SOILS2SEA DELIVERABLE NO. 2.2

BONUS

SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

Soils2Sea scenarios for nutrient reductions

SOILS2SEA

Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams

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Soils2Sea scenarios for nutrient reductions

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Contents

1. Summary

An important component in Soils2Sea is to analyse how differential regulation as well as changes in land cover, agricultural practices and climate may affect the nutrient (nitrogen and phosphorus) losses from land areas. For this purpose scenarios will be tested in order to test how robust differentiated nutrient load reduction measures are towards plausible climate change and land use changes. For this purpose coherent climate and land use/management scenarios for individual catchments and the entire Baltic basin will be developed and tested. The overall objectives of the scenario analyses in Soils2Sea are twofold:

- Analyse how changes in regulatory paradigms will affect nutrient loading to the Baltic Sea
- Analyse how climate changes and associated land use changes will affect nutrient loading to the Baltic Sea.

At the catchment scale the objectives are to:

- Analyse how spatially differentiated measures affect N and P loading at catchment scale
- Provide scenarios representing various land use and management as basis for stakeholder discussions
- Provide the basis for developing effectiveness parameters to perform upscaling of spatially differentiated measures from catchment to Baltic Sea scale.

At the Baltic scale the objectives are to:

- Analyse how combinations of changes in climatic conditions with targeted changes in land use and land management will affect nutrient loading to the Baltic Sea
- Provide scenarios for 2050 with estimates of potential future land use and climate change
- Analyse how effective spatially differentiated measures are at reducing loads to the Baltic Sea and if this changes in a future climate.

The scenarios of land use change will together with projections of changes in land management feed into scenario studies at both catchment and Baltic Basin scales. The climate change scenarios will be provided by SMHI considering available scenarios and climate model runs. These climate change scenarios will consider a 20 year period for 2041-2060 compared with baseline period of 1991-2010. Several climate model runs will be used to consider the uncertainty (i.e., 2 GCM x 2 RCM). Mitigation scenarios will be considered separately for the Baltic Basin scale and for individual catchments. The scenario analyses for the Baltic Basin scale will be conducted using the HYPE model and consider measures to reduce nutrient losses from agriculture and enhance retention in the landscape. This will also consider spatially differentiated application of all measures considered. All scenarios will be compared to a reference that represents the current situation. The measures to reduce nutrient (in particular nitrogen) losses will include:

- Reduced N fertilisation
- Maximum N utilisation required from applied manure
- No autumn fertilisation

- Use of catch crops (where possible)
- No autumn tillage or ploughing

These measures will be either applied uniformly or only to parts of the landscape depending on N retention. The measures that will be applied spatially in the landscape to enhance retention will include:

- Abandon agriculture in zones with low nutrient (nitrogen) retention
- Buffer zones along streams and rivers (of varying width)
- Establishment of wetlands
- Meandering of streams or other stream measures to enhance nutrient retention

For including the differentiated application of measures in the HYPE model there is need to calibrate the retention parameters in HYPE. For this comparative studies will be conducted between different model setup for the Danish catchments (Norsminde and Odense), where also uncertainties related to estimation of N leaching under different land use and climate change will be assessed.

The scenario analyses at catchment scales will have different focus, but in total they will support the overall objectives laid out above as well as the modelling at the Baltic Basin scale:

- Norsminde and Odense (Denmark)
    - Differentiation of measures within the landscape to reduce N loading (depending on N retention and N leaching as well as on farm structure).
    - Land use and climate change scenarios combined with spatial differentiation of measures to reduce N loading
- Tullstorps Brook (Sweden)
    - Stream measures and hyporheic zone retention
- Kocinka (Poland)
    - Retention time of groundwater and surface waters
    - Changes in agricultural fertilisation practices
- Pregolya (Russia)
    - Subset of scenarios used at Baltic Basin scale

2. Introduction

An important component in Soils2Sea is to analyse how differential regulation as well as changes in land cover, agricultural practices and climate may affect the nutrient (nitrogen and phosphorus) losses from land areas. For this purpose scenarios will be tested in order to test how robust differentiated nutrient load reduction measures are towards plausible climate change and land use changes. For this purpose coherent climate and land use/management scenarios for individual catchments and the entire Baltic basin will be developed and tested.

An initial range of scenarios will be designed to include combinations of the following factors:

- Climate change (current, low/high for 2050 using regionally downscaled CMIP5 (Taylor et al., 2012) projections from a coupled ocean atmosphere model shown to give more realistic conditions for the Baltic Sea region (Meier et al., 2012)
- Land cover and land use change considering proportion of agriculture, type of agriculture (annual and perennial crops), nutrient input intensity in accordance with CMIP5 storylines, including changes in N deposition (Dalgaard et al., 2012).
- Measures to reduce nutrient losses and enhance retention in the landscape (Dalgaard et al., 2011).
- Spatially differentiated application of all measures considered. All scenarios will be compared to a reference that represents the current situation.

Focus in the scenario studies for N will be on spatial location of N leaching reduction measures. These measures will include measures related to land use (agriculture, forestry, nature, urban), N inputs (manure and fertiliser amount, manure types, spatial differentiation in N fertilisations), crop types (arable crops versus permanent crops, including spatial location), crop rotations (crop sequence, cover crops), crop management (timing of sowing, fertilisation etc.), and drainage management (filter technologies, re-established wetlands). The scenarios will be defined to correspond to different governance schemes as defined in WP6. This may thus include different emphasis on land use and management as well as drainage management, including relocation of activities within the landscape.

Focus in the scenario studies for P will be on spatial location of P reduction measures. These P reduction measures may include targeted fertiliser and manure application, restriction on tillage, buffer zones along streams and lakes and conversion from arable land to permanent crops. Further filter technologies for reducing P outputs through drainpipes may be considered.

This report describes the scenario analyses that will be undertaken in the Soils2Sea project and how these scenarios will be implemented at both catchment and Baltic Sea scale. It further outlines the time plan for conducting these analyses, including the interaction with stakeholders as well as related research projects.

2.1 Objectives

The overall objectives of the scenario analyses in Soils2Sea are twofold:

- Analyse how changes in regulatory paradigms will affect nutrient loading to the Baltic Sea
- Analyse how climate changes and associated land use changes will affect nutrient loading to the Baltic Sea

At the catchment scale the objectives are:

- Analyse how spatially differentiated measures affect N and P loading at catchment scale
- Provide scenarios representing various land use and management as basis for stakeholder discussions
- Provide the basis for developing effectiveness parameters to perform upscaling of spatially differentiated measures from catchment to Baltic Sea scale.

At the Baltic scale the objectives are

- Analyse how combinations of changes in climatic conditions with targeted changes in land use and land management will affect nutrient loading to the Baltic Sea
- Provide scenarios for 2050 with estimates of potential future land use and climate change
- Analyse how effective spatially differentiated measures are at reducing loads to the Baltic Sea and if this changes in a future climate.

The scenario analyses at catchment scales will have different focus, but in total they will support the overall objectives laid out above as well as the modelling at the Baltic Basin scale:

- Norsminde and Odense (Denmark)
    - Differentiation of measures within the landscape to reduce N loading (depending on N retention and N leaching as well as on farm structure).
    - Land use and climate change scenarios combined with spatial differentiation of measures to reduce N loading
- Tullstorps Brook (Sweden)
    - Stream measures and hyporheic zone retention
- Kocinka (Poland)
    - Retention time of groundwater and surface waters
    - Changes in agricultural fertilisation practices
- Pregolya (Russia)
    - Subset of scenarios used at Baltic Basin scale

3. Scenario components

3.1 Previous nutrient scenario studies for the Baltic Basin

A few scenario studies have previously been conducted for the Baltic Sea Basin to explore ways to reduce the nutrient loadings. These are outlined below.

Humborg et al. (2007): Riverine transport of biogenic elements to the Baltic Sea - past and possible future perspectives (See Mörth et al. 2007 for model description).
Scenarios: (i) improved urban waste water treatment (UWWT) (all countries to Swedish treatment levels), (ii) P emissions are reduced by 0.2 kg per person and year, (iii) Livestock density in all countries equal to Denmark today.
Key results: Increased N due to increased meat production. Decreased P due to improved UWWT and damming.
Methods: Emissions database connected to lumped hydrologic model based on the generalized watershed loading function model, 105 separate catchment models.
Scientific contribution: First attempt at pan-Baltic nutrient simulations for different scenarios.
Comments: Uses static emission coefficients and retentions.

Arheimer et al. (2012a): Climate change impact on riverine nutrient load and land-based remedial measures of the Baltic Sea Action Plan.
Scenarios: Four climate change projections. UWWT efficiency of 90 % for P and 70–80 % for plants > 100,000 pp. Rural max load pp of 0.65 g P and 10 g N per day. N Load from arable land reduced by 20%.
Key results: On average N loads to sea reduce in future climate, while P loads increase, but high uncertainty. Improved WWT helps achieve BSAP P target in Baltic Proper, but not N (even with improved agriculture).
Methods: HYPE model (dynamic leaching, GW retention & SW retention on daily time-scale in sub-basins of resolution ca 350 km^2).
Scientific contribution: 1) Combined effect of climate change and nutrient reduction measures compared to BSAP, 2) Only high-resolution model to resolve soil, GW and SW processes.

Eriksson et al. (2013): Future nutrient load scenarios for the Baltic Sea due to climate and lifestyle changes.
Scenarios: 1) Climate scenarios (from Ensembles) sampling natural variability, GCMs, and emissions); 2) Population scenarios (UN medium growth), 3) Consumption (pseudo population, i.e. increased consumption counts as ‘extra people’.
Key results: All scenarios showed increasing loads. Lifestyle changes will have a larger potential impact on nutrient loads to the entire Baltic Sea relative to climatic changes.
Methods: Empirical functions (regression) linking population density and river discharge to nutrient loads.
Discharge change simulated with CSIM (calibrated to EOBS). Delta change used
Comments: There are too many dynamic processes that are assumed constant in this empirical approach.

Wulff et al. (2014): Reduction of Baltic Sea Nutrient Inputs and Allocation of Abatement Costs Within the Baltic Sea Catchment.
Scenarios: (i) fertilizer use in the transitional countries (Poland, Russia, and the Baltic States) increased to the levels now used in Germany, (ii) BaltCOST used to minimise cost of 5 measures (fertiliser reduction, catch crops, livestock reduction, restored farm wetlands, UWWT improvements).
Key results: Scenario 1 shows increased loads. The BaltCOST optimisations show that it is possible to achieve BSAP except for N in Danish straits and Baltic Proper.
Methods: Emissions database (NANI/NAPI – Net anthropogenic nitrogen inputs), MESAW for catchment retention (statistical calibrated to loads), CSIM for catchment modelling 10 km gridded model with DAISY N leaching, connected to MESAW for retention (simple multivariate N leaching functions derived from a summary of the Daisy model outcomes to make scenarios).
Scientific contribution: Use of cost minimisation tool to optimise scenarios.
Comments: Large mismatch in the complexity between DAISY for the leaching and MESAW for the retentions. Scenarios assume constant Ret_{GW} and $Ret_{SW.}$ Retentions are at the drainage basin scale. Impossible to ascertain the effect of wetlands at the drainage basin scale.

