce the anthropogenic input of nitrogen and phosphorus with around fifty percent to sensitive areas of the North Sea compared with the year 1985 as a baseline (Anon 1992). The sensitive area in Norway was defined as the coastal areas from the Swedish border to the southernmost part of Norway (Lindesnes).

NIVA developed the model and has prepared annual overviews of progress toward the fifty percent reduction target since 1990 on commission for SFT (Selvik et al., 2005). However, the scope of the annual overview has changed over the years and the whole Norway is now encompassed in the overview despite that the area for the 50% reduction target remain the same.

The main input to the system is the available statistical information on discharges or losses of nutrients collected annually by a number of official bodies in Norway. The annual preparation of data from various information sources is coordinated by SFT and data from a specific year is usually available over the summer the following year.

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The model code was rewritten in 2003/2004 and the system now appears as a model maker tool specialised for calculations of loads from sub-catchment with known interior drainage (TEOTIL2). The use of TEOTIL2 has also flourished into other areas than nutrient input into Norwegian coastal sections and overviews for single river basins and other user defined areas has been prepared in various projects.

The revised model concept has become very flexible for defining models for new areas and has been strengthened in its integration with GIS. The new revised concept has now been applied both nationally and internationally, e.g. in catchments in Hungary, FYR Macedonia and Albania (see www.drimpol.no), with good results.

3.2.2 Main model elements

The TEOTIL2 nutrient load model, as set up for Norway, produces a pollution load compilation of nitrogen and phosphorus in catchments or groups of catchments. The model compile annual loads of phosphorus and nitrogen from point and diffuse sources in each sub-catchment and accumulate these loads downstream encompassing any transformation that might be introduced along the discharge route (e.g. lake retention etc.) in order to obtain the nutrient load for the whole area under investigation. Each source is maintained as separate sources in the downstream accumulation and the source apportionment is available for the catchment outlet.

The geographical resolution is in principle decided by the resolution of the input data. Norwegian TEOTIL2 is based on hydrostatistical areas, which is an intermediate resolution based on aggregation of several of the smallest sub-catchment available in the national catchment database and enables allocation of statistical information. Each municipality will typically consist of 2-3 hydrostatistical areas.

The time resolution required for assessment of progress toward the 50 % reduction target for nutrients is yearly and this correspond to the resolution in most data supplied from the national data sources. Other time resolutions, e.g. monthly, can be produced based on any predefined distribution pattern or input data with that resolution that the user introduce.

Input data on point sources are based upon national statistical information on discharges from the major point sources. Input data on losses from diffuse sources, e.g. agricultural fields and natural areas (forest and mountain) are based on an export coefficients approach given as nutrient concentration for unmanaged land and as an area loss coefficient for the agriculture areas.

Typical (normalised) water discharges for all hydrostatistical areas are made available as input data. In the Norwegian TEOTIL2 model the main motive is to see the development in load over a number of years. It follows that annual fluctuation in water discharge and the subsequent fluctuation in load should be avoided. There is no principle obstacle to use water discharge for specific years when data is available.

Transformation processes (e.g. retention processes) is taken account by use of a fixed set of coefficients. Presently, only retention in lakes (not rivers) is considered in TEOTIL. Retention in lakes depends to a large extent on retention time, but eutrophic status is also of influence the retention (Holtan *et al,* 1995).

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It follows that the concept is fairly simple and encompasses no algorithms for processes in soil, groundwater, surface waters or sediments.

3.2.3   Diffuse losses - export coefficients

Export coefficients for forest and mountainous areas are established on the basis of a generalisation of monitoring water quality at selected unpolluted sites in Norwegian lakes and rivers. In 2005 these coefficients have been updated based on monitoring results obtained during the last 15 years (see Section 5 for details).

Export coefficients for agriculture areas are established on the basis of two empirical models developed by Bioforsk and applied on national data from the year 2000 and on the basis of time series data from the monitoring programme on soil and water in agriculture (JOVA). For the years after 2001 to date, the results are adjusted in accordance with changes in agriculture practise each year and normalised with regard to climate. Significant knowledge and experience is built into this procedure and despite the simple coefficient approach we feel that data results are reliable.

3.2.4   Point sources

The TEOTIL2 nutrient load model, as set up for Norway, encompasses the following main point sources:
- population – wastewater treatment plants (incl. industries connected to public sewerage)
- population – discharges from households not connected to public sewerage systems
- industrial discharges not connected to public sewerage systems
- aquaculture – production of market size salmon and trout

Statistics Norway (SSB) is administrating the Norwegian reporting system KOSTRA, where the municipalities report figures from their operation of waste water treatment plants as well as discharges from households not connected to public sewerage systems. Data is collected every spring and SSB carries out quality control on deliveries.

SSB produce a spreadsheet file with annual information from each treatment plant. Each plant has a unique ID and UTM co-ordinates, and can easily be allocated to the correct hydro-statistical area. With regard to data quality, there are situations where the actual discharge does not occur within the given hydro-statistical area, either due to long discharge pipelines or errors in the given co-ordinates. Since the discharge points of river basins often correspond with larger agglomerations and their waste water treatment plants it can be difficult to compare load with riverine observations without local knowledge.

SSB also produces a spreadsheet with the discharges from households not connected to public sewerage systems. The figures are estimated as a total per municipality and are in principle a diffuse source. With regard to data quality these data are considered relatively uncertain with large unexplained inter-annual variations. Households not connected to public sewerage systems are not dominating quantitatively, but in areas with well functioning waste water treatment plants the contribution from households not connected are often considered as a costly and difficult 'remaining problem'. In a few municipalities a detailed mapping of households not connected to public sewerage systems has taken place and data quality is

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subsequently improved. Since each municipality often consist of 2-3 hydro-statistical areas and this data category relates to the whole municipality, the TEOTIL Model applies a pragmatic approach, where the total from 'households not connected' are allocated to the most downstream hydro-statistical area in the municipality, as if it was a point source.

SFT requires all licensed industries to report on their discharges to water. Data is reported to the "FORURENSNING Database" on an annual basis. An extraction from the database containing data on discharges of N and P substances can usually be made available for TEOTIL2 half a year after the previous reporting period.

The licenses include a general assertion on a requirement to report on all discharges, but only selected substances may be subject to strict regulations. In practise, the reporting on substances not regulated strictly tends to be reported somewhat incidentally and the interannual variation is considerable.

However, reporting has improved over the years with the peculiar consequence that implemented measures are not always visible as a downward trend in discharges of nutrients. Location of industries based on UTM co-ordinates has improved over the years, but still some industries do not have co-ordinates. Allocation of industries to the most downstream hydro-statistical area in the municipality is made when co-ordinates are lacking. The same uncertainties related to location of the actual discharge point above or below the RID monitoring point as mentioned for wastewater treatment plants can apply to industry.

Feed consumption and production of fish is used to estimate the discharge of nutrients from fish farms through a mass balance calculation in agreement with the international recommendations, HARP Guidelines (Borgvang & Selvik, 2000). Most of the production takes place in marine waters and do not influence the comparison with riverine monitoring. Feed consumption is extracted from the ALTINN database, which is a large national system for reporting from business activities to Norwegian authorities. This system also contains information needed to estimate the biomass changes (production of fish) for each farm. Fish farmers report monthly on selected production parameters because a strict feed use regulation has been in operation as a market adaptation; these regulations have recently been cancelled. In calculations of annual discharges, data has been aggregated to year and to hydro-statistical areas before introduction to TEOTIL2. The Directorate of Fisheries and their regional offices follow up the reporting from fish farms and the completeness of data is good. For 2004 it was discovered a gap between reported feed consumption and production which led to a possible underestimation of discharges of nitrogen and phosphorus.

3.2.5 Drainage network
The accumulation of loads in the downstream direction requires a drainage network where the drainage pattern is defined, in terms of identifying the next downstream hydro-statistical area. The Norwegian drainage pattern is available as a file showing the next downstream area for all hydro-statistical areas, and enables the model to accumulate the downstream load in all river basins. TEOTIL2 contains no procedures to establish a drainage network when the model is to be used in new areas. In that case the network needs to be developed manually or by general GIS approaches.

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3.2.6   Summary of the TEOTIL Model Calculations

The TEOTIL2 model can be summarised as follows for the ith sub-basin outlet point for the given year:

$$M_{sum, i\,[kg]} = M_{agriculture, i\,[kg]} + M_{background, i\,[kg]} + M_{population, i\,[kg]} \qquad (1)$$

where

M_{sum}	calculated nutrient load (sum)
$M_{agriculture}$	diffuse loss from agricultural areas
$M_{background}$	loss from natural areas with little or no human activities and via atmospheric deposition
$M_{population}$	loss from urban areas (WWTPs, industries scattered dwellings and paved surfaces)

Equation (1) could be further detailed:

$$M_{sum, i\,[kg]} = M_{agriculture, i\,[kg]} + [M_{forest, i\,[kg]} + M_{nature, i\,[kg]} + M_{wetland, i\,[kg]} + M_{atm.\,dep., i\,[kg]}] + [M_{scatt, i\,[kg]} + M_{urban, i\,[kg]} + M_{wwtp, i\,[kg]} + M_{industry, i\,[kg]}] \qquad (2)$$

where

M_{forest}, M_{nature}, and $M_{wetland}$
losses from natural areas

$M_{atm.\,dep.}$	deposition via precipitation
M_{scatt}	diffuse loss of scattered dwellings
M_{urban}	pollution coming from paved surfaces
M_{wwtp}, $M_{industry}$	emission of point sources (industry and waste water treatment plants).

The further disaggregation of the equation would look like this:

$$M_{sum, i\,[kg]} = A_{agriculture, i\,[km2]} * C_{agriculture, i\,[mg/l]} * P_{i\,[mm]} + [A_{forest, i\,[km2]} * C_{forest, i\,[mg/l]} * P_{i\,[mm]} + A_{nature, i\,[km2]} * C_{nature, i\,[mg/l]} * P_{i\,[mm]} + A_{wetland, i\,[km2]} * C_{wetland, i\,[mg/l]} * P_{i\,[mm]} + A_{water, i\,[km2]} * C_{atm.\,dep., i\,[kg/km2]}] + [Q_{not\,collected\,ww, i} * C_{scattered, i} + A_{urban, i\,[km2]} * C_{urban, i\,[mg/l]} * P_{i\,[mm]} + \Sigma L_{wwtp\,i, k} * C_{wwtp, i} + \Sigma L_{industry, i, k} * C_{industry, i}] \qquad (3)$$

where

A-s	areas
C-s	coefficients identified for ach sub-basin based on literature values
P_i	hydrological effective rainfall
$Q_{not\,collected\,ww}$	not collected waste water in each subbasin
L-s	loads of point sources

Since the model does not consider the subsurface processes, the precipitation had to be modified to get the proper amount of water in the tributaries (hydrological effective rainfall). For this reason, based on hydrological (discharge) and precipitation data, the following equation was identified for each sub-basin:

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$$P_{i\,[mm]} = a_i * e^{b_i * P_{total,\,i\,[mm]}} \qquad (4)$$

where

P_i	corrected precipitation data for the ith sub-basin for the given year
P_{total}	measured precipitation for the ith sub-basin for the given year
a_i and b_i	constants for the ith sub-basin.

If equations (3) and (4) are combined, the following summarised equation is gained:

$$M_{sum,\,i\,[kg]} = a_i * e^{b_i * P_{total,\,i\,[mm]}} \{ A_{agriculture,\,i\,[km2]} * C_{agriculture,\,i\,[mg/l]} + C_{forest,\,i\,[mg/l]} * (A_{forest,\,i\,[km2]} * + A_{nature,\,i\,[km2]} + A_{wetland,\,i\,[km2]}) + A_{urban,\,i\,[km2]} * C_{urban,\,i\,[mg/l]} \} + A * C_{atm.\,dep.,\,i\,[kg/km2]} + Q_{not\,collected\,ww,\,i} * C_{scattered,\,i} + \Sigma L_{wwtp\,i,\,k} * C_{wwtp,\,i} + \Sigma L_{industry,\,i,\,k} * C_{industry,\,i}) \qquad (5)$$

In the above equation (5), $C_{nature,\,i\,[mg/l]}$ and $C_{wetland,\,i\,[mg/l]}$ were substituted with $C_{forest,\,i\,[mg/l]}$, because these areas were considered as ecosystems with little or no human activities, and only a forest coefficient was found in the litterature.

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4. Improving the understanding of differences in the results of Load and Source Orientated Approaches

Comparisons reveal that the two approaches in some areas give different estimates of both loads and concentrations. In order to better understand these differences, some sources of errors and uncertainties in each of the approaches are discussed. Recently, several improvements have been made to both approaches; some of these are also treated here, together with suggested future changes.
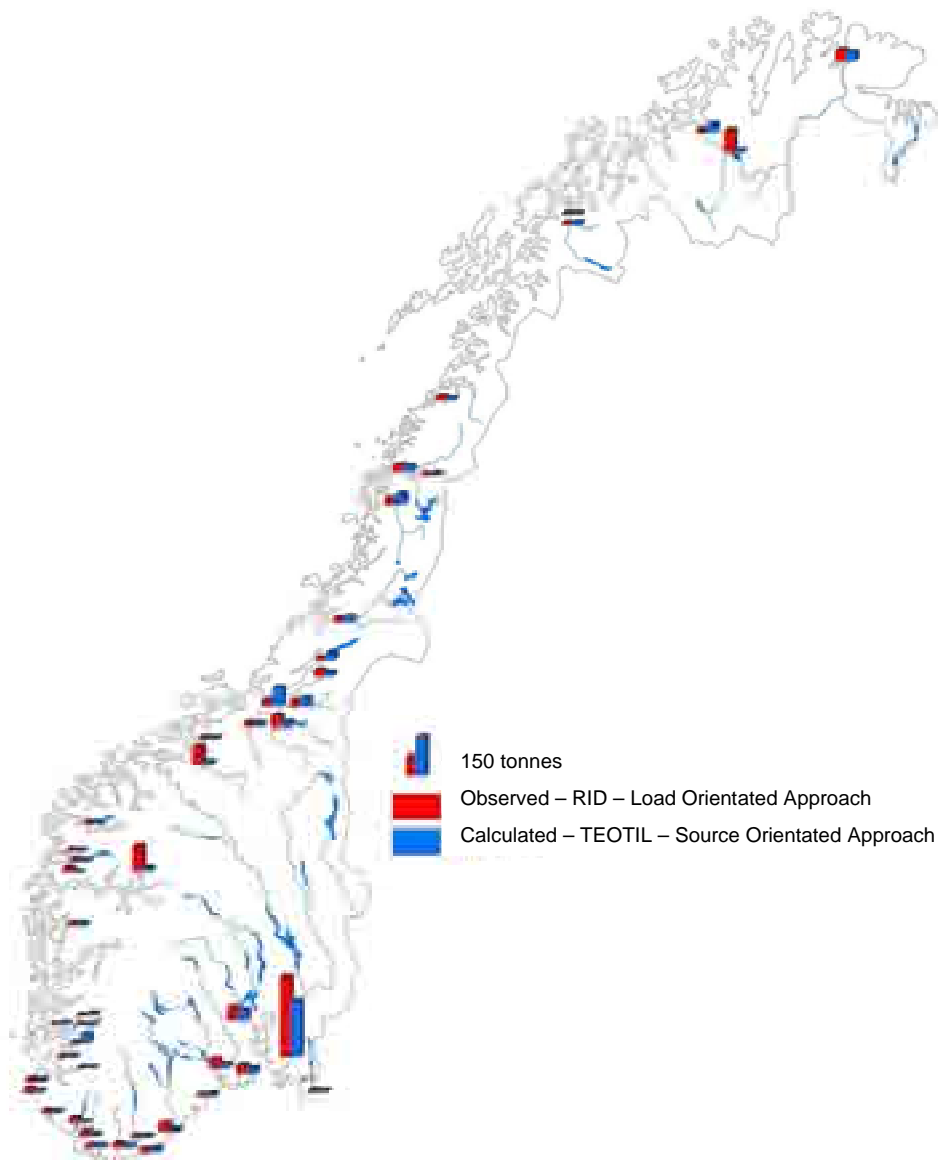
4.1 Differences in results

The results of the load and source orientated approaches were compared for phosphorus and nitrogen in all 46 rivers monitored in the RID Programme in 2004. Comparisons were performed both on loads and concentrations.

Thus, Figures 8 and 10 show loads of phosphorus and nitrogen as calculated from the RID data (LOA; red columns) and as modelled by TEOTIL (SOA; blue columns). As a general pattern, the values were reasonably similar, but for some rivers there are rather large differences, mainly with observed values being higher than the modelled values.

Similarly, the observed concentrations from the RID data and the TEOTIL modelled concentrations were fairly similar in many rivers, with differences mainly of one order of magnitude in terms of the classification system shown in Figures 9 and 11. However, for some rivers the concentration differences spanned over two or three classes. There was no clear pattern to these differences, as the observed concentrations were in some rivers higher than, and other rivers lower than, the modelled concentrations.

In section 4.3, and also in Chapters 5 and 6, the reasons for these differences will be discussed.

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Figure 8. Comparison between observed and simulated loads of total phosphorus in the rivers monitored in the RID Programme in 2004

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mg/l	quality status
0.001 - 0.007	1
0.008 - 0.011	2
0.012 - 0.020	3
0.021 - 0.050	4
0.051 -	5

Figure 9. Comparison between observed (RID) and simulated (TEOTIL) values of mean total phosphorus concentrations in the "RID rivers". The larger symbols show observed concentrations, the inner circles the modelled concentrations.

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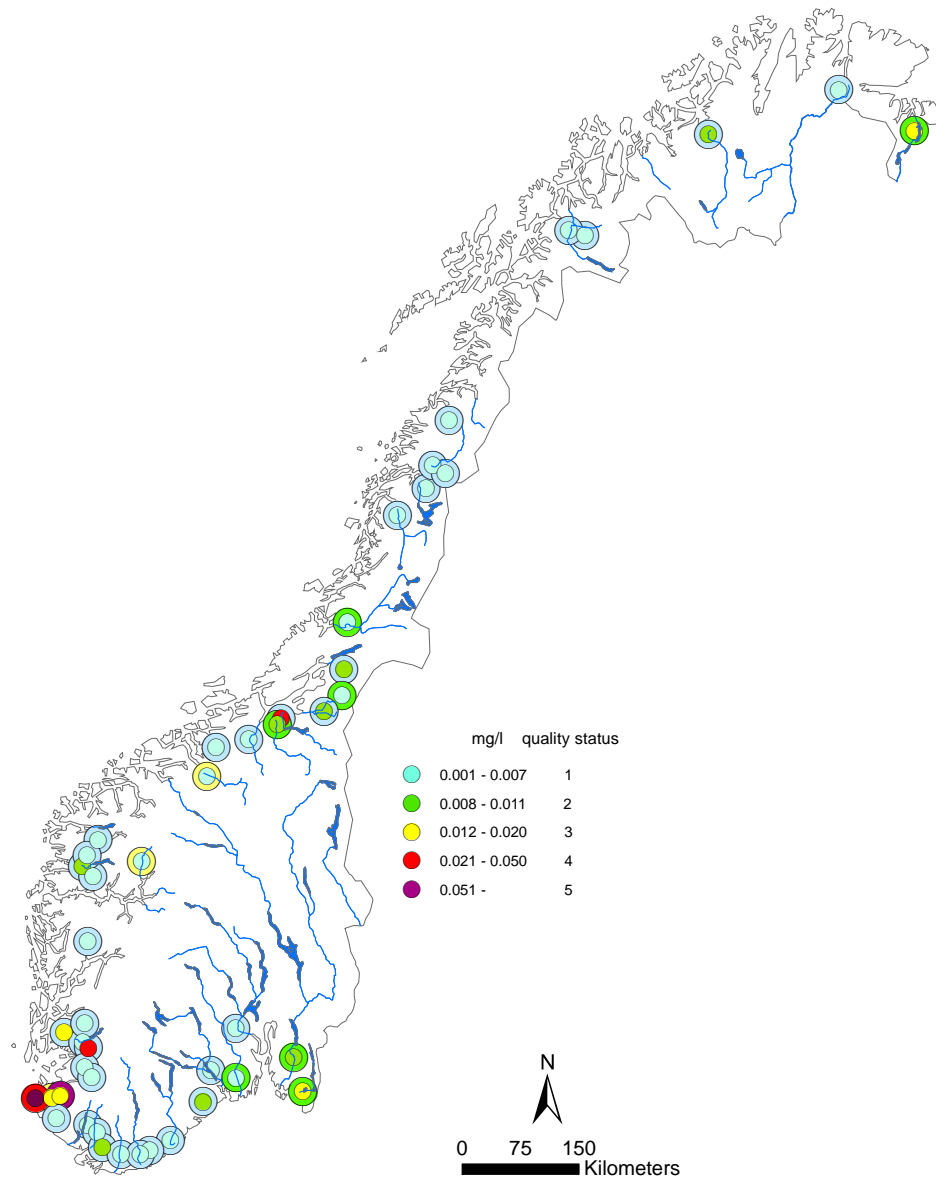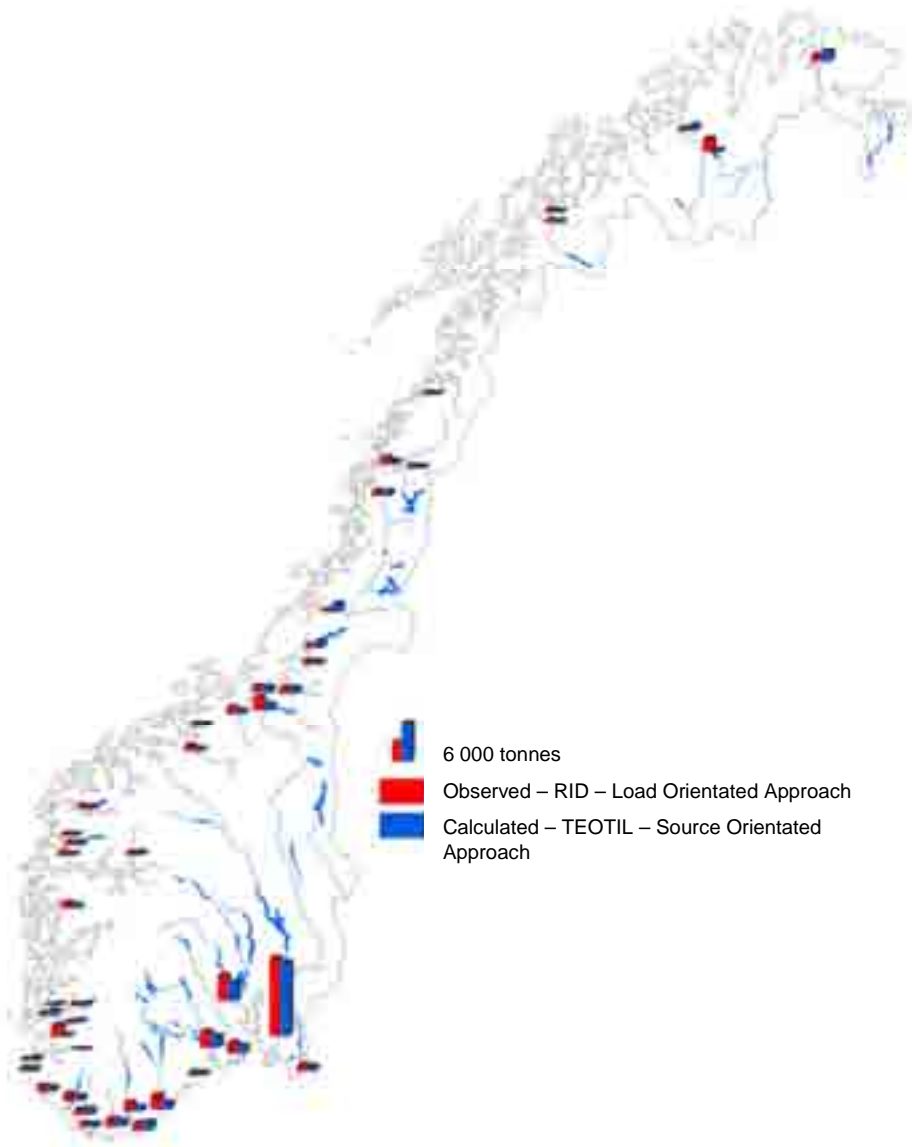(TA-2203/2006)

6 000 tonnes

Observed – RID – Load Orientated Approach

Calculated – TEOTIL – Source Orientated Approach

Figure 10. Comparison between observed and estimated nitrogen load in the rivers monitored in the RID Programme in 2004

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Figure 11. Comparison between observed and simulated values of the mean total nitrogen concentrations in the "RID rivers". The larger symbols show observed concentrations, the inner circles the estimated/simulated concentrations.

