Development of Mechanistic Models

Mechanistic Model for Nissum Fjord

Technical documentation on biogeochemical model

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Development of Mechanistic Models

Mechanistic Model for Nissum Fjord

Technical documentation on biogeochemical model

Prepared for Danish EPA (Miljøstyrelsen, Fyn)

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1 Executive Summary

The model development presented in this technical note represents the biogeochemical model development for Nissum Fjord. The Nissum Fjord model is part of a large model complex comprising several mechanistic models developed by DHI and a number of statistical models developed by Aarhus University (AU), Bioscience.

The model complex is developed with the overall aim to support the Water Framework Directive (WFD) by introducing mechanistic models in as many Danish water bodies as possible and integrating with Bayesian statistical modelling, and cross-system modelling carried out by AU, Bioscience.

Here we present the overall biogeochemical model set-up covering Nissum Fjord, together with a quality assessment of the model performance. This specific model includes three Danish water bodies:

Water body*)	ID Number
Nissum Fjord, ydre	129
Nissum Fjord, mellem	130
Nissum Fjord, Feldsted Kog	131

*) Water bodies defined for the River Basin Management Plans 2015-2021

The Nissum Fjord biogeochemical model builds on the developed hydrodynamic model of Nissum Fjord and is developed to describe the biogeochemistry within the model domain focusing on parameters relevant for WFD, including dynamics in nutrients, phytoplankton, primary production, dissolved oxygen, organic matter and benthic vegetation.

The model quality is evaluated based on three model performance measures: Percent Bias (P-Bias), Spearman Rank Correlation and Cost Function (CF). According to DHI (2019b), Model Efficiency Factor (MEF) was suggested initially, but during the model development, it was concluded that MEF was not suitable to evaluate this kind of estuarine biogeochemical models, why Cost Function (CF) was introduced. The quality measure CF was used in Erichsen and Timmermann (2017) as part of an international evaluation (Hermann *et al.* 2017). As described in DHI (2019b), the MEF evaluates the Root Mean Square Error (RMSE) to the standard deviation (based on measurements). As model results are compared against measurements at the exact point in time in dynamic estuarine systems with strong gradients, the MEF has proven not to be suited (due to its dependency on entirely right timing). The CF assesses the fit/misfit between measurements and observations also normalized to the standard deviation (based on measurements), why it is decided to use this measure in the overall assessment of model performance.

Concerning the performance measures, our ambition is to have 75% of all measures (Percent Bias, Spearman Rank Correlation, Model Efficiency Factor (MEF) and Cost Function to meet ‘excellent’, ‘very good’, or ‘good’ for all parameters and stations (lumped).

As can be seen from the present technical note, 81% of all data sets meet the success criteria when evaluated against the three performance measures, and 74% when assessing both annual performance and summer/winter performance of all data. The average model performance, estimated at two stations within the model domain for the biogeochemical model of Nissum Fjord, is summarized below:

- Model performance measures for dissolved oxygen (DO) are on average 3% (P-Bias), 0.6 (Spearman Rank Correlation) and 0.7 (CF). The average model performance for DO is categorized to be 'excellent' (P-Bias) and 'very good' (Spearman Rank Correlation and CF).
- Model performance measures for all chlorophyll-a (CH) model performance measures are on average 30.5% (P-Bias), 0.2 (Spearman Rank Correlation) and 1.1 (CF). The average model performance for CH is categorized to be 'good' (P-bias and CF) and 'poor' (Spearman Rank Correlation).
- Model performance measures for all light attenuation coefficient (K_d) are on average 31% (P-Bias), 0.1 (Spearman Rank Correlation) and 0.8 (CF). The average model performance for K_d is categorized to be 'very good' (CF), 'good' (P-Bias) and 'poor' (Spearman Rank Correlation).
- Model performance measures for all dissolved inorganic nitrogen (DIN) are on average 21.6% (P-Bias), 0.8 (Spearman Rank Correlation) and 0.8 (CF). The average model performance for DIN is categorized to be 'very good' (Spearman Rank Correlation and CF) and 'good' (P-Bias).
- Model performance measures for all dissolved inorganic phosphorus (DIP) are on average 74.9% (P-Bias), 0 (Spearman Rank Correlation) and 2.9 (CF). The average model performance for DIP is categorized to be 'good' (CF) and 'poor' (P-Bias and Spearman Rank Correlation).
- Model performance measures for all total nitrogen (TN) are 26.9% (P-Bias), 0.8 (Spearman Rank Correlation) and 0.5 (CF). The average model performance for TN is categorized to be 'very good' (Spearman Rank Correlation and CF) and 'good' (P-Bias).
- Model performance measures for all total phosphorus (TP) are 19.8% (P-Bias), 0.3 (Spearman Rank Correlation) and 0.8 (CF). The average model performance for TP is categorized to be 'very good' (P-Bias and CF) and 'good' (Spearman Rank Correlation).

The details behind the above performance are available in Table 5-1 and Table 5-2. Time-series comparisons are available here: rbmp2021-2027.dhigroup.com (Google Chrome only).

The ambition of meeting 'excellent', 'very good', or 'good' for 75% of all parameters and stations (lumped) has been well reached. In this technical note, we conclude that the Nissum Fjord biogeochemical model has been developed successfully for the Nissum Fjord water bodies and will be applied for modelling nutrient scenarios in the assessment and maximum allowable inputs (MAI).

2 Introduction

The model development presented in this technical note represents the biogeochemical model development for Nissum Fjord and builds on top of the Nissum Fjord hydrodynamic model (DHI 2019d). Documentation on the model application will be presented in the following reports. The biogeochemical model is part of the mechanistic model complex development, which includes two regional models, three local-domain models, and six estuary specific models. The model complex is developed with the overall aim to support the Water Framework Directive (WFD) by introducing mechanistic models in as many Danish water bodies as possible and integrating with Bayesian statistical modelling and cross-system modelling carried out by AU, Bioscience.

Here we present the overall biogeochemical model set-up covering Nissum Fjord, together with a quality assessment of the model performance. The Nissum Fjord model includes the three Danish water bodies listed in Table 2-1 below. The location of the Danish water bodies is documented in Erichsen *et al.* (2019).

Table 2-1 Water bodies included in the Nissum Fjord model.

Water body*)	ID Number
Nissum Fjord, ydre	129
Nissum Fjord, mellem	130
Nissum Fjord, Feldsted Kog	131

*) Water bodies defined for the River Basin Management Plans 2015-2021

The biogeochemical model computes the development during the modelling period in ecological parameters, including concentrations of nutrients, dissolved oxygen, and organic matter and the Secchi depth, due to, e.g. primary production. The results represent short term changes due to specific weather events, seasonal variations and interannual trends. This project will focus on summer chlorophyll-a and parameters influencing distribution and growth of eelgrass. A detailed description of the specific state variables included in the Nissum Fjord biogeochemical model can be found in DHI (2019c).

According to DHI (2019b), the quality measure Model Efficiency Factor (MEF) was suggested as a quality measure initially, but during the biogeochemical model development, it was concluded that MEF was not suitable to evaluate this kind of estuarine biogeochemical models. As described in DHI (2019b), the MEF evaluates the RMSE as the standard deviation (based on measurements). As we compare model results to the measurements at the exact point in time in a number of estuary systems with strong gradients and variable dynamics, the MEF has proven not to be suited (due to its dependency on entirely right timing). For the validation of the biogeochemical models, we have included the quality measure Cost Function (CF) in replacement of MEF. The CF measure was also used in Erichsen & Timmermann (2017) and describes how the difference between measured and modelled values is related to the inherent variation in field observations.

3 Modelling Concept

3.1 Mechanistic Modelling

The present technical note represents the biogeochemical part of the model complex covering Nissum Fjord. The Nissum Fjord model is one model out of eleven mechanistic models developed to increase the knowledge of pressures and status in Danish marine waters and to provide tools for the Danish EPA as part of the implementation of the WFD. Mechanistic models enable dynamic descriptions of ecosystems and interactions between natural forcing and anthropogenic pressures. Hence, mechanistic models can be applied for predictions of changes in specific components, like chlorophyll-a concentrations, due to changes in, e.g. anthropogenic pressures.

The Nissum Fjord model is defined as an estuary specific model. The mechanistic model complex development as part of the present projects includes two regional models, three local-domain models, and six estuary specific models:

- The regional models cover both specific Danish water bodies and regional waters, such as the North Sea and a small part of the North Atlantic, which is included in the North Sea-model, and the Baltic Sea, which is covered by the IDW-model (Inner Danish Waters). These models provide model results for specific water bodies but, equally important, give boundaries to local-domain models and estuary specific models.
- Local-domain models are developed to allow for resolving most small and medium-sized water bodies in the north-western Belt Sea, the south-western Belt Sea and the water bodies in and around Smålandsfarvandet.
- Estuary specific models: Six specific estuary (fjord) models are developed to allow for detailed modelling of particular estuaries.

The ecological conditions in marine waters are determined by several different natural factors like water exchange, stratification, water temperature, nutrient availability, sediment characteristics, the structure of the food web, etc. On top of that, several anthropogenic factors like nutrient loadings, fishery, etc., also impact the ecosystem and potentially the ecological status.

The model developed in this specific project aims at supporting the Danish EPA's implementation of the WFD. During this project, the models are designed to represent the present period (2002-2016) evaluated against NOVANA measurements. Here we use current data on solar radiation, current nutrient loadings, etc.

