Technical Report No. 4

Load scenarios for Ecosupport

November 2011

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Baltic Nest
Institute

The Baltic Nest Institute

The Baltic Nest Institute host the Nest model, a decision support system aimed at facilitating adaptive management of environmental concern in the Baltic Sea.

Nest can be used to calculate required actions needed to attain politically agreed targets for the Baltic Sea ecosystem. By modeling the entire drainage area, Nest is a novel tool for implementing the ecosystem approach in a large marine ecosystem. The main focus of the model is on eutrophication and the flows of nutrients from land to sea.

Reducing the nutrient input to the sea and thus decreasing the negative environmental impacts is a politically prioritized area of international cooperation. Baltic Nest Institute can contribute to this process by formulating policies that are fair, transparent and cost-efficient. The main target group for the Nest Decision Support System is HELCOM and regional water directors in the riparian countries.

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1 Introduction

In the project ECOSUPPORT, three coupled physical-biogeochemical models (ERGOM, RCO-SCOBI and BALTSEM) are used to produce an ensemble of combine climate change - nutrient load scenarios. The atmospheric driving forces for the models are produced by two global climate models, ECHAM5 and HadCM3; and these results are dynamically downscaled using the RCAO model at the SMHI, see Meier et al. (2011) and references therein. Since, results from dynamic hydrological models were not available, river runoff were constructed from the net P-E balance of the RCAO model results. Nutrient load scenarios was to be explicitly given, but effects from climate change induced river runoff variations were estimated. In total, four different climate change scenarios produced and four different assumptions on direct anthropogenic changes in nutrient loads, thus in total 16 combinations. The nutrient load scenarios comprised of; one reference with approximately unchanged loads, one pessimistic business as usual and two more optimistic, current legislation and Baltic Sea Action Plan. All the latter based on previous work. This report describes the construction of these nutrient load scenarios.

2 BALTSEM load data set

The riverine loads, comprising inputs from monitored and non-monitored rivers, and coastal areas (diffuse sources), were reconstructed from the Baltic Environmental Database (http://nest.su.se/bed) maintained at the Baltic Nest Institute, and the data collected by HELCOM within PLC-5 project and provided to BNI for BSAP revision process (http://nest.su.se/docs/Baltic Sea nutrient loads for BSAP June 5 2009.pdf). Since in the BED data are available for 1970-2000 as monthly inputs, while PLC-5 data cover 1994-2006 as annual integrals, the merging of these datasets was made in the following way. First, the time series available in BED (http://nest.su.se/bed/river_inputs.shtml) for over 150 sub-watersheds had been aggregated (pooled) over thirteen marine BALTSEM sub-basins. Next, aggregated time-series for 1994-2000 (tonnes month^{-1}) have been used to reconstruct basin-wise patterns of seasonal variation in a form of twelve monthly fractions of annual integrals (dimensionless). Finally, these patterns were used as multiplication factors to decompose annual integrals from PLC-5 aggregated for BALTSEM basins over 1994-2006 into monthly time-series.

The direct nutrient inputs from point sources, situated at the coast, have been reconstructed from annual TN and TP integrals with country-per-basin spatial resolution either published by HELCOM (1987, 1993, 1998, 2004) for each fifths year starting from 1985 or being prepared for publishing (PLC-5) with annual resolution for 1994-2006, as well as from some old papers, technical reports, and working documents similar to those used, for instance, by Larsson et al. (1985). Recomposition according to BALTSEM resolution and extrapolation backwards was made with geographical coordinates of over 325 individual point sources reported in 2000 and by the appropriate apportionment based on PLC-5 data for 1994.

Atmospheric deposition of inorganic nitrogen was reconstructed from estimates obtained by Granat (2001) and available also in BED as well as from simulations made by the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmissions of Air Pollutants in Europe
(e.g., http://www.helcom.fi/environment2/hazsubs/EMEP/en_GB/emep2006/) and available through EMEP data module of the DSS Nest (http://nest.su.se/nest). Granats data are presented as monthly mean depositions of four components (wet

and dry deposition of reduced and oxidized nitrogen) for 1970-1991 with a spatial resolution of 1° x 1° squares for the entire Baltic Region. The EMEP annual depositions of the same four components for 1980, 1985, 1990, 1995-2006 were integrated over BALTSEM basins directly in Nest, and, similarly to riverine loads, were further decomposed into monthly values with the basin-wise seasonal patterns computed from the Granats estimates for 1986-1990.