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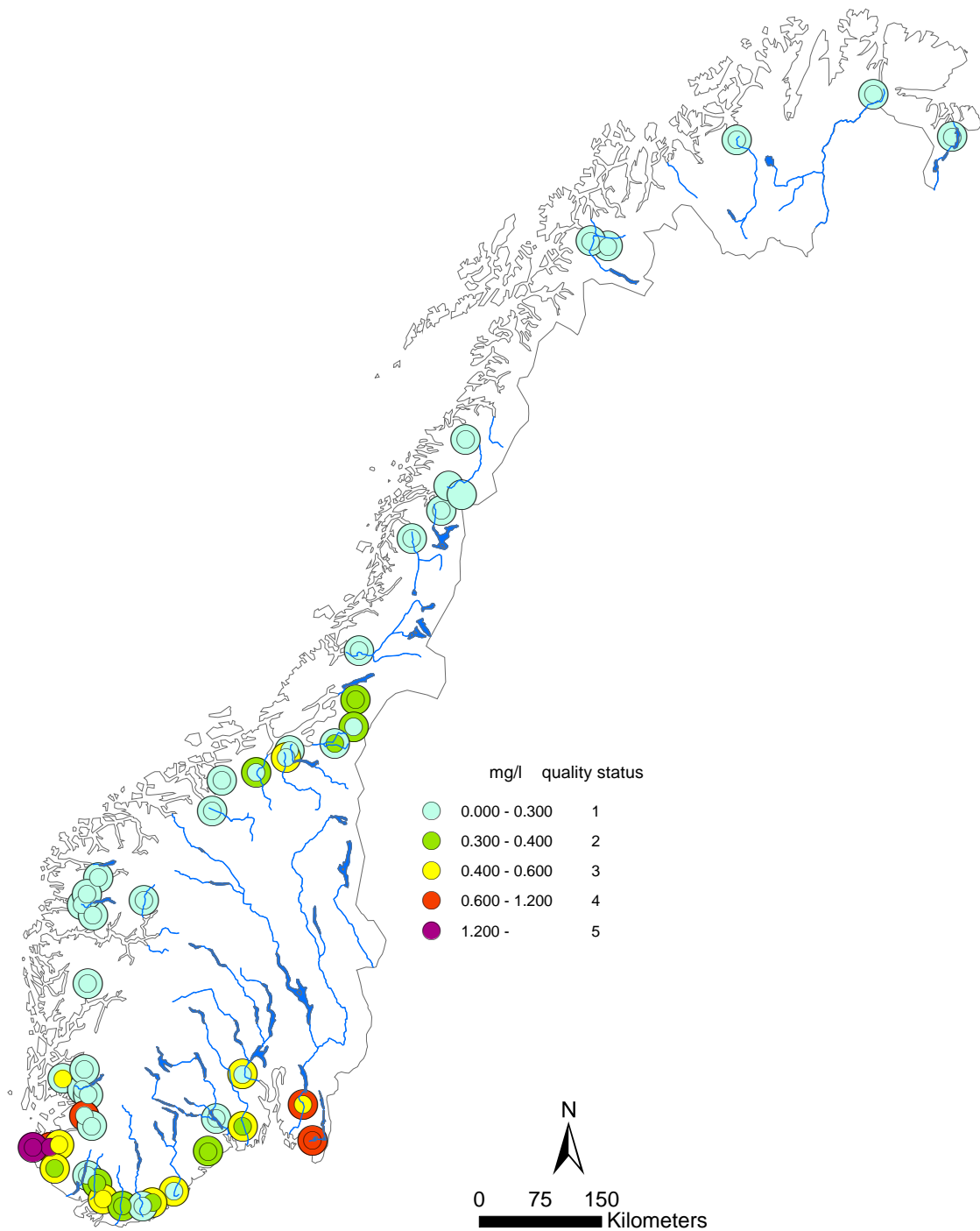(TA-2203/2006)

4.2 A more detailed comparison in selected rivers

For River Glomma (the largest river in Norway) and three catchments in Mid-Norway a more detailed analysis was done on observed and modelled concentration values, including how modelled values are changing downstream the rivers.

The results are presented in Figures 12-15. The result of the load orientated approach is given as a star at the sampling station. For the Glomma River, the modelled nitrogen values in the lower reaches of the river coincide well with the observed annual mean concentration, whereas the phosphorus values show marked differences. The changing phosphorus concentrations modelled in the main stream of the river, from low concentrations to high and then low again, are probably a result of the combined effects of point sources, inlet of tributaries with high concentrations and dilution, but a closer look at these modelled values should be done in order to check their validity. The average annual concentration in 2004 was in the range of 12-20 µg/l, which certainly lies between the modelled values ranging from 1 – 50 µg/l, but again, the model here shows some rapidly changing values downstream that should be further investigated.

In the catchments in Mid-Norway, the pattern is somewhat opposite, as it is the nitrogen concentrations that varies most from the observed to the modelled approach. Whereas both observed and modelled phosphorus concentrations for all three rivers are in the range of 1 - 11 µg/l, the modelled nitrogen concentrations are significantly higher than the observed in River Nidelva, and significantly lower than observed in River Gaula. The four figures (Figure 11-14) also show a marked advantage of the model approach, i.e. the possibility to estimate at relatively low costs where the main nutrient sources are located. In order to achieve a similar picture based on observed values a relatively costly monitoring programme is needed.

The usefulness of such a model-based nutrient apportionment map depends heavily on the reliability of the model. It is, therefore, of vital importance to improve the model and reduce its uncertainties. However, the possibility for calibration with observed values are only as good as the quality and reliability of the observed values themselves. Thus, the remainder of this report will delve into possible sources of errors in the two approaches.

Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters:
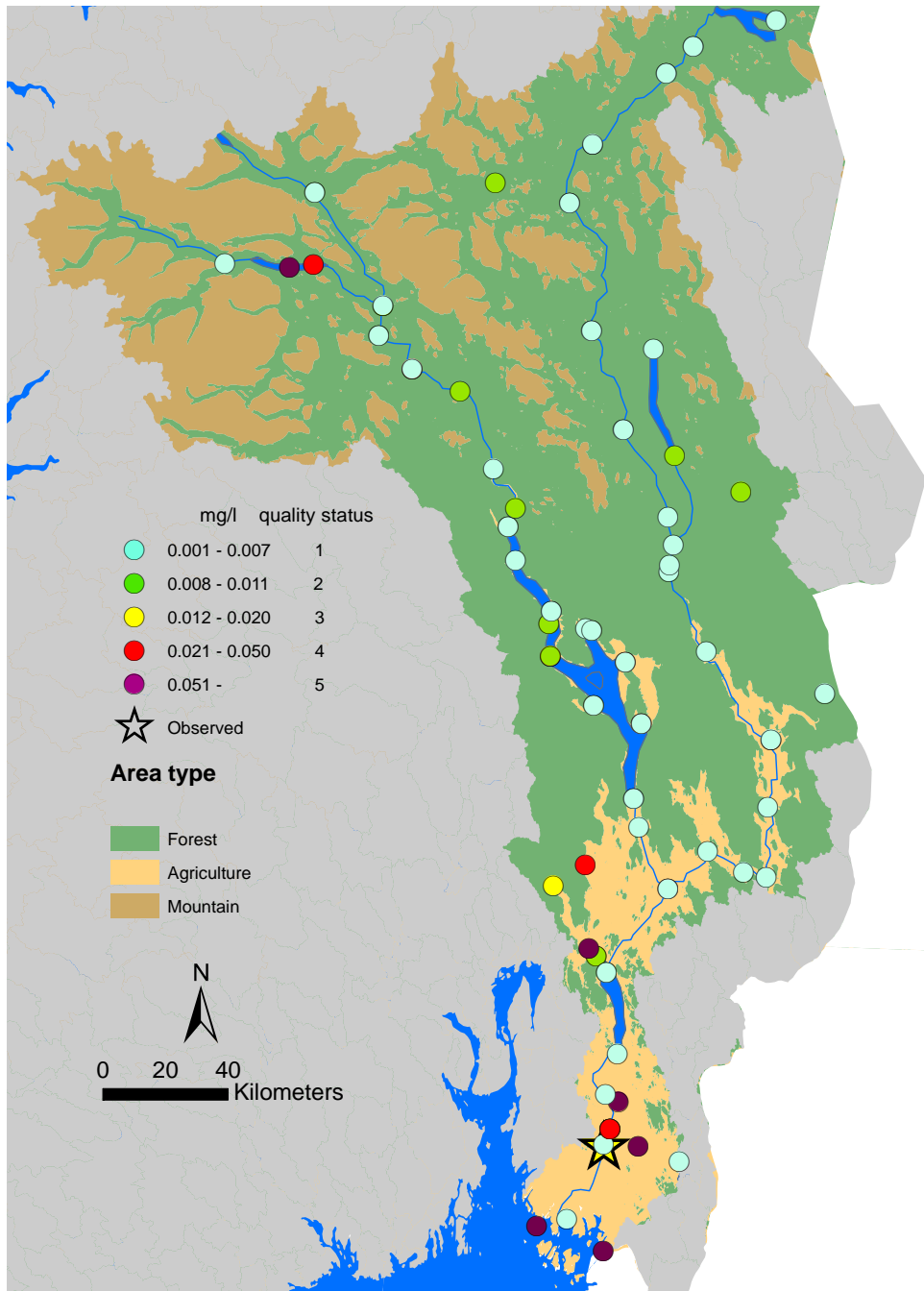May the methodologies of and the synergies between the two approaches be improved?
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Figure 12. Estimated mean total phosphorus concentration in the Glomma river catchment, and observed mean concentration at the outlet.

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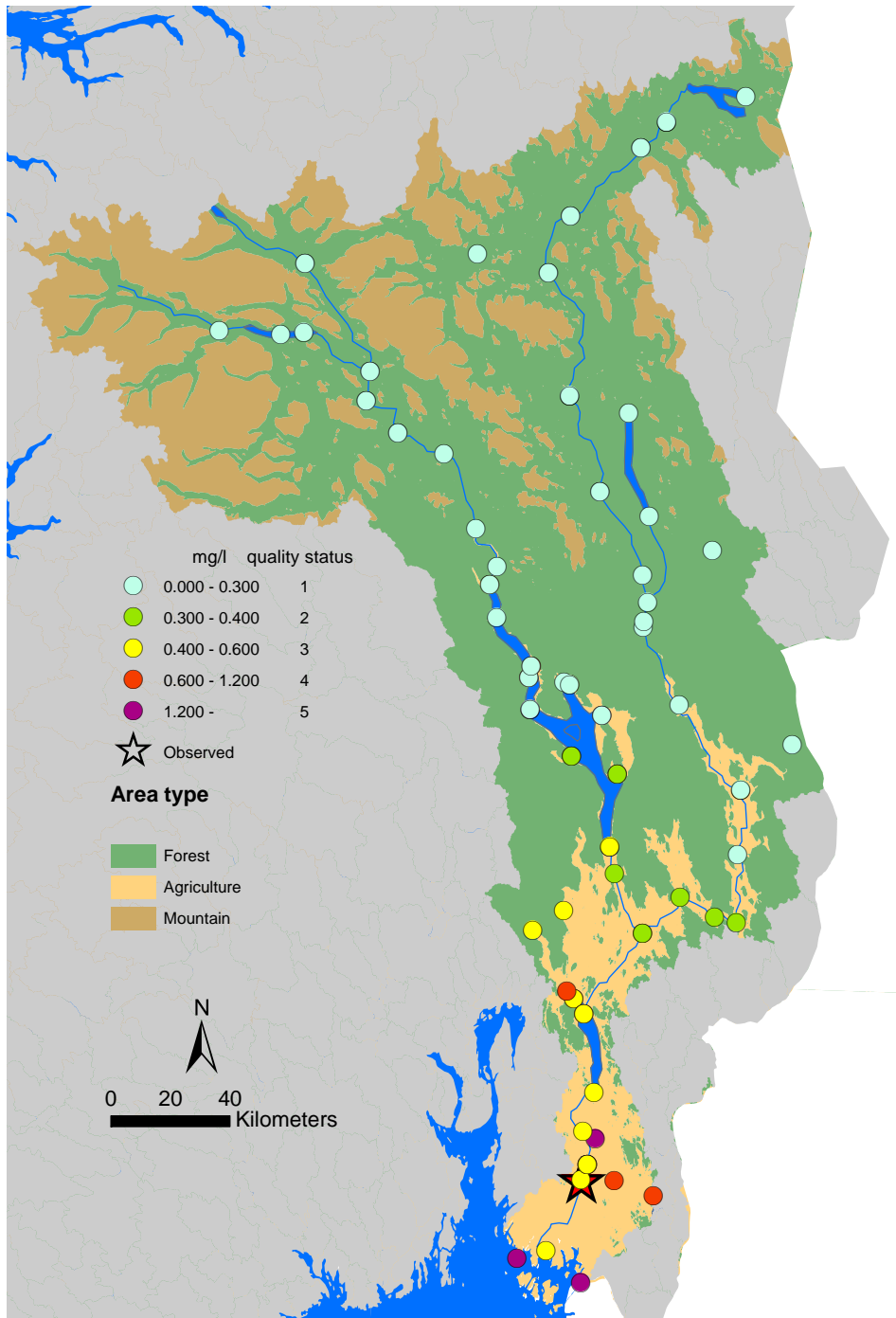*Figure 13. Estimated mean total nitrogen concentration in the Glomma river catchment, and observed mean concentration at the outlet.*

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Figure 14. Estimated mean total phosphorus concentrations in the catchments of the rivers Gaula, Nidelva and Stjørdalselva in 2004, and observed mean concentrations at the outlets.

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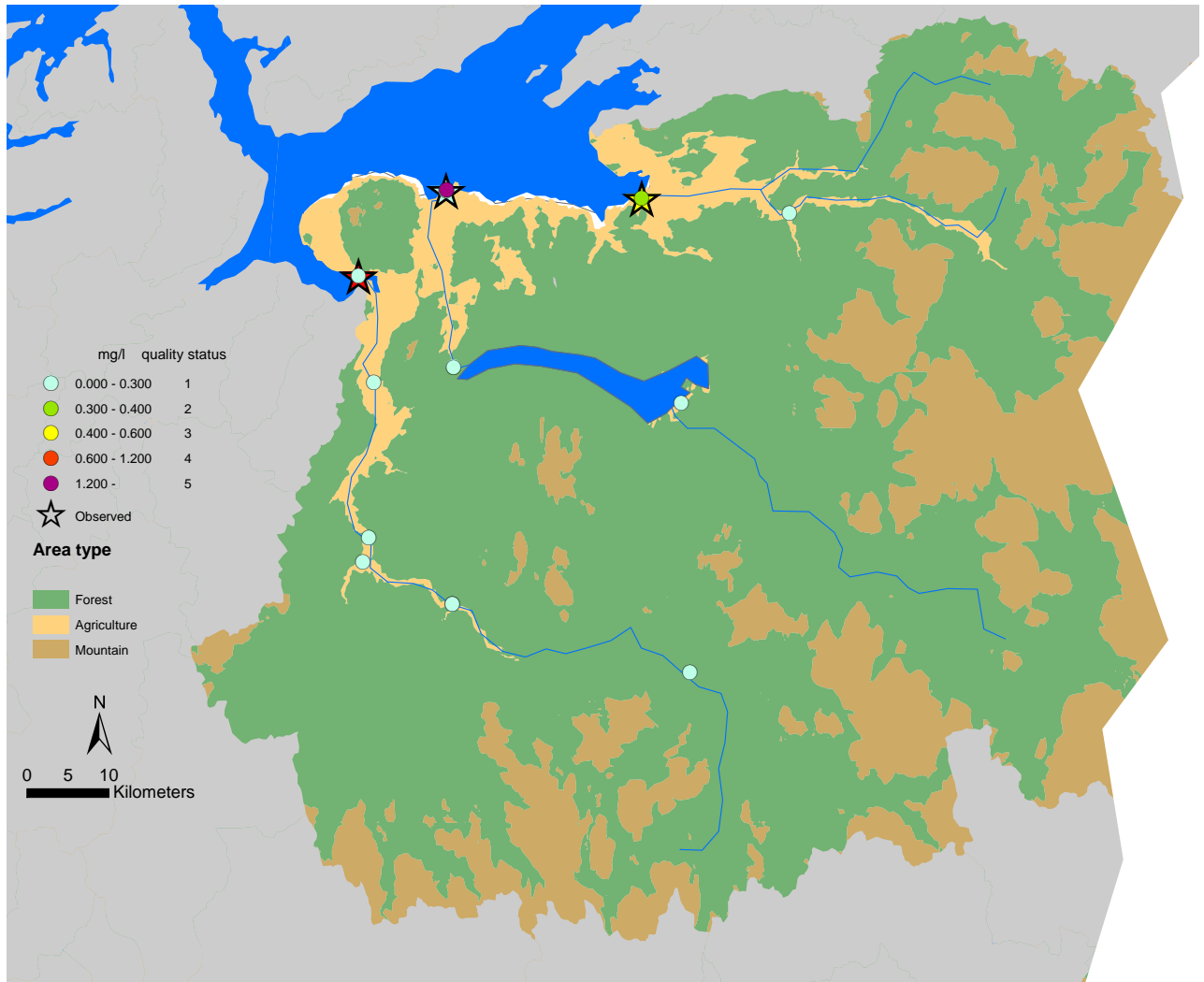(TA-2203/2006)

Figure 15. Estimated mean total nitrogen concentrations in the catchments of the rivers Gaula, Nidelva and Stjørdalselva in 2004, and observed mean concentrations at the outlets.

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4.3   Improving the understanding of the differences

4.3.1   Some reasons for the differences

As shown above, there are significant differences in the results from the SOA (TEOTIL) and LOA (RID Programme) approaches. One observed pattern was that the values as measured by the RID Programme were higher than the modelled values. One reason for this may be that the TEOTIL was run with new coefficients for background values from forests and mountainous areas in 2004. The new coefficients were significantly lower than the ones used in previous years. The model has not been calibrated with the RID data after this change, and, thus, the observed differences in 2004 are probably larger than in previous years.

Furthermore, the higher values from the RID programme were particularly pronounced in the south-eastern and southern parts of Norway, as demonstrated most clearly by the phosphorus values. This particular pattern may be due to nutrient retention in lakes, as the estimates of the inputs to this part of the Norwegian coast are heavily influenced by the accuracy of the coefficients for retention in lakes. In this area there is a high number of large lakes where nutrient retention is important. In the rest of the country there are fewer and smaller lakes. There are also less observation data for model calibration purposes.

Other reasons for differences may be linked to the statistical areas used by TEOTIL. In some cases there are poor relationships between the observation site of the RID programme and the statistical area used by the TEOTIL model. In several cases the statistical areas are too large, e.g. there may be a number of smaller water courses with observation sites within one statistical area. There are also cases where aquaculture plants or other point sources are located downstream of the observation site in the statistical area that drains to the sea. The introduction of smaller sub-catchments (REGINE) and an improved set of coordinates for exact location of discharge points for WWTP and industry may improve the accuracy of the results. In addition, the reporting from point sources should be improved.

In terms of the load orientated approach, the frequency of sampling and the choice of interpolation methodology should be investigated more thoroughly as these are believed to be major sources of errors in this approach.

Below, a short description of the already implemented improvements in the two programmes is given, together with views on how further improvements may be developed. In Chapters 5 and 6, more detailed descriptions of some of these sources of errors are given.

4.3.2   Newly implemented improvements in the load orientated approach

In a SOA it is important that no major nutrient source is unaccounted for and that e.g. all industrial plants and WWTPs report regularly (every year) in order to ensure that estimated reductions are 'real reductions', and not due to the fact that some plants failed to report one or the other year. Within the TEOTIL context the most recent years have seen a strengthening of the control of whether all important plants report regularly. However, in particular with regard to nutrients, this remain a problem as most industrial plants do not have a requirement for a discharge permit for nutrients and thus do not carry out monitoring, and also because there is

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a large number of small industrial activities that all added together may represent a total discharge that should have been taken account of.