Hasler et al. (2014): Hydro-economic modelling of cost-effective transboundary water quality management in the Baltic Sea.
Scientific contribution: Use of cost minimisation tool to optimise scenarios.
Comments: Scenarios as for Wulff et al. (2014).

Ahlvik et al. (2014): An economic–ecological model to evaluate impacts of nutrient abatement in the Baltic Sea.
Methods: Dynamics of soil phosphorus in arable land.
Scientific contribution: Combine catchment and marine models to analyse the economics of nutrient abatement. The model framework incorporates economic and ecological data. Solve for the cost-efficient way to reduce phytoplankton in the Baltic Sea.

3.2 Factors included in scenario analyses

The scenarios will include combinations of the following factors:

- Climate change (current, low/high for 2050 using regionally downscaled CMIP5 projections from a coupled ocean atmosphere model shown to give more realistic conditions for the Baltic Sea region.
- Land cover and land use change considering proportion and type of agriculture (annual and perennial crops, crop type), in accordance with CMIP5 storylines. These end-use scenarios (including economic scenarios) are available to match changes in climatic and socio-economic conditions from the CLIMSAVE project via the I.A.P. tool.
- Crop and other land use management including nutrient input intensity. For the land use.
- Measures to reduce nutrient losses from agriculture and enhance retention in the landscape.

- Spatially differentiated application of all measures considered. All scenarios will be compared to a reference that represents the current situation.

The measures to reduce nutrient (in particular nitrogen) losses will include

- Reduced N fertilisation (10% below economically optimal)
- Maximum N utilisation required from applied manure
- No autumn fertilisation
- Use of catch crops (where possible)
- No autumn tillage or ploughing

These measures will be either applied uniformly or only to parts of the landscape (sub-catchments) with less than a specified retention. The measures that will be applied spatially in the landscape to enhance retention will include:

- Abandon agriculture in zones with low nutrient (nitrogen) retention
- Buffer zones along streams and rivers (of varying width)
- Establishment of wetlands
- Meandering of streams

3.3 Data availability and preparation

Climate change scenarios for the Baltic Sea Basin will be prepared as gridded daily data sets at 25 km spatial resolution for the 2040s period. Given the relatively short-term future time slice, which is going to be included in the project, uncertainty is mainly related to GCM model uncertainty, and the choice of RCP scenario plays only a secondary role in the overall projection uncertainty (Hawkins and Sutton, 2009). Projection uncertainty will be evaluated by incorporating two GCM model results, from the Hadley Centre HadCM3 and the Max-Planck-Institute ECHAM6 models; both dynamically downscaled using the Rossby Centre RCA3 regional model. The regional model time series will then be bias-corrected using the DBS (Distribution Based Scaling) method (Wei et al., 2010) or a similar suitable bias correction method. Daily precipitation, daily mean air temperatures, global radiation and reference evapotranspiration will be delivered as forcing data for hydrological impact analyses on a 50 km grid scale.

The scenarios will further consider the global drivers for enhanced food and biomass production as well as the visions by EU and the Nordic Council of Ministers for a bio-based economy. Since the biophysical and socio-economic characteristics differ considerably between the different case study areas (catchments), land use scenarios will likely differ considerably in between catchments. However, they will be designed to follow the storylines and environmental objectives relevant for both the entire Baltic basin and the respective catchments. The resulting scenarios will thus be expectations on major land use categories (e.g. agriculture, grasslands, forestry, nature, urban, etc.) and the intensity of the management of the agricultural land (i.e. yield levels) for the different catchments as well as the entire Baltic Basin and for time slices related to the climate change scenarios.

4. Scenarios at catchment scale

4.1 Danish catchments (Norsminde, Odense)

The focus of the scenario studies in the Danish catchments will be on changes in land use and management in interaction with groundwater retention. The main analyzes will be conducted for the Norsminde catchment, where also an uncertainty analysis on the effect of geological uncertainty on the retention map will be conducted. Odense catchment will be used as a test case to test whether the effects of spatial targeting the land use and management according to groundwater retention found for Norsminde is also valid for another catchment. In the following sections the focus will therefore be on the Norsminde model. The Odense model is however very similar to the Norsminde model, except that Daisy has been used to calculate the N-leaching instead of NLES. More details about the Odense model can be found in Karlsson et al. (2015).

4.1.1 Description of catchments

The Norsminde catchment is 101 km^2 and is located on the eastern coast of Jutland (figure 1a and b). The catchment discharges into the Norsminde Fjord, which is a sensitive water body with respect to nitrogen. The most downstream gauging station in the stream (st. 270035) where total observed N-loads are available covers an area of 85 km^2. Odense catchment is 486 km^2 and is located on the island of Funen (Figure 1a and c). Both Norsminde and Odense catchments are located in glacial landscapes from the Weichsel glaciation where the upper geology is dominated by clayey till with smaller units of glacial melt water sand and post-glacial freshwater peat (Figure 1a). Due to the clay till soils are both areas to a large extent tile drained.

4.1.2 Baseline input data

Climate data
The climate data used in the models are available on a daily time scale from the Danish Metrological Institute (DMI). Precipitation the data are available on a 10 km grid and potential evapotranspiration and temperature on a 20 km grid. The precipitation data have been dynamically corrected according to Stisen et al. (2012).

Input data to NLES
Input to NLES on crop rotation and application of fertilizer and manure is for the period 1990 to 2000 based on land use data available on parish level from the Danish Statistical Databank. After 2000 crop and fertilizer/manure data are available on field block or field level from national agricultural databases (data from The General Agricultural Register (GLR in Danish) and data on yearly fertilizer use and area of catch crops from The Danish AgriFish Agency). Soil data used in NLES is from typical Danish soils. Denmark has been divided into 5 geological regions and for each region has 11-12 typical combinations of upper and lower soils been defined (Højbjerg et al., 2015).

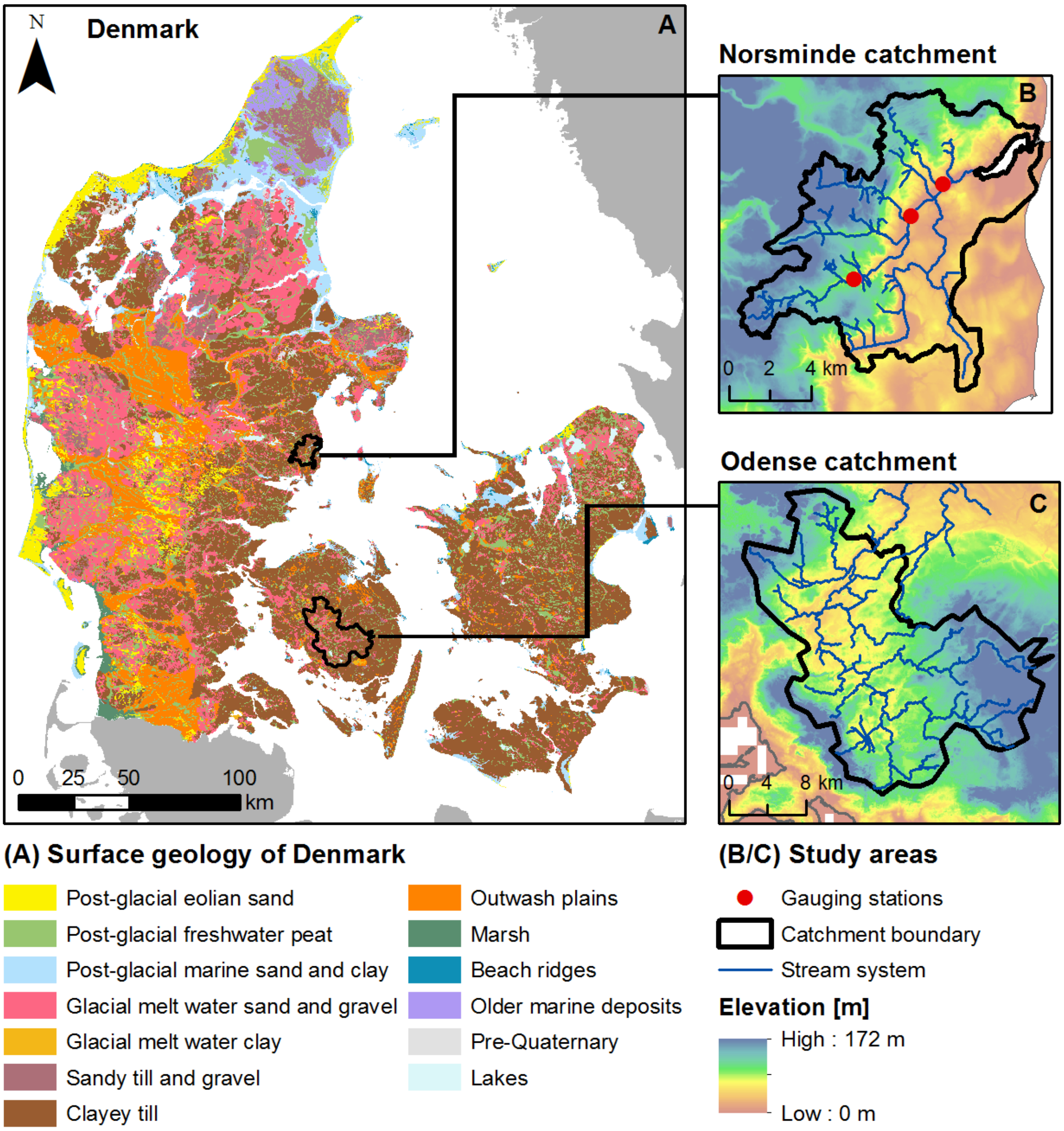

Figure 1 Location of Norsminde and Odense Catchment and the main geological soil types in Denmark

Input data to MIKE SHE

The input to the flow model in MIKE SHE is, in addition to climate data, a geological model. For Norsminde catchment 20 geological models been set up in a previous research project (NiCA, www.nitrat.dk) in order to analyze the geological uncertainty. The models are constructed stochastically using the software TProGS and 10 of the models are based on borehole data and the other 10 models on both borehole and geophysical data (using the SkyTEM system). However, it is only a part of the catchment that is stochastically generated, for the rest of the catchment a deterministic geological model based on the SkyTEM data is constructed (He et al., 2014). Based on the geological models hydrostratigraphical units are defined and for each of these units constant hydrological units are assumed. The most sensitive hydrological parameters in the model setup are estimated by calibration against observations of groundwater head in a number of wells and stream discharge from the 3 stream gauging stations in Norsminde. The remaining hydrological parameters are defined based on literature values.

The inputs to the N-transport model in MIKE SHE are the N-leaching from the root zone from NLES, the depth of the redox interface (where nitrate is reduced to N_2) and N-input to the stream from point sources. The depth of the redox interface is estimated according to the method described in Hansen et al. (2014). The spatial pattern in the interface is a function of the recharge flux and the geology (differences in redox capacity) and the actual depth of the interface is then calibrated so the simulated N-load out of the catchment matches the observed. N-input to the stream system from point sources is available from the Scientific Data Centre for Hydrological point Sources (under the Danish Nature Agency).