After the models are developed, they will be applied for scenario modelling with changed nutrient loading to assess the Maximum Allowable nutrient Inputs (MAIs).

3.2 Model Development

The model development consists of a 3D hydrodynamic model describing the physical system (water levels, current, salinity and water temperatures), and a 3D biogeochemical (ecosystem) model describing the governing biogeochemical pelagic and benthic parameters and processes like phytoplankton, dissolved oxygen, primary production, etc. The model structure is modular, meaning that a hydrodynamic model is developed independently of the biogeochemical model (for further information about the hydrodynamic model see DHI (2019a)). A more detailed description of the biogeochemical model is available in DHI (2019c), and the underlying Nissum Fjord hydrodynamic model is described in DHI (2019d).

All mechanistic models have been set up and calibrated/validated for the period 2002-2016 and reported according to the performance measures P-Bias, Spearman Rank Correlation and CF (DHI 2019b). Results from the entire modelling period are furthermore presented as time series in a WEB-tool (rbmp2021-2027.dhigroup.com, Google Chrome only) with a few examples included in section 5.3. Most data used for calibration and validation originate from the national monitoring programme NOVANA (see http://odaforalle.au.dk for more details). For some models and some parameters, other data are included, and the specific origin of those data will be referenced when used.

3.3 Modelling System

The biogeochemical model is based on the 3D modelling software MIKE 3 HD FM (version 2017) developed by DHI together with the numerical 3D equation solver MIKE ECO Lab to describe the relevant biogeochemical processes in the modelling system. The MIKE 3 FM modelling system is based on a flexible mesh approach with horizontal mesh elements of varying sizes within the modelling domain. The water column is resolved by multiple layers. The modelling system has been developed for applications within oceanographic, coastal, and estuarine environments.

The scientific documentation of MIKE 3 HD FM is given in DHI (2019a).

The main components and processes determining the status of the water quality and the response in the ecosystem (e.g. changes in eelgrass biomass) are included in the biogeochemical model. They are based on external factors (meteorology and nutrient supply). The model describes the turnover of organic material and nutrients, both in the pelagic (water column) and the benthic phase (seabed or sediment). The pelagic phase includes phytoplankton and nutrients, and the benthic department covers sediment pools of nutrients and the exchange of nutrients between the sediment and water phase. Furthermore, the benthic part of the model describes the biomass and growth of benthic vegetation at the sea bed. The mechanisms behind the biogeochemical model and the ECO Lab templates used are described in DHI (2019c).

4 Model Set-up

The biogeochemical model for Nissum Fjord builds on top of the hydrodynamic model (HD) and an integrated transport model (AD). The set-up and calibration/validation of the physical Nissum Fjord model (HD and AD) are documented in technical notes (DHI 2019d).

For the present project, the model is set up for the period 2002-2016, which means that all model input data need to cover this period.

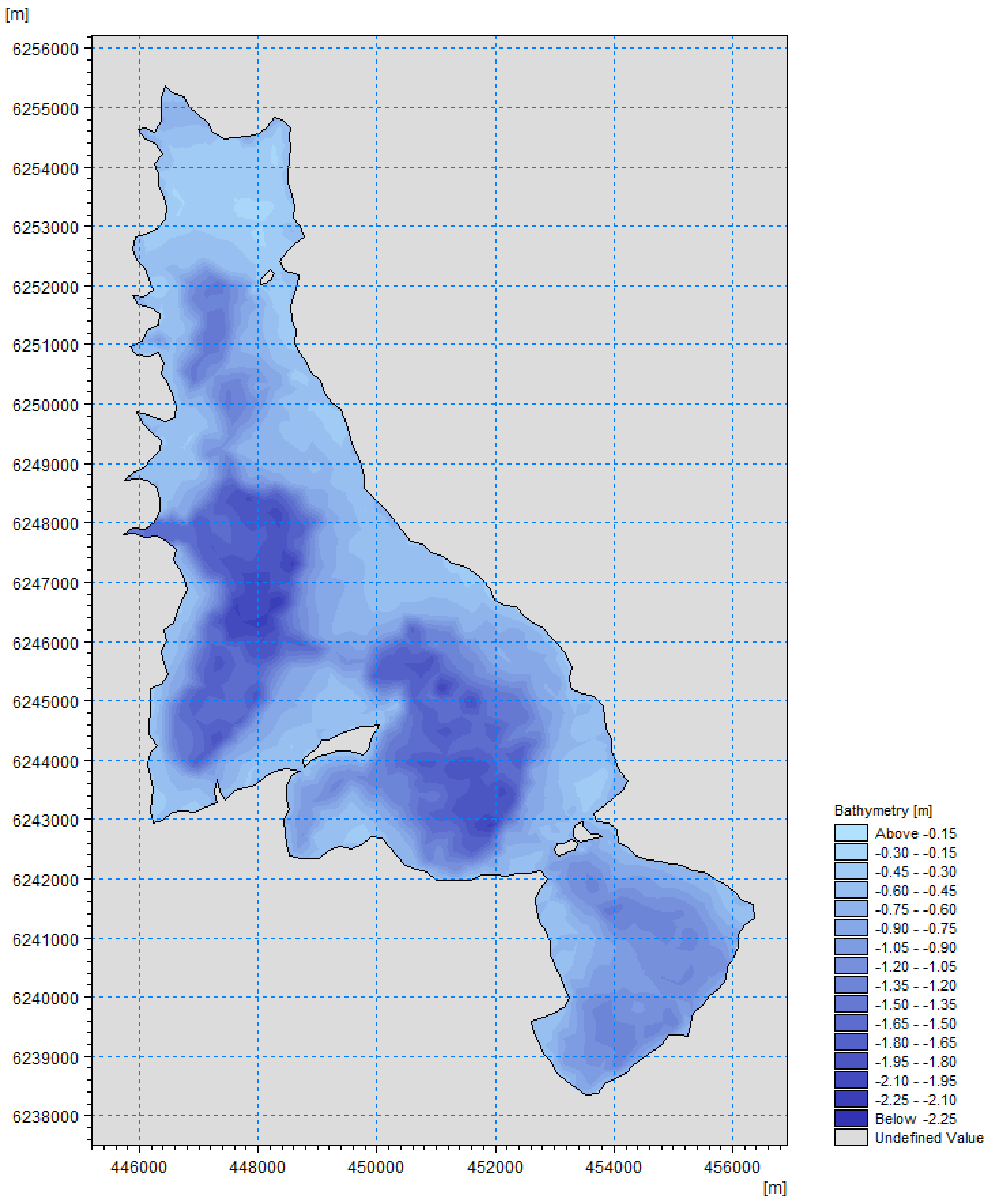

Figure 4-1 Model bathymetry of the Nissum Fjord model. Water depths refer to MSL. The model has no open boundary (sluice at Thorsminde is approximated with source/sink).

4.1 Model Domain

The model domain is determined in accordance with the area of interest of the modelling study. Also, considerations of the area of influence, being the surrounding areas that affect the area of interest, and suitable open boundary locations, affect the choice of the model domain.

The model mesh is the representation of the model domain. More specifically, the model mesh defines the model area, the location of the open boundaries, the land-water boundaries, the horizontal and vertical model resolution (discretization), and the water depths (bathymetry) of the model. The bathymetry of the Nissum Fjord model is shown in Figure 4-1, whereas Figure 4-2 shows the resolution of the horizontal mesh. The vertical mesh of the Nissum Fjord model is resolved in 10 sigma-layers with refinements (less relative layer thickness) towards the water surface and the fjord bed. Further documentation on model mesh and horizontal/vertical resolution of the Nissum Fjord HD model can be found in DHI (2019d).