A major improvement in the RID programme in 2004 was the change from sampling 145 rivers once a year, to sampling 36 rivers four times a year. The rationale for this change is as follows:

The Norwegian RID programme for the period 1990-2003 included 10 rivers monitored monthly, and 145 rivers monitored once a year. The latter 145 have generally been labelled "tributary rivers", although they discharge into the sea, and some of them are among the larger rivers of Norway. These 145 "tributary" rivers appeared to contribute considerably to the total inputs from Norwegian rivers into the sea. For some substances, such as nitrogen, they exceeded the total inputs of the ten more intensively monitored rivers (c.f. Figure 16).
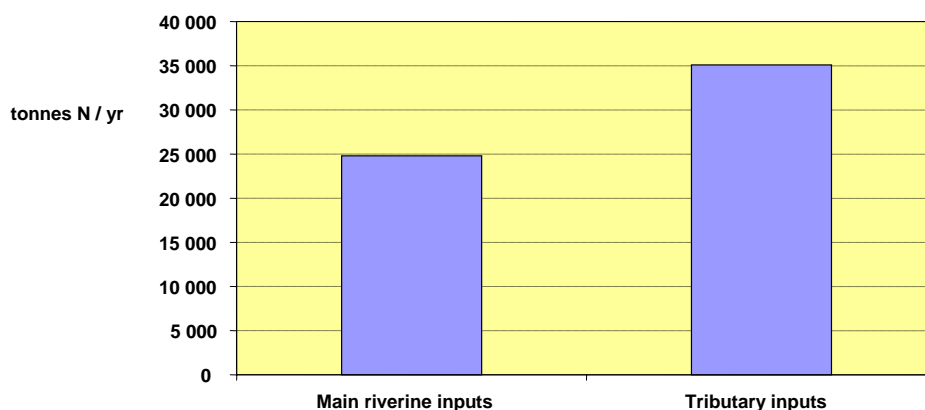

Figure 16. Annual inputs of total nitrogen in 2001 from the 10 main rivers and the 145 tributaries (Weideborg et al. 2002).

Figure 17 shows, in an example of four Norwegian rivers, how the estimated loads of total nitrogen, lead, cadmium, total phosphorus, and suspended particulate matter may vary considerably depending on the number of samples and time of the year for sampling. Another example of the importance of sampling frequency is given in Figure 18, where estimated loads based on single samples is compared to loads based on the average of 19 samples. The examples clearly show that the previous once-a-year sampling frequency in the tributaries provided a highly insufficient basis for estimating the yearly load of the RID substances, in particular in the case of water courses with high pressures, e.g. catchments with a large proportion of agricultural land and other human activities.

One sample a year is, thus, believed to be insufficient to estimate annual load in a water course. The Norwegian RID programme was therefore changed in 2004, and sampling frequency of the so-called "tributary rivers" was increased from once to four times a year. In order to maintain costs at a relatively constant level, the number of rivers monitored less frequently was reduced from 145 to 36, encompassing a careful selection of the 36. The total drainage area for the original selection of 145 tributary rivers was 134 000 km^2, whereas the selected 36 rivers cover 86 000 km^2, or 64% of the former tributary area.

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It should, however, be noted that this increase from one to four samples a year probably still is insufficient. As demonstrated in Chapter 5, even monthly regular sampling may seriously underestimate the actual loads. On the other hand, the change from one to four samples a year in 2004 has already given interesting results: When comparing the loads of the 2004 Norwegian RID programme with previous years, there are for most parameters high to very high changes in the estimated loads that can not be explained by differences in the hydrological year, but is due to an increased number of samples.

A more thorough study on the importance of sampling frequency is given in Chaper 5.
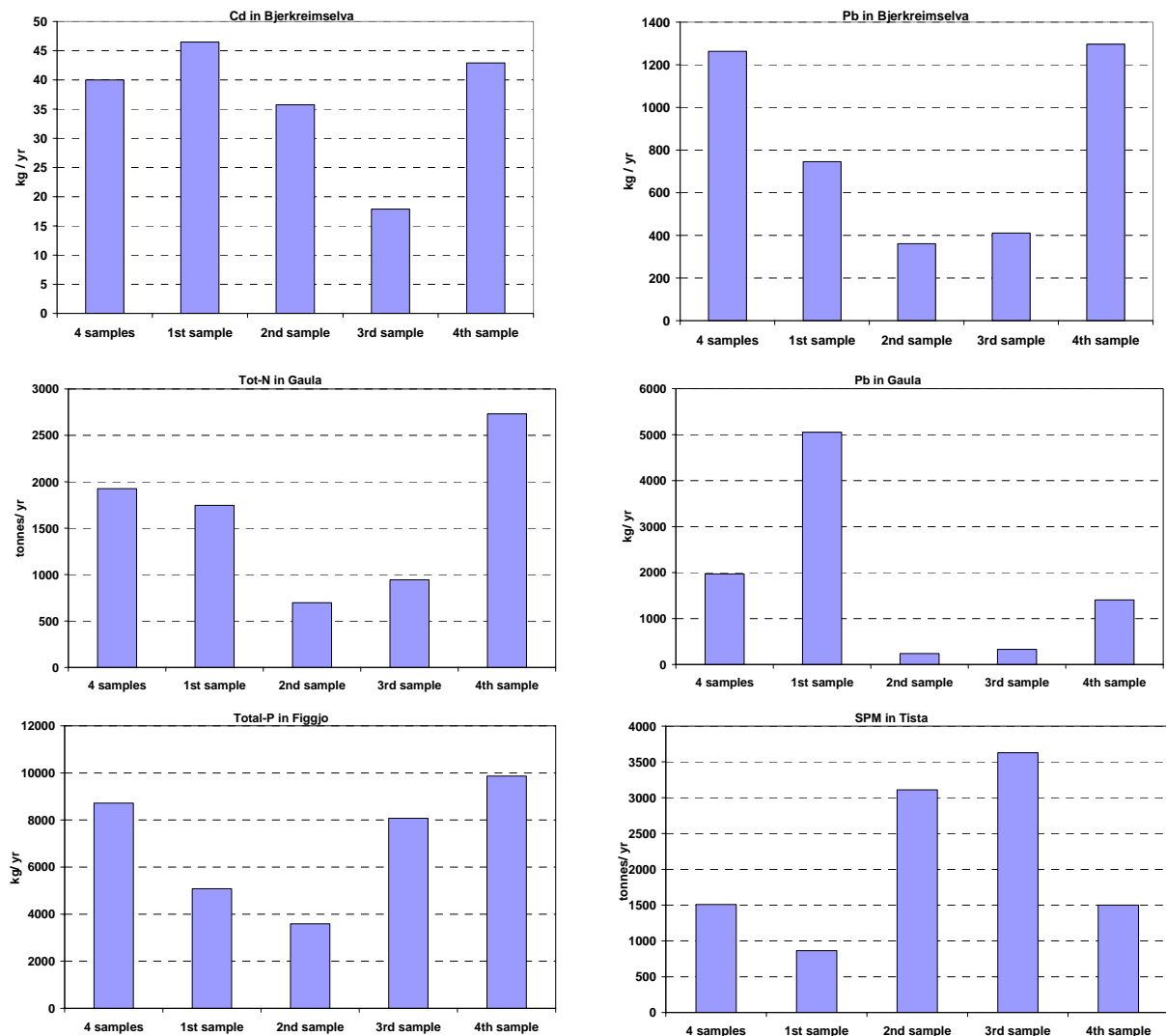

Figure 17. Examples of how the number of samples changes the total riverine load estimates of lead, nitrogen, cadmium, total phosphorus and suspended particulate matter.

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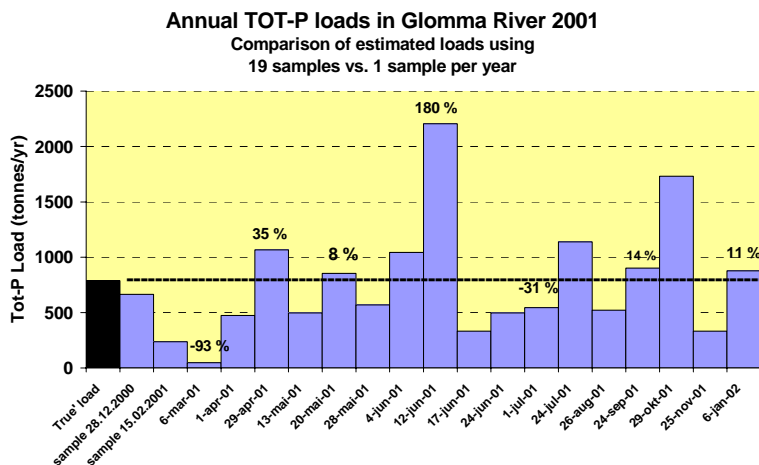(TA-2203/2006)

Figure 18. Annual load of total phosphorus in the river Glomma. The estimated load based on 19 samples is shown in the black column, and on one sample in the blue columns.

4.3.3   Newly implemented improvements in source estimation approaches

Up to and including the year 2003, the TEOTIL model used the specific flow for the normalised period 1960-1990. As from 2004, this flow is now corrected according to yearly water flow at characteristic water flow stations. The yearly loss of phosphorus and nitrogen is estimated as the sum of loss concentration and water flow. By applying this approach, the loss concentrations will remain unchanged from one year to another, as they are linked to the specifics of the type of land area, whereas the loss amounts vary according to the water flow. The maps in Figure 19 are produced based on about 700 observation sites, the results show only small regional differences. As shown in Figure 20, there are large regional differences in discharge flow in Norway.

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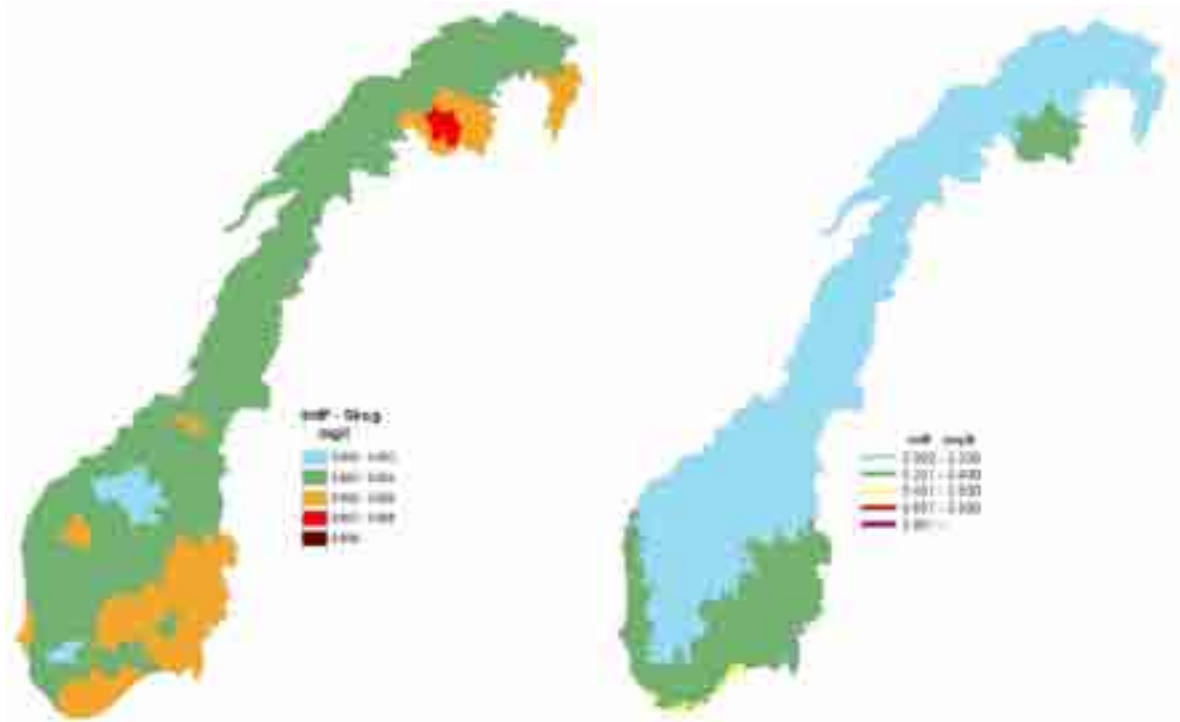
Figure 19. Mean concentration of phosphorus and nitrogen losses from forested areas in Norway 2004

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Figure 20. Discharge flow in liter per second and km² in Norway in 2004

Figure 21. The natural loss of phosphorus (left) and nitrogen (right) from agricultural areas in Norway in 2004 (anthropogenic part removed)

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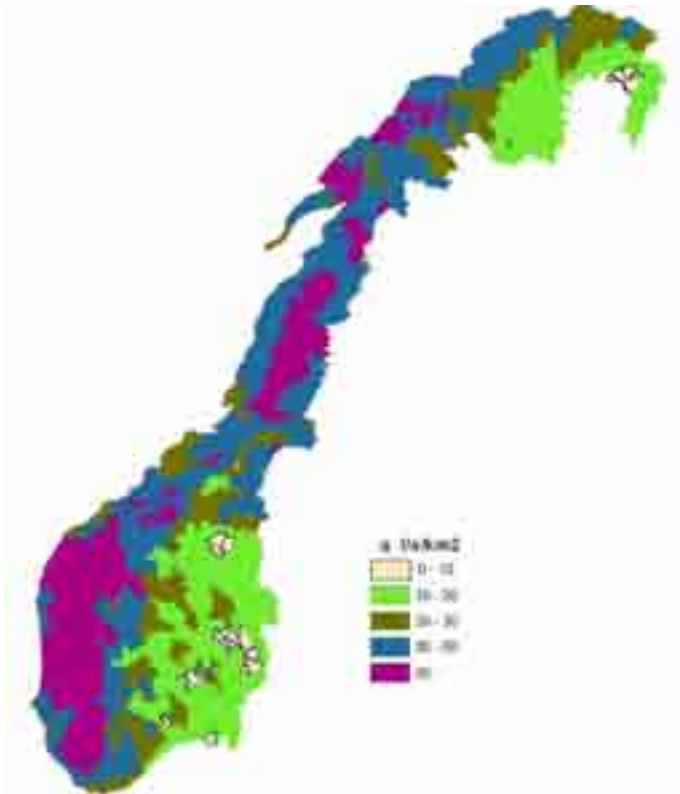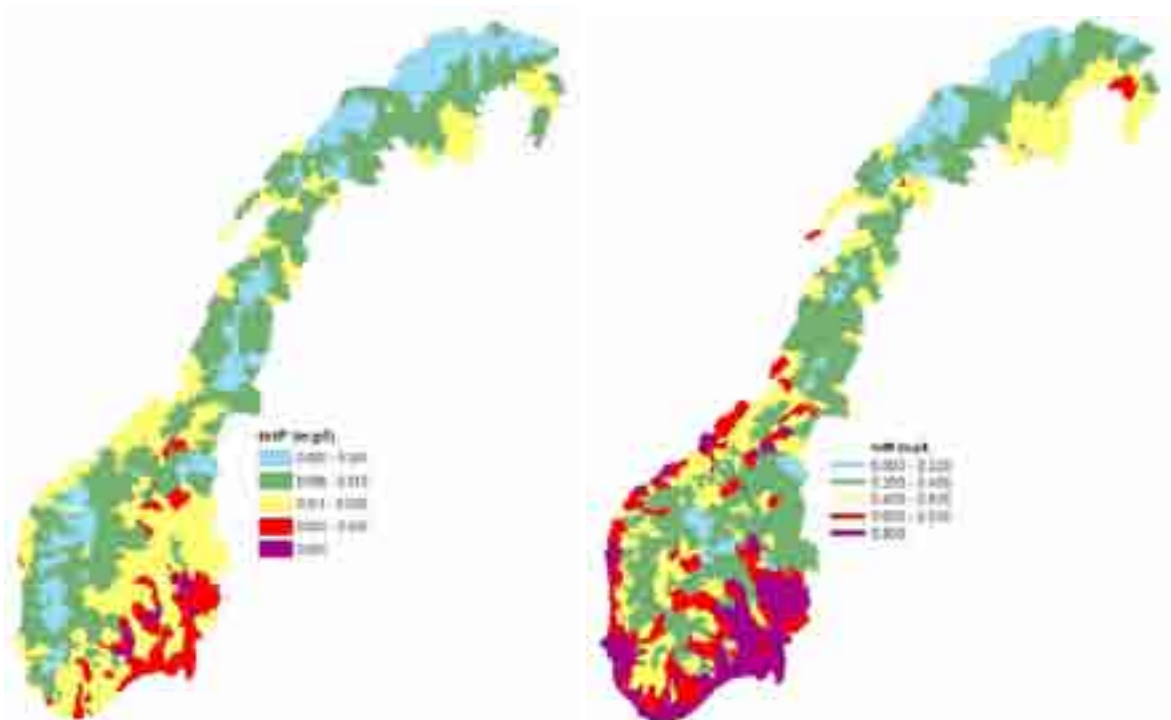(TA-2203/2006)

As shown in Figure 21, there are large regional differences in agricultural losses in Norway. The results from TEOTIL indicate only the anthropogenic losses from agricultural fields. The Norwegian Institute for Agricultural and Environmental Research (Bioforsk, an institute that also includes Jordforsk) provides coefficients for the losses of nitrogen and phosphorus from agricultural fields when the anthropogenic component is subtracted. The figures from Bioforsk in kg/ha agricultural land are converted to mg/l by dividing with the yearly specific flow.

The mean concentration for all agricultural areas in Figure 21 is 0.011 mg tot-P/l and 0.580 mg tot-N/l respectively, whereas the mean concentration of losses from forested areas (Figure 19) is 0.003 mg tot-P/l and 0.170 mg tot-N/l respectively. It seems appropriate that agricultural activities take place on the most fertile areas, and thus have a higher natural nutrient loss than from existing forested areas. It is a question though whether the estimated nutrient loss coefficients from the forested areas that would have been there if the areas were not cultivated should have shown a more similar regional pattern to the nutrient loss coefficients form existing forested areas.

4.3.4   Future possible improvements in the LOA

As demonstrated in Chapter 5, the choice of method for interpolation of values in periods without data may be of crucial importance for the load estimates. However, no clear conclusion as to which method is the best has yet been given. The demonstration of the differences in results due to different interpolation methods does, however, point to an important possible source of error in the load orientated approach, and may therefore be instrumental in understanding the reasons for differences between the load and source orientated approaches.

In addition to frequency of sampling, which has already to some extent been implemented in the RID Programme, another improvement may be to analyse parameters more selectively. Keeping in mind the cost-efficiency of the programme, parameters that throughout the years have shown a low, stable concentration may be analysed less frequently, whereas "hot-spots" with high values of selected parameters could be analysed more often. This does, however, require a more detailed follow-up of the monitoring programme, and due to the infrequent sampling of the rivers the data basis may not be sufficient to perform such selections. Furthermore, this may not be in accordance with the OSPAR requirements.

4.3.5   Future possible improvements of the SOA

Nutrient loss coefficients from agricultural areas

The nutrient loss coefficients from agricultural areas used today are given as kg/km^2 (see Figures 22 and 23). They are produced based on measurements in a limited number of experimental fields and are extrapolated to the whole country of Norway. In doing so, it is necessary to take account of both type of agricultural fields and water flow. It may be more accurate to estimate nutrient loss coefficients and, in doing so, discard the water flow from the determination of coefficients. If this was the case, the transport estimates made within TEOTIL would provide a more nuanced nutrient loss pattern as regional water flow variations

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would be taken account of in the estimates. In other words, the coefficients should reflect type, condition and use of the agricultural areas, and not climate related issues such as precipitation and water flow. Coefficients developed on such a basis (mg/l) could more likely be used over a longer time span as changes in coefficients would be needed only in cases of changed land use.
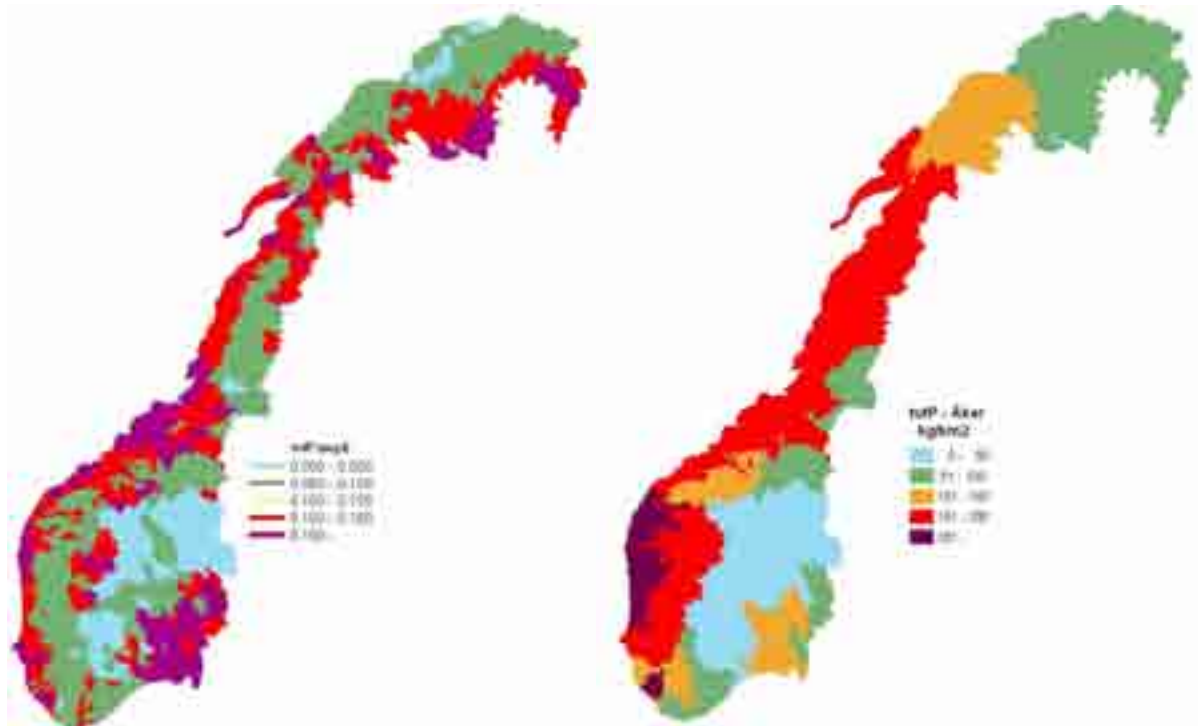

Figure 22. Phosphorus derived from agricultural areas as mean concentration in mg/l (left) and loss in kg/km² (right)

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Figure 23. Nitrogen derived from agricultural areas as mean concentration in mg/l (left) and loss in kg/km² (right)

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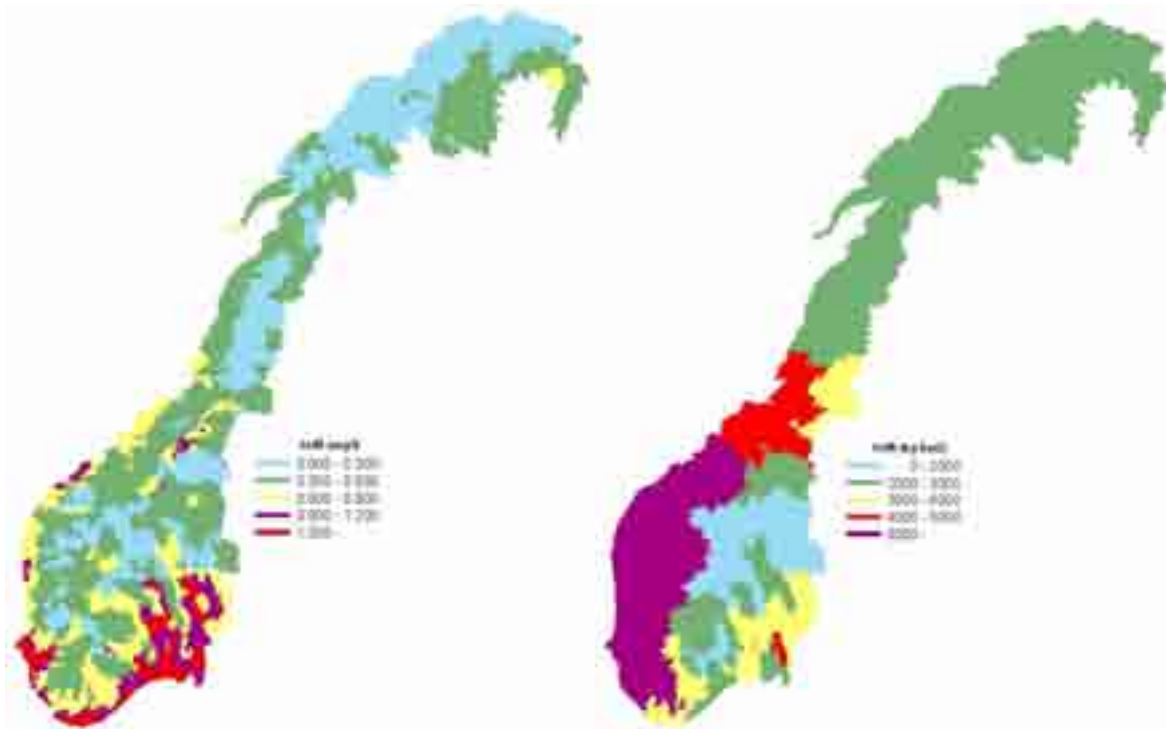(TA-2203/2006)

TEOTIL applied in sub-catchments

The TEOTIL model uses statistical areas for its nutrient load estimates. The whole of Norway is divided into about 1100 such areas (see Figure 24). The value at the outlet of a statistical area is extrapolated to the whole statistical area. The map shown in Figure 25 shows the nitrogen and phosphorus concentrations in the main rivers within each statistical area. One interesting avenue for improvement of the TEOTIL model would be to improve the model resolution, e.g. by using REGINE areas. The TEOTIL model would then be able to take account of about 20 000 sub-catchments, i.e. TEOTIL values could be produced for also small rivers. Furthermore, the REGINE catchments include in principal one relatively large lake.