4.1.3 Description of models

In Norsminde catchment a combination of the NLES model for calculating N-leaching and the MIKE SHE model for describing the transport from below the root zone and to the catchment outlet is used. A simple direct linking between the models is used without feedback, i.e. N-leaching is calculated with NLES and then used as input to the MIKE SHE model. The Norsminde model has a grid resolution of 100 m.

NLES is an empirical model to calculate N-leaching from the root zone on agricultural areas. NLES calculates a yearly N-leaching based on input data on crop rotation, input of fertilizer and manure, N-fixation, percolation, soil type and content of organic matter and clay in the soil. NLES is calibrated on N-leaching observations from Denmark and therefore reflects these observations and the agricultural practice behind. Because the agricultural practice has been changing through the baseline period (1991-2010), two different versions of the model are used; NLES 3 and NLES4. The NLES3 model is based on 1299 observations and is used for the period 1991-2000 (Kristensen et al., 2003) and the NLES4 model is based on 1467 observations and is used for the period 2001-2011 (Kristensen et al., 2008). The yearly N-leaching from NLES is afterwards disaggregated to daily values using results from the Daisy model set up for typical crop rotations and soil types. Daisy is also used to calculate the monthly percolation used in the NLES calculations.
The Daisy model is a physically-based root zone model capable of simulating water flow as well as transport and transformation of nitrogen in a 1D soil column. Daisy simulates flow

and leaching of solutes through three different pathways: matrix flow, macropore flow and drain flow (Abrahamsen and Hansen, 2000; Hansen et al., 1991). For all agricultural areas the N-leaching is calculated with NLES, but for non-agricultural areas standard values for N-leaching are used. The results for all areas are aggregated to a 100 m grid (Højbjerg et al., 2015).

MIKE SHE is a distributed physically-based hydrological model capable of simulating evapotranspiration as well as 1D unsaturated, 1D river, 2D overland and 3D saturated flow and transport with fully dynamic exchange between the components. Tile drainage can furthermore be included in the saturated zone (Havnø et al., 1995; Refsgaard and Storm, 1995). The transport of N in MIKE SHE is simulated using particle tracking. The NLES calculated N-leaching is input to MIKE SHE and for each 2 kg of N added to a grid cell is a particle released. The particles are released on the water table and tracked until they reach a sink (stream, drain, well or fjord/ocean). When a particle crosses the redox interface it is assumed to be completely reduced. Point source data is added to the simulated N-load from groundwater to the stream outside the MIKE SHE framework. The same is done with the N-retention in the stream system. The amount of N-retention in the stream is calculated very simple on a sub-catchment level (4 sub-catchments within Norsminde) and is defined as function of the stream length.

4.1.4 Scenario approach

The scenarios for Norsminde catchment will focus on implementing measures on areas with low N-retention. The scenarios are run for the baseline climate as well as 4 future climate projections (in the following called future 1-4). For each climate the N-leaching is calculated with NLES and the N-reduction map is calculated with MIKE SHE. The N-reduction map changes with the climate because a different precipitation and evapotranspiration pattern (in space and time) will change the recharge and thereby how much water and nitrate is transported below the redox interface.

For each climate scenario different scenarios will be conducted by changing the N-leaching input to the MIKE SHE model belonging to the respective climate. The N-leaching input is changed by either decreasing the N-leaching uniformly or by increasing the N-leaching on areas with high retention and applying a constant low leaching on areas taken out for targeted measures. In some scenarios the N-leaching pattern is additionally redistributed so that the highest leaching is applied on the fields with the highest retention and vice versa. The scenarios that will be run for Norsminde can be seen in Table 1. Explanations to the different columns in table 1 are given in the following:

N-load reduction target: The reduction target in the total N-load at the downstream gauging station (st.270035). This is the calibration target in the scenarios, expect for the Baseline, Target 3 (baseline) and Target 3 (future 1-4) scenarios which are not calibrated. For the Target 3 scenarios the reductions in N-load are one of the results.

Climate/N-leaching input/Retention map: Scenarios for the baseline climate as well as 4 different future climates will be conducted (future 1-4). The climate affects the N-leaching and also the retention map, why new versions of these inputs are needed in the scenario runs.

Area taken out for targeted measures: In some of the scenarios agricultural areas are taken out of normal production. On these areas targeted measures must be applied to lower the N-leaching to a leaching corresponding to the value given in the column "**N-leaching on targeted measures areas**".

Change in N-leaching on normal production areas: On the agricultural areas with normal production the N-leaching is allowed to increase with 10% in some of the scenarios. In the Uniform scenarios the leaching on these areas must be reduced by X%. This number is a calibration parameter.

Spatial pattern in N-leaching: In some of the scenarios the spatial pattern in the N-leaching input for the climate in question is kept stationary. But for some of the scenarios, the N-leaching is spatially distributed so that high leaching values are applied on areas with a high retention and vice versa.

4.1.5 Comparing methods for estimating nitrogen load under climate change

Both climate and land use changes can influence water quality and quantity in different ways and thus nitrogen (N) loading to streams. Therefore, for predicting future trends in N loading, simulations should ideally account for the combined effect of both projected climate and land use (LU) changes. In this case study, land use projections and climate change scenarios will be integrated with different hydrological models to estimate the relative and combined impact of climate and land use projections on N loading for the two catchments in Denmark. Also, model uncertainty on simulated N loading will be also investigated. The different models involved in the inter-model comparison differ profoundly in their complexity, level of process representation and data requirements. The models include empirical and physics-based (mechanistic) model approaches. Therefore, the main objective of current study case is twofold:

- Compare three models to simulate N loading for two catchments in Denmark. The three models considered are an empirical model (NLES) and two process based models DAISY and the HYPE model. NLES and DAISY will be used in conjunction with the MIKE-SHE model to estimate N loadings.
- Investigate the effect of different climate and land use change on N load for the two catchments using the two process based models DAISY and HYPE. Moreover, the effect of different land management measures on future N load will be studied. In this study we further investigate different sources of uncertainties in projections of N loads using an ensemble of simulations.

Table 1 Scenarios to be conducted for Norsminde catchment. The scenarios saying "Future 1-4" are all 4 individual scenarios, thus the total number of scenarios is 49. The value X in some of the scenarios means that the variable is a calibration parameter (Uniform) or an end result of the scenarios (Target 3).

Scenario name	**N-load reduction target (% of base-line load)**	**Climate/N-leaching input/Retention map**	**Area taken out for targeted measures**	**N-leaching on targeted measure areas (kg N/ha/yr)**	**Change in N-leaching on normal production areas (%)**	**Spatial pattern in N-leaching**
Baseline	0	Baseline	No	-	0	Baseline
Uniform (baseline)	20	Baseline	No	-	X	Baseline
Uniform (future 1-4)	20	Future 1-4	No	-	X	Future 1-4
Target 1.1 (future 1-4)	0	Baseline	Yes	10	10	Baseline
Target 1.2 (future 1-4)	20	Baseline	Yes	10	10	Baseline
Target 1.3 (future 1-4)	20	Baseline	Yes	10	10	Spatial targeted
Target 1.1 (future 1-4)	0	Future 1-4	Yes	10	10	Future 1-4
Target 1.2 (future 1-4)	20	Future 1-4	Yes	10	10	Future 1-4
Target 1.3 (future 1-4)	20	Future 1-4	Yes	10	10	Spatial targeted
Target 2.1 (baseline)	0	Baseline	Yes	20	10	Baseline
Target 2.2 (baseline)	20	Baseline	Yes	20	10	Baseline
Target 2.3 (baseline)	20	Baseline	Yes	20	10	Spatial targeted
Target 2.1 (future 1-4)	0	Future 1-4	Yes	20	10	Future 1-4
Target 2.2 (future 1-4)	20	Future 1-4	Yes	20	10	Future 1-4
Target 2.3 (future 1-4)	20	Future 1-4	Yes	20	10	Spatial targeted
Target 3 (baseline)	X	Baseline	No	-	0	Spatial targeted
Target 3 (future 1-4)	X	Future 1-4	No	-	0	Spatial targeted

Four different future climate change scenarios will be used in this case study in order to better represent the uncertainties in regional scale projections of future climate. Regional climate models (RCM) will be used to dynamically downscale the outputs from CMIP5 General Circulation Models (GCM) under the high-end Representative Concentration Pathway (RCP8.5).

To obtain potential future daily weather data sets, four GCM-RCMs will be used to generate four different climatic scenarios for two time periods: a 20 years baseline period (1991-2010) and a 20 years projection scenario (2041-2060), used as input to DAISY and HYPE models to simulate N load for the two catchments. Daily weather data include six parameters: precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity. The different climate change scenarios for the period 2041-2060 is referred hereafter as CCsci, where i denotes for the number of the climate scenario (i.e. 1 to 4).

The CO_2-enrichment effect on crop yield will be accounted for in our study case. Since DAISY does not account for the CO_2 effect, therefore the method used and outlined by Børgesen and Olesen (2011) will be used.

The land use map that will be considered in this study case was created at a 100 m resolution for the year 2005 and will serve as baseline for the simulations. After image classification, 29 and 27 land use classes were defined based on the Danish classification system for Norsminde and Odense catchments, respectively. The total agricultural areas represent 67% and 64% of the total catchment area for Norsminde and Odense catchments, respectively.

The major driver for land use change is population growth and subsequent conversion of the natural forest vegetation into developed land, essentially residential land. In order to represent the alternative tendencies of future developments in land use, different scenarios will be developed. The defined land use scenarios are referred hereafter as LUsci, where i denotes the number of the LU scenario. The generation of the scenarios is based on the assumption that for representing consistent and realistic land use change options, the socio-economic implication of these land use changes need to be taken into account (Krause et al., 2008).

For the future projections, early sowing and longer growing seasons for the different crops will be accounted for to represent future cultivars change. A relative increase of the number of growing degree days (GDD) for the different crops will be considered for the phase sowing to flowering as well as for the phase flowering to maturity. The approach outlined by Olesen et al., (2012) will be used. Regarding sowing dates, a sowing window will be set for each crop and a sowing criterion will be defined based on temperature and/or precipitation (Moriondo et al., 2011; Zhao et al., 2014) or based on surface soil moisture content (Tao et al., 2009).

The nutrient management scenarios that will be evaluated in this study include increasing current fertilization rate by 10% and incorporation of catch crop during autumn and winter for selected crop rotations. Their relative effect on future N loads will be investigated.

For model inter-comparison study, the LU map and the observed weather data for 2005 will be used. This baseline scenario was assumed to reflect current conditions for the two catchments.

To evaluate the magnitude of responses of N loads from the hydrological models to various scenarios of climate and land use and management changes, the DAISY-MIKE SHE and HYPE simulations will be performed for two 20-year time periods. The first is the baseline period, 1991-2010, for which calibration and validation were performed (the land use data in 2005 will be used). The second is the future period of 2041-2060, for which the projected climate and land use data will be used. In order to investigate the impact of climate change alone, the impact of land use changes alone, and the combined impact of climate and land use changes different sub-scenarios will be designed by altering one variable at a time. These scenarios are presented in Table 2. The impacts of climate change alone can be estimated by comparing the simulated N load of scenarios 1 and 2; the impacts of land use change can be estimated by comparing scenarios 1 and 3; finally, the combined impacts of climate change and land use changes can be estimated by comparing scenarios 1 and 4.

