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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

Estimating Confidence Intervals for Maximum Allowable Inputs (MAIs)

The expert in **WATER ENVIRONMENTS**

Miljø- og Fødevareministeriet
Miljøstyrelsen

Technical Note

December 2021

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Estimating Confidence Intervals for Maximum Allowable Inputs (MAI)

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Eelgrass in Kertinge Nor
Photo: Peter Bondo Christensen

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Project number	11822953
Approval date	20/12-2021
Classification	Open

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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, AU/DCE, DTU Aqua and DTU Compute. A steering committee followed the development during the project and was involved through dialogue and follow-up on progress, etc. This steering committee consisted of members from the Danish Ministry of Environment and Food (MFVM), Danish EPA (MST), DHI and AU.

In addition, a follow-up group consisting of members from The Danish Agriculture & Food Council, SEGES, the Danish Society for Nature Conservation, the Danish Sports Fishing Association, Danish Fishermen PO (DFPO), Sustainable Agriculture (BL), the Danish Ports, SDU 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 DHI's, AU’s, and DTU’s decision and responsibility.

CONTENTS

FIGURES

TABLES

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 and methods that were used for calculating Maximum Allowable Inputs (MAIs) of total nitrogen from Danish catchments based on target values for chlorophyll-a and eelgrass depth limit.

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

To follow up on the international evaluation, the Danish EPA facilitated a range of R&D projects with the overall aim to develop methods to calculate clear, transparent and differentiated chlorophyll-a reference values (and corresponding target values) and MAI's in as many water bodies as possible for incorporation into the third RBMP 2021-2027.

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

- 'Recommendations for the continued development of models and methods for use in the River Basin Management Plans 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 from Danish catchments based on a range of different scenarios reflecting assumptions regarding future developments in nutrient loading from neighbouring countries and the atmosphere as described in Erichsen *et al.* (2021). However, the documented MAIs do not include an estimation of the confidence of the MAIs.

The present technical note describes a method to calculate confidence intervals for the estimated maximum allowable input from Danish catchments and provides confidence intervals for water body specific MAIs from scenario 2e, which include planned nutrient load reductions from neighbouring countries and between 0-50% reduction in Danish phosphorus loading (see Erichsen *et al. (*2020b) for details).

1.1 Background

During the projects "Application of the Danish EPA's Marine Model Complex" and "Development of a Method Applicable for the River Basin Management Plans 2021-2027"[1], a number of statistical (STAT) and mechanistic (MEC) models were developed to describe the indicators used in the MAI calculations towards RBMP 2021-2027.

Both model types are developed based on existing hindcast data. The statistical models use existing measured data in the individual water bodies from 1990 to 2017 as a basis for the model development, whereas the mechanistic models are developed to describe the situation during the period 2002-2016 and are validated against existing measured data covering those years.

The two types of models were used to calculate the MAI of total nitrogen from Danish catchments based on a range of different scenarios reflecting assumptions regarding future developments in nutrient inputs from neighbouring countries and the atmosphere as described in Erichsen *et al.* (2021). However, the confidence interval for the estimated MAIs has not been estimated.

1.2 Objective

The objective of the present project is to estimate the confidence interval for the maximum allowable input (MAI) of nitrogen from Danish catchments to each of the Danish water bodies.

The basis for the confidence estimations will be MAIs from scenario 2e, P0 (Erichsen et al., (2020b), which predicts the effect from

- Full implementation of Baltic Sea Action Plan (HELCOM) and similar reduction targets in the North Sea (OSPAR)
- Implementation of RBMP 2015-2021 in all EU countries
- Full implementation of the NEC-directive concerning atmospheric N-deposition.
- 0% reduction in Danish P loadings

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[1] Videreudvikling af Miljøstyrelsens marine statistiske hhv. mekanistiske modeller til brug for vandforvaltningen

2 Method

There are two different water quality model types used to describe the indicators used in the MAI calculations towards RBMP 2021-2027. One model is based on a statistical Bayesian regression approach where monitoring data of light attenuation, chlorophyll-a concentration, physio-chemical and climate variables are used to find the relationship between nutrient input and water quality. The other model is a mechanistic 3D hydrodynamic and ecological model based on equations and documented relationships that are solved numerically using climate variables and nutrient loading as the input to the model. The slopes that describe the relationship between nutrient input and water quality variables from both model types are used to estimate MAI for all the reduction scenarios. Hence the variation of this slope is essential for the final MAI result, and therefore we test the sensitivity of the final MAI estimates given the uncertainty of the slope from the two model types.

