Memo

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10

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Subject
Nitrogen concentrations in rivers and coastal waters

Introduction

For the WFD assessment of the nitrogen concentrations in the rivers (Rhine, Meuse), annual average concentrations of total-N are compared to a target value of 2.8 mg/l. For the assessments in transitional and coastal waters, winter mean concentrations of DIN (NH_4^++NO_2^- +NO_3^-) are compared to a salinity-related target with a value of 33 µm at salinities of 30 or higher. The assessment results for rivers and coastal waters are different. While in recent years TN concentrations in the Rhine are close to the WFD target, DIN concentrations in coastal waters are generally still higher than the WFD target. In this memo, the trends in nitrogen concentrations in rivers and coastal waters are analysed and the differences in targets are discussed.

Trends in nitrogen concentrations in Rhine, Meuse and Scheldt

The concentrations of total nitrogen in Rhine and Meuse have decreased substantially since the 1970s (Figure 1). The decrease since 1970 in concentrations at Eijsden (river Meuse at Belgian/Dutch border) is significant (Mann-Kendall test, $p<0.001$) but much smaller than the decrease at Lobith (river Rhine at German/Dutch border) and the stations further downstream (Table 1). This clearly shows that the concentration changes at the main discharge points to the North Sea (Nieuwe Waterweg, Haringvliet) are mainly determined by the concentrations in the river Rhine. The total-N concentrations at all stations except Eijsden, are below the WFD threshold (Good/Moderate class boundary) of 2.8 mg/l since approximately 2010.
In the river Scheldt, total-N concentrations have also decreased significantly (Figure 2). In the past, the concentrations were much higher than those in Rhine or Meuse. Current concentrations are similar to the concentrations at Eijsden.

Conclusions:

- Total-N concentrations in Rhine and Scheldt have decreased with 40-50% since 1990
- Total-N concentrations in Meuse have decrease with 10% since 1990

Table 1. Decrease in annual mean total nitrogen concentrations (in %) at a number of monitoring stations in Rhine, Meuse and Scheldt.

Station	Station code	Decrease in annual mean total-N concentrations	
		Period 1975-2014	Period 1990-2014
Eijsden / Meuse	EIJSDPTN	-16%	-10%
Lobith / Rhine	LOBPTN	-62%	-50%
Haringvlietsluis/ Haringvliet	HARVSS	-54%	-42%
Puttershoek / Oude Maas	PUTTHK	-58%	-46%
Brienenoord / Nieuwe Maas	BRIENOD	-60%	-48%
Maassluis / Nieuwe Waterweg	MAASSS	-60%	-48%
Schaar van Ouden Doel / Scheldt	SCHAARVODDL	-54%	-42%

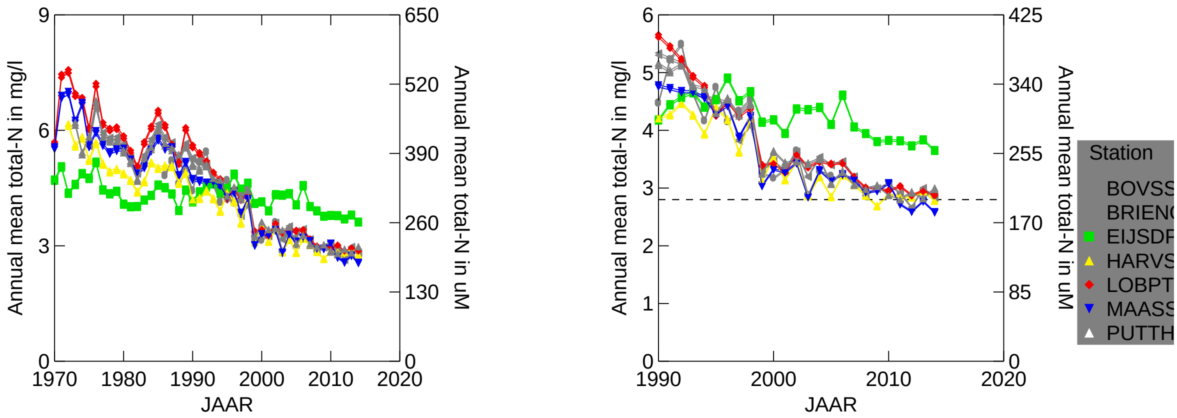

Figure 1. Annual mean total-N concentrations at a number of monitoring stations in Rhine and Meuse for the period 1970-2015 (left) and in more detail 1990-2015 (right). The WFD target for the Rhine of 2.8 mg/l is indicated. Note differences in vertical scale. For station codes, see Table 1.