In relation to the implementation of the Water Framework Directive in Norway and the work on characterisation of water bodies, numbered river segments are used as a minimum unit for describing the water quality. There are several hundred thousands of such segments in the whole of Norway. Provided that all pollution sources have accurate co-ordinates, and there are nutrient loss coefficient maps from all areas, the TEOTIL model could most likely be used to estimate the water quality in each single river segment, not only for nutrients, but for any parameter with adequate information available.

Figure 24. Statistical areas in the southern part of Norway

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Figure 25. Phosphorus (left) and nitrogen concentrations in 2004, calculated by the TEOTIL model

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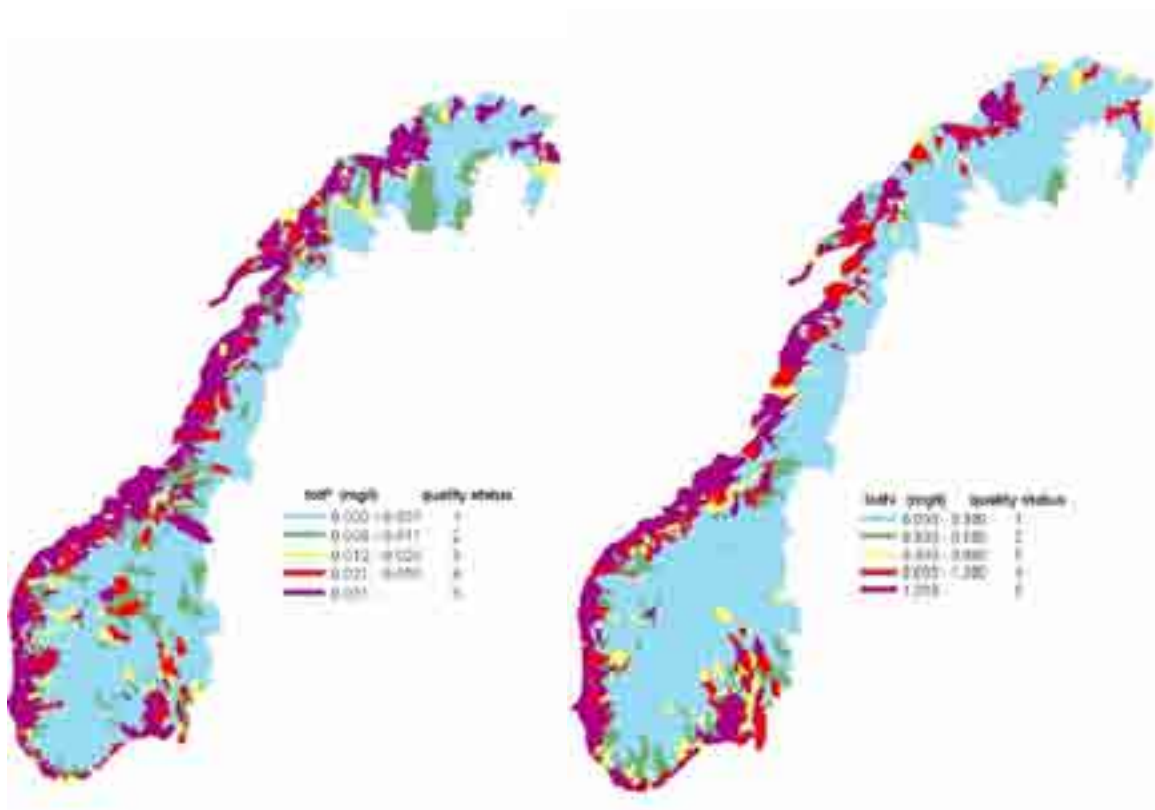(TA-2203/2006)

5.   Detailed study A: Reliability of riverine particle load estimates

This Chapter focuses on the reliability of riverine load estimates by studying two aspects of this topic in relation to suspended particulate transport:
- the importance of sampling frequency
- the importance of choice of load estimation method

The study is based on comparisons between the monthly samples collected by the RID Programme and daily samples collected by the Norwegian Water Resources and Energy Directorate, in the river Numedalslaagen in southern Norway.

The results have implications not only on loads of suspended particles, but also on substances transported partly or entirely in the particulate phase.

5.1   Two sources of errors

This chapter focuses on the reliability of the estimates of suspended particulate load in the RID Programme, by studying two aspects of this topic in one of the ten main rivers; the River Numedalslaagen:
- the importance of sampling frequency
- the importance of choice of load estimation method

The topic is made highly relevant by the ecological disaster occurring to the sugar kelp along the coasts of southern Norway. One of the reasons for the wide-spread death of the sweet tangle is believed to be excessive siltation. Thus, reliable estimates of riverine suspended particulate load is important in this part of Norway in order to evaluate the relative importance of land based and ocean based sources of particles. However, the study is also important for all estimates of particulate and particle associated load in rivers, including phosphorus, and several metals and organic pollutants. The correlation between phosphorus and suspended sediment concentrations in the river Numedalslaagen is shown in Figure 26.

5.1.1   Importance of sampling frequency
In the RID programme (*Riverine Inputs and Direct Discharges to Norwegian Coastal Waters)*, which is linked to Norway's obligations to the OSPAR Convention ((PARCOM, 1988), ten so-called "main rivers" have been selected to be monitored monthly for nutrients, pollutants and sediments. The rationale behind the selection of the ten "main rivers" is that this monitoring will give a good indication of the contaminant load to the marine areas. A load estimation equation provided by the OSPAR Convention has been used to determine the annual load based on these monthly measurements.

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However, for suspended sediments, and also for pollutants associated with sediments, a number of studies have shown that monthly, regular sampling may not give sufficiently reliable data (e.g., Walling and Webb 1981). The question is then whether these monthly measurements may be used in load estimates in order to calculate reliable loads to the Norwegian coastal waters.
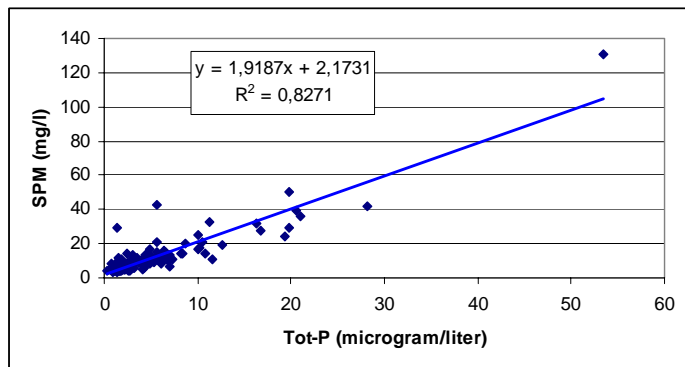

Figure 26. Correlation between Total phosphorus and suspended sediment concentrations in Numedalslaagen, 1990-2000, and 2004 (Based on RID data and analyses done at NIVA's laboratory)[1].

5.1.2 Methods for estimating pollutant loads

Ideally, with continuous discharge, Q (m^3/s), and concentration data, C (mg/l), riverine loading, L (tons/yr), is computed using the equation below, which integrates across the period of record, often given as year of observations:

$$L = \int_{t=1}^{Year} Q_t \cdot C_t \cdot d_t$$

Unfortunately, C is seldom provided as a continuous measurement due to cost restrictions (Cohn, 1995). In fact, in many national river monitoring programmes, as in the RID Programme, sampling of water quality is done only once a month or every fortnight. Water discharge data are usually more readily available as continuous measurements, provided a gauging station has been established in the river at relative proximity to the sampling site.

5.2 Description of the data used in the study

5.2.1 Monthly data from the RID Programme

Monthly data are available from River Numedalslaagen from the records of the RID Programme, back to 1990. The data are collected at Bommestad, some 5 km upstream of the

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[1] As reported in Borgvang et al. 2006, the data from 2001-2004 had total phosphorus values considered in accurate as compared to the rest of the dataset, and these are therefore omitted here.

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river outlet into the sea. The samples have been collected from the side of the river, at a relatively turbulent spot. Section 3.1 gives a more thorough description of the sampling method. The analyses of suspended solids have been done at two different laboratories; before 1999 at NIVA, in the period 1999-2003 at Analycen; and in 2004 again at NIVA.

5.2.2   Daily data from the Norwegian Water Resources and Energy Directorate

Daily data (in general based on two samples per day) were available from Holmfoss, some 13 km upstream of Bommestad. The sampling has been done with an automatic sampler, and the analyses have been done at the laboratory of the Norwegian Water Resources and Energy Directorate (NVE).

Daily data were available in 6-7 months per year, as it is difficult to run the automatic sampler during the winter season. Table 3 gives the periods of daily sampling.

Table 3. Dataset for daily samples. Normally, two samples were taken each day during the periods shown in the table.

Year	Period of daily water sampling
2001	May 11 - November 28
2002	April 10 - October 20
2003	April 14 - October 18
2004	April 27 - November 17
2005	April 29 - November 22

In order to compare the station at Holmfoss with that at Bommestad, where the RID data are collected, an automatic sampler was installed in 2005, and was running for the period 2 June – 22 November, with a gap during 6-25 August 2005. The samples from Holmfoss in 2005 were mainly used to calibrate data from water samples at Holmfoss and Bommestad in this study, but the samples are intended to be utilised for comparisons with RID data later.

The comparison between the concentrations and loads at Bommestad and Holmfoss in 2005 showed that the water samples at Bommestad had about 30% higher concentrations than at Holmfoss. The load comparisons, as calculated from average daily water discharge values in Holmfoss and Bommestad (corrected at Bommestad by a factor of 106% based on increased drainage area), showed that the load past Bommestad was about 38% higher than at Holmfoss. However, if the three highest concentrations/loads are removed, the concentration at Bommestad is only slightly higher (8%) than at Holmfoss (cf. Figure 27); and the load only 4% higher.

This suggests that at normal loads, the loads at Bommestad and Holmfoss are fairly similar. The reason for the slight increase of about 4% may range from sampling errors to erosion in the river channel or increased sediment delivery from the catchment downstream of Holmfoss.

The higher difference at high loads may have a number of causes, including, again, sampling errors, and sampling site representativity during high flows. The poor correlation between suspended sediment concentrations in the river water at Bommestad and Holmfoss during low flows, as shown in the top right panel in Figure 27, may illustrate the difficulties of taking representative samples, as well as the complexity and variability in sediment transport

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mechanisms in rivers. This topic will, however, be followed up in another study, as it is beyond the scope of this report.
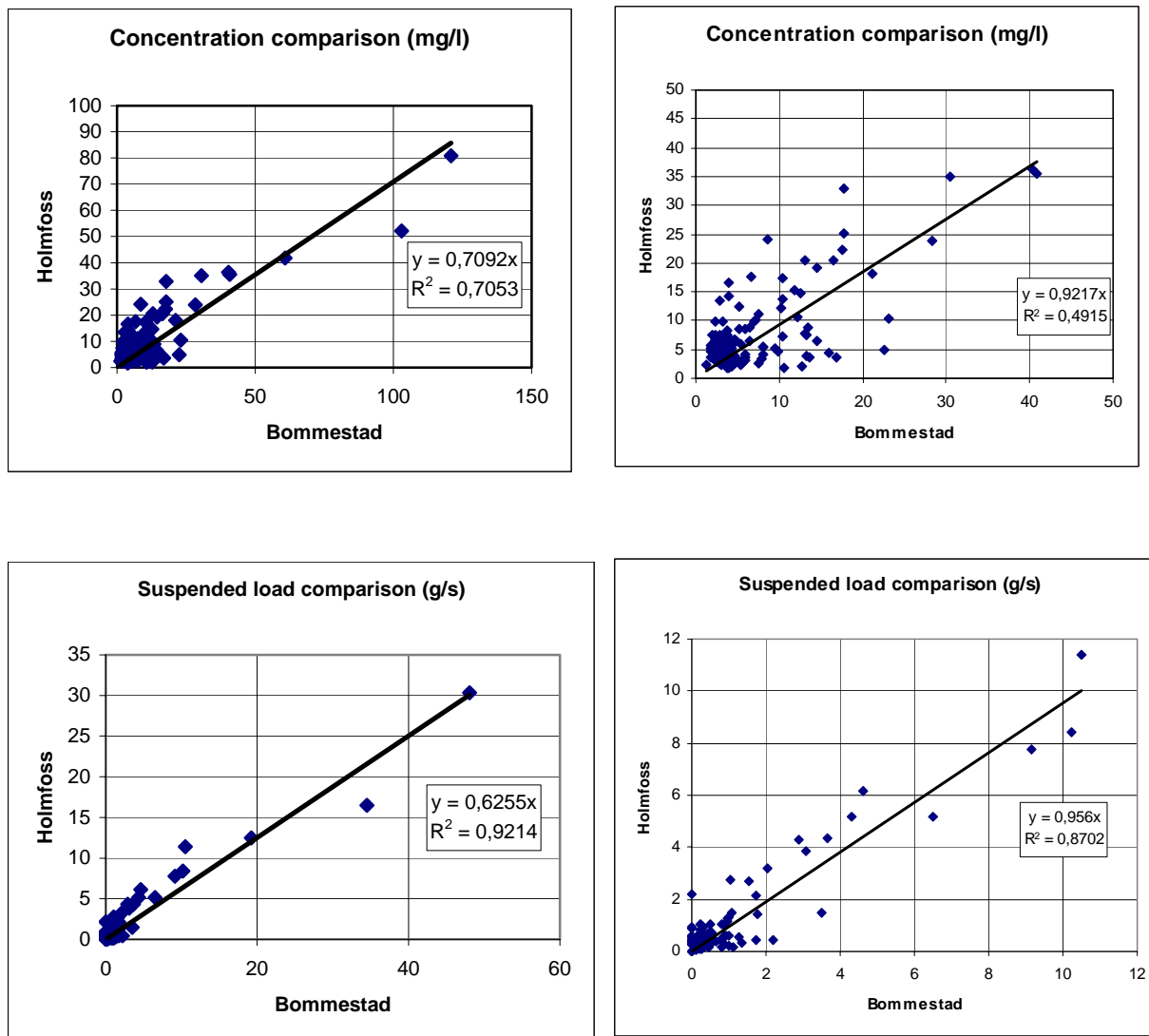

Figure 27. Concentration (top panels) and load (lower panels) comparisons between the two stations Bommestad and Holmfoss. In the right hand panels the three highest concentrations and loads have been removed.

The conclusion from this comparison is, thus, that at low and medium sediment concentrations, the station at Bommestad carries about 4 % more load than at Holmfoss, provided the data from three samples at higher concentrations and water discharges is removed from the calculation.

Based on this, it was decided to make a simplified assumption that the data on annual load from direct measurements at Holmfoss in the period 2001-2004 should only be upgraded with the water discharge factor of 106%, to represent the data at Bommestad. In other words, it was decided that the higher discrepancies seen at high water discharges/loads were too uncertain

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(only based on three samples) to be given significance at this stage. This decision does, of course, influence the comparison of the different load methods, but at the same factor for all methods.

5.2.3   Calculation of direct discharges based on NVE's daily data

The calculation of direct discharges based on the daily (or twice a day) samples, were done as follows:

Linear interpolation was done to estimate sediment concentrations between the two daily measurements. Similarly, the water discharge between the two sampling was also calculated by linear interpolation. The concentration and water discharge was calculated for each hour. Thus, 24 concentration values per day were calculated, and the average of these represents the average daily concentration; and, similarly, 24 water discharge values were calculated, their average is the daily mean water discharge.

Next, the load was calculated as the sum of these, i.e., measured water discharge times measured concentration when data existed; and interpolated water discharge times interpolated concentration.

For periods with no samples, i.e. during the winter season, NVE usually uses the sediment rating curve for interpolation. However, in this study the loads reported as "direct measurements" *only represent those periods in each year* for which daily sampling was done.

5.3   Types of Load Calculation Methods Applied

During the last 3 decades, a vast amount of different load estimation methods has been developed and tested (e.g., Bennett and Sabol, 1973; Johnson, 1979; Verhoff et al., 1980; Dickinson, 1981; Dolan et al., 1981; Fenn et al., 1985; Dann et al., 1986; Somlyody, 1986; Ferguson, 1987; Richards et al., 1987; Walling et al., 1988; Preston et al., 1989; Clarke, 1990; Crawford, 1991; Kronvang and Bruhn,1996).

The methods can broadly be categorised into three groups:
* Average Methods, including the Linear Interpolation Method
* Ratio methods or ratio estimators, including the method used by the RID-Programme
* Rating curves (regression)

Method accuracy and precision assessments has generated conflicting findings that may be explained by the analysis objective, data constraint, differences in substance studied, river hydrology, and basin type. For example, Dolan *et al.* (1981) found for a river flowing to Lake Michigan (U.S) that the ratio-method performed slightly better than the average and rating curve methods. Kronvang and Bruhn (1996) showed that for a small Danish lowland, the best performance was found by the linear interpolation method (average method). Cohn (1995) reports in favour of regression methods, while Dann et al. (1986) favored the period weighting over regression and ratio methods. Coats et al. (2002) concluded that the period weighted was the best method for dissolved constituents, the regression best for particulates, and the unstratified and stratified ratio estimators were not consistently different.

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The present study assesses the robustness of 3 estimation methods (Linear Interpolation Method; Ratio Method; and Rating Curves) for suspended solids and compares these with direct measurements in the River Numedalslaagen.

A description of each of the three methods is given below.

5.3.1   Average method (including linear interpolation)

The product of the un-weighted average of all concentrations and the total annual discharge volume, gives an average load, this method has been described as the Simple Average Concentration Method (Dann, et al., 1986). However, this method does not account for obvious concentration and water discharge relationships and the full information in the data set. Preston et al (1989) also pointed out that implicit assumptions such as independent and identically distributed data are rarely met. Violations of assumptions may lead to estimation bias especially if the sampling programmes do not collect data from the entire range of flow and concentration values (Dolan et al., 1981; Ferguson,1987).

A more sophisticated average method that utilise the full information in the daily discharge data is the *linear interpolation method*:

$$L_{Linear} = \sum_{i=1}^{Year} (Q_t \cdot \Delta\tau \cdot C_t)_t$$

where $\Delta\tau$ is the time step for discharge observations (here: days). Thus the concentrations for days not monitored is fitted by a straight line between 2 adjacent observations.

5.3.2   Ratio method (RID)

In the RID Programme, the load of a specific determinant transported by a river is estimated by taking the product of the mean flow-weighted concentration and the total flow, expressed by the following formula:

$$Load = Q_r \frac{\sum_{i=1}^{n}(C_i \cdot Q_i)}{\sum_{i=1}^{n}(Q_i)}$$

where
Ci = measured concentration in sample *i*
Qi = corresponding flow for sample *i*
Qr = mean flow rate for each sampling period (i.e., annual flow)
n = number of samples taken in the sampling period

Essentially the formula expresses the annual load (L) as the product of a flow-weighted estimate of annual mean concentration and annual flow (Qa).

As explained by Preston et al. (1989), such ratio estimators may be considered unbiased when the relation between load and discharge is linear and has an intercept of 0, and when the

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variance of load is proportional to discharge. However, this method ignores the extra information contained in the data for water discharge on the days when sampling is not performed. Since the loading rate of many substances is highly dependent on flow, substantial error can occur from using such a method.

5.3.3   Rating curves

One of the most common ways of combining sediment load data with continuous (or very frequent) water discharge data is the rating curve method. Already in 1940, Campbell and Bauder (1940) observed that the relation between the logarithm of sediment concentration and the logarithm of discharge was approximately linear. The rationale behind the curve is that sediment load, as measured in weight per time unit, increases with increasing water discharge.

The rating curve is most often fitted by ordinary linear regression on logarithmically transformed data. Since least squares regression is used to fit the rating curve between loads and water discharge it might be thought that positive and negative residuals cancel each other out, thus leaving no overall bias (high accuracy). However, many authors have suggested methods for corrections and modifications of the rating curve, as it has been shown to underestimate the actual loads (e.g., Ferguson, 1986; 1987, Asselman, 2000, Cohn et al., 1989, Richards and Holloway, 1987, Stow et al., 2001). The present study has, however, used the "original" curve with log transformation and linear regression.