The method for calculating confidence intervals is based on the error propagation from distributions of the estimated slopes, which is considered an appropriate approach, especially in situations where the complexity of the calculations prohibits analytical confidence estimates.

In broad terms, the error propagation method is a simulation method, where uncertainties in the input parameters (in this case the model estimated slopes) are "propagated" through the calculation procedure resulting in a distribution of the output parameter (in this case MAI for a water body) that can be transformed into a confidence interval. In the present application, only uncertainties related to the model estimation are included, whereas uncertainties related to, e.g. uncertainties in forcing data (e.g. meteorological data, loadings etc.) and marine monitoring data (e.g. monitoring data for chlorophyll-a and light) are not considered. Also, uncertainties related to the fulfilment of the assumption regarding nutrient reductions by neighbouring countries are not considered.

The method is based on the assumption that the estimated standard errors for the slopes represent the uncertainty of the estimated slopes in each area assuming that a parametrized distribution approximates those. From a mechanistic/biological point of view, slopes are either positive (e.g. Chlorophyll-a) or negative (e.g. light penetration depth). Negative slopes were transformed into positive slopes, and parametric distributions only allowing for positive values were used to simulate slopes.

Even with a parametric assumption of the distribution of the slopes, the MAI distribution would be complicated to derive analytically and therefore, a simulation-based approach is applied here. Further, rather than representing the uncertainty as the standard deviation of the simulated MAI's, the MAI realized from the simulated slopes represents the MAI distribution, and any representative statistic like mean, standard deviation or quantiles can be calculated from those simulations. Here, the uncertainty is represented by quantiles from the realized distribution of MAIs. While any set of quantiles could be chosen to represent the uncertainty, the choice here is the 0.1 and 0.9 quantiles to represent the 80% confidence interval of the MAI.

For the present application, the error propagation method uses the same calculation procedure as used for MAI estimates, but instead of using a fixed (mean) value for the model estimated slopes, describing the relation between nutrient loadings and an indicator, the error propagation method requires a distribution of slopes. From each distribution, 5000 randomly selected slope values are then "routed" through the MAI calculation procedure, resulting in 5000 MAI values for the same water body.

The model-derived slopes describing the relation between nutrient inputs and an indicator (chlorophyll-a and light, respectively) are central for calculating MAIs. To estimate confidence intervals for the MAIs, it is necessary to quantify the distribution of the model-derived slopes which will be used for random sampling as part of the MAI confidence calculation procedure.

The statistical models are based on Bayesian statistics, and here the distribution for each slope is automatically determined as a result of the 20,000 model runs, which is part of the model development. The water body-specific slopes between nutrient loading from January to September and summer mean concentration of chlorophyll-a are documented in Shetty et al. (2021), whereas slopes between nutrient loading from October to September and light penetration depth during the growth season are described in Christensen et al., 2021. The distribution of model-slopes represents uncertainty in the estimates, affected, partly by year-to-year variation, number of observations, model and data uncertainty, while it does not include residual (unexplained) variation in the regression.

For the mechanistic models, there is no formal method to estimate the uncertainty of the model-derived slopes, and the uncertainty of the slopes is estimated from the variation obtained from a 10-year model run, where a one-year model run produces a year-specific slope. Hence, the variation in slopes from the mechanistic model mirrors the changes in meteorological conditions and the year-to-year nutrient loadings. Based on the 10-year model run, the mean and standard deviation of the water body- and the indicator-specific slope is calculated.

Before entering the procedure for calculating MAI confidence intervals, the slopes were log-transformed and resampled from a log-normal distribution to avoid negative slopes (and zero slope). The procedure for calculating confidence intervals for each MAI follows the same procedure as described in Erichsen et al., (2020a). Briefly, status values for each indicator were adjusted for the cumulative impact of assumed reductions from other countries and atmosphere and used as a fixed value for all calculations[2]. Likewise, reference– and target values were fixed. For details on the method for calculating MAIs we refer to Erichsen et al. (2020a).