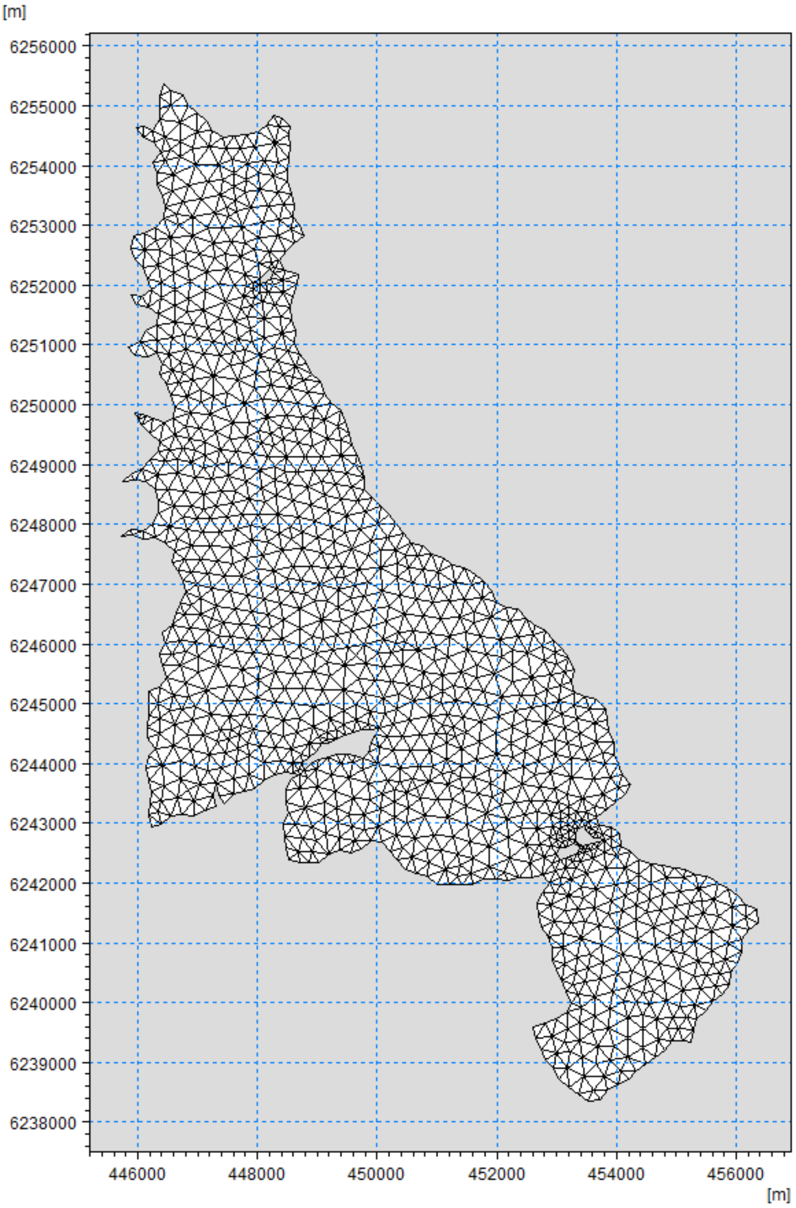

Figure 4-2 Resolution of the horizontal model mesh of the Nissum Fjord model.

4.2 Open Boundary Conditions

The Nissum Fjord model has no open boundaries. The water exchange between the fjord and the sea is controlled through a sluice located at Thorsminde in the central-western part of the fjord. In this model, the sea-fjord water exchange was modelled using point source/sink for in- and outflow. Documentation on boundary conditions for the biogeochemical model development is given in DHI (2020).

4.3 Forcings

Data on solar radiation are calculated from clearness percentages and applied as a temporally varying forcing.

Area-distributed atmospheric deposition of nitrogen (N) is provided by AU, Department of Environmental Science, and aligned with HELCOM depositions (see DHI 2020).

To estimate suspended sediment concentrations, a dynamic bottom shear stress information is needed. Wave parameters from a Spectral Wave model are included as model forcing, including significant wave height, wave period and mean wave direction, together with current conditions from the hydrodynamic model results.

Documentation on model forcing is given in DHI (2020).

4.4 Sources

The Nissum Fjord model includes sources with land-based nutrient loadings. In Figure 4-3, the location of the sources is shown. Freshwater run-off from land is included in the hydrodynamic module.

The model sources are specified as time series with daily loadings of inorganic and organic nutrients, including also total nitrogen (TN) and total phosphorus (TP). The land-based nutrient loadings are based on data from DCE/AU, Department of Bioscience on a 4^{th} order water body level.

More details are included in DHI (2020).

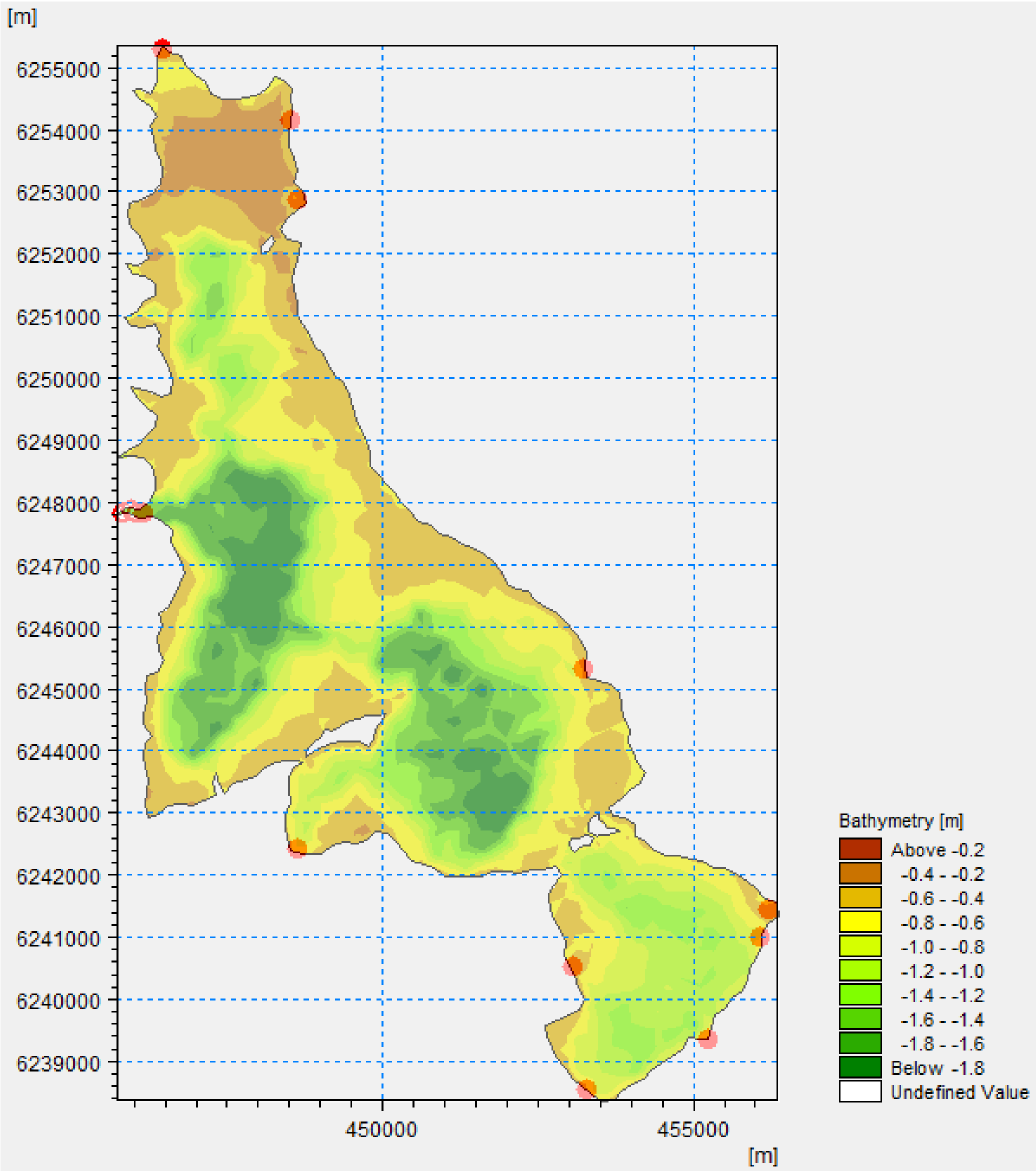

Figure 4-3 Illustration of the location of sources in the Nissum Fjord model. The source positions represent the main rivers, but loadings are scaled to include all local run-off and point sources from land to the fjord. The hollow circles indicate the location of the water exchange between the sea and fjord.

4.5 Initial Conditions

To properly initiate a model simulation, the model requires initial conditions for the various state variables. Initial values in the pelagic phase applied in the Nissum Fjord model were estimated based on measurements within the Nissum Fjord area. The available measurements from around 2002 were applied as uniform values in the entire model domain, and the model was spun-up by four times run for the year 2002 before being used for calibration/validation.

Initial fields of seabed substrates are based on mud-data from EMODnet (2016). Initial values of benthic vegetation (e.g. eelgrass) were estimated by running a MIKE ECO Lab model with defined initial biomass for the entire model domain for a three-year simulation period.

In DHI (2020), further details on initial model values are given.

5 Model Calibration and Validation

After set-up of the model, calibration and validation of the model are undertaken. The model **calibration** is the process of adjusting model process settings and model constants within the literature range to obtain satisfactory agreement between observations and model results in the local modelling domain. In practice, the model set-up and the model calibration are often performed iteratively, since a good comparison between observations and model results requires a well-proportioned model domain as well as adequate model forcings.

The model **validation** is the process of comparing observations and model results qualitatively and quantitatively for a different period from the calibration period, to demonstrate the suitability of the calibrated model more generally. The qualitative comparison is typically made graphically, and the quantitative comparison is usually made using specific performance (goodness of fit) measures (DHI 2019b; Erichsen & Timmermann 2017). As such, the model validation constitutes the final documentation of the model performance.

The Nissum Fjord model was run for the period 2002-2016, and the entire period is used for a combined calibration and validation effort, due to lack of enough observation data for separate calibration and validation tasks. Consequently, model performance measures are presented for this period. The model results compared with observations of the different biogeochemical parameters are presented for the entire period using a WEB-tool (rbmp2021-2027.dhigroup.com, Google Chrome only).

5.1 Model Calibration Procedure

Calibration of the biogeochemical Nissum Fjord model is achieved by tuning model constants to optimize model results on calibration parameters compared to measured data. The constants adjusted in the calibration procedure are numerous. They include, e.g. phytoplankton growth rates, grazing rates, mortality rates (phytoplankton and zooplankton), light attenuation constants, sedimentation rates, re-suspension rates, mineralization rates (pelagic and sediment), denitrification rates (pelagic and sediment).

The key parameters to optimize in the calibration procedure include dissolved oxygen, chlorophyll-a, light attenuation, inorganic nutrients, total nitrogen and total phosphorus. After each adjustment of calibration constants, the model is run, and time-series are compared to measured data at selected stations. The procedure is iterated until model results and measured data compare in both time and space.