Table 2 Different simulation scenarios that will be considered in the Danish case study

Scenario	**Weather data**	**Land use data**	**Number of simulations per catchment**
Scenario 1	Weather data for the period 1991-2010	LU map of 2005	1
Scenario 2	Climate change scenarios for the period 2041-2060 ($CCsc_i$)	LU map of 2005	4×1
Scenario 3	Weather data for the period 1991-2010	Land use change scenarios (different $LUsc_i$) for the period 2041-2060	1×number LUsc
Scenario 4	Climate change scenarios for the period 2041-2060 (different $CCsc_i$)	Land use change scenarios for the period 2041-2060 (different $LUsc_i$)	4×number LUsc

4.2 Tullstorp Brook

The focus of the scenario studies for the Tullstorp Brook will be on in stream measures to increase total residence times in surface waters and exchange fluxes with hyporheic zones. Thus, the overall aim is to investigate favorable conditions for an increased retention and degradation of nitrogen and phosphorous in surface water environments. The scenario analyses will be performed based on existing and generically simulated measures of restoration, or alternation of the stream hydraulics and geomorphology.

4.2.1 Description of catchment

Tullstorp Brook is a 30 km long stream located in the south of Sweden. The stream drains a 63 km^2 large area and discharges into the Baltic Sea close to the small town Skateholm. The watershed consists predominantly of glacial clays and till, and is intensively farmed with around 85% of the catchment area being agricultural land. Due to the climatic and geological conditions a majority of the agricultural land is tile drained to increase runoff from soil and provide optimal conditions for agriculture. The management of the catchment and streams for agriculture has resulted in large hydrological changes and high nutrient loads to the Baltic Sea. As a reaction on this a comprehensive management campaign has been running within the area since 2008, including implementation of wetlands and large stream restoration projects.

The restoration project is well documented and provides useful data for the scenario analysis in the form of extensive and detailed maps of streams and wetlands before and after the restoration. In addition to available data a series of field experiments have been and will be performed within the catchment including:

- Hydraulic conductivity measures of stream bed sediments
- Several tracer tests with the dye Rhodamine WT (RWT) both before and after the restoration
- A tracer test with ^{5}N enriched nitrogen, ^{32}P labelled phosphate, and tritiated water
- Measures of stream depth, width and bottom topography during the tracer tests

The data will be used to model existing scenarios before and after restoration and to constrain future scenarios to be realistic and have the effect of already observed improvements.

4.2.2 Description of models

Mathematical models are needed both for the evaluation of data and for performance of scenario analyses. The Advective Storage Path model (Wörman et al., 2002; Boano et al., 2014) have been used to evaluate data from the tracer tests resulting in estimations of residence time distributions, reactions rates, and nutrient fluxes that can be related to reaches with specific characteristics or capacities to retain and attenuate nutrients. Two key equations that can be used for the design of remediation actions in streams are the following:

$$\tau_{N,P} = \frac{x}{u}\left(1 + F(1 + K_B)\right)\left(\frac{1}{4} + \frac{D\beta}{u^2}\right)^{-0.5} \qquad (1)$$

$$m_0 = \exp\left[-\tau_{N,P}\beta\right] \qquad (2)$$

where F = retention parameter = W T / h, h = flow depth, W = exchange velocity, τ = residence time in hyporheic zone, K_B = sorption partition coefficient in the hyporheic zone, u = flow velocity, x = distance along stream, β = reaction rate and m_0 is percentage solute mass recovery at the effluence and D = dispersion coefficient. The implication of the first equation is a description of the delay of dissolved N and P in stream water as function of various stream reach parameters (on the right-hand side) that potentially can be changed using the right remediation actions. For phosphorus, such retention might be the main remediation mechanism if chemical and biological reactions are reversible. However, there is also a possibility that irreversible reactions occur in the form of mineralization of sediment bound phosphorus, long-term accumulation in lake sediments or uptake in vegetation. Nitrogen undergoes denitrification and other releases of gaseous forms (N_2O, NH_4) that can be considered to be irreversible in the stream water perspective. The associated reduction of percentage of the solute mass recovered at the effluence is reflected by the second equation.

Thus, by appropriate remediation design it is possible to modify particularly the retention parameter F (in equation (1)), but also the biochemical conditions and indirectly the sorption partition coefficient K_B and the reaction rate coefficient β can be changed. In this way degradation and attenuation of nutrients may be linked to specific geomorphic characteristics related to combinations of restoration measures.

For the residence time distributions, reduction potentials and exchange velocities of reaches with more complex characteristics the solutions have been found numerically in Matlab. Based on such analyses the F-factor (equation 1) can be expressed for a single harmonic feature as

$$F = \frac{\alpha\gamma}{\pi}\frac{\lambda}{h} \qquad (3)$$

where α and γ are two factors representing the relative geometry of two combined remediation features, λ = length of the larger feature and h = hydraulic head drop across the larger feature. This head drop can often be taken from the water surface elevation drop, but there is also an exchange caused by the dynamic head variation created by the flowing water along an uneven bed surface. Consequently, the total head drop along a water-course, Δh, can be distributed in the most optimal way associated with maximum λ/h–ratios. Therefore, the analyses include a comparison of the retention caused by a few major features versus the retention caused by a large number of minor distributed features.

Different scenarios can be analyzed based on the above equations by changing the parameters characterizing the stream reaches. Parameters that may be considered and can be changed in the model are:

- Stream morphology (meandering sinuosity, bottom profile shape)
- Stream length
- Stream water velocity
- Stream bed roughness
- Dispersion coefficient
- Biogeochemical reaction rates

To evaluate technical measures on the watershed scale, the results from the reach scale will be up-scaled using a network transport model. Special emphasis will be on the spatial distribution of both nutrient loading and transport pathways (i.e. the network of intra-connected stream reaches) and provide a direct way to investigate spatially differentiated remediation actions.

4.2.3 Scenario approach

The scenario analysis should include both a comparison of different types of measures and a study of the spatial distribution of those measures in the Tullstorps Brook catchment. Three types of scenarios will be studied:

- Before existing restoration
- After existing restoration
- Alternative restoration
    - Different measures and combination of measures
    - Different spatial distributions of the measures

The measures that can be considered in the scenario analysis may be divided into two groups, either constructed to increase retention times in surface waters or to increase exchange with the hyporheic zone.

Considered measures that increases residence times in surface waters are:

- Increasing meandering and prolonging stream pathways
- Installing embankments or sediment traps and by that increasing stagnant water volumes
- Implementing new wetlands
- Changing vegetation patterns, which changes the dispersion coefficient

Those measures may be analyzed with the models described above by changing stream length, storage zone volumes, network composition and dispersion coefficients, respectively.

Hyporheic exchange is induced by hydraulic head variations along the stream bottom as discussed above. In the scenario analysis the available hydraulic head loss over a reach can be utilized in different ways. Upcoming deliverables 4.2 and 4.3 will include proxy definitions of the head variations that arise when a new measure is implemented in the stream. Measures or geomorphic shapes that will be considered in the scenario analysis and added to a reach with flat bottom and constant slope are:

- Small submerged bed forms or objects, creating mainly dynamic hydraulic head variations along the stream bottom.
- Stepwise decreasing water surface, either by damming or by a step-shaped stream bottom, creating mainly static hydraulic head variations along the stream bottom.
- A meandering stream, creating mainly static hydraulic head variations between upstream and downstream the meander bar.

When evaluating the three measures it is important to consider the size of the features, or more specifically the aspect ratio h/λ of the head loss (h) over the length of the feature (λ), where the maximum available head loss of a reach is the total elevation decrease over that reach. Variations of this aspect ratio will be investigated and solutions were the hydraulic head drop is utilized by few larger features or several distributed smaller features will be compared. Some measures may then be chosen and evaluated in a closer manner to investigate the effect of spatial distribution of measures, for example by placing all measures in the downstream part of the catchment versus measures targeting main contamination point sources.

4.3 Kocinka

The focus of the scenario studies for Kocinka will be on changes in land use and management whose effectiveness in reducing nutrient loads to the river is affected and delayed by interactions with an extensive groundwater body. The scenarios have to address three characteristic features of the catchment: (i) patchy land use, (ii) predominantly poor soils and (iii) large changes in land use and management practices during the last 30 years due to the changing political and socio-economic conditions. The last notion is relevant to the whole of Poland and to the East European parts of the Baltic Sea basin.

4.3.1 Description of catchment

The Kocinka catchment (surface area of 257.8 km^2) is located in the south of Poland (Figures 3-5 and 3-6) in the Oder river catchment. The 40.2 km long Kocinka river discharges to the Liswarta river. The catchment is covered by 1 - 33 m thick Quaternary deposits of fluvio-glacial and aeolian origin underlain by the Upper Jurasic limestones (Figure 2). The Jurassic strata contain one of the largest groundwater bodies in Poland – the Major Groundwater Basin 326 (MGWB-326). Dominant soils are mainly sandy and clay soils. The topography is slightly undulating with elevations varying between 185 to 317 m a.s.l. The climate is temperate with an average annual precipitation of 600-700 mm/yr and average air temperatures between 7.5 to 8 °C. The catchment is mostly agricultural with pine forests dominating in the lower reach.