The system contribution and allocation were calculated based on the reference scenario, reference loadings and model slopes as described in Erichsen et al. (2021). N reductions required to reach the good ecological status (GES) for each indicator and model type were calculated using resampled model slopes and fixed values for adjusted status and target values. This resulted in a distribution of N-MAI for each indicator and each model type. In the original MAI calculations, N-MAI for an indicator was truncated/cut off either if GES values could not be reached by reducing N loading from Danish catchments (MAI truncated at reference loading) or if the indicator has reached at least GES (MAI truncated at status loading). The same was done in the error propagation routine. Hence, the value was truncated if any of the 5000 simulations resulted in N-MAIs below reference loading or above status loading. The MAI (mean and confidence interval) to obtain GES for each indicator was calculated using the distribution of MAIs from one model type, keeping MAI from the other model type fixed. To estimate the confidence interval for “national-scale” MAI, for each model-type, the 5000 MAIs for the individual models were summarized to gain 5000 “national-scale”/summed MAIs. This covers the uncertainty of MAI for each model but does not reflect the bias between the model estimates. To address some of the uncertainty due to deviating MAIs between the two models, the MAIs for both model types were combined as in the original MAI calculations, and the resulting 5000 MAIs for the individual water bodies were summarized. The distribution of MAI for each water body is reported as the 10% and 90% percentile from simulations where either STAT or MEC model slopes were fixed at the estimated mean value.

To maintain transparency, confidence intervals are reported before aggregating catchments and accounting for the nutrient reduction requirements for downstream and upstream water bodies. Hence, the reported 50th percentiles for each water body are not directly comparable with the previously reported water body specific MAI values (Erichsen *et al.* 2021).

The confidence interval for national scale MAI was calculated by sampling from the distribution of MAIs for individual water bodies and summarizing the samples for all water bodies. The confidence interval for MAI on a national scale was also calculated without taking aggregation and upstream and downstream reductions into account; hence the results are not directly comparable with previously reported national scale MAI estimates (Erichsen *et al* 2021).

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[2] In Erichsen *et al.* (2021) the impact on the Danish MAIs due to variation in scenarios from other countries and the atmosphere are summarized.

3 Results

The error propagation using 5000 samples showed that MAI for most water bodies had relatively symmetric distributions when estimated using either mechanistic (MEC) or statistical (STAT) models. Skewed MAI distributions were, however, detected in situations where part of the MAI distribution for one or both indicators was truncated. Hence, the uncertainty analysis results are presented as the 10th, 50th and 90th quantiles (designated Q10, Q50 and Q90, respectively) of the MAI distribution for each water body.

The confidence intervals (Q10-Q90) for water body specific MAIs are shown in Table 3-1 together with the median value (Q50) for each MAI distribution. The MAI distribution is calculated based on either the distribution of STAT calculated slopes (STAT) or MEC calculated slopes (MEC) as described in the method section. As aggregation of water bodies is omitted from the present confidence calculations, the median values reported here are not directly comparable with previously reported MAIs; however, unaggregated status loadings and MAI values are included in Table 3-1, allowing for a direct comparison.

Table 3-1 Confidence intervals (10th and 90th quantile) and median values (50th quantile) for water body specific MAIs estimated by error propagation of model estimated slopes. Confidence intervals (Q10 and Q90) and median values (Q50) have been calculated using slopes from 98 water bodies derived from mechanistic models and slopes from 28 water bodies derived from statistical models. For comparison, non-aggregated status-, MAI- and reference loadings used for the previous reporting are included. All loadings are in ton N year^{-1}.

WB no	WB Name	Status Load. no aggre-gation	MAI. no aggre-gation	Ref Load. no aggre-gation	Q10 MEC	Q50 (median) MEC	Q90 MEC	Q10 STAT	Q50 (median) STAT	Q90 STAT
1	Roskilde Fjord.ydre	375.6	266	135.9	259.2	266.6	272.4			
2	Roskilde Fjord. indre	388.2	379.6	110.9	378.4	379.7	380.7	379.5	379.5	379.5
6	Nordlige Øresund	1098.4	1098.4	133.8	1098.4	1098.4	1098.4			
16	Korsør Nor	39.8	30.2	8.7	30.1	30.1	30.2			
17	Basnæs Nor	68.8	52.1	10.4	51.9	52	52.1			
18	Holsteinborg Nor	22.1	22.1	4.4	22.1	22.1	22.1			
24	Isefjord. ydre	87	55.5	19.9	53.8	55	56.1	52.1	53.6	55.3
25	Skælskør Fjord og Nor	43.8	36.6	8.3	33.7	36.6	38.3			
28	Sejerø Bugt	164.1	164.1	52.5	164.1	164.1	164.1			
29	Kalundborg Fjord	69.4	40.9	13.5	40.7	40.9	41	43.3	43.5	44.5
34	Smålandsfarvand et. syd	523.2	523.2	112.5	523.2	523.2	523.2			
35	Karrebæk Fjord	1272.2	1006.8	388.1	996.4	1003.7	1008.9			
36	Dybsø Fjord	61.1	61.1	11.6	61.1	61.1	61.1			
37	Avnø Fjord	237.7	185.9	39.5	185.7	186.1	186.3			
38	Guldborgsund	419.4	419.4	87.2	419.4	419.4	419.4			
44	Hjelm Bugt	91.4	91.4	20.2	91.4	91.4	91.4			
45	Grønsund	278	207.2	44	207.8	207.9	208.1			
46	Fakse Bugt	301.5	280.3	63.1	280.2	280.4	280.6			
47	Præstø Fjord	208	133.2	50.1	120.4	135.4	145.4			
48	Stege Bugt c)	235.3	235.3	51.6	235.3	235.3	235.3			
49	Stege Nor	23.8	15.2	4.2	14.1	15.1	15.9			

