HELMHOLTZ CENTRE GEESTHACHT - CENTRE FOR MATERIALS AND
COASTAL RESEARCH

MOSSCO River data basis – Riverine Nutrient inputs

Focus: Large rivers entering the North Sea

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Abstract

Riverine inputs have a strong effect on eutrophication problems in the coastal marine ecosystem. As enhanced nutrient supply and increased N/P ratio change phytoplankton growth rates and increase primary production. Therefore riverine freshwater and nutrient inputs of German and Dutch rivers entering the North Sea were investigated.

River discharge is highest at the measurement station of Nieuwe Waterway followed by Elbe and Haringvliet. Lower discharge values are present in Ems, Schelde and Nordzeekanaal. The relative error of the raw data provided by wiki.zmaw to the data described by Pätsch and Lennhart (2011) and to our created NetCDF data is negligible. To take the additional drainage from the area downstream the last-tide free gauge into account location specific correction factors has been added in an additional NetCDF-In component, for correct river discharge estimations at the river mouth.

Nutrient loads and concentrations in the NetCDF data are consistent with the raw data and Pätsch data, except for silicate load. There a 2- and 7-fold difference exists for Ems and Weser when comparing raw data with Pätsch data for the parameter silicate. An inconsistency in the Pätsch data is assumed as silicate concentrations of both data sets are similar to raw and NetCDF data. DIN and DON loads are consistent with the reference data source.

Comparisons of N/P ratios show rather unreliable values. Especially for Ems this ratio is double as high as stated by Radach and Pätsch (2007), although nutrient values itself seem to fit to the data. Reason could be the usage of different data sets presenting unlike river catchment areas.

For German large rivers nutrients are measured several kilometers upstream the river mouth. Therefore tributaries entering downstream may contribute considerably. Loads of the most important inflows could be added. Additionally estuarine processes retain and remove 30-65% of total Nitrogen and 10-55% of total Phosphorus that would otherwise pass into the coastal ocean (Nixon et al., 1996; Seitzinger, 1996), a nutrient retention factor has to be considered for the data in use, which has not been applied yet.

In general we find more data gaps in the Dutch rivers then in the German rivers. Overall 46 of 71 time series have observational gaps. A correlation analysis was implemented to ascertain correlating parameters. Problematical is the gap filling of silicate by linear regression, as for this parameter data gaps exist in all rivers. Therefore data gaps are filled by calculating the climatology. Overall the estimates for data gaps are acceptable, as the seasonal cycles seem to be consistent with the available data set (Fig. 19 – 24). Nonetheless minimum and maximum values are under- and/or overestimated for the river loads.

Therefore further investigation using a day and amplitude-trend specific gap filling approach was done. This procedure improved predictions of missing data gaps immensely. River discharge and nutrient parameters display maximum values every 6 – 7 years, which could be interesting in case of refining the gap filling processing.

To investigate long term changes in river time series, data before 1977 and after 2012 are under subject. River discharge for Elbe is available for 1874 – 2013. To improve predictions at the river mouth data of additional measurement stations are available and analyzed with regard to river discharge and nutrient concentrations.

The total river contribution is 80% for the German Bight with relative amount from German rivers (47%) followed by Dutch rivers (27%) then French (8%) and UK (2%) rivers. UK river data is already available. Whether French river data will be requested should be discussed.

Outline

1 Aims of the project

Riverine inputs have a strong effect on the coastal zone of 50 – 100 *km* (Radach, 1992). Investigations at Helgoland showed that the receiving coastal waters were highly influenced by the temporal development of riverine inputs (Fock, 2003), as enhanced nutrient supply and increased N/P ratio can lead to changes in phytoplankton community composition and increased primary production. This in turn will affect the coastal marine ecosystems immensely by eutrophication.

Therefore studying river contribution of nutrients and other water properties is important for simulating German Bight conditions in an appropriate way. In this study our aims are:

- Data quality control
    - Data consistency
    - Corrections for location effects
- Fill data gaps
    - Linear regression
    - Interpolation using climatology approaches
- Extension of data
    - temporal
    - adding measurement stations
    - adding other rivers

2 Study area and measurement stations

At first large German and Dutch rivers were included in the analysis. Later also small German rivers and Great Britain Rivers entering the North Sea were under subject.

German rivers

Elbe (Fig. 2.1, 2.2)

- freshwater discharge measured at Neu Darchau (~191km to the North Sea)
- nutrient concentration measured at Teufelsbrück/Seemannshöft (~ 100km to Sea)

Weser (Fig. 2.1, 2.2)

- discharge and nutrient concentration measured at Intschede/Uesen (~100/80km to Sea)
- silicate concentration measured at Brake (~30km to North Sea)

Ems (Fig. 2.1, 2.2)

- discharge and nutrient concentration measured at Herbrum (~60km to North Sea)
- silicate concentration measured at Terborg (~10km to North Sea)

Dutch rivers

Vrouwenzand (Fig. 2.1, 2.2)

- discharge measured at Den Oever and Kornwederzand
- nutrient concentration measured at Vrouwenzand

Nordzeekanaal (Fig. 2.1, 2.3)

- daily discharge and biweekly nutrient concentration measured 2 km before sluice system

Nieuwe Waterweg (Fig. 2.1, 2.3)

- concentration measured every 2nd week at Maasluis (10 – 15% seawater)
- daily discharge modelled instead of measured since 1987 (using tide phase, surface elevation and sluice movement)

Haringvliet (Fig. 2.1, 2.3)

- discharge and nutrient concentration measured in big weir (regulated for outlet of freshwater , no mixing)

Schelde (Fig. 2.1, 2.3)

- discharge and nutrient concentration measured at Schaar van Ouden Doel (40km to North Sea)

3 Data quality control

3.1 Data consistency analysis

To evaluate data consistency the raw data (wiki.zmaw.de, 2014) is compared to

1. the data values referred by Pätsch and Lenhart (2011), named Pätsch data, for 1977 – 2009.
2. the data of the new created NetCDF file large_rivers_NorthSea_new.nc, called NetCDF data, for 1977 – 2012.

The NetCDF file large_rivers_NorthSea_new.nc has been created using the raw data and converting this to a NetCDF file by the modified matlab scripts create_largerivers_GETM.m and convert_river_data.m. Pätsch data also refer to raw data as their data source. The purpose is to detect possible mistakes or inconsistencies in the processing scripts. Notice that also raw data has been compared to NetCDF data of 1977 – 2009, but as relative errors are more or less the same as for the extended time frame, the comparison until 2012 is used. Thereby already changes in flow patterns can be distinguished by analyzing raw data until 2009 in comparison to raw data until 2012.

The relative error is calculated using the following equation

$$(1)\quad E_P = \frac{(D_P - D_R)}{D_P} \qquad ,$$

where E_P is the relative error for the Pätsch data D_P (similarly E_N and D_N for the NetCDF data) to the raw data D_R.

3.1.1 River discharge

River discharge is on average

- clearly highest at the measurement station of Nieuwe Waterway (~ 1440 m^3/s)
- followed by Elbe and Haringvliet
- lower flow rates are measured for Vrouwenzand and Weser
- lowest discharge values are present in Ems, Schelde and Nordzeekanaal

The relative error is negligible between raw, Pätsch and NetCDF data (Fig. 3.1).

In the river discharge time series of large rivers entering the North Sea, the flow rates have mostly a seasonal cycle. Highest variability is seen in Nordzeekanaal (Fig. 3.2). Radach and Pätsch (2007) reported annual discharge of 133 $km^3\ yr^{-1}$ ± 26 $km^3\ yr^{-1}$ and discovered an oscillation of river discharge, whereby the maximum values occurring every 6 – 7 years, decreasing in magnitude. This pattern, depending on precipitation over Europe, should be kept in mind for filling data gaps.

3.1.2 Nutrient load and concentration

Nutrients (total nitrogen (totN), nitrate (NO_3), total phosphorus (totP) and phosphate (PO_4)) in the NetCDF data are consistent with the raw data and Pätsch data (Fig. 3.3 – 3.6). Therefore only raw data as well as E_P and E_N are displayed here. The maximum relative error is $E_{P =}$ 0,135 for PO_4 concentration and $E_{P =}$ 0,233 for PO_4 load.

While totN and NO_3 data show only a minor decrease when analyzing their concentration and river load time series, there is a clear decrease in concentration and load of PO_4 and totP from ~ 1990 on (Fig. 3.7 – 3.14). Radach and Pätsch (2007) stated that riverine nutrient inputs vary largely on a short time scale and show a seasonal cycle. This applies also in the analysis using the NetCDF data. The nutrient parameters display maximum values every 6 – 7 years, which is important for later gap filling processing.

3.1.3 Silicate load and concentration

Silicate ($SiOH_4$) concentration shows only a minor error of E_P=0,005 and E_N=0,0002 (Fig. 3.15). In contrast a 7-fold difference in silicate river load for Weser and a 2-fold difference for Ems exist, when comparing raw data with data reported by Pätsch et al. (2011), whereas the silicate load in the NetCDF file show a maximum error of E_N=0,044 (Fig. 3.16). Therefore Pätsch data seems to be inconsistent for this parameter. This can be verified by calculating river load of silicate with the provided Pätsch data for silicate concentration and river discharge. The resulting river load magnitude show similar values as in the NetCDF data whereby the silicate load reported by Pätsch have the relative errors mentioned above. So the silicate data (as long as available) in the NetCDF file can be used for further processing. The time series analysis shows a seasonal varying $SiOH_4$ concentration and load, with constant minima and maxima (Fig. 3.17 – 3.18), so without any trend. For Weser and Ems no reasonable statements are possible due to the short data time series as result of huge data gaps (see section 4.1.).

3.1.4 DIC and DOC load

River loads of dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) have only a minor error when comparing Pätsch data and the NetCDF data with raw data. The relative error is ~ 0.9 compared to the raw data for all rivers (Fig. 3.19 – 3.22). DIC and DOC loads show a negligible error between the two data sets.

No DIC and DOC concentrations have been calculated because these values are not mentioned by Pätsch and Lenhart (2011).

3.1.5 N/P analysis

The comparisons of N/P ratios, which are important for phytoplankton growth, show inconsistencies. Especially totN/totP ratio for Ems is double as high as stated by Radach and Pätsch (2007) (Tab. 1). The N/P ratio is presented here as totN/totP and DIN/DIP(PO_4). The molar Redfield ratio 16 (mol N/ mol P) is equal to the value 7,23 (totN/totP).

It is uncertain where this discrepancy is coming from. The new NetCDF data is based on the raw data and the previous investigation showed only minor errors when comparing raw data and NetCDF data. Another issue is that Pätsch used dissolved inorganic phosphate for the DIN/DIP ratio, while in our data set only phosphate was available. This can cause differences in the calculated ratios. Furthermore the totN/totP ratios have smaller errors according to the NetCDF data than the DIN/DIP ratios. This inconsistency probably results from different data sources used for the Pätsch data from 2007.

Nutrient values especially phosphorus loads decrease more rapidly than nitrogen loads (Radach and Pätsch, 2007). A longer time period could lead to higher N/P ratios. Also the time series in figure 3.23 – 3.24 indicates this. Radach and Pätsch (2007) already detected a high increase in the N/P ratio depending on the time frame. The years 1987 – 2000 showed a range more than doubled compared to 1977 – 1986.

Table 1 N/P ratio. Data refers to (1) Radach and Pätsch (2007) for 1977 – 2000 compared to NetCDF data for (2) 1977 – 2000 and (3) 1977 – 2012.

	DIN:DIP (1) *(mol N/mol P)*	**DIN:PO4 (2)** *(mol N/mol P)*	**DIN:PO4 (3)** *(mol N/mol P)*	**totN:totP (1)** *(mol N /mol P)*	**totN:totP (2)** *(mol N/mol P)*	**totN:totP (3)** *(mol N/mol P)*
Elbe	87,6	102,195	108,353	45,4	45,889	45,163
Ems	126,2	280,924	281,014	55,7	78,210	82,436
Weser	57,8	116,365	131,868	40,8	51,066	51,666
Vrouwen-zand		228,417	347,065		50,466	52,887
Schelde		45,870	52,524		24,457	28,622
Nordzee-kanal		23,572	25,892		23,933	25,956
Nieuwe Waterweg		44,923	108.353		30,453	45,163
Haringvliet		62,259	69,256		45,554	47,983
All rivers average	48,9	97,112	148,005	33,3	41,417	47,805

3.2 Corrections for location effects

3.2.1 River discharge correction factors

The river discharge is usually measured at the last tide-free gauge, several kilometers away from the river mouth, whereby additional contribution occurs downstream. Furthermore to monitor the river discharge, the mixing of water masses at the river mouth has to be considered.

To take the additional drainage from the area downstream the last-tide free gauge into account location specific correction factors have to be added (pers. comm. Wolf; Pätsch and Lenhart (2011)).

- **Elbe** → add **21%** of discharge
    - Correction factors: Seemannshöft: 1,078 ;Brunsbüttel 1,144; **Cuxhaven: 1,21**
- **Weser** → add **19%** of discharge
- **Ems** → add **30%** of discharge

An additional NetCDF-In component was created so that now corrected discharge values and nutrient loads are available. But it is still questionable how discharge values after the last tide-free gauge can be estimated and how close to the open sea the discharge can be measured without having an unpredictable amount of seawater inflow? The river discharge in the Netherlands is mostly measured at the river mouth. It is questionable how massive the influence of tide is at this measurement points.

3.2.2 Nutrient correction factors

Also nutrients are measured several kilometers upstream the river mouth in the German rivers. Therefore tributaries entering downstream may contribute considerably. Loads of the most important inflows (for Elbe: *Oste, Lühe, Schwinge, Este, Stör, Krückau, Mühlenau/Pinnau*) should be added.

Discharged nutrients are used within estuaries so that river loads not remain as estimated. As estuarine processes retain and remove 30-65% of totN and 10-55% of totP that would otherwise pass into coastal ocean (Nixon et al., 1996; Seitzinger, 1996), a nutrient retention factor has to be considered for the data in use. Also the conversion from inorganic to organic forms should be reflected for input calculations. But it is still under debate how to quantify the loss of river borne nutrients before they enter the coastal sea.

4 Filling data gaps

4.1 Data gaps

In 46 of 71 time series observational gaps are found. In 26 cases these are gaps of 1 – 3 complete years. In general we find more data gaps in the Dutch rivers then in the German rivers (Tab. 2 – 3). Our first approach to fill data gaps of a long time period (1 – 3 years) is linear regression (see section 4.3.). Therefore a correlation analysis was implemented (see section 4.2.) to ascertain correlating variables to be used for linear regression. For German rivers the same parameter combination was used for regression as in Radach and Pätsch (2007).

In the Dutch river data additionally gaps of shorter periods (several days up to months) are present. Data gaps in almost all parameters and for several months – years are found in daily river data of Vrouwenzand, Nordzeekanaal and Haringvliet. Problematical is the gap filling of silicate with linear regression, as for this parameter data gaps exist in all rivers.

The second approach uses the climatology of the individual time series data to assume data values when measurements are missing. Furthermore dayspecific amplitude values were adjusted.

Table 2 Data gaps in German river observational measurements.

	Elbe	**Ems**	**Weser**
DIC			missing
DIN			
DOC			missing
NH4			
NO3			
PO4		1977 – 1980	1977 – 1980
SiOH4	1977 – 1987	1977 – 1988 1995 – 2012	1977 – 1992 1995 – 2012
TALK			missing
totN	1977	1977 – 1979	1977 – 1979
totP	1977		

Table 3 Data gaps in Dutch river observational measurements. The time frame in brackets has only partially gaps of several days – months.

	Vrouwenzand	**Schelde**	**Nordzeekanaal**	**N.Waterway**	**Haringvliet**
DIC	missing		missing	(1990 – 2012)	(1990 – 2012)
DIN	1995 – 1997 (1990 – 2012)	1995 – 1997	(1990 – 1994) 1995 – 1997 (2007 – 2010) 2011 – 2012	(1990 – 2012)	1995 – 1997 (1990 – 2012)
DOC	missing		missing	(1990 – 2012)	(1990 – 2012)
NH4	1995 – 1997 (1990 – 2012)	1995 – 1997	(1990 – 1994) 1995 – 1997 (2007 – 2010) 2011 – 2012	(1990 – 2012)	1995 – 1997 (1990 – 2012)
NO3	(1990 – 2012)		(1990 – 1998) (2007 – 2010) 2011 – 2012	(1990 – 2012)	(1990 – 2012)
PO4	(1990 – 2012)		(1990 – 1998) (2007 – 2010) 2011 – 2012	(1990 – 2012)	(1990 – 2012)
SiOH4	1995 – 1998 (1990 – 2012)	1995 – 1998	1977 – 1978 (1990 – 1994) 1995 – 1998 (2007 – 2010) 2011 – 2012	1995 – 1998 (1990 – 2012)	1995 – 1998 (1990 – 2012)
TALK	missing		missing	(1990 – 2012)	(1990 – 2012)
totN	(1990 – 2012)		(1990 – 1998) (2007 – 2010) 2011 – 2012	(1990 – 2012)	(1990 – 2012)
totP	(1990 – 2012)		(1990 – 1998) (2007 – 2010) 2011 – 2012	(1990 – 2012)	(1990 – 2012)

4.2 Parameter correlation analysis

The correlation coefficient of totN to NO_3 loads and totP to PO_4 loads in the German rivers are higher than 0,6 (Tab. 4) and as Radach and Pätsch (2007) already used this correlation we stayed with this method.

Finding parameters correlating with silicate is problematical. Uncertain is how to close these gaps. Should the gaps are filled by regression with the same parameter of other rivers or by other parameters in the same river? This is determined based on the results of the correlation analysis. Only in the river Schelde silicate correlated well with totN (Tab. 5), while for Elbe and Vrouwenzand NO_3 have a moderate correlation coefficient.

The Elbe silicate data seems to be a good predictor for Weser and Schelde silicate gaps (Tab. 6). For Nordzeekanaal, Nieuwe Waterway and Haringvliet the silicate data of Schelde river could be used. Notice that correlation coefficient values which were used for gap filling in the next chapter are printed bold in tables. 4 – 6. Notice that Radach and Pätsch (2007) used the same parameters for linear regression but the only 4 years of the explanatory variable, temporally nearest to the gaps, not the whole available time frame as here.

Table 4 Correlation analysis of German rivers.

	Explanatory variable	**Variable with gaps**	**Correlation coefficient**	***Correlation coefficient of Pätsch***
Elbe	NO3	totN	**0,7050**	*0,9385*
Elbe	PO4	totP	**0,8729**	*0,6307*
Ems	NO3	totN	**0,9165**	*0,9842*
Ems	totP	PO4	**0,6068**	*0,5568*
Weser	NO3	totN	**0,8607**	*0,9717*
Weser	totP	PO4	**0,8619**	*0,8345*

Table 5 Correlation analysis for silicate: correlations with other variables in each river.

SiOH4	**Discharge**	**NO3**	**PO4**	**totN**	**totP**
Elbe	0,4399	0,6152	0,0496	0,5199	-0,1047
Ems	0,2231	0,3268	0,0891	0,3599	0,1355
Weser	0,2940	0,3467	0,1008	0,4160	0,0342
Vrouwenzand	0,3459	0,5345	0,3195	0,4853	0,1856
Schelde	0,5042	0,3529	0,1488	**0,7510**	0,4099
Nordzeekanaal	0,1095	0,4815	0,0469	0,3098	-0,0026
N. Waterway	0,3121	0,4413	0,0716	0,4063	0,1031
Haringvliet	0,4215	0,4289	-0,0071	0,3903	0,0213

Table 6 Correlation analysis for silicate: correlations with silicate data from other rivers.

SiOH4	**Elbe**	**Ems**	**Weser**	**V.zand**	**Schlede**	**Nzkanaal**	**N.Water-way**	**Haring-vliet**
Elbe	1	0,4317	0,8221	0,5336	0,7269	0,8225	0,8231	0,7791
Ems	0,4317	1	0,3237	0,2335	0,1917	0,3585	0,3541	0,3617
Weser	0,8221	0,3237	1	0,3683	0,4906	0,8394	0,7086	0,5822
V.zand	0,5336	0,2335	0,3683	1	0,4821	0,6341	0,6120	0,6270
Schelde	**0,7269**	0,1917	0,4906	0,4821	1	0,6024	0,6963	0,6932
Nzkanaal	0,8225	0,3585	0,8394	0,6341	0,6024	1	0,8604	0,8323
N.Water-way	0,8231	0,3541	0,7086	0,6120	0,6963	0,8604	1	0,9008
Haring-vliet	0,7791	0,3617	0,5822	0,6270	0,6932	0,8323	0,9008	1

4.3 Gap filling with linear regression

In this section data gaps in several parameters were filled by linear regression according to the results of the correlation analysis. First gaps in German rivers were filled (Fig. 4.1 – 4.6) by using regression parameters y (= data with gaps), x (=explanatory variable), a and b from $y= ax + b$, with regard to the correlation coefficient r.

