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AGRITIL - Nutrient loss model for agriculture

Modelling soil, organic carbon, nitrogen and phosphorus losses from Norwegian agricultural areas to surface water

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SAMMENDRAG/SUMMARY:

This report describes the development of models to calculate losses of soil particles, phosphorus, nitrogen and organic carbon from agricultural land to first order streams. The results from the models serve as input data to the TEOTIL model which estimates the net losses from agriculture and all other sources.

The agricultural models (AGRITIL) were calibrated for catchments in the Agricultural Environmental monitoring programme and are limited by the availability of data for different regions in Norway.

Utvidet sammendrag på side 7

Extended summary from page 9

LAND/COUNTRY: Norway

GODKJENT /APPROVED	PROSJEKTLEDER /PROJECT LEADER
Per	Marianne Bechmann
PER STÅLNACKE	MARIANNE BECHMANN

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Preface

NIBIO has been contracted by the Norwegian Agriculture Agency to develop a model for gross losses of nitrogen and phosphorus to waters from agricultural areas in Norway. The model includes loss of soil, fractions of nitrogen and phosphorus and organic carbon. This report is based on the preliminary project report presented by Bechmann et al. (2022).

Sigrun H. Kværnø has been responsible for development of the model on soil, total phosphorus, dissolved reactive phosphorus and organic carbon, and she has contributed to the development of the nitrogen model.

Franziska K. Fischer has been responsible for development of the nitrogen model and has contributed to the discussion of the other models.

Marianne Bechmann has been project leader and has contributed to the development of models for all constituents.

Hans Olav Eggestad has contributed to the input data for model development and the national data. Hans Olav Eggestad, Jian Liu and Anne Falk Øgaard have contributed to discussions on model-development, and Per Stålnacke and Annbjørg Øverli Kristoffersen have contributed through a reference group.

The quality check was performed by Per Stålnacke.

This report is written in English, but with the use of Norwegian units: 1 decare (daa)= 0.1 hectare.

Ås, 22.03.24

Marianne Bechmann

Content

Sammendrag

I denne rapporten presenteres en modell (AGRITIL) som kan beregne tap av jordpartikler, fosfor, nitrogen og organisk karbon fra jordbruksareal til førsteordens bekker i hele Norge. Resultatene brukes videre i TEOTIL-modellen som estimerer nettotap (dvs. tap i elvemunninger) fra jordbruk og andre kilder (dvs. kildefordeling).

Modellene som presenteres i denne rapporten, er alle empiriske - bestående av et sett empiriske ligninger og koeffisienter, alle utviklet for å inkludere viktige hydro- og biogeokjemiske prosesser på nedbørfeltskala. Den primære datakilden for modellutviklingen har vært data fra Program for jord- og vannovervåking i landbruket (JOVA), supplert med andre data fra nasjonal og internasjonal forskning og overvåking. Nedbørfeltene i JOVA representerer de viktigste jordbruksarealene i landet når det gjelder avrenning under ulike forhold mht. klima, jord og jordbrukspraksis.

Nitrogenmodellen ble utviklet som en regresjonsmodell basert på data fra seks av JOVA-feltene. Totalt nitrogentap fra jordbruksareal avhenger i modellen av avrenning, 2-års gjennomsnittlig nitrogenbalanse, jordtekstur, temperatur i mai til august, areal med gras, areal uten jordarbeiding om høsten og areal med fangvekst. Modellen ble validert med uavhengige overvåkingsdata fra andre JOVA-felt og på svenske overvåkingsdata. Nitrogentap fra innmarksbeite er estimert med en egen ligning.

Jordtapsmodellen er basert på erosjonsrisiko, som representerer jordtap for vårkorn med høstpløying. Erosjonsrisiko regnes om til jordtap ved gitt kombinasjon av vekstfordeling og jordarbeiding ved å multiplisere med vekst- og jordarbeidingsspesifikke koeffisienter, og deretter trekke fra jordpartikler som holdes tilbake av grasdekte vannveier og kantsoner. Jordtap er estimert separat for ulike prosesser/erosjonsformer.

Fosformodellen (P) består av to delmodeller for estimering av tap av partikkelbundet fosfor (PP) og løst fosfat (PO_4-P). PP-tapet beregnes som P-innhold i jorda multiplisert med jordtapet og en anrikningsfaktor som tar hensyn til høyere P-innhold på mindre jordpartikler. Tap av løst fosfat (PO_4P) beregnes ved to separate regresjonsligninger, en for mineraljord og en for organisk jord, som tar hensyn til P-innholdet i jorda, jordtap og avrenning.

Karbon (C)-modellen er delt inn i delmodeller for estimering av tap av partikkelbundet organisk karbon (POC) og løst organisk karbon (TOC). POC-tapet beregnes på samme måte som PP-tap, utfra jordtap, organisk karboninnhold i jorda og en anrikningsfaktor. Tapet av løst organisk karbon (DOC) beregnes med koeffisienter avhengig av jordas karboninnhold og avrenning.

Input-data som brukes i modellene består av lett tilgjengelige data fra nasjonale kart og databaser: NIBIOs arealbrukskart, NIBIOs jordsmonnkart med informasjon om teksturklasse, karboninnhold, planering og erosjonsrisiko; NGUs geologiske kart for bestemmelse av teksturklasse og erosjonsrisiko i områder der løsmassene ikke er kartlagt; NIBIOs jordanalysedatabase Jorddatabanken for bestemmelse av jordas karboninnhold i ikke-kartlagte områder og jordfosforstatus (P-AL); NVEs avrenningsdata korrigert av NIBIO for bedre å representere jordbruksarealer; METs data (1 km x km grid) for nedbør og temperatur; vekstfordeling og husdyrtall fra Søknad om produksjonstilskudd; miljøtiltak fra eStil/RMP; gjødselmengde fra Mattilsynet og SSB.

Beregningsskalaen for modellene er NVEs REGINE-enheter, og beregningene gjelder kun for jordbruksarealer. Retensjon av jord og næringsstoffer i jordbrukslandskapet er inkludert i den grad det er representert i kalibreringsdataene på nedbørfeltskala og i modellens inputdata. Retensjon nedstrøms små jordbruksdominerte nedbørfelt er ikke inkludert.

Beregninger av risiko for tap fra jordbruksareal bruker gjennomsnittlig vær sammen med årlige data for jordbruksdrift for å estimere effekten av jordbruksdrift og tiltaksgjennomføring alene, uten påvirkning fra mellomårsvariasjon i vær- og avrenningsforhold. De årlige estimatene bruker årlige

verdier for både vær og jordbruksdrift. Bruk av risikomodellene vil gjøre det mulig å identifisere effekten av jordbruksdrift og iverksatte tiltak.

De endelige modellene er brukt for alle REGINEs nedbørfelt i Norge for årene 2013 til 2022, både for risiko og årlige estimater. Resultatene viser at modellene fanger opp regionale forskjeller i tap av de ulike stoffene: Høyt tap av nitrogen i områder med høy avrenning. Høyt tap av jordpartikler og partikkelbundet fosfor i områder dominert av korn- og/eller potet- eller grønnsaksproduksjon, og erosjonsutsatt jord utviklet på marine avsetninger (Sørøst-Norge og Trøndelag). Høyt tap av løst fosfat i områder med høyt fosforinnhold i jorda, høy avrenning og høy andel organisk jord (langs kysten fra Sør- til Nord-Norge). Høye tap av organisk karbon i områder dominert av høy avrenning og høyt organisk karboninnhold i jorda (Sør- og Vestlandet).

Noen deler av modellene trenger ytterligere oppmerksomhet i fremtiden. Den største begrensningen for modellutvikling har vært tilgjengeligheten av kvantitative data, både data som kunnskapsbase for modellutvikling, data med riktig oppløsning og kvalitet som skal brukes som input i modellene og data for kalibrering av modellene i enkelte deler av Norge. Usikkerheten i modellestimatene er størst i områder som avviker fra grunnlaget for modellutviklingen (JOVA-nedbørfeltene), og derfor spesielt stor på Vestlandet og i Nord-Norge. Videre er usikkerheten stor ved nedskalering til REGINE-nedbørfelt siden noen av inputdataene er på kommune- og til og med fylkesnivå.

Summary

In this report, models to calculate losses of soil particles, phosphorus, nitrogen and organic carbon from agricultural land to first order streams are presented. The results from the models' results serve as input data to the TEOTIL model which estimate the net losses (i.e. river mouths) from agriculture and other sources (i.e. source apportionment).

The models presented in this report, are all empirical - consisting of a set of empirical equations and coefficients – all developed to include important hydro and biogeochemical processes at the catchment scale. The primary source of data for the model development has been data from the JOVA monitoring programme, supplemented with other data from national and international research. The catchments in JOVA represent the most important agricultural areas in the country regarding climate, soil and management practices.

The nitrogen model was developed as a regression-model based on data from the JOVA catchments. Total nitrogen loss from arable land depended on runoff, 2-year average nitrogen balance, dominating soil textures, temperature in May to August, area of grassland, area with no-tillage in autumn and catch crop area. The model was validated with independent monitoring data of other JOVA catchments and on Swedish monitoring data. A separate equation estimates nitrogen losses from pasture.

The soil loss model was based on erosion risk, which represents soil loss given spring cereals with autumn ploughing. Erosion risk was converted to soil loss at the given combination of crops and tillage by multiplying with crop and tillage specific management factors and thereafter subtracting soil particles retained by grass covered buffer zones and grassed water ways in gullies. Soil loss was estimated separately for different processes/erosion forms.

The phosphorus (P) model consisted of two sub-models for the estimation of loss of particle bound phosphorus (PP) and dissolved phosphate (PO_4-P). The PP loss was calculated as P content in the soil multiplied with the soil loss and an enrichment factor taking into consideration higher P content on smaller soil particles. The PO_4-P loss was calculated by two separate regression equations, one for mineral soil and one for organic soil, taking into account the P content in the soil, soil loss and runoff.

The carbon (C) model was subdivided into sub-models for the estimation of loss of particle bound organic carbon (POC) and dissolved organic carbon (TOC). The POC loss was calculated in a similar way as PP loss, from soil loss, organic carbon content in the soil and an enrichment factor. The dissolved organic carbon (DOC) loss was calculated by coefficients depending on soil OC content and runoff.

Input data used in the models included readily available data from national maps and databases: NIBIO's land use map, NIBIO's soil map including information on soil texture class, soil carbon content, artificial levelling and erosion risk; NGU's geological map for determining soil texture class and erosion risk in areas where soils have not been mapped; NIBIO's soil analysis database Jorddatabanken for determining soil carbon content in unmapped areas and soil phosphorus status (P-AL); NVE's runoff data corrected by NIBIO to better represent agricultural land; MET's gridded data (1 km x km) precipitation and temperature data; crop distribution and livestock numbers from Søknad om produksjonstilskudd; environmental measures from eStil/RMP; fertilizer amounts from Mattilsynet and SSB.

The calculation scale of the models was the NVE REGINE catchment units, and the estimation was carried out for agricultural land only. Retention of soil and nutrients in the agricultural landscape was included to the extent it is represented in the catchment scale calibration data and in the model's input data. Retention downstream the small agricultural catchment scale was not included.

Estimations of risk of losses from agricultural land uses mean weather data for the period 1991-2020 and annual data on agricultural management. The annual estimates use annual values for both weather and management. Using the risk models based on mean weather data will allow identification of effects of agricultural management and implemented measures.

The final models estimated losses for all REGINE catchments in Norway for the years 2013 to 2022, using both mean and annual weather data. The results showed that the models captured regional differences in losses of the different elements: High losses of nitrogen in areas with high runoff. High losses of soil particles and particle bound phosphorus in areas dominated by cereal and/or potatoes or vegetable production, and erosion prone soils developed on marine deposits (Southeast Norway and Trøndelag); High losses of dissolved phosphate in areas with high phosphorus content in the soil, high runoff and high proportion of organic soils (along the coast from southern to northern Norway); High losses of organic carbon in areas dominated by high runoff and high soil organic carbon content (southern and western Norway).

Some parts of the models need further attention in the future. The largest constraint to model development has been the availability of quantitative data, both data to serve as a knowledge base for model development, data at proper resolution and quality to be used as input in the models and data for calibration of the models in certain parts of Norway. The uncertainty of the model-estimates is highest in areas which differs from the basis of the model-development (the JOVA-catchments), and therefore especially high in western and northern parts of Norway. Furthermore, the uncertainty is large when downscaling to REGINE catchments since some of the input data are at municipality and even county scale.

1 Introduction

TEOTIL is the national model that calculates annual inputs of total nitrogen and total phosphorus from land-based sources in Norway to water bodies and coastal areas in all NVE's REGINE catchment units (watercourses), as well as from fish farms for salmon and trout in seawater. TEOTIL was originally developed by NIVA in 1990 and was last updated in 2006. An important part of TEOTIL has been the JOVAest models (Eggestad et al. 2001) for nutrient loss from agricultural areas, developed by NIBIO. JOVAest consisted of two empirical equations that estimate losses of total nitrogen (TN) and total phosphorus (TP) from agricultural areas. The equations were developed using data from the Agricultural Environmental Monitoring Programme (JOVA). Estimations in JOVAest were carried out at the regional scale, for 42 regions consisting of multiple municipalities in each region. JOVAest estimated TN and TP losses to first order streams. Retention of the nutrients in streams and lakes was handled by the TEOTIL model.

In 2021, the Ministry of Climate and Environment contracted NIVA and NIBIO to investigate if the existing TEOTIL model should be updated, and whether a new and improved model should be developed. The pre-feasibility study concluded (Bechmann et al. 2022) that the JOVAest equation for nitrogen should be updated and further developed, and that the JOVAest equation for phosphorus should be replaced by another management-oriented phosphorus loss model that is widely used in mitigation analyses and load calculations at river basin scale: Agricat 2 (Kværnø et al. 2014). In addition, it was decided that the new model system should provide data for loss of soil (suspended sediments), organic carbon (OC), and the fractions phosphate (PO_4-P) and nitrate (NO_3-N) in addition to total nitrogen (TN) and total phosphorus (TP). The pre-project was followed up by a new project in 2023-2024, in which the model development took place.

The requirements to the new models were that they should:

- cover the most important processes causing soil and nutrient losses;
- be applicable to and provide reliable results for all of the agricultural land in Norway, covering all types of soil, terrain, climate and agricultural production systems;
- reflect important changes in agricultural practices and mitigation measures;
- provide results for both anthropogenic losses and so-called background losses (losses from agricultural land if these areas were under no anthropogenic influence);
- be feasible to set up and run on the national scale;
- be based on readily available input data at the national scale;
- use NVE's REGINE catchment units as calculation scale.

This report presents a description of the model development process and the resulting models.

2 Data used for model development

Input data for the model development are described in this chapter.

2.1 The Agricultural Environmental Monitoring Programme (JOVA)

The Norwegian Agricultural Environmental Monitoring Programme (JOVA) is a national programme for monitoring in agricultural dominated catchments in Norway. The JOVA-programme was initiated in 1992 with the aim to document soil and nutrient losses, based on measurements of runoff and water quality. In addition, the aim is to document the environmental effects of agricultural management practices and measures through sampling and processing of data from the monitored catchments and other relevant data sources.

The catchments monitored in JOVA represent the most important agricultural areas in the country with regard to climate, soil and management practices. This includes regions with intensively cropped areas and areas with high density of livestock as well as areas with low intensity grassland.

The measurements of soil and nutrient losses in the JOVA catchments are based on continuous water flow measurements and flow proportional composite sampling over periods of approximately 14 days. In addition, management information is collected from farmers of what has been done on the land and how much crop yield they have achieved. However, all catchments also have other land use types. Forests and residential areas account for between 30 and 60% of the catchments. The measured losses from the catchments must therefore be adjusted for the losses from other areas before being used in model development for agricultural areas. For nitrogen, this is by default in the database system done by setting the losses from non-agricultural land to 10% of the losses from agricultural land (per unit area). For phosphorus, a default standard coefficient of 6 g TP/daa is used (Bechmann et al. 2021). It is further assumed that all of the soil loss originates from agricultural land.

Table 2.1. Characteristics of the JOVA-catchments.

Catchment	Municipality	Area **(km^2)**	Agric. area (%)	Temp **(°C)**	Prec. (mm)	Soil*	P-AL (mg/100 g)	Agric. **managem.**	Start **year**
Skuterud (Sku)	Ås	4.5	61	5.5	785	Clay, sand	8	Cereals	1993
Mørdre (Mør)	Nes	6.8	65	4.3	665	Silt, clay	10	Cereals	1990
Kolstad (Kol)	Ringsaker	3.1	68	4.2	585	Loam	13	Cereals	1985
Vasshaglona (Vas)	Grimstad	0.86	55	6.9	1230	Sand, loam	25	Veget./pot./ cereals	1991
Hotran (Hot)	Levanger	20	56	6.1	1000	Clay	10	Cereals, grass	1992
Time (Tim)	Time	1.0	88	7.4	1180	Sand	21	Grass	1985
Skas-Heigre (Ska)	Sandnes, Sola, Klepp	28	84	8.3	1330	Sand, organic	17	Grass	1995
Naurstad (Nau)	Bodø	1.5	35	4.5	1020	Organic	10	Grass	1994
Volbu (Vol)	Øystre Slidre	1.7	41	1.6	575	Sand	8	Grass	1991

*Clay = silt loam, silty clay loam, clay, heavy clay; Loam = sandy loam, loam; Silt = silt, sandy silt; Sand = loamy sand, sand; Organic = deep organic soil, organic topsoil with sand subsoil.

In this study, nine of the catchments were included (Figure 2.1; Table 2.1). Data from the monitoring can be downloaded from jovadata.nibio.no and has been summarized in Bechmann et al. (2021). The development of the nitrogen model included six catchments with most comprehensive data on agricultural management and long-term time series of continuous runoff and water quality measurements. The catchment Time and the two larger catchments with less detailed agricultural data (Hotran and Skas-Heigre) and the closed, former JOVA catchment Grimestad were included in development of the models for soil, phosphorus and carbon losses, and used for validation testing of the nitrogen model.

The TEOTIL model calculates losses for calendar years. However, the agricultural models were developed using data for agrohydrological years (May 1 to April 30), because nutrient losses depend on timing of agronomic operations and the crop cycle: The agrohydrological year follows a spring sown crop from spring tillage and sowing, throughout the growing season till harvest and autumn tillage (if carried out), then covers the autumn and winter period and ends in spring before sowing of the next spring crop. No-till-in-autumn for spring cereals will in this way have a continuous effect from autumn till spring next year. For winter crops, the agrohydrological year will cover the tillage and sowing in autumn and the state of the soil given these conditions in autumn and winter, while the growing season and harvest of this crop will be covered by the following agrohydrological year.

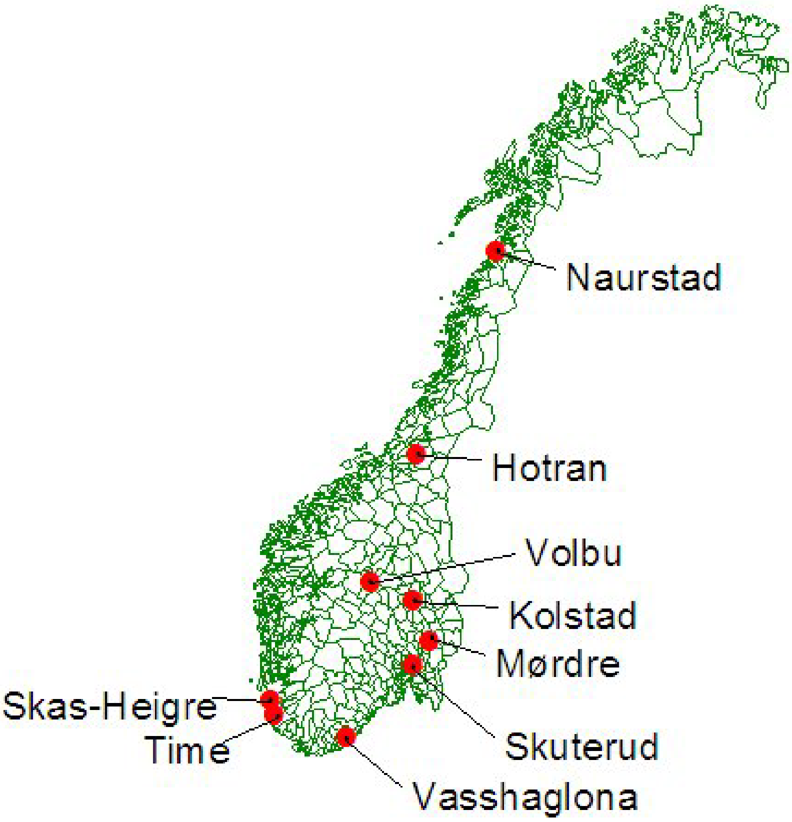

Figure 2.1. The nine JOVA-catchments with long-term continuous data on runoff and water quality.

2.2 Other experimental sites

Table 2.2 shows experimental sites that have been used primarily in the development of the dissolved P (PO_4-P) model. The sites are field scale catchments monitored in the JOVA programme (Vandsemb and Bye) and plot size field lysimeters (Apelsvoll, Kjelle, Kvithamar and Fureneset).

Table 2.2. Model development sites on field and plot scale.

Name	Scale	Location	Crop	Soil type	P-AL
Vandsemb [1]	Field scale catchment	Akershus	Cereal	Silty clay loam, silt	15
Bye [1]	Field scale catchment	Innlandet	Cereal, potatoes	Sandy loam	6
Apelsvoll [2]	Plot scale lysimeter	Innlandet	Cereal, potatoes	Sandy loam	8
Apelsvoll [2]	Plot scale lysimeter	Innlandet	Grass	Sandy loam	10
Kjelle [3]	Plot scale lysimeter	Akershus	Cereal	Silty clay loam	20
Kvithamar [4]	Plot scale lysimeter	Trøndelag	Cereal	Silty clay loam	9
Fureneset [5]	Plot scale lysimeter	Vestland	Grass	Sand	9
Fureneset [5]	Plot scale lysimeter	Vestland	Grass	Organic	5

[1] JOVA database; [2] Riley and Eltun (1994); Korsæth and Eltun (2008); [3] Bøe et al., 2024; [4] Myhr et al. 1996; Oskarsen et al., 1996; ; [5] Sandvik et al. (1997).

3 Nitrogen loss

3.1 Overall model concept

The concept of the model is empirical. This means that monitoring data of the target variable, unit-area N losses (N losses divided by agricultural catchment area) and of variables potentially explaining the N losses (e.g. agricultural management or weather conditions) are used as basis. By different statistical methods, correlations between the explanatory variables and the target variable are identified (chapter 3.2). In this way, correlations are selected only statistically but do not require causality. This means that they are not necessarily in accordance with the process understanding. The important part of model development is then to evaluate whether the statistically sound correlations are indeed in agreement with what is known from experimental studies. This means, empirical models don't follow physical or chemical laws, they only explain the variance of a variable by other variables as found by the provided dataset. To ensure that the model is not overfitted for describing only the dataset used for development, an evaluation with independent data is required (chapter 3.4.2). The performance of the model is also just known for sites which are similar to the sites used for model development. Based on the JOVA dataset the area for which the model can be applied has been identified (area of applicability; chapter 3.4.4). For sites outside this area of applicability, the performance of the model is unknown – it can be good or poor. To enlarge the area for the empirical model, data for testing the model are required.

Retention downstream the small agricultural catchment scale is calculated by NIVA in the TEOTIL model.

3.2 Model development

A similar approach as for the former equation (Eggestad et al., 2001) was followed for developing a revised equation to estimate annual losses of nitrogen from agricultural areas to surface waters. In a first attempt, only variables possibly explaining the annual nitrogen losses were selected (expert-decisions by the authors). The variables covered agricultural management, geomorphological site conditions, weather, and runoff. Beside the understanding of processes driving nitrogen losses by runoff, also the availability of data at national scale was considered while selecting potentially explanatory variables.

All variables were separately tested for significant correlation with annual nitrogen losses and for correlation between each other using Kendall's rank correlation. This was done to explore relationships between the explanatory variables of the dataset and to identify appropriate methods for the compilation of an equation. This first analysis showed strong correlations between many variables and strong influences of the individual sites and their unique site characteristics. Different statistical methods were tested. The main methods were, first, forward stepwise multiple linear regression, second, lasso and ridge regression, and third, Random Forest. All approaches showed equifinality. This means that many different equations were found which described the variation of measured nitrogen losses similarly well. However, many regression equations did not comply with the general process understanding of nitrogen leaching and therefore, had to be rejected. The Random Forest approach gave results with similar goodness of fit as the common regression methods. However, also this approach was refused due to the strong collinearity between the variables and the 'black box' characteristic of Random Forest models, although variable importance measures are retrievable. Instead, the experience of all approaches was used to manually select those variables which resulted by an ordinary least square regression in an equation which agrees with the understanding of processes affecting nitrogen losses by runoff.

All statistical analysis and the processing of data were performed with R version 4.3.1 (2023-06-16 ucrt) using R studio 2023.9.0.463 (Posit team, 2023). For lasso and ridge regression, the R package glmnet (Friedman et al., 2010) was used, and for Random Forest the R package randomForest (Liaw & Wiener, 2002). Further main R packages were corrplot (Wei & Simko, 2021), ggplot2 (Wickham, 2016) and data.table (Dowle & Srinivasan, 2023).