WB no	WB Name	Status Load. no aggre-gation	MAI. no aggre-gation	Ref Load. no aggre-gation	Q10 MEC	Q50 (median) MEC	Q90 MEC	Q10 STAT	Q50 (median) STAT	Q90 STAT
56	Østersøen. Bornholm	859.5	521.5	183.5	521.5	521.5	521.5			
57	Østersøen. Christiansø	3.2	1.6	0.1	1.6	1.6	1.6			
59	Nærå Strand	97.8	23	22.2	22.2	23	31.6			
62	Lillestrand	11.1	6.4	2.6	6	6.3	6.6			
68	Lindelse Nor	49.6	49.6	10.8	49.6	49.6	49.6			
72	Kløven	43	43	10.6	43	43	43			
74	Bredningen	128.1	44.4	42.2	42.2	44.6	48.6			
80	Gamborg Fjord	79.6	72.6	22.3	71.3	72.4	73.4			
82	Aborg Minde Nor	151.7	34	34	34	34	34			
83	Holckenhavn Fjord	289.5	100.5	80.6	98.6	101	105.2			
84	Kerteminde Fjord	26.6	21.4	4.4	19.6	21.2	22.5			
85	Kertinge Nor	23.6	20.7	5	20.6	20.7	20.7	20.5	20.7	20.8
86	Nyborg Fjord	18.8	13.2	8	13	13.2	13.3			
87	Helnæs Bugt	216	141.5	66.9	141.4	141.4	141.4			
89	Lunkebugten	15.7	10.4	5	10.4	10.4	10.4			
90	Langelandssund	443.5	389.7	114.1	389.4	389.6	389.8			
92	Odense Fjord. ydre	70.5	54.2	18.3	53.2	54.2	54.9	54.2	54.4	54.6
93	Odense Fjord. Seden Strand	1287.9	768.3	390.5	841.7	846.4	850.9	768.9	768.9	768.9
101	Genner Bugt	34.6	18.8	13	18.6	18.6	18.6	15.9	15.9	15.9
102	Åbenrå Fjord	130.2	70.6	58.9	82.2	82.4	82.7	70.6	70.6	70.6
103	Als Fjord	138.9	86.9	34.9	86.9	86.9	86.9	60.9	66.9	77.8
104	Als Sund	67.8	67.8	15	67.8	67.8	67.8			
105	Augustenborg Fjord	61.9	61.9	28.5	61.9	61.9	61.9	61.9	61.9	61.9
106	Haderslev Fjord	239.3	133.3	104.4	132.2	133.4	134.6			
108	Avnø Vig	59.7	28.2	20.2	25.7	28.3	30.5			
109	Hejlsminde Nor	138.5	94.3	57.6	89.5	94.2	97.7			
110	Nybøl Nor	66	49.4	29.5	45.5	48.9	51.9			
113	Flensborg Fjord. indre	51.4	27.1	19.1	27.2	27.2	27.2	27.2	27.2	32.8
114	Flensborg Fjord. ydre	101.2	101.2	30.5	101.2	101.2	101.2	101.2	101.2	101.2
122	Vejle Fjord. ydre	406.3	303.9	169.3	287.8	287.8	287.8			
123	Vejle Fjord. indre	561.4	497.9	287.7	496.9	497.9	498.9	494.5	496.8	498.5
124	Kolding Fjord. indre	493	226.2	187.7	220.5	226.9	238.9	226.2	291.7	329.2
125	Kolding Fjord. ydre	35.4	22.7	18.6	22.7	22.7	22.7			
127	Horsens Fjord. ydre	51.2	29.4	6.4	20.1	21	21.8			
128	Horsens Fjord. indre	781.8	425.9	225.1	401.1	425.6	447.1	337.8	368.5	449.6