5.2 Presentation of Key Model Results

During the model calibration procedure, an extensive amount of data on state variables and processes is produced. To allow for a smooth and homogeneous quality assurance, few standard plots and time series are generated automatically and evaluated during the baseline and scenario execution.

Examples of modelled key validation parameters are presented as 2D fields in Figure 5-1 to Figure 5-4 and illustrate the spatial variation of the validation parameters. In the following, a brief assessment of the spatial distribution of key parameters, within the water bodies covered by the model domain, will be given.

Average concentrations of dissolved oxygen in bottom waters during 2016 are presented in Figure 5-1 and range from a minimum of 7-7.5 mg/l in the outer part of Nissum Fjord to maximum values above 13 mg/l found in water bodies close to land in Nissum Fjord (Figure 5-1).

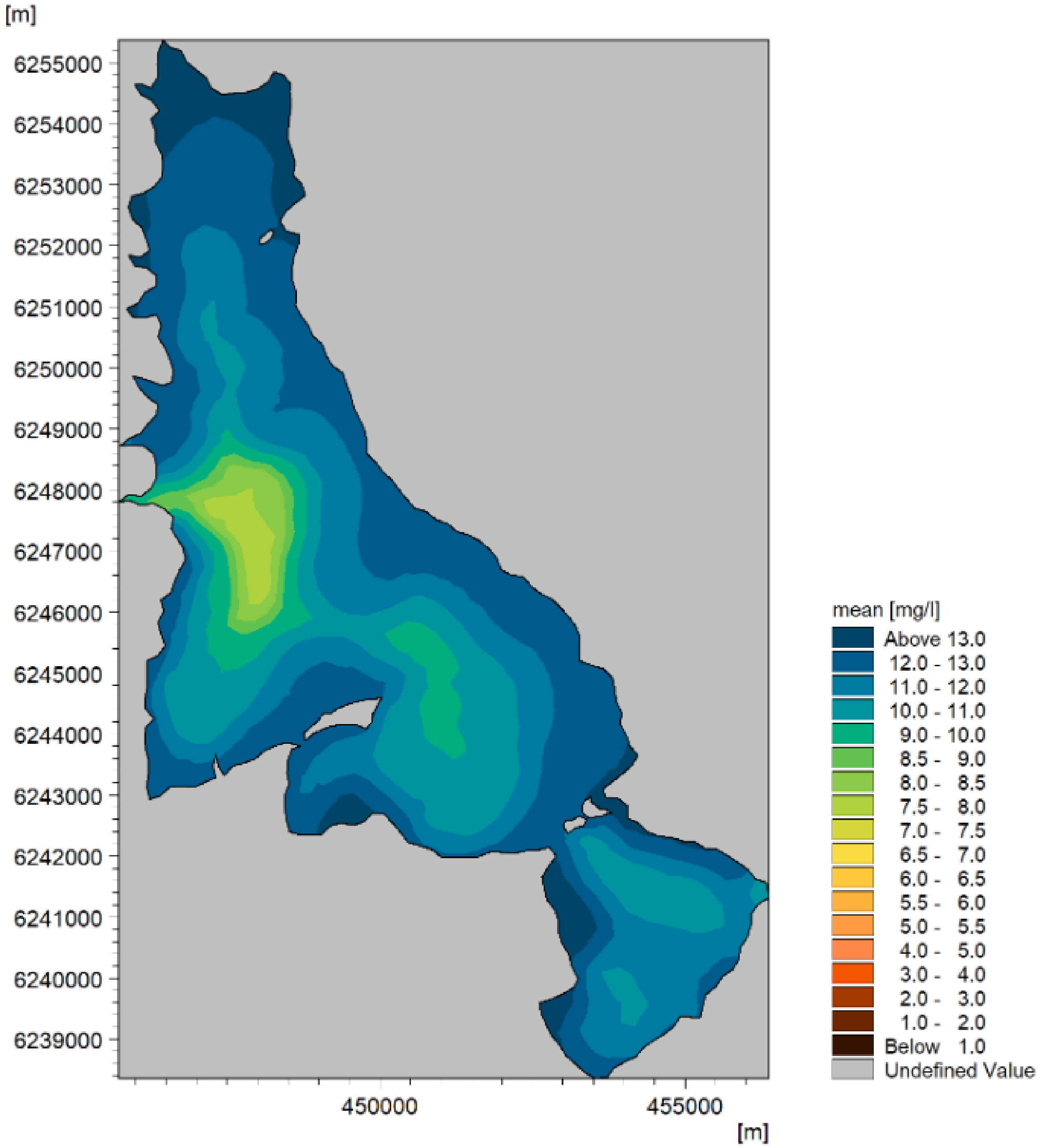

Figure 5-1 Modelled yearly average bottom water concentrations of dissolved oxygen (DO, mg/l) for 2016.

Yearly average concentrations of surface chlorophyll-a during 2016 range from less than 0.001 mg/l in the northern part of Nissum Fjord to 0.022-0.024 mg/l in the southern part of Nissum Fjord (Figure 5-2).

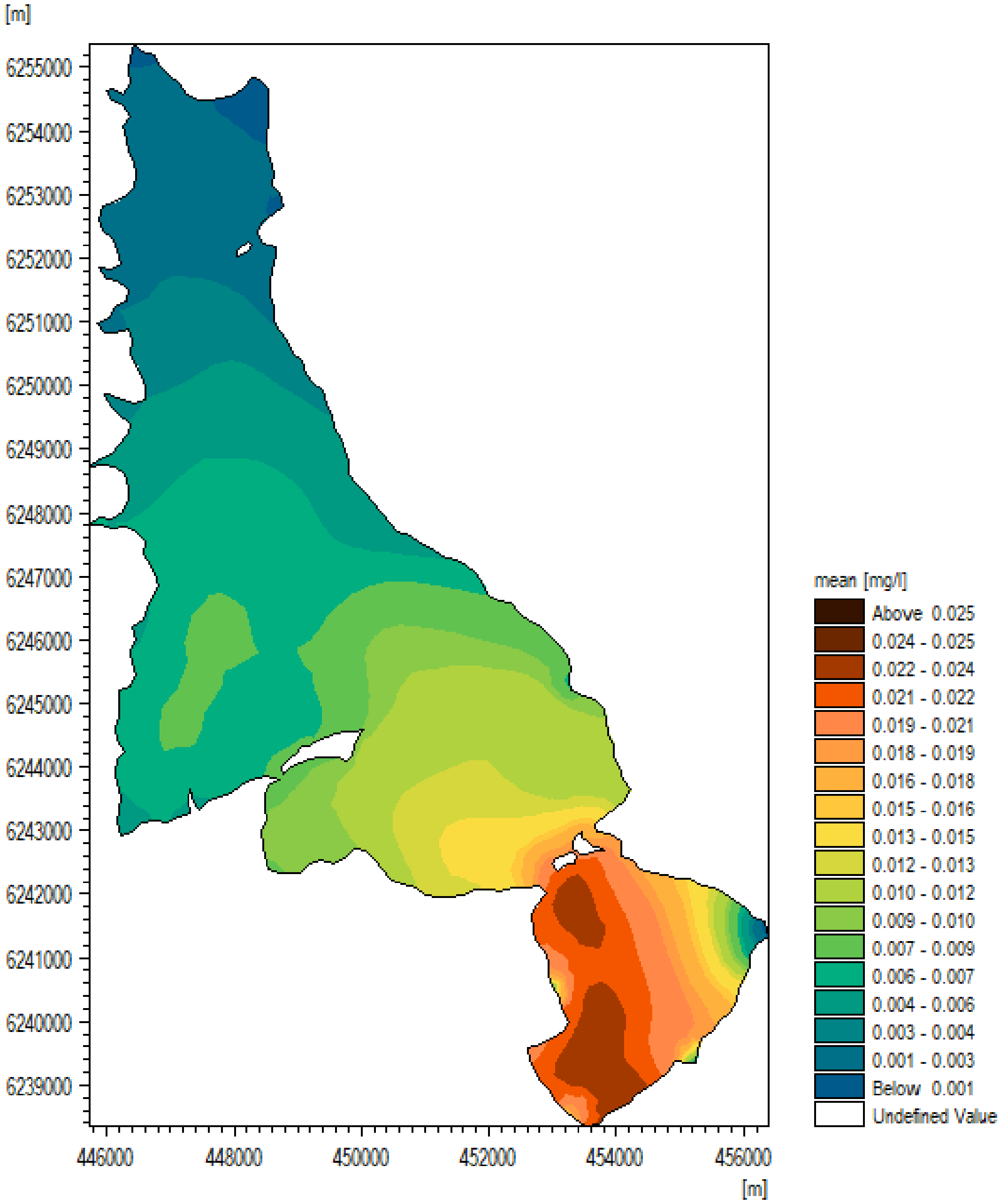

Figure 5-2 Modelled yearly average surface water concentrations of chlorophyll-a (CH, mg/l) for 2016.

The annual average concentrations of surface total nitrogen during 2016 are highest in the southern part of Nissum Fjord with values ranging between 1.5 – 1.8 mg/l (Figure 5-3). In the northern part of the fjord total nitrogen values range between 1.0 – 1.4 mg/l.