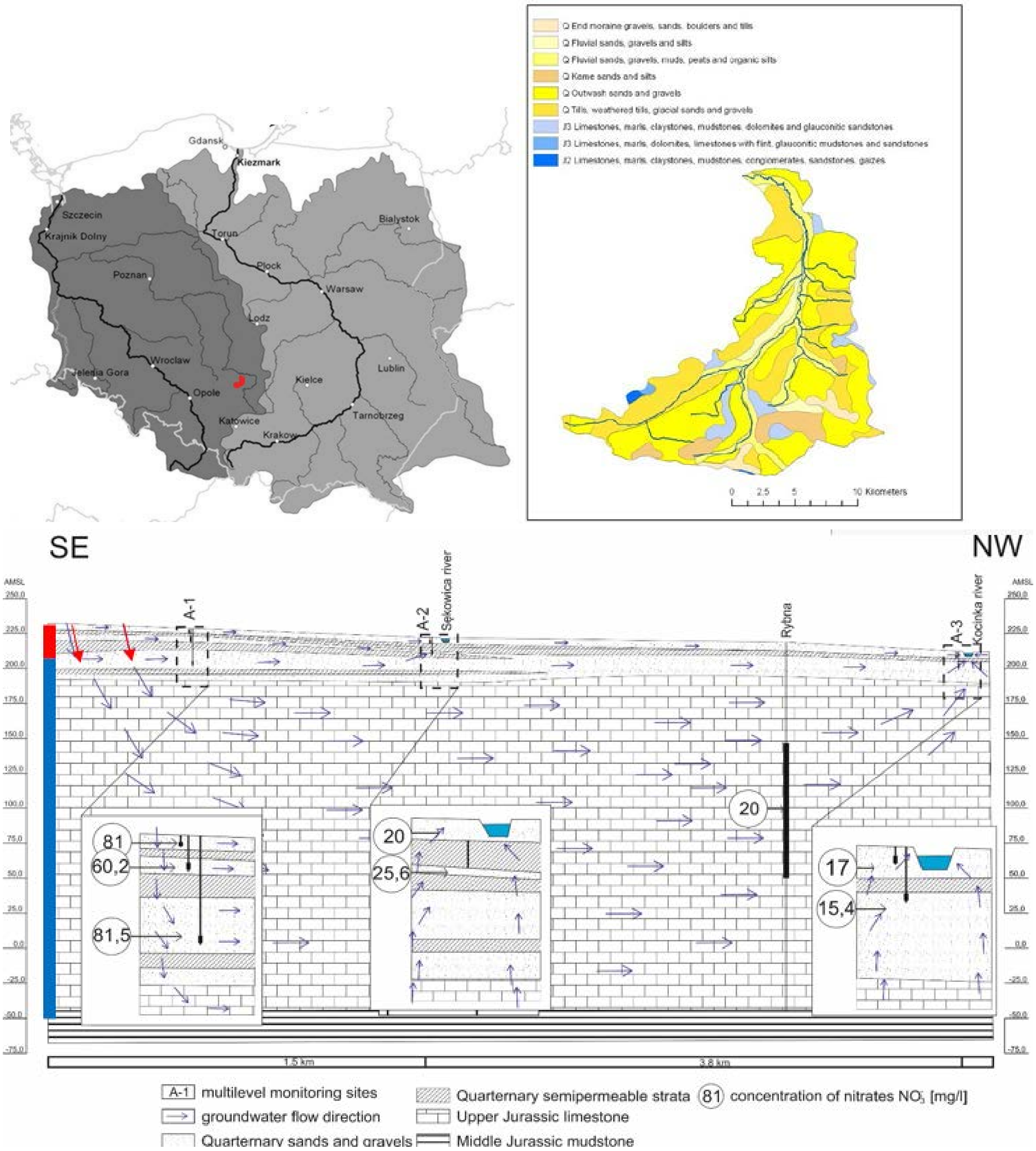

Figure 2 Location and structure of the Koncinka catchment in Poland.

4.3.2 Baseline input data

Because of the dynamic changes in the land use and agricultural practices before, during and after the baseline period emphasis has to be put on an appropriate identification and reconstruction of trends in land use and fertilization levels which might result in varying loads of nutrients leached from soils to the underlying aquifers. The two major turning points in this respect were the decline of the centrally planned economy in the 1980s and Poland’s accession to the European Union in 2004.

The climate data are available on a daily time basis for the neighboring Częstochowa and Wieluń meteorological stations from the Institute of Meteorology and Water management (IMGW).

Data on land use and soil properties taken from the available databases (e.g., CORINE) are verified and elaborated by own observations. The same applies to the fertilization data which are verified through interviews with farmers. The detailed information on fertilization levels in different parts of the catchment are available only for the recent situation. The spatially aggregated data available from the Central Statistical Office of Poland (GUS) will be used to reconstruct the temporal trends in fertilization levels for the area of interest. An alternative approach for the period before 1989 is application of the then recommended fertilization levels which were generally followed in practice, at least in the state owned farms.

Application of SWAT requires the knowledge of large number of parameters related to the meteorological conditions (daily precipitation, daily max. and min. air temperature, daily average wind speed, daily relative humidity, daily sum of solar radiation) as well as to the agricultural practices and crop and soil conditions (e.g. crops rotation, crops parameters, precise timing of agricultural practices). Quantification of all of these parameters even for a small size catchment is virtually impossible and the effective values of the unknown parameters will be set in through model calibration. There are two major point sources of nutrients to the catchments, which are two waste water treatment plants. Their loads will be estimated on the basis of own observations. Also estimates of the parameters related to tile drainage (depth to drains, time necessary to drain soil to the water holding capacity, time lag of water flow from drain to the river) will be obtained from the field observations.

Historical river discharge data are available only for the period 1974 – 1983. The average discharge and the baseflow discharge at the IMGW gauging station for that period were 218 mm/yr and 158 mm/yr, respectively. Regular observations of discharge and nutrient concentrations that commenced in the project in 2014 will be a basis for HYPE calibration.

A main input to MODFLOW and MT3D are data on infiltration levels and nutrient loads below the root zone. The steady state groundwater flow model (MODFLOW) was set up for the average annual precipitation for the period 1967 – 2004. The transient state transport model (MT3D) was calibrated with groundwater tritium observations for the period 1991 – 2013. Calibration of the transport model, which is used to route nutrient loads through the groundwater system to the surface catchment, is an ongoing process based on the new tritium data and the better quantification of the hydrogeological parameters.

4.3.2 Description of models

In the Kocinka catchment we will compare and integrate results of E-HYPE and local HYPE with a 3D MODFLOW model and with the generic GIS-based model (Vulnerability Map of Poland - VMP) of groundwater flow timescales which is based on the hydrogeological data available for the whole of Poland. The MODFLOW model provides explicit information on how nutrients inputs to aquifers transform into time series of nutrient loads in groundwater discharging to the streams and in groundwater outflowing to the neighboring catchments.

MODFLOW requires spatially distributed input data on nutrient leaching which will be provided by SWAT/NLES. Both MODFLOW and VMP provide Information on time scales of nutrient transport in groundwater but use of VMP is more operational for areas where no numerical groundwater flow and transport models are available. The VMP model will be supplemented with nitrate routing algorithms in order to support HYPE with the information on attenuation and retardation of nitrates in the groundwater component. The VMP will also be used to estimate the amounts of nitrate stored in the aquifers due to past changes in fertilization and leaching.

Due to heterogeneity of the catchment with respect to the natural conditions and land use patterns application of HYPE will require dividing the catchment into several sub-catchments. Such division is necessary not only in order to cope with the diverse land uses in different parts of the catchment but also to address the role of the direct groundwater inflows to the streams concentrated in the central part of the catchment.

4.3.4 Scenario approach

The scenarios for Kocinka catchment will have to address the above-mentioned characteristics of the catchment related to the spatial diversity of the natural conditions and to the still changing socio-economic conditions. Because of that we suggest an examination of two baseline scenarios for the periods 1974 – 2010 and 1991 – 2010. The former covering the period of intensive agricultural activities associated with fertilization levels exceeding the current values. Consequently, the effects of the following trends and measures have to be studied:

- Abandonment of agricultural land on poorest soils. Such areas will be transformed into low density residential areas, forest or abandoned land (with a potential for the spontaneous afforestation). Cessation of agricultural activities may result in the increased release of nutrients to groundwater. Estimation of such nutrient inputs must be based on the knowledge of nutrient levels in soils. Dynamics of these processes will depend on socio-economic conditions (e.g. subsidies for reforestation).
- Nowadays, winter cereals are the dominant crop, autumn tillage and fertilization are widespread while catch crops are not very common. Changes in these practices have a great potential for reducing nutrient leaching from soils.
- The use of mineral fertilizers In Poland increased by 30% since the accession to the EU while crop production increased by only 5%. The average level in Silesian Voivodship is 65 kg N/ha (average in Poland 67 kg N/ha) which is still low comparing to the EU average and is growing slowly.
- The focus on landscape measures in Poland is on flood protection and small-scale water retention while the ecological and water quality issues are often neglected. In the Kocinka catchment there are no schemes for river renaturation and restoration of riverine wetlands. On the contrary, there are plans for channelization of some river stretches.

Table 3 presents the factors that need to be considered in the proposed scenarios, the total number of which is 54.

Table 3 Components of scenario studies in the Kocinka catchment. The number to the right shows the number of scenarios that include the respective component

Primary concentration of N in deeper jurastic aquifer	
A - from 1974 to 2010	18
B - from 1991-2010	18
0 - without primary concentration in deeper jurastic aquifer	18
Land use	
Baseline	22
Future	32
Climate	
Baseline	2
Future	52
Agriculture	
Baseline	15
Reduction N-fertilisation 10% below economically optimal	3
No autumn N-fertilisation	3
No autumn tile or ploughing	3
Use of catch crops	3
No autumn fertilisation in 10% of agricultural area	3
No autumn fertilisation in 50% of agricultural area	3
No autumn tile or ploughing in 10% of agricultural area	3
No autumn tile or ploughing in 50% of agricultural area	3
Use of catchcrops in 50% of land where this is possible	3
No autumn fertilisation and no autumn tile or ploughing in 10% of agricultural area	1
No autumn fertilisation and no autumn tile or ploughing in 25% of agricultural area	1
No autumn fertilisation and no autumn tile or ploughing in 50% of agricultural area	1
Landscape measures	
None	45
Abandon 5% worst agricultural area	3
Reforestation 10% worst agricultural area	3
Changing 5% of agricultural land in low density residental area	3

4.4 Pregolya

The focus of the scenario studies for the Pregolya River will be on climate and socio-economic changes. The HYPE model will be the tool to analyse these scenarios, therefore all input information for HYPE is needed to make scenario simulations for the Pregolya River:

- Weather (air temperature, precipitation, wind, air humidity, cloudiness)
- Nutrient load from the point sources (load from the sewage system of all settlements will be estimated through the number of inhabitants)
- Nutrient load from the agriculture (input of fertilizers, livestocks);
- Land use
- Soil type

- River network

Main characteristics of climate change scenarios:

- Baseline period (20 years): 1991 – 2010
- Projection period (20 years): 2041-2060 (named as 2050th)
- Spatial resolution 25-50 km

Main characteristics of the socio-economic scenarios[1]:

- Baseline period – 2011-2012
- Scenarios up to 2020
- Scenario BAU (Business as usual)
- Scenario DF (Documented future)
- Scenario GA (elements of introducing of *good agricultural* practice applicable to the practice of Russian Federation)

All existing local plans of socio-economic development include growth of agriculture for the Russian part of the catchment and do not include any concrete measures for reducing the nutrient load. Therefore the modeling study will focus on the analysis of projected increase of the nutrient load due to nowadays practice and official plans of economic growth. It will give a quantitative estimation of possible increase of the nutrient load followed the agriculture development while no reduction measures will be implemented. Based on this information we may formulate quantitatively the environmental targets to follow in the future to combine both – to allow agricultural economic growth and keeping or even reducing nutrient load from the Pregolya catchment.

The main idea of scenario modeling is presented in the Figure 3. The basic model run series ("0") will be made for baseline climate (1991-2010) and baseline socioeconomic conditions (2011-2012). The series "1" will cover future climate (2041-2060) and present socio-economic conditions (2011-2012). All scenarios for possible socio-economic development (BAU, DF, GA) will be analyzed for future climate conditions, not for baseline climate.

All scenarios (BAU, DF, GA) include changes in basic socio-economic drivers – land use structure, agriculture practice and intensity, point sources (UWWT). It is expected that model runs will be made for all these scenarios separately, and inter-comparison of them will give a basis for recommendations:

- Series '2' will test changes according to keeping present trends (3 years: 2012-2014) in socio-economic drivers (scenario BAU)
- Series '3' will test changes according to documented plans for socio-economic drivers (scenario DF)
- Series '4' will test changes according to implementation of some elements oa good agricultural practice (scenario GA);

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[1] Scenario BSAP (Baltic Sea Action Plan implementation) will be not analysed in this Project as till now local plans for implementation of BSAP are under development for both national (Polish and Russian) parts of the catchment. Detailed comprehensive plans are needed, as it is expected that improving of WWTP facilities will help to reach only 50-70% of the BSAP targets for the Russian part of the catchment, and therefore parallel measures in agriculture will be needed.