Overall the estimates for data gaps are more or less ok, as the seasonal cycles seem to be consistent with the available data set (Fig. 4.1 – 4.6). Nonetheless this method under- and/or overestimates maximum and minimum values of the nutrient river loads. Therefore further investigation is needed to improve predictions of missing data gaps. Also the calculations of deviations could be helpful to improve the interpretation of estimated data values.

To demonstrate silicate data gap filling with linear regression, these gaps are filled in the river Schelde with both mentioned methods, filling $SiOH_4$ gaps with other parameters in the same river (Fig. 4.7) and with the same parameter in another river (Fig. 4.8).

The correlation coefficients are in both cases ~ 0,7, but although the seasonal cycles seem to fit to the data set, the linear regression underestimates the minimum and maximum values of silicate fluxes in the Schelde river. The improvement of these estimates is a potential future research goal.

4.4 Gap filling with climatology

Another option to fill the present data gaps is calculating the climatology. For each day of the year the mean were calculated, using the available data of the whole time series.

4.4.1 Climatology

Filling the gaps with climatology shows acceptable results for Silicate in the Schelde river (Fig. 4.15) as there is no observable trend in the silicate time series. Whereas other nutrient loads have an obvious trend (Fig. 4.9 – 4.14). By using the climatology, values are considerably underestimated. To resolve this problem, a trended climatology was calculated with adjusted amplitudes to improve the gap filling procedure.

4.4.2 Climatology with trends

In this section a trend of day specific climatology values were calculated to improve predictions of data gaps and data amplitudes.

First the trendline of amplitude values and minimum values of all years were calculated using the linear regression method in 4.3. In this approach for every missing data point, day specific values has been calculated with regard to the climatological cycle and the trend in minimum and maximum values in every year using the following equation:

$A_y = m_y + a_y \times C_r$,

whereby m_y is the trendline of the yearly minimum values and a_y the trendline of the yearly amplitude values. C_r is the relative climatology calculated by

$C_r = (C - m_C) / a_C$,

with m_C as the minimum value of the climatological year C and a_C the max amplitude value of C.

In the following figures (Fig. 4.16 – 4.22) the observation data is compared to the trended climatology. Trends for total nitrogen and phosphorus in the Elbe as well as for total nitrogen and phosphate in the rivers Weser and Ems are obviously decreasing with time. In contrast silicate values in the Schelde river show a slightly positive trend with time. It is likely that in this scenario maximum values are better predicted by the trended climatology (Fig. 4.9 – 4.15) then by the original climatology (see section 4.4.1).

5 Data extension

5.1 Temporal data extension

Discharge data of Elbe river is measured since 1848. Similar measurement times are assumed for the rivers Ems and Weser. So the temporal extension of the present data set should be possible, depending on the actual records. Daily measurements of Elbe discharge are already provided since 1874 and further temporal extensions are in process.

5.2 Adding measurement stations

River discharge and nutrient concentration magnitudes originate from measurement stations further upstream in German rivers and often from different measurement stations. This could lead to problems when estimating the magnitude of these properties at the river mouth. Therefore measurement stations at the river mouth should be taken into account, to explore the relationship between measurement location and nutrient concentration on the river.

For this purpose data of additional measurement stations (Fig. 5.1) has been requested from the NLWKN and FGG Elbe and are now available. The stations near Emden (Ems), Nordenhamn (Weser), Cuxhaven and Brunsbüttel (both Elbe) are the closest to the river mouth.

5.2.1 Analysis of the German rivers

To illustrate the importance of considering the distance between measurement station and river mouth here nutrient time series of three different measurement stations along three German rivers are assessed, namely Elbe, Weser and Ems.

In the Elbe the measurement stations Cuxhaven and Brunsbüttelkoog are considerably closer river mouth then Seemannshöft (providing the measurement data for the previous examination).

Nitrogen values show a clear discrepancy in the last 15 years. While nitrogen concentrations are similar from ~ 1990 – 2000 at the three measurement stations, the latest measurements (2000 – 2015) show a clear decrease in nitrogen concentrations at Cuxhaven (Fig. 5.2). Phosphorus measurements show variable but low values at Seemannshöft and Cuxhaven, whereby concentrations values are highly variable and significantly higher at Brunsbüttelkoog (Fig. 5.3).

For Weser data used for simulations are from Intschede, whereby Brake and Nordenhamn are nearest to the river mouth. In this case total nitrogen values at all stations are in an equal range while total phosphorus concentrations clearly differ at the three stations, whereby concentrations close to the river mouth are extensively higher (Fig. 5.4 – 5.5). This indicates that the N/P ratio changes along the river, which could affect phytoplankton growth rates.

In the Ems measurement values for total nitrogen at Terborg are slightly higher than at Herbrum while total phosphorus values are extremely high at Terborg compared to phosphorus values measured at Herbrum. Measurement data at Gandersrum, which is located already outside the river, are extremely high (Fig. 5.6 – 5.7).

This short examination showed that nutrient concentration values change along the river system and that further research is necessary to improve estimations of riverine inputs into the North Sea. Special attention is necessary on dilution effects as well as retention processes in the river estuary (see section 4.2).

5.3 Adding other rivers

Additional time series data for 28 small rivers along the German Bight coastline are available. As stated before (see section 4.2), also small rivers or tributaries entering large rivers downstream the measurement station may contribute considerably. Therefore loads of the most important inflows (for Elbe: *Oste, Lühe, Schwinge, Este, Stör, Krückau, Mühlenau/Pinnau*) should be added.

The results from previous model studies (OSPAR 2009) showed that in coastal areas the nutrient budget is predominantly determined by local river sources and Atlantic sources, with the relative influence decreasing with the distance from the specific source.

Riverine sources (Germany 28%, the Netherlands 23%, French 8% and UK 5%) provide almost two third of the total nutrient content in the German maritime area (OSPAR 2010). The total river contribution is 80% for the German Bight with relative amount from German rivers (47%) followed by Dutch rivers (27%) then French (8%) and UK (2%) rivers.

Topics possibly demanding further attention

The nutrient tracking in the North Sea was covered only by two models. More models, covering the wide area, are required. Also additional analysis examining differences in the transboundary nutrient transport extend is needed. To investigate downstream effects of this transport, an analysis and synthesis of nutrient transport consequences to water body specific phytoplankton content is necessary. Furthermore the nutrient input from atmosphere should be a topic in future examinations.

Great Britain rivers

- *Contact person: Sonja van Leeuwen (Cefas)* sonja.vanleeuwen@cefas.co.uk

This British riverine data set was worked up for the OSPAR workshops, and they still maintaining the database on and off. As the purpose of the OSPAR ICG-EMO workshops is modelling they have put effort into creating daily time series for all rivers, for as many nutrients as they can gather, without any gaps. The procedure Sonja van Leeuwen uses is similar to that of Johannes Pätsch. For daily UK loads this is probably the best source. For monthly or annual loads there are other sources available, as the official OSPAR RID (reporting loads) or the European Union databases.

Based on results from the transboundary nutrient transport (for further information ask Hermann Lenhart) from Cefas the Southern UK rivers are probably the rivers influencing the German Bight most: Chelmer, Colne, Stour at Harwich, Gipping, Thames, Medway, Great Stour, Rother, Cuckmere, Ouse at Newhaven, Adur, Arun, Avon at Bournemouth, Stour at Bournemouth, Frome, Itchen, Test

These range from East Anglia down to the Isle of Wight in the Channel. The rivers on the North Sea coast include: Thames, Chelmer and Colne (who both exit into the Blackwater Estuary), Stour at Harwich and Gipping (who both exit in the Stour estuary at Harwich), Medway, Great Stour.

Data files of all these rivers have been provided by Sonja van Leeuwen, for the period 1940-2016, plus associated time series plots.

Note that there are no gaps, and that interpolation and climatologies are applied when necessary. All data from before 1972 for nutrients is climatology, and all data later than 2011 as well. Data availability may differ per station. Flow data occasionally does go back further for individual stations. If a nutrient/compound is not present in the data the whole time series will display the missing value of -999. The UK does not measure total nitrogen or Kjeldahl nitrogen. Most nutrient measurements are bi-weekly or monthly.

Please note that this data includes catchment corrections direct discharges (i.e. sewage, industrial loads). Also data without direct discharges is available. If this is preferred contact Sonja van Leeuwen (not a good idea for the Thames, as sewage for London is discharged directly into the estuary), also when the Humber and Wash rivers (part of Northern English rivers) is needed.

5.4 MOSSCO River data basis

The MOSSCO River data basis consists of the described German, Dutch and UK rivers including the described parameters. On our website the interactive map shows the available river data. The concentration-plots of nitrogen and phosphorus in riverine discharge water visualizes nutrient values in these rivers. In additions to the daily time series (thin line) the 1-year moving average (thick line) is shown. Data gaps are filled with the explained Amplitude-Trend-Climatology method. Sources for the original data are:

- Dutch and German rivers:
    - Pätsch, J. & Lenhart, H.J., 2004 Daily loads of nutrients, total alkalinity, dissolved inorganic carbon and dissolved organic carbon of the European continental rivers for the years 1977 - 2002. ZMK Berichte Nr. 48, 159 pp.
    - Radach, G. & Pätsch, J., 2007 Variability of continental riverine freshwater and nutrient inputs into the North Sea for the years 1977 2000 and its consequences for the assessment of eutrophication. Estuaries and Coasts. 30(1): 66-81.
- UK rivers:
    - H.-J. Lenhart, D.K. Mills, H. Baretta-Bekker, S.M. van Leeuwen, J. van der Molen, J.W. Baretta, M. Blaas, X. Desmit, W. Kühn, H.J. Los, A. Menesguen, R. Neves, R. Proctor, P. Ruardij, M.D. Skogen, A. Vanhoutte-Brunier, M.T. Villars, S. Wakelin, Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea, Journal of Marine Systems, Vol. 81,pp 148-170, 2010, doi:10.1016/j.jmarsys.2009.12.014
    - UK water quality data was provided by the Rivers Agency (Northern Ireland), the Environment Agency (England and Wales, contains Natural Resources Wales information © Natural Resources Wales and database right) and the Scottish Environment Protection Agency (Scotland). Flow data was provided by the National River Flow Archive, UK. Data processed to daily values by S. M. van Leeuwen, CEFAS, UK, pers. Comm, UK Crown copyright on provided daily time series.

6 Appendix

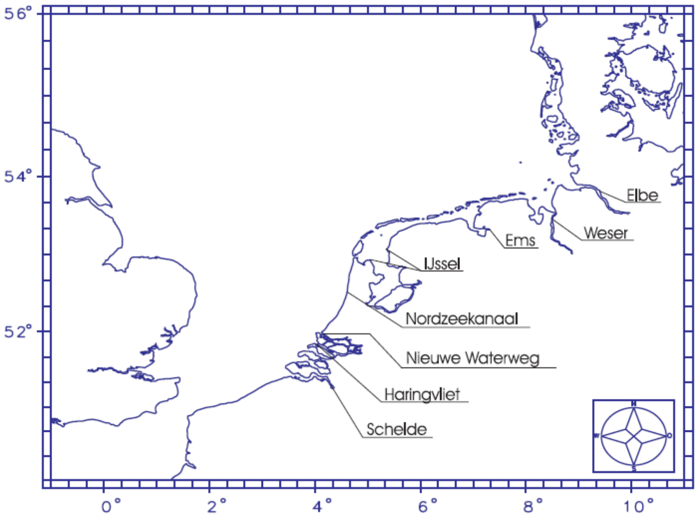

Figure 2.1 The main continental rivers entering the North Sea (Pätsch and Lenhart, 2011).

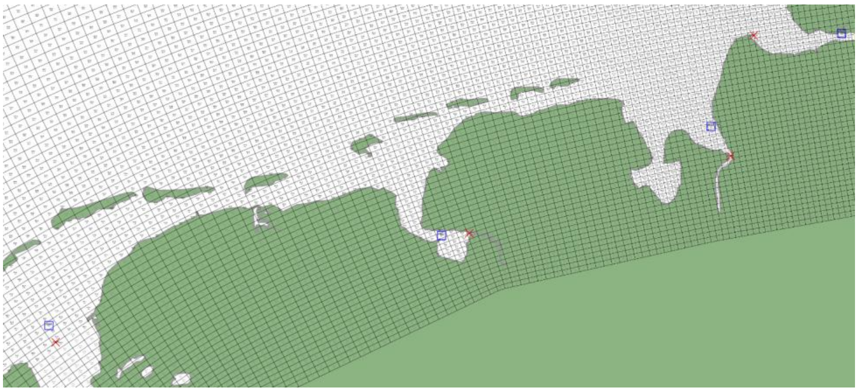

Figure 2.2 Measurement (red) and simulation (blue) stations of the rivers Elbe, Weser, Ems and Vrouwenzand (Kerimoglu, unpublished, 2014).

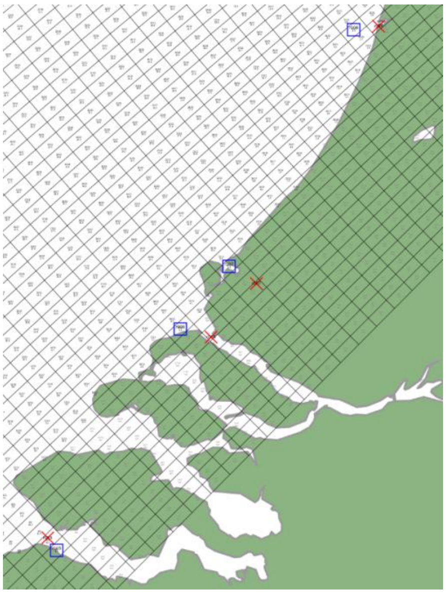

Figure 2.3 Measurement (red) and simulation (blue) stations of the rivers Nordzeekanaal, Nieuwe Waterweg, Haringvliet, Schelde (Kerimoglu, unpublished, 2014)

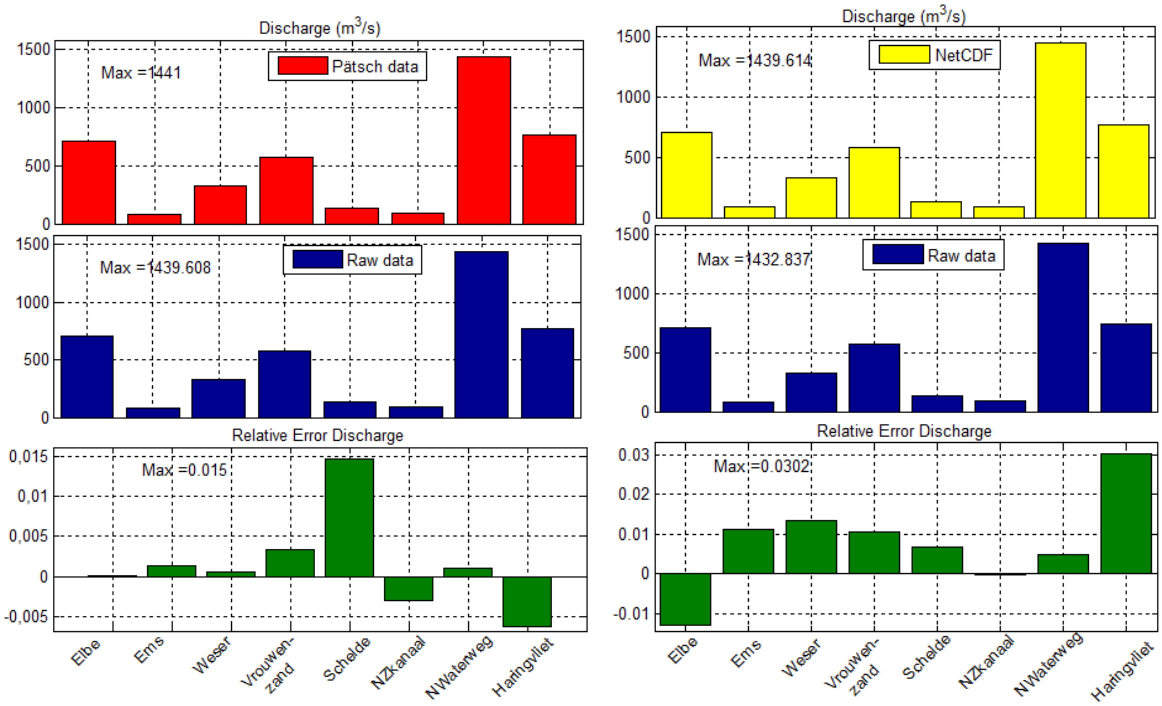

Figure 3.1 Freshwater discharge means and their relative errors (left: D_P, D_R and E_P 1977 – 2009; right: D_N, D_R and E_N 1977 – 2012).

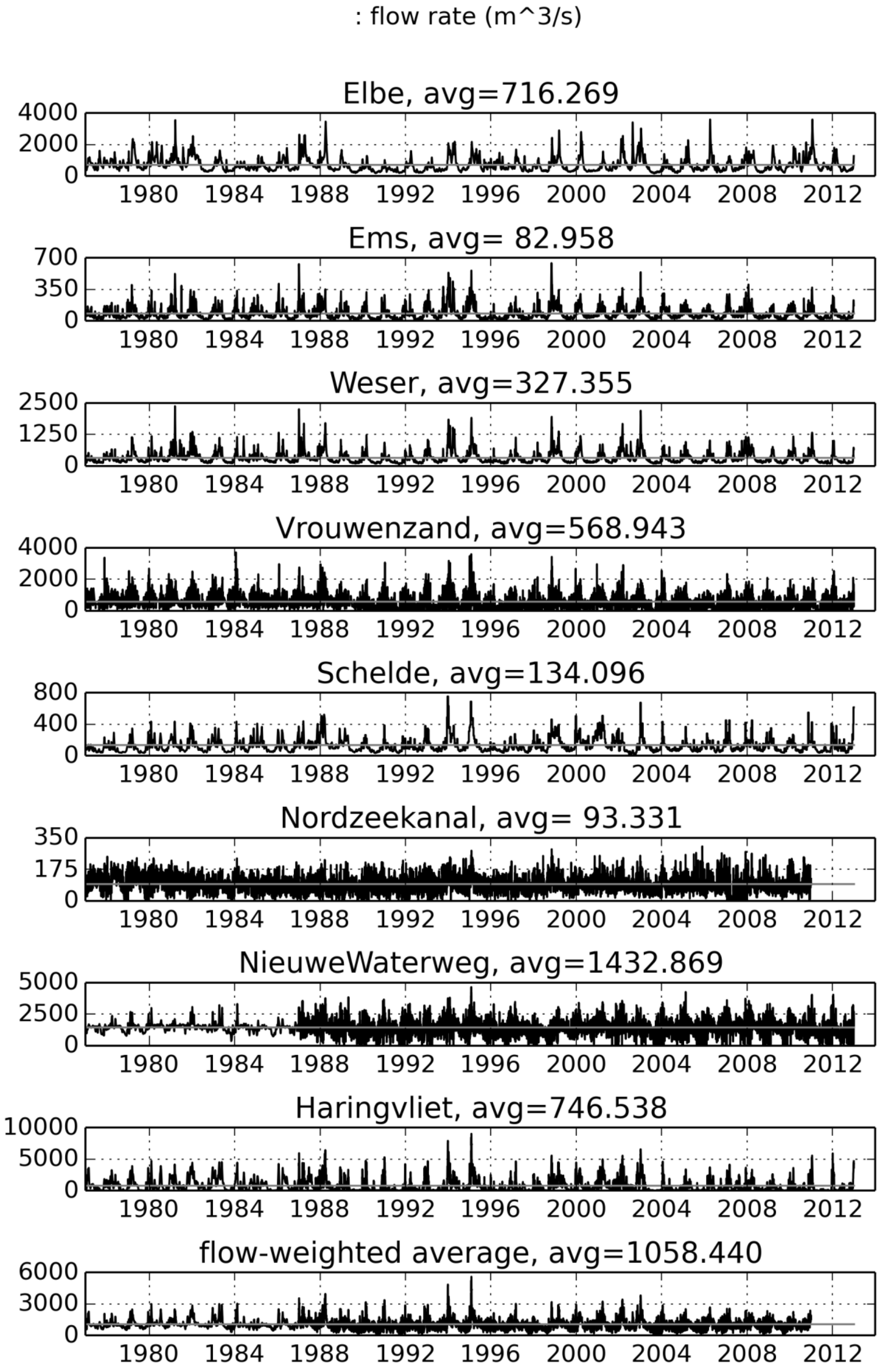

Figure 3.2 Freshwater discharge, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

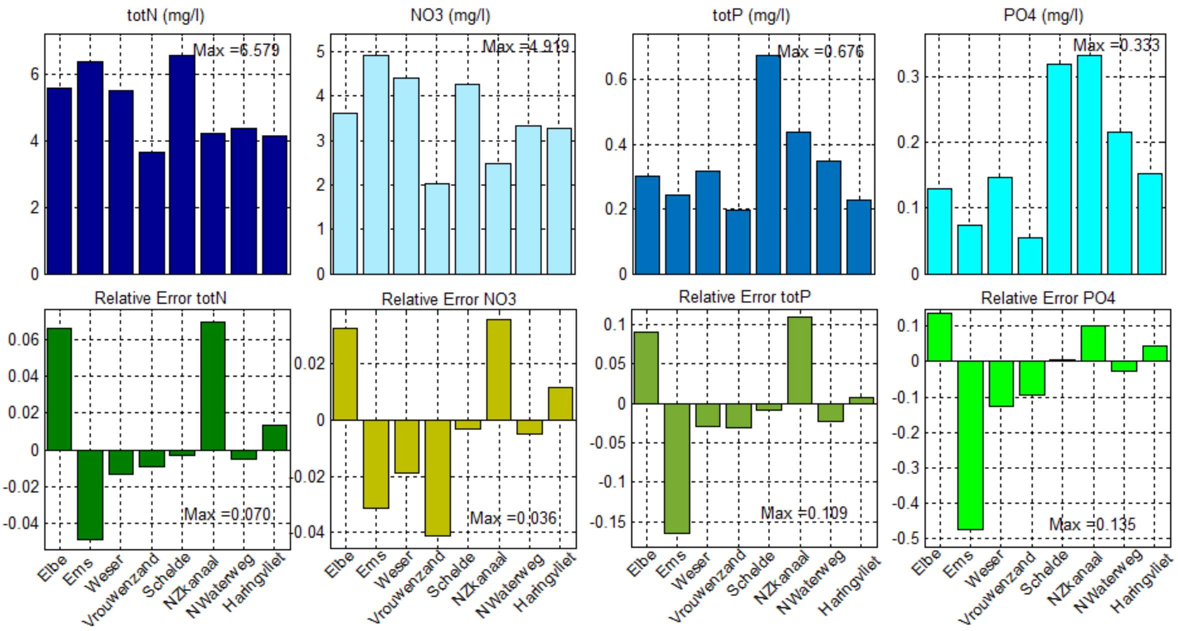

Figure 3.3 Nutrient concentration means (D_R: 1977 – 2009) and their relative errors to D_P (E_P).