3.3 Development dataset

For the development of the regression, data from the JOVA catchments Sku, Kol, Mør, Nau, Vas, and Vol were used. For all these catchments, variables covering influences on nitrogen losses from agricultural management, geomorphological site conditions, and weather including runoff were generated. The data for the variables originate from different sources. Agricultural management data are provided by the farmers for each individual field. These data include date and type of tillage activities, date, type and amount of fertilization, crop type, seed date, date of harvest, amount of yield, and residue management. In some catchments, not all farmers provide their management data. It was assumed that the available management data represent also the management of the area without information. Nitrogen balances were calculated at field scale as simple nitrogen balances (Nbal) in kg/daa/yr as suggested by Korsæth & Eltun (2000) as follows:

$$
\begin{aligned}
Nbal = \; & \textit{applied mineral fertilizer in kg N/daa/yr} \\
& + \textit{applied manure in kg/daa/yr} * \textit{N concentration in manure} \\
& - \textit{crop yield in kg/daa/yr} * \textit{crop N concentration.} \qquad \textit{(eq. 3.1)}
\end{aligned}
$$

Assumed nitrogen concentrations in manure are listed in table A1 in the attachment. Assumed nitrogen concentrations of harvested crops are listed in table A3 in the attachment. The annual nitrogen balance per catchment was calculated as area-weighted average nitrogen balance. The two-year average nitrogen balance is the average nitrogen balance of the current year and the previous year. This takes into account the delayed mineralization of organic nitrogen in manure. Soil texture data were taken from the official national soil map as provided through Kilden (nibio.no/kilden). These data were verified with analyses from a few soil samplings in the catchments. Unfortunately, soil texture data are not available from systematic soil samplings covering the complete agricultural area of each catchment despite its importance in nutrient flow processes. No data of soil organic nitrogen concentrations are available at national scale. Therefore, soil organic nitrogen concentration could not be used as variable for the model development despite its importance in risk of nitrogen loss. Temperature and precipitation data were taken from weather stations in or close by the catchment areas. In the catchments Mørdre, Kolstad, Time, Vasshaglona and Naurstad the weather stations are located inside the catchments and run by the JOVA programme or LMT (Mørdre). In the Volbu and Skuterud, the weather stations are close by (0,1 and 1,7 km, respectively) and run by NMBU (Søråsjordet station for Sku) or NIBIO's LMT (lmt.nibio.no, Løken station for Vol). Annual runoff data were taken from the JOVA database. Only those years with less than 10% missing runoff data were used. Total N and NO_3-N losses were calculated as described in Bechmann et al. (2009).

Based on the data described above more than 60 variables were compiled. A total of 163 site-years of data from the JOVA monitoring was used for the development of the regression. This dataset is referred to as the 'development dataset' in the following chapters on nitrogen losses.

3.4 The nitrogen model

3.4.1 Equation for nitrogen loss estimations

Different equations for arable land (area type 21 and 22 of the National Land Resource Map (AR5) and pasture (area type 23) were defined.

The final regression equation for estimation of annual total nitrogen losses in kg N/daa/yr (N_loss) from arable land included the variables annual runoff in mm/yr (Q_{ann}), two-year average nitrogen balance in kg N/daa/yr (Nbal_2yMean), the relative area share with silt and clay soils (RelAgrArea_SiltClay), the relative area share with organic soils (RelAgrArea_Organic), the annual mean daily temperature from May to August in °C (TempMean_MayAug), the relative area share with grass during winter (RelAgrArea_Grass), the relative area share with catch crops (RelAgrArea_CC), and the relative area share with stubble or directly drilled winter wheat (RelAgrArea_StDd). The area share is always related to the agricultural area in the catchments.

$$\begin{aligned} N\_loss = \quad & -1.59 + 0.0054 * Q_{ann} + 0.1144 * Nbal\_2yMean \\ & - 3.4867 * RelAgrArea\_SiltClay - 5.1374 * RelAgrArea\_Organic \\ & + 0.4070 * TempMean\_MayAug \\ & - 2.2649 * RelAgrArea\_Grass - 1.7276 * RelAgrArea\_CC \\ & - 0.5343 * RelAgrArea\_StDd \end{aligned} \qquad (eq.\ 3.2)$$

The goodness of fit (R^2) of the regression was 0.87 with a p-value smaller than 0.0001. The residual standard error was 1.13 kg/daa/yr.

Table 3.1. Overview of regression statistics of the multiple linear regression to estimate annual total nitrogen losses by runoff with the variables annual runoff in mm/yr (Qann), two-year average nitrogen balance in kg N/daa/yr (Nbal_2yMean), the relative area share with silt and clay soils (RelAgrArea_SiltClay), the relative area share with organic soils (RelAgrArea_Organic), the annual mean daily temperature from May to August in °C (TempMean_MayAug), the relative area share with grass during winter (RelAgrArea_Grass), the relative area share with catch crops (RelAgrArea_CC), and the relative area share with stubble or directly drilled winter wheat (RelAgrArea_StDd).

Coefficients	Estimate	Std. Error	t value	p value
(Intercept)	-1.5904	1.31	-1.21	0.2263
Qann	0.0054	0.00	14.73	0.0000
Nbal_2yMean	0.1144	0.04	2.55	0.0117
RelAgrArea_SiltClay	-3.4867	0.44	-7.93	0.0000
RelAgrArea_Organic	-5.1374	0.45	-11.41	0.0000
TempMean_MayAug	0.4070	0.08	5.14	0.0000
RelAgrArea_Grass	-2.2649	0.96	-2.36	0.0194
RelAgrArea_CC	-1.7276	1.59	-1.09	0.2777
RelAgrArea_StDd	-0.5343	0.81	-0.66	0.5092

The variables annual runoff (Q_{ann}), two-year average nitrogen balance (Nbal_2yMean), the relative area share with silt and clay soils (RelAgrArea_SiltClay), the relative area share with organic soils (RelAgrArea_Organic), the annual mean daily temperature from May to August (TempMean_MayAug) and the relative area share with grass during winter (RelAgrArea_Grass) are documented to be statistically significant in the equation (see table 3.1), while the effect of the variables relative area share with catch crops (RelAgrArea_CC) and the relative area share with stubble or directly drilled winter wheat (RelAgrArea_StDd) was non-significant but included since these factors have been documented in former studies (Bechmann et al., 2023).

Figure 3.1 shows the measured nitrogen losses as used for the regression development against the nitrogen losses estimated with equation 3.2. From this figure it is obvious that high N losses were underestimated for the catchments Vas and Kol (points below the 1:1 line) while site-specific low N losses were overestimated (points above the 1:1 line).

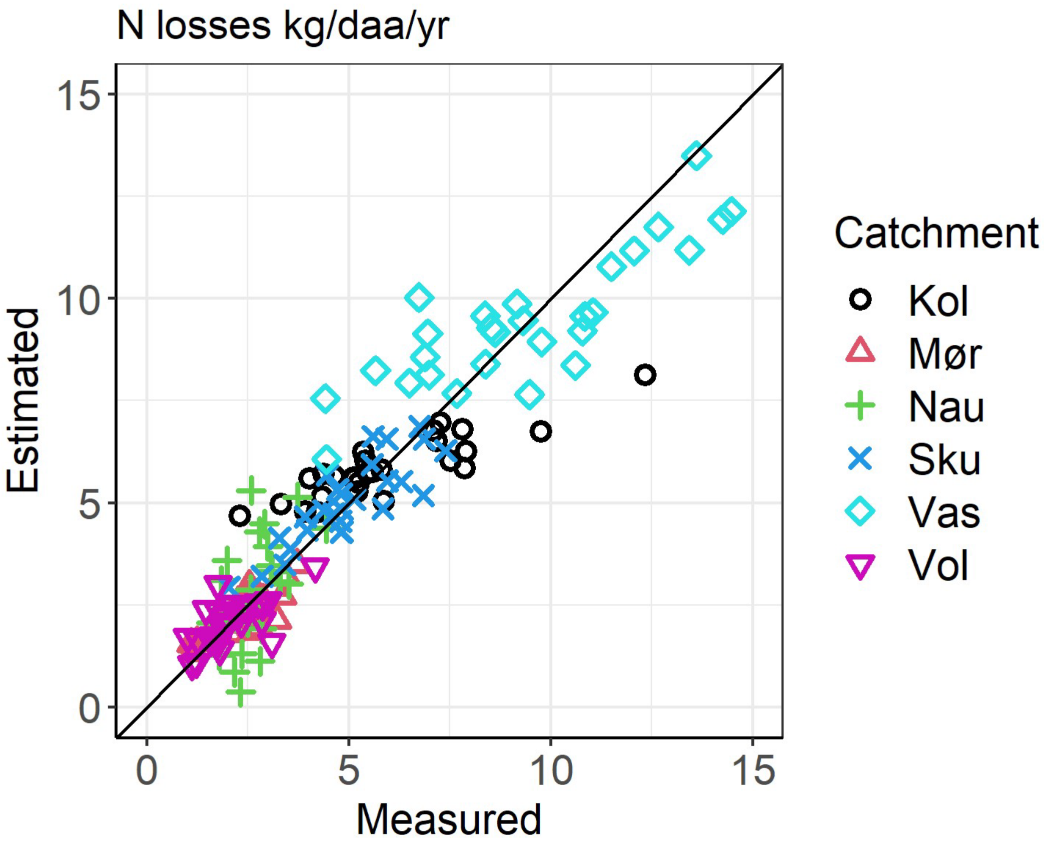

Figure 3.1. Measured versus estimated annual total nitrogen losses in kg N/daa/yr of 161 site-years of the monitoring catchments Kolstad (Kol), Mørdre (Mør), Naurstad (Nau), Skuterud (Sku), Vasshaglona (Vas), and Volbu (Vol). The black line is the 1:1 line.

Equation 3.2 was used to estimate annual total N losses from agricultural area classified as arable land (area type 21 and 22) in the National Land Resource Map (AR5). For areas classified as pasture (area type 23) a different equation was chosen to account for the distinctly different type of land use and site conditions. JOVA includes no catchment with significant area share of pasture and no study of nitrogen losses from pasture in Norway is known. It was decided to choose a conservative approach and to use the relationship between runoff and total nitrogen losses as observed at the catchment Naurstad. This catchment covers mainly grass production on arable land, also partly used as pasture and shows the lowest slope of the regression equation between runoff Q_{ann} and total nitrogen losses. The following equation was used to estimate annual total nitrogen losses from pasture areas:

$$N\_loss = 0.0023 * Q_{ann} \qquad (eq.\ 3.3)$$

This equation will be used until data for a revision of the equation are available. A verification and, if necessary, a revision is recommended.

Nitrate-nitrogen (NO_3-N) losses were set to 80% of the total nitrogen losses from arable land. The proportion is based on a JOVA dataset covering 296 site-years of 9 catchments. There, the mean proportion of NO_3-N to total N losses was 78% with a standard deviation of ±9%. This is similar to the proportion found at the plot study site Apelsvoll (84%; Korsæth & Eltun, 2000). Naurstad is the only catchment showing a considerable different proportion of NO_3-N with an average of 32%. The most distinct difference separating Naurstad from the other catchments is the large area share of organic soils. The hypothesis that N losses from organic soils are dominated by other than nitrate-bound N could not be approved by the review of existing studies on runoff quality from organic soils under cold climate. A lysimeter study at Fureneset with organic soils showed NO_3-N proportions of 70-80% (Sandvik et al., 1997). Kløve et al. (2010) observed a mean proportion of NO_3-N and NH_4-N to total N of 42% and 8.6% respectively. They (Kløve et al., 2010) also stated that the proportion of organic-N in runoff from drained organic soils is usually around 50%. In contrast, Pham et al. (2023) observed in a 3-year study total N losses of 1 to 4 kg N/daa/year with a NO_3-N proportion of 74% for subsurface runoff of drained cultivated peat soils. Regarding differences in N-compounds in surface and subsurface runoff, Korsæth (2008) observed, for mineral soils, a mean proportion of 38% NO_3-N, 22% NH_4-N and 40% organic N to total N in surface runoff and 84%, 0% and 16% in subsurface runoff, respectively. None of the mentioned studies distinguish between dissolved and particular organic N losses. In conclusion, the results of the studies cannot answer the questions whether NO_3-N proportions of total N losses monitored at Naurstad are typical for organic soils used for grass production under Norwegian conditions but rise the questions whether 1) surface runoff at Naurstad plays a substantial role for total runoff, 2) NH_4-N losses are a substantial part of total N losses at Naurstad, 3) dissolved and/or particulate organic-N losses are major contributors to total N losses. Until these questions can be answered, a proportion of 80% NO_3-N to total N is assumed, independent of soil and land use conditions of agricultural area classified as arable land. For pasture areas, a proportion of 50% was assumed. This takes into account that soils of area type 23 are assumed to be not artificially drained and N losses occur rather through surface than subsurface runoff, and that the proportion of NO_3-N to total N is low in surface runoff from pasture (Pilon et al., 2019; Young et al., 2023).

In addition to the annual actual N losses also N loss risk by farmers' management was estimated. The N loss risk shows the interannual variation of N losses induced by farmers' management in the individual years independent of interannual weather variation. For this, actual annual runoff and summer temperature in eq. 3.2 and eq. 3.3 were replaced by long-term averages (1991-2020) of annual runoff and of annual mean daily temperature in May to August. It should be mentioned that, in this way, the effect of annual weather variation is not fully excluded as the nitrogen balance, and partly the possibility to grow catch crops, are also influenced by weather conditions. The nitrogen balance can be affected e.g. in the way that unfavourable weather conditions limit crop growth and so N uptake over an unforeseeable long period of time after N fertilizer application.

3.4.2 Evaluation of the nitrogen loss model

Equation 3.2 was evaluated with the monitoring data of the catchment Time, which were not used for the development of the regression equation. The regression fitted well for the catchment Time. Differences of measured and estimated nitrogen losses were low (RMSE = 0.80 kg N/daa/yr; see also Figure 3.2).

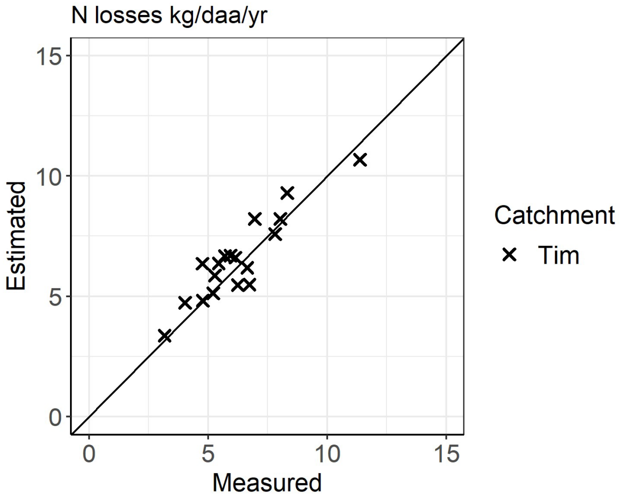

Figure 3.2. Measured versus estimated annual total nitrogen losses in kg N/daa/yr of the JOVA catchment Time (Tim) for the years 1993 to 2020. The black line is the 1:1 line.

The good fit of estimated and measured nitrogen losses in Time occurred despite the high uncertainty in the N balances of Time. This suggests a low effect of the N balance in eq. 3.2. According to the equation, 1 kg/daa change in the N balance will change the N losses by 0.11 kg/daa. Considering the relationship of N balances and N losses as shown in Fig. 3.3, a stronger effect of the N balance in the equation was expected. There are multiple reasons for this discrepancy. On the one hand, runoff is the most dominating variable driving N losses according to the regression statistics (Table 3.1). The close relationship of runoff and total N losses is also evident from Figure 3.4. On the other hand, beside its direct effect in the equation, the N balance affects N loss estimates also through complex interactions with the other variables due to the limited diversity of combined site conditions in the development dataset. These complex correlations between variables became obvious by the Kendall rank correlation tests between the variables of the equation. (Info: The Kendall rank correlation coefficient τ (tau) ranges between -1 and 1. The closer tau to -1 or 1, the close the relationship of the two variables). Two-year average N balance is significantly positively correlated with mean daily temperature in May to August ($p < 0.05$, tau=0.49) and with the relative area share of soils with silt and clay dominated texture ($p < 0.05$, tau=0.30). The latter correlation is again probably caused by the significant negative correlation of silt and clay dominated soil with grass area ($p < 0.05$, tau=-0.73). Grass area again is significantly negatively correlated with the 2-year average nitrogen balance ($p < 0.05$, tau=-0.33). These described interactions are just the most distinct relationships of variables in the development dataset while further minor relationships between the variables exist (not shown).

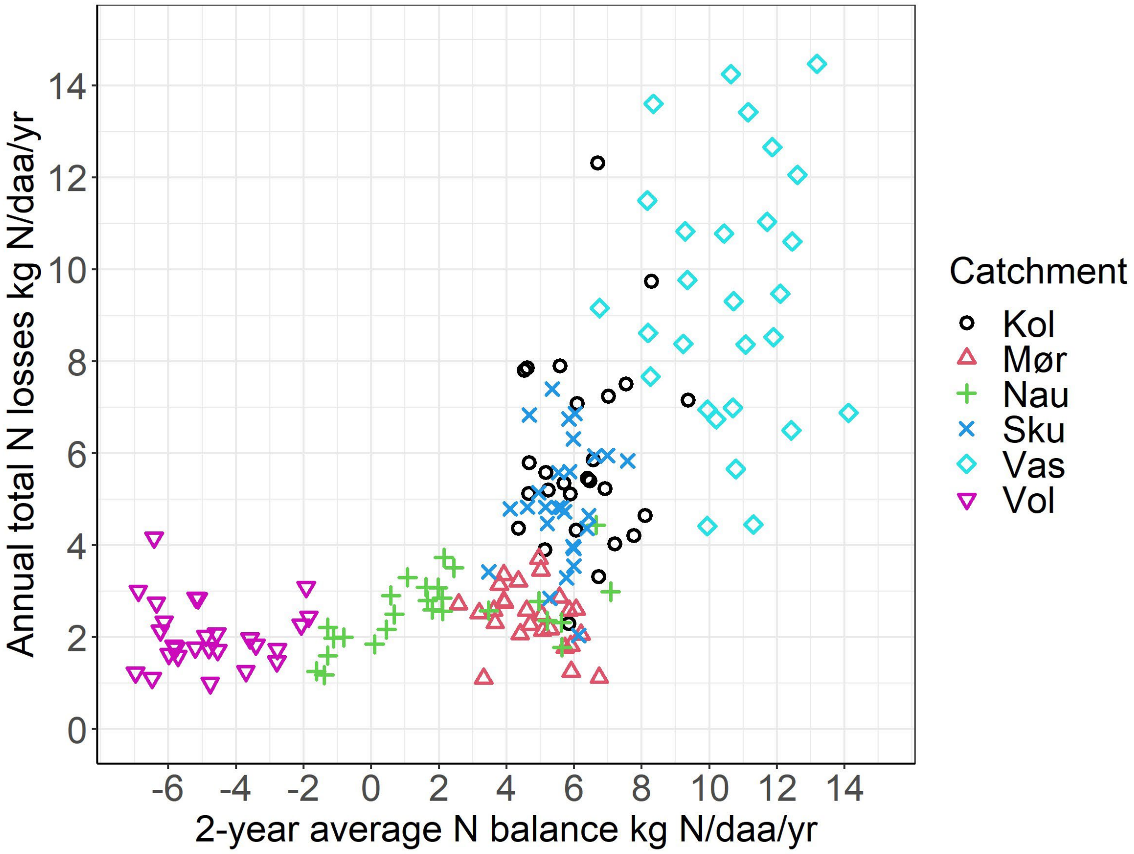

Figure 3.3. Annual total nitrogen (N) losses in kg N/daa/yr depending on 2-year average nitrogen balance in kg N/daa/yr for the JOVA catchments Kolstad (Kol), Mørdre (Mør), Naurstad (Nau), Skuterud (Sku), Time (Tim), Vasshaglona (Vas), and Volbu (Vol) for the years 1993 to 2020.

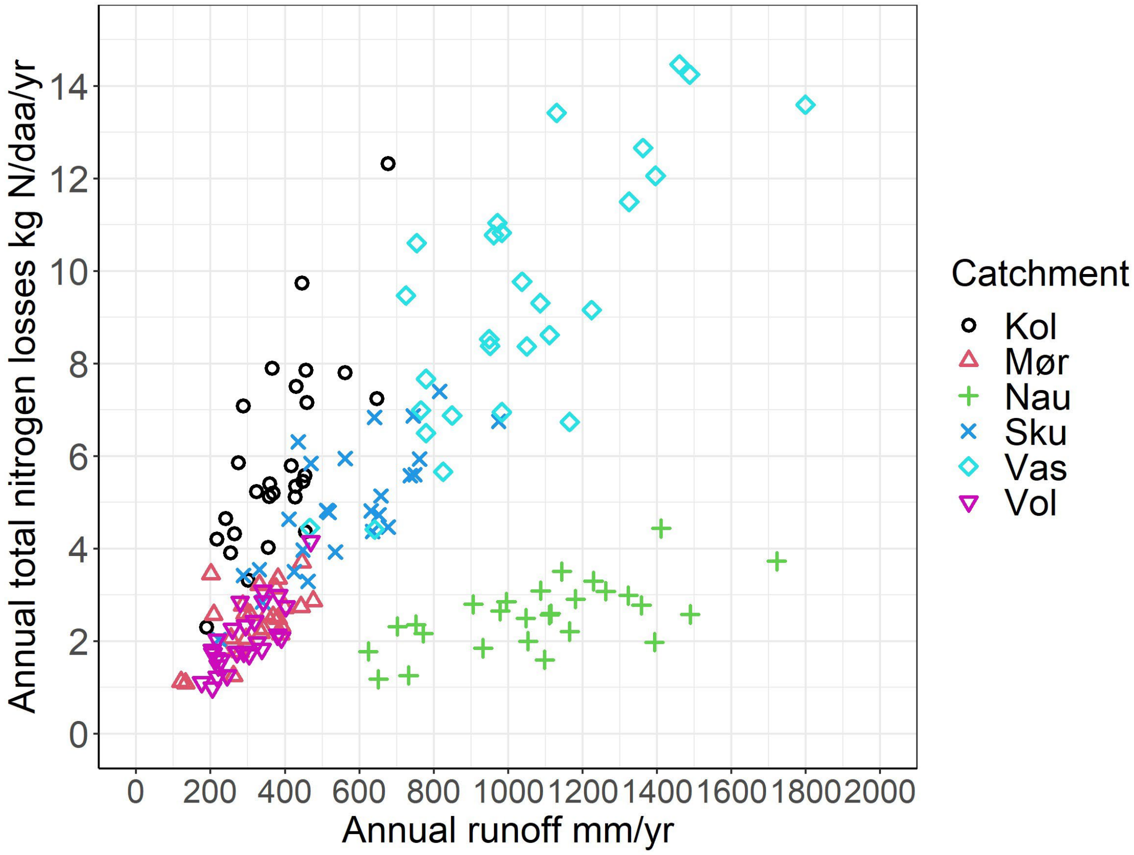

Figure 3.4. Annual total nitrogen losses in kg N/daa/yr depending on annual runoff in mm/yr for agrohydrological years for the JOVA catchments Kolstad (Kol), Mørdre (Mør), Naurstad (Nau), Skuterud (Sku), Time (Tim), Vasshaglona (Vas), and Volbu (Vol) for the years 1993 to 2020.

3.4.3 Evaluation of N loss estimates at national scale

Data availability at national scale is far less detailed than for the monitoring catchments. The general availability of data was considered before including variables in the regression. However, no criteria for minimum spatial resolution of the input data were set. For certain variables, the spatial scale of input data is very rough. For example, for calculating the nitrogen balance, information about synthetic fertilizer is available only as sold amount of nitrogen at county level (see chapter 7.16). This can lead to considerable incorrect assumptions of variable values in certain regions. In order to estimate the degree of this problem for each variable of eq. 3.2, the development data were compared to the national input data of the REGINE units covering the JOVA catchments respectively. This means that, e.g. Nbal_2yMean in 2019 of Skuterud was compared to Nbal_2yMean in 2019 of the REGINE unit covering Skuterud.

In addition, the two catchments Skas-Heigre (Ska) and Hotran (Hot) were used for evaluation of applied runoff data and of N losses estimated with the national input data. Both catchments were not used for the development of the equation as farming management was not documented there. This enabled a comparison of estimated N losses with independently measured N losses.