4.4.1 Description of catchment

Pregolya River is the main river that feeds the Vistula Lagoon. It is formed by the confluence of the Instruch and Angrapa rivers (Figure 4). According to estimations via GIS tool (Domnin and Chubarenko, 2008), the basin of Pregolya River itself amounts to 1,700 km^2, the Instruch River catchment is 1,350 km^2, the Angrapa River catchment is 2,200 km^2, the catchment of Pissa River (with the basin of Vishtynets Lake) totals 1,500 km^2, the Golubaya River catchment amounts to 540 km^2, and the Lava River catchment is 7,200 km^2.

There are a number of expert assessments of the nutrients load from the Pregolya River catchment area (Zotov 2001; Aleksandrov and Gorbunova, 2010; HELCOM, 2014). It estimates the load for nitrogen in the range of 3700-5100 tons N per year, and phosphorus - within the 490-740 tons P per year.

Pregolya River catchment area is a transboundary with the Polish part constituting about 51%, the Russian part about 49% and the Lithuanian part less than 0.5%. As a transboundary catchment it comprises diverse socio-economic situations in its different parts and the two countries have developed different systems of management and decision-making. We found that the area used for arable land in Warmian-Masurian Voivodeship is 3 times larger than in the Kaliningrad Oblast (which involved less than 50% of available land). Livestock numbers are also higher in the Warmia and Mazury, for example the number of cattle in 7 times larger. Analysis of the demographic situation in the Warmian-Masurian Voivodeship and the Kaliningrad region showed a similar population density - 60 and 63 people per km^2, as well as differences in migration - the official population projections for 2020 + 60% and - 4% respectively.

The following data are available for modelling:

- Sub-basins area - satellite radar data surveying SRTM, GIS calculations.
- The average height above sea level – satellite radar data surveying SRTM, GIS calculations.
- Soil types - Soil maps of the Kaliningrad region and Poland, GIS calculations.
- Land use – Land use map of the Kaliningrad Oblast, Corine Land
- Land cover data for the Poland area (Corine Land Cover), GIS calculations.
- Point sources – estimation via population and livestock number (2011-2012) based on data available from the Federal State Statistical Service of Kaliningrad Oblast.
- Precipitation and average temperature – data for 1990-2010 obtained from SMHI.
- Water discharge – data from the hydrological bulletins (1981-1996).

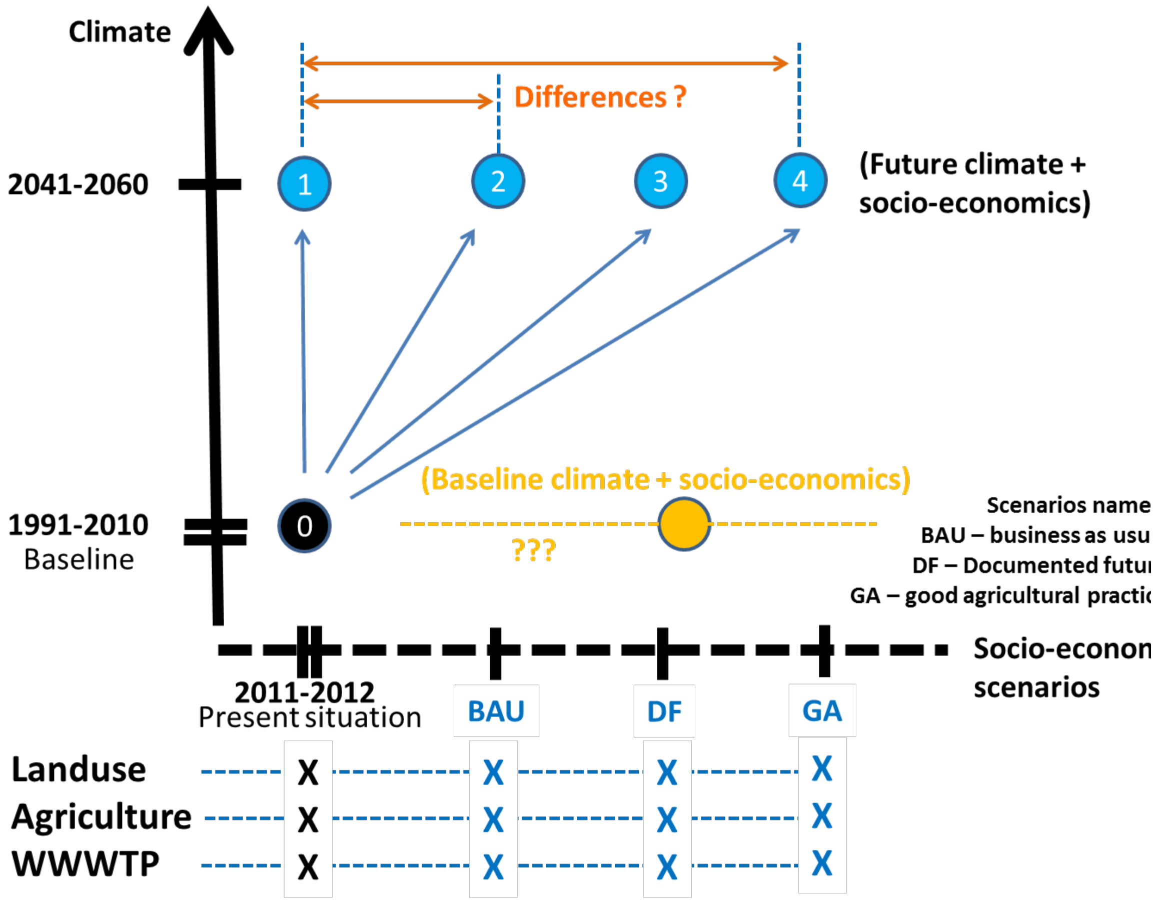

Figure 3. Scheme of scenarios planned to apply for the Pregolya River catchment.

a) b)

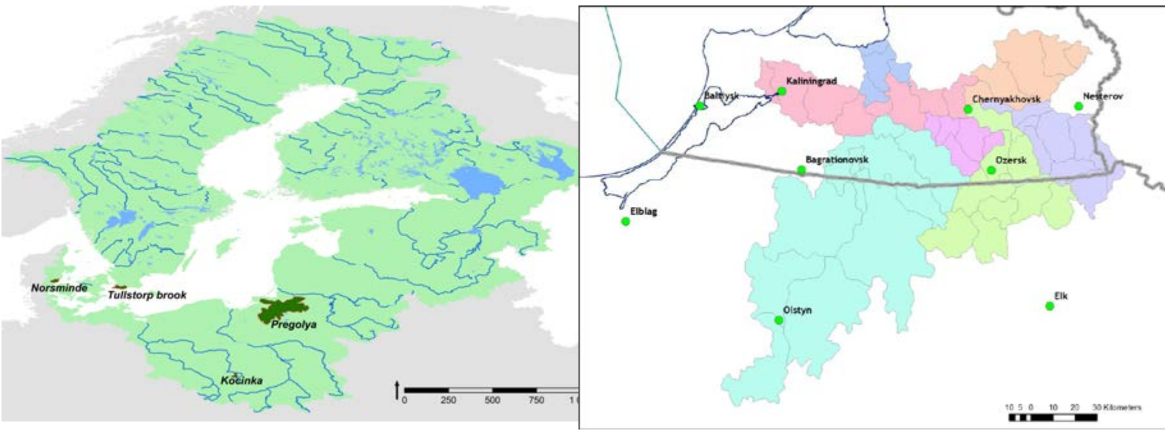

Figure 4. The Pregolya River catchment area is located in the south-eastern part of the Baltic Sea catchment area (a), it comprises from 7 main river sub-basins presented in different colours and shared between Poland and Russian Federation (b).

4.4.2 Description of models

Analysis of runoff from the catchment area of the Pregolya River will be carried out using a model HYPE (HYdrological Predictions for the Environment), developed by the Swedish Hydrometeorological Institute (SMHI).

4.4.3 Scenario approach

The BAU scenario assumes preservation of the observed trend of development of agriculture and population during 3 years (2012-2014). Figures 5 – 10 present the variations in the area of arable land, number of cattle and pigs in both Russian and Polish parts of the catchment. These statistical data were obtained for the Russian part of the catchment - from State Statistics Service for the Kaliningrad Oblast of the Russian Federation, and for the Polish part of the catchment - from FAO database.

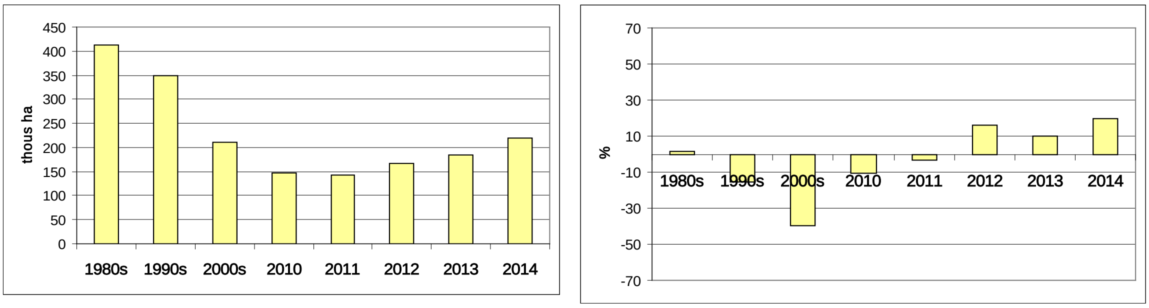

Figure 5. Trends in the area of arable land in Kaliningrad Oblast according to the data of the Territorial Authority of Federal State Statistics Service.

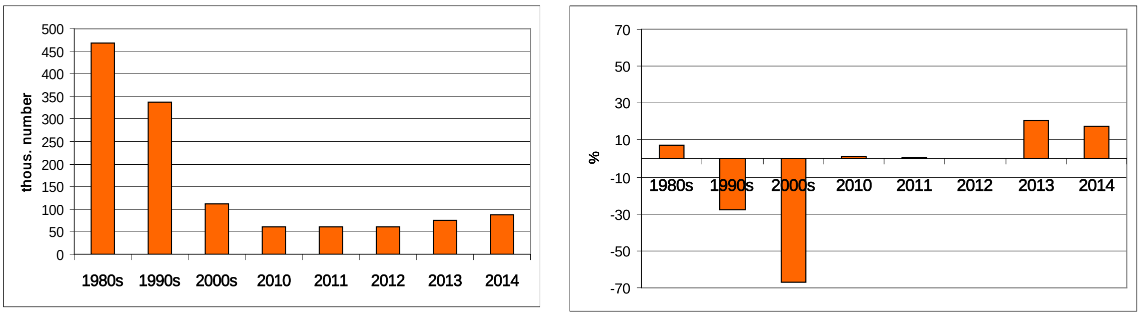

Figure 6. Trends in the number of cattle in Kaliningrad Oblast according to the data of the Territorial Authority of Federal State Statistics Service.