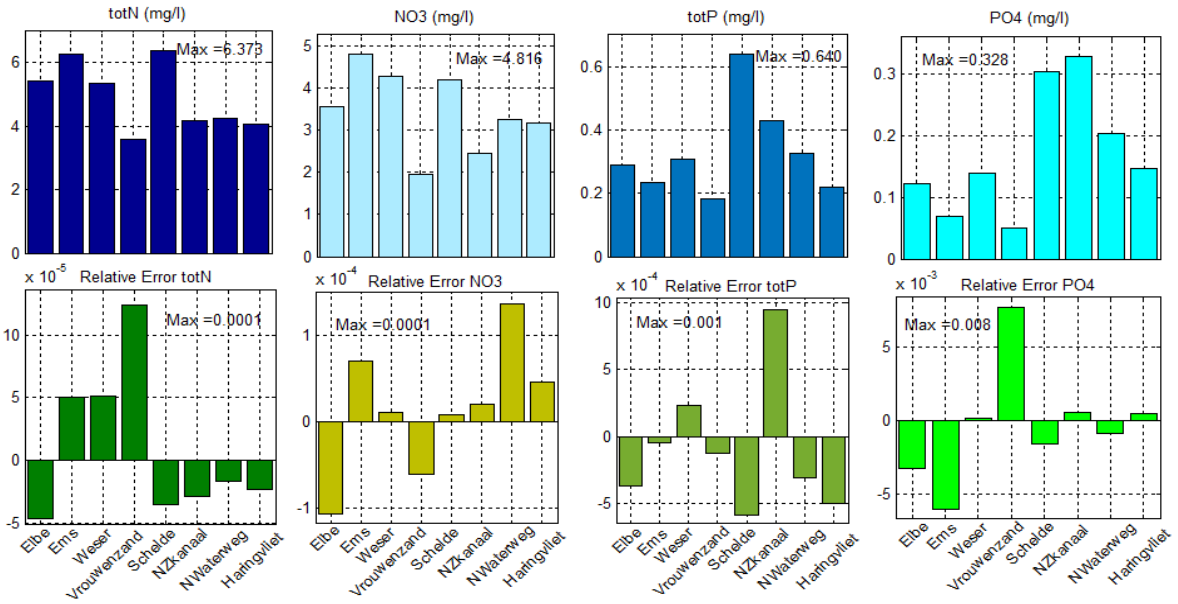

Figure 3.4 Nutrient concentration means (D_R: 1977 – 2012) and their relative errors to D_N (E_N).

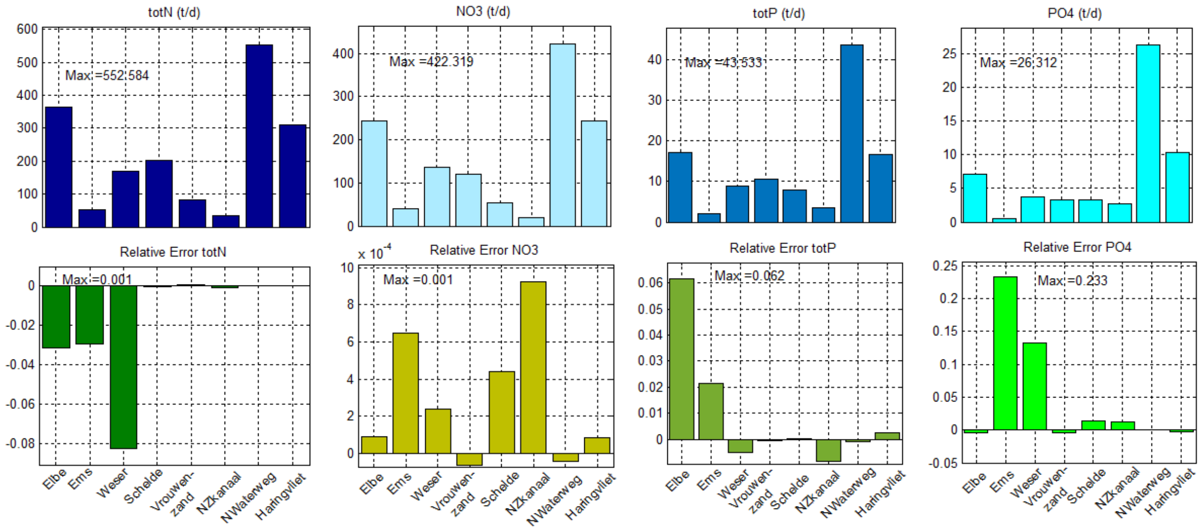

Figure 3.5 Nutrient load means (D_R: 1977 – 2009) and their relative errors to D_P (E_P).

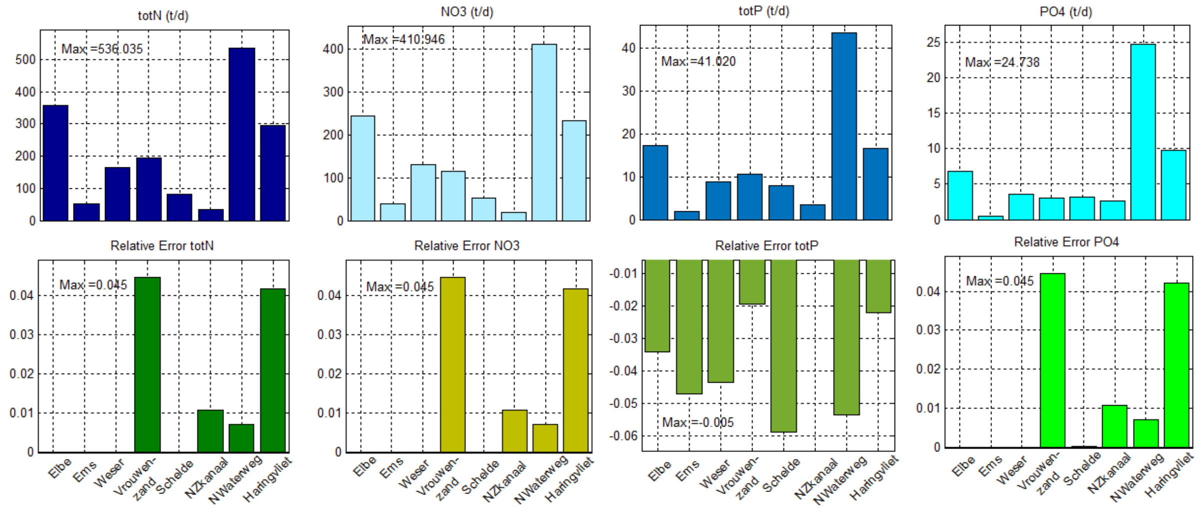

Figure 3.6 Nutrient load means (D_R: 1977 – 2012) and their relative errors to D_N (E_N).

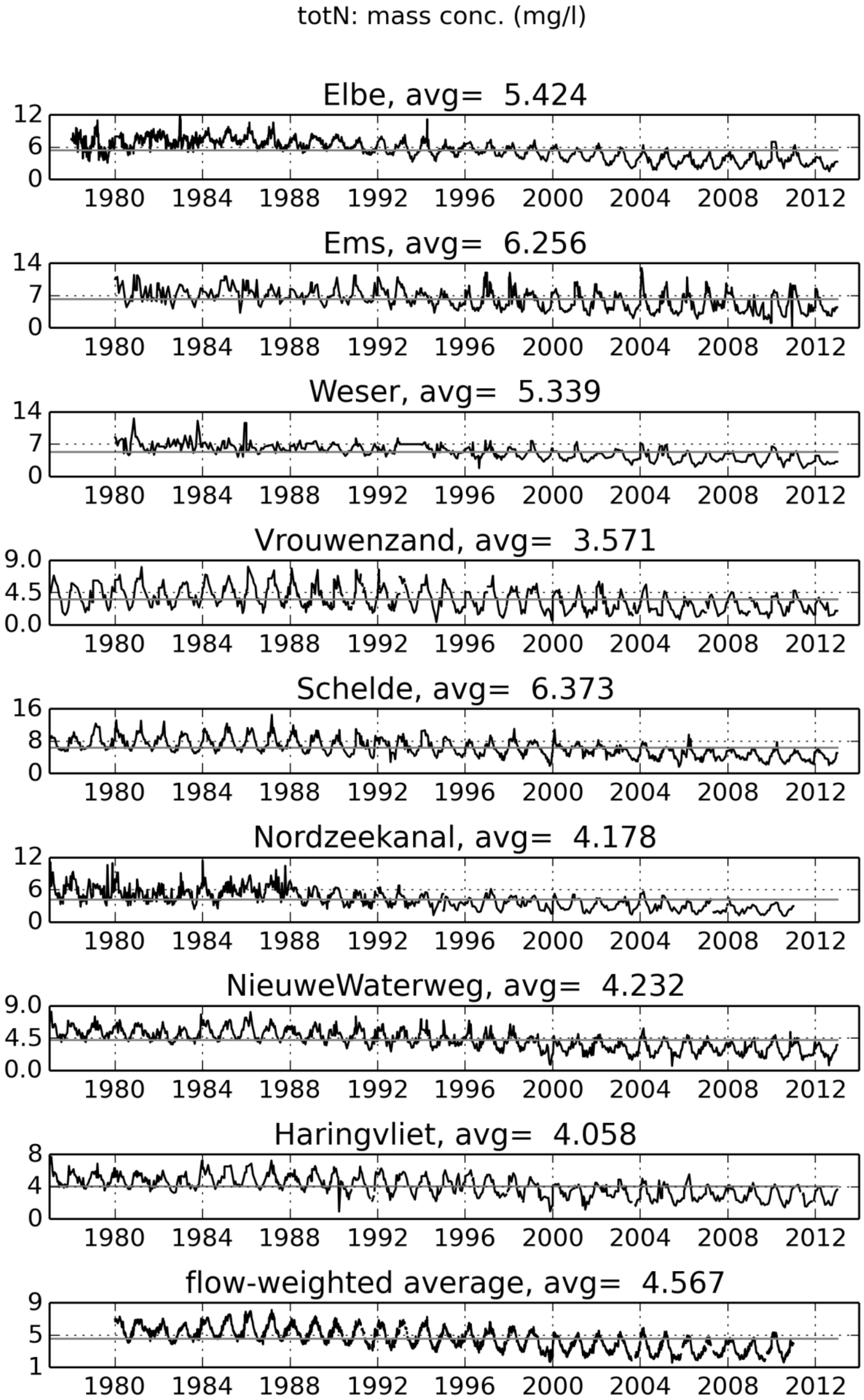

Figure 3.7 Nitrogen concentrations, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

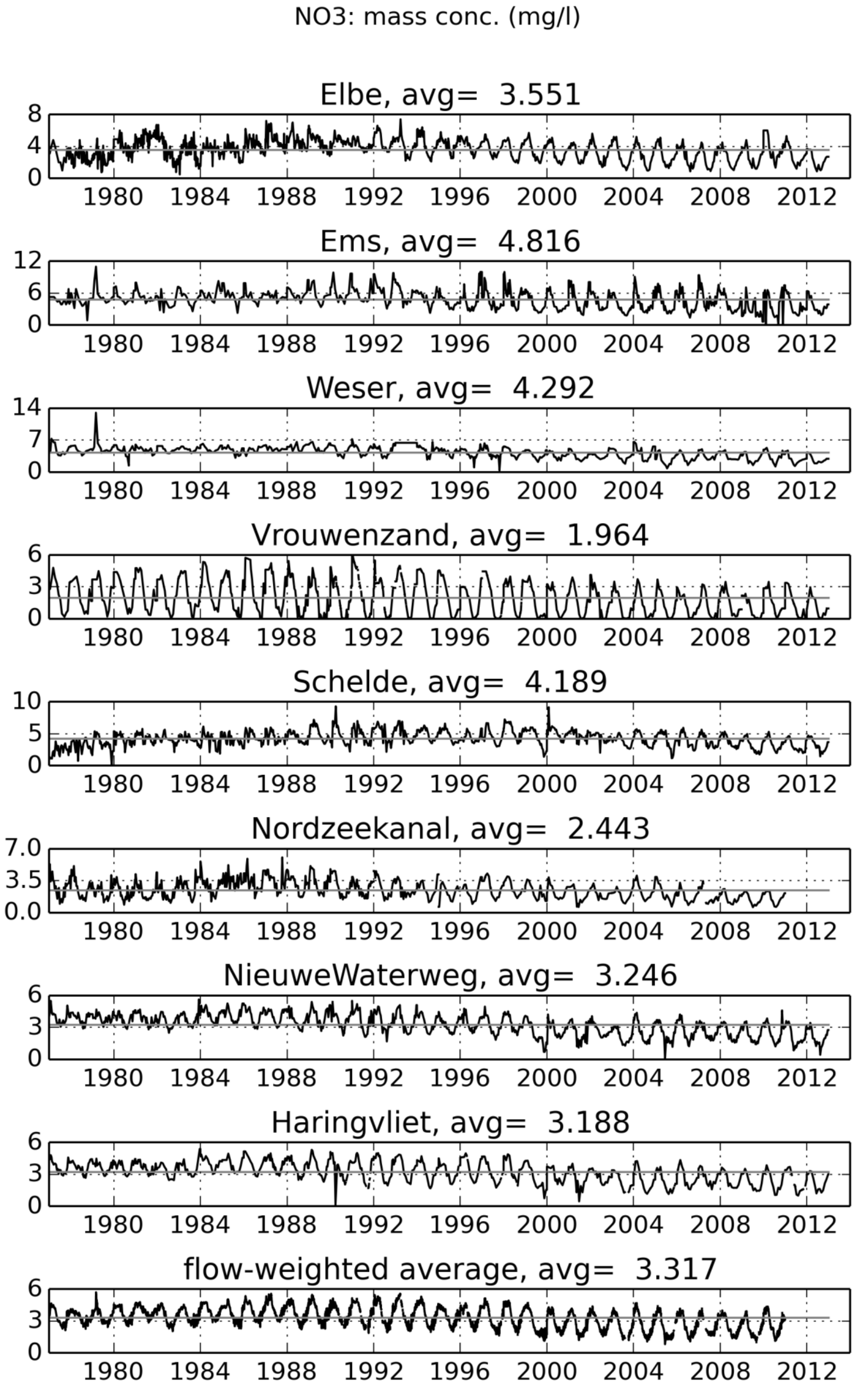

Figure 3.8 Nitrate concentrations, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

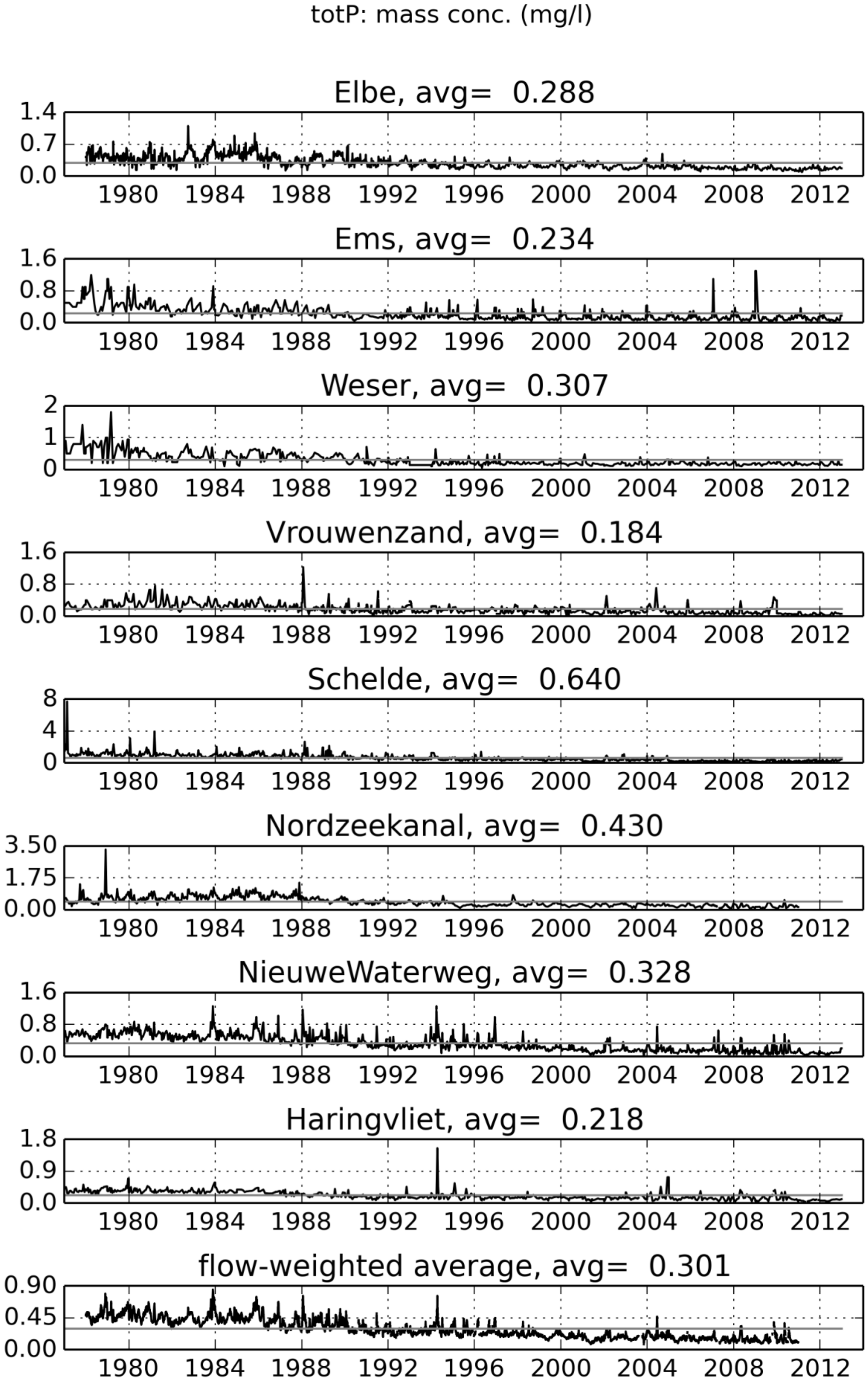

Figure 3.9 Phosphorus concentrations, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