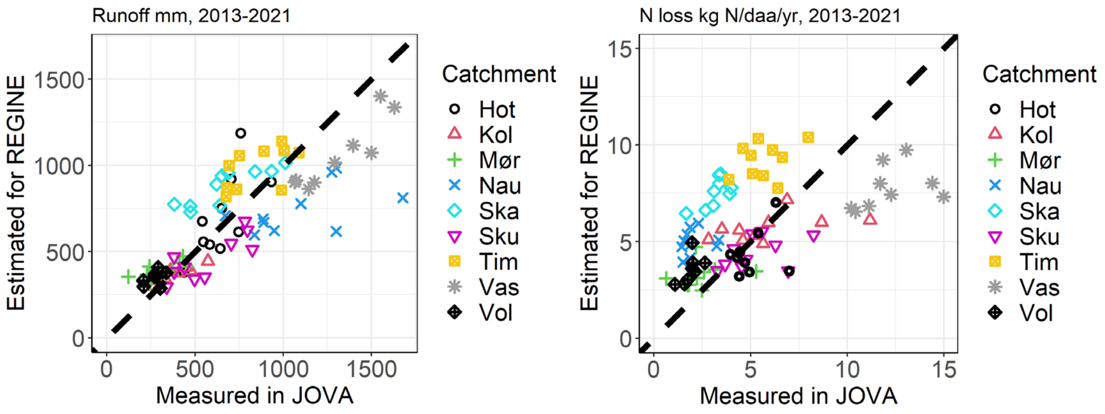

Figure 3.5 Annual runoff in mm/yr (left) and annual nitrogen losses in kg N/daa/yr (right) of the years 2013 to 2021 measured at the JOVA catchments (x-axis) and estimated for corresponding REGINE units which cover the JOVA catchments respectively (y-axis).

Annual runoff of the years 2013 to 2021 measured for the JOVA catchments Vas, Nau, and Sku was lower than assumed for the corresponding REGINE units (Figure 3.5). It was the other way round for the JOVA catchments Tim and Ska. There were minor differences for the JOVA catchments Hot, Vol, Mør, and Kol although distinct differences appeared in single years. The overall difference in annual runoff calculated as root mean square error (RMSE) was 216 mm but ranged for the individual catchments between 66 mm (Kol) and 406 mm (Nau). The two-year average nitrogen balances were lower for the JOVA catchments Kol, Mør, Nau, Tim, and Vol and higher for Vas than assumed for the corresponding REGINE units. The overall difference of Nbal_2yMean calculated as RMSE was 4.9 kg N/daa/yr but ranged for the individual catchments between 1.7 (Sku) and 9.5 kg N/daa/yr (Vol). The relative area share of silt and clay soils marginally differed between the JOVA catchments and corresponding REGINE units. The same applied to the area share of organic soils for all JOVA catchments of the development dataset excluding Nau. In this catchment, the area share of organic soils was 1 while for the corresponding REGINE unit the area share of organic soils was assumed to be 0.045. The relative area share of grassland persisting over winter was lower for the catchments Nau, Tim, and Vol and higher for the catchments Sku, Kol, Mør, and Vas than assumed for the corresponding REGINE units. The overall difference in grass area was 0.23 but ranged for the individual catchments between 0.05 (Vol) and 0.51 (Vas). The relative area share with catch crops was mainly zero for the JOVA catchments while it was on average 0.013 for the corresponding REGINE units. The relative area share with stubble or direct drilled winter cereal were mainly higher in the JOVA catchments than in the corresponding REGINE units, excluding for Sku for which it was the other way round. Overall, the difference was 0.12. The temperature in May to August was mainly higher for the JOVA catchments than for the REGINE units (RMSE = 1.36 °C). RMSE per catchment ranged between 0.1 (Mør) and 2.6 °C (Nau). All in all, it resulted finally in higher annual N losses for the catchments Tim, Nau, and Vol than for the corresponding REGINE units (RMSE = 3 kg N/daa/yr) and in lower annual N losses for Vas than for the corresponding REGINE unit (RMSE = 4.7 kg N/daa/yr) (Figure 3.5). The differences in annual N losses between the JOVA catchments Kol, Mør, and Sku and the corresponding REGINE units were scattered around equality with a RMSE of 1.75 kg N/daa/yr. The annual N losses of Hot, one of two JOVA catchments without detailed management data, were almost equal to or slightly lower than those estimated for the corresponding REGINE unit (RMSE 1.4 kg N/daa/yr). The annual N losses measured for Ska were considerably higher than estimated for the corresponding REGINE unit (RMSE 4.4 kg N/daa/yr). Reasons for the differences in the variable values and the N losses between JOVA catchments and corresponding REGINE units were multifarious and therefore, difficult to quantify. In general, the main reasons were assumed to be the low spatial resolution of required data at national scale, variability of the variables within the REGINE units, incomplete data in the JOVA catchments, and, finally, the expected error of the regression equation to estimate annual N losses (1.13 kg N/daa/yr).

3.4.4 Applicability and utility

The complex collinearities of the variables in the development dataset described in chapter 3.4.2 might limit the applicability of eq. 3.2 for areas different from JOVA catchments in the development dataset. Empirical models are in general limited to the conditions covered by the development dataset. This means also that collinearities between multiple variables restrict the applicability of the model also to datasets with same correlations between the variables. Therefore, the applicability of the developed equation for the dataset available for the territory of Norway was tested.

The area of applicability (AOA) of the model was calculated with the R package CAST (Meyer et al., 2024) which is based on a study of Meyer & Pebesma (2021), among others. In general, this is done by calculating the dissimilarity (distance) of the dataset for prediction from the dataset used for development of the model. In our case, the dataset for prediction was the dataset for N loss estimations for all REGINE units with arable land and the development dataset was the JOVA dataset. Calculations of the distances result in a so-called Dissimilarity Index (DI) (Meyer et al., 2024) for each REGINE unit and each year. A threshold is used to define whether the REGINE unit covers variable values with an acceptable DI. In our case, the threshold was based on the maximum DI of the variable values of the single JOVA site-years and the remaining JOVA dataset, excluding outliers. Moreover, it was defined that a REGINE unit becomes an AOA when DI is at least in half of the years below the threshold. The AOA was once calculated considering all variables and once using only Q_{ann} and Nbal_2yMean.

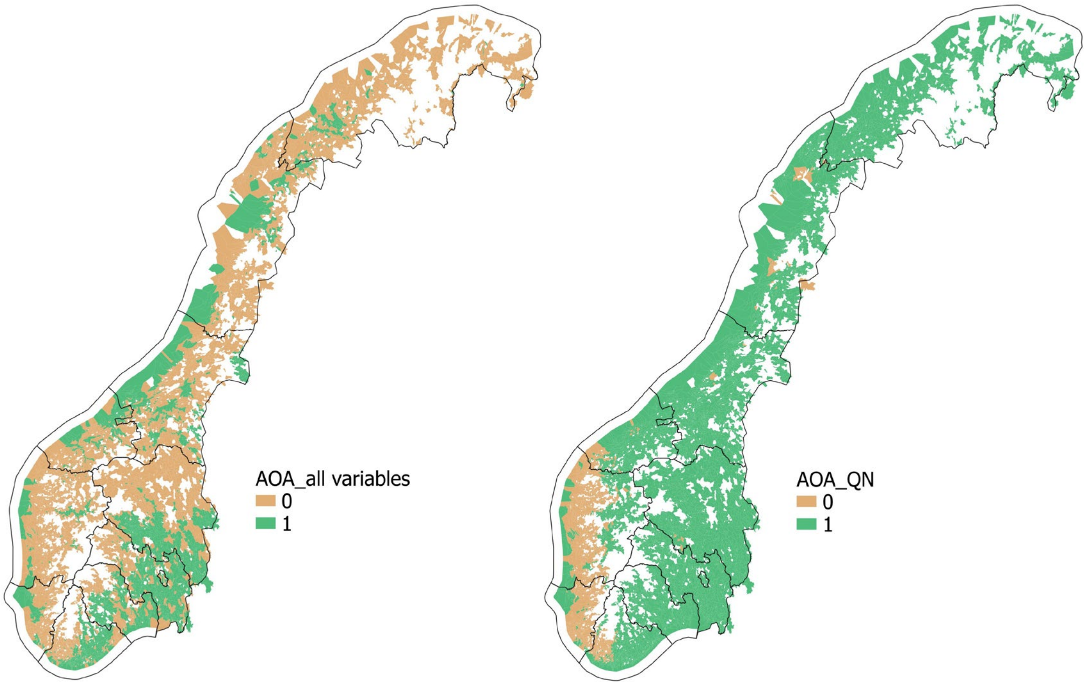

Figure 3.6: Maps of Norway with area of applicability (AOA) based on all variables of eq. 3.2 (left figure) and exclusively based on the variables Qann and Nbal_2yMean (right figure) for REGINE units covering arable land. AOA was calculated following Meyer et al. (2024). An AOA value of 1 (green area) means that the values of the variables and combinations of them for a REGINE unit are similar to those in the JOVA dataset. An AOA value of 0 (brown area) means that the input data of the REGINE unit is dissimilar to the JOVA dataset and estimations of N losses by eq. 3.2 are of high uncertainty.

The area of applicability was around 50% of the total arable land of Norway when all variables of eq 3.2 were considered. Main AOA was located in south and southeast of Norway, along the west coast and a few other scattered sites (Figure 3.6, left side). AOA was of similar size when calculated with the variables Qann, Nbal_2yMean, RelAgrArea_SiltClay, and RelAgrArea_Organic (not shown). AOA increased to 88% of the arable land of Norway (Figure 3.6, right side) when the calculation of AOA was restricted to Q_{ann} and Nbal_2yMean, assuming that runoff and nitrogen balance are of highest importance. However, soils are of crucial importance in processes affecting N loss from land to water and should not be neglected.

The AOA of eq. 3.2 is depending on the assumed criteria. Here, a moderate approach was used, with at least of half of the years required to be below the threshold DI. AOA can be smaller or larger by requiring that DI is below the threshold in more or fewer years. Considering that runoff might further increase in some regions due to climate change, the AOA would further decrease when the model is not regularly revised by updated JOVA data. For REGINE units outside AOA, their N loss estimates are neither "right" nor "wrong", but they are of unknown uncertainty. An evaluation with independent monitoring data of first order catchments in areas outside AOA could overcome this constraint. For this, areas with high runoff (e.g. mean annual runoff of more than 1500 mm) and low and high N balances should be prioritized as the potential for N losses is highest there.

Considering the positive evaluation (chapter 3.4.2), eq. 3.2 can give fairly good N loss estimates in areas in AOA but unknown uncertainty is introduced to the estimates by the quality of the input data. Taking for example the actual spatial resolution of the N balances and the type of available input data (e. g. sold synthetic fertilizer at county scale), the actual average N balance of agricultural area in the REGINE unit might be considerably higher or lower than the assumed N balance.

The main strength of national, annual N loss estimations is the information about nation-wide pattern and temporal trends. As input data for the TEOTIL model it provides valuable information on the contribution of agricultural areas to surface waters at large scale (e.g. at least river basin sub-districts). Zooming to an individual REGINE unit and interpretation of its annual agricultural N loss estimates is possible but a solid comparison of used input data with locally known detailed information is highly recommended, e.g. for runoff or N balances when provided by most farmers in the REGINE unit.

In theory, eq. 3.2 can also be used for calculation of scenarios as long as the data for the scenarios are covering conditions covered by the JOVA dataset. Unfortunately, growing of catch crops which is an important measure to reduce N losses, is only sparsely included in the JOVA dataset. In only 19 site-years, catch crops were grown and then just with an area share of agricultural area in the catchments of around 13% on average, ranging between 0.1% and 41.7% This is probably also the reason why the variable RelAgrArea_CC was not significant (table 3.1). As described in chapter 3.4.1, the variable was accepted as its coefficient is in accordance to catch crop effects known from other studies.

3.5 Estimation of background losses of total nitrogen

Nitrogen loss from areas that have remained untouched by humans for a long time depends on soil, terrain and weather/climate.

Measurements have been made of nitrogen losses from forest and natural catchments under Norwegian and Nordic conditions (Bloem et al. 2020; De Wit et al. 2021). According to Bloem et al. (2020), nitrogen loss from forests and natural areas vary from 0.06 to 1.5 kg/daa/year for Norwegian as well as for Nordic catchments. Average nitrogen loss based on available data are 0.3 kg/daa/year from the Norwegian catchments and 0.24 kg/daa/year from the Nordic catchments (Bloem et al. 2020). These figures include both managed and natural forests. Nitrogen loss from forests under active management, e.g. logging, are affected by human activity and nitrogen losses are higher in periods of logging than they would have been under natural conditions (Bloem et al. 2020). Also, some forests are fertilized with nitrogen, which may increase the risk of nitrogen loss. Figure 3.7 and Table

3.2 show the difference in nitrogen loss between forests and agriculture in Norway and Nordic countries.

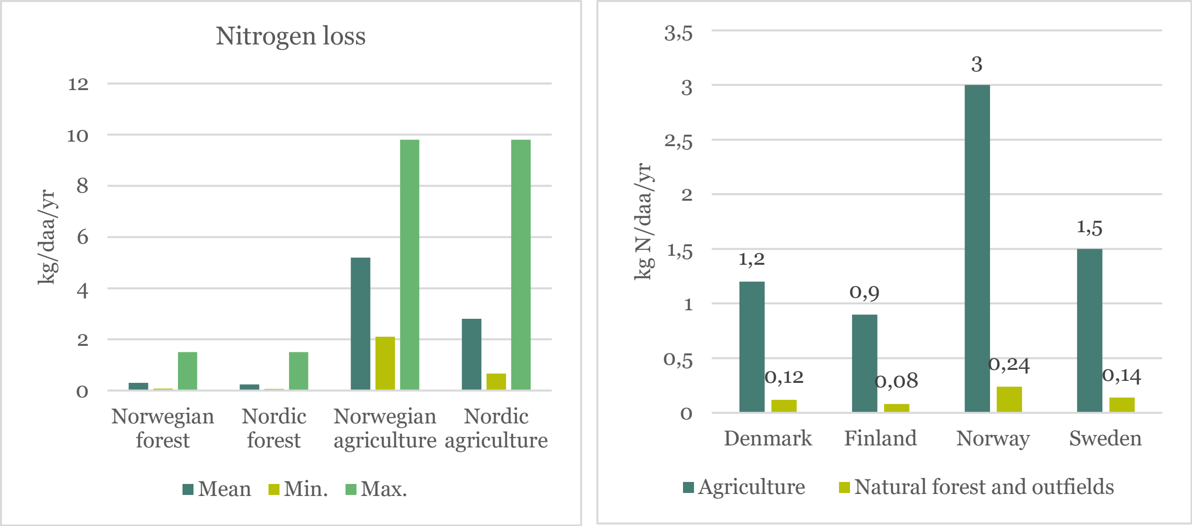

Figure 3.7. Nitrogen losses (kg/daa/yr) from forested catchments in Norway, forests in the Nordic countries and nitrogen losses from agriculture in Norway and the Nordic countries including Norway (kg/daa agricultural area/year). Average, minimum and maximum (Bloem et al. 2020, left). Nitrogen loss from forest/natural catchments and catchments dominated by agriculture (De Wit et al. 2020, right).

Table 3.2. Nitrogen loss (kg/daa/year) from Norwegian and Nordic catchments with forest/natural land and agriculture (kg/daa agricultural areas/year) as well as percentage nitrogen loss from forest/natural land (Bloem et al. 2020).

	Forest/natural	Agricultural	Forest/natural in % of agriculture
	kg/daa/yr		%
Norwegian	0.3	5.2	**5.8**
Nordic	0.24	2.8	**8.6**

De Wit et al. (2020) summarised measurements of nitrogen losses from catchments in the Nordic countries dominated by agriculture and natural areas of forest and natural land. Nitrogen loss from natural forest and wildlife catchments corresponds to 10 % or less of measured nitrogen losses from agriculturally dominated catchments in all four countries (Figure 3.7).

Due to climate change, it is likely that increased precipitation will lead to increased nutrient loss from natural background runoff. There are only a few long time series that illustrate the loss of nitrogen from forests and natural areas (Bloem et al. 2020). Moreover, time series with data from natural areas, corresponding to background runoff, are often from areas far to the mountains and thus do not illustrate background runoff in areas where agriculture is conducted.

Data from a catchment area of forest and natural areas in Valdres do not show any clear trend in nitrogen loss over time (1993-2020). However, an international compilation shows that nitrogen deposition has declined over large parts of Europe and North America (Austnes et al. 2022). In that study, surface water nitrate concentrations decreased significantly in 46% of the sites, increased in a few sites (4%) and showed no trend in the remaining sites. Datasets from Norwegian catchments with natural land use showed a decrease in loss of nitrate (not significant) and an increase in total nitrogen (De Wit et al. 2020, Figure 3.7).

Overall, there are few long time series for areas that may represent background runoff from agricultural areas. In general, nitrogen losses from areas with natural land use account for about 10%

of nitrogen losses from areas dominated by agriculture. Nitrogen losses from catchments increase with increasing proportions of agriculture in the area (Bechmann and Stålnacke, 2020). On the other hand, nitrogen losses from natural pristine areas may partly represent shallow soils, and it must be assumed that nitrogen losses in lowlands from areas with thicker soils under natural conditions will be higher. All in all, there are several factors that point in different directions, and the assumption that the background loss of nitrogen accounts for 10% of the nitrogen loss from agricultural land may be a useful estimate. According to de Wit et al. (2021), available data from long time series do not provide an opportunity to draw conclusions about trends in the development of nitrogen losses from natural areas. There are different trends in different areas, nitrogen concentrations have decreased over the period 2000-2018, but due to climate change there may have been increased precipitation and runoff (de Wit et al. 2020).

Based on the summary of studies on nitrogen losses from agricultural, forest and natural areas, the background N losses were estimated as follows:

Background TN loss = 0.1 x modelled TN loss from the agricultural area *(eq. 3.4)*

However, the lowest losses of total nitrogen measured from natural areas are 0.05 kg N/daa and this will be forced to be the lowest level of background losses for agricultural areas. On the other hand, if agricultural management cause extremely high total nitrogen losses, this should not influence the calculations of background losses. Therefore, a maximum limit of background losses is set to 1.5, corresponding to highest measured loss from natural areas, which is a forested area close to the Vasshaglona JOVA-catchment.

3.6 Modelling results on national scale

Estimated 10-year average N losses range between 0.8 and 10.3 kg N/daa/yr for the river basin subdistricts (vannområder) as shown in the left map of Figure 3.8. At the scale of REGINE units, estimated 10-year average N losses vary between around zero and 20 kg N/daa/yr (not shown). Lowest losses are estimated for subdistricts in Troms and Finnmark while losses increase towards the South through Nordland to Trøndelag. Southern half of Norway shows a distinct difference in estimated N losses between West and East. Estimated N losses of the river basin subdistricts in south-east Norway are mainly in the order of 2 – 6 kg N/daa/yr while losses are mainly between 6 and 10 kg N/daa/yr in subdistricts of south-west Norway. The pattern of estimated N losses is characterized by the distribution of annual runoff. As discussed in chapter 3.4.4, N losses from runoff higher than ~1500 mm/yr are of special uncertainty and should be interpreted with care. However, this doesn't strongly affect the overall picture shown in Figure 3.8. The right map of Figure 3.8 shows the estimated N losses for the year 2021. The pattern of N losses is similar to that of the 10-year average while absolute values are a magnitude lower in the subdistricts of south-west Norway.

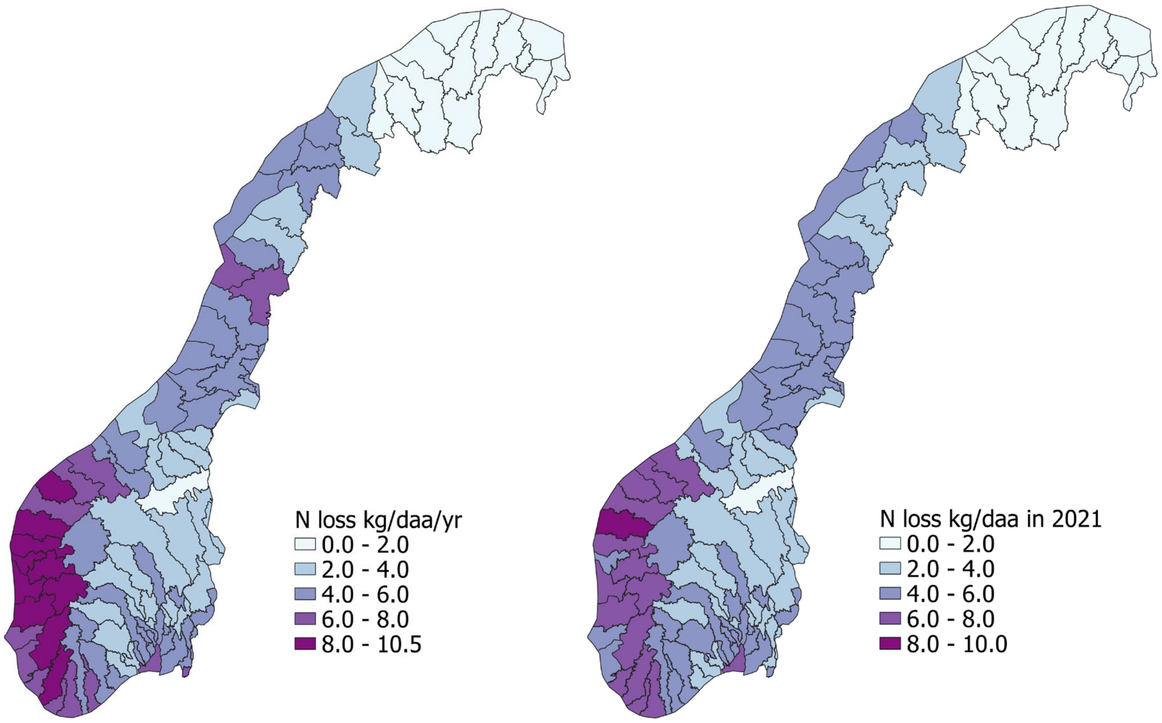

Figure 3.8. Mean annual nitrogen (N) losses in kg/daa/yr of the years 2013 – 2022 (left map) and N losses in kg/daa in the year 2021 (right map) from agricultural area to surface waters averaged for all river basin subdistricts in Norway, respectively.

4 Soil loss

4.1 Overall model concept

The soil particle (SS) loss model is a modified version of the Agricat 2 model (Kværnø et al. 2014), which calculates loss of both soil particles and particulate phosphorus from agricultural land. The Agricat 2 model consist of a set of empirical equations and coefficients based on measured data from national and international studies. The soil loss is based on erosion risk, representing soil loss given spring cereals with autumn ploughing, by 1) converting erosion risk to soil loss at the given combination of crops and tillage by multiplying with crop and tillage specific management factors and 2) subtracting soil retained by grass covered buffer zones.

The soil loss module uses the national erosion risk maps for sheet/rill erosion and gully erosion as input (Kværnø et al. 2020), together with information about crops from the national databases and maps containing information about applications for agricultural subsidies for crop and animal production (Søknad om produksjonstilskudd) and environmental measures (Regionalt miljøtilskudd i jordbruket, RMP).

Calculations of soil loss are, for each REGINE unit, subdivided on erosion risk classes for the calculations of sheet/rill erosion and soil loss through sub-surface drainage pipes, and not subdivided for gully erosion. There is no spatial routing (connectivity) of sediments across soil map units in the landscape. Retention in the agricultural landscape is included to the extent it is represented in the catchment scale calibration data and in the model's input data. Retention downstream the small agricultural catchment scale is calculated by NIVA in the TEOTIL model.

4.2 Model development and calibration

4.2.1 Adaptation of original equations

The original Agricat 2 model was the basis for the model development (Kværnø et al. 2014). Before the model was calibrated and developed further, the potential for updating the different parts of the original model was evaluated. It was concluded that some of the coefficients in the functions for the crop and tillage specific management factors could be revised due to updated knowledge and data availability. The original factors were not revised for the management categories grass ley, autumn harrowing and spring cereal with autumn ploughing, while they were replaced for the following management categories:

- The function for **stubble** was updated with data from the Kjelle plot study (Bøe et al., 2024). The new function is similar to the old one, but the constants have changed. This resulted in a slightly better effect of stubble as a measure, especially in the lower erosion risk classes.
- The coefficient for **winter cereal with autumn ploughing** was changed from 1.2 to 1 because the necessary data to estimate area of winter cereal will not be available at the time when the regular annual calculations for the TEOTIL model are made. This means that on autumn ploughed area there will be no distinction between the effects of winter and spring cereal. The *possibility* to use the 1.2 coefficient is however retained in the model system.
- **Potatoes and vegetables** were removed from the winter cereal category (coefficient = 1.2) to separate categories. The coefficient was set to 2 for potatoes and 1.5 for vegetables, i.e. a more negative effect of both categories. The coefficient for potatoes was selected after screening international literature on the topic and analysing data from the Norwegian field scale monitoring site Bye (part of the JOVA programme; Bechmann et al. 2023). In the Bye

field the tillage has been autumn ploughing in all monitoring years, and the crop either spring cereal or potatoes. The data show that soil loss in potato years was approximately twice the soil loss in cereal years, i.e. a management coefficient of 2 for potatoes. The international studies most comparable to Norwegian climatic conditions were from Switzerland and Canada, and they showed similar results (Chow et al. 1990; Chow and Rees 1994; Prasuhn 2012). A coefficient for vegetables was difficult to derive from literature, and no data were available from Norway. It was therefore set to 1.5, assuming it to be intermediate between autumn ploughing for spring cereals and potatoes.