WB no	WB Name	Status Load. no aggre-gation	MAI. no aggre-gation	Ref Load. no aggre-gation	Q10 MEC	Q50 (median) MEC	Q90 MEC	Q10 STAT	Q50 (median) STAT	Q90 STAT
129	Nissum Fjord. Ydre	329.5	162.2	97.4	143.7	160.5	174.1			
130	Nissum Fjord. mellem	144.9	52.2	34.7	47.3	51.8	56.1	43.5	52.8	74.3
132	Ringkøbing Fjord	4747.6	2466.7	1679.3	2463.6	2477.3	2490.8	2477.6	2477.6	2477.6
133	Vesterhavet. nord	77.1	77.1	12.5	77.1	77.1	77.1			
138	Hevring Bugt	157.2	157.2	40.9	157.2	157.2	157.2	156	157.2	157.2
139	Anholt c)	9.1	9.1	5.8	9.1	9.1	9.1			
140	Djursland Øst	856.2	674.4	219	673.3	674.6	675.8			
141	Ebeltoft Vig c)	14.1	14.1	6.5	14.1	14.1	14.1			
142	Stavns Fjord	5.4	4.3	1.4	4.3	4.3	4.3			
144	Knebel Vig	18.5	14.9	5.4	14.6	14.9	15.2			
145	Kalø Vig	171	171	57.4	171	171	171	171	171	171
146	Norsminde Fjord	140	93.3	46.5	93.2	93.2	93.2			
147	Århus Bugt og Begtrup Vig	466.9	458.7	177.7	458.5	458.7	458.9	459.1	459.4	459.7
154	Kattegat Læsø c)	77.8	77.8	36.2	77.8	77.8	77.8			
157	Bjørnholms Bugt. Riisgårde Bredning. Skive Fjord og Lovns Bredning	1837.2	648.4	501.6	642.9	658.2	669.7			
158	Hjarbæk Fjord	1795.2	537.4	410.5	525.7	537.9	558			
159	Mariager Fjord. indre	515.8	142.4	79.4	138.4	146.2	179.1			
160	Mariager Fjord. ydre	447	301.8	84.8	271	307.3	345.7			
165	Isefjord. indre	811.6	491.2	163	484	489.3	494.3	422.5	474.4	527.9
200	Kattegat Nordsjælland	194.3	130.1	65.8	130	130	130			
201	Køge Bugt	1108.9	843.4	249.2	843.2	843.7	844.2	848.1	850	851.9
204	Jammerland Bugt og Musholm Bugt	1326.9	929.3	308.2	928.1	929.8	931.4			
206	Smålandsfarvand et. åbne del	268.4	247.4	33.5	247.7	248.7	249.8			
207	Nakskov Fjord	453.6	405.1	43.5	403	404.5	406.1			
208	Femerbælt	556.1	544.7	91.6	487.4	487.9	488.3			
209	Rødsand og Bredningen	520.6	321.7	121.8	303.1	320.5	335.3			
212	Fåborg Fjord	29.6	20.2	9.9	19.8	19.8	21			
214	Det sydfynske Øhav	510.7	268.7	142.1	267.2	267.4	267.6	247.2	248.1	249
216	Lillebælt. syd	441	298.3	155.5	298.2	298.2	298.2	298.2	298.2	298.2
217	Lillebælt Bredningen	238.3	117	68.7	115	116.9	118.7	117	117	118.4
219	Århus Bugt. syd. Samsø og Nordlige Bælthav	363.9	222.5	81.1	222.5	222.5	222.5			
221	Skagerrak	1422.8	1422.8	409.4	1422.8	1422.8	1422.8			