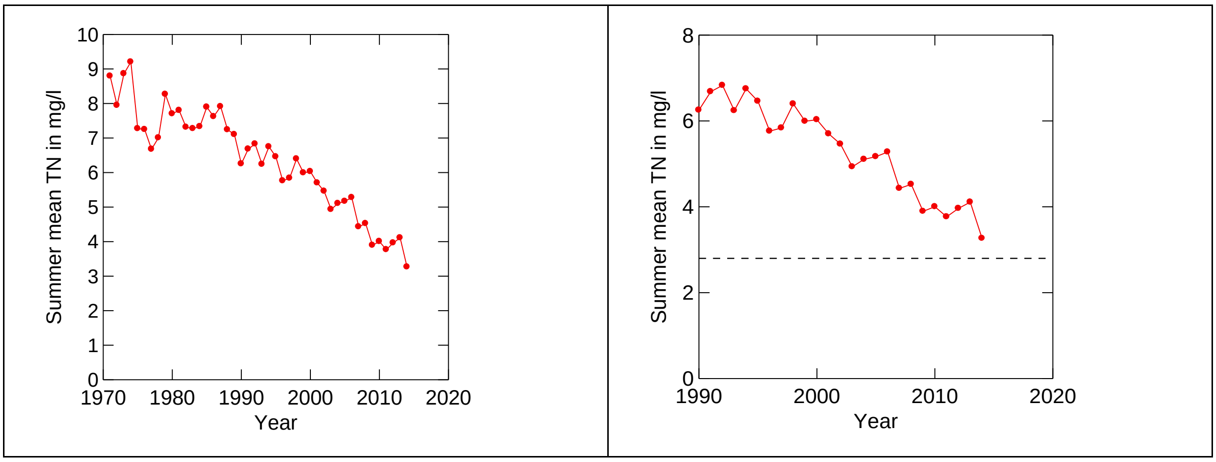

Figure 2. Summer mean total-N concentrations at the Belgian/Dutch border in the river Scheldt for the period 1970-2015 (left) and 1990-2015 (right).Note differences in vertical scale.

Trend in riverine loads to the North Sea

The decreases in total-N concentrations are reflected in the Dutch riverine loads of total-N to the North Sea, which show a decrease of approximately 39% over the period 1990-2014. This is slightly lower than the observed decrease in total-N concentrations in the Rhine, which is mainly due to the effect of higher riverine loads in years with high freshwater discharges (e.g. years 1995, 1999, 2002).

Total-N loads reported by Belgium (mainly loads of the river Scheldt) are approximately ten times lower than the loads from Rhine+Meuse, and show a decrease of 30-40% since 1990.

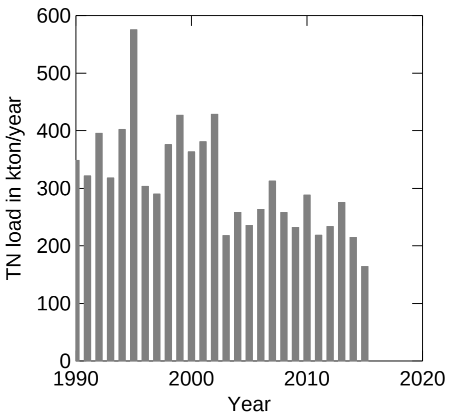

Figure 3. Riverine load of total-N to the North Sea from the Netherlands (=Rhine and Meuse) (OSPAR RID data).

Conclusions:

- Riverine N loads to the North Sea from the Netherlands (Rhine and Meuse) have decreased with approximately 40% since 1990

Trends in nitrogen concentrations in coastal waters

The concentrations of nutrients at a specific point at sea are determined by the riverine loads and the (natural background) concentration in the ocean. Consequently, if concentrations are not influenced by geochemical or biological processes, there is a linear relation between nutrient concentrations and salinity. With a decrease in nutrient concentrations in freshwater, there will also be a decrease in nutrient concentrations at coastal monitoring stations, but the extent of the decrease is salinity dependent (Figure 4). This figure illustrates that, in order to achieve a x% reduction in nutrient concentrations at salinities >20 in coastal waters, a much higher reduction in freshwater concentrations is required. In other words, the OSPAR target of a 50% reduction in nutrient loads will result in a <<50% reduction in nutrient concentrations in most parts of the North Sea.