- **Fruit and berries** were moved from the autumn harrowing category to the grass ley category, based on information from the Agricultural advisory service (NLR, A.K. Heen, pers. comm.).
- **Catch crops** are originally considered to have the same effect as stubble, and this has not been changed in the new version. This applies to undersown catch crops. For catch crops sown after harvest of the main crop, it was chosen to use the same function as for autumn harrowing.
- **Fallow** was removed from the winter cereal category (coefficient = 1.2) to the autumn ploughing category (coefficient = 1), as a compromise since the registered data do not distinguish between physical and chemical fallow, the latter being less disruptive to the soil structure.
- The function for **grass ley** was not changed in the new version. However, while all of the ley area registered in the data sources used to be treated as grass covered area in autumn and winter, it was instead assumed that part of the ley area is ploughed in autumn. This part is therefore set to a fixed value of 10 %, under the assumption that ley is renewed every five years, and 50 % of the renewed ley area is ploughed in autumn, the remaining 50 % being not tilled, or tilled in spring. Consequently, 10 % of the ley area was moved to the autumn ploughing management category and removed from the grass ley category.

For the measures grass covered buffer zones and grassed water ways, there was no new information available, and the original equations in Agricat 2 were retained.

4.2.2 Adaptation to scale and introduction of new equations

The AGRITIL model calculates loads of soil particles and nutrients at the catchment scale. Thus, the sub-model for agricultural areas also needs to operate on this scale. The original Agricat 2 model calculates soil and P losses from individual erosion risk (soil map) polygons, and the results have been summed up to catchment or other relevant scale. The main focus has been on showing the relative differences between effects of different measures, and there has been less emphasis on the actual magnitude of the soil and P losses. In later years the model has been used more frequently to estimate the contribution from agriculture to total soil and P loads to recipients. This is also what the model will be used for in the TEOTIL system, so the results need to show a decent fit at the small catchment scale. This has previously been solved in various ways. In general, the summed-up soil loss from the erosion risk map polygons have been considered representative of the catchment soil loss to the first order stream. In some cases, calibration factors have been introduced after calibrating the model on catchment monitoring data. Moreover, when the revised erosion risk map was published in 2020/2021 (Kværnø et al. 2020), means of calculating soil loss from the non-quantitative gully erosion map were developed to supplement the quantitative data from the sheet/rill erosion map. However, the methods used have not been consistent.

For adaptation of Agricat 2 to the TEOTIL model, an approach was developed that builds on and combines previous approaches. This was done by an iterative calibration process which made the model results obtain the best fit to the measured data from JOVA catchments.

The calibration data were high-quality catchment scale measured data from the JOVA monitoring program (chapter 2). The challenge with catchment scale water quality data is to determine the contribution of different sources and processes to the total loads at stream outlet. With respect to soil loss, the main processes are sheet, rill and gully erosion (erosion in depressions in which concentrated runoff occurs), soil loss through sub-surface drainage pipes and stream bank erosion. Damaged hydrotechnical structures also contribute considerably to erosion, as concluded from e.g. field observations in river Leira's catchment (Borch et al., 2009) and in Rakkestad, Eidsberg and Trøgstad municipalities (Hauge and Borch, 2012;2013; Hauge, 2014). In most of the JOVA catchments, agriculture is the dominating land use and considered to contribute to a large part of the measured soil loss, but areas with other land use probably contribute as well.

The calibration was carried out using mean values for the monitoring period, since the erosion risk map represents a long-term average erosion risk and not annual erosion risk.

The only source of national scale quantitative estimates for soil loss from agricultural areas, is the so called "sheet erosion risk map" from NIBIO (Kværnø et al., 2020). This map includes sheet and rill erosion and soil loss through the drainage system. The sheet and rill erosion has been calculated by the semi-process-based erosion model PESERA (Kirkby et al., 2008), which has been adapted to Norwegian conditions and calibrated on Norwegian plot and field scale data (six sites in East and Southeast Norway, with straight slopes and no gully erosion). Soil loss through the drainage pipes has been calculated by an empirical equation developed on Norwegian plot and field scale data (13 sites in East, Southeast, West and Mid Norway).

The quantitative data from the sheet erosion map were initially assumed to provide reliable estimates for sheet and rill erosion and soil loss through the drainage pipes. The data from the map applies to a standard condition of autumn ploughing and spring cereal, and the Agricat 2 model was used to calculate the soil loss resulting from the average crop and tillage distribution for the monitoring period.

The soil loss at actual management was subtracted from the soil loss measured at the catchment outlet. The remaining soil loss was assumed to originate from other erosion processes in the agricultural fields (gully erosion etc.) and other sources (erosion on other land use, stream bank erosion). Sedimentation of soil particles was not explicitly estimated, but is partially accounted for in the soil map, and partially through the model calibration.

To obtain a more complete estimate of total soil loss from the agricultural areas, a quantitative model for gully erosion had to be developed. This was a challenge, as quantitative data for gully erosion are scarce both in Norway and in other countries. A review by Poesen et al. (2003) reported that gully erosion constituted between 10 and 60 % of total soil SS from various sites in northern Europe. Recently, there has been carried out a survey of gully formation by remote sensing and manual measurements in the Skuterud catchment in the years 2018/2019 to 2020/2021 (Barneveld et al. 2022). In this study the annual gully erosion was measured to 5, 11 and 67 kg/daa. Before that, manual measurements have been carried out in the Skuterud and Mørdre catchments in the period 1995 – 2004 (Øygarden et al. 2003), but those data do not always distinguish between gully erosion and rill erosion. Some of the Norwegian field scale experimental sites do have gullies and occasional gully erosion, but the amount of soil loss caused by gully erosion has not been separated from sheet and rill erosion. In a small catchment in the Romerike area, with autumn ploughed, artificially leveled clay soil, monitoring of runoff and soil loss showed that after implementing measures in the gully (no tillage in the depression and installment of a manhole), the soil loss was on average about 50 % lower than the period before measures were implemented (Lundekvam, 1997; 2001). This could indicate that gully erosion contributed to up to 50 % of total soil loss. All of this information was used as a benchmark in the model development. The model was designed to take into account relevant factors that would result in differences between different catchments, and for which input data were readily available, most notably the "gully erosion risk map" from NIBIO (Kværnø et al. 2020).

It is important to note that estimated rill/sheet erosion and gully erosion should not be viewed as entirely separate entities in this model system, even though they are calculated by separate models based on differing input data. The sheet/rill erosion map provides continuous values for soil loss in kg/daa, while the gully erosion map only provides the location for gully erosion risk. Certain threshold values for runoff and topography have been used to determine where a straight slope ends in the sheet/rill erosion risk map and turns into a gully in the gully erosion risk map. The threshold values are uncertain and probably not equally representative for all conditions. Also, the microtopography, which can play an important role in distributing overland flow into smaller rills or larger gullies, is not accounted for since the maps are based on a 10x10 m DEM. Therefore, the sheet/rill map can be considered to represent a "basic" or "minimum" average sheet and rill erosion risk, while the gully map can possibly be considered to represent both gully erosion *and/or* rill erosion not accounted for in the sheet/rill map.

To be able to calibrate the soil loss models for agricultural land on the JOVA monitoring data, soil loss from other land use and stream bank erosion also had to be estimated and subtracted from the total particle loss measured at the catchment outlet. Reliable quantitative data for soil loss from these sources are sparse. The contribution from other sources to total soil loss was therefore not explicitly calculated. It was merely assumed, based on the total amount of available information (field observations and measurements) that other sources (mainly stream bank erosion) contribute significantly to soil loss in the Mørdre, Hotran and Naurstad catchments After careful consideration it was decided to calibrate the soil loss model on 70 % of the measured soil loss for Mørdre and Hotran, and 100 % for the other catchments (Naurstad was excluded from calibration). For Mørdre, the high proportion of soil loss attributed to other sources is supported, by monitoring data from a field scale subcatchment, Vandsemb, with more or less the same soil and terrain as the main catchment (flat silt plain and a sloping artificially levelled clay soil ravine). The measured soil loss here is considerably lower than at the outlet of the catchment. Also, in the main catchment, severe erosion (gully erosion and landslides) has been observed on pasture areas along the stream. In the forested parts of the ravines along the stream severe streambank erosion has been observed. The relative discrepancy between measured soil loss and soil loss derived from the erosion risk maps and preliminary gully erosion model, was approximately the same for Hotran and for Mørdre.

The final calibration resulted in the introduction of two calibration factors (multipliers) to be used for both sheet/rill and rill/gully erosion: A climate factor and a soil/landscape factor. The climate factor was set to 0.8 for catchments with more than 1000 mm precipitation, to reduce overestimation of soil loss in areas with precipitation higher than the models' applicability. This was justified by a hypothesis that the model behind the erosion risk map, PESERA, tends to underestimate the effect of subsurface drainage systems in the wet climates along the coast, thus overestimating surface runoff and erosion. This factor could possibly be a function of precipitation, but the number of calibration sites was too low to determine a function. The soil/landscape factor was set to 1.7 in REGINE units with >10 % of the agricultural land being artificially levelled, and 1.1 in other catchments. While artificial levelling is already included in the erosion risk maps, by means of soil properties and topography, there are other aspects that the maps do not cover, that are directly and indirectly linked to the artificial levelling. For one, hydrotechnical structures in areas with artificial levelling are today often in poor condition, and severe erosion can be observed around such structures. Secondly, artificial levelling is to a large degree carried out in areas with landscape (ravines) and soils (marine clay) that are prone to stream bank erosion, a process which is aggravated by agriculture. This is also evident from a map of ravines and land slide features, supplied by NGU (NGU, K. Mølmann, pers. comm.), corresponding with the degree of artificial levelling.

Figure 4.1 shows the correlation between soil loss calculated by the final model and measured soil loss. A good fit is expected since these are the data the calibration was carried out on. However, since the calibrated factors need to be "universal" and applicable to ungauged areas, a perfect fit was not possible to obtain. Hence, soil loss for Skas-Heigre was somewhat overestimated by the final model, and slightly underestimated for several other catchments.

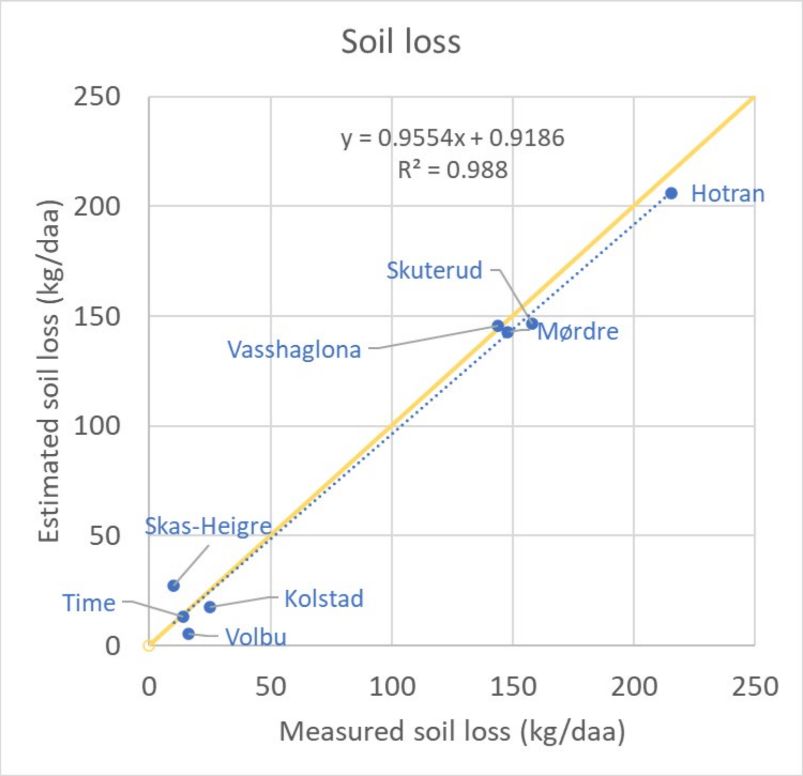

Figure 4.1. Measured and estimated soil loss for JOVA catchments, after calibration of the soil model. The "measured" soil losses from Mørdre and Hotran have been reduced by 30 % prior to calibration, to account for other sources of soil loss.

4.2.3 Annual and risk estimation of losses

The original Agricat 2 model is a "risk" model focused on effects of measures, i.e. it does not take into account annual variation in weather and runoff conditions, only variation in management. The same was the case with the model calculating P losses from agriculture in the previous versions of the TEOTIL model. In the new version of TEOTIL, it was desired to estimate actual annual losses.

To run the model in annual mode, a method to convert the long-term average erosion risk into annual values was developed. This was challenging due to the episodic, sometimes apparently "random" or "catastrophic", nature of erosion and the otherwise complex processes involved. In Norway, snow and frost are important factors, but the effects of these factors are particularly difficult to predict. Furthermore, the timing of the runoff events in relation to agricultural management may be of high importance for the measured soil loss (Øygarden 2000).

Initially, the correlations between measured annual soil losses and runoff in the individual JOVA catchments were analysed. The correlations were significant, but rather poor in most catchments. Numerous additional weather and runoff related variables were introduced in the analysis to see if any of these would improve the model. The new variables included different aggregation levels (annual, seasonal, monthly) for runoff, precipitation and air temperature and derived factors like freezing index, freeze/thaw cycles during winter, number of days with precipitation exceeding certain thresholds, erosivity index, etc. Stepwise multiple linear regression was used as a method, as well as more expert-based screening of the data. The conclusion was that there was limited benefit from introducing these variables. The fit would improve for some catchments, but no universal equation was found. The regression analysis indicated significant influence of different variables in different catchments, or sometimes the same or similar variables were significant, but with opposite effects.

Due to the discrepancies in effect of the different variables, it was decided to implement a simple approach: The relative runoff factor, i.e. multiplying the soil loss with the runoff for a specific year and divide by the mean runoff for a specified period corresponding with the period for which the erosion risk map applies for. Annual runoff per REGINE unit was supplied by NIVA, who calculates these values from data provided by NVE. Such data were available for the period 1990-2020, while the erosion risk map applies to the period 1980-2010. The mean runoff was therefore calculated from the data for the period 1990-2010, as a compromise.

4.2.4 Background soil loss

Calculation of background soil loss was done by back-calculating from background particulate P loss (section 5.2.3).

4.3 Model equations for soil loss

Total soil loss is the sum of soil loss originating from sheet/rill and gully erosion and soil loss through the drainage system. It covers the sum of background soil loss and anthropogenic soil loss.

4.3.1 Sheet and rill erosion

The sheet/rill erosion map provides amount of soil loss caused by surface runoff (*SSapl_sr*) and soil loss through the drainage system (*SSapl_d*), considering autumn ploughing with a spring cereal crop. To take into account actual crops, tillage and weather/runoff conditions, *SSapl_sr* and *SSapl_d* are multiplied with the management (crop + tillage) factors, *CTact_sr* and *CTact_d,* respectively, two runoff factors (*QF1 and QF2*) and a soil factor (SF):

$$SSact\_sr\ (kg/daa) = SSapl\_sr \times QF1 \times QF2 \times SF \times CTact\_sr \qquad (eq.\ 4.1)$$

$$SSact\_d\ (kg/daa) = Ssapl\_d \times QF1 \times QF2 \times SF \times Ctact\_d \qquad (eq.\ 4.2)$$

QF1 is calculated from the relevant year's total runoff (*Qann*) and the mean total runoff (*Qmean*):

$$QF1\ (-) = Qann/Qmean \qquad (eq.\ 4.3)$$

Qann, based on NVE data, is provided annually by NIVA. *Qmean* is the mean of *Qann* for the years 1990-2010.

QF2 is a calibration factor = 0.8 for areas with precipitation >1000 mm, otherwise the value is 1.

SF is a soil/landscape factor = 1.7 for REGINE units with >10 % artificially levelled soil, otherwise the value is 1.1.

The management factors *CTact_sr (*for sheet/rill erosion) and *CTact_d* (for soil loss through the drainage system) are soil loss ratios derived from experimental data mainly from Nordic countries, with some additional information from North American and European studies. For some management categories constant coefficients for *CTact* are used, while for other management categories *CTact* is calculated as a function of erosion risk:

$$CTact\_sr\ (-) = a \times SSapl\_sr^{b} \qquad (eq.\ 4.4)$$

$$CTact\_d\ (-) = 1.67 \times a \times SSapl\_d^{b} \qquad (eq.\ 4.5)$$

The coefficients a and b in these equations depend on the management category. The management categories and coefficients a and b are shown in table 4.1.

Tabell 4.1. Model management categories with their respective crops, tillage and measures, and coefficients a and b in the equation for management factors (eq. 4.4. and 4.5).

Management category	Crops	Measures	a	b
Ley	Grass ley, permanent grass, fruit, berries, flowers.	Grass ley	1.2294	-0.548
Stubble	Spring cereal, oil seed winter cereal, legumes, fodder crops, seed production.	No tillage in autumn, direct drilled winter crops, undersown catch crops.	1.0456	-0.349
Autumn harrowing	Spring cereal, oil seed, winter cereal, legumes, fodder crops, seed production, vegetables, potatoes.	Autumn harrowing, catch crops sown after harvest of main crop.	2.3561	-0.264
Autumn ploughing	Spring cereal, oil seed, legumes, fodder crops, seed production., fallow, grass ley.	-	1	0
Winter cereal	Winter cereal.	-	1 (1.2)	0
Vegetables	Vegetables.	-	1.5	0
Potatoes	Potatoes.	-	2	0

4.3.2 Rill and gully erosion

The gully erosion map shows lines with expected long term average risk of gully erosion, but with no quantitative values linked to it. Also, as mentioned earlier, this map may also show areas where, under certain conditions, rills may form instead of gullies.

The equation calculates rill + gully erosion on autumn ploughed area (*SSapl_rg*) from the total length of gully lines (*Lapl_g*) in soil map polygons with a slope degree exceeding 2 % and the erodibility factor *K*, calculated from the EROD input factor to PESERA (available from the NIBIO soil map database):

$$SSapl\_rg\ (kg/daa) = (Lapl\_g \times 0.3 \times 1300 \times K^2)/Atot \qquad (eq.\ 4.6)$$

$$K\ (-) = (EROD - 2.5685)/3.9063 \qquad (eq.\ 4.7)$$

K is restricted to values in the range 0.01 to 1. *Atot* is the total area of agricultural land in the catchment and is included when the result is presented in kg/daa. The factor 1300 represents the bulk density of topsoil, while 0.3 is a factor calibrated on the JOVA data.

The long term average rill + gully erosion on autumn tilled area is converted to rill + gully erosion for actual management and actual runoff, by multiplying *SSgw_rg* (eq. 4.10 in section 4.3.3*),* which equals *SSapl_rg* (eq. 4.6) corrected for the presence of grassed water ways, with a catchment mean management factor, *CTact_rg,* the runoff factors *QF1 and QF2* and the soil/landscape factor *SF*:

$$SSact\_rg\ (kg/daa) = SSgw\_rg \times QF1 \times QF2 \times SF \times CTact\_rg \qquad (eq.\ 4.8)$$

$$\begin{aligned} CTact\_rg\ (-) = {} & APley \times CTley\_rg + APstu \times CTstu\_rg + APapl \times CTapl\_rg \\ & + APveg \times CTveg\_rg + APpot \times CTpot\_rg \qquad (eq.\ 4.9) \end{aligned}$$

where *AP* is proportion of each management category to the total agricultural area, and the coefficients are the individual managment category factors: *CTley_rg* = 0.05 for grass, *CTstu_rg* = 0.2 for stubble, *CTapl_rg* = 1 for autumn ploughing and autumn harrowing, *CTveg_rg* = 1.5 for vegetables, and *CTpot_rg* = 2 for potatoes.

4.3.3 Grassed water ways

Grassed water ways will limit erosion in the gullies. This is implemented in the model by introducing the length of grassed water ways (Lgw) from the eStil/RMP line feature map to equation 4.6, subtracting it from the total length of gully lines:

$$SSgw\_rg\ (kg/daa) = ((Lapl\_g - 0.95 \times Lgw) \times 0.25 \times 1300 \times K^2)/Atot \qquad (eq.\ 4.10)$$

The additional effect of grassed water ways to retain particles from the surrounding areas (contributing area to the gullies), is described in the section 4.3.4.

4.3.4 Grass covered buffer zones

The surface soil loss (*SSact_sr* and *SSgw_rg*) are affected by retention in buffer zones. Soil loss through the drainage system (*SSact_d*) bypasses underneath the buffer zones. The retention in buffer zones, including both riparian edge of field buffer zones (grasdekt kantsone i åker), buffer strips on slopes (grasstripe i åker) and grassed water ways in gullies (grasdekt vannvei i åker), is calculated as a function of the width of the buffer zone (*Wbz*):

$$RETbz\ (-) = (eksp(0{,}28 + 4{,}49 \times \ln(Wbz) - 1{,}65 \times \ln(Wbz)^2 + 0{,}2 \times \ln(Wbz)^3))/100 \qquad (eq.\ 4.11)$$

A width of 8 m is used, representing a 6 m wide grass covered buffer zone plus a 2 m wide mandatory zone of natural bank vegetation. For simplicity, this width is used also for grassed water ways and grass strips on slopes. The effect of the buffer zone is calculated for the proportion of each erosion risk class assumed to be affected by the buffer zone (explained in section 7.15).

The soil loss from the soil surface after retention in a buffer zone (*RETbz* > 0) or no retention in a buffer zone (*RETbz* = 0) is calculated separately for sheet/rill erosion (*SSbz_sr*) and rill/gully erosion (*SSbz_rg*), and summed up to represent total soil loss from the surface, *SSact_s*:

$$SSbz\_sr\ (kg/daa) = SSact\_sr \times (1 - RETbz) \qquad (eq.\ 4.12)$$

$$SSbz\_rg\ (kg/daa) = SSact\_rg \times (1 - RETbz) \qquad (eq.\ 4.13)$$

$$SSact\_s\ (kg/daa) = SSbz\_sr + SSbz\_rg \qquad (eq.\ 4.14)$$

Here, *SSact_sr* is the soil loss caused by sheet/rill erosion (eq. 4.1) and *SSact_rg* is the soil loss caused by rill/gully erosion (eq. 4.8).

The buffer zones only affect the soil loss from the area of the “influence zone”. From areas outside of this influence zone, all particle loss enters open water courses, under the assumption that eroded particles enter e.g. manholes in fields or close to the fields (e.g. in road ditches) *before* obstacles due to terrain and land use are encountered.

Apart from the 2 m mandatory zone, zones of natural riparian vegetation are not taken into account. However, the calibration on catchment scale corrects for the effect of natural buffer zones.

4.3.5 Total soil loss

The total soil loss (*SSact_tot*) for the given management and including effect of grassed buffer zones and grassed water ways is calculated as the sum of soil loss from the surface (*SSact_s, eq. 4.12*) and soil loss through the drainage system (*SSact_d, eq. 4.2*):

$$SSact\_tot\ (kg/daa) = SSact\_s + SSact\_d \qquad (eq.\ 4.13)$$

4.3.6 Soil loss from pasture

Soil loss from pasture is calculated in the same way as already explained for sheet, rill and gully erosion, but with 100 % grass cover on all of the pasture area and no impact of buffer zones.

4.3.7 Background soil loss

Background losses refer to the part of the soil and nutrient losses that would have occurred from the agricultural areas had they not been cultivated but rather under natural vegetation. Due to limited empirical data on background soil losses, it was decided to back calculate it from the calculated background loss of particle bound P (section 5.5), assuming a low value for total P (0.0005 ‰) in the soil:

$$SSback\ (kg/daa) = eksp((ln((PPback/0.0005)/0.75) + 0.27 \times ln(10) - 2.48)/(1 - 0.27)) \qquad (eq.\ 4.14)$$

If SSback exceeds 0,5 x *SSact_tot*, where *SSact_tot* (eq. 4.13) is the total soil loss under anthropogenic influence, i.e. agriculture, then SSback is set equal to 0.5 x *SSact_tot* to avoid that the background losses are higher than the antropogenic losses.

4.4 Modelling results on national scale

The model was run in both risk and annual mode for the years 2013 to 2022. Figure 4.2 shows the result of the risk mode calculation for 2021 for all river basin sub districts (vannområder) in Norway. Annual soil loss per unit area of agricultural land varied between nearly zero and approximately 300 kg/daa/yr for the sub districts. However, the variation when using REGINE units (not shown) was higher, with soil losses up to about 1300 kg/daa/yr. The highest losses were calculated for areas dominated by cereal and/or potatoes or vegetable production, and erosion prone soils developed on marine deposits, in Southeast Norway (Akershus, Østfold, Vestfold, Telemark, Buskerud) and Trøndelag. The lowest soil losses were calculated in areas with low precipitation, dominated by grass production, and/or with less erosion prone soils, i.e. in the northern parts of Innlandet and southeastern part of Trøndelag, and in Finnmark. Intermediate soil losses were calculated in wetter areas with grass production and in drier areas with cereal/potato/vegetable production.

When summing up the soil loss for the river basin sub districts, the highest total loss of soil from agriculture (retention not taken into account) were calculated for more or less the same areas as mentioned above, but also for larger basins with lower soil loss per unit area of agricultural land. Subbasins with particularly high soil loss were:

- Skagerak: Glomma sør for Øyeren, Øyeren and Leira-Nitelva, Morsa, Glomma-Kongsvingerregionen, Mjøsa, Aulivassdraget, Numedalslågen and Midtre Telemark.
- The Norwegian Sea: Inn-Trøndelag, Gaulavassdraget and Nordre Fosen.