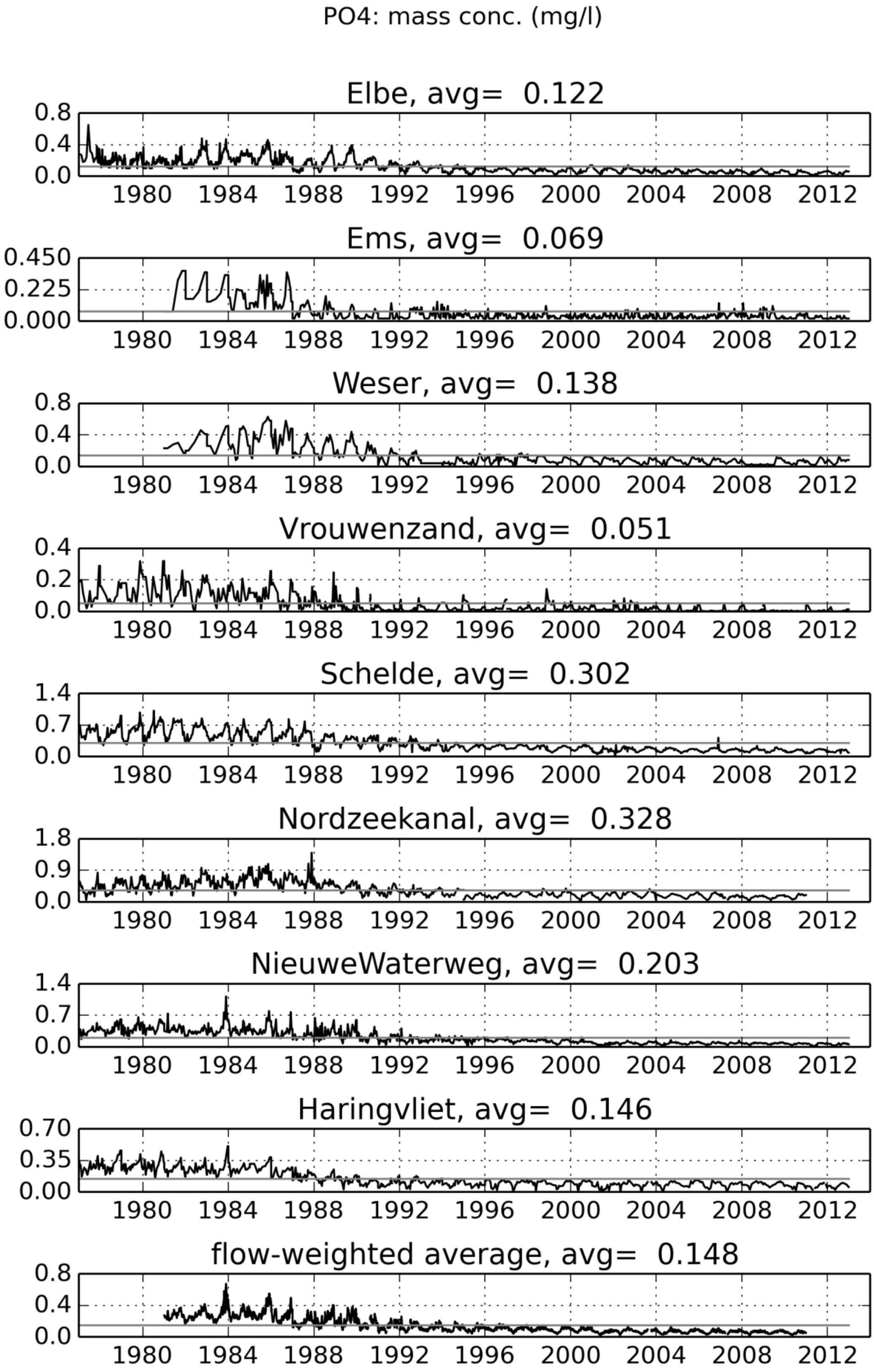

Figure 3.10 Phosphate concentrations, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

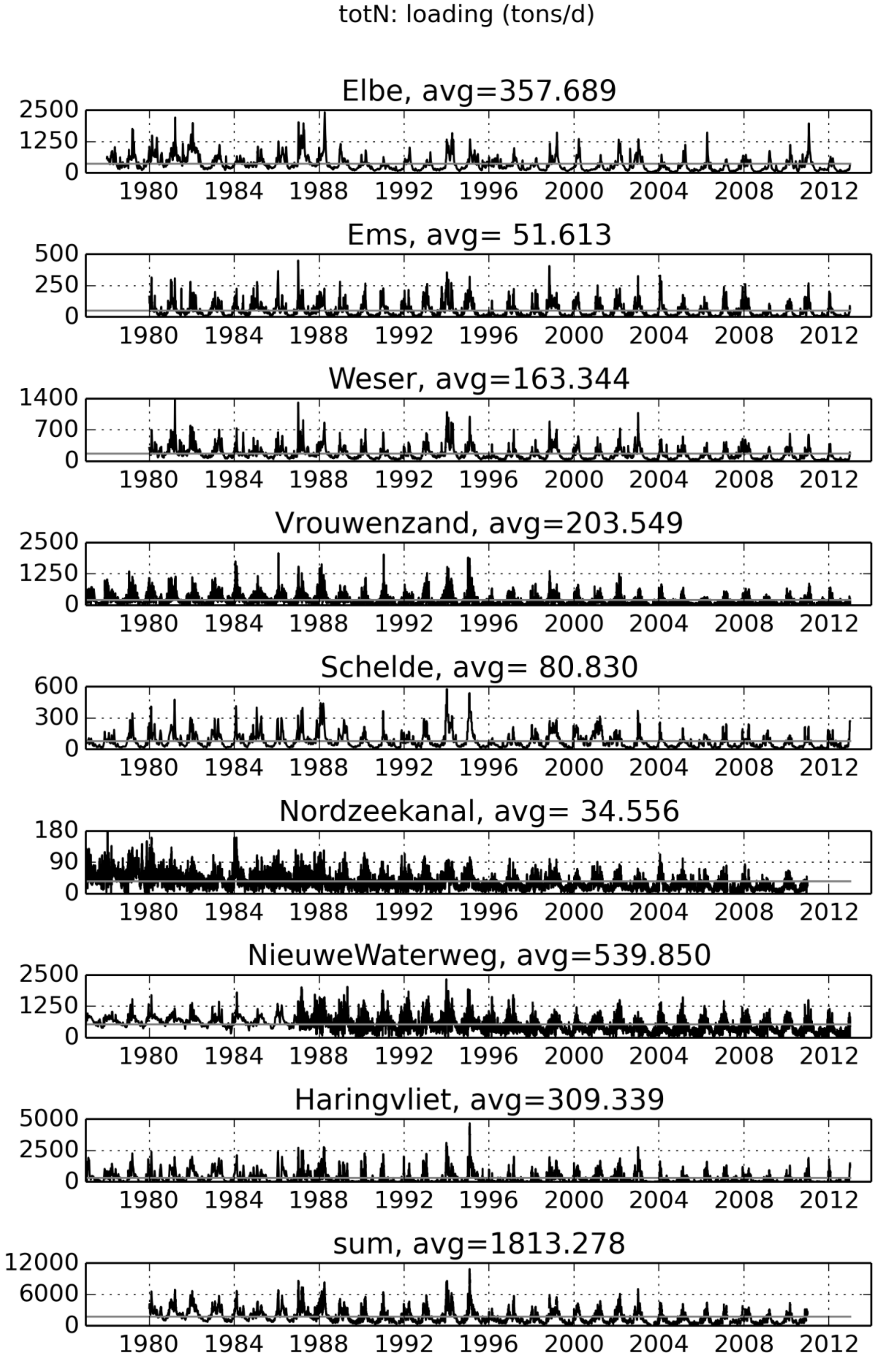

Figure 3.11 Nitrogen load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

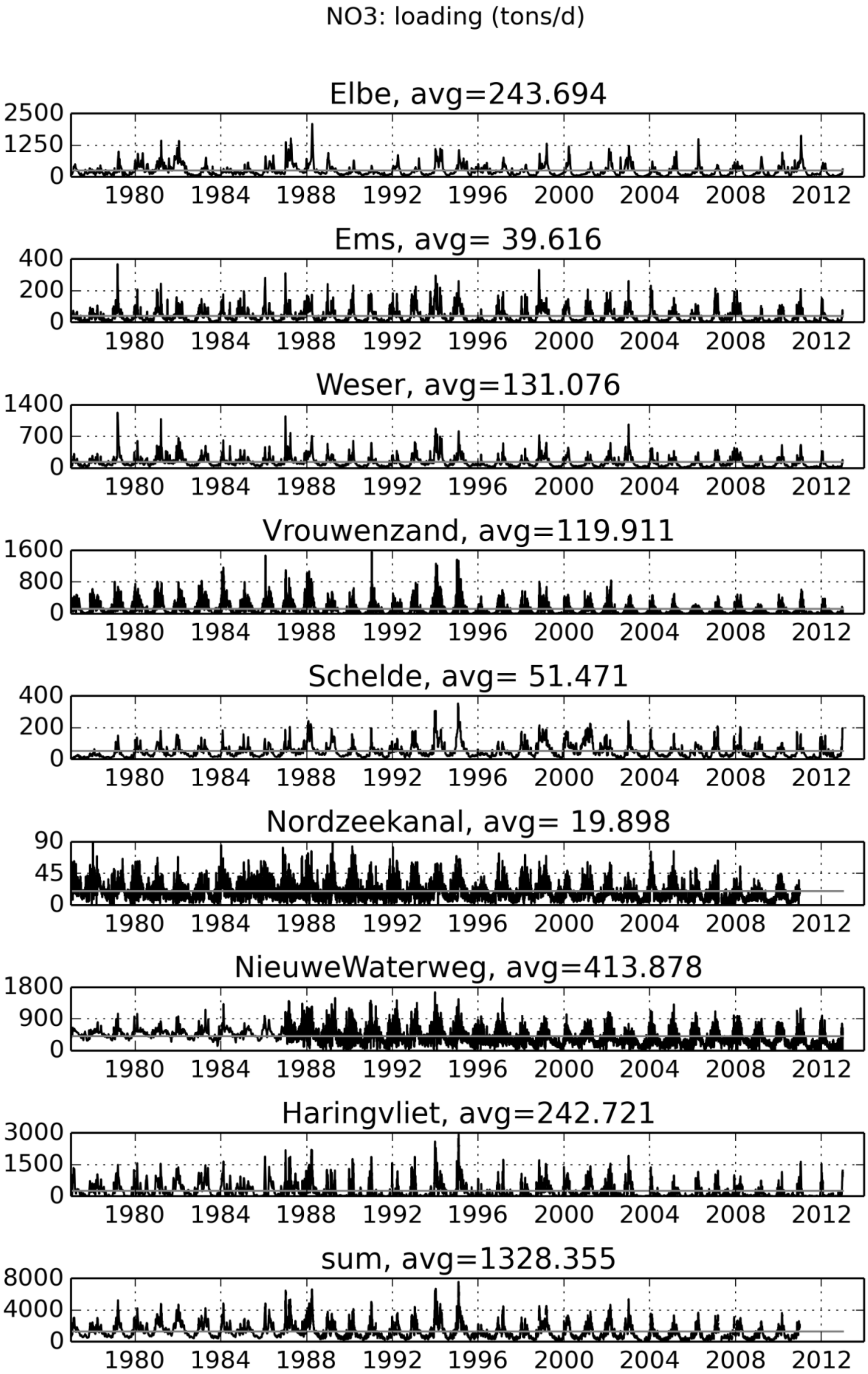

Figure 3.12 Nitrate load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

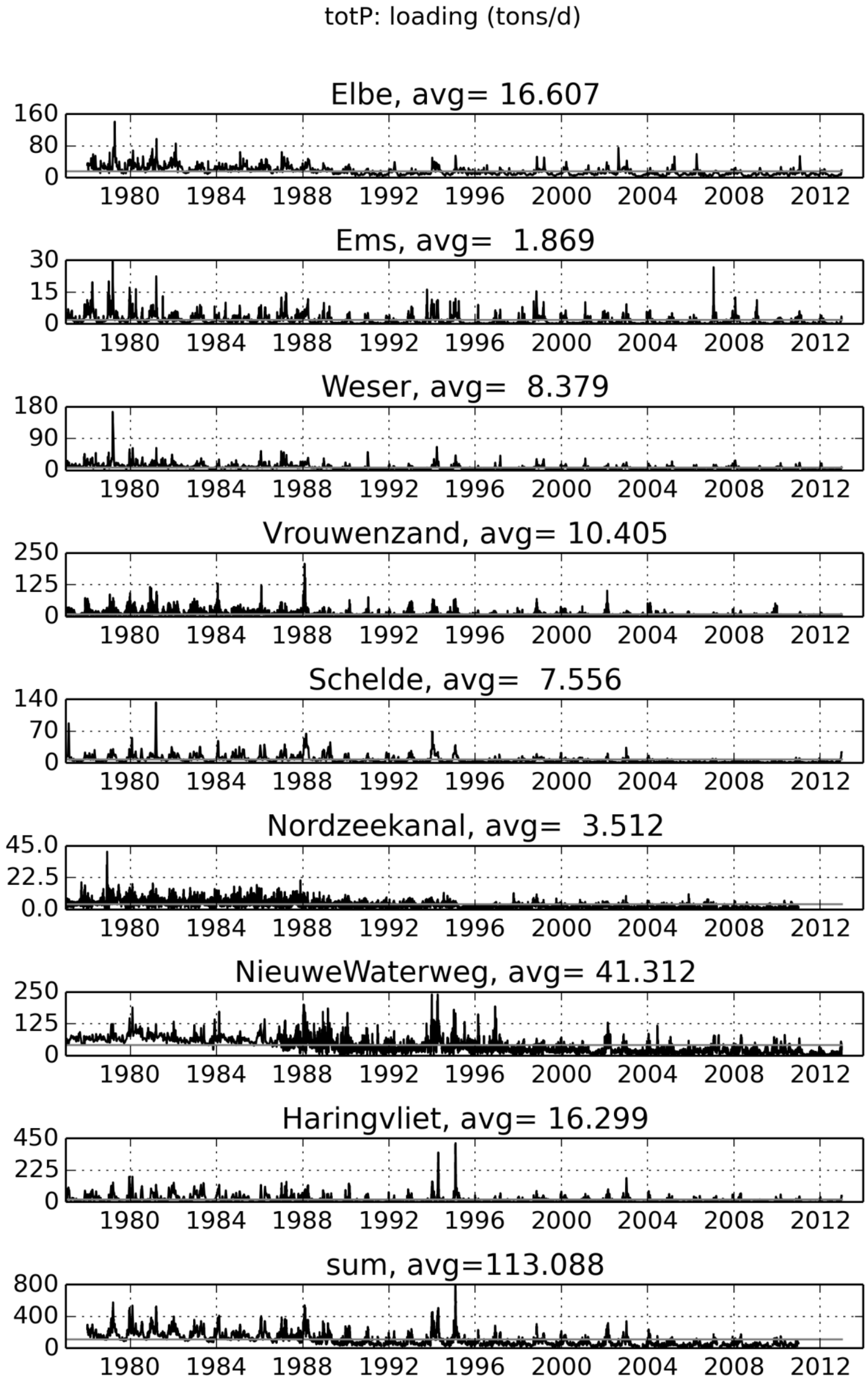

Figure 3.13 Phosphorus load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

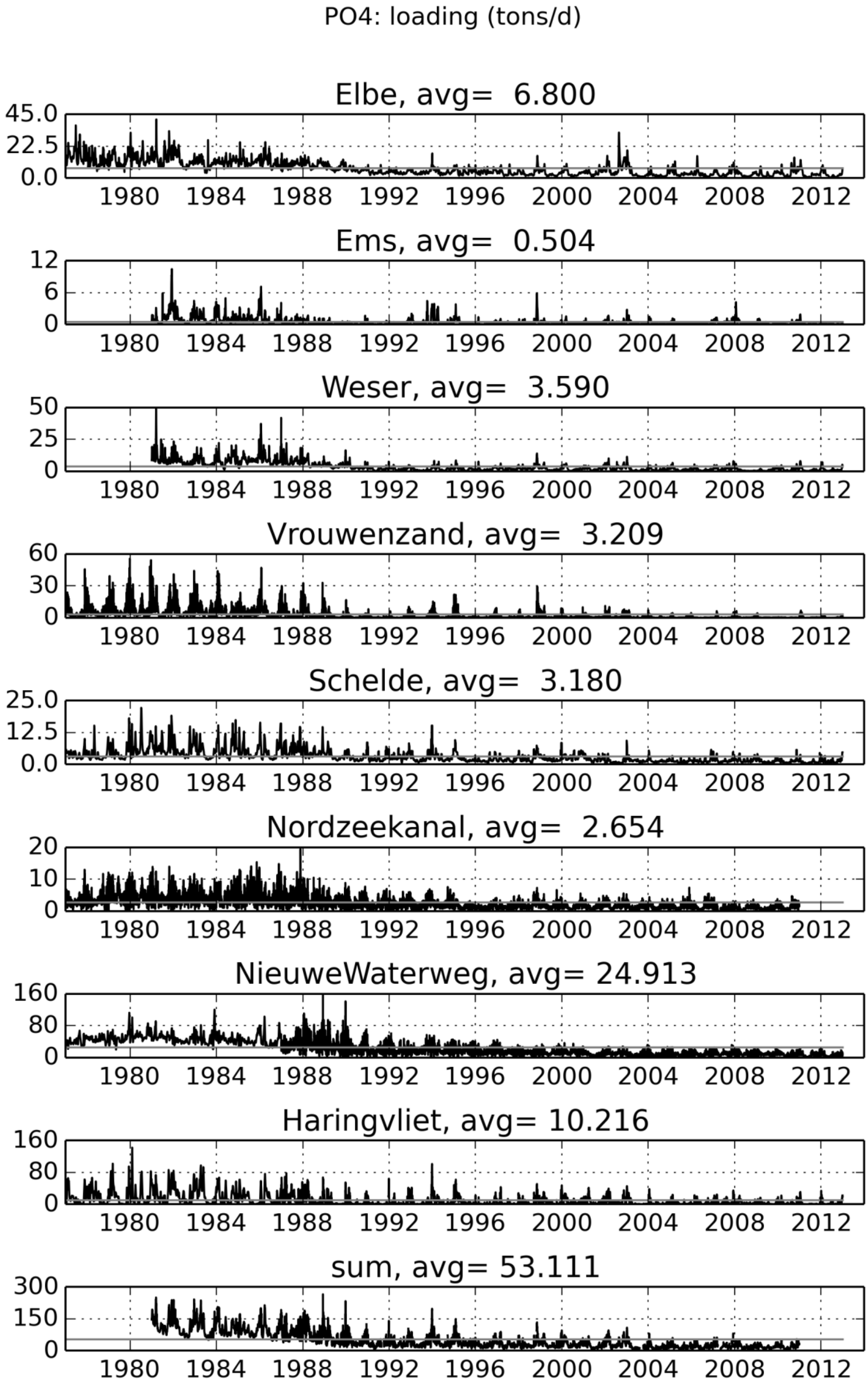

Figure 3.14 Phosphate load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

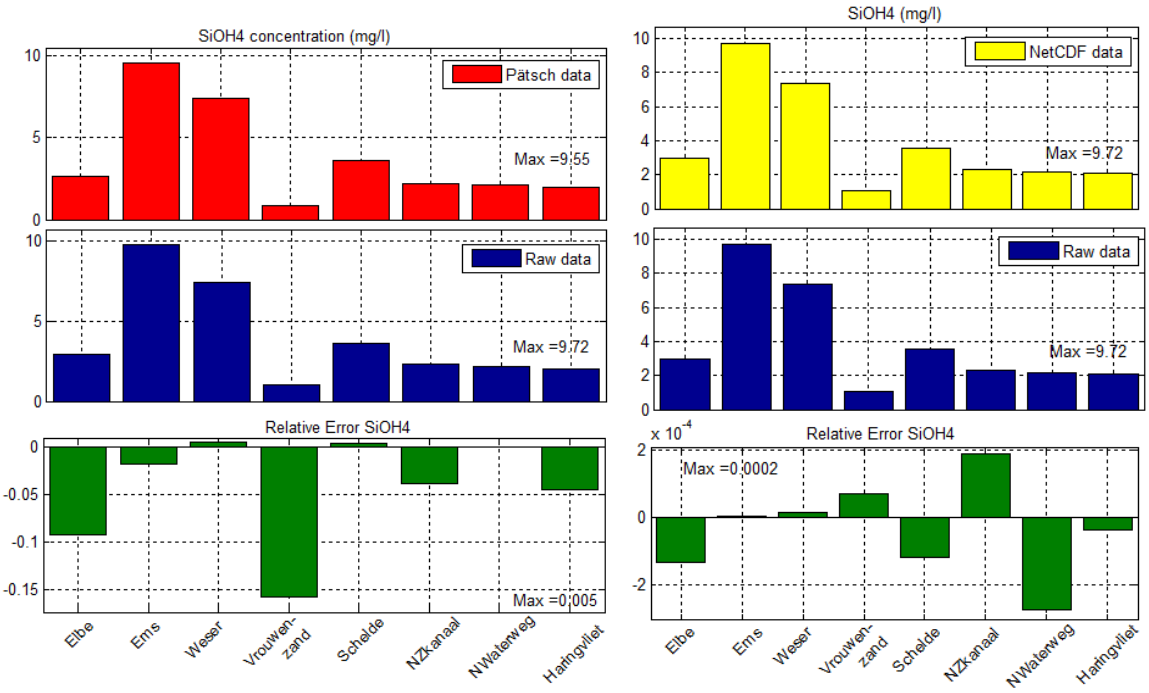

Figure 3.15 Silicate concentrations means and their relative errors (left: D_P, D_R and E_P 1977 – 2009; right: D_N, D_R and E_N 1977 – 2012).