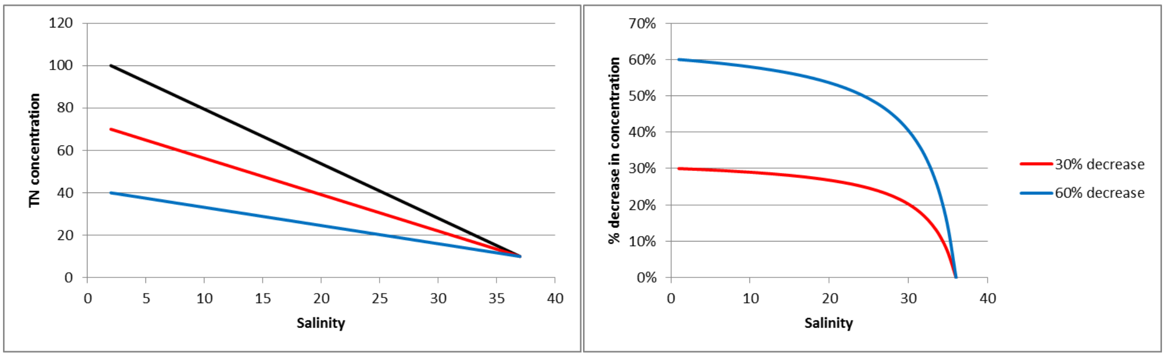

Figure 4. Mixing diagram of Total-N concentrations against salinity at different levels of Total-N concentrations in freshwater (left), and the decrease in concentrations (in %) at different salinities in the case of a 30% and a 60% decrease in freshwater concentrations.

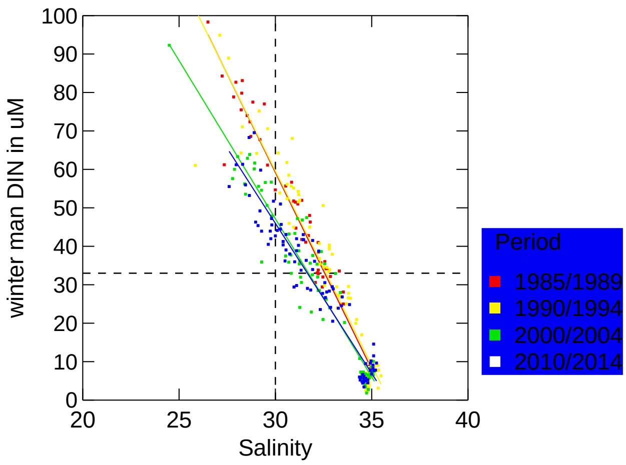

Figure 5. Mixing diagram of winter mean DIN concentrations at the MWTL North Sea stations against salinity for various series of years. Broken lines indicate salinity 30 and WFD target (Good/Moderate class boundary) of 33 µM.

The decreases in nitrogen loads to the North Sea are reflected in the concentrations of nitrogen at the various monitoring stations in the coastal waters. Figure 5 shows the mixing diagrams for winter means of DIN at monitoring stations in the North Sea, stretching from coastal stations to offshore stations. The regression lines show that DIN concentrations at salinity 30 in the years 2010-2014 were approximately 23% lower than those around 1990, but still well above the WFD target of 33 µM.
Observations for individual stations show decreasing concentrations, roughly in line with the decrease that can be expected for a specific site based on the decreases in riverine loads and the average salinity of that site. Figure 6 shows the development of the winter mean DIN concentrations for the years 1990-2015 at a number of monitoring stations in coastal waters. The figure also shows the expected trend in concentration by extrapolation of the concentration in 1990 using the decrease of 40% in riverine loads since 1990. The expected decreases at the monitoring stations range from 29-37%. The calculated linear trend line for DIN concentrations has the same slope as the expected trend. This shows that the decrease in concentrations at the monitoring stations is proportional to the decrease in riverine nitrogen loads.