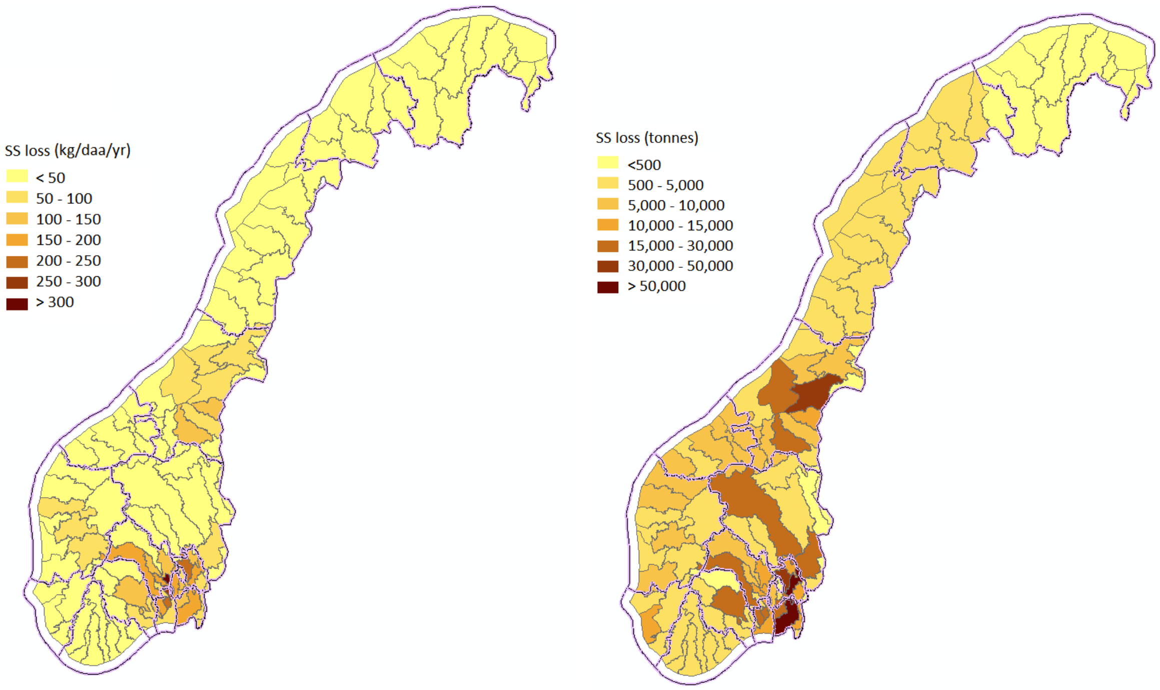

Figure 4.2. Estimated soil (SS) loss for all river basin sub districts in Norway, in tonnes (right) and g/daa agricultural land per year (left). Risk mode with long term average weather/runoff conditions with management from the year 2021.

5 Phosphorus loss

5.1 Overall model concept

The phosphorus (P) loss model constitutes one module for loss of particle bound P (PP), based on a modified version of the Agricat 2 model, and one module for loss of dissolved P (phosphate, PO_4-P). Both modules consist of empirical equations and coefficients based on measured data from national and international studies. The PP loss is calculated as P content in the soil multiplied with the soil loss and an enrichment factor taking into consideration higher P content on smaller soil particles. The PO_4-P loss is calculated by a regression equation taking into account the P content in the soil, soil loss and runoff. The effects of management (crops, tillage) and grass covered buffer zones are taken care of in calculations of the soil loss, while the effect of P content in the soil is calculated in the PP and PO_4-P models.

The input data to the models are soil loss from the soil loss model described in chapter 4, in addition to physical soil data (texture class) from NIBIO's soil map, soil phosphorus content derived from the farmer's soil samples data (NIBIO's soil analyses database "Jorddatabanken"), and runoff data from NVE, delivered by NIVA and adapted by NIBIO.

Calculations of P loss are carried out for each REGINE unit, subdivided on erosion risk classes for the calculations of PP loss caused by sheet/rill erosion and soil loss through drain pipes, and not subdivided on erosion risk classes for PP loss caused by gully erosion and PO_4-P loss. There is no spatial routing (connectivity) of sediments and PP across soil map units in the landscape. Retention in the agricultural landscape is included to the extent it is represented in the model calibration data and in the model's input data. Retention downstream the small agricultural catchment scale is calculated by NIVA in the TEOTIL model.

5.2 Model development and calibration

The Agricat 2 equation for PP loss has earlier been evaluated at plot and field scale (Kværnø m.fl. 2014). For the development of the new P model, the equations were reevaluated and calibrated for the catchment scale, using data from the JOVA monitoring program. The PO_4-P model was developed using JOVA data.

5.2.1 Adaptation of original PP equations

The original Agricat 2 PP model was changed to improve the fit between measured and estimated PP loss. The changes were decided during the calibration process (section 5.2.3).

The enrichment factor "EF" used in Agricat 2 (Kværnø et al. 2014), a function by Menzel (1980) was replaced by the function by Sharpley (1985), which seemed to give a slightly better fit for the JOVA catchments. The restriction on EF, which was previously set to a maximum value of 5, was also increased to 10 to allow for higher enrichment to improve the fit of the model with measured data.

Further, EF was modified by the introduction of two correction factors to account for influence of P status in the soil (increased enrichment with increased P-AL). The first factor was included to account for the observation that enrichment seems to increase with increasing P content in the soil. This was noted when running the Agricat 2 model for the JOVA catchments, results showing underprediction of PP for catchments with high P-AL values: Vasshaglona, Skas-Heigre and Time. Unfortunately, there were very limited data to be used in development of such a correction factor, so a simple split function, presented in section 5.3.2, was created based on the JOVA data.

A second factor was included in the P loss equation for rill/gully erosion, which reduces the enrichment factor by 50 % for rill/gully erosion. The assumption is that large-rill and gully erosion is more concentrated and thus enrichment is lower than for sheet and small-rill erosion. This is supported by studies showing that rill erosion is a less selective process than interrill erosion (Proffitt and Rose, 1991; Schiettecatte et al., 2008).

5.2.2 Development of a new model for PO_4-P loss

The PO_4-P model was developed by linear regression, resulting in two equations:

The equation for PO_4-P loss for mineral soil is a function of soil loss, runoff and P-AL. It was developed using measured data from areas with predominantly mineral soils, both JOVA catchments (table 2.1, section 2.1), smaller catchments/fields from the JOVA programme and field plots from other studies (mean values for the time series, a total of 21 observations) (table 2.2, section 2.2). The model is shown in section 5.3.3 (eq. 5.9). The goodness of fit for this model was $R^2_{adj} = 0.89$; RMSE = 8.98 and $p < 0.0001$. The correlations between the individual variables ln(SS), Q and P-AL, and the goodness of fit for the final model, are shown in figure 5.1.

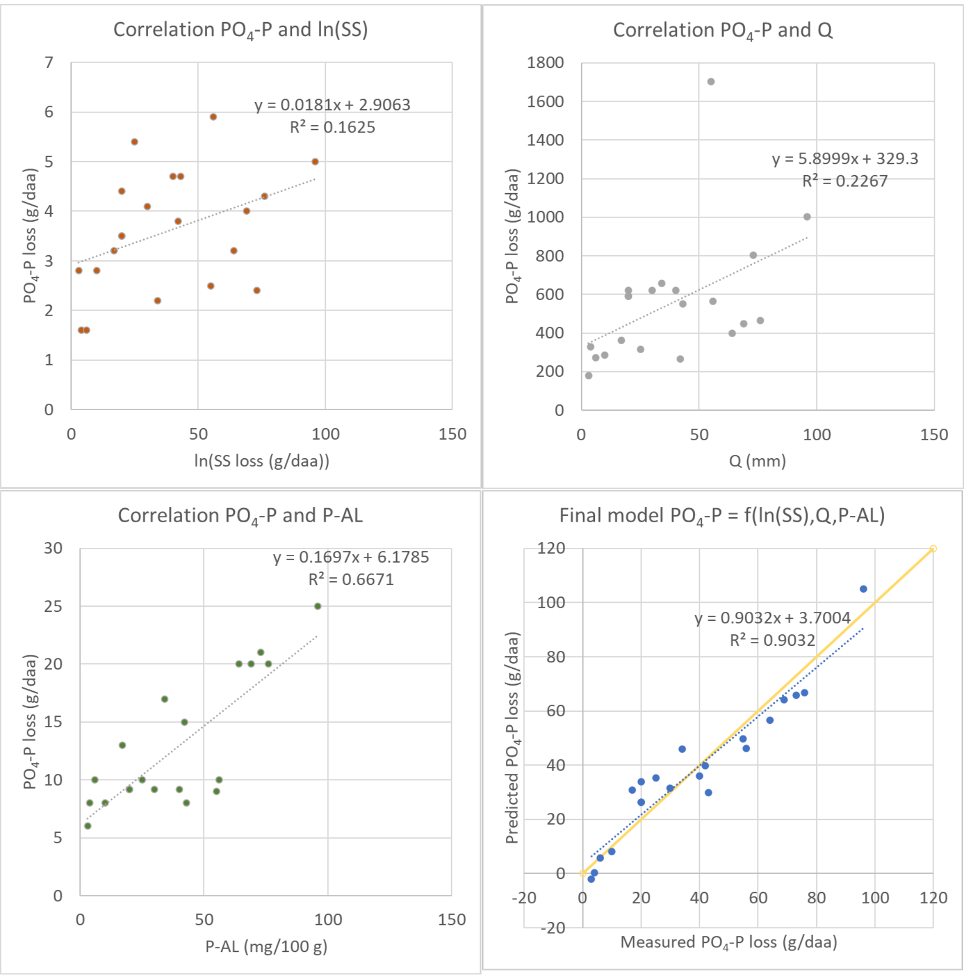

Figure 5.1. Correlations between PO_4-P loss and variables ln(SS), Q and P-AL (left and top right), and goodness of fit for the final regression model including all three variables (bottom right). For mineral soils.

The equation for PO_4-P loss for organic soil is PO_4-P concentration as a function of P-AL and converted to PO_4-P loss by including runoff in the equation (Figure 5.2). The model was based on data from the Naurstad catchment (table 2.1), Fureneset plot with deep organic soil (table 2.2; Sandvik et al. 1997) and two column lysimeters from Jæren, one with shallow organic soil and the other with deep organic soil (Sævarsson, 2014). The model is shown in section 5.3.3 (eq. 5.10).

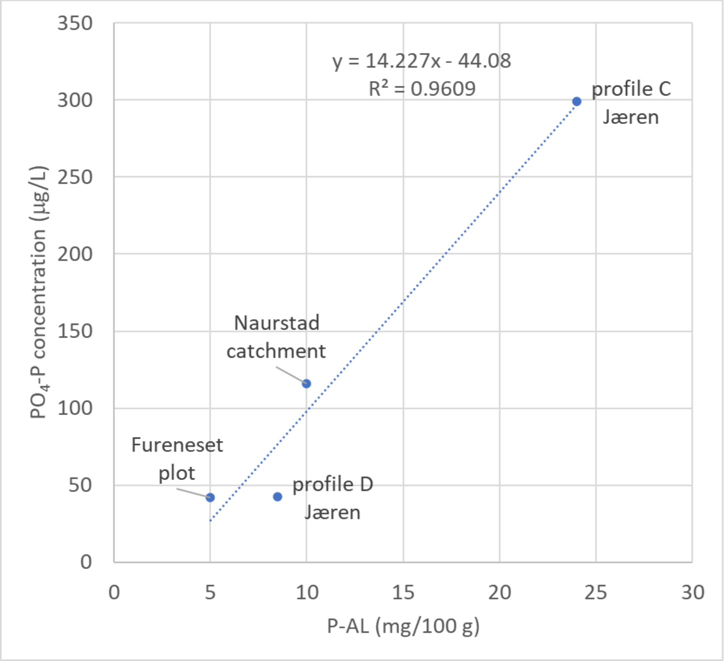

Figure 5.2. Regression model for PO_4-P concentration as a function of P-AL. For organic soils.

The estimated PO_4-P loss was restricted to a maximum of 200 g/daa, corresponding to the highest recorded PO_4-P loss available from monitoring data, i.e. from the last 20 years of monitoring in the Naurstad catchment (the earlier part of the time series is thought to be more affected by contribution to PO_4-P by wastewater). Another restriction, a maximum runoff of 1700 mm, was implemented to avoid extremes in areas with high runoff, as there was no information available on PO_4-P loss and concentrations in higher runoff ranges. The value was based on data from Fureneset (Sandvik et al., 1997). Although runoff data were available for the whole time series in Fureneset, and reaching a maximum of approximately 2500 mm, the PO_4-P loss data were only available as averages for the whole period. Thus, the average runoff of 1700 mm was used as a limit.

5.2.3 Calibration/validation

The calibration was carried out using mean values for the monitoring period, since the erosion risk map represents a long-term average erosion risk and not annual erosion risk.

First the soil loss model was calibrated until it provided satisfactory results (see section 4.2). The results from the soil loss model for the catchments were used to calculate the PP loss using the original Agricat 2 equations.

TP loss for the JOVA catchments was calculated as PP loss plus PO_4-P loss. The results were compared to the measured mean annual phosphate (PO_4-P) and PP loss. The "measured" PP loss was assumed to equal the measured TP loss minus the measured PO_4-P loss. The dissolved organic P (DOP) fraction is consequently included in the "measured" PP. While the measured soil loss in Mørdre and Hotran was reduced by 30% prior to calibration (see section 4.2.2), to account for other sources of soil loss, measured TP and PO_4-P was left unchanged since the P content of soil particles from other sources is generally low.

Figure 5.3 shows the correlation between the P fractions calculated with the final P model and the measured mean values for the JOVA catchments. The overall fit was fairly good, with $R^2 = 0.79$ for PO_4-P, 0.95 for PP and 0.96 for TP. The most prominent outlier was Skas-Heigre, for which the model considerably overestimated PO_4-P loss. The reason for this is unclear. The catchment has some special characteristics that could influence the PO_4-P concentrations, like regular use of water pumps to remove excess water from the fields, ponds etc. Skas-Heigre also showed the largest deviation for PP loss, which was caused by overestimated soil loss. Overestimation of the soil loss may be related to sedimentation of soil at the pumping station. The underestimation of PP and consequently TP in Mørdre and Hotran results from underestimated soil loss (calibrated to only 70 % of the measured soil loss in these catchments). It should be noted that the input data for management and P-AL in Skas-Heigre and Hotran are more uncertain than for the other catchments, as this information has not been collected to same level of detail as in the other catchments.

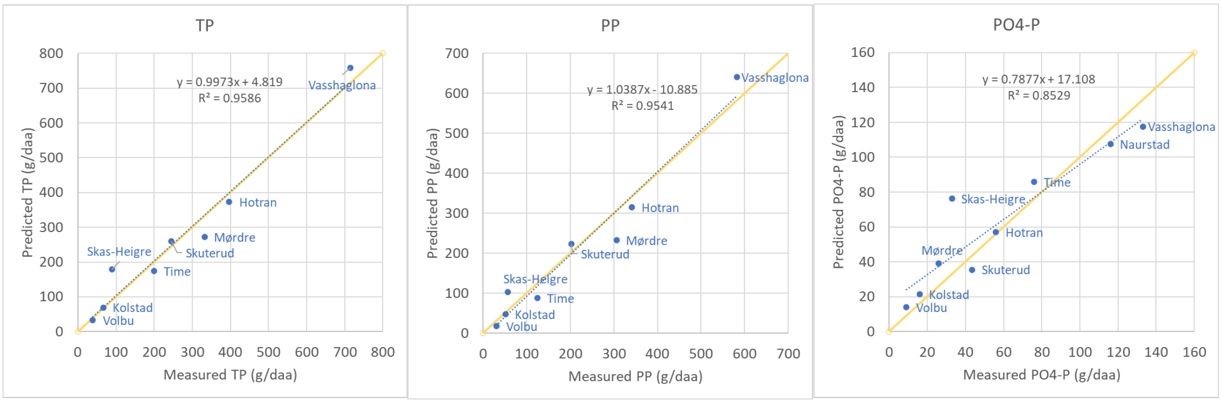

Figure 5.3. Measured and estimated TP, PP and PO_4-P loss for JOVA catchments, after calibration of the respective models. The yellow line is the 1:1 line.

5.2.4 Phosphorus background loss

Calculation of background P loss was based on runoff amount, coefficients representing a fixed P concentration, and type of geological superficial deposits. Marine clay deposits were assigned with a higher P concentration coefficient (25 mg/daa/mm runoff) than all other deposits (14 mg/daa/mm).

The background for this method is that higher background losses of P can be expected in marine clay areas because of a naturally higher phosphorus content than other deposits since they often contain phosphorus-rich apatite minerals. Erosion risk can also be considerable even under natural vegetation, especially where the sloping ravines have formed in the marine clay. There are few marine-clay-areas that have not been cultivated and therefore there are only a few measurements of phosphorus loss from natural areas with marine clay (Skarbøvik et al., 2013; Schneider and Skarbøvik, 2022). The value for marine deposits was adapted from Skarbøvik et al. (2013), in which this value represented a forested catchment (Dalen catchment in the Morsa river basin, Southeast Norway) with 25 % marine clay deposits. The runoff here had been measured to 440 mm and the TP loss 9 g/daa. This corresponds to 20 mg/daa/mm runoff, but to account for the proportion of clay deposits in the catchment, the value was increased to 25 mg/daa/mm.

The value for other deposits was based on an average value from other studies (Bloem et al., 2020; de Wit et al., 2020). On average for areas with forest and natural land, these studies reported that the phosphorus loss from forests and natural areas had been measured to on average 5-6 g/daa/year (Figure 5.4), varying from 0.02 to more than 14 g/daa/year. Studies in natural areas are often located in areas where it is not relevant to engage in agriculture, therefore the phosphorus loss from such areas cannot be directly used as a basis for assessing background runoff from agricultural areas. A mean value of 6 g/daa was chosen to represent the non-marine deposits, and it was recalculated to 14 mg/daa/mm runoff by using the runoff from the Dalen catchment (440 mm). A value of 6 g TP/daa is also used as a standard value when calculating the contribution from forest and natural land in the JOVA catchments (Bechmann et al. 2021).

It was further assumed that 70 % of the background P loss is particle bound and 30 % dissolved, based on the studies from Finland and Sweden (de Wit et al. 2020).

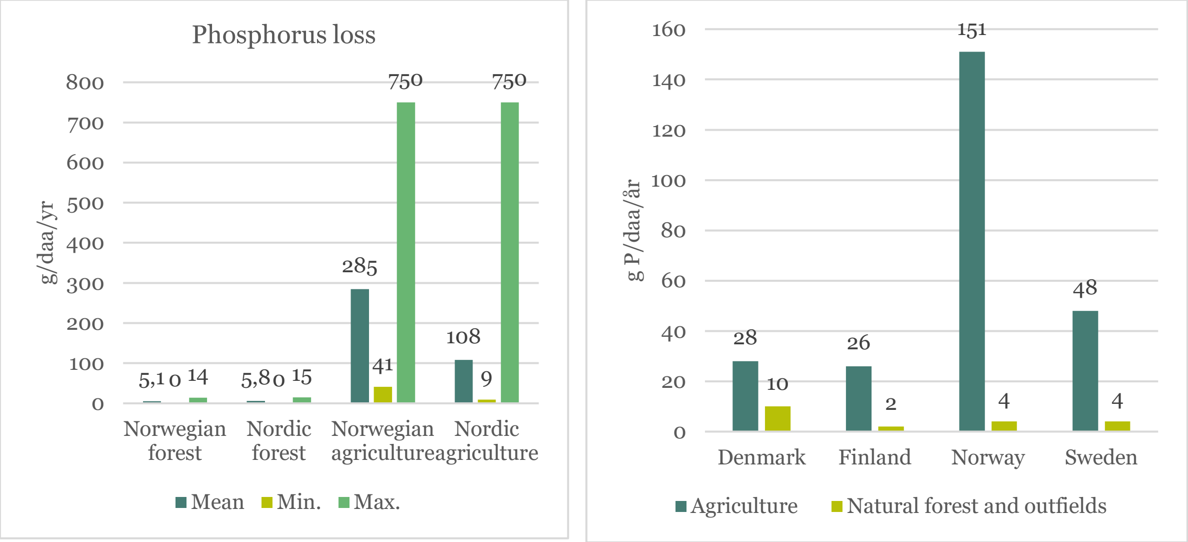

Figure 5.4. Loss of total phosphorus (g/daa/year) from Norwegian and Nordic forests and natural areas, as well as from agriculture (Bloem et al. 2020, left). Loss of phosphorus from forest/ natural catchments and agricultural catchments (De Wit et al. 2020, right).

5.3 Model equations for P loss

5.3.1 Loss of particle bound P

The PP loss caused by sheet/rill erosion and soil loss through the drainage system on one hand (PP_srd) and PP loss caused by gully erosion on the other hand (PP_rg), are calculated separately and then summed up to total PP loss, PP_tot:

$$PP\_srd\ (g/daa) = (SSbz\_sr + SSact\_d) \text{ x } Psoil \text{ x } EF\_srd \text{ x } 1000 \qquad (eq.\ 5.1)$$

$$PP\_rg\ (g/daa) = SSbz\_rg \text{ x } Psoil \text{ x } EF\_rg \text{ x } 1000 \qquad (eq.\ 5.2)$$

$$PP\_tot\ (g/daa) = PP\_srd + PP\_rg \qquad (eq.\ 5.3)$$

$Psoil$ is the mean soil total P content for the catchment, and is calculated as a function of P-AL and the texture class, by the general equation:

$$Psoil = P\text{-}AL \times (10^{c \times \log(P\text{-}AL) + d})/100000 \qquad (eq.\ 5.4)$$

The coefficients a and b are specific for three soil categories: 1) sand + silt, 2) loam and 3) clay (Table 5.1). For the REGINE units $Psoil$ was calculated as the weighted mean $Psoil$ considering the proportion of the three different texture categories.

Table 5.1. Soil texture specific coefficients c and d in the equation for calculating total P content in the soil (Psoil, eq. 5.5).

Soil texture class	c	d
Sand, loamy sand, silt	-0,6898	1,6264
Sandy loam, loam	-0,6298	1,6600
Silt loam, silty clay loam, clay, heavy clay	-0,7487	1,7967

The enrichment factors EF_srd and EF_rg are calculated by a function by Sharpley (1985), modified by the introduction of correction factors calibrated on JOVA data:

$$EF\_srd = EFK1 \text{ x } EKSP(2.48 - 0.27 \text{ x } \ln((SSbz\_sr + SSact\_d) \text{ x } 10)) \qquad (eq.\ 5.5)$$

$$EF\_rg = EFK1 \text{ x } EFK2 \text{ x } EKSP(2.48 - 0.27 \text{ x } \ln(SSbz\_rg \text{ x } 10)) \qquad (eq.\ 5.6)$$

Where *SSbz_sr* is the soil loss caused by sheet/rill erosion under actual management and considering grassed buffer zones, if present (eq. 4.12), *SSbz_rg* is the soil loss caused by rill/gully erosion under actual management and considering grassed buffer zones and grassed water ways, if present (eq. 4.13), and *SSact_d* is the soil loss through the drainage system under actual management (eq. 4.2).

EFK1 is a split function introduced to take into account that enrichment tends to increase with increasing P content in the soil:

$$EFK1 = 1 \text{ for } P\text{-}AL < 15$$

$$EFK1 = 0{,}2 \times P\text{-}AL - 2 \text{ for } P\text{-}AL >= 15 \text{ og } < 20 \qquad (eq.\ 5.7)$$

$$EFK1 = 2 \text{ for } P\text{-}AL > 20$$

EFK2, which results in lower P enrichment for rill + gully erosion than for sheet + rill erosion, is set to 0.5.

EF_srd and *EF_rg* are limited downwards to 1 and upwards to 10.

5.3.2 Loss of dissolved P

The total PO_4-P loss, PO_4-P_tot, is the sum of PO_4-P loss from mineral and organic soil:

$$PO_4\text{-}P\_tot\ (g/daa) = PO_4\text{-}P\_min + PO_4\text{-}P\_org \qquad (eq.\ 5.8)$$

The PO_4-P losses cover PO_4-P released from eroded soil particles, from the soil profile, from plant residues and from incidental loss from manure. Two empirical models for calculating the loss of PO_4-P were developed (see section 5.2.1).

For mineral soils, PO_4-P loss is calculated by:

$$PO_4\text{-}P\_min\ (g/daa) = -49.229 + 7.4695 \times \ln(SSact\_tot) + 0.0285 \times Q + 3.533 \times P\text{-}AL \qquad (eq.\ 5.9)$$

where *SSact_tot* (eq. 4.13) is the total annual soil loss (sheet, rill and gully erosion as affected by crops, tillage and buffer zones and grassed water ways, if present), Q is the total annual runoff in mm and P-AL is the phosphorus status of the soil in mg/100 g (mean values for the REGINE unit for Q and P-AL).