3 Scenarios

The challenge is to combine climate effects with a few management scenarios, and to make them practically useful in the modeling context. Still there are relatively few available management scenarios on nutrient load to the Baltic Sea available, most of them were designed in the context of the preparation of the eutrophication segment of the HELCOM Baltic Sea Action Plan (BSAP), cf. Wulff et al. (2007); Humborg et al. (2007); HELCOM (2007). Here there were four main cases were defined: ban on phosphates in detergents, best practice in agriculture, improved sewage treatment, and a pessimistic scenario of intensified agriculture in transitional countries. Scenarios were presented based on various combinations of the main cases. The Ecosupport scenarios are also built on these cornerstones.

3.1 Definitions

Below follows the definitions of the four scenarios. The change in land loads for these are summarized in Table 3.1.

3.1.1 Reference, *REF*

The reference scenario simply manifests human pressure being constant as in recent years, that is based on the average of 1995-2002. Riverine loads will however change in response to varying river runoff as described below.

3.1.2 Current legislation, *CLEG*

This scenario is based on the assumption that all country apply EU directives on sewage treatment and the NEC directive on air emissions. In the preparation of the BSAP in 2007, BNI made a calculation of the load reduction that would be result of improved sewage treatment (HELCOM, 2007; Humborg et al., 2007). BNI at the National Environmental Research Institute in Denmark estimated a reduction of the nitrogen deposition on the Baltic Sea of about 25% if the EU-NEC (Nitrogen Emission Ceiling) directive were implemented(K. M. Hansen, pers.

comm.). Thus, a 25% decrease in atmospheric nitrogen deposition was assumed in the *CLEG* scenario.

3.1.3 Baltic Sea Action Plan, *BSAP*

In the eutrophication segment of the Baltic Sea Action Plan, maximum allowable loads for each major sub-basin is presented together with corresponding load reductions compared to a reference period 1997-2003. In our case we make use of the reductions instead of the maximum allowable loads, which gives slightly different loads. We combine these reduction with a possible further decrease in atmospheric nitrogen deposition, i.e., 50 %.

3.1.4 Business as usual, *BAU*

This scenario is based on the assumption of an expanding agriculture in, especially transitional countries. In Humborg et al. (2007), the anticipated increase of the loads under these assumptions has been estimated to about 340 000 ton N/yr and 16 000 ton P/yr.

				BSAP				
	KT	DS	BP	BS	BB	GR	GF	SUM
N	-20000	-15000	-94000	0	0	0	-6000	-135000
P	0	0	-12500	0	0	-750	-2000	-15250
				CLEG				
	KT	DS	BP	BS	BB	GR	GF	SUM
N	-43	-120	-16363	0	0	0	-5684	-22210
P	0	0	-4418	0	0	-640	-1313	-6371
				BAU				
	KT	DS	BP	BS	BB	GR	GF	SUM
N	0	0	234551	0	0	44496	61952	341000
P	0	0	11201	0	0	2070	2805	16076

Table 3.1: The absolute changes in loads compared to the reference period for the different management scenarios.

3.2 Methodology of producing basin-wise time series

The most straightforward way would be to implement directly the load changes for the different scenarios (Table 3.1) to the models, and in the case of the *BSAP* scenario, the maximum allowable loads. However, the three models are calibrated to slightly different standard loads and with different assumptions on bioavailability of organic loads (Eilola et al., 2011). Thus, we apply changes of loads to the reference period loads for the different scenarios, and compute relative changes instead. The relative changes can be applied to concentrations in rivers for each model separately, so that loads will change also with changing runoff as a lowest order of magnitude estimate of the climate change effect on loads.

The first step is to average from the data set described above, the loads from rivers, atmosphere and coastal point sources for the reference period (1995-2002). The river loads comprise of contributions from ammonia, nitrate and organic nitrogen, and inorganic and organic phosphorus, while coastal point sources are given as total nitrogen and phosphorus only. Atmospheric deposition is divided into wet and dry deposition of ammonia and nitrate, and an estimate of average phosphorus deposition (that is a constant deposition is assumed). The average loads 1995-2002 is shown in Table 3.2.

The BSAP and improved sewage treatment load reductions are given in the seven basin resolution of the BSAP; while the increase in loads of the BAU scenario is given as a total but here assumed to be distributed in proportion to present loads to the Baltic proper, Gulf of Finland and Gulf of Riga, see Table 3.1 above. Also in the scenarios, it is not specified whether the reductions affect primarily inorganic or organic nutrient. Thus, we sum the loads of the reference period (Table 3.2) to the seven basin resolution and also sum inorganic and organic contributions. The overall loads is summarized in Table 3.3.