The concentrations can be compared to the salinity-related WFD target, which is:
*DIN$_{WFD\ target}$ (in µM) = 184.7-5.057*Salinity* (for salinities below 30) (Prins 2007)
For higher salinities the target was fixed at 33 µM.

In Figure 6 both the salinity-related WFD target is shown for all salinities and the target of 33 µM for salinities >30. The figure shows that at the stations in the Rhine outflow (Goeree and the Noordwijk transect) the DIN concentrations are above the salinity-related WFD target. For the stations in or close to the Wadden Sea, the DIN concentrations are closer to the salinity-related WFD target.
The fact that the Wadden Sea stations are closer to the salinity-related target may be due to natural retention of N in IJsselmeer and Wadden Sea.

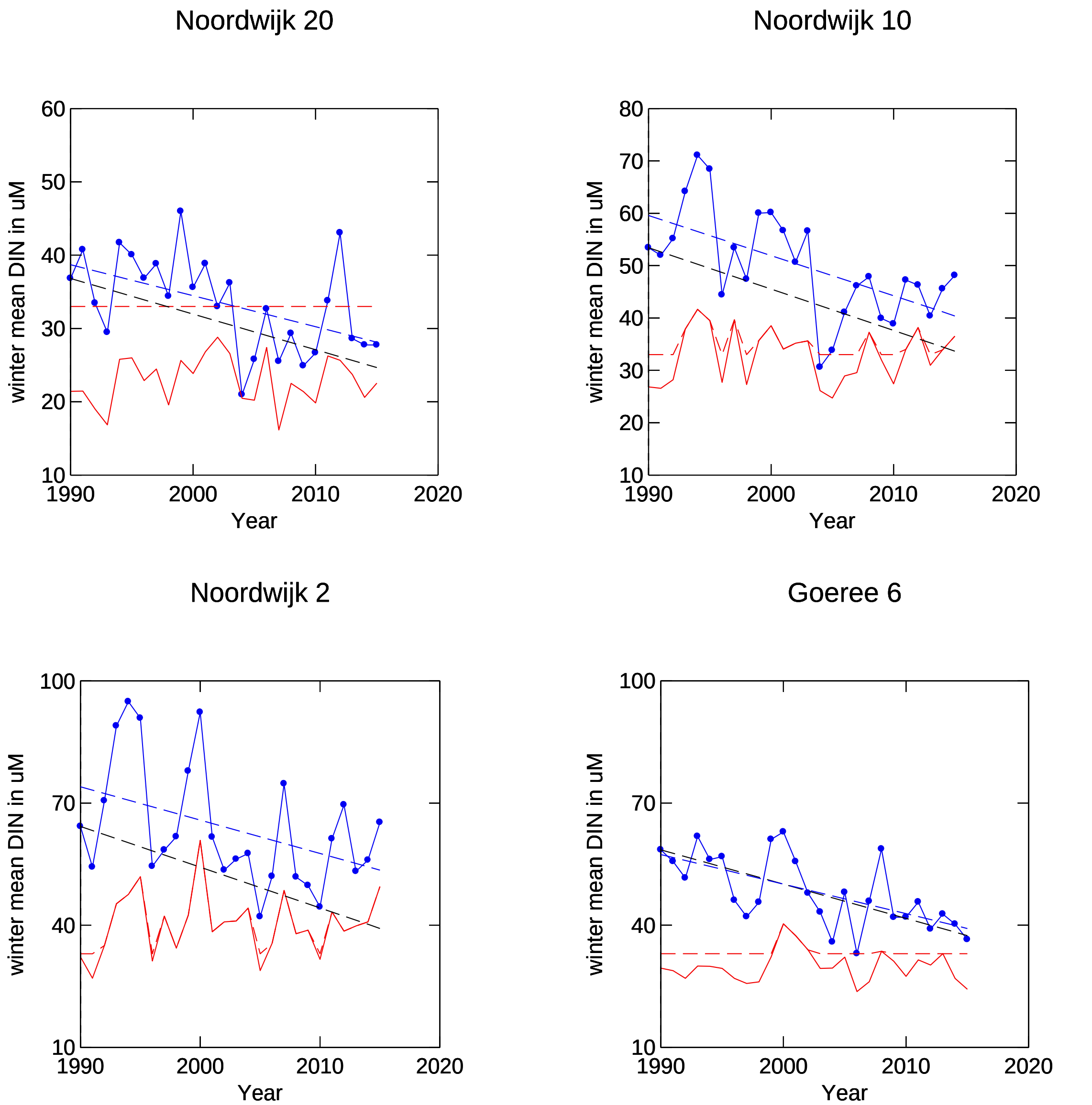

Figure 6a.Winter mean DIN concentrations (blue line) with linear trend (broken blue line), the salinity-related WFD target (red line) and the WFD target at salinities >30 (broken red line) and the expected decrease in concentrations based on the decrease in riverine loads (broken black line). See text for detailed explanation.

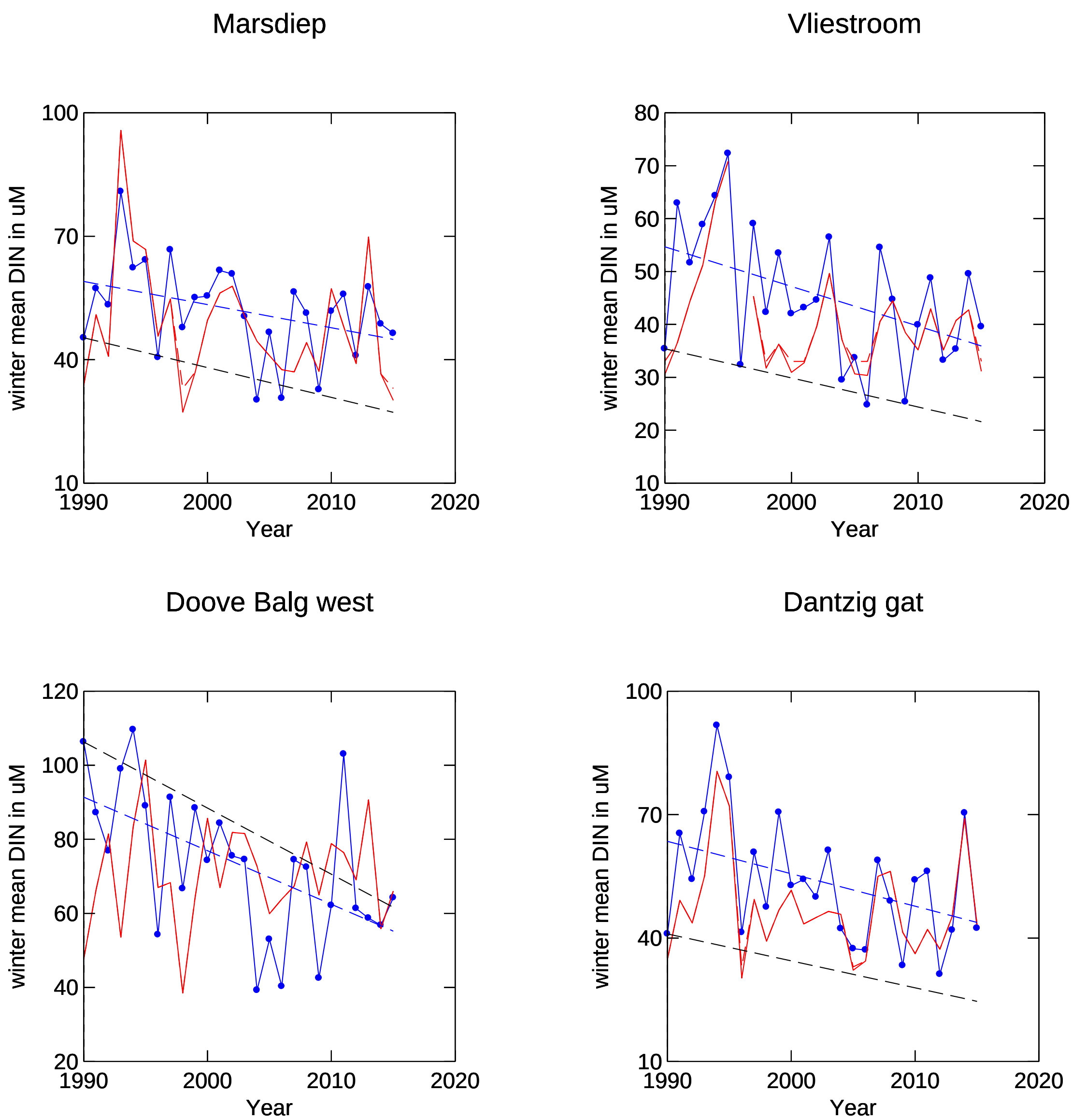

Figure 6b.Winter mean DIN concentrations (blue line) with linear trend (broken blue line), the salinity related WFD target (red line) and the expected decrease in concentrations based on the decrease in riverine loads (broken black line). See text for detailed explanation.

