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Application of the Danish EPA's Marine Model Complex and Development of a Method Applicable for the River Basin Management Plans 2021-2027

Management Scenario 2b – Land-based nutrient scenarios (equal anthropogenic loadings (kg/ha))

Miljø- og Fødevareministeriet
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Eelgrass in Kertinge Nor
Photo: Peter Bondo Christensen

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Preface

This report is commissioned and funded by the Danish Environmental Protection Agency (EPA). The data, methods and results included in the report are intended to be an integrated part of the material behind the Danish River Basin Management Plans (RBMP) 2021-2027.

The work reported was managed and performed by DHI and AU/DCE. During the project, a steering committee followed the development, and was involved through dialogue and follow-up on progress, etc. The steering committee consisted of members from the Danish Ministry of Environment and Food (MFVM), the Danish EPA (MST), DHI and AU.

In addition, a follow-up group consisting of members from The Danish Agriculture & Food Council, SEGES, Sustainable Agriculture (BL), the Danish Society for Nature Conservation, the Danish Sports Fishing Association, Danish Fishermen PO (DFPO), the Danish Ports, and KL/municipalities was affiliated with the project. The follow-up group has been continuously informed about the progress of the project at meetings convened by the MFVM.

Choice of methods, data processing, description and presentation of results have been solely AU's and DHI's decision and responsibility. A draft version of this report has been reviewed by MST and the follow-up group.

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1 Introduction

When preparing the Danish River Basin Management Plans 2015-2021 (RMBP 2015-2021), DHI and Aarhus University (AU) developed a number of mechanistic (DHI) and statistical (AU) models that were used for calculating chlorophyll-a target values defining the threshold (GM) between 'Good Ecological Status' (GES) and 'Moderate Ecological Status'. The models were also used for calculating Maximum Allowable Inputs (MAIs) of total nitrogen (N) from Danish catchments based on the GM threshold value and a proxy for eelgrass depth limit. Hence, the development aimed at both the model development and the development of a method for calculating the MAIs.

As part of the political, regulatory package 'The Food and Agriculture Agreement from 2015' an international evaluation of the procedures used in the RBMP 2015-2021 was conducted. The evaluation was finalised autumn 2017 with a report (Herman *et al.* 2017) including a number of recommendations for improving the scientific background behind the RBMP 2021-2027.

To follow up on the international evaluation, the Danish EPA facilitated a range of research and development projects (R&D) projects with the overall aim of developing methods to calculate robust, transparent and differentiated chlorophyll-a reference values (and corresponding GM values) and MAIs in as many water bodies as possible for implementation into the RBMP 2021-2027.

Two central R&D projects relate to the continued model development in the assessment of reference chlorophyll-a values (and corresponding target values) and final MAI calculations. Other projects support different aspects of the final MAI calculations, but here we focus on the following two central R&D projects:

- 'Recommendations for the continued development of models and methods for use in the River Basin Management Plan 2021-2027. Follow-up on the international evaluation of marine models behind the River Basin Management Plan 2015-2021' (Erichsen & Timmermann 2018)
- 'Application of the Danish EPA's Marine Model Complex and Development of a Method Applicable for the River Basin Management Plans 2021-2027'.

The outcome of the above research projects is a set of MAIs based on a range of scenarios reflecting different assumptions regarding future developments in nutrient loading from neighbouring countries and the atmosphere as described in Erichsen *et al.* 2020. In the present technical note, the assumptions and input data behind management scenario 2b and corresponding results are described. In management scenario 2b it is assumed that all countries, incl. Denmark, is aiming at an equal anthropogenic N-loading measured in kg N/ha.

2 Preconditions for MAI Calculations

The Danish MAIs will, among other things, also depend on future loadings from neighbouring countries and atmospheric N-depositions as described in more detail in Erichsen *et al.* 2020. In addition, some water bodies may also respond to Danish land-based P loadings, which is why one set of Danish land-based N-MAIs corresponds to a set of Danish land-based P-MAIs.

In order to calculate a set of Danish land-based N-MAIs with the developed models, we need to make assumptions on future loadings and management strategies from neighbouring countries (management scenarios), and Danish land-based P loadings.

With respect to reductions in neighbouring countries, the Danish EPA has defined a set of preconditions to be used for constructing management scenarios defining potential developments in future non-Danish land-based loadings and atmospheric deposition. For each scenario, Danish land-based N-MAIs are calculated based on 0%, 10%, 20%, 30% and 50% Danish land-based P reductions, respectively.