For simplicity, load change is only applied to the riverine nutrient loads. However, not all models are explicitly feed with coastal point sources, but has instead these sources added to the riverine contributions. Therefore, the reduction/increase factors will be slightly different depending on if coastal point sources are included in river loads or not. The change in concentration in river waters is computed from

$$f1 = \frac{RivLoad_{Ref} - L_{Reduction}}{RivLoad_{Ref}} - 1 \tag{3.1}$$

and for models that includes also coastal point sources in their riverloads the change is computed from

$$f2 = \frac{RivLoad_{Ref} + PointLoad_{Ref} - L_{Reduction}}{RivLoad_{Ref} + PointLoad_{Ref}} - 1. \tag{3.2}$$

The reduction/increase factors are shown in Table 3.4. Naturally, the factors should be zero for the *REF* scenario.

The loads in the model scenarios should be computed from

$$RivLoad(t) = (1 - f \times R(t))C_{avg}Q(t) \tag{3.3}$$

where C_{avg} is the 1995-2002 averaged concentration in the rivers per basin and $Q(t)$ is the time dependent water flow of the rivers. $R(t)$ is a ramp function that linearly implement the change over the period 2007 to 2020, i.e.,

$$R(t) = \min\left[\frac{\max\left[t - 2007, 0\right]}{13}, 1\right]. \tag{3.4}$$

3.3 Examples of load time-series

The final land loads are obtained by using the river runoff of the different climate scenarios and multiply with average concentrations times the adjustment factor as described above. As an illustration the land loads of the 16 combinations of nutrient load and climate change scenarios for the BALTSEM simulations are shown in Fig. 3.1. As further emphasized in Table 3.5, the different climate scenarios give relatively similar long-term average loads for the same load scenario, but the inter-annual variability is quite large. There is also an evident climate change signal towards increased loads due to increasing runoff.