For organic soils, PO_4-P loss is calculated by:

$$PO_4\text{-}P\_org\ (g/daa) = (14.227 \times P\text{-}AL - 44.08) \times Q/1000 \qquad (eq.\ 5.10)$$

Both equations were restricted to a minimum of 1 g/daa and a maximum of 200 g/daa, and the input values for Q were restricted to 1700 mm.

5.3.3 Total P loss

The overall equation for calculating total P loss (TP_tot) is the sum of total loss of particle bound P (PP_tot) and dissolved P (PO_4-P_tot):

$$TP\_tot\ (g/daa) = PP\_tot + PO_4\text{-}P\_tot \qquad (eq.\ 5.11)$$

5.3.4 P loss from pasture

For pasture, the loss of PP and PO_4-P is calculated in the same way as for the rest of the agricultural area. Due to lack of soil mapping for pasture, it is assumed that pasture is located on mineral soils only, so the equation for organic soils is not used for pasture.

5.4 Background P loss

Background P loss, TP_back, is calculated by the equation:

$$TP\_back = PP\_back + PO_4\text{-}P\_back = 0.7 \times Pcoeff \times Q/1000 + 0.3 \times Pcoeff \times Q/1000 \quad \text{(eq. 5.12)}$$

The Pcoeff is set to 25 mg/daa/mm for marine clay deposits, and 14 mg/daa/mm for other geological deposits (see section 5.4). An area weighted mean Pcoeff is calculated from areas of marine and non-marine deposits (section 7.7).

The coefficients 0.7 and 0.3 takes into account that 70 % of the background P loss is assumed to be particle bound and 30 % dissolved. The results of the calculation are restricted so that TP_back does not exceed 0.5 x TP_tot.

5.5 Modeling results on national scale

The model was run in both risk and annual mode for the years 2013 to 2022. Figures 5.5 and 5.6 show the result of the risk mode calculation for 2021 for all river basin sub districts (vannområder) in Norway.

TP loss per unit area of agricultural land varied between 10 and almost 600 g/daa/yr for the sub districts (figure 5.5). The variation for REGINE units (not shown) was higher, with TP losses up to about 1300 g/daa/yr. The highest losses were calculated for areas dominated by cereal and/or potatoes or vegetable production, and erosion prone soils developed on marine deposits, in Southeast Norway (Akershus, Østfold, Vestfold, Telemark, Buskerud) and Trøndelag, and in areas with primarily grass production, but high precipitation and runoff and high livestock density (Vestland). The lowest TP losses were calculated in areas with low precipitation, dominated by grass production, and/or with less erosion prone soils, most notably along the Swedish border in Innlandet and Trøndelag and in Finnmark, but also Innlandet in general, nortwestern part of Telemark and most of Troms.

When summing up the TP loads for the river basin sub districts, the highest total loss of TP from agriculture (retention not taken into account) showed a pattern more or less resembling the pattern as described above. Subbasins with particularly high TP loads were:

- Skagerak: Glomma sør for Øyeren, Øyeren, Leira-Nitelva, Morsa, Mjøsa, Aulivassdraget and Numedalslågen.
- The North Sea: Jæren and Sunnfjord.
- The Norwegian Sea: Inn-Trøndelag, Gaulavassdraget and Nordre Fosen.

Figure 5.6 shows the estimated PO_4-P loss for the sub basins. The most important factors in the PO_4-P equation are runoff, organic soil and P-AL, hence calculated PO_4-P loss per unit area of agricultural land was highest in the coastal water basin sub districts in Agder, Rogaland, Vestland and Møre og Romsdal in particular, and also in Trøndelag and Nordland. Calculated PO_4-P loss is lowest in Finnmark, Troms and Innlandet. Summed up PO4-P loss in tonnes is particularly high in the sub-districts:

- Skagerak: Mjøsa and Glomma sør for Øyeren.
- The North Sea: Jæren, Haugaland, Sunnhordaland, Sunnfjord and Nordfjord.
- The Norwegian Sea: Inn-Trøndelag, Nordre Fosen and Romsdal.

Figure 5.7 shows the proportion of PO_4-P loss to TP loss. The lowest proportions of PO_4-P are calculated for the most erosion prone areas in Southeast Norway, Trøndelag and also eastern Finnmark. In these areas, PO_4-P loss constitutes less than 20 % of the TP losses, i.e. particulate P constitute more than 80 % of TP. In Innlandet and the rest of Southeast Norway and Trøndelag, PO_4-P loss typically constitute 20-40 % of the TP loss. The highest contribution of PO_4-P loss is seen in southern, western and northern Norway because of the already mentioned high runoff, P-AL and coverage of organic soil (Figure 5.7).

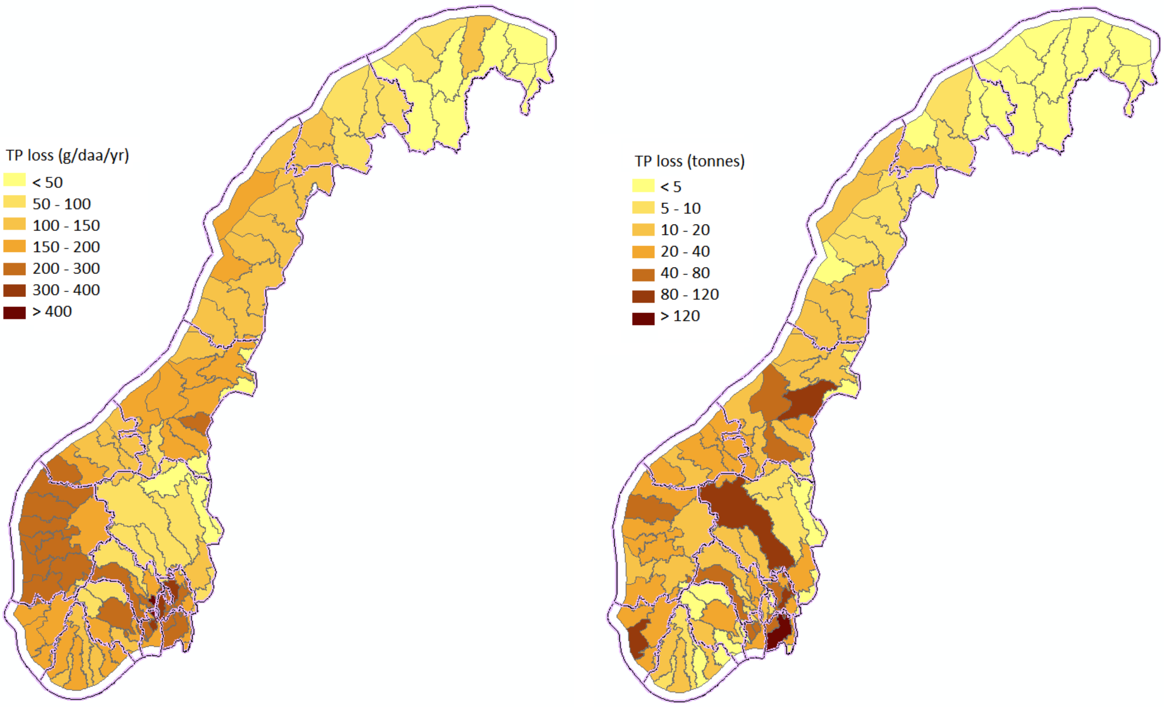

Figure 5.5. Estimated TP loss for all river basin sub districts in Norway, in tonnes and g/daa agricultural land per year. Long term average weather/runoff conditions with management from the year 2021.

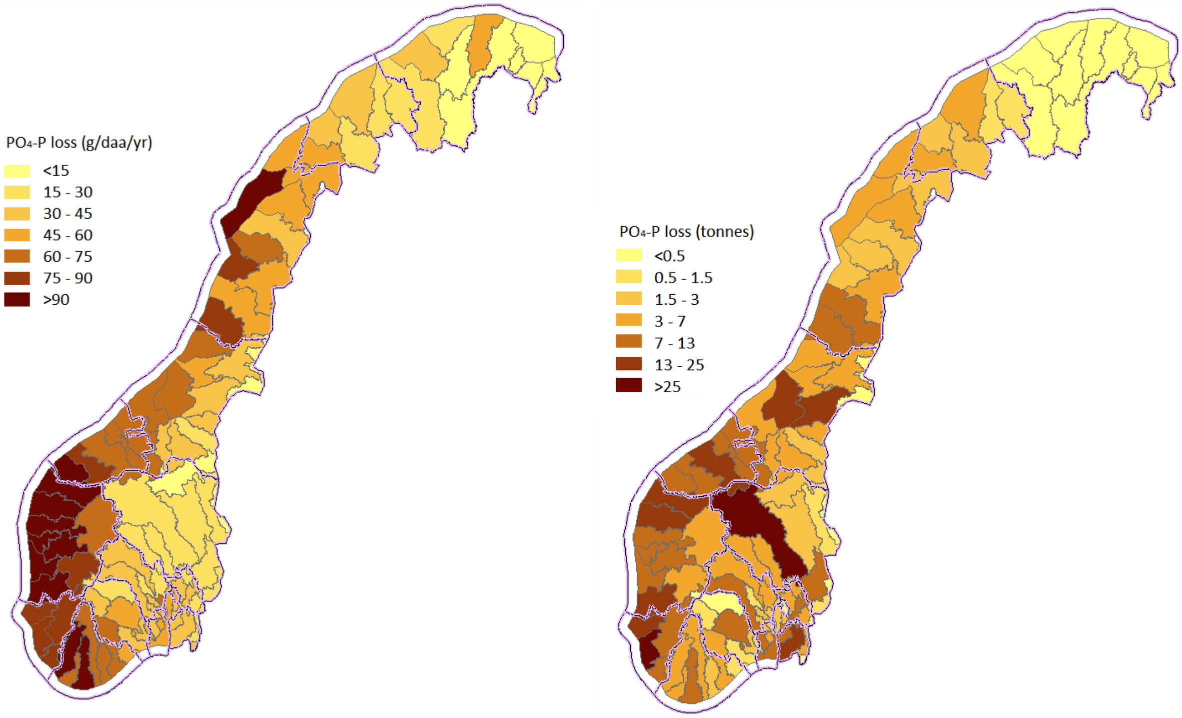

Figure 5.6. Estimated PO_4-P loss for all river basin sub districts in Norway, in tonnes and g/daa agricultural land per year. Long term average weather/runoff conditions with management from the year 2021.

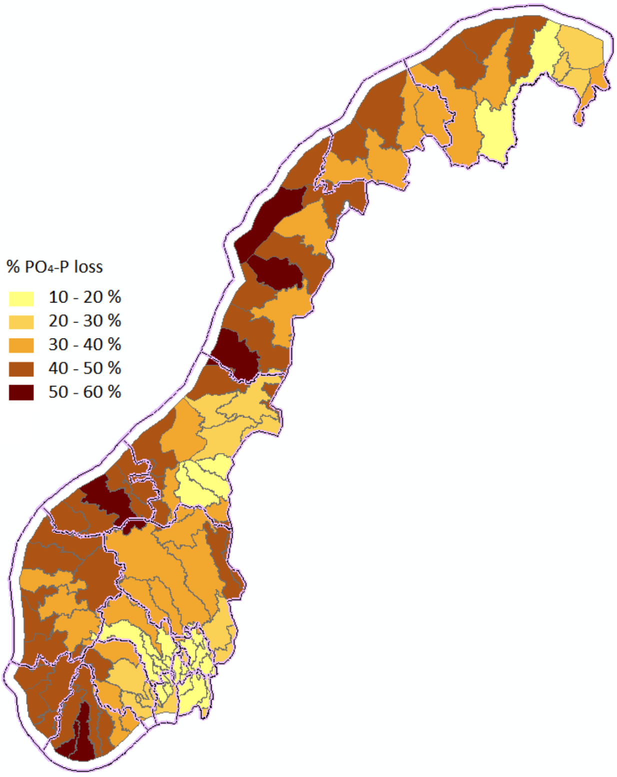

Figure 5.7. PO_4-P loss as a proportion (%) of TP loss, calculated for all river basin sub districts in Norway. Long term average weather/runoff conditions with management from the year 2021.

6 Carbon loss

6.1 Overall model concept

Loss of total organic carbon (TOC) from the agricultural area is calculated by a simple approach: Loss of particle bound OC (POC) is calculated from soil loss and organic carbon content in the soil (SOC), while loss of dissolved organic carbon (DOC) is calculated from SOC and runoff.

The input data to the model are soil loss from the soil loss model described in chapter 4, runoff data from NVE, provided by NIVA and adapted by NIBIO, and SOC derived from NIBIO's soil map database and Jorddatabanken (farmer's soil samples data).

Calculations of TOC loss are carried out for each REGINE unit, subdivided on erosion risk classes for the calculations of POC loss caused by sheet/rill erosion and soil loss through sub-surface drainage pipes, and not subdivided for POC loss caused by gully erosion and DOC loss. There is no spatial routing (connectivity) of sediments and POC across soil map units in the landscape. Retention in the agricultural landscape is included to the extent it is represented in the model calibration data and in the model's input data. Retention downstream the small agricultural catchment scale is calculated by NIVA in the TEOTIL model.

6.2 Model development and validation

The POC model was built in the same way as the PP model, assuming POC as a function of soil loss, SOC and an enrichment factor. The resulting equation is given in section 6.3.1. The model was briefly tested by comparing the results to measured mean annual loss on ignition (LOI) from the JOVA catchments (Table 6.1). The measured LOI was corrected for clay content using coefficients (Krogstad 2009). The results were in a reasonable range, but with large deviations for some catchments. It was not determined what the causes of the discrepancies could be, but some possible factors are: 1) contributions to POC from manure are not included; 2) the comparison was made between JOVA catchments (measured values) and REGINE unit (predicted values), which inevitably leads to differences. For example, the high value measured in Vasshaglona is probably due to both higher proportion of vegetables and potatoes, and thus higher erosion, than in the mainly grass covered REGINE unit; 3) not representative correction coefficients for LOI, considering we are dealing with sediments in water, and not soil. Maybe the underprediction in Skuterud and Hotran, the most clay rich catchment, could partly be explained by this. This needs to be investigated in further development of the model.

Table 6.1. Measured and model predicted POC loss from JOVA catchments.

Catchment	Measured POC loss	Predicted POC loss
Mørdre	2.9	2.7
Volbu	1.2	0.6
Kolstad	1.2	1.2
Time	2.1	3.3
Hotran	8.9	5.3
Vasshaglona	18.0	3.2
Skas-Heigre	2.3	3.1
Skuterud	5.5	3.5

The DOC model was based on very limited data, from a couple of studies in Finland (Mattsson et al. 2005; Manninen et al. 2018). The resulting model (section 6.3.2) was simply a set of three coefficients for DOC concentrations in water (mg/L), converted to DOC loss by including runoff (mm) in the equation. The coefficients varied between 10 and 20 mg/L. A few samples with measured data for DOC were available also from a Norwegian catchment that previously was part of the JOVA programme, the Grimestad catchment in Vestfold. The average measured concentration here was 11 mg/L (data downloaded from the Norwegian Environment Agency's Vannmiljø web application; Miljødirektoratet 2024), which is within the range of the selected coefficients.

The POC and DOC models require reevaluation and improvement in the future.

6.3 Model equations for carbon loss

6.3.1 Particle bound organic carbon (POC)

Loss of particle bound organic carbon, *POC_tot*, is calculated as the sum of OC loss caused by sheet/rill erosion and soil loss through the drainage system (*POC_srd*), and OC loss caused by rill/gully erosion (*POC_rg*). POC_srd and POC_rg are calculated from the soil loss (*SSbz_sr, SSact_d* and *SSbz_rg* in eq. 4.12, 4.2 and 4.13 respectively), the content of organic carbon in the soil (*SOC*) and an enrichment factor (*EFoc*) from Sharpley (1985):

$$POC\_tot\ (kg/daa) = POC\_srd + POC\_rg \qquad (eq.\ 6.1)$$

$$POC\_srd\ (kg/daa) = (SSbz\_sr + SSact\_d) \times SOC \times EFoc \qquad (eq.\ 6.2)$$

$$POC\_rg\ (kg/daa) = SSbz\_rg \times SOC \times EFK2 \times EFoc \qquad (eq.\ 6.3)$$

where

$$EFoc\ (-) = 8.943 \times (SScw \times 10)^{-0.317} \qquad (eq.\ 6.4)$$

EFoc is restricted to values in the range between 1 and 10. The effect of buffer zones and constructed wetlands is included in the calculation of the soil loss. Equations 6.2 and 6.3 are not corrected for potentially lower effect of buffer zones and wetlands on carbon loss than on soil loss.

EFK2 is a factor which results in lower OC enrichment for rill + gully erosion than for sheet + rill erosion and is set to 0.5.

SOC is available from the soil database behind the soil map (average per erosion risk class per REGINE unit), and for areas missing official soil map, from the Jorddatabanken database (average per REGINE unit).

6.3.2 Dissolved organic carbon (DOC)

DOC loss is calculated by coefficients for DOC concentrations (DOCcoeff) and runoff (Q):

$$DOCcoeff\ (mg/L) = 10 \text{ if } SOC < 3.5\ \%$$

$$DOCcoeff\ (mg/L) = 13 \text{ if } SOC \geq 3.5\ \% \text{ and } < 20\ \% \qquad (eq.\ 6.5)$$

$$DOCcoeff\ (mg/L) = 20 \text{ if } SOC \geq 20\ \%$$

The DOC loss is then calculated from the DOCcoeff and runoff (Q):

$$DOCact\ (kg/daa) = DOCcoeff \times Q / 1000 \qquad (eq.\ 6.6)$$

6.4 Modelling results on national scale

The model was run in both risk and annual mode for the years 2013 to 2022. Figure 6.1 shows the result of the risk mode calculation for 2021 for all river basin sub districts (vannområder) in Norway. Annual TOC loss per unit area of agricultural land varied between nearly zero and approximately 35 kg/daa/yr for the sub districts. The variation for REGINE units (not shown) was higher, with TOC losses up to about 120 kg/daa/yr. The highest TOC losses were calculated for areas dominated by high runoff, high soil organic carbon content and grass production, in southern and western Norway (Agder, Rogaland, Vestland). The lowest TOC losses were calculated in areas with lower runoff in Innlandet and Finnmark.

When summing up the TOC loss for the river basin sub districts, the highest TOC loss from agriculture (retention not taken into account) was calculated for more or less the same areas as mentioned above, but also for larger basins with lower TOC loss per unit area of agricultural land. Subbasins with particularly high TOC loss were (the four with the highest loss):

- Skagerak: Mjøsa and Glomma sør for Øyeren.
- The North Sea: Jæren.
- The Norwegian Sea: Inn-Trøndelag.

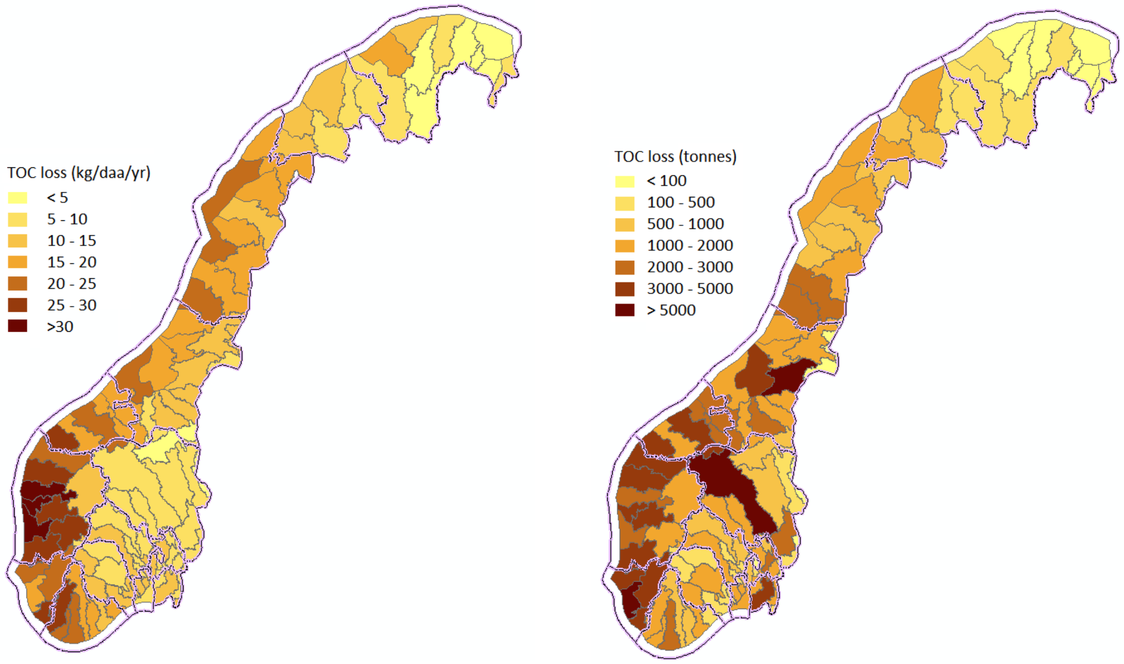

Figure 6.1. Estimated TOC loss for all river basin sub districts in Norway, in tonnes and kg/daa agricultural land per year. Long term average weather/runoff conditions with management from the year 2021.

7 Input data

7.1 REGINE units

Source:	Norwegian Water Resources and Energy Directorate (NVE) *REGINE*
Spatial scale:	REGINE units (1:50000)
Temporal scale:	Permanent
Application:	Nitrogen, phosphorus, carbon, soil particles

REGINE (REGIster over NEdbørfelt i Norge) is Norway's national catchment database. It is provided by the Norwegian Water Resources and Energy Directorate (NVE). A detailed description of REGINE can be found at NVE's website. The smallest of the REGINE units, as identified by their water system number ("vassdragNr") was used as spatial target scale for estimation of nutrient losses. REGINE is updated frequently but changes are mainly negligible. Therefore, a single version is used for past and future estimations of sediment and nutrient losses. The geodata of REGINE was downloaded on 7 March 2023 from geonorge.no.

7.2 Water runoff

Source:	Norwegian Water Resources and Energy Directorate (NVE) Norwegian Institute for Water Research (NIVA) *NVE Årsavrenning punkt*
Spatial scale:	REGINE units (1:50000)
Temporal scale:	Annual
Application:	Nitrogen, phosphorus, carbon, soil particles

Water runoff is crucial for estimation of sediment and nutrient losses. Data of water runoff in Norway are provided by NVE. For the REGINE units, long-term average runoff (1991 – 2020) is available. Additionally, daily flows at 1 km x 1 km grids are simulated with the daily rainfall-runoff model HBV. NIVA combines both datasets to generate annual runoff for the REGINE units. These data are provided to NIBIO for estimations of sediment and nutrient losses from agricultural area to surface waters. However, these data cover all areas including mountains with relatively low evapotranspiration and hence higher runoff compared to the agricultural low-lying areas. I addition, the agricultural areas, e.g. in western Norway, generally have higher temperature than an average area, mountains included. Furthermore, the proportion of agricultural area is small in most REGINE units and runoff also depends on land use. A comparison of annual runoff as measured for the JOVA catchments with annual runoff of spatially corresponding REGINE units showed distinct deviations (Figure 7.1). In most cases, the REGINE runoff estimates were higher than the monitored runoff. An overestimation of water runoff from agricultural area causes overestimation of nutrient losses. Therefore, REGINE runoff estimates were corrected to better represent runoff from agricultural area.

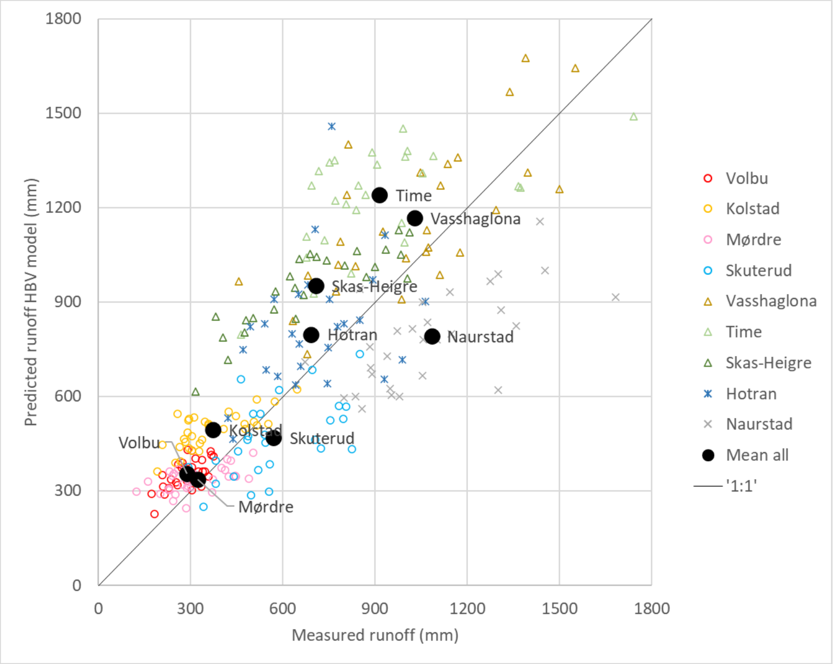

Figure 7.1. Plot showing measured runoff in JOVA catchments versus HBV modelled runoff estimated for the respective REGINE units by NIVA.