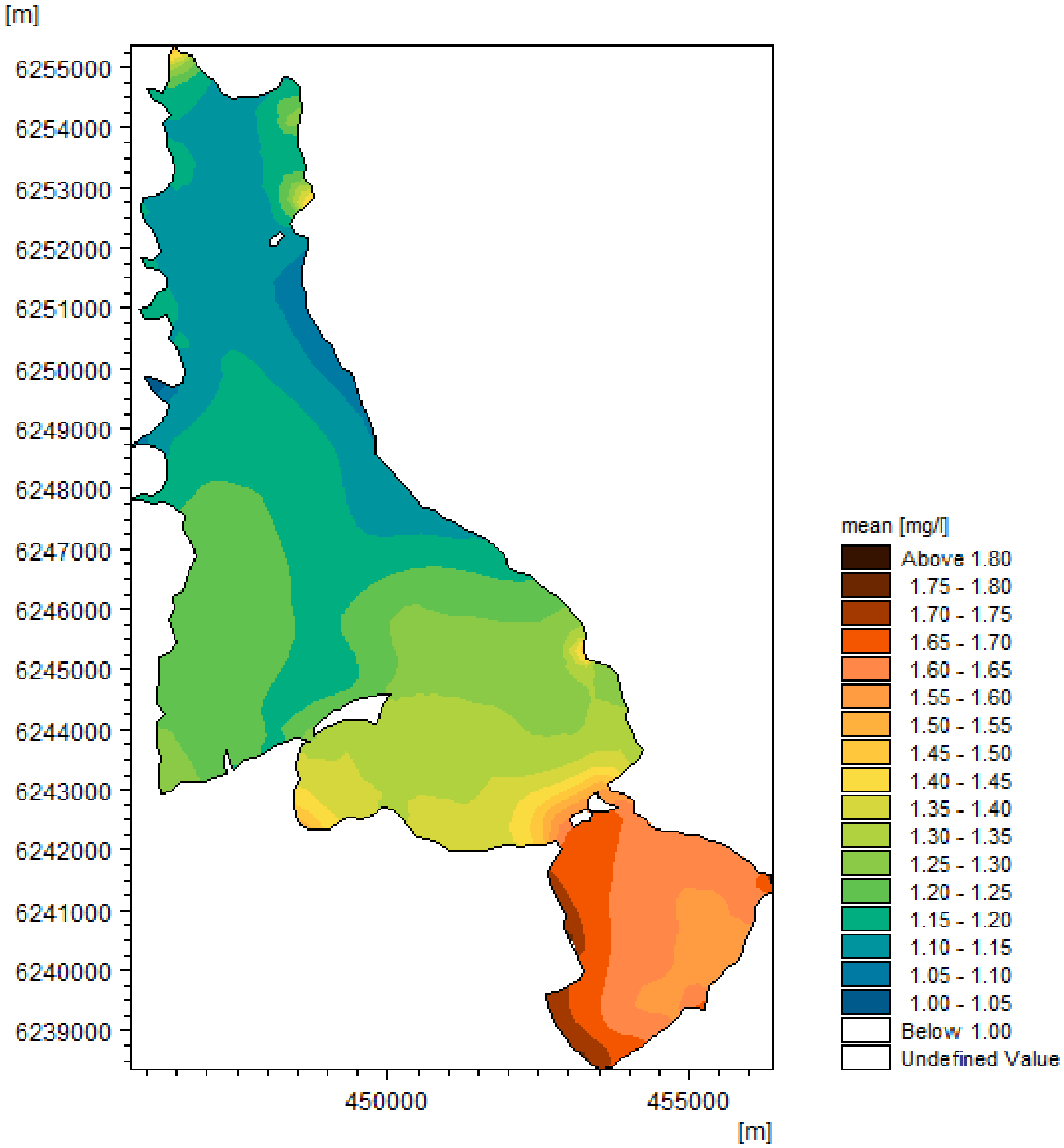

Figure 5-3 Modelled yearly average surface water concentrations of total nitrogen (TN, mg/l) in 2016.

Yearly average concentrations of surface total phosphorus during 2016 are between 0.9 mg/l to 2.8 mg/l (Figure 5-4). Highest values are observed in the southern part.

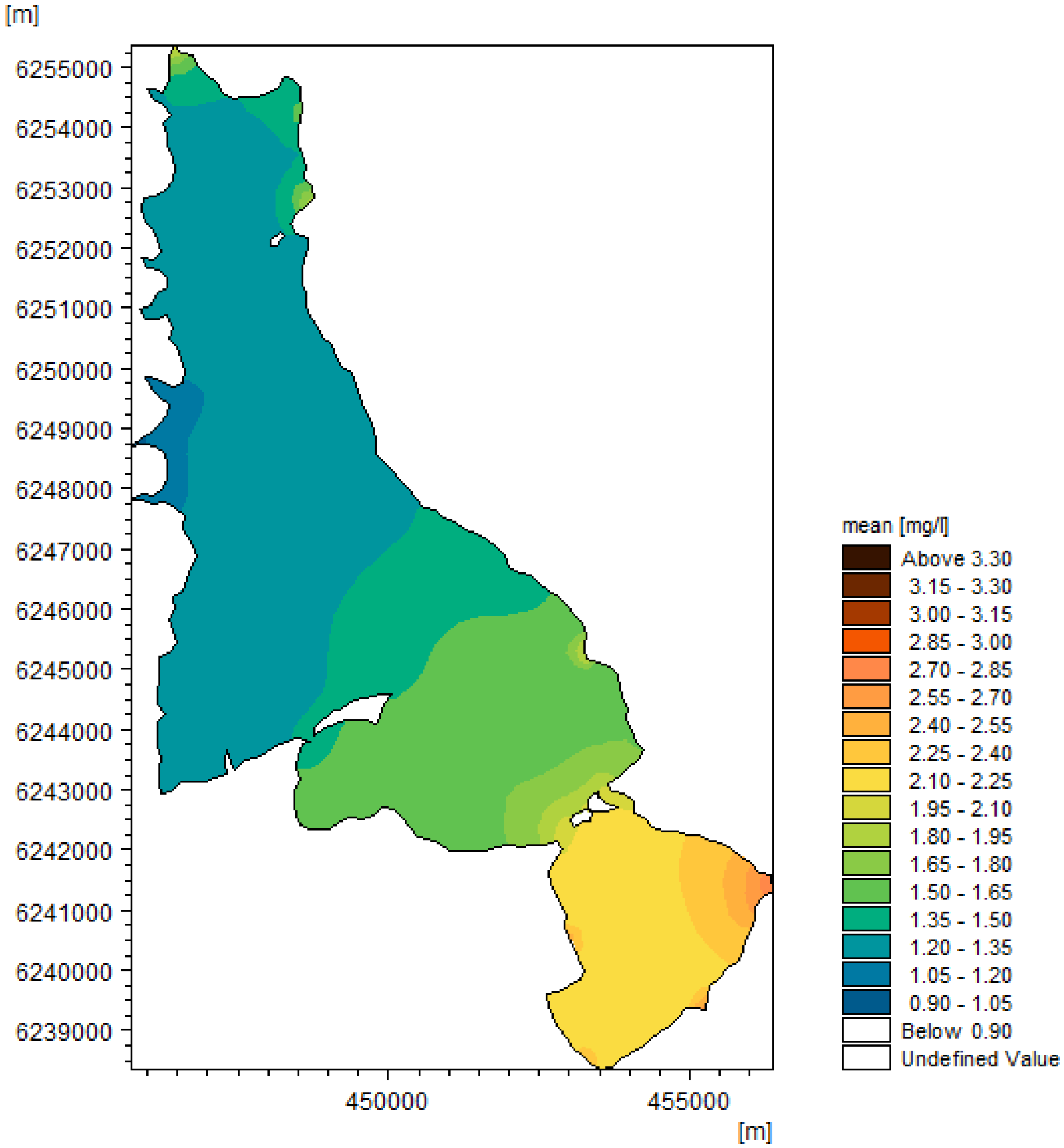

Figure 5-4 Modelled yearly average surface water concentrations of total phosphorous (TP, mg/l) in 2016.

5.3 Model Performance

The Nissum Fjord biogeochemical model was calibrated and validated against measured data (observations) on modelled ecosystem parameters at selected stations within the model domain. Figure 5-5 shows the location of four stations within the model domain. Of the four stations, two stations had enough measurement data in the period 2002-2016 (at least one year of weekly or bi-weekly data) to be included in the model calibration and validation (RKB22 and RKB23). The biogeochemical calibration/validation parameters include dissolved oxygen (DO), chlorophyll-a (CH), light attenuation (K_d), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total nitrogen (TN) and total phosphorus (TP). Generally, the Nissum Fjord model compares well to the measurements in terms of model parameters (see Figure 5-6 to Figure 5-12), and the overall performance measure (summarized in Table 5-1 and Table 5-2) confirms a statistically good agreement between measurements and model results.

Figure 5-5 Locations used for performance measures in Nissum Fjord (only stations with an ID).

5.3.1 Calibration/Validation at Station RKB22

In the following, we present an example of the calibration/validation from Nissum Fjord at station RKB22 and refer to rbmp2021-2027.dhigroup.com (Google Chrome only) for more details on the Danish measurement stations. The location of station RKB22 is shown in Figure 5-5.

The comparison at station RKB22 shows a good agreement between the measurements and the Nissum Fjord model for 81% of the parameters according to the three performance measure P-bias, Spearman Rank Correlation and CF (see Table 5-1 together with DHI (2019b) and Erichsen *et al*. (2017) regarding the applied measures).