In Norway, the rating curves have been used to interpolate between direct sampling values of suspended sediments, provided that frequent and event-orientated sampling is performed.

5.4   Results: Importance of sampling frequency

5.4.1   Direct comparison of monthly and daily samples

Figure 28 shows the water discharge and suspended sediment concentrations based on daily sampling at Holmfoss in the period 2001 to 2004. The high variability in both parameters is clearly illustrated by this graph. Furthermore, the graph shows how high water discharges in general causes increased concentration levels. Figure 29 shows the suspended sediment concentrations in the same period, but now compared to the suspended sediment concentrations as measured monthly in the RID programme. Exploratory analysis showed that the RID sampling in almost all cases missed the peak-values as observed in the daily NVE-data set. This illustrates the low probability of sampling at high water discharges in a programme with regular sampling frequencies.

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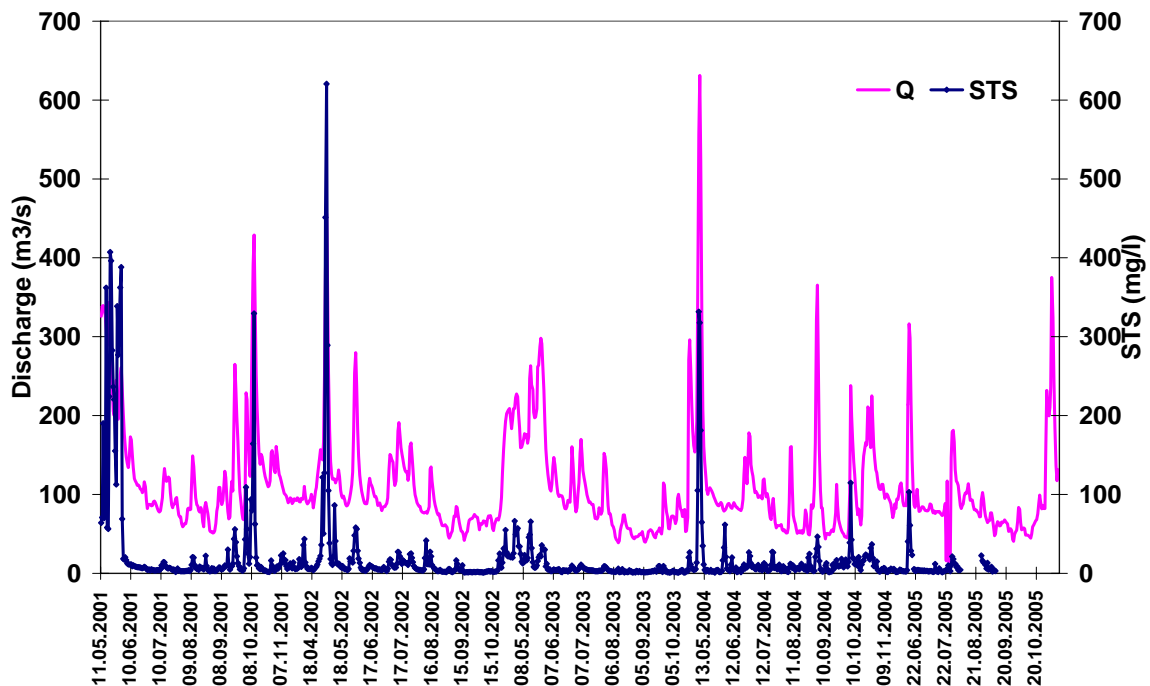(TA-2203/2006)

Figure 28. Water discharge and suspended sediment concentration (daily measurements) in the period 2001-2005 in Numedalslaagen. (STS=SPM=suspended particulate matter).
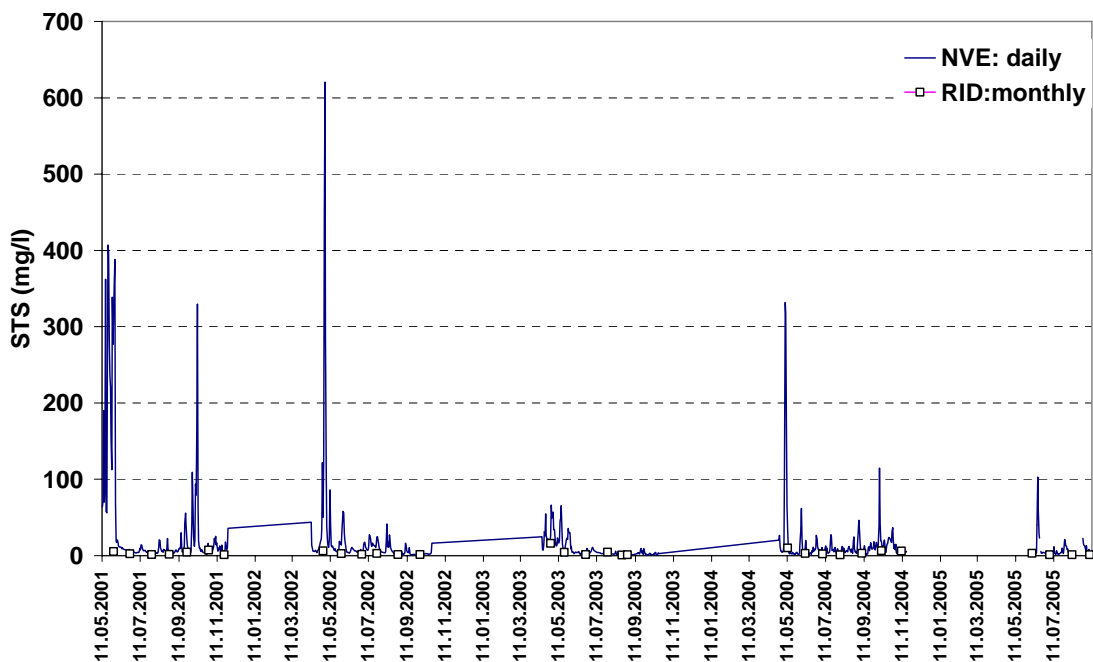

Figure 29. Concentrations of STS performed daily by NVE (line) and in the RID programme (squares). (STS=SPM=suspended particulate matter.)

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5.4.2   Comparisons of rating curves based on data from montly and daily sampling

The above findings, i.e. that the RID samples missed most of the high flows, are reflected in the sediment rating curves shown in figure 30, where daily and monthly data series are compared.

Both curves reflect the same *daily* data series (2001-2004), but the curve in the top panel shows monthly (RID) data series from 1990-2004 whereas the lower shows monthly data series from 2001-2004. This exercise was done in order to investigate whether a longer time series of monthly data would improve the curve significantly, i.e., move it closer to the curve for the daily measurements. However, this comparison only showed that the two curves varied very little, and, hence, that the curves based on RID data gave significantly lower loads for the same water discharge than the curve based on daily measurements. The difference increases with increasing water discharge, due to the steeper curve from the daily data set.
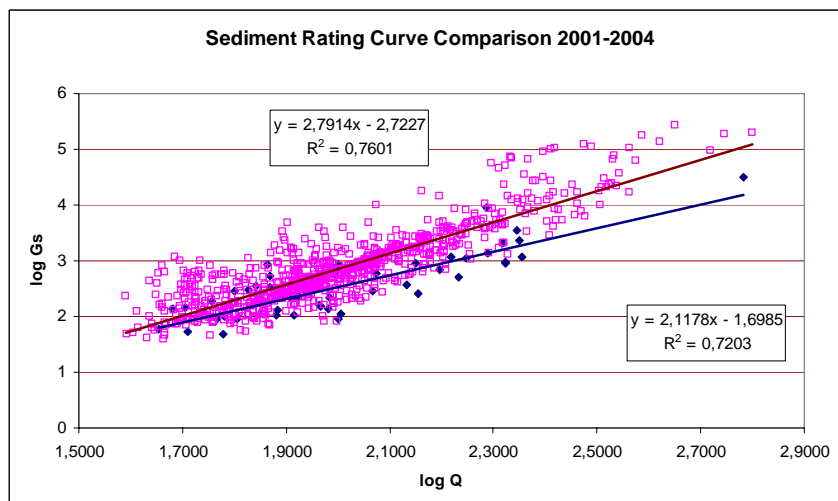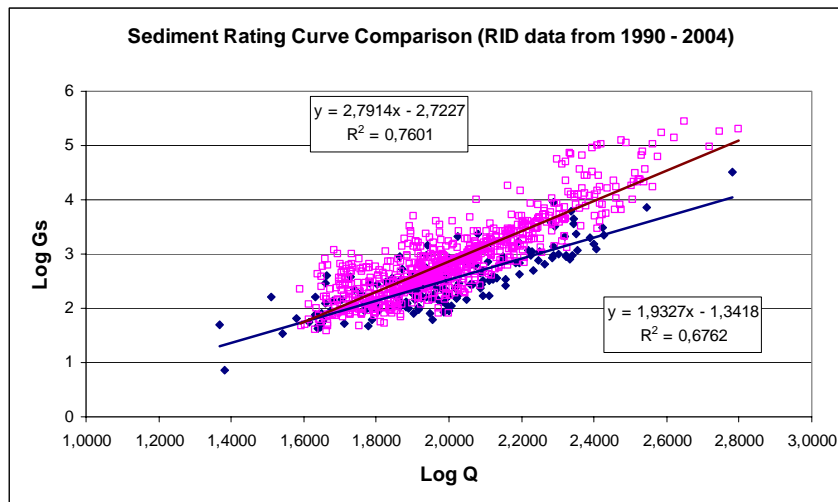

Figure 30: Comparison of sediment rating curves based on daily sampling (pink squares) for 2001-2004 (except winter season), the blue squares are based on RID data sampled monthly. Top panel shows monthly samples from the period 1990-2004, lower panel from the period - 2001-2004.

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5.4.3   Variations with sampling date

The above results led to the question of whether a change in sampling date would give significantly different load estimates.

Thus, monthly data were selected from the daily data series, by selecting data from the 1st day, 10th day and 20th day of the month, respectively. These new "constructed" data series were used to determine the loads according to the linear interpolation method. In addition, NVE data from the RID sampling dates were used.

The result showed that estimated loads at monthly frequency based on different dates, gave a high variability (Figure 31). This reflects the high variability in concentrations and loads over time. In fact, the estimates showed an overall range of 5 to 1002 %, where 100% represent the 'true' loads as measured by the daily measurements. The loads based on the ordinary RID-samples were the ones that most strongly underestimated the daily NVE-loads.
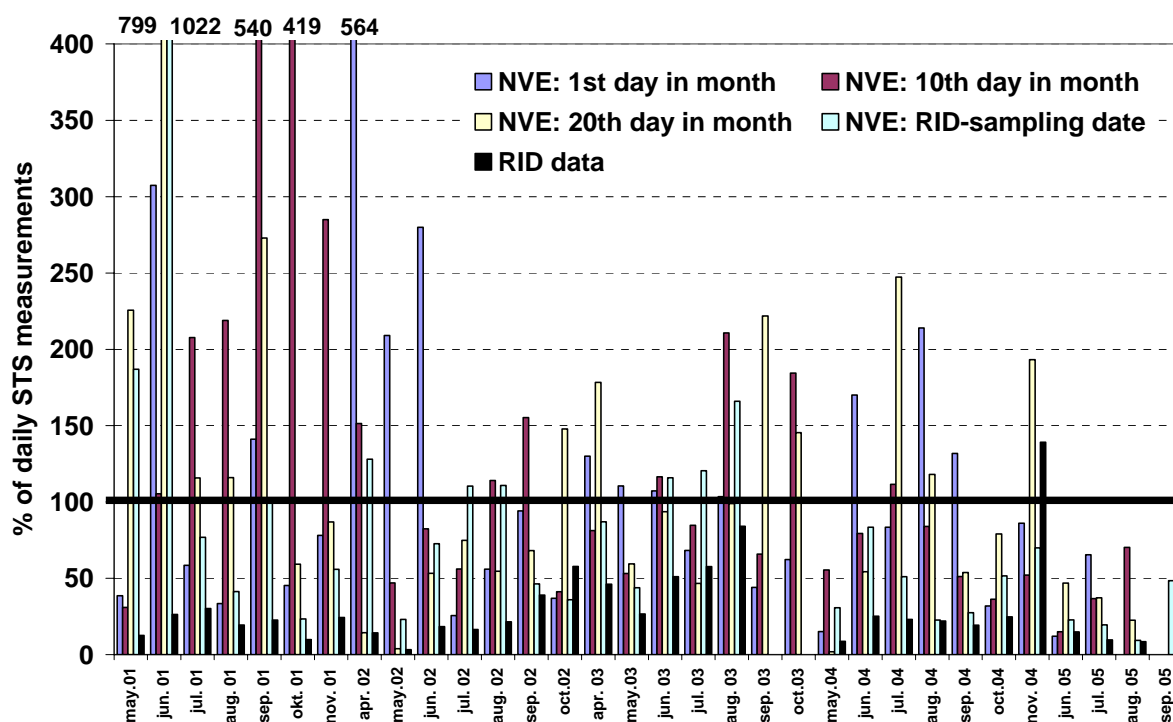

Figure 31. Deviation in STS-loads (in percentage) between daily NVE-samples (100%) and four different sub-sampling from the same data set at a monthly sampling frequency as well as the estimated load with the monthly RID-data (black bar).

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5.5 Results: Load calculation methods

Three different load calculation methods were tested. The linear interpolation, the ratio estimator and the rating curve. The main outcome is that there seems to be a general underestimation in all load estimation methods.

The first comparison (Figure 32) was done based only on the monthly RID data. This showed that using different load estimation methods gave high variations in loads some years, and relatively similar loads other years. However, as compared to the direct measurements from year 2001 onwards, it was only in 2003, with relatively low loads, that the estimates were within a reasonable range of the direct measurements. In 2001, 2002 and 2004 the estimated loads based on the RID data were less than a third of the direct measurements. It must also be noted that the direct measurements are based on no more than 7 months of measurements (cf. Table 3), so the actual difference is even higher.
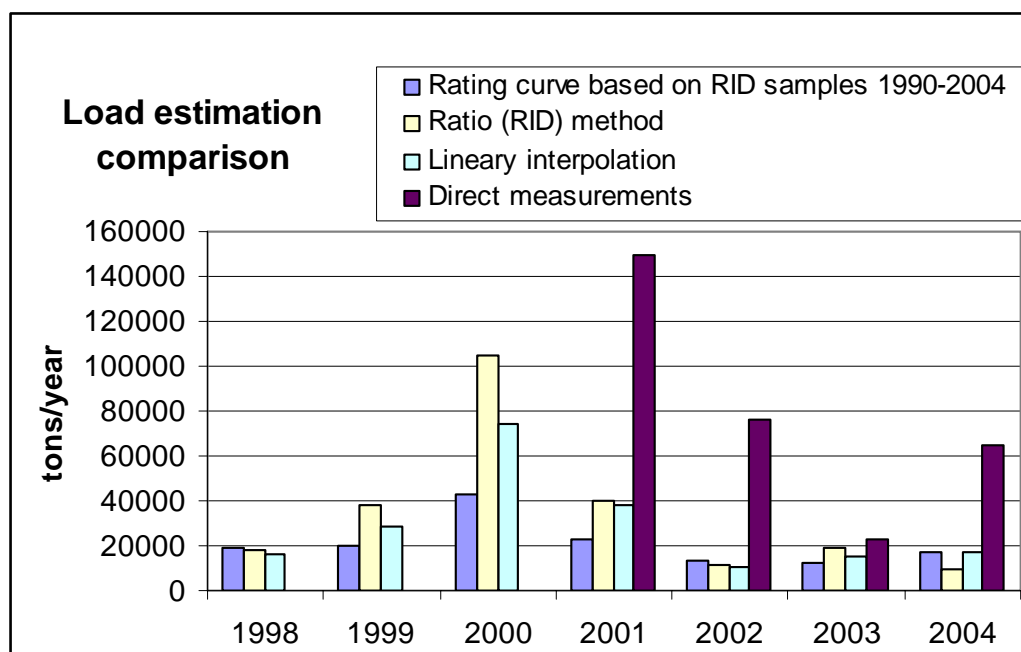

Figure 32. Comparison of suspended sediment loads in Numedalslaagen, based on three different load estimation methods as well as on direct measurements (daily sampling for parts of the years 2001-2004, see Table 3 for details on sampling periods).

Of the three methods applied, the Ratio method (RID method) showed the highest estimates in four of the years and the lowest in 2004. The lineary interpolation method gave higher values than the rating curve method in three of the years, but similar or lower values in the others. The rating curve estimates based on RID data from the period 1990-2004 gave, in general, low estimates. This is not surprising, since a number of authors have suggested modifications to the method precisely because it tends to underestimate loads at high water discharges (e.g., Ferguson, 1986; 1987, Asselman, 2000, Cohn et al., 1989, Richards and Holloway, 1987,

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Stow et al., 2001). Such modifications of the rating curves will be explored for the Numedalslaagen data at a later stage.

In this study, however, an analysis on differences in loads as caculated from rating curves constructed from different data sets was performed. One advantage of the rating curve is that it may be continuously improved by using new data. Thus, in order to evaluate this method further, three rating curves were constructed:

- Curve based on the RID Programme's data from 1990-2004
- Curve based on NVE's daily data from 2004
- Curve based on NVE's daily data from 2001-2004

The corresponding water discharge was found as follows:

- For the sediment rating curve based on RID data collected at Bommestad, the water discharge as measured at Holmfoss was scaled up with a factor of 106%.
- For the sediment rating curve based on NVE data from water samples collected at Holmfoss, the water discharge at Holmfoss was used directely.

Sediment Rating Curve based on daily samples in 2004

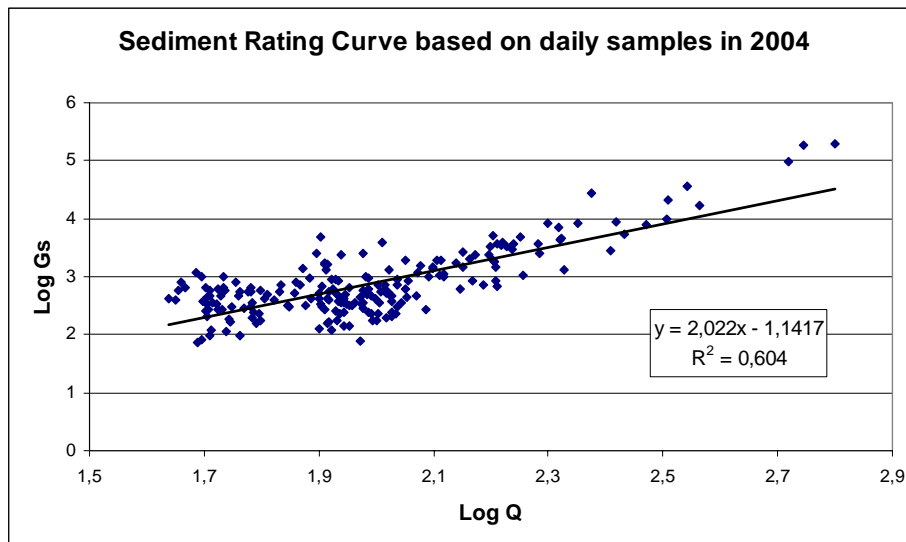$y = 2,022x - 1,1417$
$R^2 = 0,604$

Figure 33. Sediment rating curve based on daily samples in the period of 27 April-17 November 2004, at Holmfoss. Log Gs is the logarithm of the suspended load (kg/s) and Log Q is the logarithm of the water discharge (m^3/s). The rating curve formula may be expressed as Gs = 0.072 Q$^{2.022}$

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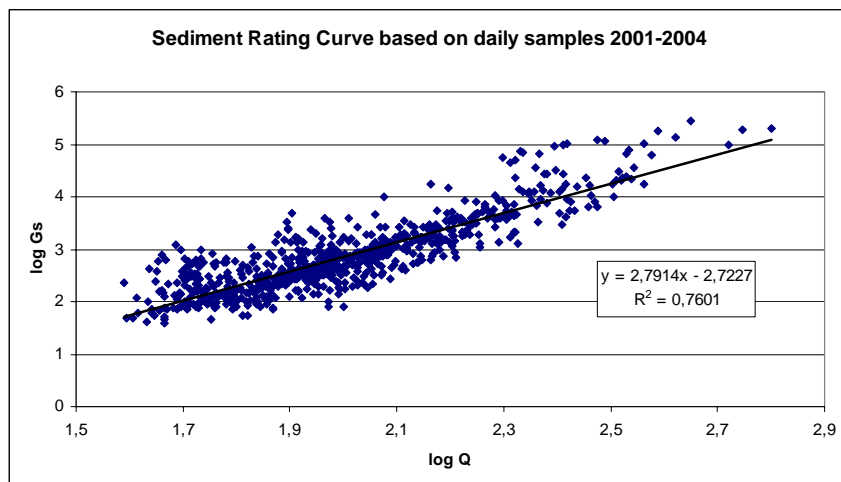(TA-2203/2006)

Figure 34: Sediment rating curve based on daily samples in 2001-2004 (cf. Table 3 for exact periods of sampling in each year), at Holmfoss. Log Gs is the logarithm of the suspended load (kg/s) and Log Q is the logarithm of the water discharge (m^3/s). The rating curve formula may be expressed as Gs = 0.00189 $Q^{2,7914}$
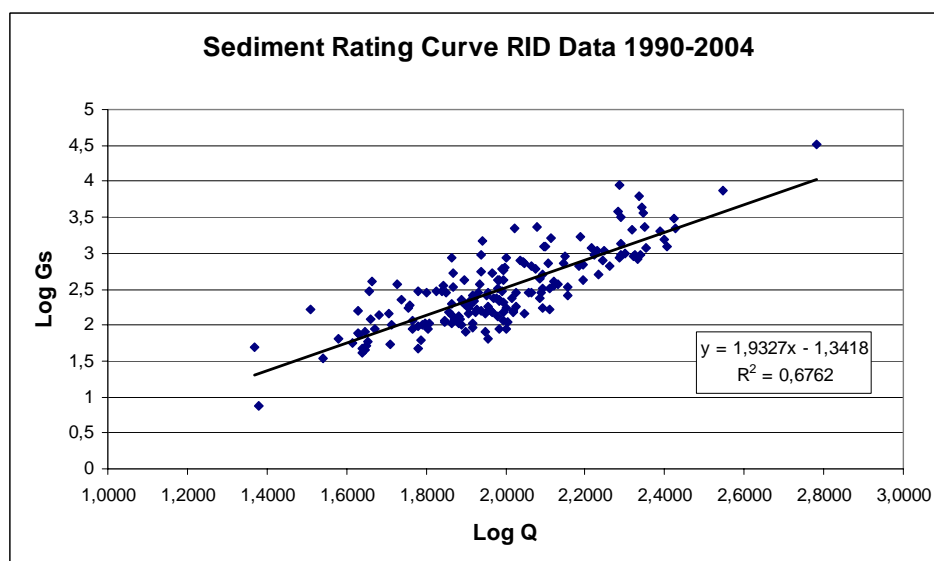

Figure 35. Sediment rating curve based on monthly samples in the period of 1990-2004, at Bommestad. Log Gs is the logarithm of the suspended load (kg/s) and Log Q is the logarithm of the water discharge (m^3/s). The rating curve formula may be expressed as Gs = 0.046 $Q^{1.9327}$

A comparison of the three curves (Figures 33-35) shows that the curve based on daily data over a four-year period is the steepest, whereas the curve based on monthly RID samples has the lowest increment. Thus, for high water discharges, a substantially higher load is calculated from the first curve based on daily data, than from the latter, based on monthly. The reason for this is the failure of obtaining samples during high flows from a programme of monthly regular sampling, as also shown by the other results of this study (e.g. Figure 29). The curves were used to calculate loads based on daily water discharges. Figure 36 compares the results

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of these calculations. The RID estimates and direct measurements (2001-2004) are included for comparison reasons.
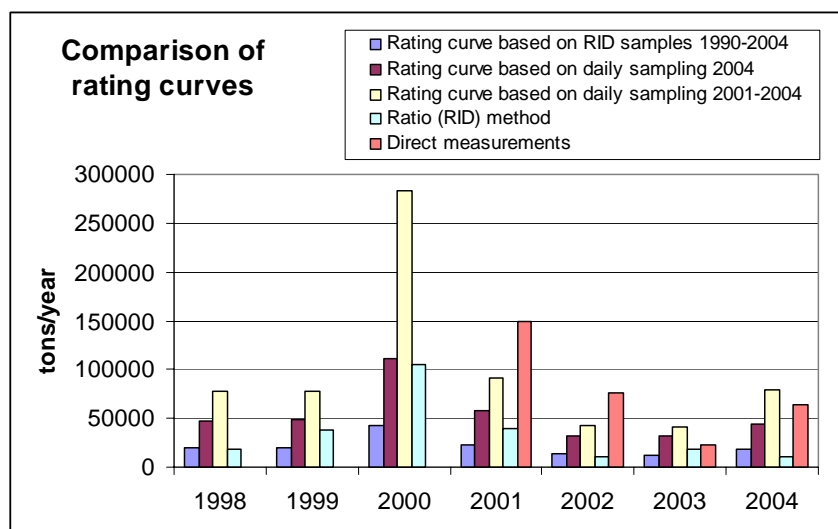

Figure 36. Results of suspended load estimates by using rating curves based on different datasets. Traditional RID method and direct measurements (daily sampling for parts of the years 2001-2004, see Table 3 for details on sampling periods) are included for comparison.