Conclusions

- Winter mean DIN concentrations in Dutch coastal waters show a decrease that is proportional to the decrease in riverine N-loads
- Winter mean DIN concentrations exceed the salinity-related WFD target, in particular at the coastal stations near the Rhine outflow
- At stations in or close to the Wadden Sea, winter mean DIN concentrations are closer to the WFD target

Linking the nitrogen targets for river and coastal waters
In addition to a salinity-related DIN target, a salinity-related WFD target for TN was derived by Prins (2007):

$TN_{March\text{-}September} = 2.55 – 0.069*Salinity$ (in mg/l)

The relation between the mean TN for March-September and the annual average TN concentration can be derived from observations by geometric mean regression:

$TN_{Year} = 0.026 + 1.050*TN_{Mar\text{-}Sep}$ (in mg/l)

Using those relations, the salinity-related TN_{Year} target for rivers is 2.7 mg/l. In the ICPR the target for the Rhine was finally set at 2.8 mg/l.

Natural background concentrations of TN_{Year} at salinity 35.3 were derived from data for the most offshore stations (WALCRN70, NOORDWK70, TERSLG235) that have a median concentration of 0.167 mg/l at a salinity of 35.0.
This gives the salinity-related WFD target

$TN_{Year} = 2.8 – 0.0752*$ Salinity (in mg/l)

In conclusion, there are salinity-related target for annual average TN and winter mean DIN concentrations. The stations in the river Rhine show that there is a mismatch between the TN and the DIN targets. Whereas TN concentrations in the Rhine are near or below the target of 2.8 mg/l, the DIN concentrations are still above the DIN target of 185 µM.
In North Sea and Wadden Sea the pattern looks different. At North Sea monitoring stations, DIN concentrations of the years 2005-2015 deviate from the salinity-related DIN target. The same is true for the Tn concentrations, but the deviation from the salinity-related TN target is smaller (Figure 8). At Wadden Sea stations, the deviation of concentrations from the target is small, with the exception of TN concentrations at station Dantziggat (Figure 8).

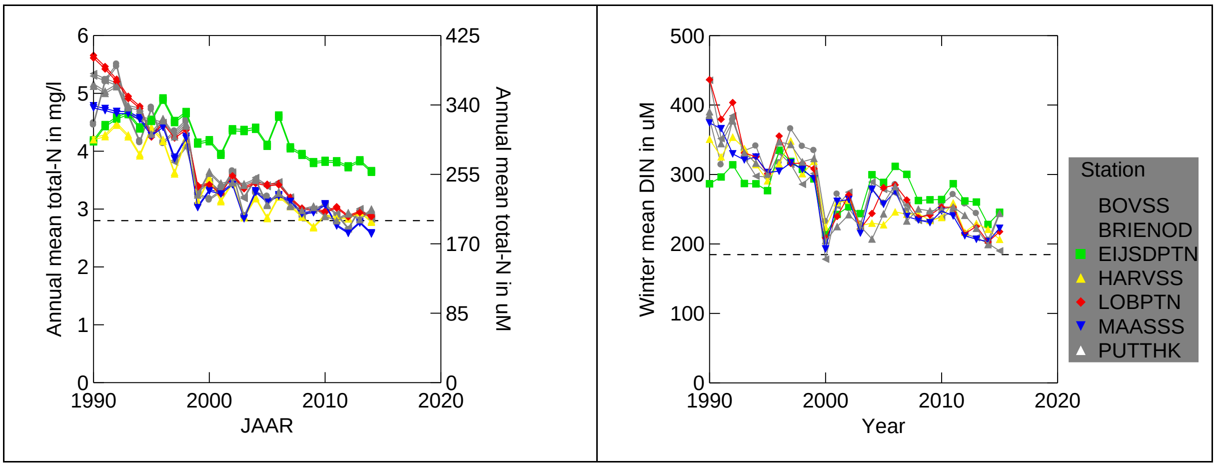

Figure 7. Concentration of annual average total-N and winter mean DIN at monitoring stations in the rivers Rhine and Meuse. The WFD targets are indicated by the broken line. For Lobith, no DIN data are available.