WB no	WB Name	Status Load. no aggre-gation	MAI. no aggre-gation	Ref Load. no aggre-gation	Q10 MEC	Q50 (median) MEC	Q90 MEC	Q10 STAT	Q50 (median) STAT	Q90 STAT
222	Kattegat Ålborg Bugt c)	1063	1063	313.3	1063	1063	1063			
224	Nordlige Lillebælt	619.9	385.9	151.9	385.9	385.9	385.9			
225	Nordlige Kattegat ÅlbækBugt	705.6	705.6	195.1	705.6	705.6	705.6			
231	Lillebælt Snævringen	180.7	61	30.7	60.2	61.6	62.8	63.7	64.1	64.5
232	Nissum Bredning	879.7	490.4	297.4	525.2	525.2	525.2	529.3	529.5	541.2
233	Kaas Bredning og Venø Bugt	1075.3	621.2	336.2	732.5	757.2	777.9			
234	Løgstør Bredning	703.4	304.1	214.2	310.5	311.4	312.4			
235	Nibe Bredning og Langerak	3942.5	2877.6	870.2	2874.1	2930.2	2989.9	2955.7	2955.7	2955.7
236	Thisted Bredning	1090.9	378.6	268.9	374	383.4	453.6			
238	Halkær Bredning	619.6	113.9	113.9	113.9	113.9	113.9			

The results show that the model uncertainty for most water bodies has a minor impact on the MAI estimates, resulting in very narrow confidence intervals. The confidence interval (Q10-Q90) is < ± 10% of median MAI for 94 out of 98 water bodies estimated with MEC models and 22 out of 26 water bodies estimated with STAT models. For 6 water bodies, the uncertainty was > ± 10%. The maximum uncertainty for an individual water body was 37% and 40% for MEC and STAT, respectively. For all water bodies with a nutrient reduction requirement (i.e. MAI< Status load), Q90 was also < Status load, and water body-specific MAIs were estimated with little variation, induced by the uncertainty in the model-slopes indicating a certain need for nutrient reduction requirements in these water bodies.

The confidence interval for the summarized MAI (sum of MAIs for individual water bodies) was estimated using the MAI distribution from 98 water bodies calculated with mechanistic models and MAI distribution from 28 water bodies calculated with statistical models. The confidence interval (Q10-Q90) for the summarized MAI distribution calculated with MEC models was ± <1% and ± <1% for MAI calculated with STAT models. These summed MAIs include areas that have been truncated and therefore do not illustrate the uncertainty caused by variation in the slopes. The distributions are shown in Figure 3-1 and Figure 3-2, respectively.

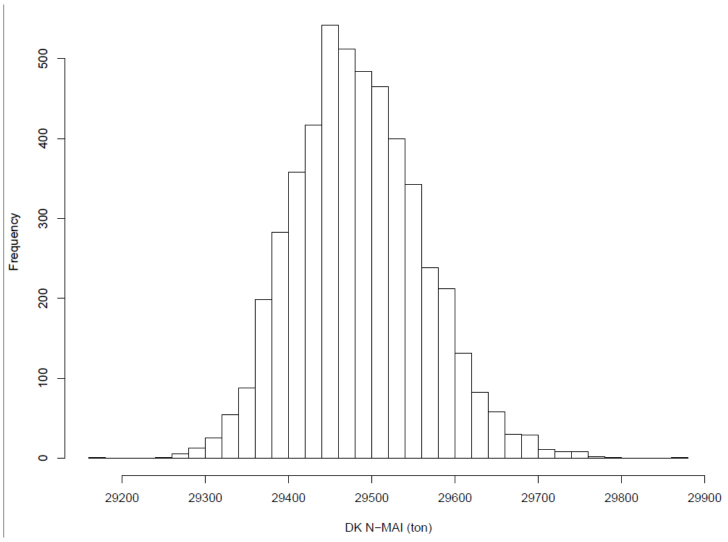

Figure 3-1 Distribution of “summarized MAI” (sum of water body specific MAIs from 98 water bodies) calculated with mechanistic models. The Q10, Q50 and Q90 for the distribution are 29.4 ktons, 29.5 ktons, 29.6 ktons, respectively.