In this technical note, we have not assessed the feasibility of the scenarios defined by the Danish EPA, but solely provided N-MAIs that will ensure that the targets are reached given that the preconditions related to nutrient loading from other countries, atmospheric N deposition and P loading from Danish catchments are fulfilled.

2.1 Management-Scenario Definitions

As mentioned above, the Danish EPA has defined a set of assumptions regarding nutrient inputs from other countries and the atmosphere to be used as preconditions for the Danish land-based N-MAI calculations. The preconditions are grouped into three management scenarios and one scenario related to the interpretation of the Water Framework Directive (WFD-scenario). The different assumptions are described in general terms in Erichsen *et al.* 2020, whereas the present technical note describes management scenario 2b in more detail (also see 'bold' description below).

2.1.1 Management-Scenario 2 – Regional Treaties and RBMP 2015-2021

The second group of scenarios encompasses assumptions for the land-based loadings from neighbouring countries that are not based on adopted treaties. The assumptions include:

a) Neighbouring countries are assumed to have had the same percentage of nutrient reduction as Denmark when Danish land-based N-MAIs are reached. The reduction percentage is relative to the basis period 1997-2001.

b) Neighbouring countries are assumed to have the same area-specific anthropogenic loadings (kg/ha) as Denmark when Danish N-MAIs are reached.

c) Loadings from neighbouring countries are unchanged compared to the present-day loadings (2014-2018).

d) Danish land-based N-MAIs assuming updated BSAP targets. A new set of targets is being developed in HELCOM and will be adopted by the end of 2021.

e) Additional Wadden Sea P-reductions[1]

[1] This scenario is in addition to what has been reported in previous technical notes (e.g. Erichsen *et al.* 2020) and is a supplement to the series of management scenarios.

For the above five sub-scenarios, the atmospheric deposition will be kept as described in management scenario 1, i.e. full implementation of the NEC-directive with respect to atmospheric N-deposition (see Erichsen *et al.* (2020) for details).

2.1.2 Method

The background for this scenario is an assumed precondition where all countries, incl. Denmark, is aiming at an equal anthropogenic N-loading measured in kg N/ha.

Here we assume that land-based N-loadings correspond to a reference part (or background) and an anthropogenic part. The calculation of Danish MAIs is still done individually for each individual water body, but in management scenario 2b we ensure that the summed total land-based N-loadings corresponds to an area loading in kg N/ha that equal that of neighbouring countries when assessing the anthropogenic part alone.

The method developed for estimating N-MAIs in Danish water bodies operates with reductions, why we run a number of reduction scenarios (between 5-45% reduction with steps of 1%) in the neighbouring countries to ensure a dataset applicable for the assessment in management scenario 2b.

The data behind the present scenario is described in section 2.1.3, whereas an update of the model results is described in section 0.

2.1.3 Scenario Loadings

The full overview of the scenario reductions applied for management scenario 2b in other countries than Denmark, and atmospheric depositions are summarised in Table 2-2, and explained briefly in the following sections.

Present-Day Loadings

In management scenario 2b the present-day loadings to the Baltic Sea and the North Sea from all other countries than Denmark are applied.

These loadings correspond to the loadings included in the calibration and validation of the mechanistic models and are described in more detail in Erichsen & Birkeland (2020).

According to HELCOM data (fx data behind the upcoming PLC7 report (https://helcom.fi/helcom-at-work/projects/plc-7/) the average land-based N-loadings to Baltic Proper (BAP), Danish Straits (DS) and Kattegat (KAT) between 2014-2018 is 351 ktons N. According to data presented in Erichsen & Timmermann (2020) the reference loadings correspond to 55% of present-day loadings, or 191 ktons N. Similar numbers from Denmark are 58 ktons N and 17 ktons N (Erichsen & Timmermann 2020). In Table 2-1 data are summarized and areal land-based N-loadings presented.

Table 2-1 Land-based N-loadings from Denmark alone and to BAP, DS and KAT summed. The anthropogenic part is found as the difference between present-day loadings and reference loadings.

	Catchment [km^2]	Present-day loadings [ktons N]	Present-day loadings [kg N/ha]	Reference loadings [ktons N]	Reference loadings [kg N/ha]	Anthropogenic loadings [kg N/ha]
Denmark	43,570	58	13.3	17	3.9	9.5
BAP, DS & KAT	688,890	351	5.1	191	2.8	2.3

NEC-Directive

According to Blicher-Mathiesen & Sørensen (2020), the reductions in atmospheric N deposition after full implementation of the NEC-directive altogether amount to 16% or a 10% reduction in 2027, if the different countries' predictions are implemented. The full reduction of 16% is used for management scenarios 1 and 2, whereas the prediction of 10% reduction is used for management scenario 3a (see Erichsen *et al.* 2020 for details).