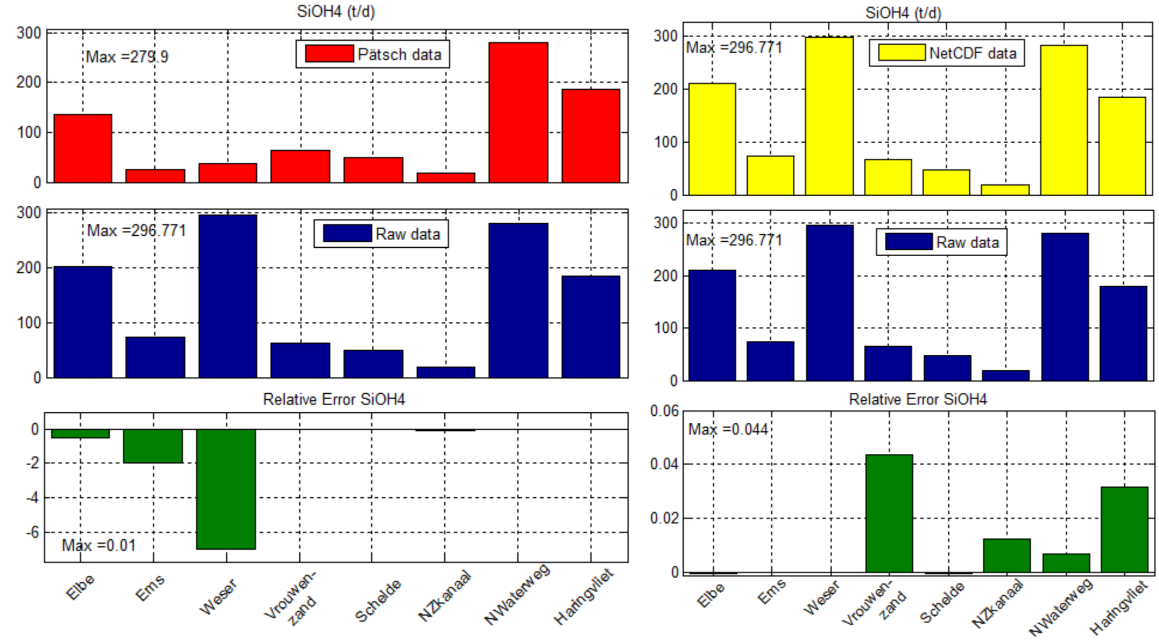

Figure 3.16 Silicate load means and their relative errors (left: D_P, D_R and E_P 1977 – 2009; right: D_N, D_R and E_N 1977 – 2012).

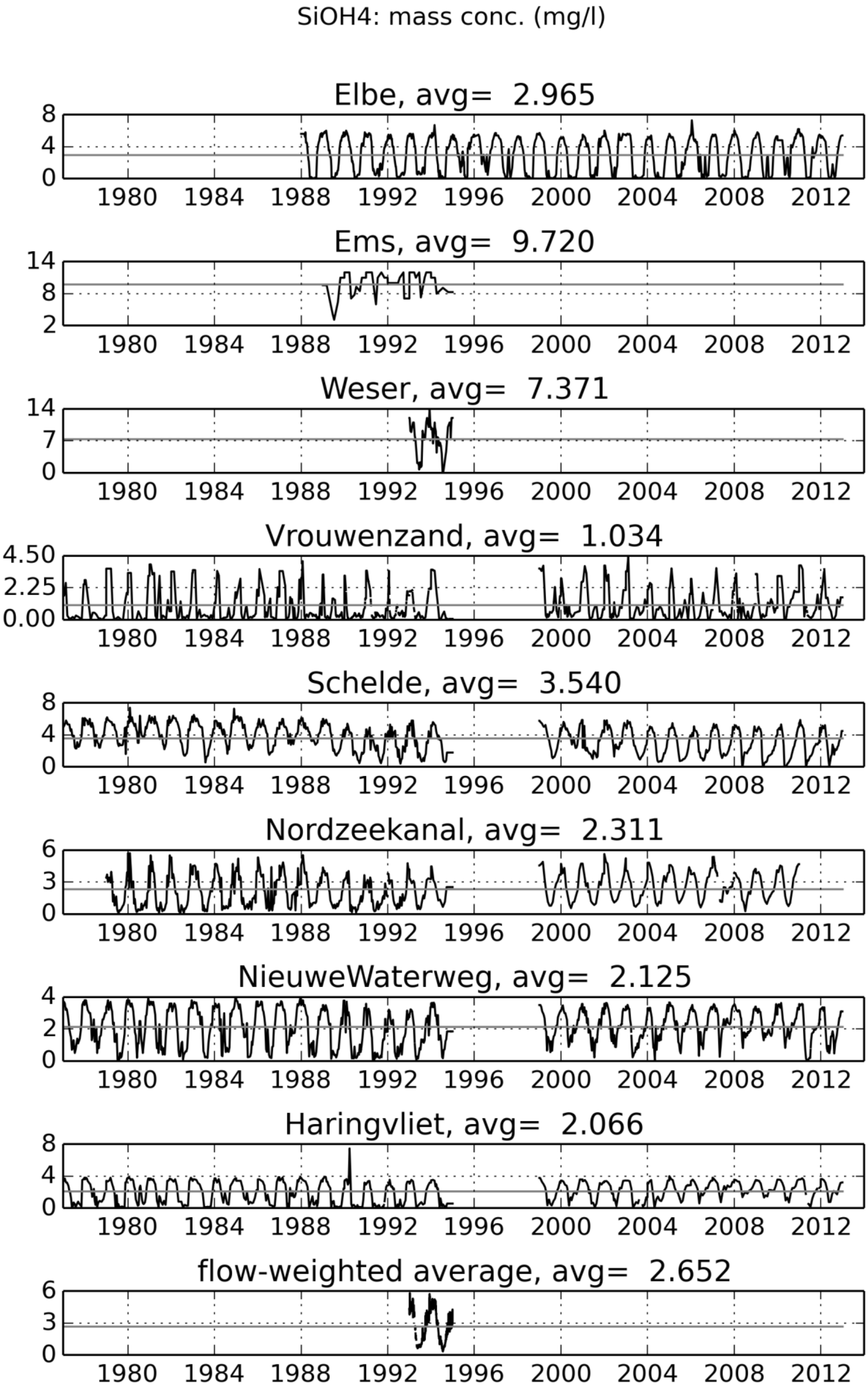

Figure 3.17 Silicate concentrations, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

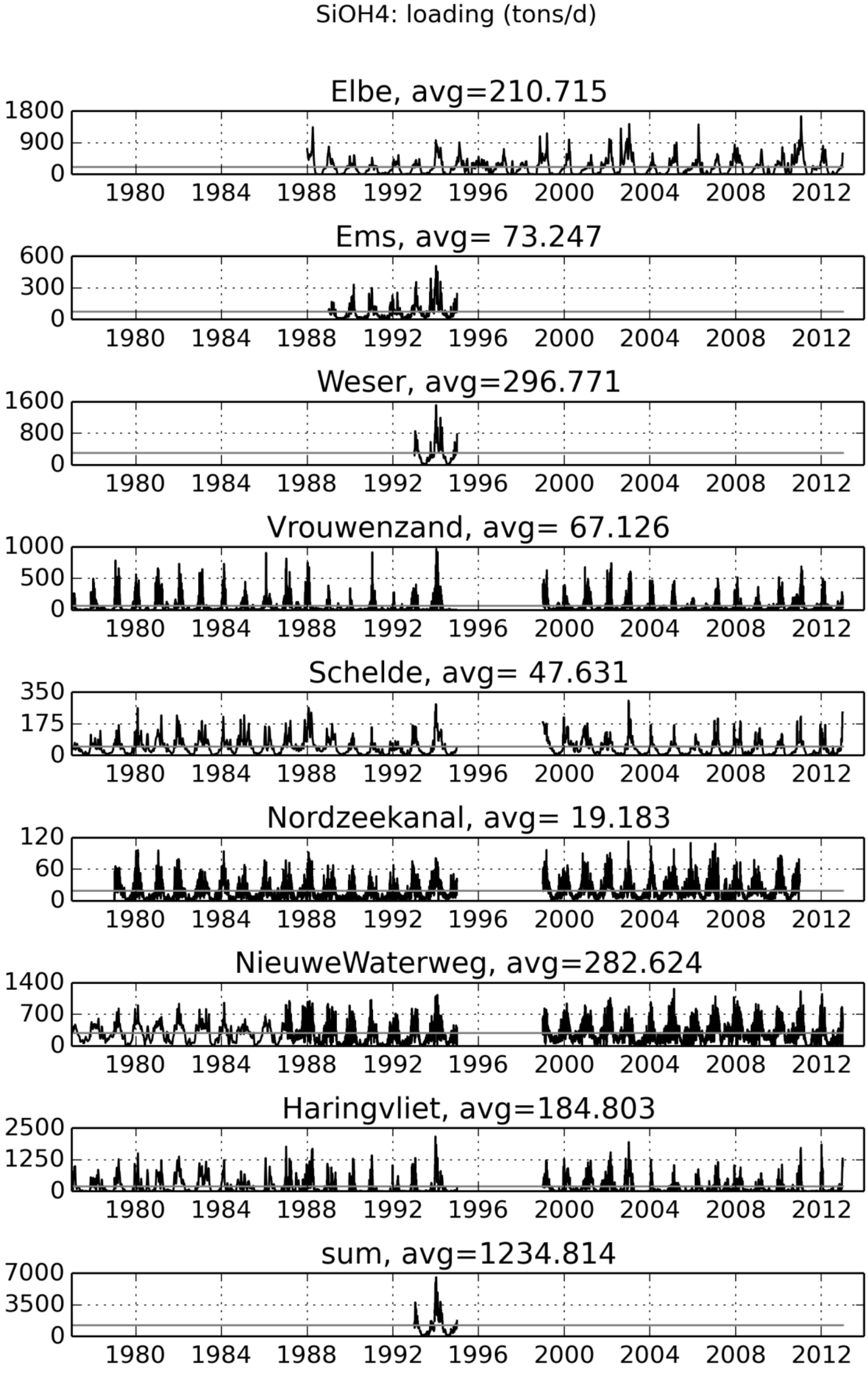

Figure 3.18 Silicate load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

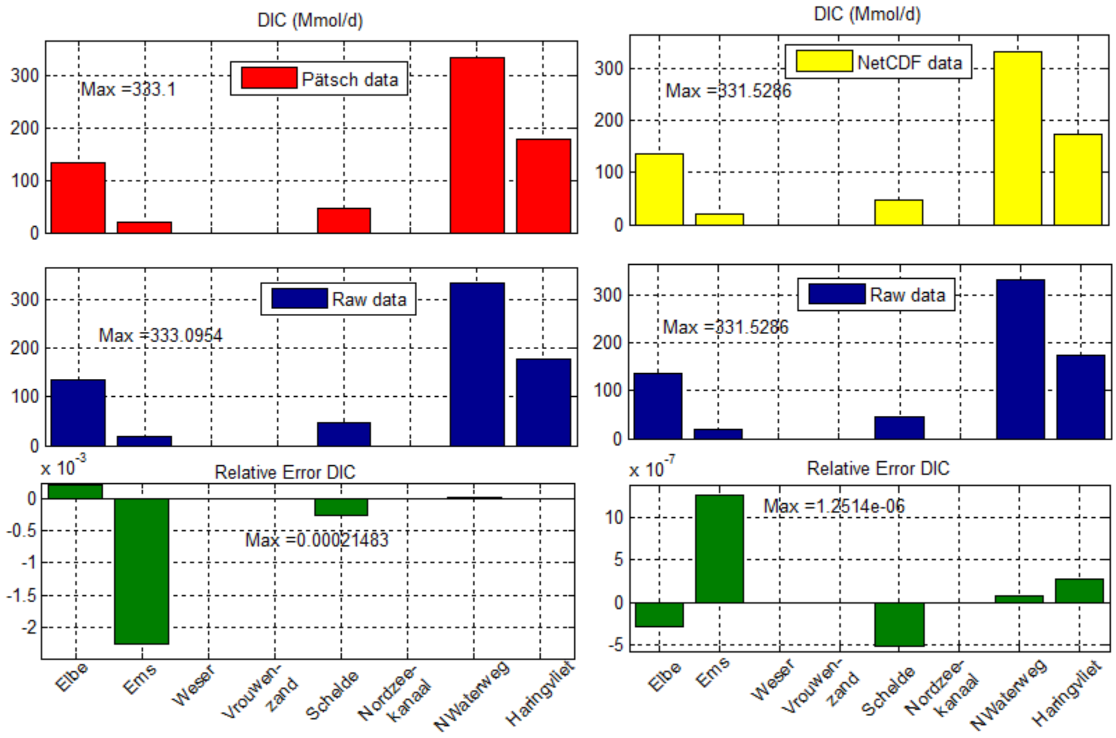

Figure 3.19 DIC load means and their relative errors (left: D_P, D_R and E_P 1977 – 2009; right: D_N, D_R and E_N 1977 – 2012).

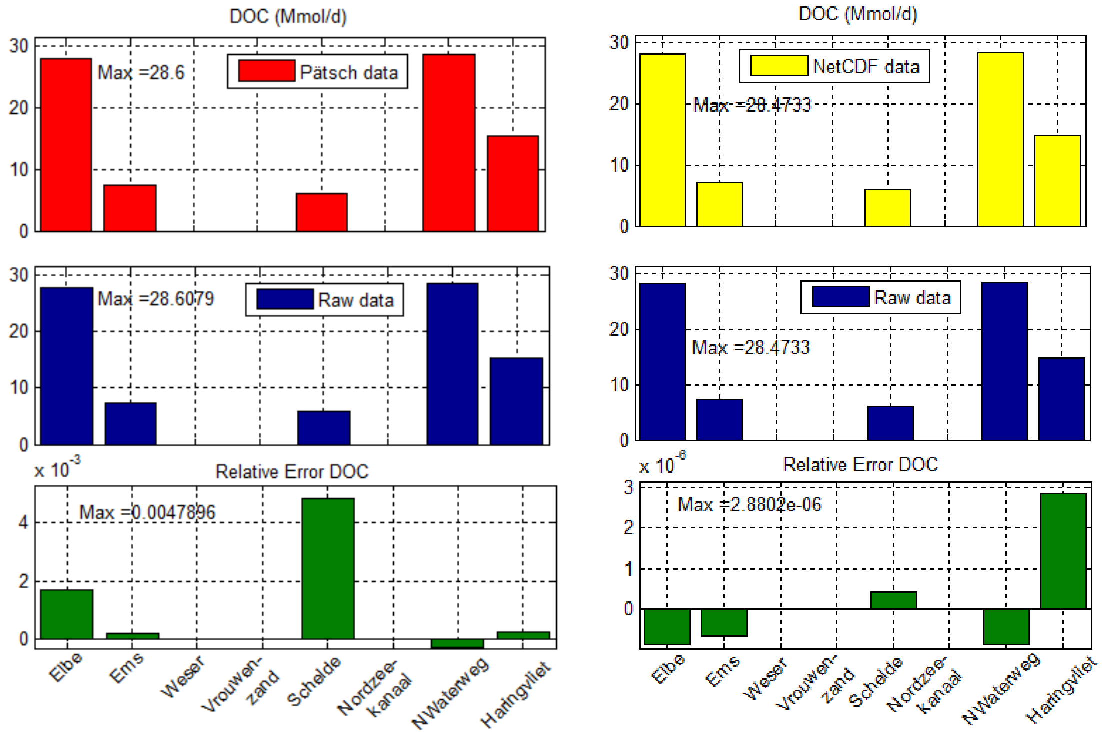

Figure 3.20 DOC load means and their relative errors (left: D_P, D_R and E_P 1977 – 2009; right: D_N, D_R and E_N 1977 – 2012).