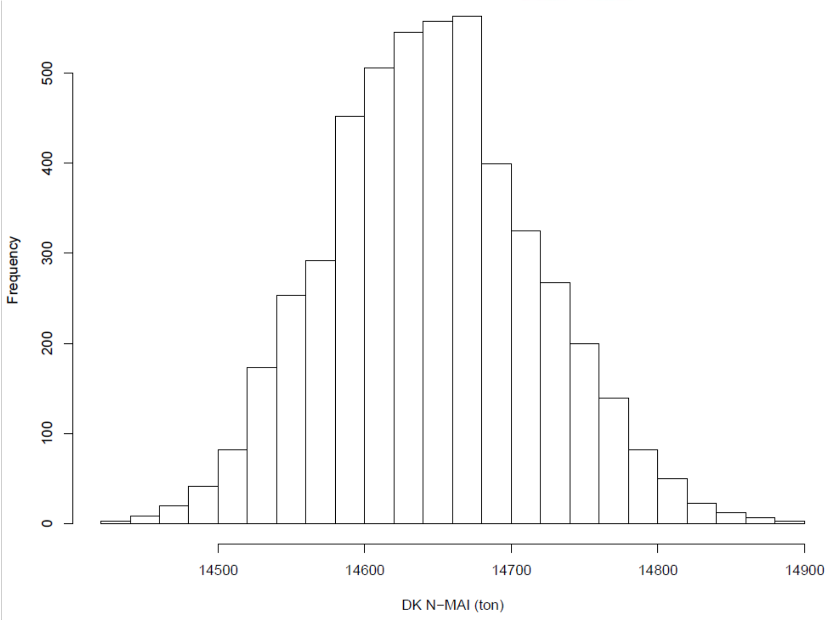

Figure 3-2 Distribution of "summarized MAI" (sum of water body specific MAIs from 28 water bodies) calculated with statistical models. The Q10, Q50 and Q90 for the distribution are 14.6 ktons, 14.6 ktons, 14.7 ktons, respectively.

To illustrate the uncertainty due to both variation in slopes and possible model bias, we selected a subset of areas where MAI has been calculated using both a MEC and STAT model and where the distribution of MAIs was unaffected – or only slightly affected – by truncations in both models. This led to a subset of 11 areas. The model-specific MAI distributions were combined using the original MAI calculation procedure for each water body. Two examples of water body specific MAIs are shown in Figure 3-3/Figure 3-4 and Figure 3-5/Figure 3-6, respectively.

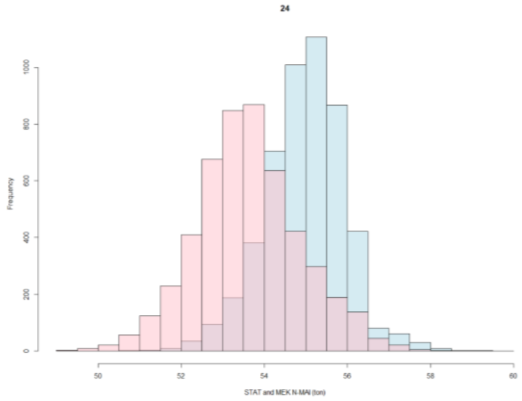

Figure 3-3 MAI distribution for Isefjord, ydre, calculated with STAT (red) and MEC (blue) models.

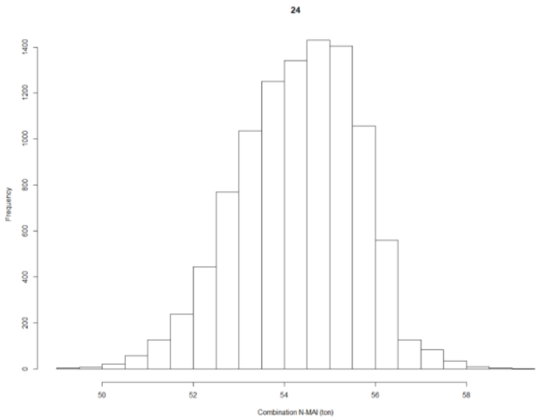

Figure 3-4 MAI distribution for Isefjord, ydre, calculated by combining STAT and MEC models.

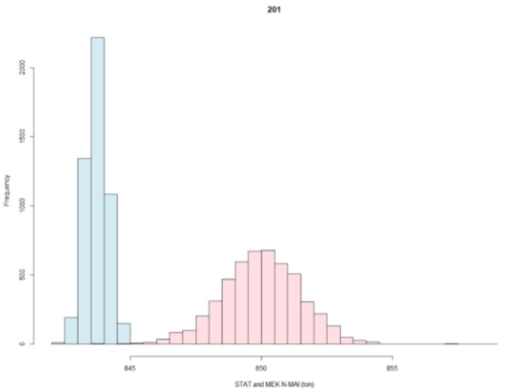

Figure 3-5 MAI distribution for Køge Bugt calculated with STAT (red) and MEC (blue) models.