Data are delivered by AU, and the reductions are resolved on an overall water body scale and implemented in the Danish land-based N-MAIs calculations (see Figure 2-1 for data).

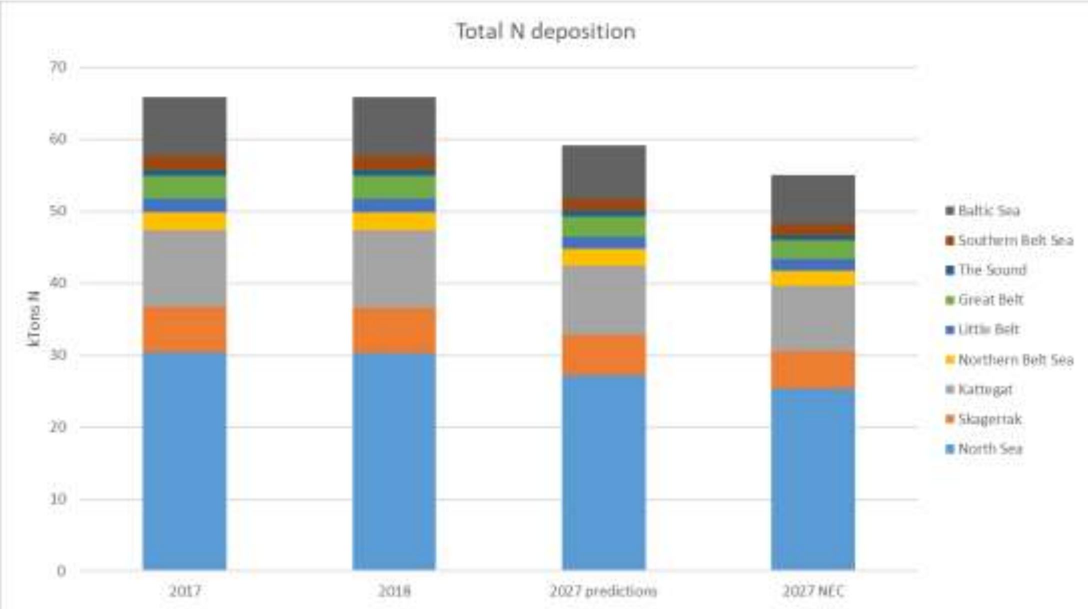
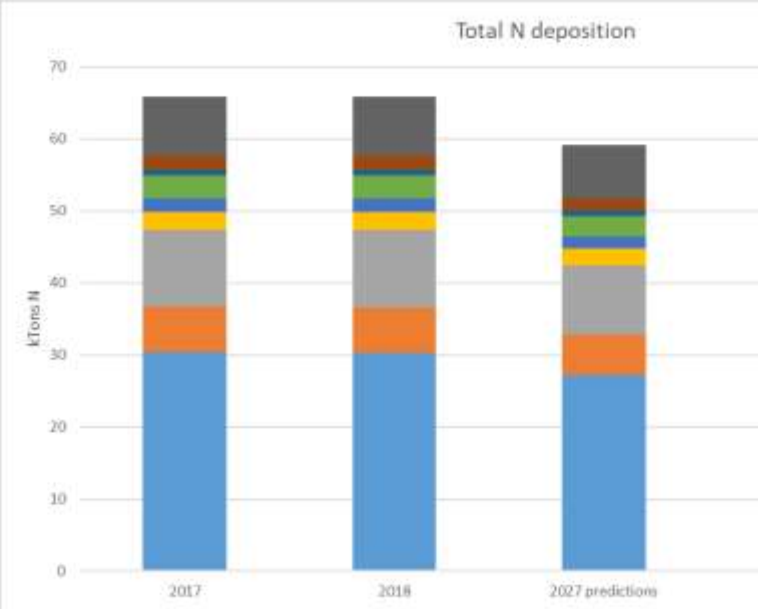


Figure 2-1 Atmospheric N depositions summarised at overall water body level. '2017' and '2018' represent present-day atmospheric N-depositions whereas '2027 NEC' represents agreement behind the directive, and '2027 predictions' represent the different country prognosis.

Table 2-2 Overview of input data used to construct management scenario 2b.