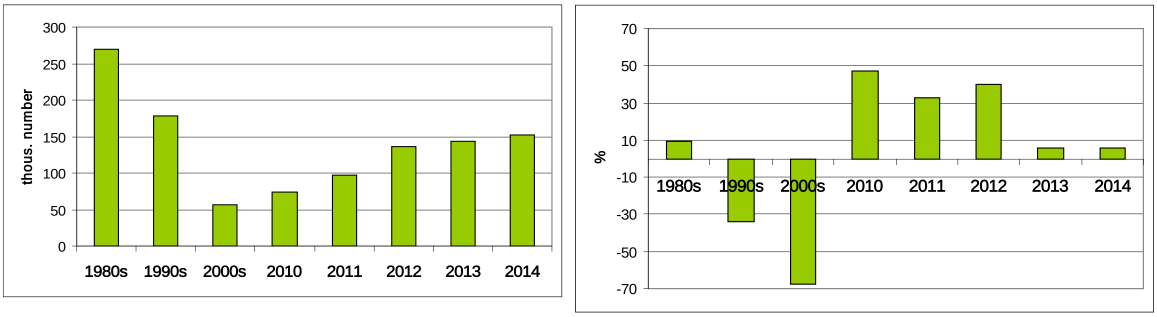

Figure 7. Trends in the number of pigs in Kaliningrad Oblast according to the data of the Territorial Authority of Federal State Statistics Service.

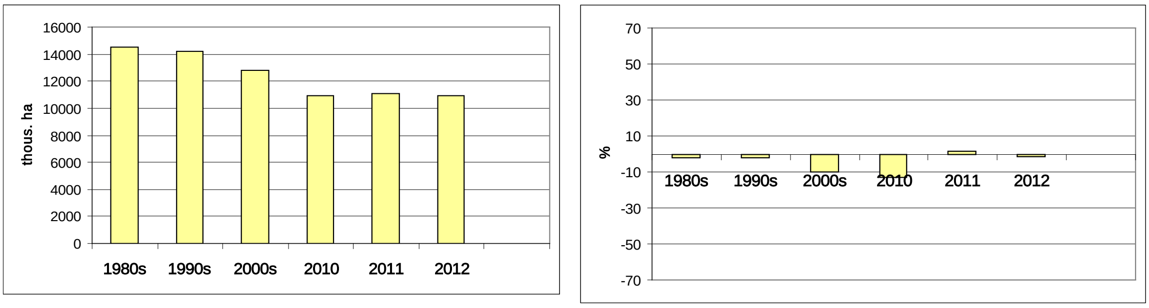

Figure 8. Trends in the area of arable land in Poland (FAO database)

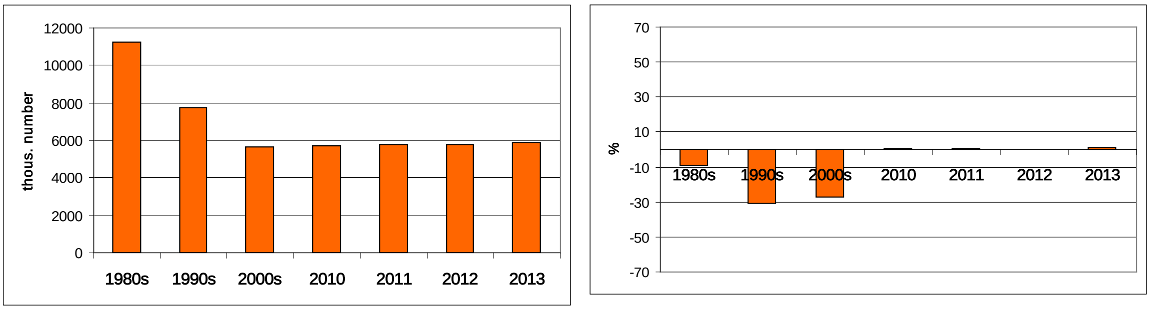

Figure 9. Trends in the number of cattle in Poland (FAO database).

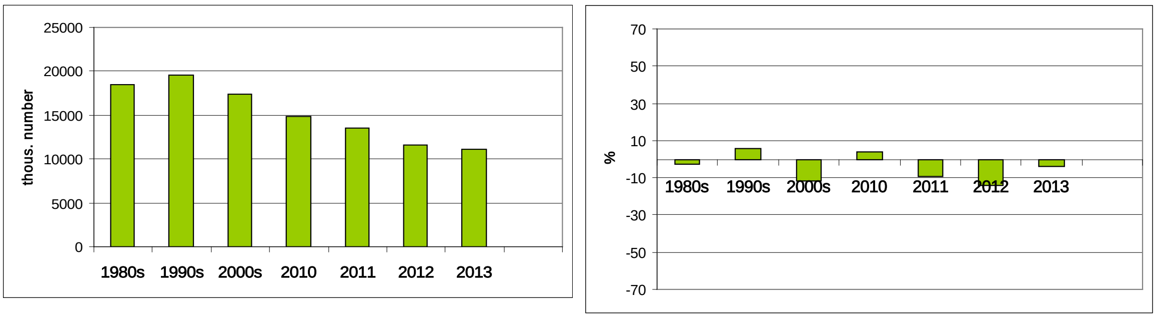

Figure 10. Trends in the number of pigs in Poland (FAO database).

The DF scenario is based on the analysis of the official projections. Further socio-economic development of Warmian-Masurian Voivodeship and environmental measures (including to prevent the runoff of nutrients) significantly depend on the implementation of the European Union program "Operational Program Eastern Poland 2014-2020". A significant increase in agricultural production is not expected in the Polish part of the Pregolya River catchment, and hence an increase in nutrient load is not expected as well.

Analysis of the "Strategy of socio-economic development of the Kaliningrad Oblast in the long term" showed an expected increase in the area of arable lands by 70%, cattle livestock by a factor of 3.5 and the main crops harvest by a factor of more than 2. In the case of the implementation of these plans the nutrient load from the Russian side of the catchment (from croplands, pastures and point sources from livestock) will increase significantly.

Now the special “Program for the Kaliningrad Oblast on Assessment of Voluntary Resettlement of Compatriots Living Abroad to the Russian Federation” is realised. According to the (Strategy of Socio-Economic Development of the Kaliningrad Oblast, 2012) it is estimated that the population will increase up to 1.6 million people by 2020 (Figure 11). In the Warmian-Masurian Voivodeship according to demographic projections of the Main Statistical Office in Olsztyn the number of population will decline, and will in 2020 amount to 1.4 million people (Prognoza ludnosci, 2009).

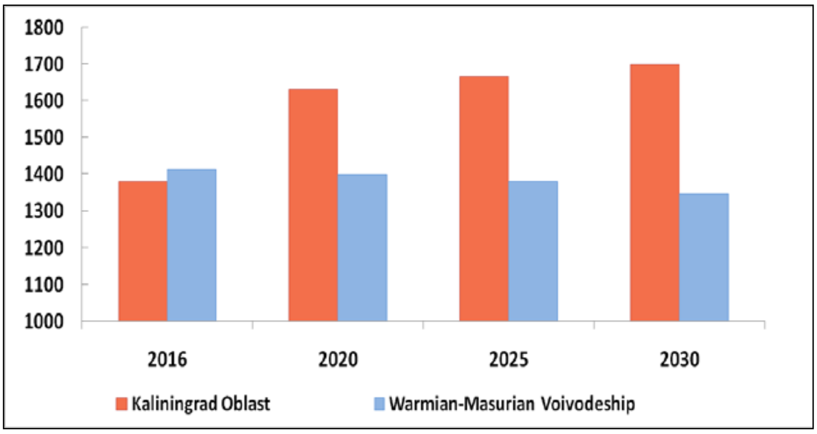

Figure 11. Demographic projections for Kaliningrad Oblast and Warmian-Masurian Voivodeship (thousands of inhabitants).

Table 4 shows an increase of values for different drivers for the two scenarios for Kaliningrad Oblast and Warmian-Masurian Voivodeship. In general, scenario BAU will give an increase by 15-25% for the Russian part of the catchment and a small decrease for the Polish part of the catchment. The scenario DF shows a tremendous (and probably unrealistic) development in the agricultural sector for the Russian part and a small (3-5%) growth for the Polish part of the catchment.

It should be acknowledged that the present levels of agriculture development in Polish and Russian parts of the catchment are very different – agriculture on the Polish side is much more developed. Therefore the Polish agricultural sector will be more intensive by 2020 despite of the increase (both present trends and documented plans) compared to agriculture on the Russian side of the Pregolya River catchment (Table 5).

Table 4. Estimated increase (up to 2020) in numbers of different drivers for two scenarios for Kaliningrad Oblast (KO) and Warmian-Masurian Voivodeship (WMV) – scenario BAU and DF.

	Business As Usual		Documented Future	
	KO	WMV	KO	WMV
Arable	+20%	0%	+70%	+3%
Livestock				
Cattle	+15%	0%	+950%	+5%
Pigs	+15%	0%	+350%	+5%
Population	+25%	-6%	+70%	+3%

Table 5. Comparison of drivers for the Kaliningrad Oblast (KO) and Warmian-Masurian Voivodeship (WMV) in the baseline and two scenarios. The factors show the relative trends in WMV and KO.

	Baseline period	Business As Usual	Documented Future
Arable	2.5 times WMV > KO	2 times WMV > KO	1.5 times WMV > KO
Livestock			
Cattle	5 times WMV > KO	4 times WMV > KO	2 times WMV < KO
Pigs	3 times WMV > KO	2.5 times WMV > KO	1.5 times WMV < KO
Population	WMV=KO	15% WMV < KO	40% WMV < KO

Scenarios for present and future climate combined with present socio-economic situations and scenarios BAU (business as usual) and DF (documented plans for the future) combined with future climate will be implemented.

Analyses of the nutrient emissions from these scenarios will show a range of emission expected in the future as well as fractions with which natural (climate) and anthropogenic (socio-economic development) drivers contribute to this emission.

Some recommendations for measures to reduce nutrient losses in agriculture (maximum N utilisation required from applied manure; no autumn fertilisation; use of catch crops where possible; no autumn tillage or ploughing) could be tested for the Pregolya River catchment.

5. Scenarios at Baltic Sea scale

The focus of these scenarios is loads to the Baltic Sea, so the focus of the scenario analysis will be changes to loadings to the Baltic Sea. These can be presented as aggregations of loads to each of the defined Baltic Sea basins (as defined by HELCOM). The relative effects of the various scenarios will be compared as well as showing absolute changes for each of the scenarios. Given time, changes to concentrations across the catchment may also be considered (for example to determine if load reductions to sea lead to increases in local concentrations on land).

The scenarios will be evaluated against a baseline from 1991 to 2010. A twenty year baseline was chosen to achieve a compromise between the longer 30 year period generally used for climate baselines and a shorter period which would ideally be used to define stationarity in the nutrient input. Measures will be simulated using the baseline climate and compared to the baseline model run to determine the relative effect that different measures will have on total loads to the sea.