The REGINE unit runoff derived from the HBV model shows considerable deviation from measured runoff in the JOVA catchments. The reason for this can be that the HBV model has been calibrated on and parameterized for larger stream systems, often dominated by land uses like forest, mountains and even glaciers. Since the agricultural models in TEOTIL calculate nutrient losses to first order streams from agricultural areas alone, it was decided to attempt on adjusting the HBV runoff (Q_{hbv}) to fit better for these areas by multiplying with a runoff correction factor (Q_{agr}_corrf):

$$Q_{agr}\_corrf = Q_{agr}/Q_{hbv} \qquad (eq.\ 7.1)$$

Where Q_{agr} is runoff calculated for agricultural land by a simple water balance approach calibrated for the JOVA catchments. Long term (normal period 1991 – 2020) mean annual runoff for agricultural areas, Q_{agr}, was calculated as the difference between mean annual precipitation P_{agr} and mean annual actual evapotranspiration Ea_{agr}:

$$Q_{agr} = P_{agr} - Ea_{agr} \qquad (eq.\ 7.2)$$

Mean P_{agr} for the period 1991 – 2020 was derived from raster maps available from the Norwegian Meteorological Institute (see section 7.4), combined with polygons classified as agricultural land (area type 21, 22 – arable land, and 23 - pasture) in the land use map AR5 (section 7.6). Ea_{agr} was calculated as the sum of E_a in the growing season (Ea_{grow}) and E_a for the rest of the year, “offseason” (Ea_{off}):

$$Ea_{agr} = Ea_{grow} + Ea_{off} = Ep_{grow}\ x\ F_{cropclim} + Ep_{off}\ x\ F_{cropclim} \qquad (eq.\ 7.3)$$

Ep_{grow} and Ep_{off} represent potential evapotranspiration during the growing season and offseason, respectively.

Ep_{grow} was calculated from long term mean values for precipitation (P_{grow}) and “water balance” (WB_{grow}) in the growing season:

$$Ep_{grow} = P_{grow} - WB_{grow} \qquad (eq.\ 7.4)$$

Values for P_{grow} and WB_{grow} were derived from annual values (years 1991 to 2015, not available for later years) in a 1x1 km^2 grid in polygon map format (maps “vekstsesongens nedbør”, “vekstsesongens nedbør/fordamping”, see section 7.5). According to the documentation for these maps, WB_{grow} is calculated as $P_{grow} - Ep_{grow}$, thus the equation above yields Ep_{grow}. Ep_{grow} was calculated for all the grid cells for individual years, and afterwards the grid cell mean Ep_{grow} was calculated. From this the mean Ep_{grow} for agricultural land in each REGINE unit was calculated.

Futher, it was assumed that Ep_{grow} contributes to 90 % of total Ep for the whole year, and Ep_{off} to 10 % (pers. comm. H. Riley, NIBIO):

$$Ep_{off} = Ep_{grow}/0.9 - Ep_{grow} \qquad \text{(eq. 7.5)}$$

Both Ep_{grow} and Ep_{off} were restricted so that they would not exceed the precipitation in their respective periods: If $Ep_{grow} > P_{grow}$, then $Ep_{grow} = P_{grow}$, and if $Ep_{off} > P_{agr} - P_{grow}$, then $Ep_{off} = P_{agr} - P_{grow}$.

Ep was converted to Ea by multiplying with a factor $F_{cropclim}$. It was assumed that water availability would be sufficient offseason to maintain Ea_{off} equal to Ep_{off}, i.e. $F_{cropclim} = 1$. In the growing season, on the other hand, it was assumed that dry periods will occur so that on average $Ea_{grow} < Ep_{grow}$, and hence $F_{cropclim} < 1$. $F_{cropclim}$ was determined by crop distribution and precipitation excess in the growing season. The factors for each combination of crop and climate are shown in table 7.1. They were calculated from suggested factors provided by Riley (pers. comm.). The wetness of the growing season was defined as dry if $P_{grow} – Ep_{grow} < 50$ mm, wet if $P_{grow} – Ep_{grow} > 150$ mm, and otherwise medium, based on calibration on JOVA data.

Table 7.1. $F_{cropclim}$ for combinations of crops and climate.

Wetness in growing **season**	Grass	Potatoes, vegetables	Cereal, oilseed, etc.
Dry	0.73	0.53	0.53
Average	0.88	0.70	0.68
Wet	0.97	0.87	0.83

The calibration on JOVA data required that measured runoff be adjusted somehow to account for the influence of other land uses. In some catchments forest areas are significant, in others agriculture dominates. Good data for evapotranspiration from forests are missing, so it was simply assumed that forests and other land use would behave like grass, and Qagr for the forest was calculated as described above. Then the proportions of agriculture and other land use were used to recalculate the measured runoff to apply to agricultural areas only. This resulted in a slightly higher runoff from agricultural areas compared to the measured runoff, and slightly lower runoff from other land use.

Figure 7.2 shows the measured and predicted runoff for the JOVA catchments. Black circles represent the original Q_{hbv} and red circles are the new Q_{agr}. Naurstad and Skas-Heigre showed poor correlation with both the Q_{hbv} and Q_{agr}. The reason for this is not clear, and it was made no further attempt to try to match Q_{agr} to the the measured Q from these catchments. For the rest of the catchments, Q_{agr} generally fitted better to the measured Q than did Q_{hbv}, the only exception being for Mørdre. Figure 7.3 shows the uncorrected runoff in all REGINE units to the left, and the corrected runoff to the right.

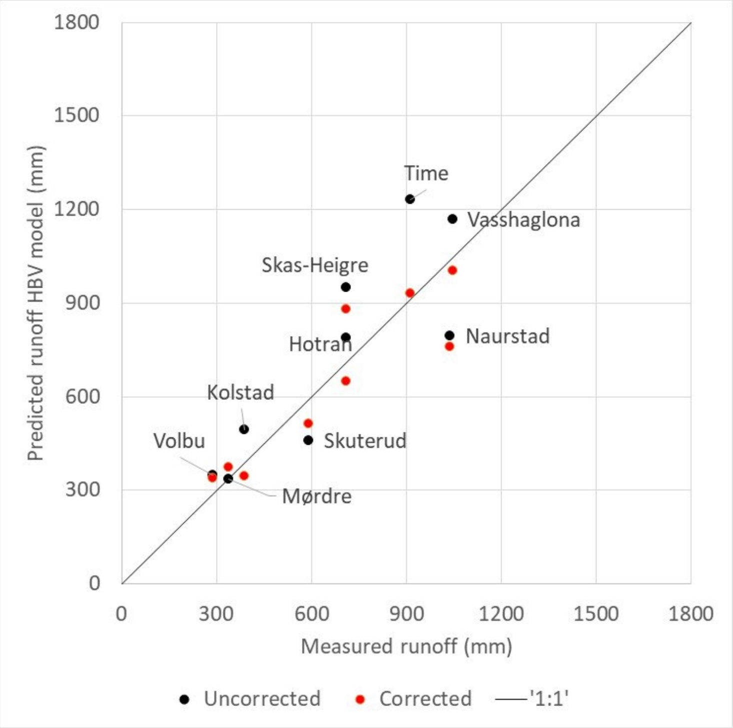

Figure 7.2. Predicted versus measured mean runoff for the JOVA catchments. The predicted values are for uncorrected (black) and corrected (red) HBV estimates.

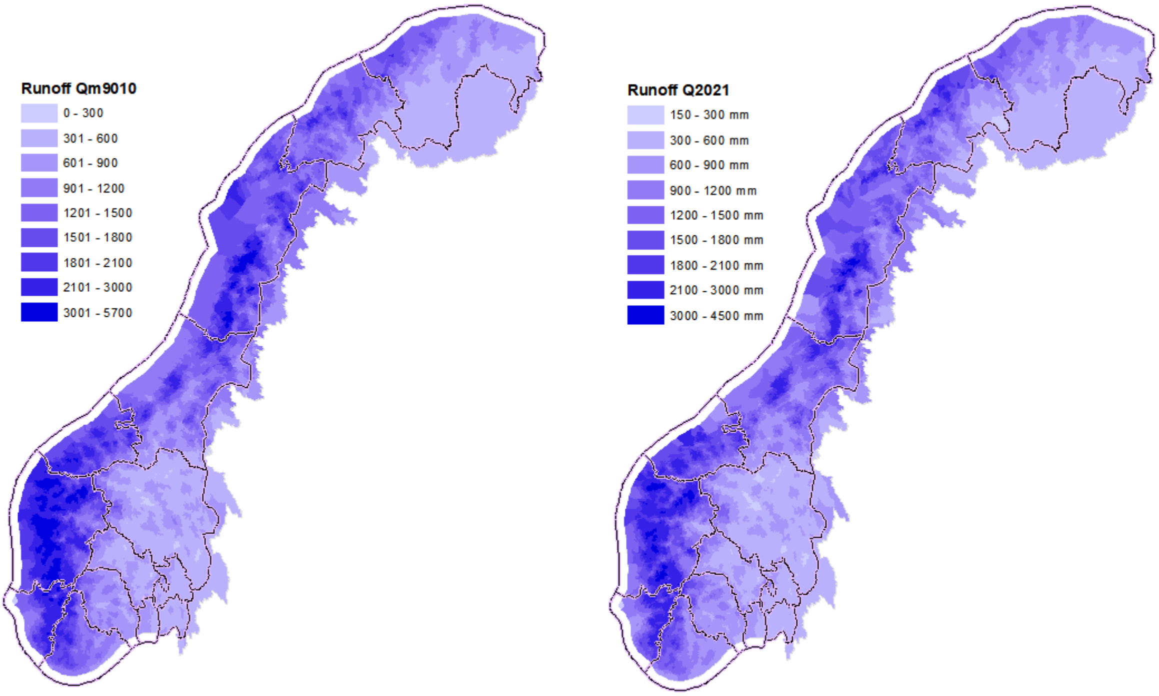

Figure 7.3. Estimated total runoff in the year 2021, left figure for uncorrected HBV estimates and right figure for corrected HBV estimates.

For annual estimations of PO_4-P, POC and N, the corrected annual runoff was used as input. In the risk calculations, the mean corrected runoff for the period 1991-2020 was used as input.

For annual estimations of soil loss, the average long term soil loss considering autumn ploughing (derived from the erosion risk maps) was multiplied with the “relative runoff” (annual runoff divided by the long-term mean runoff (1990-2010)). In the risk calculations, the relative runoff was set to 1 (eq. 4.3).

7.3 Temperature

Source:	Norwegian Meteorological Institute (MET)
Spatial scale:	1 km x 1 km
Temporal scale:	Daily
Application:	Nitrogen

Long-term, spatially and temporally highly resolved temperature data over the mainland of Norway is provided by the Norwegien Meteorogical Institute. The Nordic Gridded Climate Dataset (NGCD) includes daily mean temperature in a spatial resolution of 1 km x 1 km (Lussana et al., 2018a; Lussane et al., 2018b). The dataset is freely available at the MET Norway Thredds Service. The version 23.09, type2 was downloaded in October 2023.

For estimation of N losses, the variable "TempMean_May.Aug" was calculated as average daily temperature of all days in May to August for each year per 1-km^2 pixel. TempMean_May.Aug per REGINE unit was calculated as average of all pixels in the REGINE unit respectively.

7.4 Annual precipitation

Source:	Norwegian Meteorological Institute (MET) *Precipitation* Norwegian Institute of Bioeconomy Research (NIBIO) *Jordsmonnkart database*
Spatial scale:	1 km x 1 km (MET) 1:5000 (NIBIO)
Temporal scale:	Annual
Application:	Nitrogen, phosphorus, carbon, soil particles

Two sources of annual precipitation data have been used in the modelling: 1) mean (1980-2010) annual precipitation in soil map polygons, available from the database behind the NIBIO soil map, provided by the NIBIO division of Survey and Statistics, and 2) gridded (1 x 1 km) monthly and annual precipitation available from the Norwegian Meteorological Institute's Thredds service.

The soil map polygon precipitation was used as basis for determining an erosion risk calibration factor in the SS model, since this dataset corresponds to the period for which erosion risk is calculated.

The gridded precipitation was used as input in the model for calculating runoff correction factors for the REGINE units (section 7.2).

7.5 Precipitation and water balance in the growing season

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Vekstsesongens nedbør + Vekstsesongens nedbør/fordamping*
Spatial scale:	1 x 1 km
Temporal scale:	Annual
Application:	Nitrogen, phosphorus, carbon, soil particles

The maps "vekstsesongens nedbør" (precipitation in growing season) and "vekstsesongens nedbør/fordamping" (water balance in growing season) were used to calculate mean potential evapotranspiration used as input in the model for calculating runoff correction factors for the REGINE units (section 7.2). They were provided in shapefile format by NIBIO's Division for Survey and Statistics.

7.6 Agricultural area

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Arealressurskart AR5*
Spatial scale:	1:100
Temporal scale:	Permanent
Application:	Nitrogen, phosphorus, carbon, soil particles

The land use map "Arealressurskart AR5" is used to identify the agricultural land, and to distinguish pasture from arable land. The agricultural area changes slightly from year to year. However, changes are small and the annual consideration of these changes would cause disproportionately increased effort in the data processing. Therefore, a single version is used for past and future estimations of sediment and nutrient losses. The geodata of the AR5 map were downloaded in 2023 from geonorge.no. The AR5 geodata were used in the same way for sediment and all nutrient loss estimations.

7.7 Geological superficial deposits

Source:	Geological Survey of Norway (NGU) *Løsmassekart*
Spatial scale:	1:250.000- 1:20.000
Temporal scale:	Permanent
Application:	Nitrogen, phosphorus

The NGU's geological map for superficial deposits is used for two purposes: To estimate soil texture class and erosion risk in areas lacking a soil map, further explained in sections 7.8 and 7.10, and to determine the distribution of clay soils developed on marine deposits.

The distribution of marine clay soils is used for calculating the coefficient (Pcoeff) for background P losses in the P model. An area weighted mean Pcoeff is calculated from the areas of marine and non-marine deposits. The classes in the map that are assumed to represent marine clay, are "jordart" number 40, 41 (marine and fiord deposits) and 43 (marine, fiord and beach deposits, thin layer/irregular distribution).

7.8 Soil texture classes

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Jordsmonnkart* Geological Survey of Norway (NGU) *Løsmassekart*
Spatial scale:	1:5000 (NIBIO) 1:250.000- 1:20.000 (NGU)
Temporal scale:	Permanent
Application:	Nitrogen, phosphorus

Soil texture classes are provided by NIBIO's soil map through kilden.no. The soil map does not cover the full extent of the agricultural area. For the not mapped agricultural area, soil texture classes were derived from the NGU's geological map for superficial deposits by assuming one texture class for each map unit class (Table 7.2). Both geodata sets were combined to one geodata set with eleven different soil texture classes covering the total agricultural area including pasture.

Table 7.2. Soil texture classes – relationship between mapped classes in soil map and geological map, and aggregated categories in the P and N models.

NIBIO soil map texture classes	NGU geological map classes	Model aggregation category	
		P model	**N model**
10: Sand and loamy sand, ≥ 40 % gravel	80-82, 88: Unspecified landslide material	Sand + silt	Sand + loam
11: Sand, 20-40 % gravel	20-22: Glaciofluvial deposits	Sand + silt	Sand + loam
12: Sand, < 20 % gravel	-	Sand + silt	Sand + loam
13: Loamy sand, < 40 % gravel, sandy silt and silt, 20-40 % gravel	10-12, 14-17: Glacial till	Sand + silt	Sand + loam
14: Loamy sand, < 20 % gravel	37, 42, 50, 60: Beach deposits (lake, glacial lake, marine), fluvial deposits, eolian deposits	Sand + silt	Sand + loam
15: Sandy silt and silt, < 20 % gravel	30, 31, 35, 36, 53-57: Glaciolacustrine deposits, lacustrine deposits, glacial lake deposits, flood deposits,	Sand + silt	Silt
16: Silt loam, < 20 % gravel	43: marine, fiord and beach deposits, thin layer/irregular distribution	Clay	Clay
17: Sandy loam, loam, sandy clay loam and clay loam, any gravel content; silt loam, silty clay loam and clay, > 20 % gravel	0, 1, 13, 70-73, 101, 102, 120-122, 305-317, 321: Glacial till clays, various deposits (weathered, anthropogenic, landslide, not classified)	Loam	Sand + loam
18: Silty clay loam, < 20 % gravel	40, 41: marine and fiord deposits	Clay	Clay
19: Clay and heavy clay, < 20 % gravel	301-304: soil, clay and flood landslides	Clay	Clay
99: Organic soil (> 20 % SOC)	90, 100, 110, 130: Peat	Organic	Organic

For estimation of P losses, soil texture class is used to calculate total P content in the soil from P-AL (section 7.12). Soil texture classes were summarized to soil categories. Soil texture classes 10 to 15 were defined as sand and silt dominated soils, class 17 as sandy loam and loam dominated soils, 16 to 19 as clay dominated soils and class 99 as organic soil. For each erosion risk class in each REGINE unit, the areal proportion per soil category was calculated. All areal proportions were used to calculate the total P content in the soil.

For estimations of N losses, soil texture classes were summarized to soil categories. Soil texture classes 10 to 14 and 17 were defined as sand dominated soils, classes 15, 16, 18, 19 as silt and clay dominated soils and class 99 as organic soil. For each REGINE unit, the areal proportion per soil category was calculated. The areal proportion of organic soils and the proportion of silt and clay dominated soils are used as variables in the equation.

7.9 Soil organic carbon

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *National soil map database and Jorddatabanken*
Spatial scale:	1:5000 (soil map) farm (Jorddatabanken)
Temporal scale:	Permanent
Application:	Carbon

Soil organic carbon (SOC) content is available from the soil database behind NIBIO's soil map, and from NIBIO's soil sample database "Jorddatabanken".

For estimation of TOC loss, both datasets were used.

7.10Soil erosion risk

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Erosjonsrisikokart (flateerosjonskart + drågerosjonskart)*
Spatial scale:	1:5000
Temporal scale:	Permanent
Application:	Phosphorus, carbon, soil particles

Erosion risk, i.e. the long-term average (1980-2010) soil loss considering spring cereal with autumn ploughing, is used to calculate loss of soil particles, phosphorus, and carbon. The NIBIO erosion risk map consists of two maps:

- The sheet/rill erosion risk map is a polygon feature map (more specifically attributes in the national soil map) that provides four erosion risk classes from 1 – low erosion risk to 4 – very high erosion risk. An extended map attribute table which is not publicly available, contains continuous values in kg/daa. The map is simplified to one polygon per erosion risk class for each REGINE unit, and for each of these polygons we calculate the area weighted mean risk of sheet/rill erosion and soil loss through the drain pipes in kg/daa (form the continuous values), and the area porportions of four main texture classes to be used in calculation of phosphorus content in soil (section 7.4).
- The gully erosion map consists of line features, and the total length of gully lines on area with slope degree >2 % is summed up for each REGINE unit and serves as input to calculating rill/gully erosion.

The erosion risk maps with extended attribute table, version of August 2023, were provided by NIBIO Division of Survey and Statistics.

As mentioned earlier (section 7.7), the soil map covers only part of the agricultural area. For the rest of the area was used a new map with erosion risk calculated by a simplified method. This map was created by Barneveld (unpubl.). It calculates sheet/rill erosion and soil loss through subsurface drainage pipes by regression models based on the existing erosion risk map. Input to the model consists of data for precipitation, terrain (10x10 m DEM) and soil texture class derived from the NGU's geological map for superficial deposits (section 7.4). Gully erosion was not calculated for these areas. This additional map did not provide full coverage for the soil map either, so erosion risk and texture class distribution for the still missing areas had to be calculated based on the existing data. For REGINE units with more than 50 % soil map coverage (including both official soil map and additional soil map), erosion risk and texture class distribution were simply extrapolated to the rest of the area. For REGINE units with less than 50 % soil map coverage, the average for aggregated REGINE units were used (first five digits in the vassdragsNr ID and, if still missing data, first three digits).

For pasture, erosion risk maps are usually not available, and was not included in the calculations by Barneveld either. Thus, the erosion risk for the rest of agricultural land in the REGINE unit was assumed to be representative also for the pasture areas, which means using the same distribution of erosion risk classes and same mean erosion risk in kg/daa per class. This is a simplification that does not take into account the following factors, which are currently not possible to quantify:

- Different carbon content, soil type and terrain and thus different erosion risk is likely;
- The pasture is less likely to be artificially drained;
- The grazing intensity (stocking density, grazing duration, hoof pressure), determining the degree of soil degradation, will vary in different areas.

7.11 Artificial levelling

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Jordsmonnkart*
Spatial scale:	1:5000
Temporal scale:	Permanent
Application:	Soil particles

Information about artificial levelling of soils is available from the NIBIO soil map, and was provided by NIBIO Division for Survey and Statistics.

This information is used to calculate the proportion of artificially levelled agricultural area, which is used as proxy factor in the SS model, to indicate areas of increased erosion risk. For areas lacking soil map, it is assumed that the extent of artificial levelling is negligible.

7.12 Soil P status (P-AL)

Source:	Norwegian Institute of Bioeconomy Research (NIBIO) *Jorddatabanken*
Spatial scale:	Farm ('matrikkelnummer')
Temporal scale:	Permanent
Application:	Phosphorus

We prepared a dataset for P-AL per REGINE unit based on data from soil sample analyses from farms all over the country. These data are stored in the so called «Jorddatabanken», a database managed by NIBIO. Unfortunately, no new data have been added since the year 2016.

In the database, the location of most of the samples are identified by the farm ID "Knr/Gnr/Bnr" (kommunenummer, gårdsnummer and bruksnummer). P-AL values equal to zero and exceeding 200 mg/100 g were excluded from the database, and the mean P-AL was calculated for each municipality (kommune) from the entire time series of P-AL data (1988 to 2016; figure 7.4). REGINE units with 100 % of the agricultural land falling into one single municipality, were assigned with the mean P-AL for this municipality. REGINE units with agricultural land crossing boundaries between multiple municipalities were assigned with a mean P-AL weighted by the REGINE units' proportion of agricultural land in those municipalities.

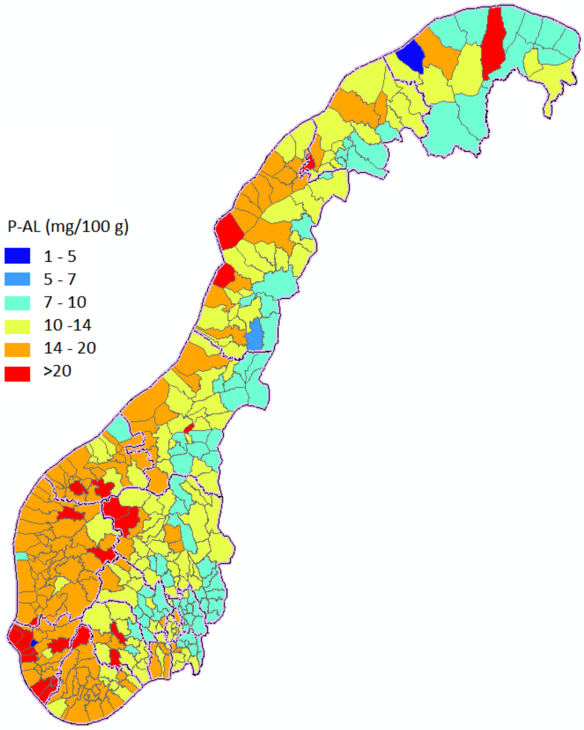

Figure 7.4. Mean P-AL per municipality fot the period 1992-2016, calculated from data in NIBIOs Jorddatabanken.

7.13 Crop distribution

Source:	Norwegian Agriculture Agency (Landbruksdirektoratet) *Søknad om produksjonstilskudd*
Spatial scale:	Farm (‘hovednummer’)
Temporal scale:	Annual
Application:	Nitrogen, phosphorus, carbon, soil particles

All the crops in the “Søknad om produksjonstilskudd” (farmers’ production subsidies) database are reclassified into main crop categories, being:

For soil, P and OC models: spring cereal, winter cereal, grass ley, vegetables and potatoes, according to table 7.3.

For N model: Spring cereal, winter cereal, grass, vegetables and potatoes, fruits, green cereal, legumes, fodder crops, seed breeding, and fallow.

The areas of each class are summed up per municipality, and from this the proportion of the crop categories to the total agricultural area is calculated for each municipality.

For the REGINE units, it is determined how much agricultural land is located in the municipalities the REGINE unit is located in. If there is only one municipality in the REGINE unit, the crop distribution for this municipality applies. If there is more than one municipality, an area weighted crop distribution is calculated.

The procedure includes area corrections to ensure that all areas add up in the end. For example, if the RMP data (section 7.10) indicate the presence of a particular crop category that is not accounted for in the crop distribution, or the area of this crop is too low, then the crop distribution is adjusted automatically to include the crop identified from RMP and reducing all other crop categories proportionately.

Renting of land is not taken into account.

The crop distributions will be fairly uncertain with this procedure. While in theory it is possible to link a proportion of the crop data to the individual farms' locations, this is not feasible at present and also does not completely eliminate uncertainties.

Figure 7.5 shows the coverage of grass ley on arable land in the growing season of 2021, for all REGINE units.