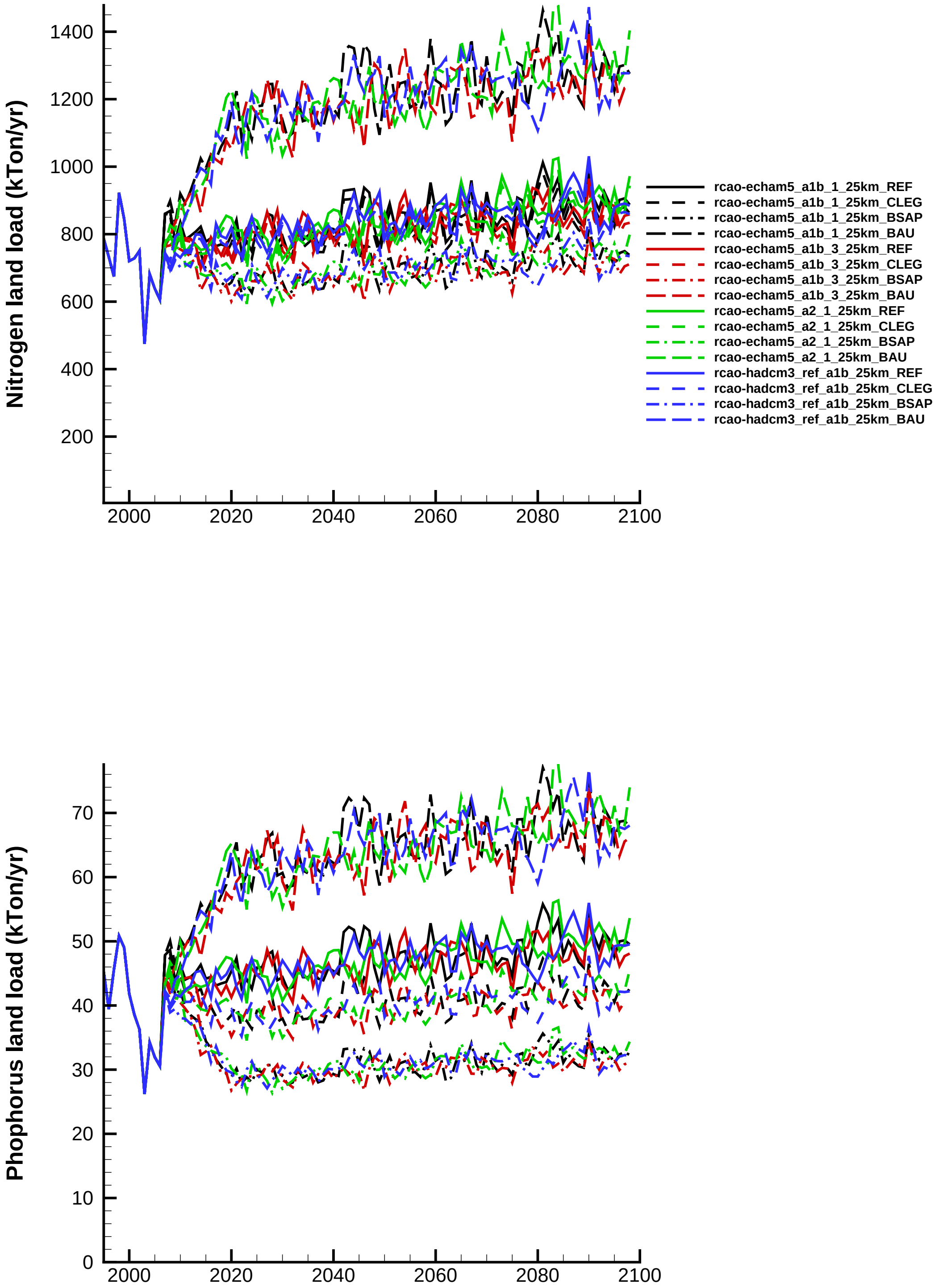

Figure 3.1: Annual average land loads summed over the whole of the Baltic Sea of nitrogen (top) and phosphorus (bottom) for all combinations of load and climate change scenarios. The different load scenarios are drawn with different line styles and the climate scenarios with different colors.

	BALTSEM basin no.													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Sum
Riv NH4	483	865	621:	463	804	103	384	6670	16907	2805	3059	3028	7032	43224
Riv NO3	11834	21216	11168	13494	13797	4442	7477	67073	118259	19174	11270	37325	38818	375347
Riv OrgN	6770	4972	5392	2141	4076	917	2311	41021	97752	33517	35986	27535	48670	311060
Point N	2179	780	426	923	2532	2244	789	908	8172	5583	3377	1318	13552	42783
Atm NH wet	1253	2460	2700	3292	4252	372	4124	9637	29417	8597	3044	3110	3440	75698
Atm NOx wet	1354	2541	2884	2989	3775	387	4601	11303	35858	10880	3714	3510	4164	87960
Atm NH dry	657	1312	1296	2330	2915	157	2024	4369	8261	1645	584	675	657	26882
Atm NOx dry	697	1183	1291	1464	1769	288	2345	6136	18840	5294	1255	2062	2475	45099
Sum N	25227	35329	25183	27096	33920	8910	24055	147117	333466	87495	62289	78563	118808	1008053
Riv PO4	118	314	137	225	255	60	363	3022	6466	906	867	1215	1518	15466
Riv OrgP	300	357	215	168	270	37	222	5284	6024	1539	1781	2736	3837	22770
Point P	97	75	44	109	106	194	99	60	436	339	124	244	3324	5251
Atm P	66	127	140	125	151	14	219	597	2598	1005	548	263	356	6209
Sum P	581	873	536	627	782	305	903	8963	15524	3789	3320	4458	9035	49696

Table 3.2: The average loads (in ton/yr) 1995-2002 to each of the BALTSEM basins from the different sources.

	Basins							
	KT	DS	BP	BS	BB	GR	GF	SUM
	Nitrogen							
River	63321	40237	357854	55496	50315	67888	94520	729631
Point	3385	5699	9869	5583	3377	1318	13552	42783
Sum land	66706	45936	367723	61079	53692	69206	108072	772414
Atmopheric	19628	23990	136915	26416	8597	9357	10736	235639
Sum	86334	69926	504638	87495	62289	78563	118808	1008053
	Phosphorus							
River	1441	1015	21381	2445	2648	3951	5355	38236
Point	216	409	595	339	124	244	3324	5251
Sum Land	1657	1424	21976	2784	2772	4195	8679	43487
Atmospheric	333	290	3414	1005	548	263	356	6209
Sum	1990	1714	25390	3789	3320	4458	9035	49696

Table 3.3: The average loads 1995-2002 for the seven major basins of the Baltic Sea.