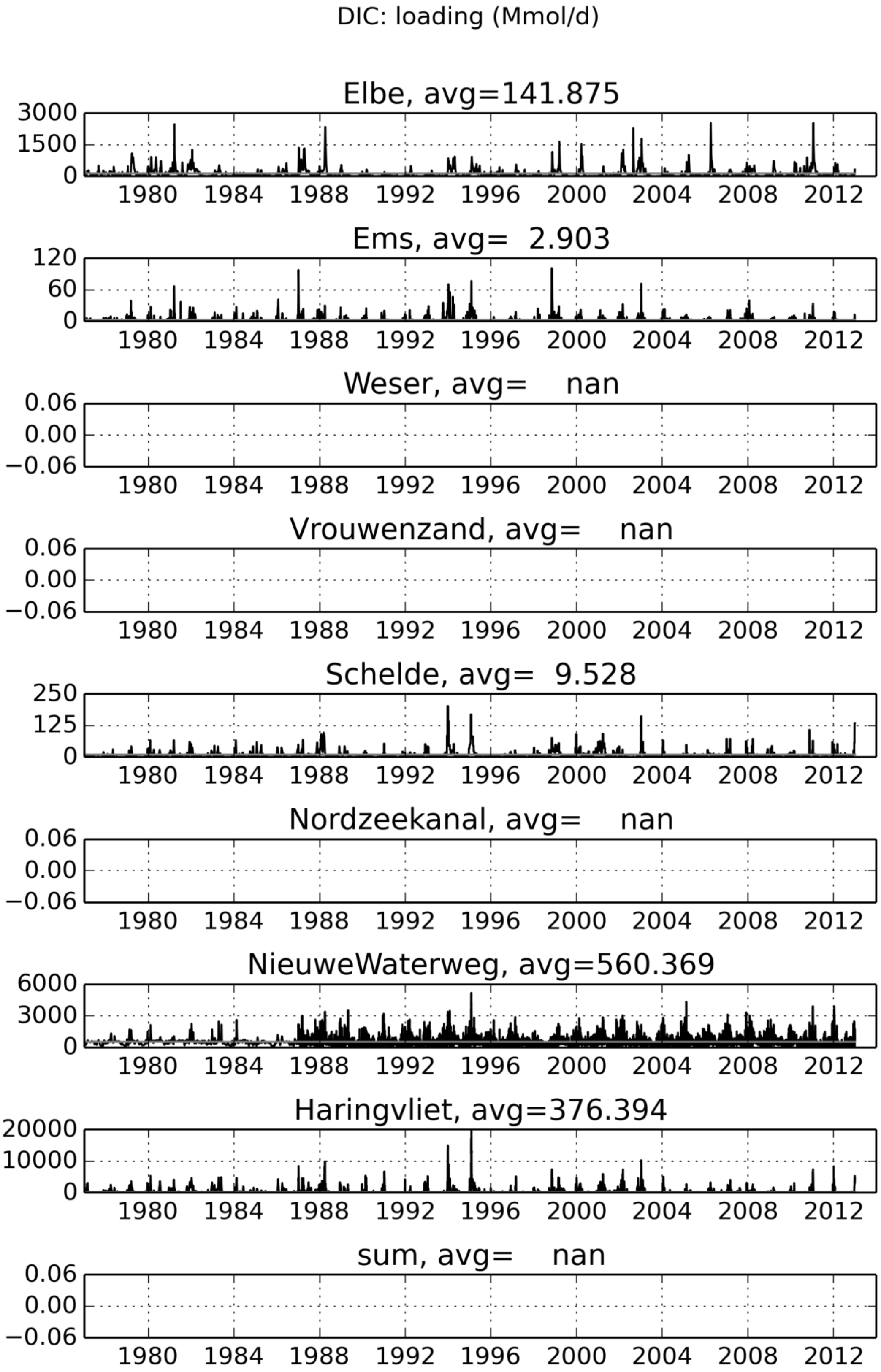

Figure 3.21 DIC load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

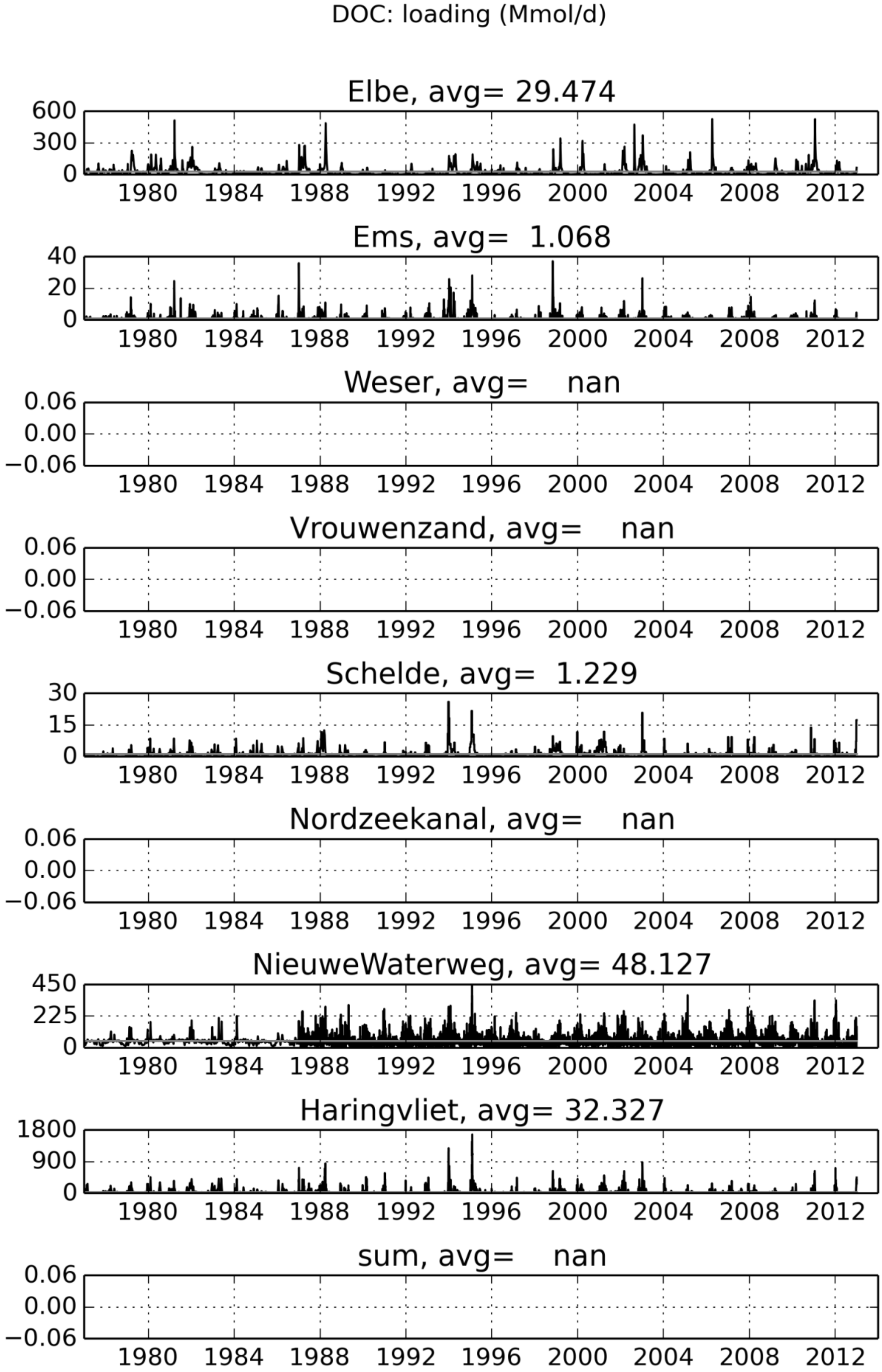

Figure 3.22 DOC load, 1977 – 2012. Gray lines indicate the average throughout the time span shown.

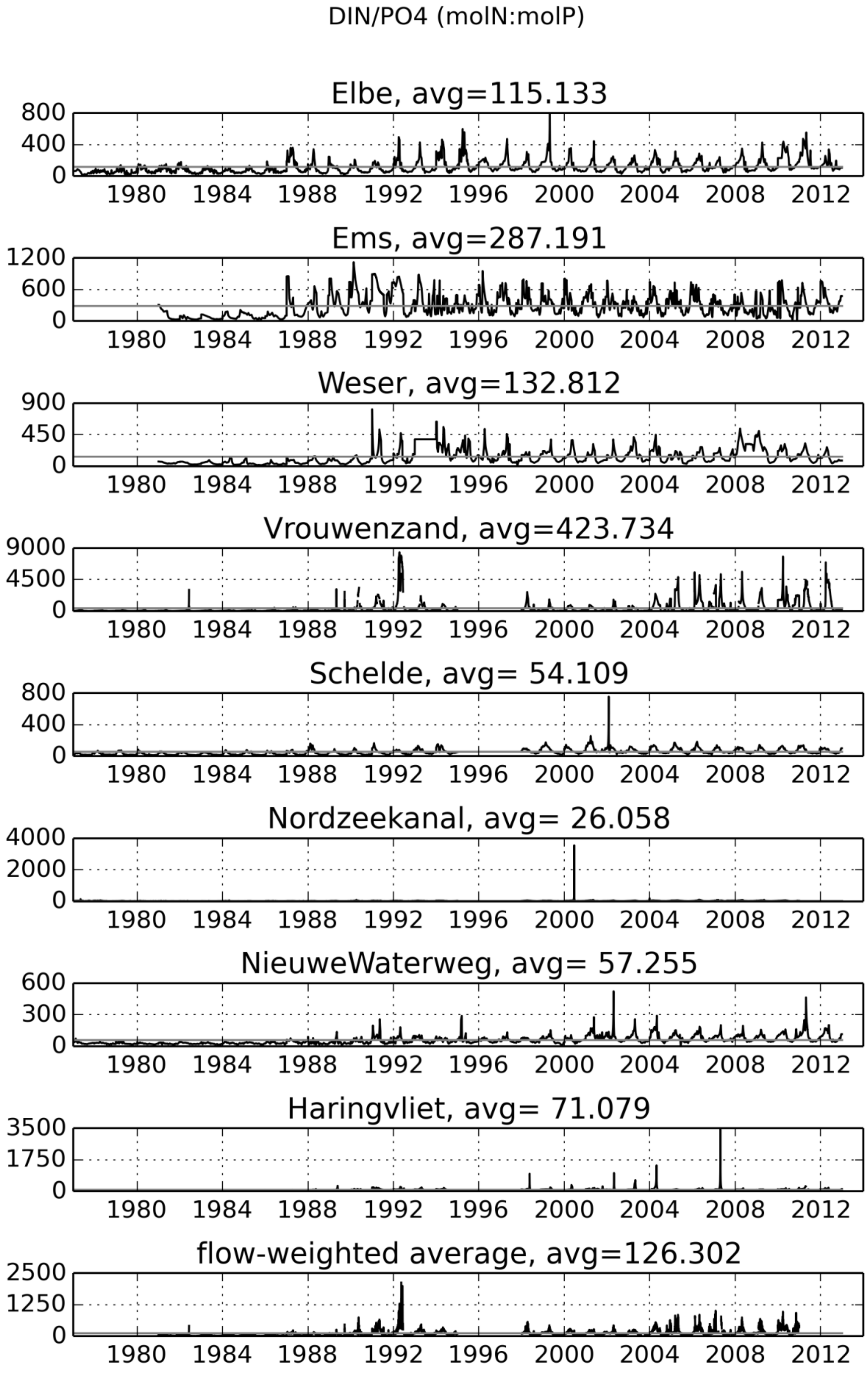

Figure 3.23 Molar ratios of DIN/PO4, 1977 – 2012. Gray lines indicate the average throughout the time span shown. *(Redfield ratio corresponds to 7.23)*

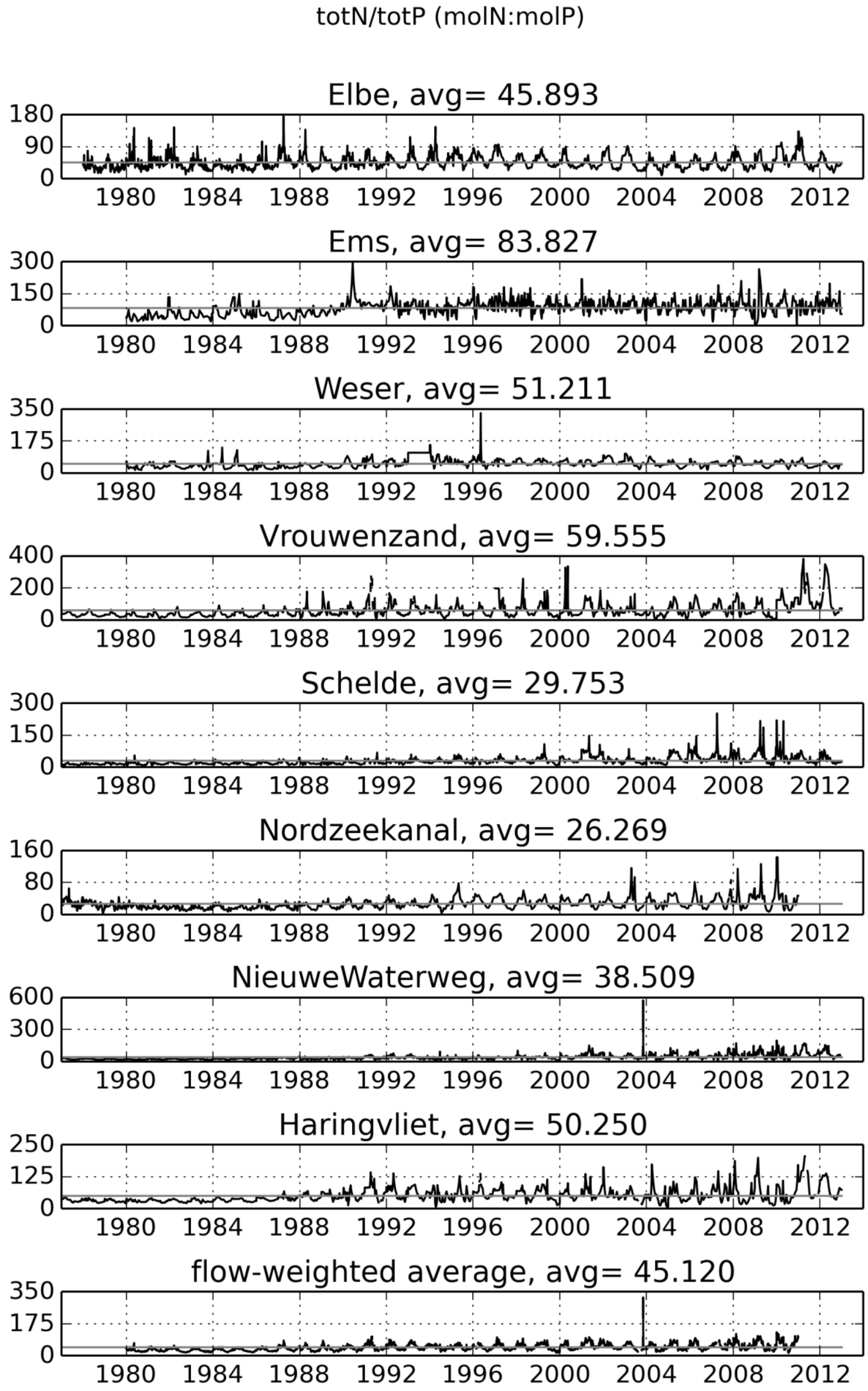

Figure 3.24 Molar ratios of totN/totP, 1977 – 2012. Gray lines indicate the average throughout the time span shown. *(Redfield ratio corresponds to 7.23)*

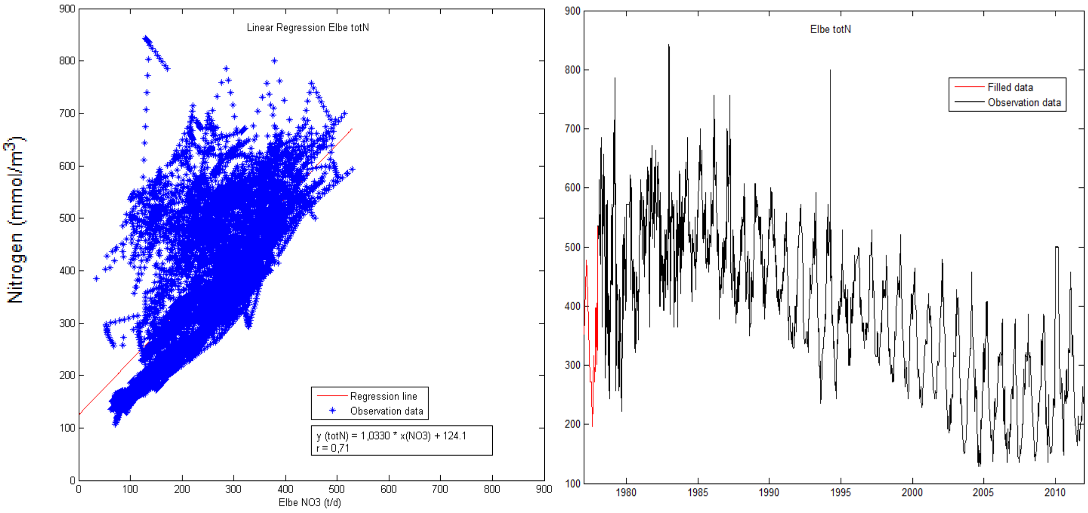

Figure 4.1 Linear regression (left) and filled data time series (right) for totN in Elbe.

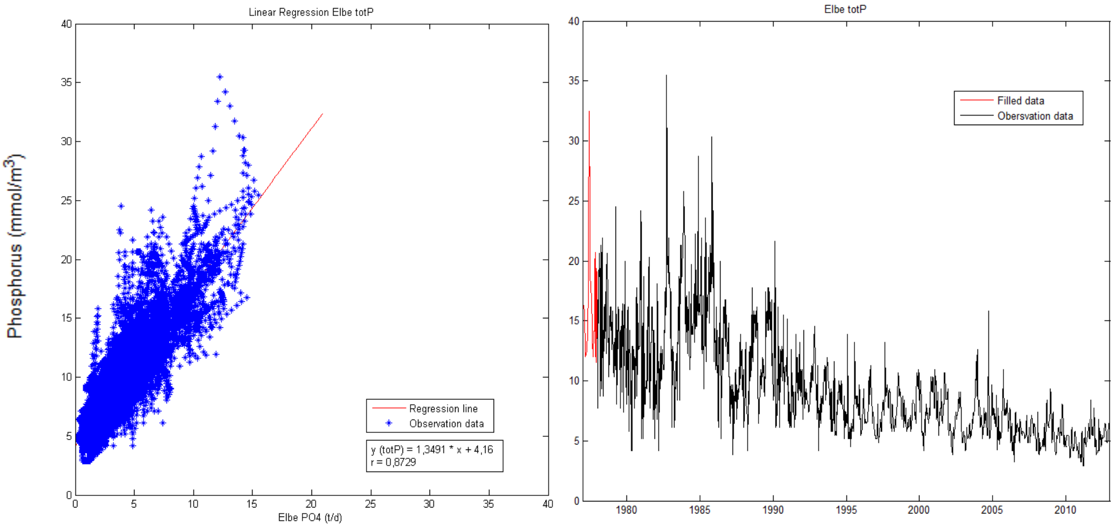

Figure 4.2 Linear regression (left) and filled data time series (right) for PO4 in Elbe.

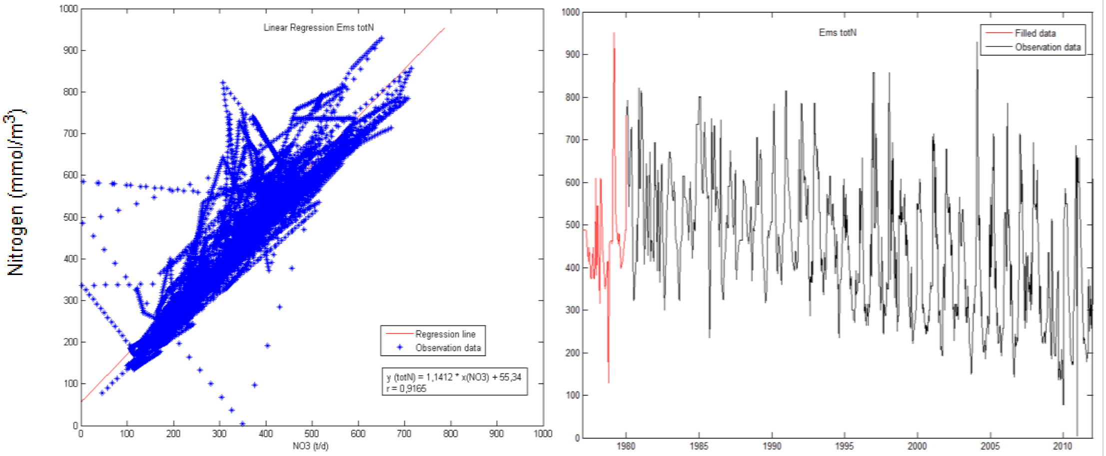

Figure 4.3 Linear regression (left) and filled data time series (right) for totN in Ems.

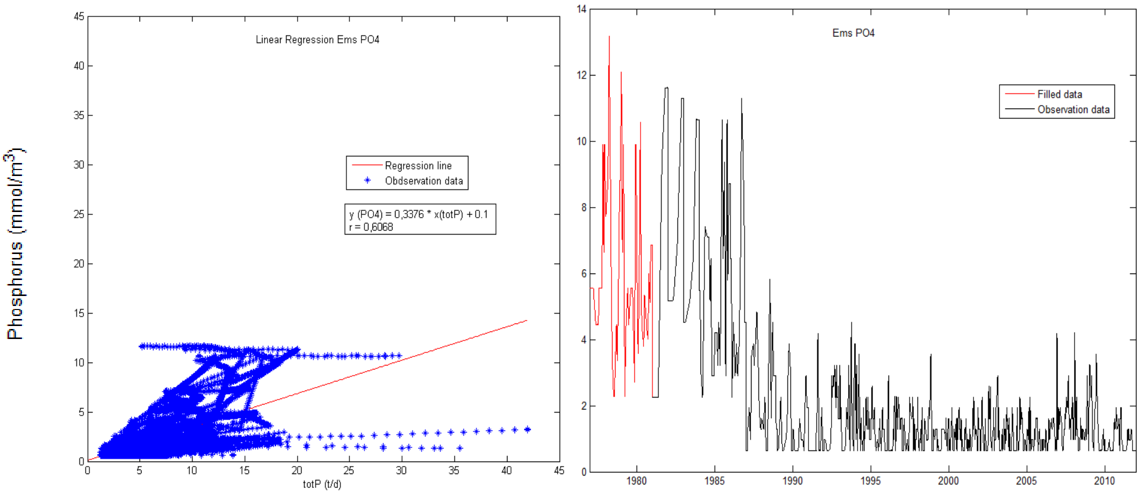

Figure 4.4 Linear regression (left) and filled data time series (right) for PO4 in Ems.