Future climate and future land use will be simulated using 20 year time-slices (with a spin up period). Time slices are preferred over transient runs as long-term changes in nutrient storage within soils are difficult to validate and have a large impact on scenario results. It is therefore important to communicate that these are NOT projections for the future, but scenarios simply to compare the relative effects of different variables (can also be thought of as a sensitivity test).

For each scenario we will compare the effects on loads of IN, ON, TN, SP, PP and TP to the Baltic Sea. This can be done for

(a) individual rivers (for example for the case studies) and then
(b) aggregated to the Baltic Sea basins (as defined by HELCOM) and
(c) to the Baltic Sea as a whole.

5.1.1 Baseline data

The baseline data are the E-HYPE V3.0 model inputs as described in Hundecha et al. (2016) for the water model. Baseline data for nutrient modelling including crops and crop management as well as point sources is currently being updated to 2012-2013 using the Eurostat farm structure survey and data reported to EEA for urban and industrial point sources. The baseline forcing data is the WFDEI (Weedon et al. 2015) gridded data set consisting of ERA-INTERIM reanalysis corrected to GPCC gauge interpolations.

5.1.2 Model setup

The model setup will be a new version of the E-HYPE model for which the reference data baseline and calibration is currently being updated in SOILS2SEA. Previous versions of the model are described in Arheimer et al. (2012b), Donnelly et al. (2015) and Hundecha et al. (2016).

5.1.3 Scenario approach

The scenario components outlined in Section 3.2 will be combined to explore effects of combination of driving forces (climate change, land use) and management measures at farm and landscape scale. The aim will be to evaluate their relative effects on loads to the Baltic Sea. However, only a limited number (10 to 15) of combinations can realistically be explored at the Baltic Basin level. More combinations may be feasible at catchment scale. Table 6 gives a proposal for combinations to be tested at the Baltic Basin level.

Table 6. Proposed scenarios at Baltic Sea scale.

	Scenario	**Land use**	**Climate**	**Agriculture**	**Landscape measures**
1	Baseline To-day	Baseline	Baseline (WFDEI)	Baseline	None
2	Future Cli-mate	Baseline	Future	Baseline	None
3	Future climate and land use	Future	Future	Baseline	None
4	Uniform Regulation	Baseline	Baseline	Additional measures applied uniform – 10 % below economi-cally optimal	None
5	Differentiated regulation	Baseline	Baseline	Upscaled changes from DK - based on SLC variability	None
6	Abandon worst agricul-tural areas	Baseline	Baseline	5 % worst Ag land area cease farming-based on Balt-HYPE source ap-portionment	None
7	Agricultural measures to worst areas	Baseline	Baseline	X % worst areas apply measures. Which measures? (all ag measures?)	None
8	Landscape measures	Baseline	Baseline	Baseline	X % worst areas apply landscape measures (Buffer zones on all streams in these area, increase stream meander
9	Landscape measures in WFD poor status areas	Baseline	Baseline	Baseline	Landscape measures in all rivers with poor status
10	Uniform regulation	Future (1 future)	Future (1 future)	Additional measures applied uniform	None
11	Differentiated regulation	Future (1 future)	Future (1 future)	Upscaled changes from Denmark	None
12	Abandon worst agricul-tural areas	Future (1 future)	Future (1 future)	X % worst areas cease farming	None
13	Agricultural measures to worst areas	Future	Future	X % worst areas apply measures	None

6. Scaling of measures from catchment to Baltic Sea scale

At the Baltic Sea scale, with over 10,000 sub-basins, it will be impossible to explicitly design and place remedial measures. Instead, scaling of the measures to the Baltic Sea scale will require creation of algorithms connecting physiographic concepts defined in the model with the measures to be placed. For example, wetlands could be placed in all subbasins with a low enough slope, a certain proportion of agricultural land upstream, and with a wetland size a function of the upstream catchment area, up to a maximum size. Wulff et al. (2014) defined a maximum allowable wetland restoration per Baltic river catchment which was a function of the organic agricultural soils, i.e. high shares of organic soils meant large catchment areas could be converted to wetlands (resulting in 0.1 to 15 % of the agricultural land within a river catchment being available for conversion to wetlands). They also describe maximum realistic limits for reductions in fertiliser use (20%) and livestock numbers (30%) and limit catch crop use to existing agricultural land defined as spring sown cereals (this for example could be directly applicable in HYPE).

Characteristics of the model which could be used include:

- Catchment area
- Catchment elevation, mean slope and standard deviation of slope (although this is dependent on the resolution of the DEM)
- Areas of different soil-types, land uses and crop types within a sub-basin and upstream (e.g., how much agricultural land is in a particular sub-basin locally and how much is in the total area upstream of a point). Soil types are coarse, medium, fine, shallow and organic. Land uses are agriculture (annuals, perennials, rainfed or irrigated), pastures (rainfed or irrigated), forest (broadleaf, needle or mixed), urban, open, wetlands, lakes. Crop types are divided into Pasture Irrigated; Pasture Rainfed; Perennial Irrigated; Perennial Rainfed; Seasonal Irrigated Autumn-sown; Seasonal Irrigated Spring-sown; Seasonal Rainfed Autumn-sown; Seasonal Rainfed Spring-sown
- Related to the crop-types, we can have two crop types on one agricultural unit and something to do with rotation and fertiliser inputs
- Existing wetlands or lakes (although smaller artificial wetlands are not likely to be captured in the land use databases we use as inputs)
- Climate statistics
- Planting date has earlier been static, but we will now allow this to vary with climate change (limited by day length)
- Stream length within a sub-basin (and upstream of a sub-basin) – note this is a very rough estimate

Model outputs which could be used include

- Total retention to sea
- Source apportionment of nutrients to sea (i.e. which sub-basins and land uses contribute most to sea) (Figure 12).

Characteristics readily available but not currently part of the model include

- Nutrient status in the WFD (available from EU – this could be used to only put measures where they are most needed)
- Any of the raw data to the model (e.g. gridded land use, soil-type, DEM – this could be used to define a heterogeneity index for upscaling of the differentiated regulation from MIKE-SHE)

A 30 m DEM which could be used to find areas suitable for wetlands (although we do not know the quality of this data set yet) https://asterweb.jpl.nasa.gov/gdem.asp

Figure 12. Example of model output presentation(http://vattenwebb.smhi.se/scenario/) for Sweden, which can also be applied for Baltic Sea scale model. The larger the red circle, the more a subbasin contributes to loads to sea.

7. Use of scenarios in stakeholder discussions

Following the first set of Case Study Workshops in the case study sites of Kocinka, Tullstorp and Norsminde there is a second set of workshops foreseen for late 2016 (for the results of the first workshop series see: http://soils2sea.eu/case_studies_uk/index.html).

At the second set of workshops it is foreseen to discuss different policy options, based on the outcomes of the first workshops, in depth. It will for example be discussed, how effective, acceptable, efficient, or feasible these options would be. The results of these workshops will feed into a policy brief developed within BONUS Soils2Sea.

The results from the scenario analysis (in form of maps or numbers) will be a valuable part of the discussions. They will feed in to discussion to demonstrate why new options are needed or how efficient certain options could be in relation to reducing eutrophication at the local level. Based on the scenario work done in the different case studies, the content of each workshop will have a different focus. These are described in more detail below.

Norsminde

The scenario work in the Danish Case Study focuses on map-based N-load calculations. The different results of the calculation can be presented and discussed during the stakeholder workshop. One interesting detail to discuss is the effect of changing agricultural practice on the N-leaching. With the help of the scenarios, specific areas can be identified where measures to reduce N-leaching are needed. This will demonstrate what actions could be taken to reach certain reduction level and therefore foster the discussion with stakeholders.

Tullstorp

Focus of the scenario related work in this Swedish Case study will be on remediation actions in streams. These actions have the goal to increase the dissolved exchange with the hyporheic zone and increase flow transit time. Possible actions are overflow dams, meanders, introduction of new substrate and vegetation.

Local and distributed effects as well as retention and chemical decay can be accounted for in the scenario analysis. This will be of interest for the stakeholders in the case study region, because it can visualize the retention and reduction of N and P in the streams. Using the equations patters developed in Soils2Sea the already implemented restoration in Tullstorp Brook will serve as a demonstration. The results from the demonstration will steer the discussion with the stakeholders.

Kocinka

Concerning land use, the area of Kocinka is not comparable with the case studies in Denmark and Sweden. With rather small farms and scattered fields, farming is in many cases only a secondary income. This also reflects on the use of fertilizers and manure, which is in comparison to the other northern case studies relatively low.

For the stakeholder workshop these issues have to be addressed and it is envisioned to focus on specific measures und use the scenarios to show the possible results. These measures could be a change of fertilizing patterns (e.g. change from autumn to spring fertilization), extended use of catch crops, and introduction of new measures in streams to increase the flow transit time. These effects on the N and P loadings can be demonstrated by the scenarios.

With the results from the local case study sites and first results from a Baltic Sea scale an up-scaling workshop is foreseen in 2017. At this workshop (possibly in co-operation with other BONUS projects) results from the scenarios for the whole Baltic Sea as well as results from the local scenarios will be discussed.

8. Schedule for scenario design and use

A milestone for completion of the Balt-HYPE model is set for March 2017; however we intend to aim to have the model ready in a finalised version for scenario runs by Dec 2016. We will need a finalised version of the model to create the source apportionment for defining scenarios based on differences in retention and to begin running scenarios. Defining of input data for scenarios that are NOT dependent on simulated retention or other simulated water quality parameters can run in parallel with model development.

The time schedule for the scenario studies is as follows:

- Catchment scale scenario studies (spring/summer 2016)
- Discussion of climate change and land use scenarios with other BONUS projects (April 2016)
- Discussion of preliminary scenario results with stakeholders in workshops in autumn 2016
- Revision of catchment scale studies (winter 2016/2017)
- Design of land use and management change scenarios under CC (spring 2016)
- Design of upscaling methods to Baltic Scale (2016)
- Scenario analyses at Baltic Sea scale (2017)

8.1 Division of work

1. Climate data: SMHI to bias-correct climate data to WFDEI reference data set. (Unclear if we need to bias-correct to higher resolution data or point data for case studies?)
2. Future Landuse data: AU to extract from CLIMSAVE and produce gridded land use aggregated in classes relevant for HYPE and case study models
3. Agricultural management at Baltic Sea scale (AU responsible for suggestions for this): This needs to be defined for the following scenarios
   (a) Uniform regulation
   (b) Differentiated regulation based on differentiated GW retention
   (c) Differentiated regulation based on differentiated total retention (abandon X % worst areas) – is this 5 % of today’s agricultural land? Other suggestions?
4. Landscape measures at Baltic Sea scale (AU responsible for suggestions for this): Which sub-basins to apply measures to (suggestions are X % of worst sub-basins and/or those with poor ecological status in WFD).
5. Analysing effects at catchment scale: Local partners in collaboration with AU/SMHI
6. Analysing effects at Baltic Sea scale: SMHI
7. Interaction with stakeholders: Ecologic in collaboration with local partners

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