The figure shows that the rating curve based on daily data from 2001-2004 gives the highest yields. It is assumed that the direct measurements are, indeed, higher than what is indicated in the figure, since these are only based on the spring, summer and autumn part of the year. Thus, it is most probable that the rating curve based on data from 2001-2004 best reflects the annual loads. However, there are still significant variations between the estimated loads and the direct measurements. There are a number of reasons for such differences, including

- Uncertainty regarding the loads calculated from direct measurement, since the loads during the winter season are unknown
- Reported underestimation of sediment rating curves when modifications are not done
- The relationship between water discharge and sediment load is not infallible; with R squares of about 0.7 the variations in sediment loads with water discharge are considerable and will inevitable cause errors in the estimation

5.6 Conclusions and further research

This study has shown some of the uncertainties associated with measurements and estimations of riverine loads. In particular, it has shown that regular, monthly sampling may seriously underestimate the actual loads and that different load estimation models give significantly different results.

The reason for the underestimation of loads due to monthly regular sampling is mainly that too few samples are collected at high water flows. This leads to the question of how often one needs to sample in order to arrive at a relatively more representative load estimate. However, it may not just be a question of the number of samples, but of employing a targeted sampling

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to ensure that the high water flow periods are covered. Provided funding, this task will be explored more fully in 2006.

The estimation models are only as good as the input data, and for the linear interpolation and the ratio method (RID), as well as the rating curve based on the RID data, underestimations (as compared to direct measurements through daily sampling) can be explained by the lower sediment concentrations in the RID dataset than in the dataset based on daily sampling. The sediment rating curve method has the advantage that the curves may be based on a series of years, and, thus, be improved by adding more data, provided that no major changes in sediment sources occur in the catchment area over time. The curve constructed from daily values from 2001-2004 gave the highest load estimates, and probably the most correct ones. However, a number of error sources exists, amongst these the fact that the relationship between sediment load and water discharge is not infallible. An analysis of different modifications of the curve is planned for 2006.

These analyses of suspended particulate loads in Numedalslaagen will also have implications for load estimates of particle associated substances, such as phosphorus, several metals and organic pollutants.

In terms of improving the understanding of the differences in results of the load and source orientated approaches, the study of sediment loads in Numedalslaagen has pointed at some significant sources of errors and uncertainties in the load orientated approach.

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6. Detailed study B: Improving coefficients for losses of nitrogen and phosphorus from forest and mountainous areas

In this Chapter, the results of an effort to improve the coefficients for background values, i.e. the losses of nitrogen and phosphorus from forests and mountainous areas, is reported. The report explains the four-step methodology and demonstrates the results of this new approach.

6.1 Introduction

The Norwegian TEOTIL model has been used to quantify nutrient losses from all sources, including forest and mountainous areas, over the last fifteen years. It is a model maker tool, developed for calculations of loads in sub-catchment with known interior drainage. The model consists of a number of pre-defined functions that the user may apply to make his own model for transport of a selected constituent in a specified drainage basin or basins. The model is written in Visual Basic (see section on SOA for more information about the model and results).

With regard to losses from forests and mountainous areas, the coefficients were defined early -90 ies and have remained unchanged since then. This part of the synthesis report describes how the said coefficients have been updated, and provides area specific coefficients for the whole of Norway (see maps in Section 3). The work will benefit both the SOA (used in the yearly report made on discharges/losses of nutrients from all sources in Norway) and the LOA (e.g. the yearly RID report within the OSPAR framework), as well as improving the framework for comparing the results of these two approaches.

The main objectives of this study was to
1. Undertake a systematic review of existing measured data on losses of nutrients for the whole of Norway
2. Categorise all areas in order to improve the differentiation between area types
3. Develop improved coefficients for losses of nitrogen and phosphorus from forest and mountainous areas in Norway

Losses of nitrogen and phosphorus from forest and mountainous areas represent a considerable portion of the total discharges/losses to water bodies in Norway. The importance of providing accurate estimates of these losses is apparent e.g. with regard to:
- The international commitments Norway has made to reduce nutrient discharges/losses to surface waters with 50% (PARCOM Recommendation 88/2)
- Commitments linked to the Water Framework Directive and the identification of reference conditions in all Norwegian water bodies (lakes, rivers, ground waters, transitional waters and coastal areas)
- Improve the basis for the development of adequate Action Plans/River Basin Management Plans, including the importance of the various sources of nutrients

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The coefficients applied to date on background losses of nutrients are based on an expert judgement of measured data available end of the -80ies. The results of *inter alia* the JOVA-programme (Agricultural Environmental Monitoring Programme) indicate that the coefficients used to date differentiate inadequately between area categories and/or regions and thereby underestimate the variations in natural nutrient losses throughout Norway. Here again, the implementation of the WFD and the focus on catchments as a basis for monitoring and River Basin Management Plans require accurate background loss data.

Within OSPAR, PARCOM Recommendation 88/2 has been the subject of a number of different interpretations with regard to e.g. whether the reduction target relates to discharges/losses at source (SOA) or inputs to the sea (LOA), relates to anthropogenic discharges/losses or total losses/discharges.

In Norway the Norwegian Pollution Control Authority (SFT) has questioned the reasons for the large differences between measured riverine load estimates (RID) and estimated inputs generated with the TEOTIL model. One obvious reason is that the estimates of nitrogen and phosphorus losses from forest and mountainous areas are insufficient and inadequately differentiated.

6.2   Methods and results

Contrary to what was the case in previous years, the new coefficients are given as concentrations (µg/l) in order to be able to take account of variations in year specific hydrological regime.

The development of revised and improved coefficients of nitrogen and phosphorus losses from forested and mountainous areas in Norway may be described in four steps, as set out in the following.

STEP 1

The main data source used in the project is provided by the data collected within acidification surveys in Norway. All together 1544 lakes were sampled in 1995 (Skjelkvåle, B.L. et.al. 1996, see also Figure 37), and the results used in this context to develop improved nitrogen and phosphorus loss coefficients. The acidification survey includes samples from other years than 1995. In the context of phosphorus, 92% of the 1544 lakes have been sampled just once. More than three samples (i.e. more than three years) were taken only in 2% of the lakes. With regard to nitrogen, the corresponding figures are 85% and 15% respectively.

For the purpose of this project, in lakes with more than one sample, the average concentration was used. The 'beauty' of the Acidification Survey for the Synthesis report is that the selected lakes are mostly located in areas with minor anthropogenic influence.

The maps are developed by means of the information system ArcView. In order to develop the final concentration maps, a map of observed concentrations showing forested areas and another map showing other areas, called mountainous areas in this context, were required.

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Most of the methodological work consisted of finding this representative selection of adequate sites. One prerequisite was that the observation site should represent a local catchment, i.e. all observations representing large lakes with large catchments were discarded. This is because lakes have an internal purification effect on nitrogen and phosphorus. This effect, which is dependent upon the lake's residence time, normally increases with increasing lake surface area. Therefore digital maps of REGINE catchments showing lake surface area and catchment areas were used. Only the observation points with an upstream lake surface area above 2 km^2 and a catchment area above 50 km^2 were taken account of.

Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters:
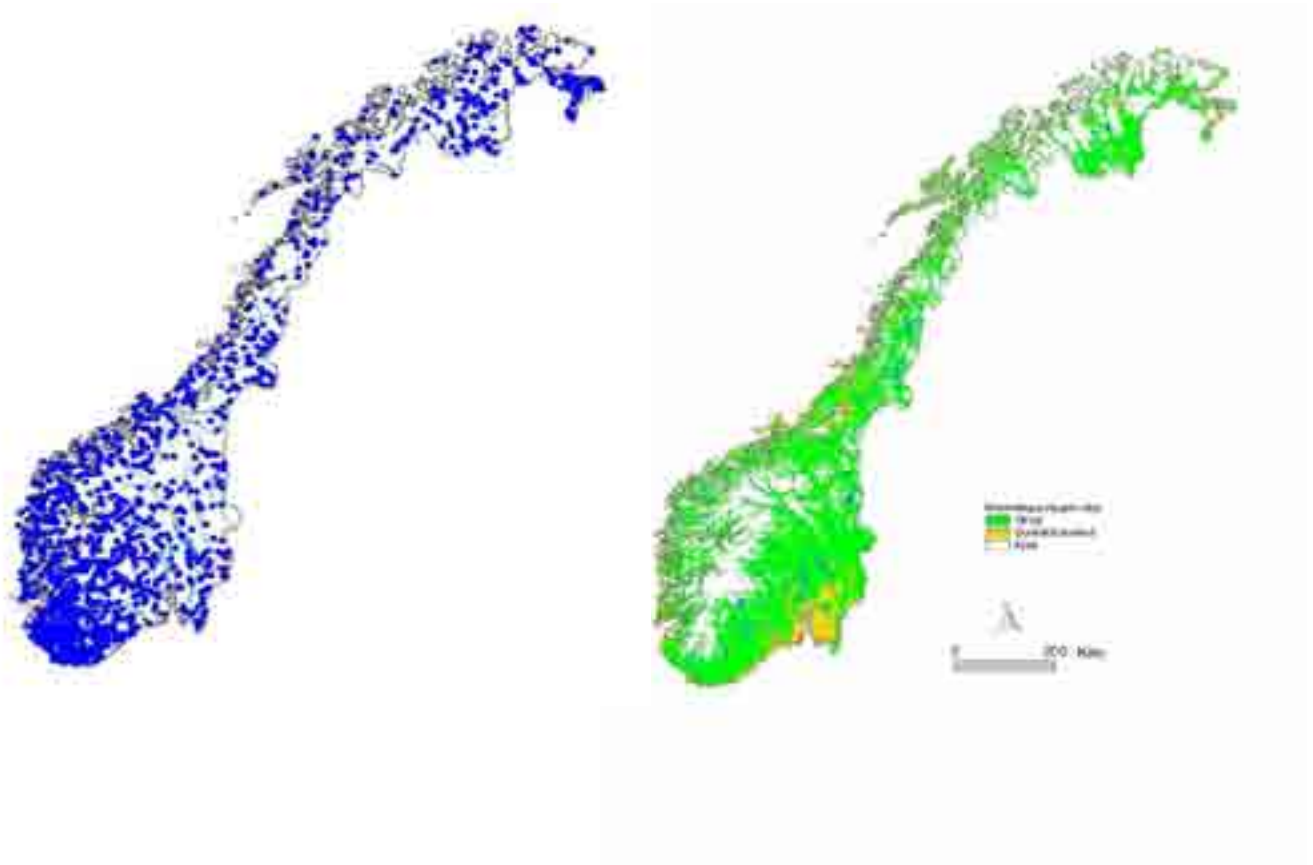May the methodologies of and the synergies between the two approaches be improved?
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Figure 37. Starting point of 1544 observation sites (left panel) and land use STEP 1(right panel)

STEP 2

By using the TEOTIL model and the information on population, industrial and aquaculture plants, and agricultural areas distribution, measurements likely to be influenced by anthropogenic inputs were discarded. This was possible as the model estimates inputs from the said sources in the about 1100 catchments (statistical areas) that Norway is divided into.

The resolution of the model is, however, too coarse to obtain sufficient certainty as regards each single observation site. This is because there are e.g. on average three statistical areas and more than 50 REGINE areas within each county. One REGINE area consists in principal only one important lake. It follows that one observation site may be entirely within a non-anthropogenic sub-catchment within the statistical area, i.e. some of the observation sites that according to TEOTIL procedures were discarded because possibly influenced by anthropogenic sources, should have been maintained. Observation sites with phosphorus concentrations equal to or below 3 µg/l were in all cases considered as non-anthropognic and included in the final selection of sites.

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STEP 3

There are available land use maps for the whole of Norway. Additionally, there are data on percentage of forested areas of lakes' catchments. This type of information was used to classify the observation sites into forest of mountainous. Observation sites that, according to the maps were located in mountainous areas and according to database information had a catchment area with more than 50% forest, were categorised as forest, and vice versa.

The phosphorus- and nitrogen values/observation sites in forest and mountainous areas retained after STEP 3 are shown in Figures 38 and 39. The mean values for all observation sites in forest were 3.0 µg/l total P and 177 µg/l total N. For mountainous areas the corresponding concentrations were 2.9 µg/l and 149 µg/l. One 'easy to use approach' would have been to use these mean concentrations for the whole of Norway.
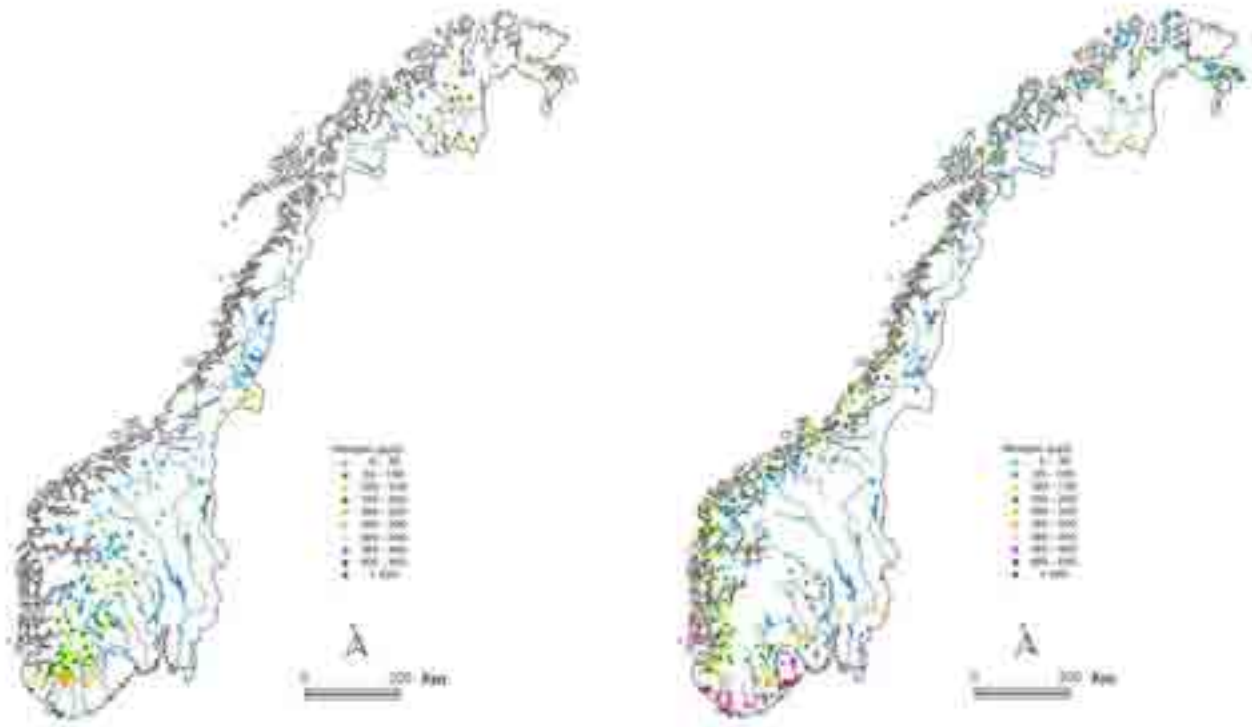
Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters:
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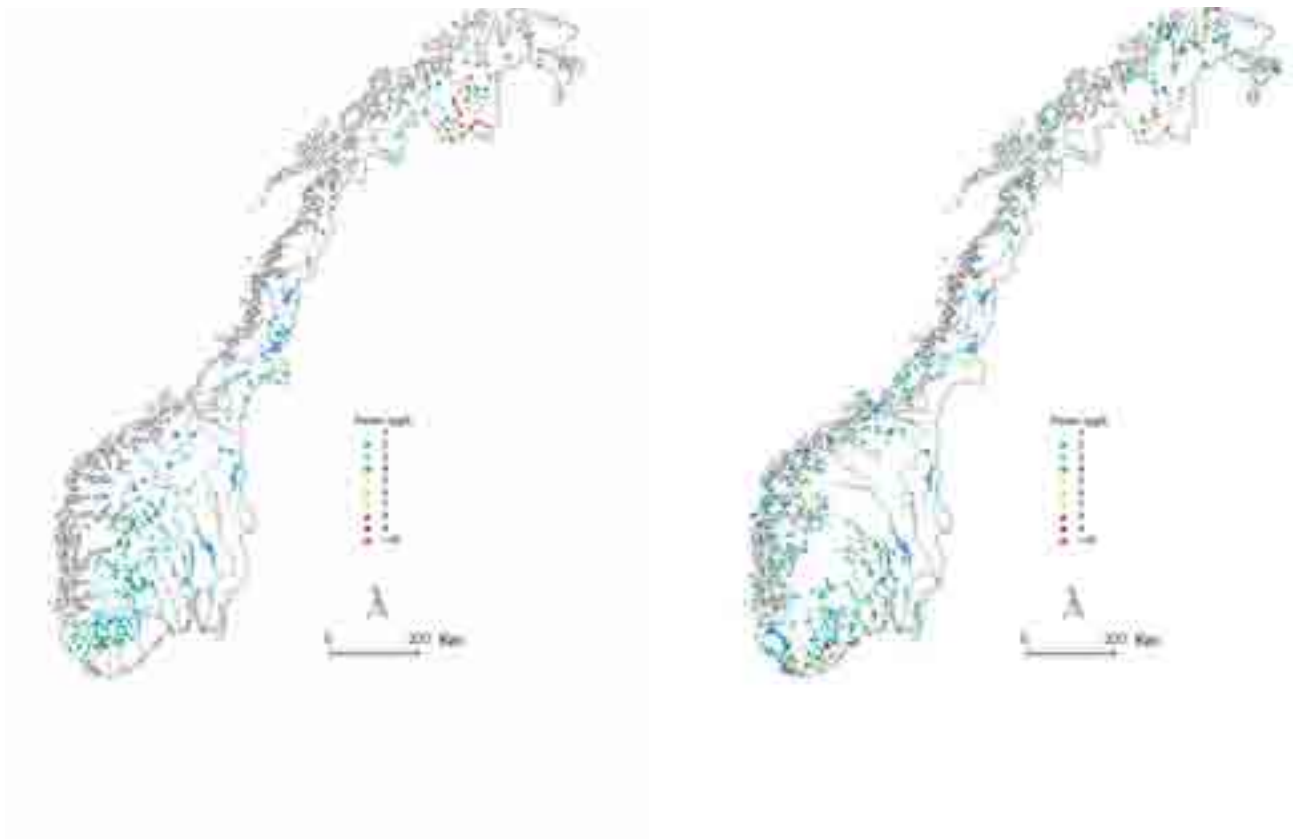*Figure 38. Nitrogen concentrations in observation sites located in mountainous areas (left) and forested areas (right)*

Figure 39. Phosphorus concentrations in observation sites located in mountainous areas (left) and forested areas (right)

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STEP 4

GIS analysis were used to improve the maps further, i.e. by taking account of regional differences. One map was developed for forested areas and one for mountainous areas. There was not sufficient information available in terms of number of observation sites in order to produce maps for moorland, wetlands and populated areas.

Arcview/Spatial Analyst was used to produce concentration maps for the whole of Norway. The Inverse Distance Method (IDW) is based on 12 neighbouring points with a functional value that equals 1; this counteracts large regional differences.

The first draft version of STEP 4 maps nevertheless showed some smaller areas with large concentration gradients that were due to single points with relatively high concentrations. Such concentrations may be due to e.g. specific geological areas, but in this case it is most likely that they were influenced by anthropogenic sources unaccounted for in the TEOTIL model.

Eight such single, high values were discarded from the selection prior to the development of the final maps. The relatively high phosphorus, and partly also nitrogen concentrations in the northeastermost parts of Norway (Finnmarksvidda) are retained as there were a number of high values over a large area.