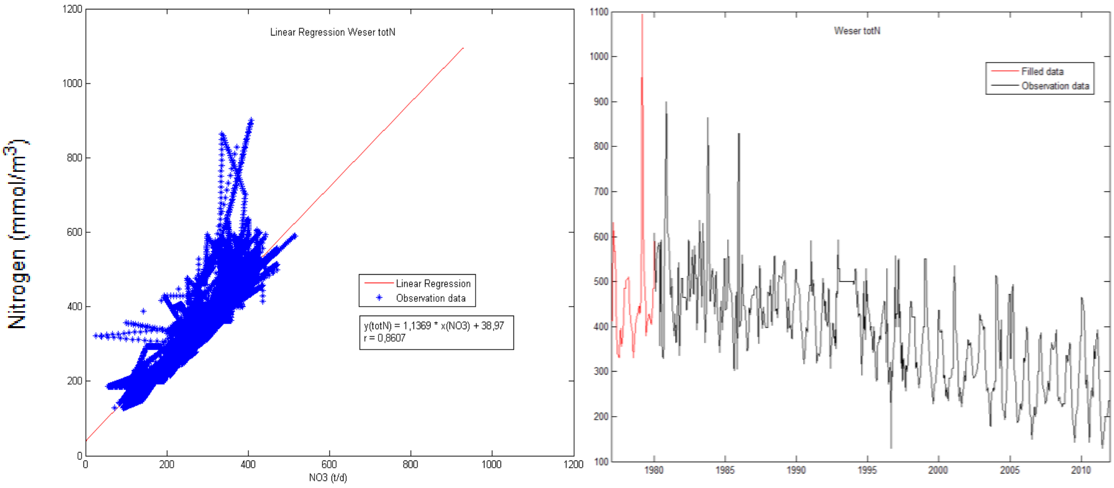

Figure 4.5 Linear regression (left) and filled data time series (right) for totN in Weser.

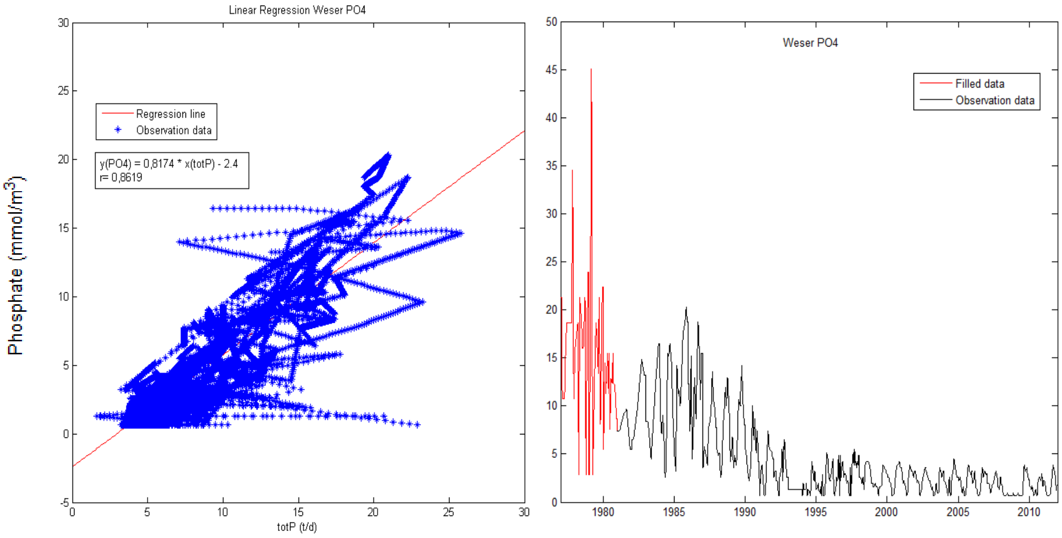

Figure 4.6 Linear regression (left) and filled data time series (right) for PO4 in Weser.

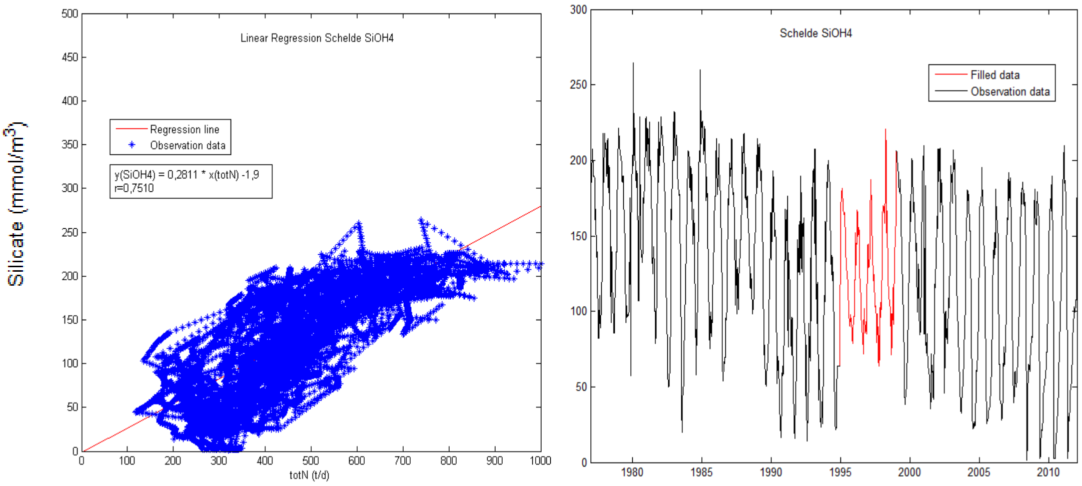

Figure 4.7 Linear regression (left) and filled data time series (right) for SiOH4 in Schelde.

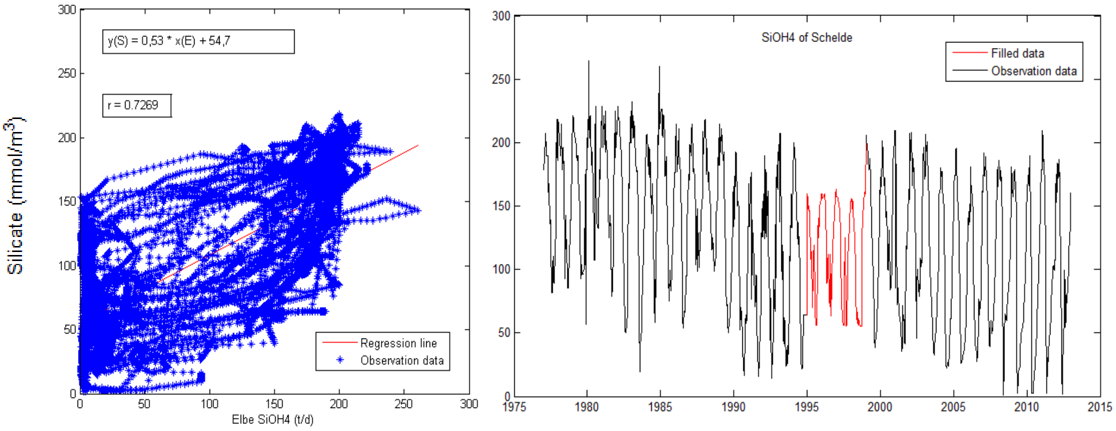

Figure 4.8 Linear regression (left) and filled data time series (right) for SiOH4 in Schelde.

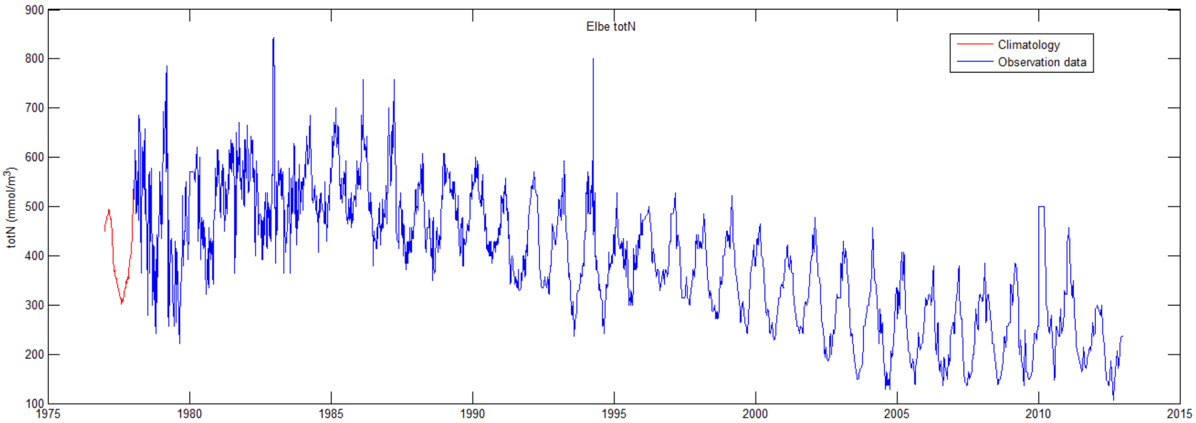

Figure 4.9 Time series of Elbe totN (blue) filled with climatology (red) (1977 – 2012).

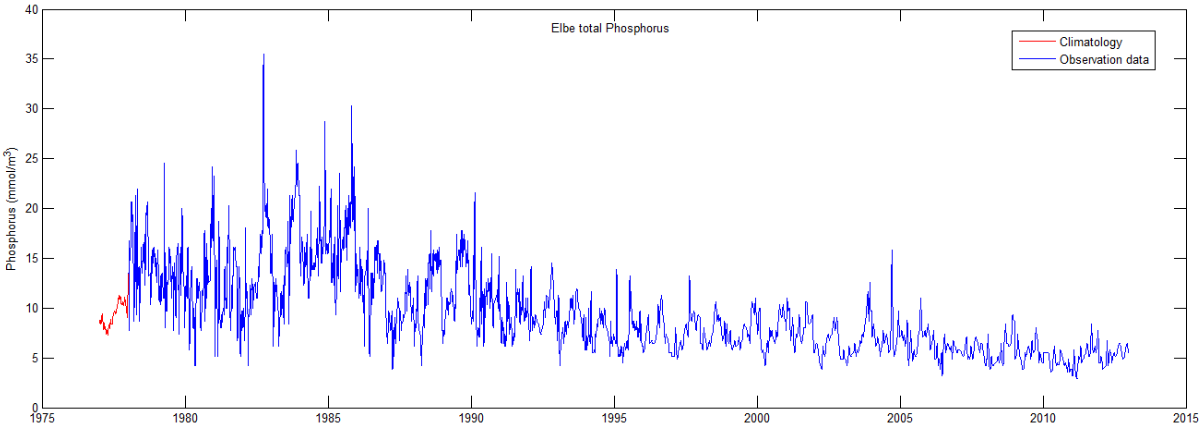

Figure 4.10 Time series of Elbe totP (blue) filled with climatology (red) (1977 – 2012).

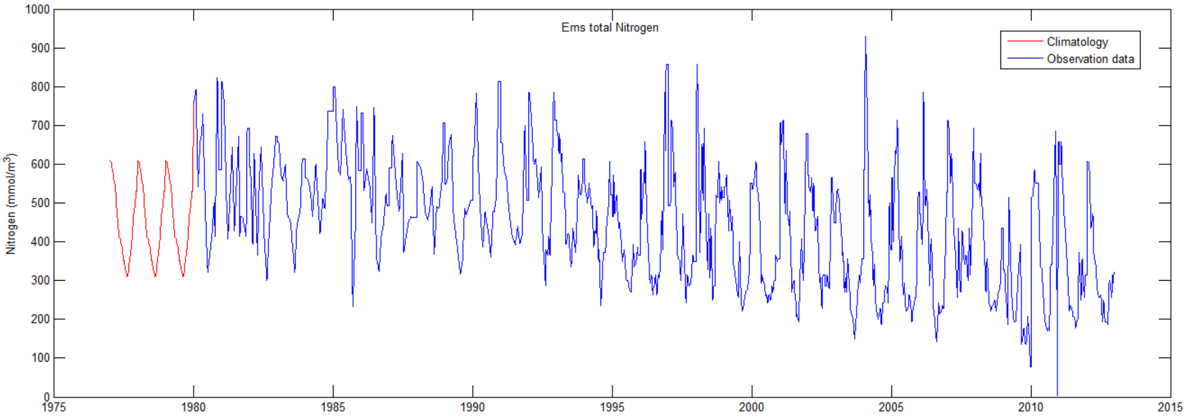

Figure 4.11 Time series of Ems totN (blue) filled with climatology (red) (1977 – 2012).

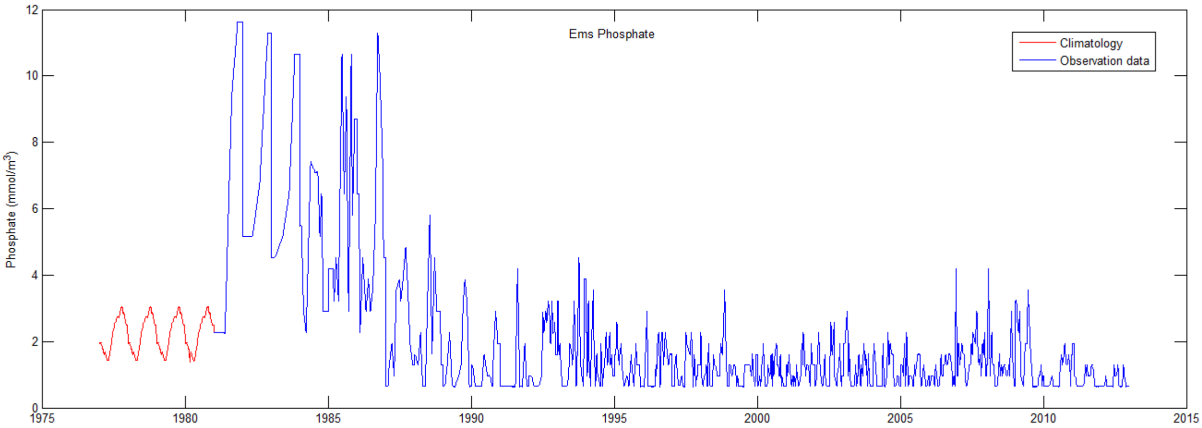

Figure 4.12 Time series of Ems PO4 (blue) filled with climatology (red) (1977 – 2012).

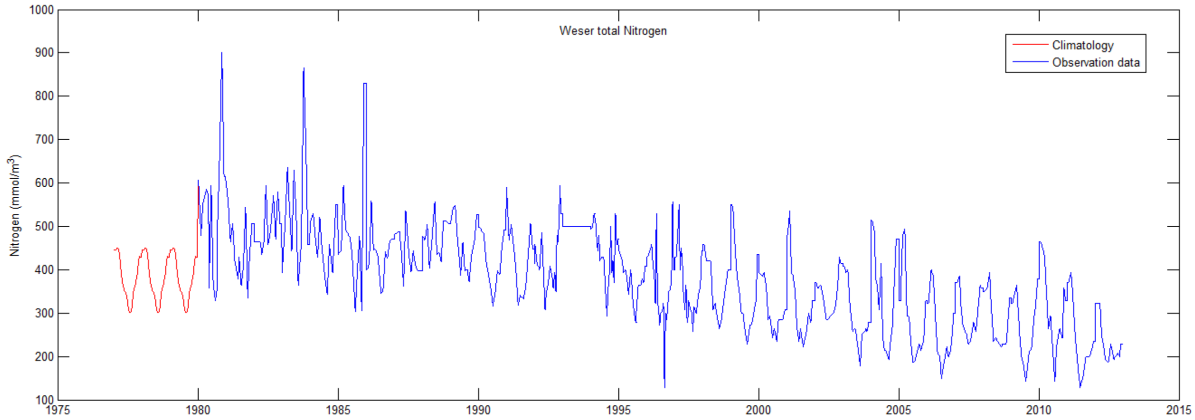

Figure 4.13 Time series of Weser totN (blue) filled with climatology (red) (1977 – 2012).

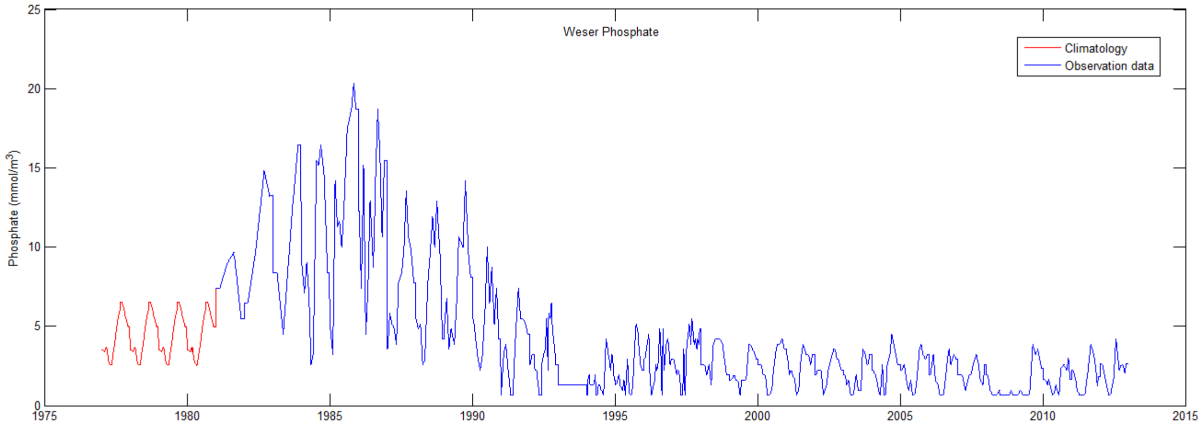

Figure 4.14 Time series of Weser PO4 (blue) filled with climatology (red) (1977 – 2012).

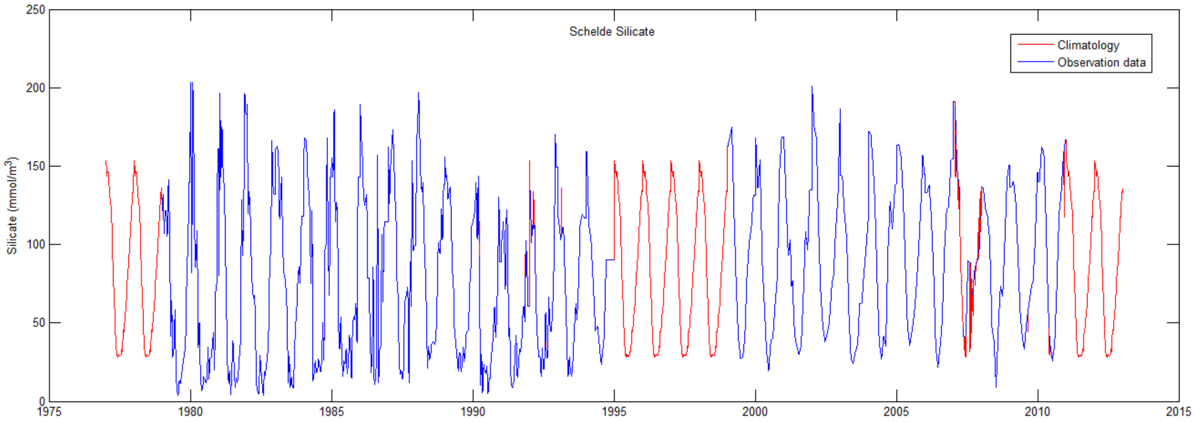

Figure 4.15 Time series of Schelde SiOH4 (blue) filled with climatology (red) (1977 – 2012).