In Figure 5-6, measured and modelled concentrations of dissolved oxygen (DO) at station RKB22 in the surface and bottom waters (here 2 m) are shown. From the figure it is seen that for DO the variability and seasonality of the surface and bottom waters are well represented by the model. This is in agreement with the statistical performance measures (see Table 5-1), where measured and modelled DO compare ‘excellent’ (P-Bias) and ‘very good’ (Spearman Rank Correlation and CF) at station RKB22.

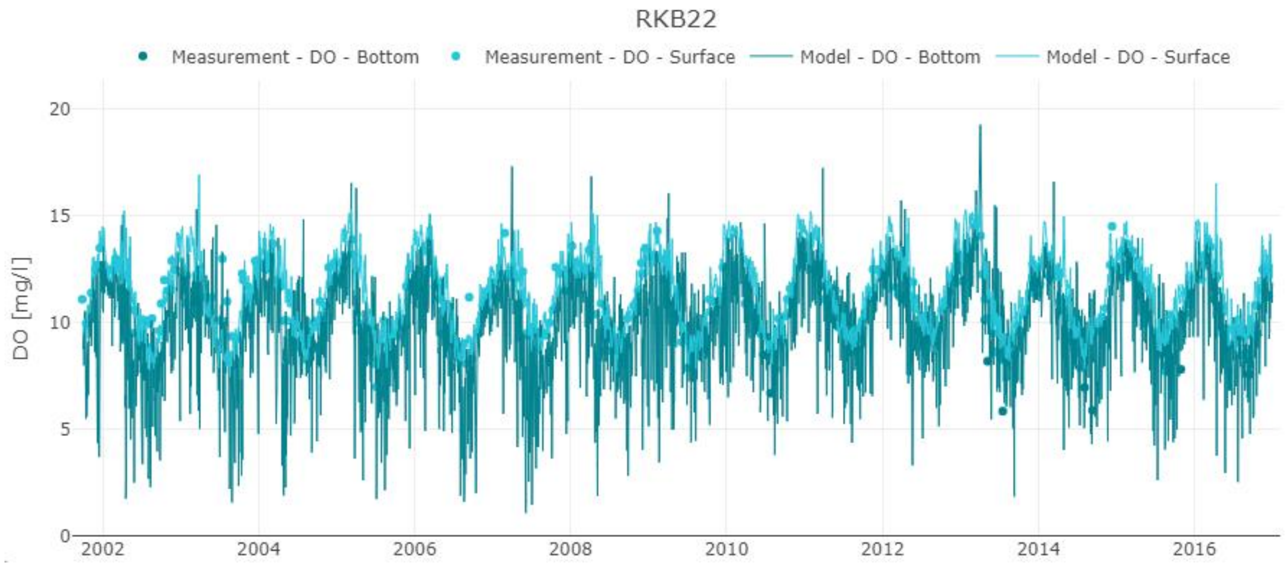

Figure 5-6 Comparison of measured and modelled concentrations of dissolved oxygen (DO, mg/l) at station RKB22 in the surface and bottom (2 m) waters. Dots represent measurements, and the solid line shows modelled data for the entire period.

For chlorophyll-a (CH), the model tends to overestimate summer concentrations and underestimate winter concentrations of observed chlorophyll-a (see Figure 5-7). From the statistical performance measures, CH compares ‘good’ (P-Bias and CF) and ‘poor’ based on Spearman Rank Correlation (Table 5-1).

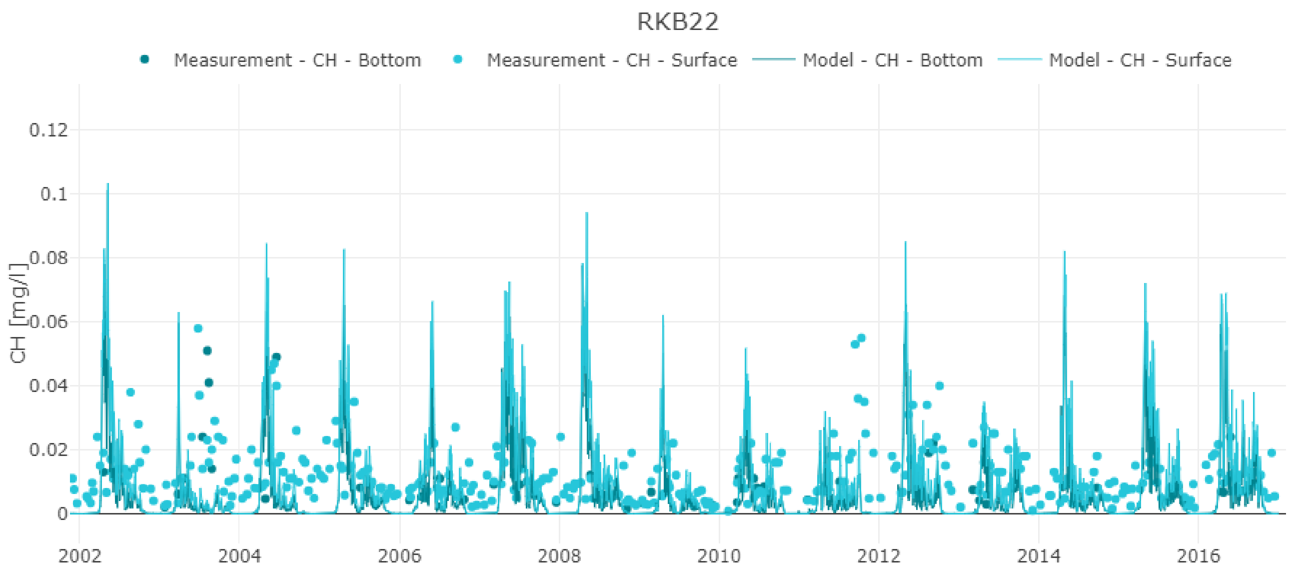

Figure 5-7 Comparison of measured and modelled concentrations of chlorophyll-a (CH, µg/l) at station RKB22 in surface and bottom (2 m) waters. Dots represent measurements, and solid lines show modelled data for the entire period.

The measured light attenuation coefficient (K_d) presented in Figure 5-8 shows a relatively large variability for RKB22. The lower parts of the seasonal dynamics predicted by the model represent the seasonality in measured data. However, especially the high K_d values in the observed data do not compare accordingly. The statistical performance for the annual period is 'good' (P-bias, Spearman Rank Correlation and CF) for this parameter (see Table 5-1).

When considering the quality measure CF for this parameter, it is noted that on average the model error is 70% of the standard deviation of the measurements and based on this measure, the model meets 'very good' model performance. The model performance for summer (March to September) measurements of K_d evaluated by P-Bias is categorized to be 'good', suggesting that the model prediction captures the absolute values during summer months. The K_d parameter in the biogeochemical model is developed to account for light attenuation including effects from chlorophyll-a, particulate organic material, coloured dissolved organic matter as well as fine inorganic sediments.

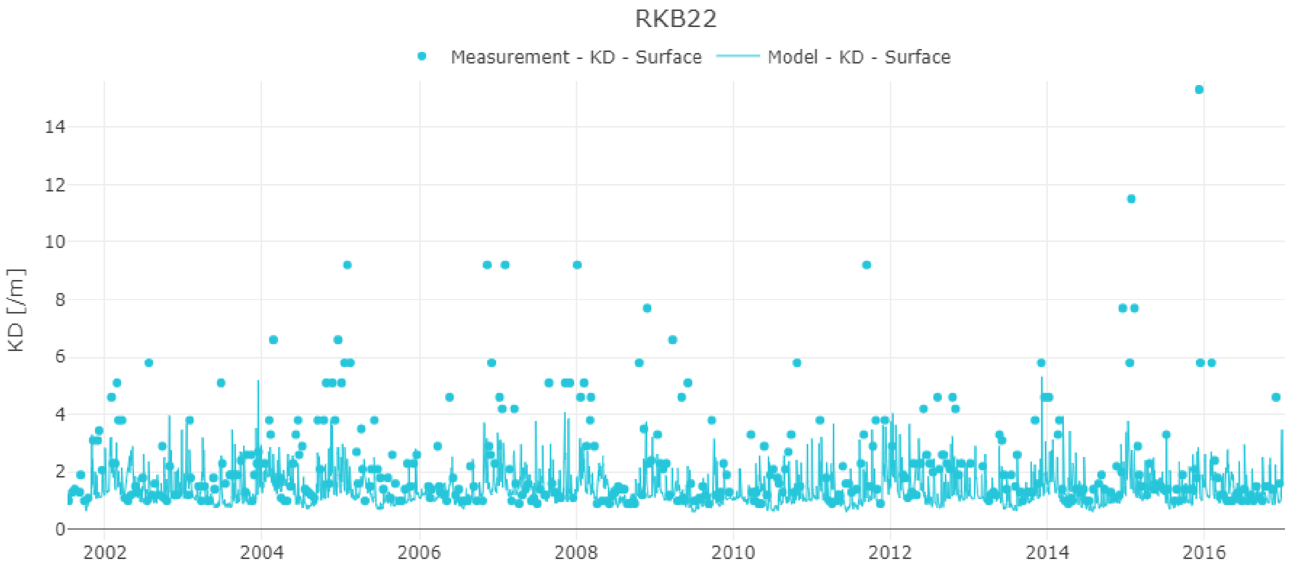

Figure 5-8 Comparison of measured and modelled light attenuation coefficient (K_d , m^{-1}) at station RKB22 in the surface waters. Dots represent measurements, and the solid line shows modelled data for the entire period.