The final GIS technique produced maps (Figures 40-43) show some very small areas with different concentrations than the surrounding areas. The data basis was considered insufficient to retain with a satisfactory degree of certainty most of these details. A manual correction was therefore performed, resulting in the consolidated final maps shown in Figures 44-47.

When applying the TEOTIL model in 2004 and 2005, coefficients as kg/km^2 were used. This entails that the nutrient losses from mountainous and forested areas remain unchanged from one year to another, representing an average hydrological year. Figures 48 and 49 show concentration based maps where the kg/km^2 figures are divided by average 30-year water flow. The new consolidated concentration maps typically show lower values than the 'old maps', in particular in the south-eastern parts of Norway.

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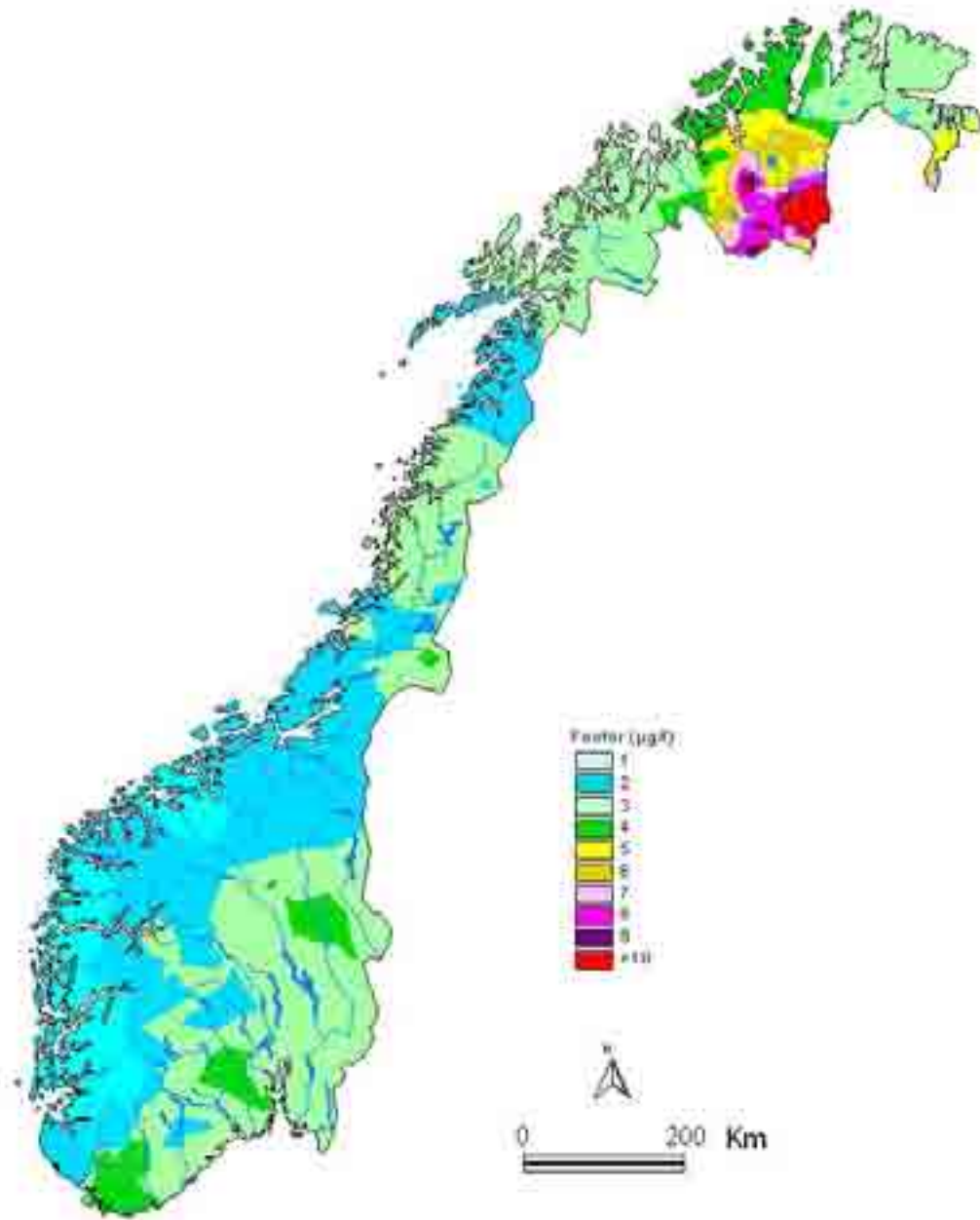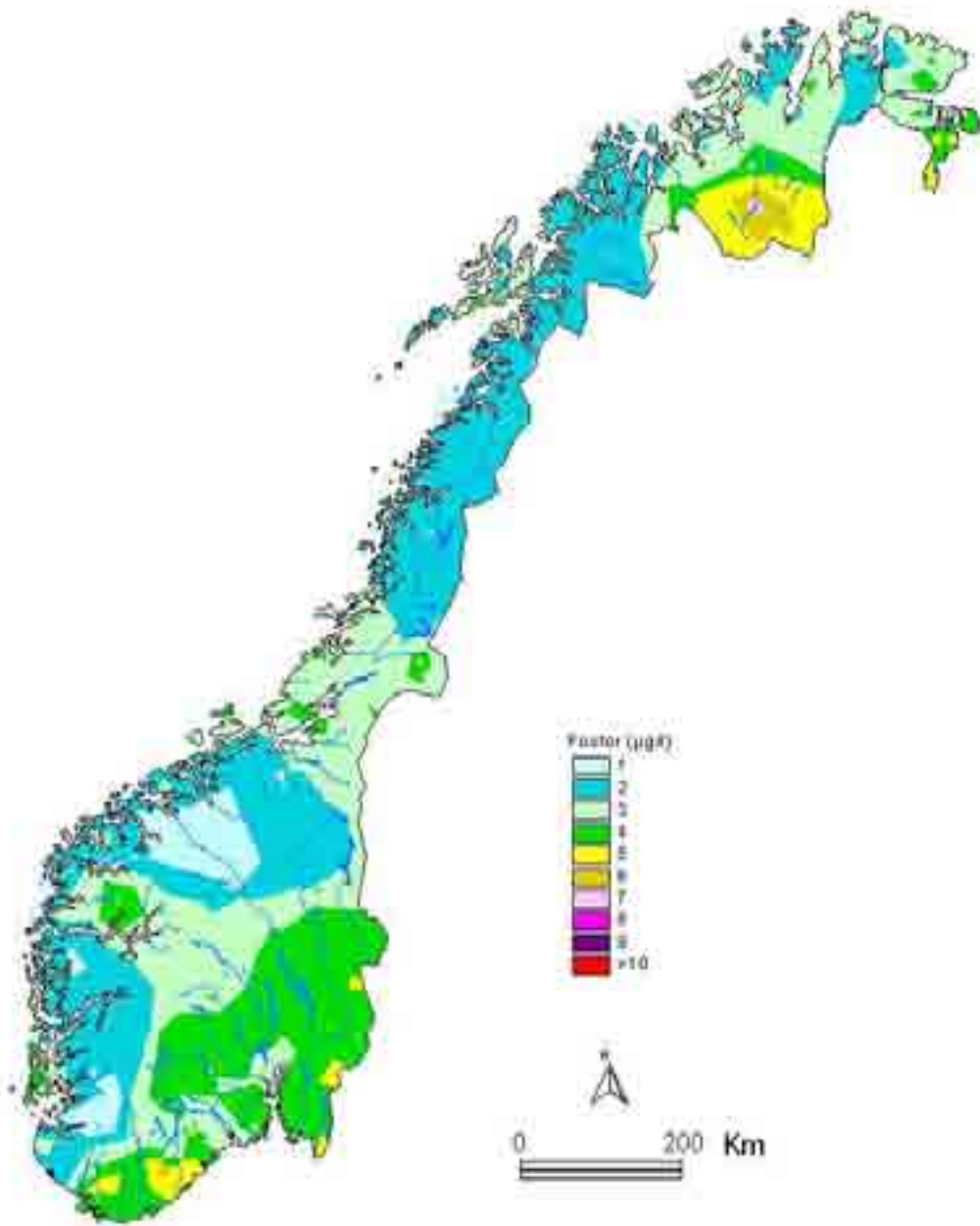(TA-2203/2006)

Figure 40: Phosphorus concentrations in mountainous areas produced by using GIS.

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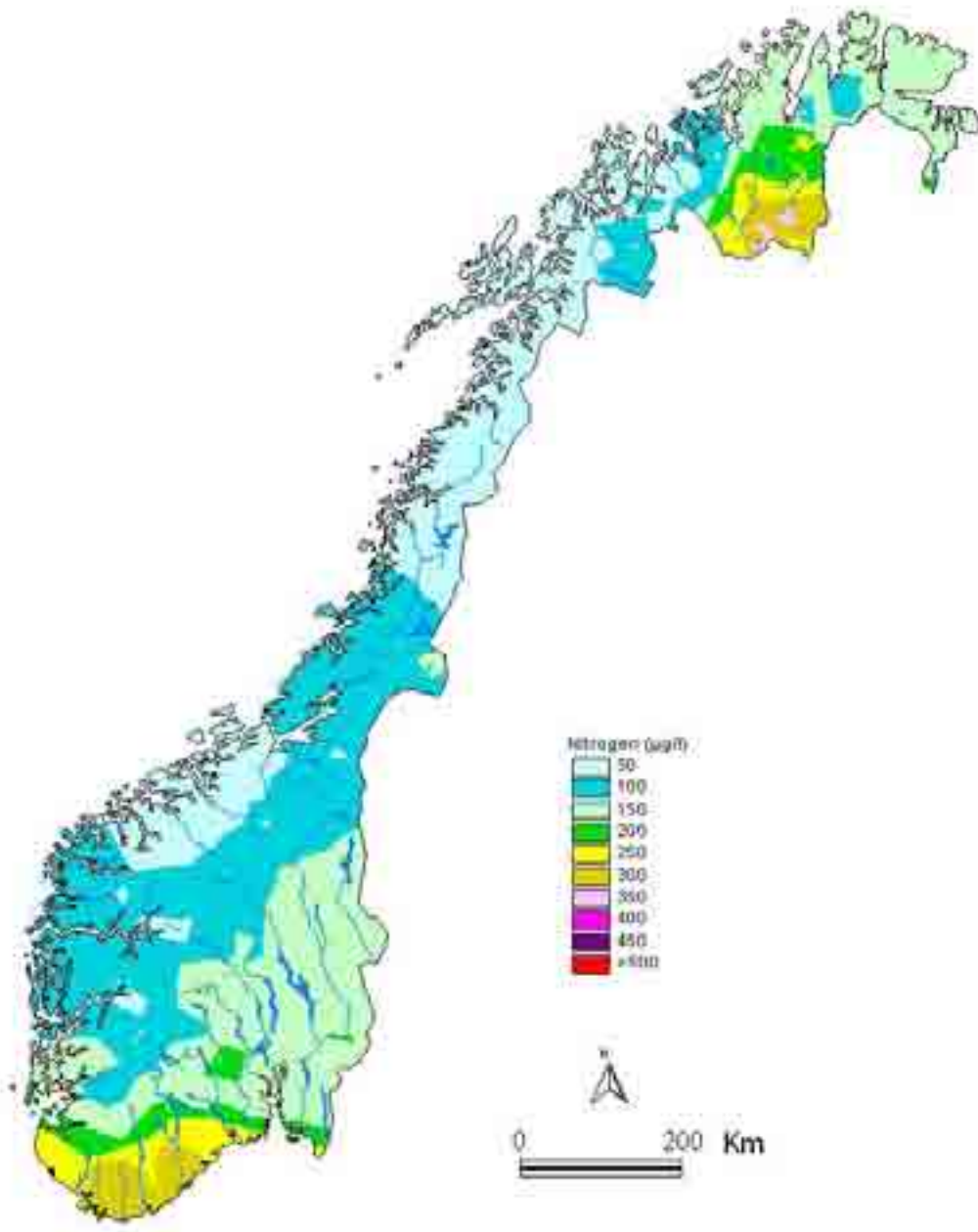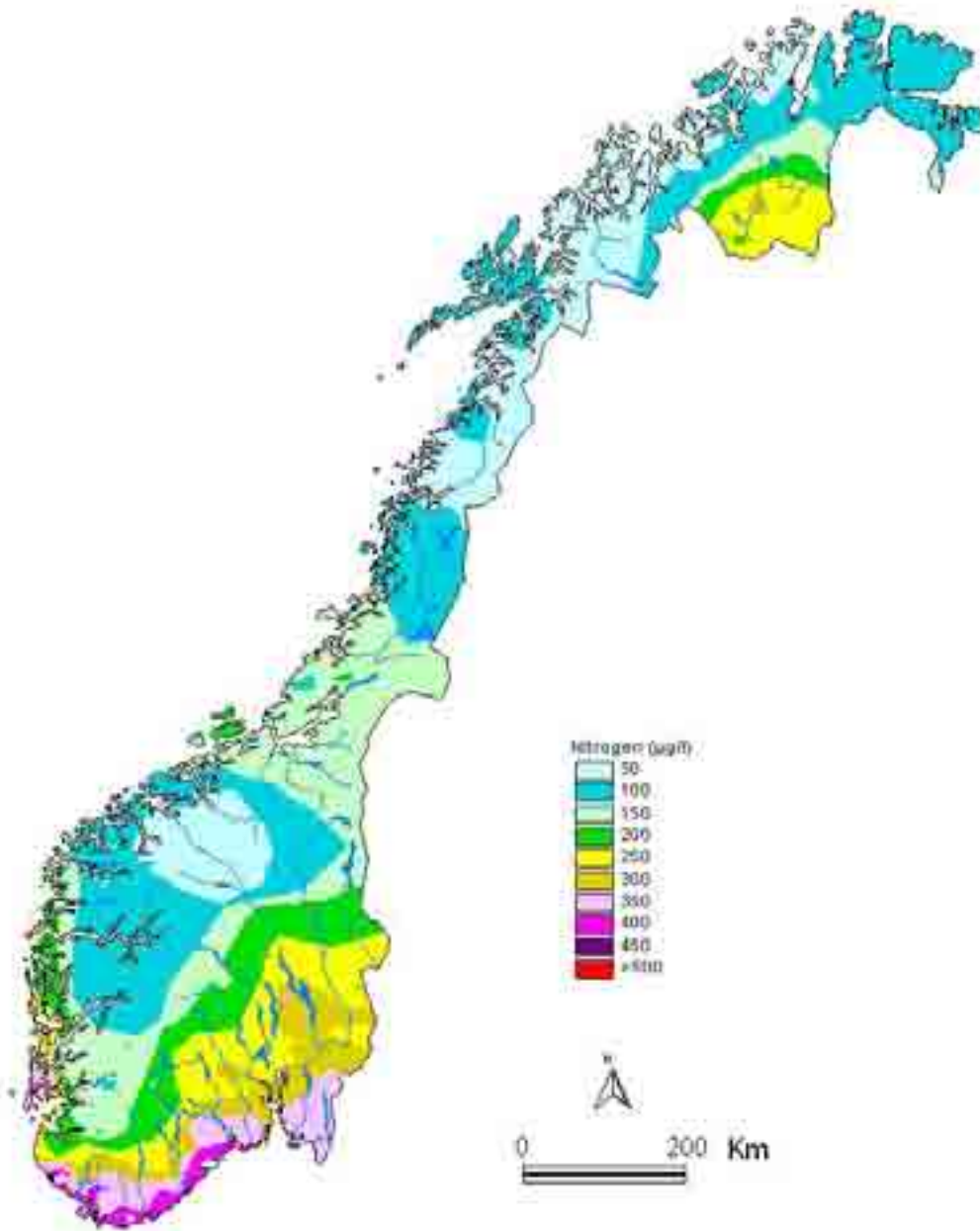(TA-2203/2006)

Figure 41. Phosphorus concentrations in forested areas produced by GIS

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Figure 42. Nitrogen concentrations in mountainous areas produced by GIS

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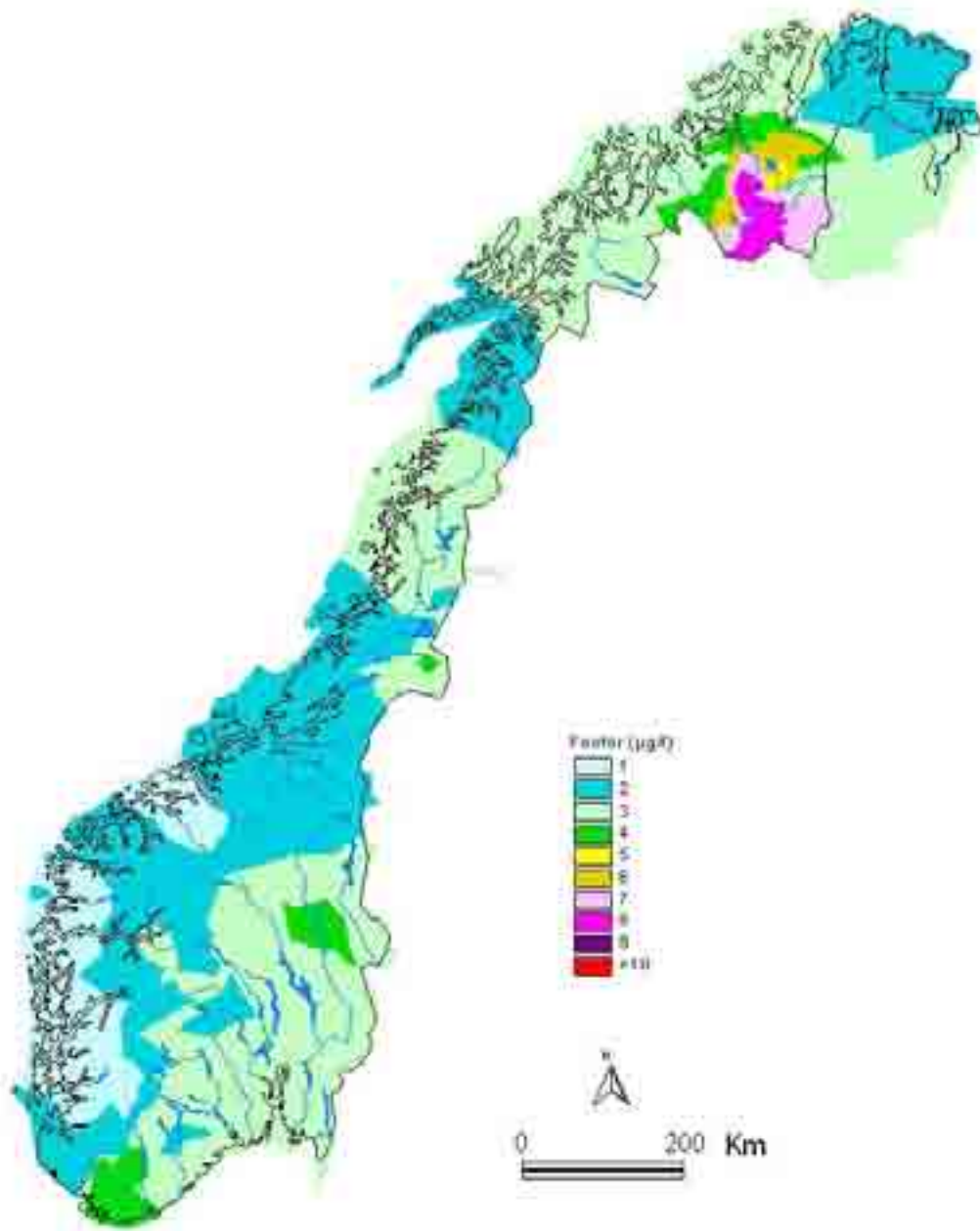*Figure 43: Nitrogen concentrations in forested areas produced by GIS*

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Figure 44. Phosphorus concentrations in mountainous areas after manual correction

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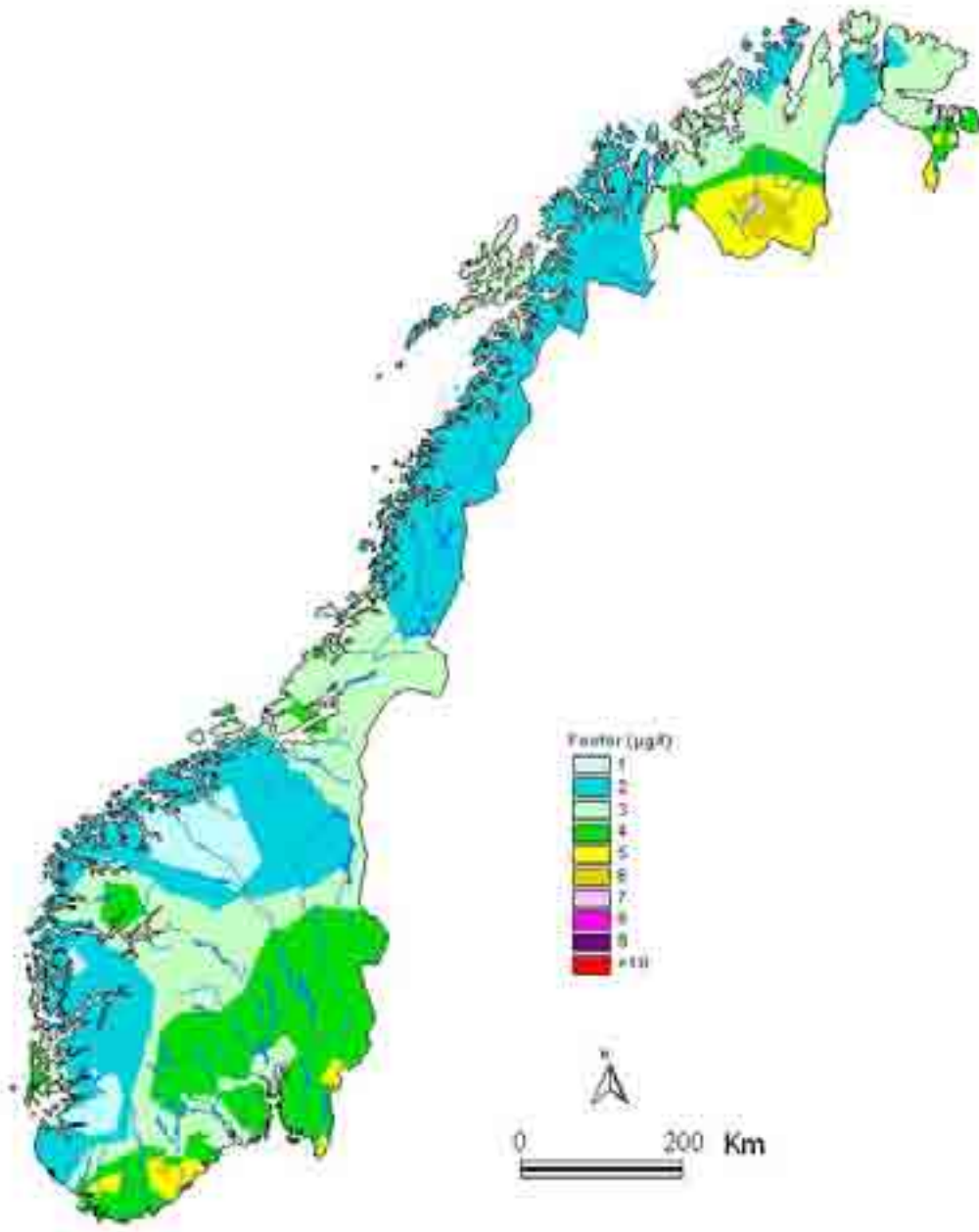(TA-2203/2006)