	Basins						
	KT	DS	BP	BS	BB	GR	GF
	Change rivers only - point sources unchanged						
BSAP							
N	-31.59	-37.28	-26.27	0.00	0.00	0.00	-6.35
P	0.00	0.00	-58.46	0.00	0.00	-18.98	-37.35
CLEG							
N	-0.07	-0.30	-4.57	0.00	0.00	0.00	-6.01
P	0.00	0.00	-20.66	0.00	0.00	-16.20	-24.52
BAU							
N	0.00	0.00	0.66	0.00	0.00	65.54	65.54
P factor	0.00	0.00	0.52	0.00	0.00	52.39	52.39
	If coastal point sources in are included in rivers						
BSAP							
N	-29.98	-32.65	-25.56	0.00	0.00	0.00	-5.55
P	0.00	0.00	-56.88	0.00	0.00	-17.88	-23.04
CLEG							
N	-0.06	-0.26	-4.45	0.00	0.00	0.00	-5.26
P	0.00	0.00	-20.10	0.00	0.00	-15.26	-15.13
BAU							
N	0.00	0.00	62.57	0.00	0.00	62.57	62.57
P	0.00	0.00	46.13	0.00	0.00	46.13	46.13

Table 3.4: The reduction/increase factors (in %) for the different scenarios in the two cases of treatment of the coastal point sources.

	Nitrogen			
	REF	*CLEG*	*BSAP*	*BAU*
rcao-echam5-a1b-1	888711	862938	735370	1280684
rcao-echam5-a1b-3	863996	838872	712827	1249147
rcao-echam5-a2-1	903613	877480	747429	1302251
rcao-hadcm3-ref-a1b	876216	850958	724499	1261824
	Phosphorus			
	REF	*CLEG*	*BSAP*	*BAU*
rcao-echam5-a1b-1	49518	42168	32087	67999
rcao-echam5-a1b-3	48320	41115	31140	66490
rcao-echam5-a2-1	50236	42766	32562	69029
rcao-hadcm3-ref-a1b	48825	41603	31676	67010

Table 3.5: The land loads (in ton/yr) to the Baltic Sea averaged for the last 30 years of the scenarios.

4 Concluding remarks

4.1 Relation to the Baltic Sea Action Plan load targets

In the eutrophication segment of the BSAP, load targets, so called maximum allowable inputs were accepted. For the whole of the Baltic they were 600 000 tons/yr of nitrogen and 21 000 tons/yr of phosphorus (HELCOM, 2007). In Table 3.5 it is evident that the designed scenarios give a substantially higher load also in the so-called *BSAP* scenario. This is only partly due to climate change induced nutrient load increase, primarily it depends on our construction of the scenarios.

The 1995-2002 average total land loads are 772414 and 43487 tons/yr of nitrogen and phosphorus, respectively, (Table 3.3), which is higher than the reference loads used in the development of the BSAP (i.e., 736 720 and 36 310 tons of nitrogen and phosphorus, respectively, HELCOM (2007)). This is to some extent due to the different reference period, i.e., 1995-2002 compared to 1997-2003 for the BSAP, but primarily due to differences between the BALTSEM load data set as such and the data set used in the BSAP. A comparison between the data set used here and the one presented in Wulff et al. (2009) indicates that the present data set give only a slightly higher nitrogen load but the phosphorus load is about 6 000 ton/yr higher in the period 1997 - 2003. A rigorous work was put into filling gaps and missing data from the official sources making the BALTSEM load data set much more complete than other load data sets, such as e.g. the one in Wulff et al. (2009), and this is the reason also for the higher loads. However, this implies that for the *BSAP* scenario both that the reduction factors are in a sense underestimated for phosphorus and that at least for the BALTSEM simulations target loads have an offset of about 6 000 tons/yr compared to maximum allowable loads given in the BSAP. This offset will be somewhat different for the different models depending on their loads in the reference periods which may deviate from the BALTSEM loads. This stresses also the importance of filling the missing data of the HELCOM PLC data set.

4.2 Climate contra management change

By comparing the total land loads in the reference data set (Table 3.3) with the results for the *REF* scenario (Table 3.5), we see that nitrogen land loads increase from 772 000 tons/yr to between 864 000 - 904 000 ton/yr depending on climate scenario. Thus, an increase of 100 000 tons/yr, which is comparable with the reduction goal of the BSAP. This can also be seen by that the nitrogen load in the *BSAP* scenario by the end of the Centrury is not that different than at present. The phosphorus land loads increase from about 43 500 tons/yr to 48 300 - 50 200 tons/yr, which is also substantial and counteracts the reductions decided in the BSAP with some 30 - 44 %.

4.3 Validity of the scenarios

There are rapid developments of various catchment models that allows better predictions of both effects from climate change on water and nutrient cycles as well as estimations of effect from management strategies. These models will give more adequate scenarios for the future. Nevertheless, the present scenarios represent a wide enough range to show the response of the Baltic Sea ecosystem to combined climate and nutrient load changes.

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