For dissolved inorganic nitrogen (DIN), the dynamics in seasonality and absolute values are well represented by the Nissum Fjord model (see Figure 5-9). From the statistical performance measures, annual DIN compares 'excellent' (CF), 'very good' according to Spearman Rank Correlation, and 'good' based on P-Bias (Table 5-1).

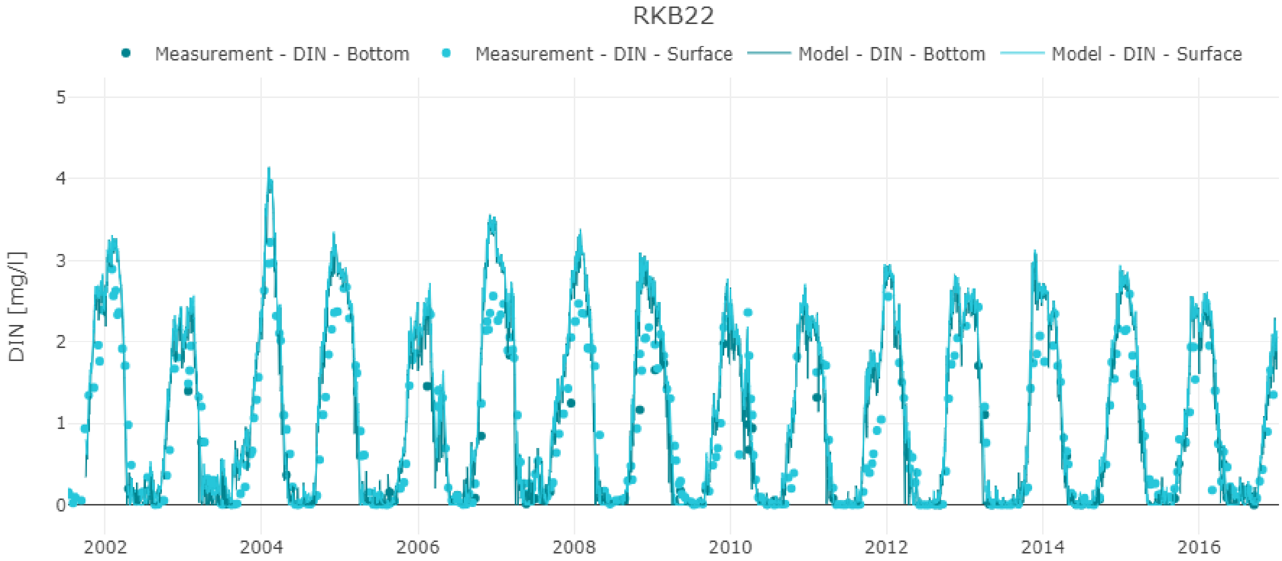

Figure 5-9 Measured and modelled concentrations of dissolved inorganic nitrogen (DIN, mg/l) at station RKB22 in the surface and bottom (2 m) waters. Dots represent measurements, and solid lines show modelled data for the entire period.

When comparing measured and modelled concentrations of DIP (see Figure 5-10), we see relatively similar summer/autumn concentrations after a definite drop in spring. During the winter, the model shows a somehow more dynamic pattern than observed in the measurements. The spikes in both surface and bottom waters predicted by the model are a result of re-suspension. Hence, the overall patterns are well represented by the model, which is further supported by the statistical performance measures, where the model performance for all DIP is 'very good' for winter DIP measured from P-Bias, and 'good' (P-Bias and CF) and 'poor' (Spearman Rank Correlation) for annual DIP at RKB22 (Table 5-1).

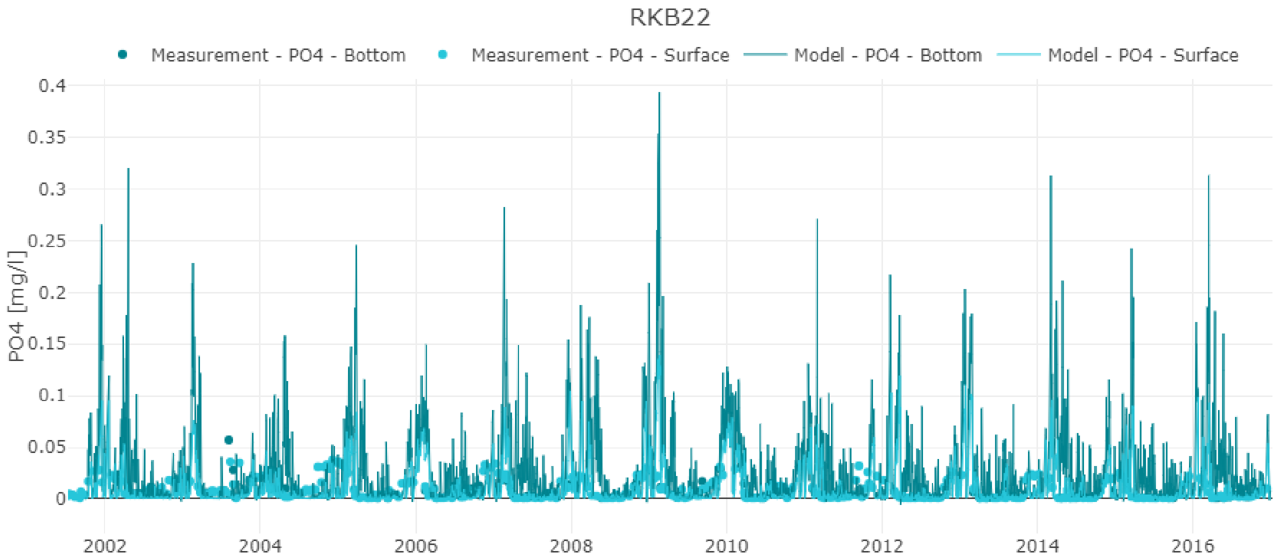

Figure 5-10 Measured and modelled concentrations of dissolved inorganic phosphorus (DIP, mg/l) at station RKB22 in the surface and bottom (2 m) waters. Dots represent measurements, and solid lines show modelled data for the entire period.

In Figure 5-11, comparisons of measured and modelled total nitrogen (TN) at station RKB22 in surface water and bottom (2 m) water are shown. For TN, the seasonality is well represented by the model. During winter, however, the model tends to overestimate concentrations. The statistical performance measures for TN support a good agreement between measurements and modelled data (see Table 5-1), where TN compare ‘very good’ (Spearman Rank and CF) and ‘good’ (P-bias) at station RKB22.

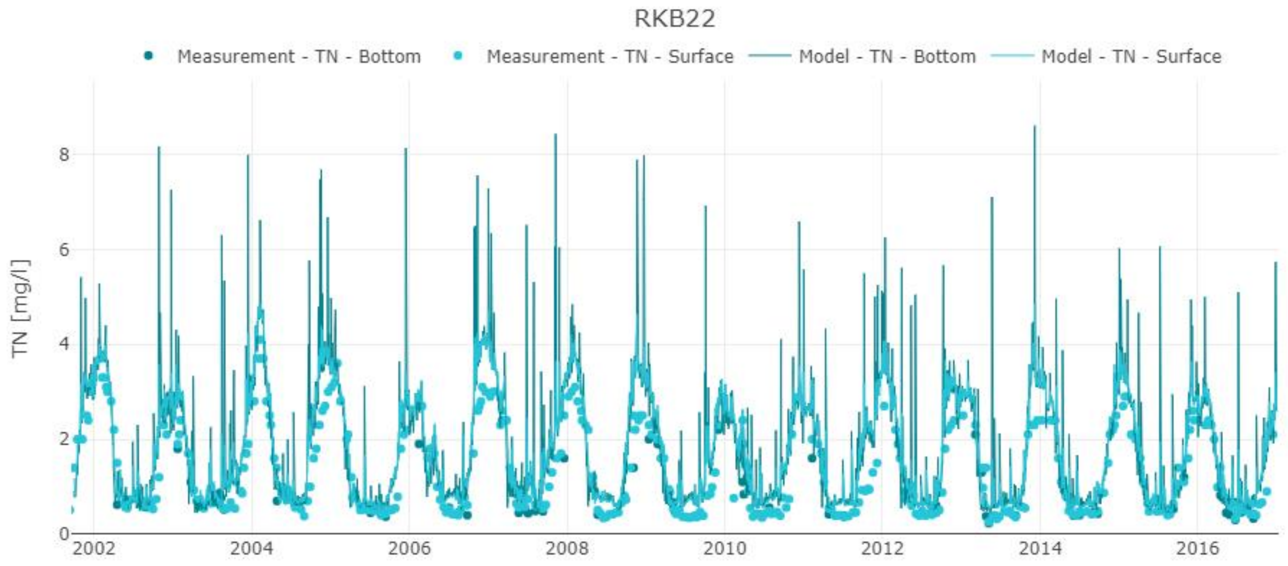

Figure 5-11 Comparison of measured and modelled concentrations of total nitrogen (TN, mg/l) at station RKB22 in surface and bottom (2 m) waters. Scatter data represent measurements, and solid lines show modelled data for the entire period.