Figure 45. Phosphorus concentrations in forested areas after manual correction

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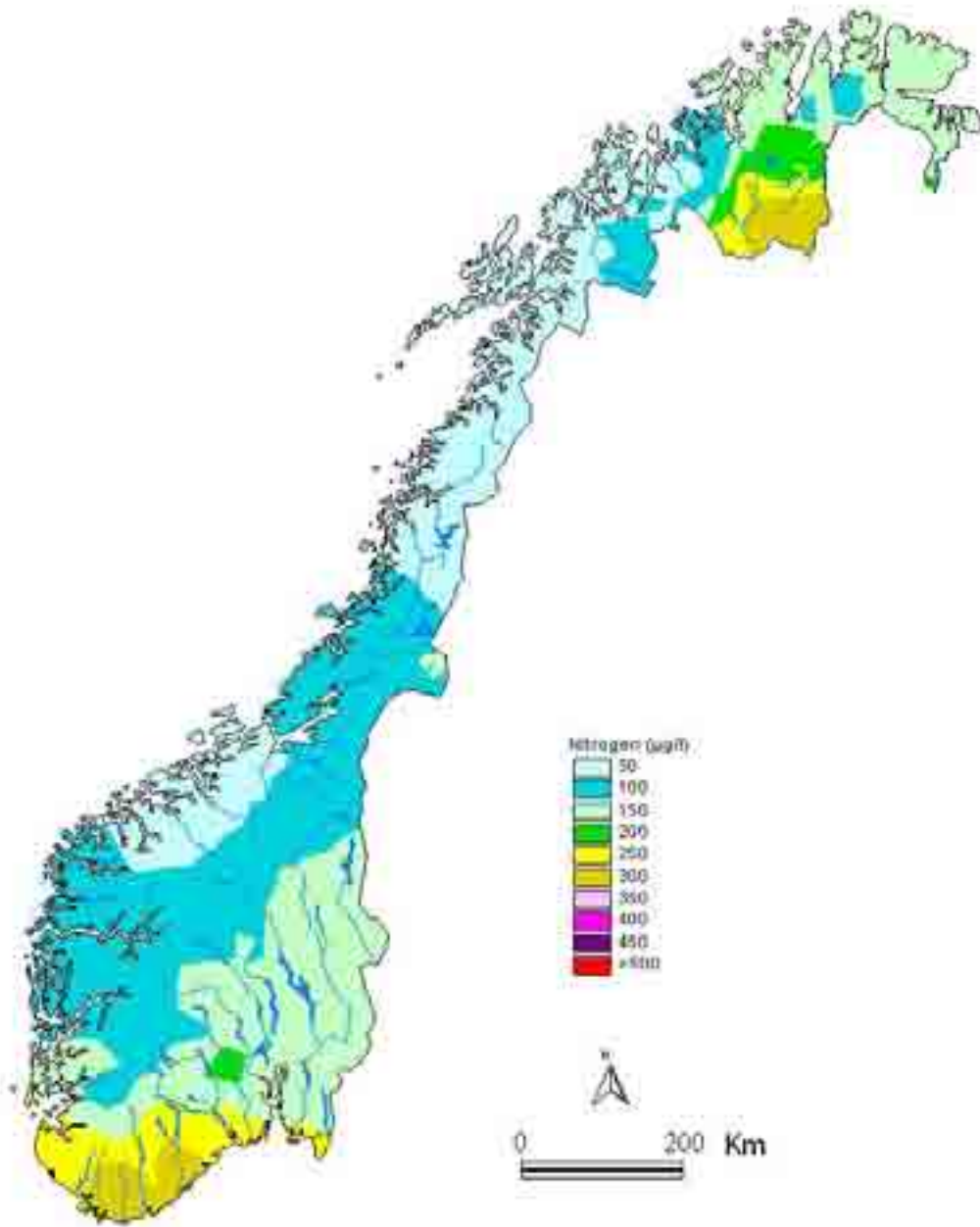(TA-2203/2006)

Figure 46. Nitrogen concentrations in mountainous areas after manual correction

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Figure 47. Nitrogen concentrations in forested areas after manual correction

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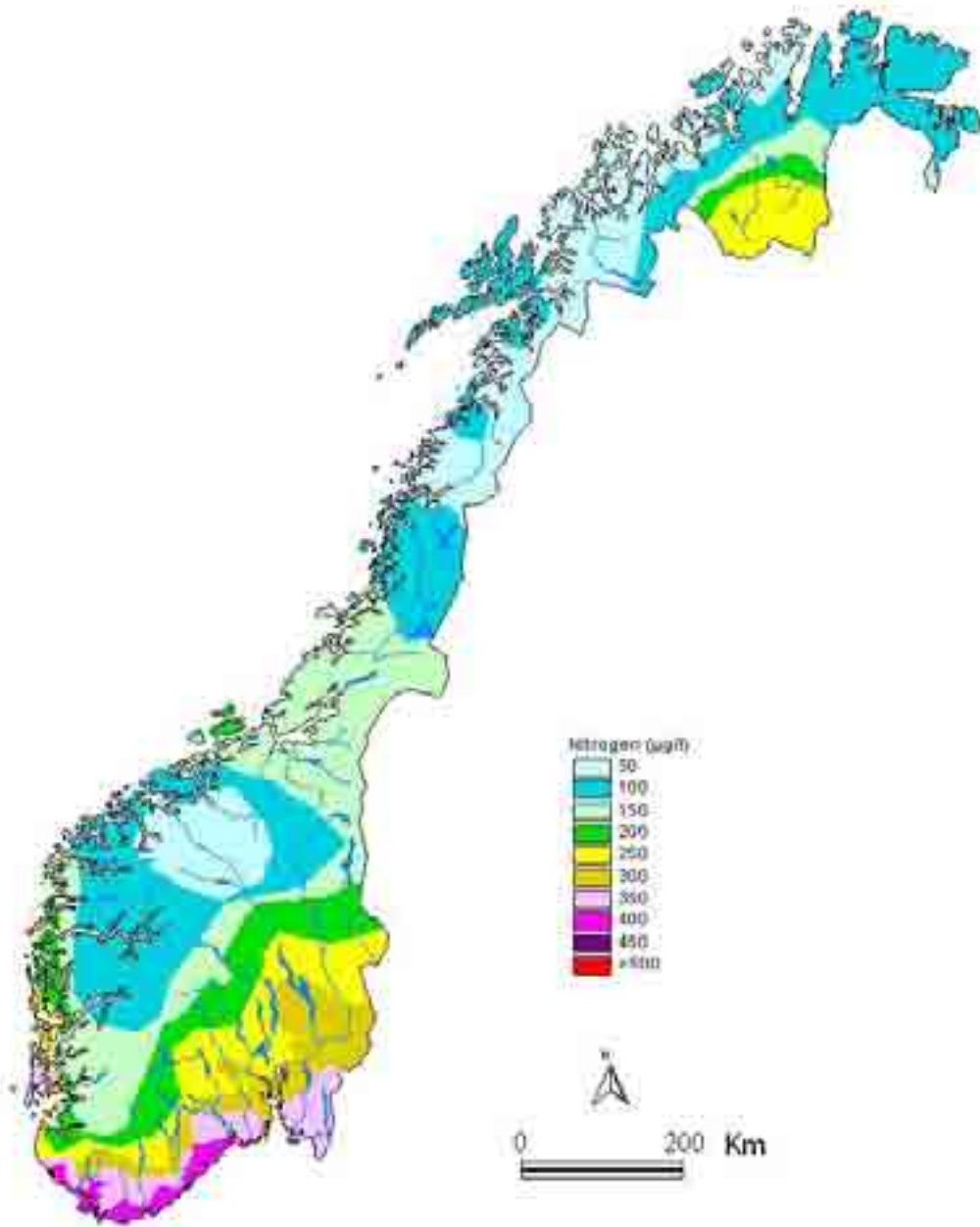(TA-2203/2006)

Figure 48. Phosphorus concentrations in forested areas used in the TEOTIL model in 2004 and 2005

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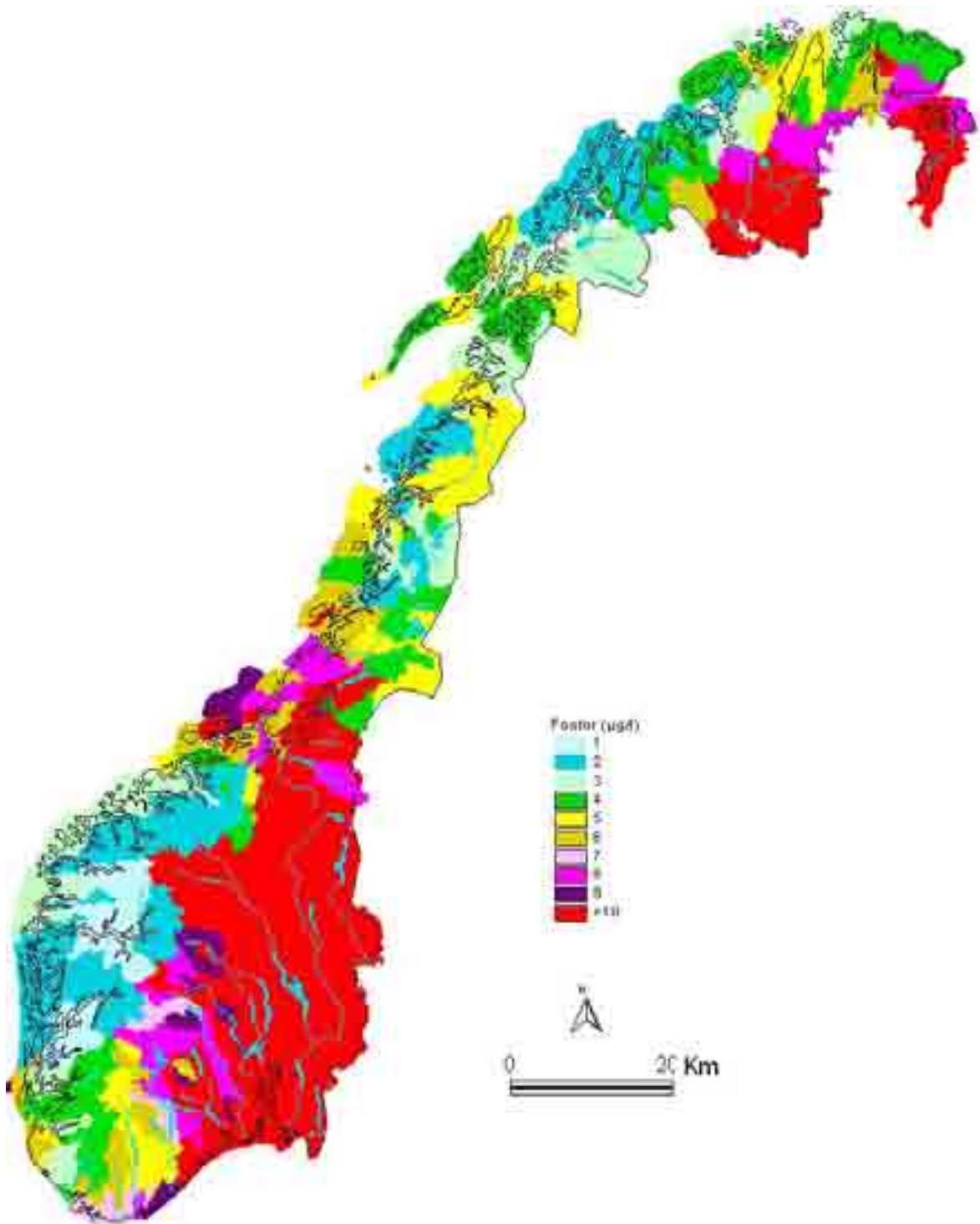(TA-2203/2006)

Figure 49. Nitrogen concentrations in forested areas used in the TEOTIL model in 2004 and 2005

Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters:
May the methodologies of and the synergies between the two approaches be improved?
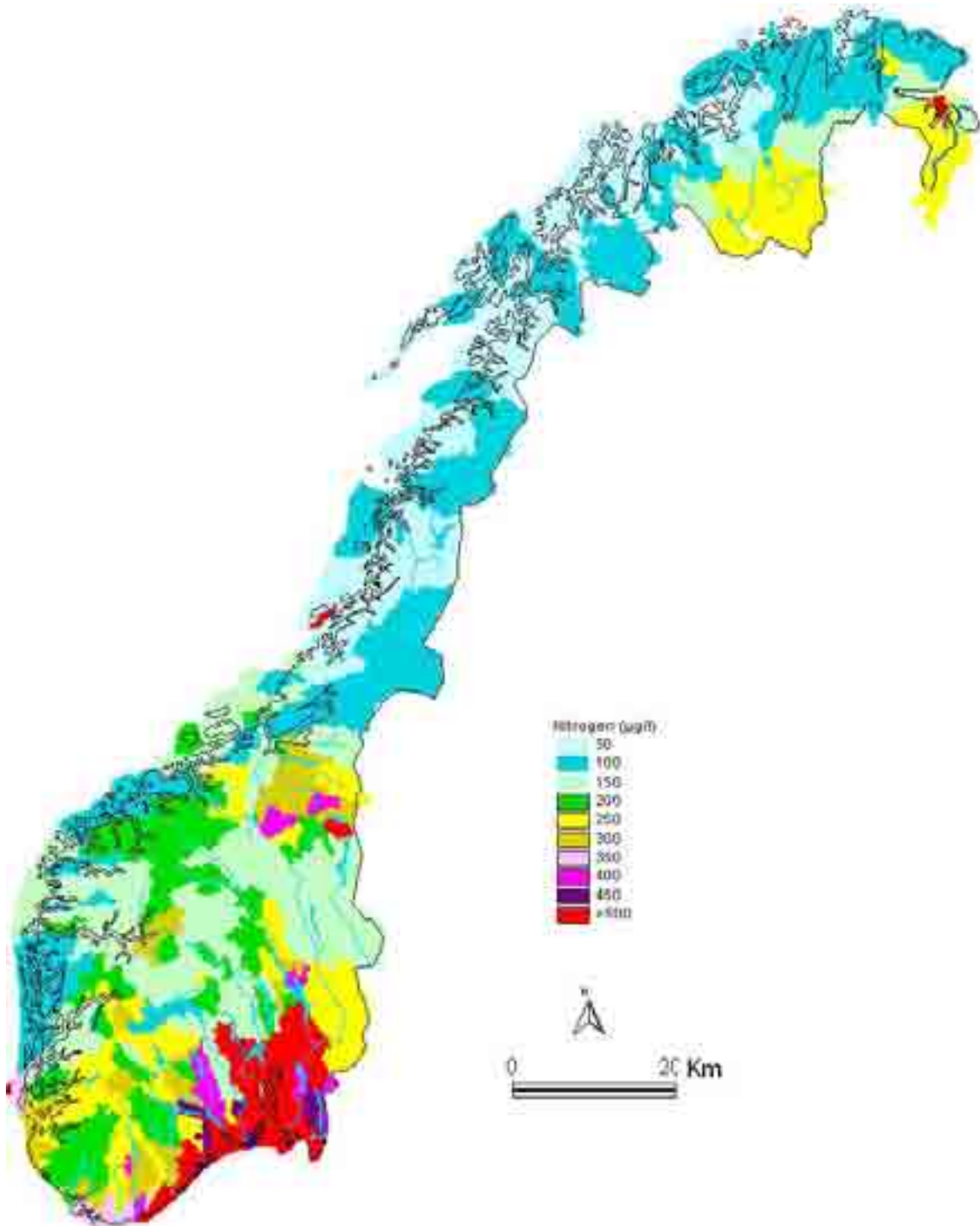(TA-2203/2006)

7. Synergies – how may they be accentuated?

> The report aimed at demonstrating the differences between the results arrived at by using the two approaches, and pointing at improvements that may also increase the synergies of the two approaches. In order to improve the correlation between observed and modelled loads a thorough and long-term comparison is necessary.

The comparison of the results of the two approaches revealed that they estimate different loads in some areas and rivers of Norway. This is not surprising; in spite of the fact that the two methods to some extent are interrelated, as the TEOTIL model uses RID data for calibration; there may be several reasons for these differences, and some of the most likely have been treated in this report. Some variations in results are linked directly to the differences in the approaches *per se*, such as the fact that locations of the measurement stations in the RID Programme may not coincide with the statistical areas used by the TEOTIL model. Others may be explained by the change made in 2004 of the coefficients for background runoff from forests and mountainous areas, and the fact that the model has not yet been calibrated after this change.

However, such comparisons as have been done in this report should also give a good basis for evaluating the two methods in more detail. There are a number of sources of errors within each of the methods, and the goal should be to reduce these as much as possible. The fact that the TEOTIL model is interlinked with the data from the RID Programme as these are used for calibration purposes points to the importance of improving the results of the load estimates. Sources of errors that have been treated in this report include:

- For the LOA:
    - Frequency of sampling
    - Choice of interpolation methodology
- For the SOA:
    - Improvements of statistical areas, finer resolutions
    - Improvement of coefficients, particularly for background values (forest and mountainous areas)
    - Retention in lakes
    - More complete datasets on sources, as all sources are not thoroughly reported

In addition, potential improvement issues have been highlighted in the Norwegian LOA undertaken through the RID monitoring programme (see Borgvang *et al* 2006), such as:
- Improve the input data for the spatially distributed version of the HBV-model that was used to simulate the water discharge for the 36 rivers monitored quarterly, as well as for the now unmonitored 109 rivers, although the introduction of this model in the 2004 programme already represents a major step forward compared to the previous way of estimating the water discharge in the 145 rivers based on the 30 year average, and adjusted with precipitation data for the actual year.
- Improve the reporting on industrial discharges

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Borgvang *et al.* (2006) also showed that, as opposed to what has been seen in other countries in Europe, the correlation between water quality and human activities in the river and lake basins in Norway are not readily seen. Some potential explanations may include:

- The land use and other background data may be incomplete, and the mean concentration values used for correlation may not be representative values for these rivers (the latter challenge is presently being studied in research projects where RID data are compared to more frequently sampled data, see Chapter 5).
- The estimates of background concentrations may be inaccurate (see Chapter 6).
- The variation in land use and human impacts in Norwegian rivers is not large, and the concentrations of several of the parameters monitored in RID are relatively low as compared to other European rivers. Thus, small changes will have relatively larger consequences in Norwegian rivers than in more polluted rivers.

Furthermore, in order to improve the platform for trend analyses not only linked to the LOA as such, but also the differences of results between LOA and SOA, it is important to:

- Undertake a more detailed analysis and quantification of historical RID-loads as the 2004 study showed inconsistencies in data that prevent adequate trend analysis
- Study in more detail the consequences of the change in analysis and detection limits for some parameters (lower detection limits during the most recent years), for making comparison with early 1990 figures easier.
- Assess the historical data base and remove clear single observation errors
- Harmonise water flow and chemical sampling stations
- Get 'rid' of inconsistencies in point source data, since the number of industrial plants reporting losses varies considerably from year to year
- Undertake a harmonised complete assessment of all historical inputs
- Assess the results from the Norwegian PARTRAN-project (see Chapter 6), showing that there are discrepancies between the transport calculations according to the RID principles and other reputed methods such as linear interpolation and the 'rating curve method'.

There are thousands of small rivers and creeks in Norway, and a total of 455 000 lakes covering an area that is about 5 per cent of the land area. It goes without saying that it is impossible to monitor all rivers and lakes both from a financial and practical perspective. The Norwegian RID programme included 10 main rivers and 145 tributaries up to and including the year 2003. As from 2004 the number of tributaries has been reduced to 36 in order to improve the estimated loads (change from one to four samples a year). With regard to monitoring of lakes, that has an importance also with regard to the quantification of nutrient inputs to the seas many lakes will have nutrient retention (included as a module in the TEOTIL model), there is currently only one main national monitoring programme including a large number of lakes (the Acid Precipitation Programme, 100 lakes every year, 1000 lakes every 10 years). In that context it can be noted that the Proposal for design of a Norwegian Monitoring Network for Reference Sites includes about 400 lakes and 250 river sites distributed in different ecoregions and types (Lyche Solheim *et al.* 2006).

For the LOA a major challenge is thus to define appropriate upscaling procedures (monitor one water body that is typical for maybe ten others) and thereby to find the right balance between number of monitoring sites (rivers and lakes), sampling frequency and resource allocation. One step towards improving that balance was made when the number of RID

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tributaries was reduced from 145 to 36 at the same time as the sampling frequency was increased from one to four samples a year.

For the SOA approach the 'upscaling' procedures are also important (monitor a scientifically adequate number of sufficient types of agricultural fields throughout the country, as well as industrial plants) and thereby find the right balance between number of fields and plants, and resource allocation.

Thus, in conclusion, the reported efforts from this work have shown that a comparison of the two methods is useful inasmuch as it pinpoints the needs for improvements for each of the approaches, helps prioritise these improvements, with the ultimate goal of achieving optimal monitoring programmes as a sound scientific basis for selecting the most appropriate abatement measures within River Basin Management Plans.

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Load and Source Orientated Approaches for Quantifying Nutrient Discharges and Losses to Surface Waters: May the methodologies of and the synergies between the two approaches be improved?

Summary
The report is linked to the work within the OSPAR Convention, on quantifying nutrient losses from rivers to the sea. Since 1990, reporting on discharges/losses and inputs of nitrogen and phosphorus have been high on the international arena. There are, however, different practices among countries in terms of quantification and reporting on riverine inputs into marine waters. Nutrient inputs from land to sea may basically be estimated through two different approaches – the load orientated approach (LOA) and the source orientated approach (SOA). In this report, these two approaches are studied in more detail, through comparisons of the results obtained by using the two approaches, and through an analysis of the sources of errors in each approach. The potential sources of errors treated here include frequency of sampling and choice of interpolation methodology for the load orientated approach; and improvements of statistical areas, improvement of coefficients, retention in lakes, and more complete datasets on sources for the source orientated approach.

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