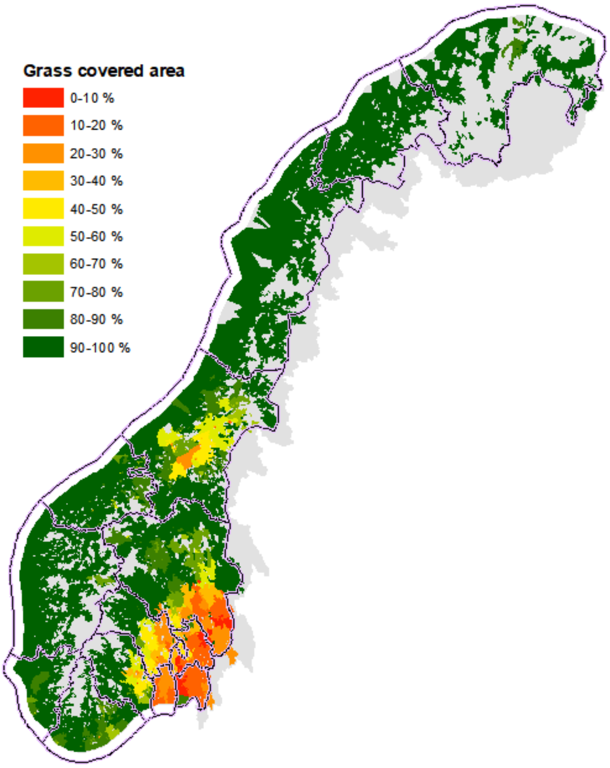

Figure 7.5. The estimated coverage of grass ley (area type 21 and 22 – arable land) in the growing season of 2021.

7.14Tillage, catch crops, and grass on erosion prone areas

Source:	Norwegian Agriculture Agency (Landbruksdirektoratet) *eStil/RMP*
Spatial scale:	Farm field (polygon features)
Temporal scale:	Annual
Application:	Nitrogen, phosphorus, carbon, soil particles

Tillage is deduced from the total area of the main crop categories (section 7.12) and the area of relevant measures given in the eStil/RMP polygon feature map. The map also includes areas with catch crops and grass ley used to prevent erosion. More specifically, the map contains the following measures: Grass ley on areas in erosion risk classes 3 and 4 and/or on areas prone to flooding, no tillage/spring tillage for spring crops (stubble), no tillage/spring tillage for spring crops (stubble) on areas prone to flooding, direct drilling of winter cereal and oil seed, undersown catch crops, catch crops sown after harvest of the main crop. The maps from the period 2013 to 2018 contains two measures in addition: no tillage/spring tillage for grass ley in erosion risk classes 1 and 2, and autumn harrowing.

In the SS and P models, the measures are categorized into the main classes grass ley, stubble, undersown catch crops, catch crops sown after harvest, and autumn harrowing. The area of all these measures in the eStil/RMP map is calculated for each erosion risk class in each REGINE unit. The crops on these areas are then given, so that the crop distribution from section 7.13 is recalculated to apply to the areas without RMP measures. The tillage on areas without measures is assumed to be autumn ploughing. It is assumed that 10 % of the ley area that is *not* included in the RMP maps is autumn ploughed each year.

In the N model, the measures are categorized into the main classes grass, stubble, and catch crops. Undersown and autumn sown catch crops had to be grouped due to limited area of both categories in the development dataset.

Figure 7.6 shows the coverage of stubble on cereal area in autumn 2021 through winter 2022, per REGINE unit, calculated from the eStil/RMP data from 2021.

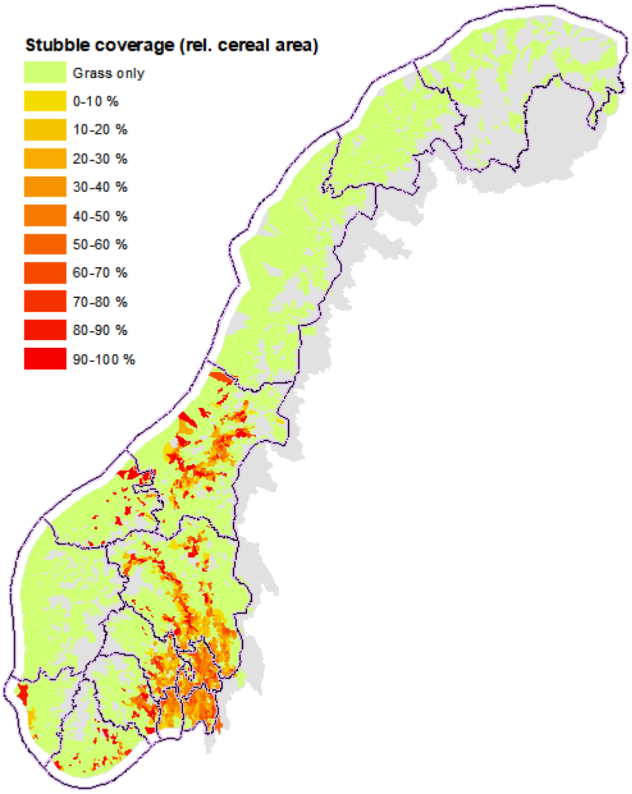

Figure 7.6. The estimated coverage of stubble on cereal areas (area type 21 and 22 – arable land) in autumn 2021 through winter 2022.

7.15 Buffer zones and grassed water ways

Source:	Norwegian Agriculture Agency (Landbruksdirektoratet) *eStil/RMP*
Spatial scale:	Farm field (line features)
Temporal scale:	Annual
Application:	Phosphorus, carbon, soil particles

The measures in the eStil/RMP line map are grass covered buffer zones along water courses, grass strips on slopes and grassed water ways in gullies. The length of all the lines are summed up per erosion risk class per REGINE unit, and forms the basis for calculating retention in buffer zones for each erosion risk class. The length of grassed water ways is in addition calculated for the total REGINE unit, to be used in the calculation of reduced gully erosion in case of grassed water ways are present.

Table 7.3. Categorization of crops and RMP measures in the soil loss model.

Management category **in model**	Crop/tillage	Prod.tilsk. categories	RMP categories
Grass	Grass ley, permanent grass, fruit, berries, flowers.	Prod.tilsk. 210 Fulldyrket eng; 211 Overflatedyrket eng; 272 Epler; 273 Pærer; 274 Plommer; 271 Moreller og kirsebær; 280 Jordbær; 282 Andre bærarter; 283 Andre fruktarter; 285 Planteskoleplanter for salg og blomster for salg dyrket på friland.	§ 28 Gras på arealer utsatt for flom og erosjon*; § 33 Grasdekte vannveier og grasstriper i åker; § 34 Grasdekt kantsone i åker; § 35 Kantsone i eng)**.
Stubble	Spring cereal and oil seed with spring tillage, no tillage and/or cover crops, and winter cereal with direct drilling, peas, beans, fodder crops.	240 Vårhvete; 242 Bygg; 243 Havre; 237 Oljevekster; 239 Korn til krossing; 213 Andre grovfôrvekster til fôr; 223 Grønngjødsling; 235 Engfrø og annen såfrøproduksjon; 236 Erter, bønner og andre belgvekster til modning; 231 Annet korn og frø som er berettiget tilskudd.	§ 27 Ingen jordarbeiding om høsten; § 29 Ingen jordarbeiding på flomutsatte arealer; § 30 Direktesådd høstkorn og høstoljevekster; § 31 Fangvekst som underkultur.
Autumn harrowing	Spring and winter cereal with autumn harrowing. Spring and winter cereal, vegetables and potatoes with catch crops sown after harvest of the main crop.	240 Vårhvete; 242 Bygg; 243 Havre; 237 Oljevekster; 239 Korn til krossing; 247 Høsthvete høstet inneværende vekstsesong; 238 Rug og rughvete høstet inneværende vekstsesong; 264 Grønnsaker på friland, inkl. matkålrot og urter; 230 Poteter.	§ 32 Fangvekster sådd etter høsting. 2013-2018: Høstharving
Autumn ploughing	Spring cereal and oil seed with autumn ploughing, peas, beans, fodder crops, fallow, grass ley***	240 Vårhvete; 242 Bygg; 243 Havre; 237 Oljevekster; 239 Korn til krossing; 213 Andre grovfôrvekster til fôr; 223 Grønngjødsling; 235 Engfrø og annen såfrøproduksjon; 236 Erter, bønner og andre belgvekster til modning; 231 Annet korn og frø som er berettiget tilskudd; 290 Brakka areal.	-
Winter cereal	Winter cereal with autumn ploughing.	247 Høsthvete høstet inneværende vekstsesong; 238 Rug og rughvete høstet inneværende vekstsesong.	-
Vegetables	Vegetables	264 Grønnsaker på friland, inkl. matkålrot og urter.	-
Potatoes	Potatoes	230 Poteter.	-

* In 2013-2018 two different categories of measures covering all erosion risk classes, in 2019-2022 one category of measures covering erosion risk classes 3-4 only. ** Not included as area with grass. *** The proportion of grass ley area that has been tilled in autumn.

The effect of the buffer zone is calculated for the proportion of each erosion risk class assumed to be affected by the buffer zone. This information is derived by identifying which erosion risk classes the individual buffer zones are located in and calculating the total length of buffer zones within each erosion risk class. The area affected by buffer zones is then calculated by multiplying the length of the buffer zone with a 58 m influenze zone for riparian buffer zones and grass strips on slopes, as these buffer zones are affected from one direction only, and a 108 m influenze zone for grassed water ways, affecting areas on both sides of the gully. The proportion of area affected by buffer zones is further calculated as the area affected divided by the total area.

These measures are accounted for in the SS, C and PP loss models (directly in the SS model, affecting the POC and PP through the input to these models from the SS model), and not in the N loss model.

7.16Synthetic fertilizer

Source:	The Norwegian Food Safety Authority (Mattilsynet)
Spatial scale:	County
Temporal scale:	Annual
Application:	Nitrogen

Information on annual synthetic fertilizer application is not available, neither of individual farms nor of municipalities. The only information is annual data from sale statistics of synthetic fertilizer per county provided by Mattilsynet. Sold total nitrogen amount per county was equally distributed over the arable area for each year respectively. This resulted in a synthetic N application rate on arable land of 7.6 kg N/daa/yr on average of all years. Synthetic N application rates range from 4.3 to 23.2 kg N/daa/yr.

7.17Organic fertilizer – Manure

Source:	Statistics Norway (Statistisk sentralbyrå)
Spatial scale:	Municipality
Temporal scale:	Annual
Application:	Nitrogen

Information on annual organic fertilizer application is not available, neither of individual farms nor of municipalities. The only information is the number of livestock per farm per year for which farmers had applied for subsidies. Assuming an average rate of N production per animal per year, the approximate amount of available manure-bound nitrogen (manure-N) can be calculated. The assumed N production rate per animal per year is listed in attachment Table A2.

A proportion of manure-N is lost by gaseous emissions in the barn, during storage and by application. To account for this, the amount of N per animal per year was reduced by standard factors as listed in attachment Table A2. The net nitrogen production by the total livestock per farm was summarized to municipality level and related to the total agricultural area per municipality. This resulted in a manure N application rate of 7.5 kg N/daa/yr on average of all years and the total agricultural area. Manure N application rates range from 0 to 25.3 kg N/daa/yr.

7.18Yield

Source:	Statistics Norway
Spatial scale:	Municipality
Temporal scale:	Annual
Application:	Nitrogen

Yield data are generally provided by Statistics Norway, but the degree of their availability depends on crop type. Yield of cereals, peas, and oil seeds is reported by the farms during the process of subsidy application. These data can be directly processed at municipality level. Yield of all other crops is only available either at county or country level. In these cases, data of average yield per dekar per county or of the country were combined with farmer's data on area per crop from subsidy applications. In this way, yield data for all relevant crops could be downscaled from country or county to municipality level, albeit assuming equal yields across the country or county respectively. Nitrogen removal by harvest was calculated by the product of yield and nitrogen concentration per crop type using standard values (see table A3 in the appendix).

8 Limitations and uncertainties

Some parts of the models need further attention in the future. The largest constraint to model development has been the availability of quantitative data, both data to serve as a knowledge base for model development, data at proper resolution and quality to be used as input in the models and data for calibration of the models in certain parts of Norway.

In the sections below is a short overview of the possible improvements of the models, and what is required for better model performance.

8.1 Data for model development

The models rely on knowledge and data describing the processes of soil and nutrient losses. At the national scale, the models need to represent "all" possible combinations of soils, topography, climate, vegetation and management. Information at such a detailed level is impossible to achieve. We have used all available data sources that provides this type of information, but the data are limited.

The JOVA-programme, which has been the main source of model development data in this project, provides high quality data in the form of long time series of continuous runoff and water quality measurements and detailed information about the influencing factors, like weather and agricultural management. However, the catchments are not representative for all agricultural areas in Norway. For example, western Norway from Hordaland to Møre and Romsdal is not represented, and Northern Norway is represented by one single catchment. In addition, monitoring of catchments with variable land use makes it hard to distinguish between the contributions from the individual land uses and individual productions on the agricultural area. Such effects have been derived from plot study sites and experimental research.

The soil, phosphorus and carbon models were developed using both JOVA data and additional data from smaller scale studies in Norway and other countries. These smaller scale data give more insight into effects of individual factors, but at the same time, they can be quite particular and highly dependent on local conditions, how the experiment was set up, etc. Also, small scale studies, like plot studies, are not automatically representative on the larger scale, and often the processes on the "intermediate" scale, like field or hillslope scale, are hard to determine and quantify. Sedimentation and retention of soil particles in the landscape is an example of that – it is not readily measured, and it is difficult to model with simple models and simple input data.

To be more specific, the following points are limitations and uncertainty in the models or should be addressed in future development of the models:

- Improving the knowledge base and quantitative data for **streambank erosion, forested areas and pasture**, and **background losses** from agricultural areas. This includes more measurements under Norwegian conditions. In addition, site-specific data for livestock density on pasture would be of benefit.
- Include estimates for **connectivity** within the catchments. This must go hand in hand with an evaluation of the erosion risk map. For now, soil loss from all areas in the REGINE catchments enter the first order stream, irrespective of e.g. distance to the stream. For fields draining to inlets for surface water or open ditches, this is a fair assumption. However, no data are available to readily identify the location of such features or to estimate their importance as pathways for soil and nutrient losses. The soil loss derived from the erosion risk maps is calibrated for the JOVA catchments, and as such accounts for larger scale processes. A more specific approach for connectivity would improve the quantification of soil losses.

- The **gully erosion model** needs a better foundation of quantitative data. This can only be achieved through more extensive measurements and also more process-based modelling on smaller scales, which can both increase the understanding of processes and provide quantitative data for developing the large-scale models.
- The approach to calculate **annual variation in soil loss** is very simplistic, using the relative runoff ratio as a multiplier to the risk-based approach for losses. The event-based nature of soil loss is extremely difficult to model, even using process-based models. So, more effort should be put into determining how the annual losses can be calculated.
- The **soil/landscape calibration factors** in the soil loss model should be further developed. They are currently based on calibration on the JOVA data and linked to the proportion of artificially levelled soil and the extent (length) of geological ravines and landslide features. These factors therefore strongly depend on the measured soil loss in the Mørdre and Hotran catchments, but the cause of the high soil losses there is not fully understood.
- The process of **P enrichment** is included in the PP model, and the original equation based on amount of soil loss alone was supplemented with a simple correction to account for apparent increase in enrichment with increasing P-AL in the soil. The approach needs further attention to verify this phenomenon and the equation (or modify the equation).
- The **management factors** in the soil loss model are based on quite extensive data from Norway and Nordic countries, but management practices like vegetables and potatoes are underrepresented or lacking in the data sources, and therefore highly uncertain.
- The **carbon model** needs further development, with emphasis on carbon enrichment, possible contributions to carbon loss from manure, and validation of the calculated loss of dissolved organic carbon, which was based on limited data from Finland. There are some data available in Norway, but unfortunately often low sampling frequency, few years with data and few sites where agriculture dominates.
- Processes causing losses of N and P from **organic soil** are poorly documented and quantitative data are scarce. The model estimates are hence uncertain and additional experimental data from other sites than Naurstad and Fureneset are required.
- One constraint to the effect of **N balance** is the difficulties in getting precise estimates for N balance. Both input and output of the balance cover a lot of uncertainty, e.g. content of nitrogen in grass-yield, in manure and the final effect due to loss through denitrification.
- Knowledge on quantity of emitted total N from soil by **denitrification** is low. Most studies are focusing on emissions of greenhouse gases. However, total N emissions from soil can be considerable. Studies for quantification of gaseous total N losses are highly recommended. However, simple approaches are still needed to bring knowledge from small scale study sites to national scale.
- **Drainage systems** have strong influence on processes affecting pathways of nitrogen. In general, wet soils foster the chance for denitrification and so gaseous N emissions. Fast discharge of soil water through drainage pipes fosters the probability of N loss by runoff. In the N model, the intensity of drainage is not directly considered but its effect in combination with the dominating texture classes. In consequence, it is assumed that the combination of drainage intensity and dominating soil texture in the JOVA catchments is generally applicable across Norway. This assumption needs to be verified and, if necessary, the model accordingly revised.
- Inappropriate **irrigation** can cause N losses by runoff, especially in agricultural systems with high N input as e.g. in vegetable production. A literature review should be done to quantify the

potential for N losses by irrigation in Norway, and, if necessary, considered in the model. For this, data of sites and intensity of irrigation across Norway would be required.

- So far, effects of nitrogen leaching to **groundwater** and groundwater contributing to measured runoff and measured nitrogen losses at the JOVA catchment outlets is assumed to be negligible, or just unknown. Knowledge about this is important as it can play an important pathway for nitrogen. Detailed studies on groundwater and its effect on measured runoff and nitrogen losses for all JOVA catchments are important for further improvement and evaluation of the N model. Moreover, little information is available about N concentrations in groundwater in agricultural dominated areas.
- The data used for model development cover **runoff** amounts of up to approximately 1500 mm per year. The maximum runoff from the corrected HBV maps is around 4500 mm per year. It is uncertain if runoff amounts can reach such high levels on agricultural land, and it is not known how nutrient losses are affected, e.g. with respect to dilution. Quantification of nutrient losses from representative agricultural areas with high runoff in Western Norway and Northern Norway is desired.

8.2 Input data to the models

Input data quality is important for the resulting model estimates. The data which serve as input to the models, are not always available at the desired scale, or they are available, but too time consuming and/or difficult to process. The data also contain numerous uncertainties and sometimes errors.

Below is an overview of input data constraints.

- **Runoff** estimates for agricultural land are quite uncertain. The HBV model estimates seem to be partly wrong for agricultural areas. A correction factor was included, but with a simplistic approach. Process-based modelling could give further improvements.
- **Soil map** with the required input data for texture class, organic carbon content and erosion risk is available for approximately 60 % of arable land. The rest is provided through maps of high uncertainty, based on the NGU geological map.
- **P-AL** is kept constant over years, since updated data after 2016 are not available. With improved availability of data, this variable will be changed regularly.
- The spatial resolution of **crop distribution** input data is low, at municipality level, which is mostly because of technical issues with linking the data to individual farms due to regular changes in administrative unit numbers and farm numbers, errors in tables linking different datasets together (e.g. hovednummer and matrikkelnummer), time consuming processing of maps (eiendomskart), etc.
- The **annual crop and management distribution** are not entirely correctly represented in the model, since the TEOTIL model requires data for calendar year, while crop and management follow agro-hydrological years (May 1 in one year to April 30 next year). As an example: For the calendar year 2022, the estimates for agricultural land are based on crop distribution in the growing season 2022 and state of the soil between harvest and December 31 2022. This fails to take into account the state of the soil from January 1 to approximately April/May 2022, which was registered in the RMP data from 2021. There is really no compromise solution for this, and a split calculation with datasets from two seasons is currently not feasible.
- The crop distribution problem described above, extends to representation of the **winter cereal** area. This had to be neglected since data are not available in the year the model will be run, but instead the next year. This is a bit unfortunate, as winter cereals can have negative

impacts on erosion, as has been shown in several experiments in Norway and other Nordic countries.

- **Synthetic fertilizers** application is required for calculation of nitrogen balances. The only known source for this information is sold synthetic fertilizer per county. This implies two main uncertainties: it is the sold, not the applied fertilizer, and the spatial scale is county while field or at least farm scale would be required.
- **Manure** application is required for calculation of nitrogen balances. So far, amount of manure is derived from number of animals as registered in SSB at the farm scale and assumed to be equally distributed in the municipality where the farm is located. No information about amount of manure transported to other areas is available. This can cause over- and underestimations of nitrogen balances.
- **Nitrogen fixation** through legumes, mainly clover on meadows, is not yet considered in the calculation of the nitrogen balance. Reason for this is that the density of legumes in meadow are not known and that the level of fixation is depending on the intensity of fertilization.
- **Crop yield** is required for the calculation of nitrogen balances. Amount of N removed by crop harvest is depending on assumed N concentration in the crops. So far, constant standard values are assumed for it. This conceals regional and interannual differences in N concentrations, especially for crops with highly varying protein content. Moreover, yield of several crops but especially of grass and vegetables are of high uncertainty. For grass, average yield of hay (converted from registered grass yield) per county and for vegetables, average yields of the country are available from SSB.

9 Conclusions and future work

In this project, a set of simple models for calculating losses of nutrients and soil particles from agricultural areas has been developed. The results from the models are used as input to the TEOTIL model. The models incorporate updated knowledge and extended data sources compared to the original JOVAest models for N and P loss from agricultural areas. The model approaches have been changed or modified compared to these former models, and new elements have been included in the calculations: fractions of N and P, soil particles and organic carbon.

Application of the models for the years 2013 to 2022 show that the models manage to reflect important regional differences in losses of soil and nutrients, as effect of soil, terrain and climate: The models estimate high losses of nitrogen in areas with high runoff, high losses of soil particles and particle bound phosphorus in areas dominated by cereal and/or potatoes or vegetable production, and erosion prone soils developed on marine deposits (Southeast Norway and Trøndelag); high losses of dissolved phosphate in areas with high phosphorus content in the soil, high runoff and high proportion of organic soils (along the coast from southern to northern Norway); high losses of organic carbon in areas dominated by high runoff and high soil organic carbon content (southern and western Norway).

Furthermore, the model results include effects of changes in agricultural practices and agricultural mitigation measures like crop distribution, autumn tillage method, nitrogen balance, catch crops and soil phosphorus status, grass-covered waterways and buffers along streams.

Due to the identified limitations and uncertainties in the present model, it is suggested to revise the models at regular intervals. The prioritized topics for revision are:

- The runoff estimates for agricultural land
- The gully erosion model
- The approach to calculate annual soil loss
- The soil/landscape calibration factors in the soil loss model
- The function for P enrichment as function of P-AL in the P model
- The management factors for vegetables and potatoes in the soil loss model
- The carbon loss model
- The processes in forests and pastures, and background losses
- The nutrient losses in high runoff areas (western and northern Norway)
- The equation to estimate N losses from pasture
- The proportion of nitrate-N to total N in runoff from organic soils

All of these points require more quantitative data, and the work can also be supplemented by process based modelling.

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Attachment

Table A11. N concentrations in manure of the most relevant animals as assumed in the JOVA monitoring.

Animal	Manure type	N concentration in manure (%)
Cattle	solid	0.46
Cattle	fluid	0.33
Pig	solid	0.6
Pig	fluid	0.6
Sheep/Goat	solid	0.81
Sheep/Goat	fluid	0.6
Hens	solid	1.48
Chicken	solid	1.78

Table A2. N production rate per animal per year used in the N model.

Animal	N production kg N/animal/yr	N emission factor
Dairy cows	134.71	0.3021
Suckler cows	93.00	0.2607
Cattle	74.96	0.3108
Breeding pigs	24.38	0.3404
Piglets	1.41	0.3404
Pigs for slaughter	3.20	0.3404
Sheep	11.60	0.2581
Lamb	7.73	0.2581
Laying hens	0.67	0.1419
Live chickens	0.05	0.1432
Broiler chicken	0.03	0.1432
Turkey	0.45	0.1867
Dairy goats	16.90	0.2869
Goats	8.50	0.2869
Horses	50.00	0.2069
Mink	4.27	0.1475
Deer	12.00	0.2069
Llama	22.70	0.2069
Alpaca	11.35	0.2069
Rabbits	0.78	0.2000

Table 2A3. Assumed N concentrations in harvested crops and crop groups.

Crop (group)	N concentration in yield (%)
Barley	1.5
Beetroots	0.28
Broccoli	0.45
Brussels sprouts	0.65
Carrot	0.44
Cauliflower	0.28
Celery	0.25
Chinese cabbage	0.19
Curled parsley in field grown	0.225
Early cabbage	0.2
Foddercrops	0.4
Fruits	0.2
Hay/silage	2.5
Iceberg lettuce	0.69
Leek	0.25
Oat	1.5
Oilseeds	3.13
Onion	0.5625
Other lettuces field-grown	0.69
Peas	3.3
Potatoes	0.31
Radishes	0.14
Red cabbage	0.22
Ridge cucumber	0.15
Root celery	0.25
Sweet corn	0.51
Table swedes	0.5
Triticale	1.62
Turnip-rooted parsley	0.42
Turnips	0.2
Wheat	1.7
Winter cabbage	0.2
Rye	1.5

NIBIO
NORSK INSTITUTT FOR
BIOØKONOMI

Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter.

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