Danish water areas affected	N load reduction in management scenario 2b. Reductions are in % of current (2014-2018) load	P load reduction applied in management scenario 2b. Reductions are in % of current (2014-2018) load	Adopted treaties

Western Baltic Sea (Light blue areaAccording to Blicher-Mathiesen & Sørensen (2020), the reductions in atmospheric N deposition after full implementation of the NEC-directive altogether amount to 16% or a 10% reduction in 2027, if the different countries' predictions are implemented. The full reduction of 16% is used for management scenarios 1 and 2, whereas the prediction of 10% reduction is used for management scenario 3a (see Erichsen *et al.* 2020 for details). Data are delivered by AU, and the reductions are resolved on an overall water body scale and implemented in the Danish land-based N-MAIs calculations (see Figure 2-1 for data).  Figure 2-1)	5-45% (steps of 1%)	27%	Effect of BSAP to DS and BAP
Great belt and Kattegat (dark blue area)	5-45% (steps of 1%)	27%	Effect of BSAP and German RBMP, using Helcom allocation scheme
Southern Little Belt (yellow area)	5-45% (steps of 1%)	27%	Effect of German RBMP

North Sea water bodies and Limfjorden (brown area)	5-45% (steps of 1%)	0%	Effect of German RBMP
Atmospheric deposition, all Danish water bodies	16%	0%	NEC directive

2.2 Method for Calculating Danish N-MAI

Based on the assumed future load reductions from neighbouring countries and atmospheric deposition as described above, N-MAIs from Danish catchments to each of the 109 water bodies is calculated. This is based on the status value of the indicators in each water body, as well as a defined target value (*Erichsen & Birkeland 2020b*). The status values for the two indicators are based on measurements. Target values are defined as a “slight deviation from reference conditions”, where reference conditions refer to a state with minimal human influence. Based on the method described in Erichsen *et al*. (2020), each target value will have a MAI which will support the system to achieve GES.

Since all Danish water bodies are connected to a higher or lesser degree, the reduction needed for a single water body cannot be assessed in isolation. In addition, it is necessary to consider the load reduction requirement estimated for nearby water bodies. To account for connected water bodies, the following scheme was applied:

1) Catchments are assigned to each water body. Local catchments are assigned to the inner part (sub-catchments) of estuaries (upstream water bodies), whereas two or more local catchments (main-catchments) are assigned for downstream water bodies (e.g. the outer part of estuaries) and more open water bodies.

2) Load reductions (in %) for each individual water body are calculated as described in Erichsen *et al.* (2020) and transformed into a N-reduction requirement in tons using the load of the assigned catchment.

3) For up-stream water bodies (with local catchments) the calculated reduction is a minimum requirement that should be obtained independently of downstream waterbody requirements.

4) Reduction requirements for downstream water bodies are corrected, considering any minimum reduction handled by up-stream water bodies.

5) Reduction requirements are transformed into MAIs by subtracting the required load reduction from the average annual load and aggregated to the corresponding local and/or regional catchment.

2.3 Results

Based on the above-described assumption (implementation of the Baltic Sea Action Plan, German nutrient reductions according to RBMP 2015-2021, additional Wadden Sea P-reduction and reductions in atmospheric N deposition according to the NEC directive) the different reduction requirements and corresponding MAIs are calculated.

In Figure 2-2, the results of the different nutrient reductions from neighbouring countries (5-45% of current loading) and the corresponding Danish MAIs, are transformed into an anthropogenic areal contribution are pictured (blue curve). Similarly, the anthropogenic contributions (in kg

N/ha) from neighbouring countries are shown. To fulfill the preconditions for management scenario 2b we aim at a situation where the anthropogenic loadings (in kg N/ha) are similar between Denmark and neighbouring countries. From Figure 2-2, we read that the two curves are equal at an anthropogenic contribution of 3.1 kg N/ha, which according to Table 2-1 equals average loadings of 7.0 kg N/ha from Danish catchments and 5.9 kg N/ha from neighbouring countries.

If we compare the changes from 13.3 kg N/ha (Danish present-day loadings) to 7.0 kg N/ha (equal anthropogenic loadings) the corresponding N-MAI equals a total load of 27,293 tons N (or a need for reductions of 30,807 tons N).