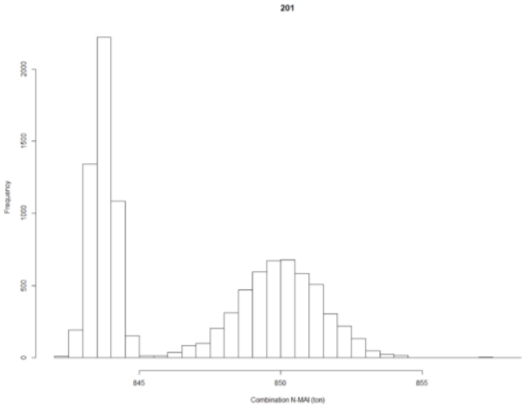

Figure 3-6 MAI distribution for Køge Bugt calculated by combining STAT and MEC models.

These two examples show that the MAI distributions can be either completely overlapping, partly overlapping or wholly separated. For the latter situation, we can conclude that at least one of the models must be biased. Meaning that one or both models have an offset, estimating the “true” MAI in the scenario, but since we don’t have an objective way to choose the most correct model, an average value between the two different model MAIs is still considered the best guess of the “true” MAI.

By summarizing MAIs for water bodies calculated with two model types and avoiding MAI distributions affected by truncation, the resulting summarized MAI distribution includes both uncertainty related to model-slope uncertainty as well as model bias. The resulting distribution is shown in Figure 3-7, and it has a confidence interval (Q10-Q90) < ± 2% of median MAI – since the distribution is not a perfect normal distribution, but rather a more long-tailed distribution, the Q2.5-Q97.5 are a bit further out than else expected, when compared to Q10-Q90, but still < 4%.

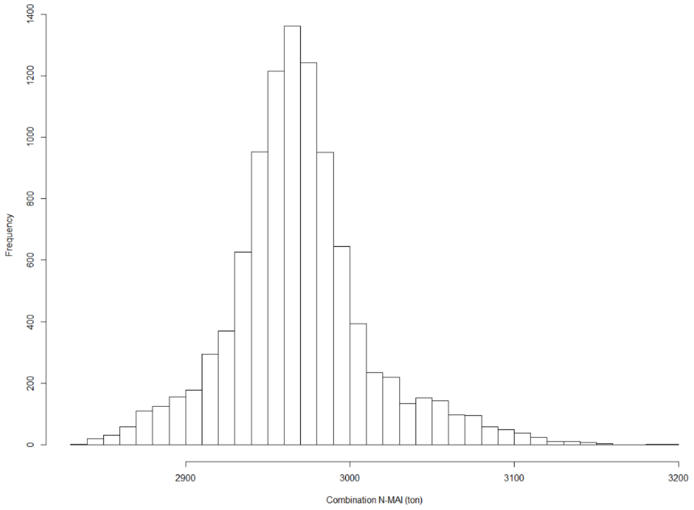

Figure 3-7 MAI for water bodies calculated with both MEC and STAT models and where the distributions are not affected by truncation. This is based on data from 11 waterbodies (22 model results).

4 Closing remarks

The error propagation method was used to estimate the sensitivity of model-slope uncertainty for the estimation of maximum allowable nutrient input (MAI) to individual water bodies. The results revealed that the confidence intervals (Q10-Q90) for the MAIs were < ± 10% of the median MAI for 93 out of 98 water bodies estimated with MEC models and 22 out of 28 water bodies estimated with

STAT models. For five and six water bodies, the uncertainty exceeded 10% of MAI for the MEC and STAT models, respectively, and the maximum uncertainty for a single water body was 40% (Nissum Fjord, mellem).This is an expression of how the uncertainty of one crucial parameter (the slopes of the nutrient input-quality element relationship) propagates through the calculation of MAI and does not cover uncertainty of state (based on monitoring data), model bias, uncertainties in forcing data (e.g. meteorological data, loadings etc.). Uncertainties related to the fulfilment of the assumption regarding nutrient reductions by neighbouring countries are not considered.

The best estimate of the confidence interval for a “national-scale” MAI was calculated summarizing water body MAIs calculated with both MEC and STAT models where MAI distributions were unaffected by truncation. The results revealed that the 80% confidence interval (Q10-Q90) was <2%. This is an attempt to include some model bias in the uncertainty measure but is restricted to only a subset of water bodies, and hence it should be considered as a minimum estimate.

These results indicate that the MAIs and the nutrient reduction requirements are estimated with a high degree of certainty given the conditions mentioned above.

5 References

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