The seasonal dynamics in TP projected by the model (see Figure 5-12) tend to predict more accurately for surface water compared to bottom water values. The spikes in TP in bottom waters are a result of re-suspension. The model performance for TP at station RKB22 is ‘very good’ (CF) and ‘good (P-Bias). From the quality measure Spearman Rank Correlation, the model performance for this parameter is ‘poor’.

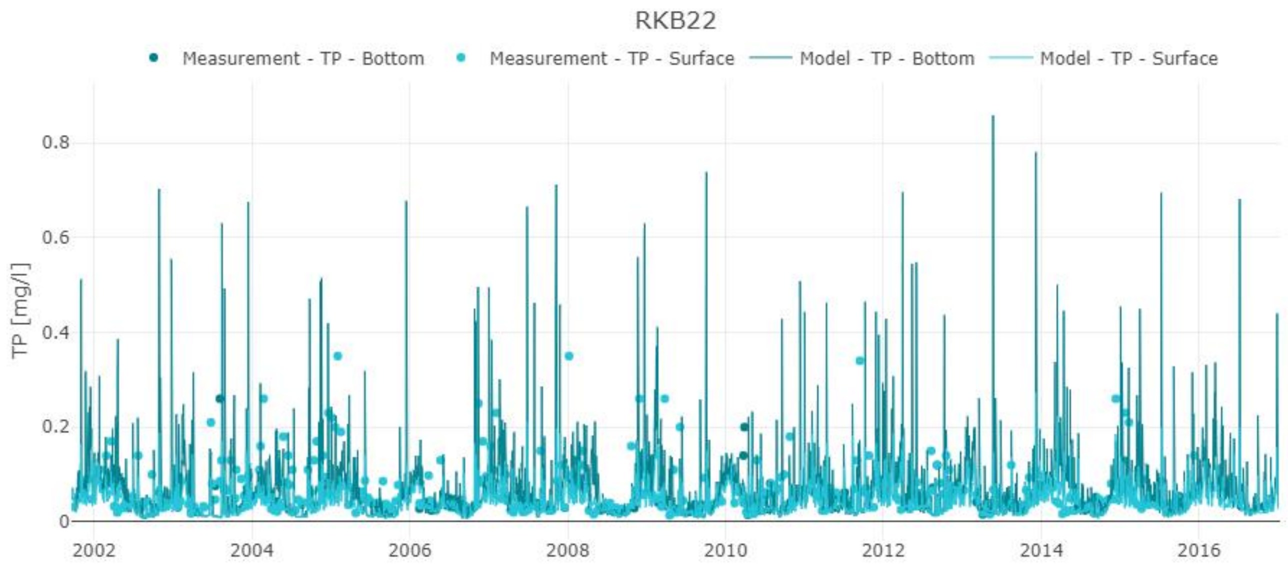

Figure 5-12 Comparison of measured and modelled concentrations of total P (TP, mg/l) at station RKB22 in surface and bottom (2 m) waters. Scatter data represent measurements, and solid lines show modelled data for the entire period.

5.3.2 General Calibration/Validation

For the calibration/validation period (2002-2016) two out of the four stations had a sufficient amount of measurement data (at least one year of weekly or bi-weekly data) to be included in the model performance analysis. Figure 5-5 shows the location of the two stations (stations RKB22 and RKB23) with measurements of ecosystem parameters (chlorophyll-a (CH), light attenuation (K_d), dissolved oxygen (DO), dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), total nitrogen (TN), and total phosphorus (TP)) during the period 2002-2016. Time series data are presented using the WEB-tool (http:// rbmp2021-2027.dhigroup.com).

In Table 5-1 and Table 5-2, the model performance is evaluated based on three performance measures: P-Bias, Spearman Rank Correlation and CF.

In the tables, colour codes are included to highlight the overall model performance as ‘excellent’, ‘very good’, ‘good’ or ‘poor’. For the biogeochemical model covering Nissum Fjord, we aim at ‘excellent’, ‘very good’ or ‘good’ model performance for 75% of the data sets on measures. All model performances (both annual and summer/winter) evaluated against the three different quality measures at two stations were found to be ‘excellent’, ‘very good’ or ‘good’ in 74% of the measurements (see Figure 5-13 and Table 5-1 and Table 5-2). The annual model performance was found to be ‘excellent’, ‘very good’ or ‘good’ in 81% of the measurements.

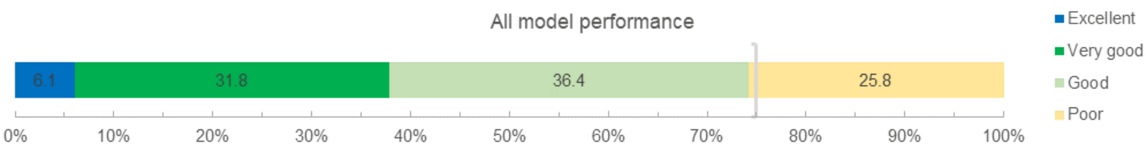

Figure 5-13 Bar chart illustrating all model performance evaluated against three different quality measures and all parameters. The vertical line indicates the aim of 75% being ‘excellent’, ‘very good’ or ‘good’.

According to P-Bias (Table 5-1 and Table 5-2), the model meets ‘excellent’, ‘very good’ or ‘good’ for 82% of all measurements (including specific winter and summer evaluations) and 79% when evaluating the annual measurements only. A ‘good’ model performance measured by P-Bias for summer and winter measurements indicates that the predicted absolute values of summer chlorophyll-a, summer light attenuation, and winter inorganic nutrient concentrations correspond well to the observed values. In general, the P-Bias obtains negative values for most of the parameters, indicating that the model underestimates observed values. On average, P-Bias evaluates the model performance for dissolved oxygen to be ‘excellent’; for TP the model performance is on average ‘very good’; for CH, K_d, DIN, and TN the average performance is ‘good’. The model performance for DIP evaluated from P-Bias is on average ‘poor’.

As for the quality measure Spearman Rank Correlation (Table 5-1 and Table 5-2) the model performance meets ‘excellent’, ‘very good’ or ‘good’ in 50% of all measurements (including specific winter and summer evaluations) and 64% in the annual measurements. A good annual correlation obtained from the Spearman Rank Correlation measure indicates a good seasonal correlation, where the predicted dynamics correspond well with the observed seasonal variability. On average, the Spearman Rank Correlation evaluates the model performance for dissolved oxygen, DIN and TN to be ‘very good’. For TP, the average performance is ‘good’, and the model performance for K_d, CH and DIP evaluated from Spearman Rank Correlation is on average ‘poor’.

According to the performance measure CF (Table 5-1 and Table 5-2), the model meets ‘excellent’, ‘very good’ or ‘good’ in 91% of all measurements and 100% of annual measurements at the two stations (Table 5-1 and Table 5-2). On average, the CF evaluates DO, K_d, DIN, TN, and TP to be 'very good' for all measures and 'good' for CH and DIP.

Table 5-1 Review of model performance at station RKB22 based on measured and modelled data for the validation period 2002-2016. Blue colour indicates an 'excellent' model; dark green indicates a 'very good' model; light green indicates a 'good' model, and yellow indicates a 'poor' model.

Parameter	P-Bias (%)	Spearman Rank Correlation	CF	Number of observations
TN annual	31.8	0.84	0.51	425
TP annual	-35.4	0.28	0.73	394
DIP annual	31.1	0.18	1.40	424
DIP winter[a]	-10.1	-0.17	3.11	74
DIN annual	23.9	0.84	0.40	425
DIN winter[a]	25.8	0.80	1.10	73
CH annual	-29.3	0.24	1.24	426
CH summer[b]	-21.7	-0.01	1.17	202
DO annual	4.7	0.85	0.52	350
K_d annual	-41.8	0.38	0.63	359
K_d summer[c]	-30.7	0.09	0.69	233

[a] January, February, December

[b] May-September

[c] March-September

Table 5-2 Review of model performance at station RKB23 based on measured and modelled data for the validation period 2002-2016. Blue colour indicates an ‘excellent’ model; dark green indicates a ‘very good’ model; light green indicates a ‘good’ model, and yellow indicates a ‘poor’ model.

Parameter	P-Bias (%)	Spearman Rank Correlation	CF	Number of observations
TN annual	22.1	0.84	0.56	172
TP annual	-4.3	0.38	0.79	172
DIP annual	157.0	0.23	2.69	172
DIP winter[a]	101.3	-0.28	4.26	33
DIN annual	18.3	0.84	0.52	171
DIN winter[a]	18.4	0.68	1.34	32
CH annual	-45.4	0.57	0.89	173
CH summer[b]	-25.6	0.00	1.07	78
DO annual	-1.3	0.41	0.92	148
K_d annual	-30.9	-0.04	1.04	89
K_d summer[c]	-20.8	-0.14	0.96	59

[a] January, February, December
[b] May-September
[c] March-September

6 Conclusion

This technical note shows that the model performance for the biogeochemical model covering Nissum Fjord meets the performance measure ‘excellent’, ‘very good’ or ‘good’ in 81% of the annual measurements and 74% in both yearly and summer/winter measurements evaluated against three quality measures. The ambition is to meet the above criteria in 75% of all measurements for all parameters and all stations (lumped). The performance of the Nissum Fjord model is 1% below the goal. The model is sensitive to the re-suspension of nutrients where the exact timing influences the performance, which will be considered in further analysis. Hence, we conclude that the biogeochemical model covering Nissum Fjord is well suited for modelling scenarios as part of the overall development of mechanistic models towards the RBMP 2021-2027.

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