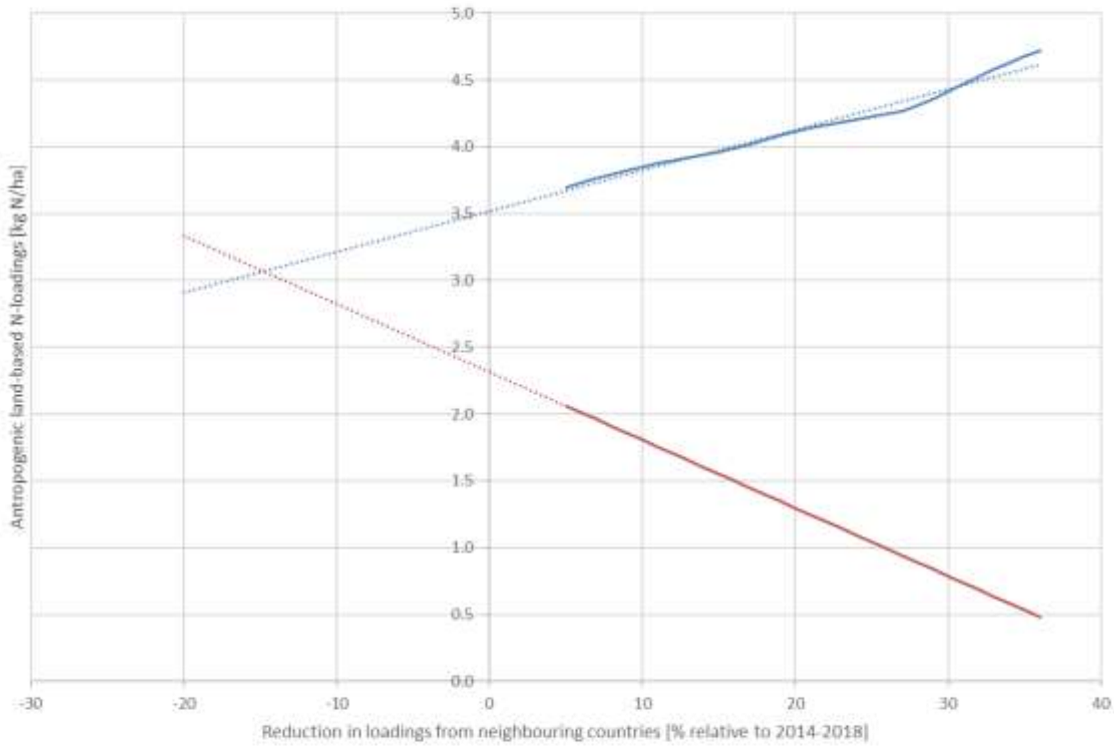


Figure 2-2 Changes in land-based N-loadings (in kg N/ha) due to changes in reductions in land-based N-loadings in neighbouring countries. Blue curve shows the changes in Danish catchments and red curve show the changes in Baltic Proper (BAP), Danish Straits (DS) and Kattegat (KAT) catchments.

2.4 Closing Remarks

The estimated Maximum Allowable Nitrogen Input (N-MAI) to Danish water bodies presented in this report is based on the preconditions that the BSAP, the RBMP 2015-2021, additional Wadden Sea P-reductions (20% and 30%), and the NEC directive will be fully implemented. These treaties have been adopted but not yet fully implemented. These assumptions, which have not been assessed as part of this study, are accepted as preconditions.

If the preconditions are fulfilled, and the MAI for Danish water bodies is reached by the end of 2027, all Danish water bodies will most likely not have reached Good Ecological Status (GES) as defined in the WFD. This is because:

- The MAI estimation is based on the depth of light as a proxy for the indicator eelgrass depth limit. Hence, even if light has reached the target value, recovery of eelgrass after light improvements may take years to decades. In addition, other factors, such as sediment suitability, lack of seedlings, etc., may delay or prevent eelgrass recovery.

- With the given preconditions in management scenario 1, one or both of the indicators (chlorophyll-a and light) may not reach the target value despite reductions from Danish catchments. In these situations, the reduction requirement for that indicator is cut off/truncated at the reference loading. A cut-off at reference loading indicates that due to the scenario and associated preconditions, a specific MAI for that water body that ensures GES cannot be obtained, and administrative choices have to be made, like applying an average reduction from neighbouring water bodies, reductions to down-stream water bodies or a general MAI (kg/ha) for those water bodies. However, the implication is that GES for both indicators cannot be expected in these water bodies, even if MAI is obtained.

- The method is not based on the one-out-all-out principle as required in the WFD, but on an average of two indicators. Hence, it is expected that both indicators will be as close to the target value as possible, but one will theoretically be above and one below the target value.

- In this management scenario, we are using the boundary between good and moderate status as the target value for each of the indicators. Due to uncertainties, there is a 50% chance that the indicator value will end in good status and a 50% chance that the indicator value will end in moderate status, if MAI for that indicator is reached, assuming the measured indicator follows a symmetrical distribution.

- As some ecosystems respond with significant time-lags to changes in loadings, it will take years before the full environmental effects of nutrient reductions can be observed. Hence, reaching MAI will provide the conditions for obtaining GES but the achievement of GES will likely be delayed.

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