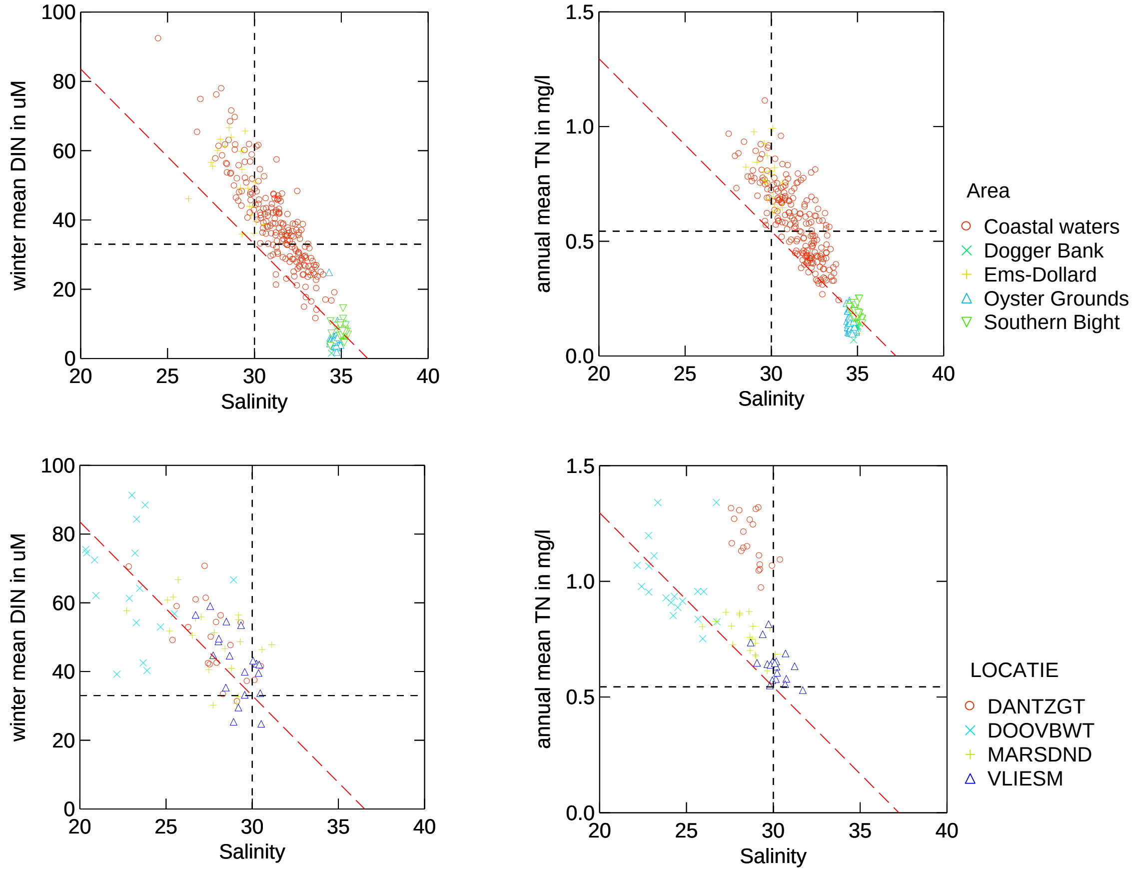

Figure 8. Concentrations of winter mean DIN (left) and annual average total-N (right) at monitoring stations in the North Sea (top) and the Wadden Sea (bottom). Data for the years 2005-2015. The broken red line shows the salinity-related target for DIN and TN.

Nitrogen concentrations can also be expressed as ‘distance to target’: the ratio of Concentration/Target.
Figure 9 shows the distance to target for a transect of stations from the rivers to offshore North Sea for the years 2005-2015, and similar results for stations in and near the Wadden Sea. There is a difference between DIN and total-N, but there is not a consistent pattern for all monitoring stations. As shown in Figure 8, at the offshore stations (Noordwijk70, Walcheren70) both DIN and TN concentrations do not deviate much from the salinity-related target, which indicates that the natural background concentrations that were used are correct.
At the river stations, the distance to target for DIN and TN is nearly the same for the Meuse (Eijsden), but differs between DIN and TN for the stations in the Rhine, with small differences between the stations. This suggests that for the river Rhine either the TN target is relatively high or the DIN target is relatively low, while for the Meuse a different combination of TN/DIN targets would be needed than for the Rhine.
At the North Sea stations, distance to target for DIN and TN match at some stations, in particular the nearshore and the offshore stations while at the intermediate stations the distance to target for DIN is higher than for TN (e.g. WALCRN20, NOORDWK10, 20).
In the Wadden Sea the distance to target for DIN and TN match with the exception of Dantziggat.
In addition to the inconsistencies between DIN and TN, there are also inconsistencies between areas and stations. The distance to target for both TN and DIN at the coastal stations of the

North Sea is larger than at the stations at the river Rhine or the stations in the Wadden Sea. This despite the fact that the Rhine is the main source for elevated levels of nitrogen in all these areas, and thus distance to target should be similar at all stations in a fully consistent system of targets (with exception of offshore stations with low river influence).
The salinity-related DIN and TN targets were developed with the assumption of linear relations between salinity and nutrient concentrations (translated in linear relations between salinity and targets). Deviations from this linear relation may occur because of loss processes in the transect from freshwater stations to marine stations (e.g. retention, denitrification, etc.) and due to sources of nitrogen along this transect.
As a consequence of the inconsistencies in the pattern of the distance to target between DIN and TN, it is not straightforward to decide whether TN targets for the rivers or DIN targets for coastal waters should be adapted. Moreover, the differences between coastal stations and between North Sea and Wadden Sea show that also in the coastal/marine environment local processes should be included to arrive at a fully consistent set of targets for DIN.

Conclusions

- targets for annual average total-N concentrations are used for the Rhine
- targets for winter mean DIN concentrations are used in coastal waters by application of a salinity-related target
- there are inconsistencies between the targets for total-N and DIN, but there is no straightforward solution to solve this

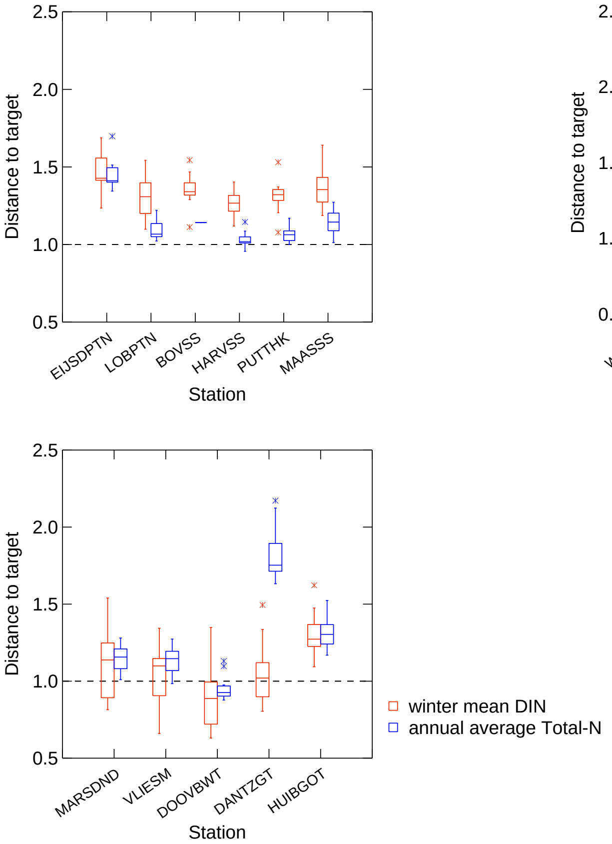

Figure 9. Distance to target (calculated as the ratio Concentration/Target) for winter mean DIN and annual mean TN at a number of stations in Meuse, Rhine, North Sea (left) and Wadden Sea/Ems-Dollard (right).

References

Prins, T.C. (2007). Stikstofnormen Kust- en Overgangswateren. RIKZ, Middelburg, memo 19 november 2009, 22 pp.