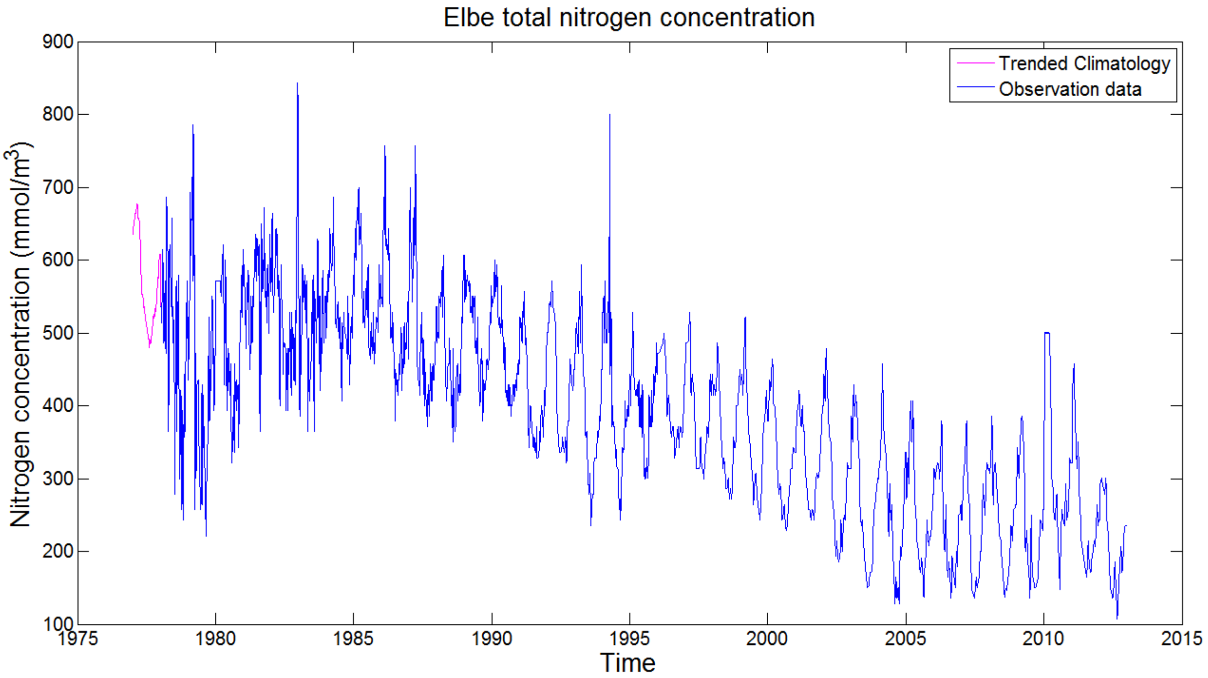

Figure 4.16 Time series of Elbe totN (blue) filled with trended climatology (red) (1977 – 2012).

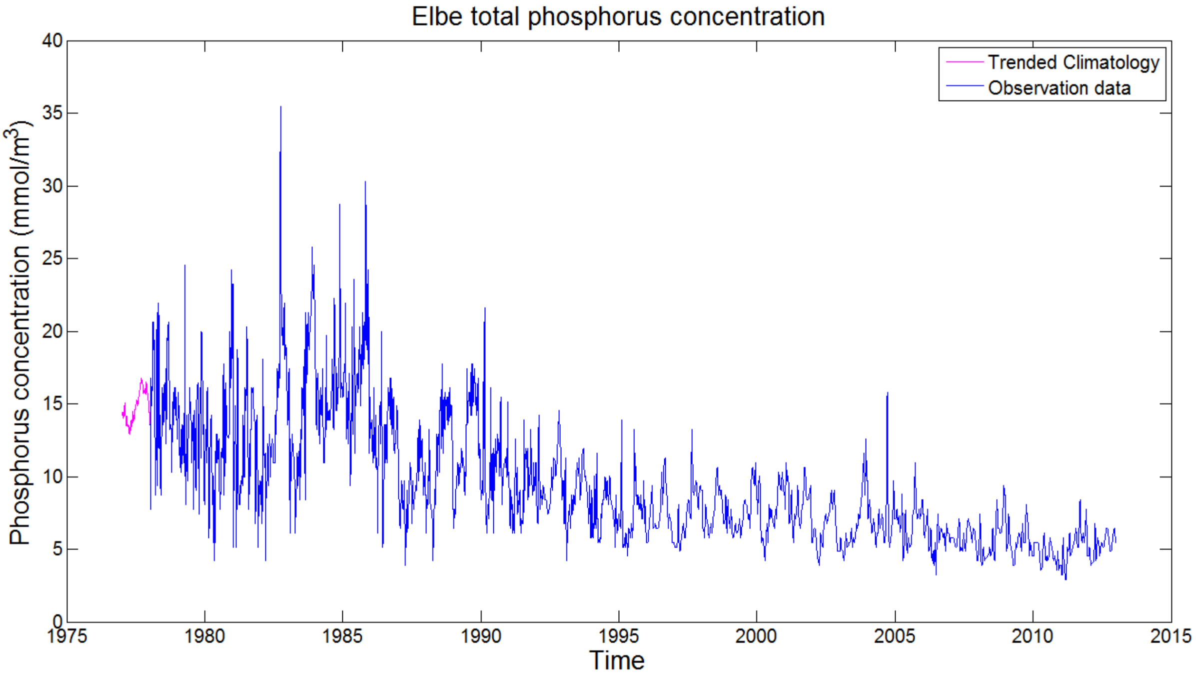

Figure 4.17 Time series of Elbe totN (blue) filled with trended climatology (red) (1977 – 2012).

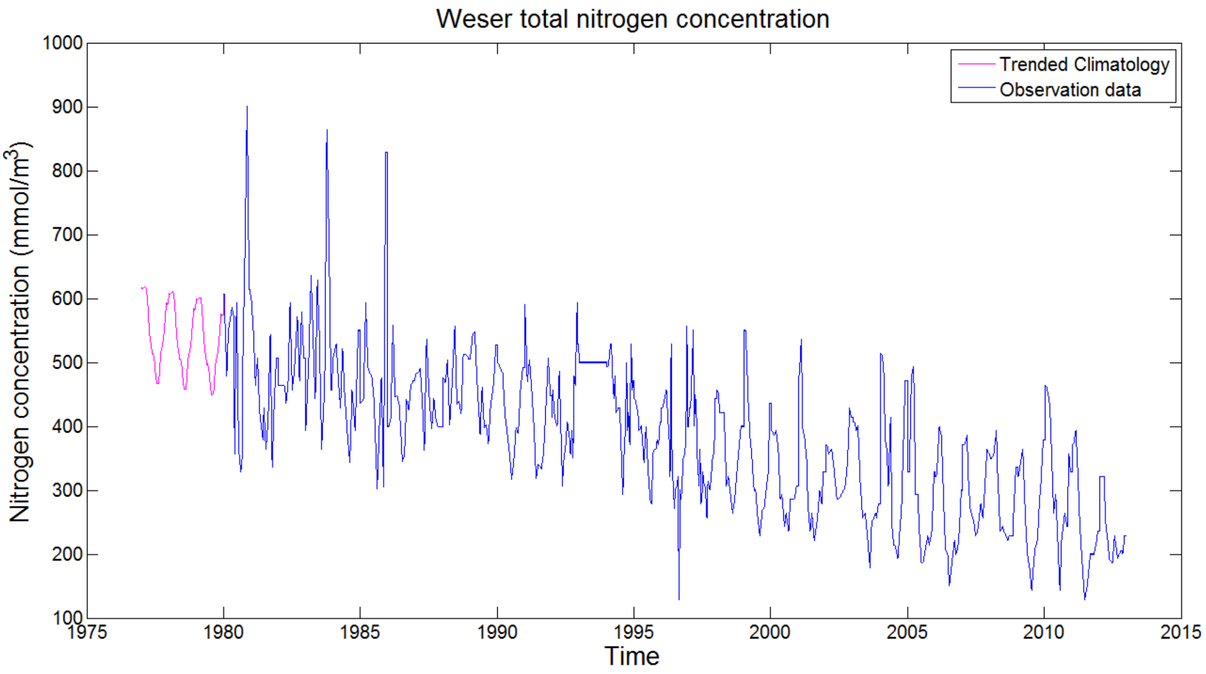

Figure 4.18 Time series of Weser totN (blue) filled with trended climatology (red) (1977 – 2012).

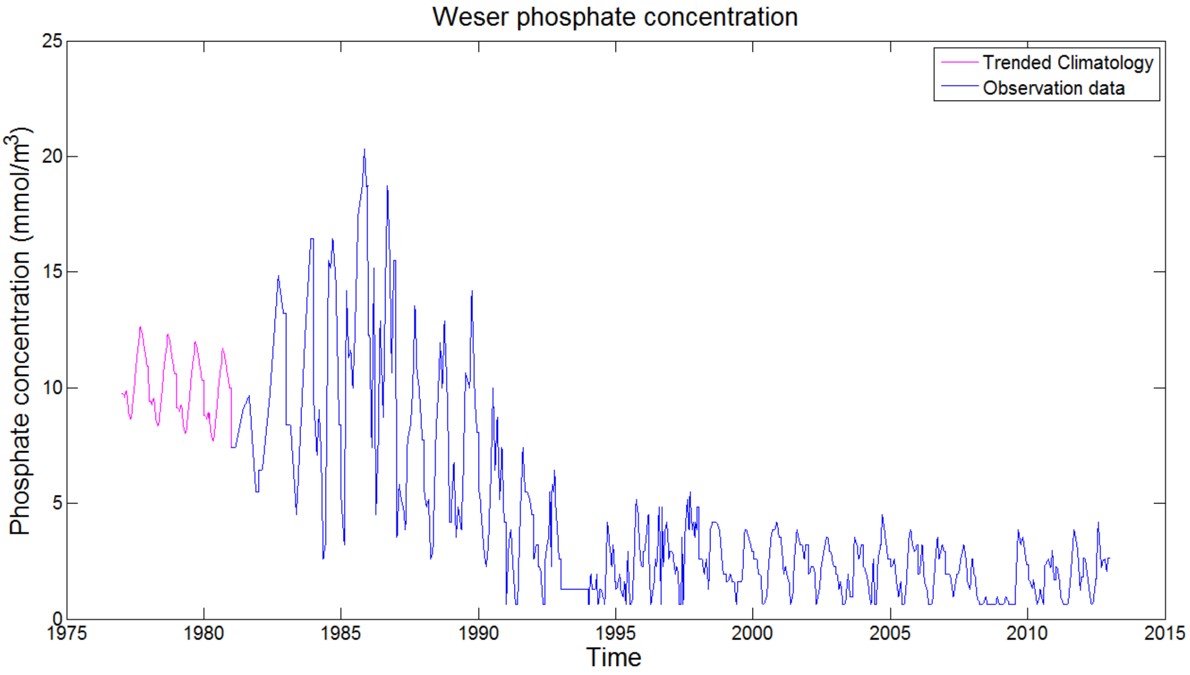

Figure 4.19 Time series of Weser PO_4 (blue) filled with trended climatology (red) (1977 – 2012).

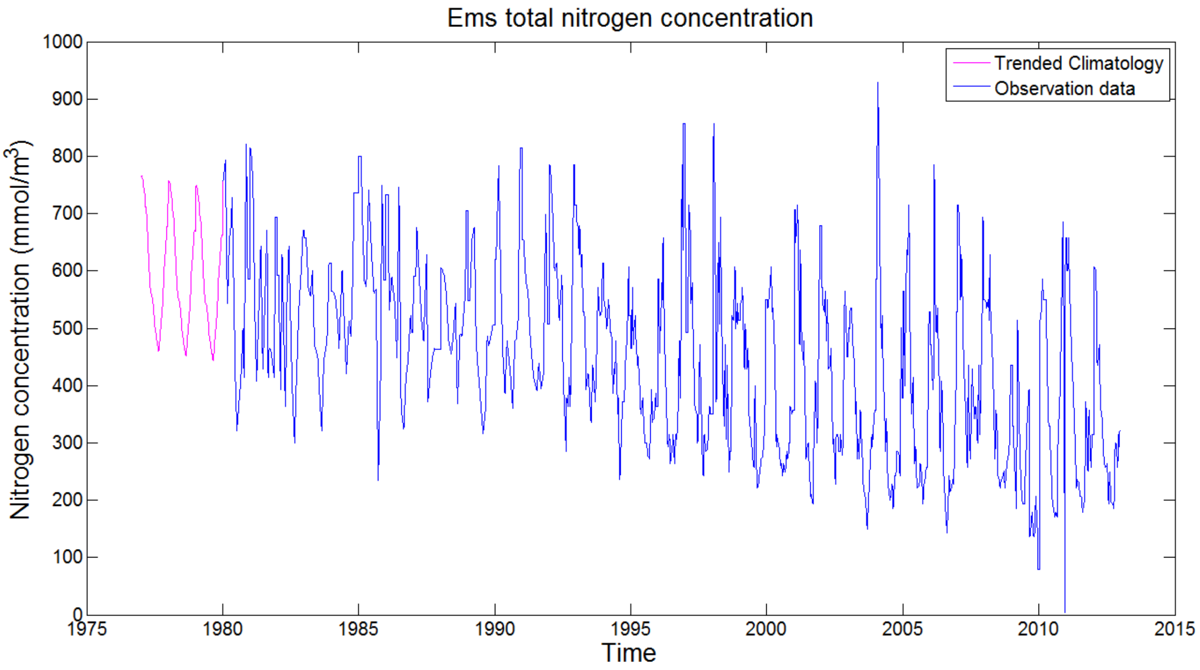

Figure 4.20 Time series of Ems totN (blue) filled with trended climatology (red) (1977 – 2012).

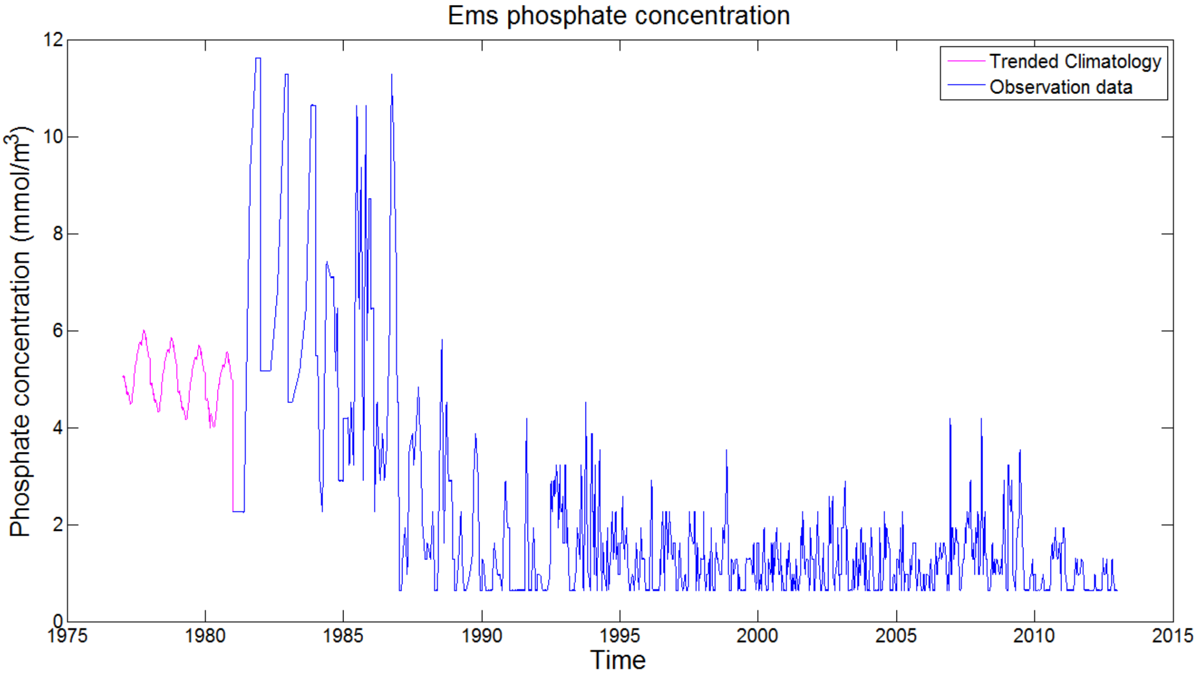

Figure 4.21 Time series of Ems PO_4 (blue) filled with trended climatology (red) (1977 – 2012).

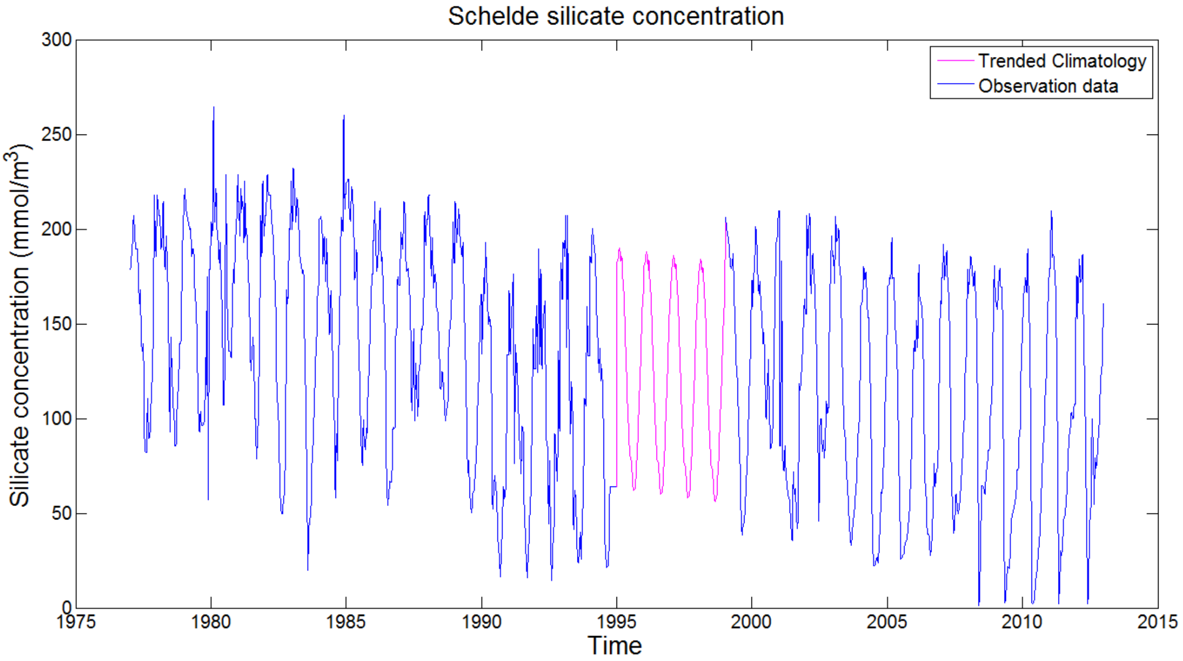

Figure 4.22 Time series of Schelde SiOH$_4$ (blue) filled with trended climatology (red) (1977 – 2012).

Figure 5.1 Measurement stations of German rivers (Ems, Weser and Elbe, left to right) and possible additions. The kilometer values reveal the distance of the measurement station, where data is provided, to the river mouth.

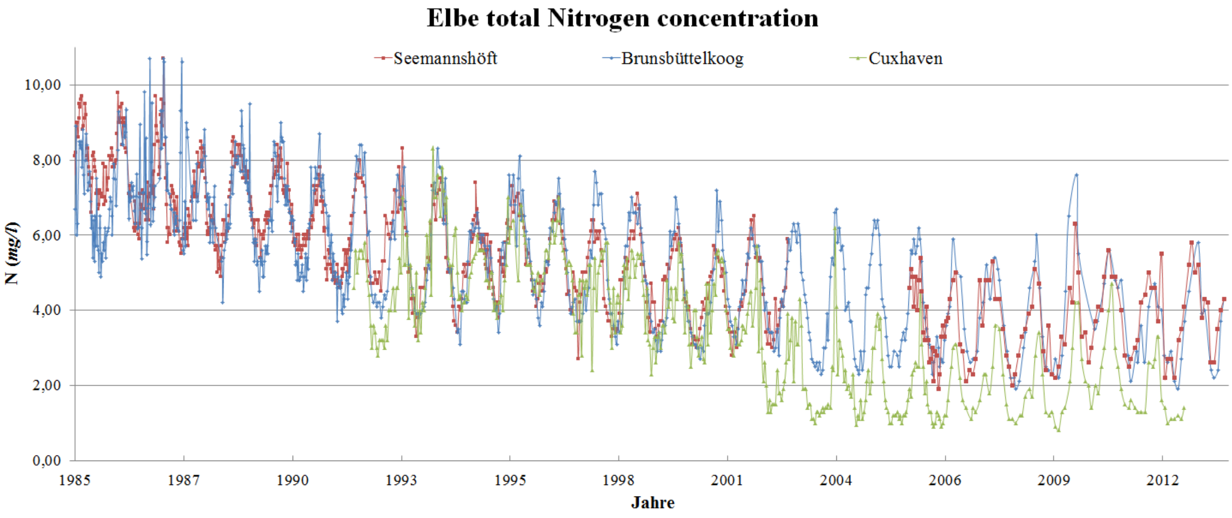

Figure 5.2 Elbe total nitrogen concentration at different measurement stations along the river (1980 – 2012).

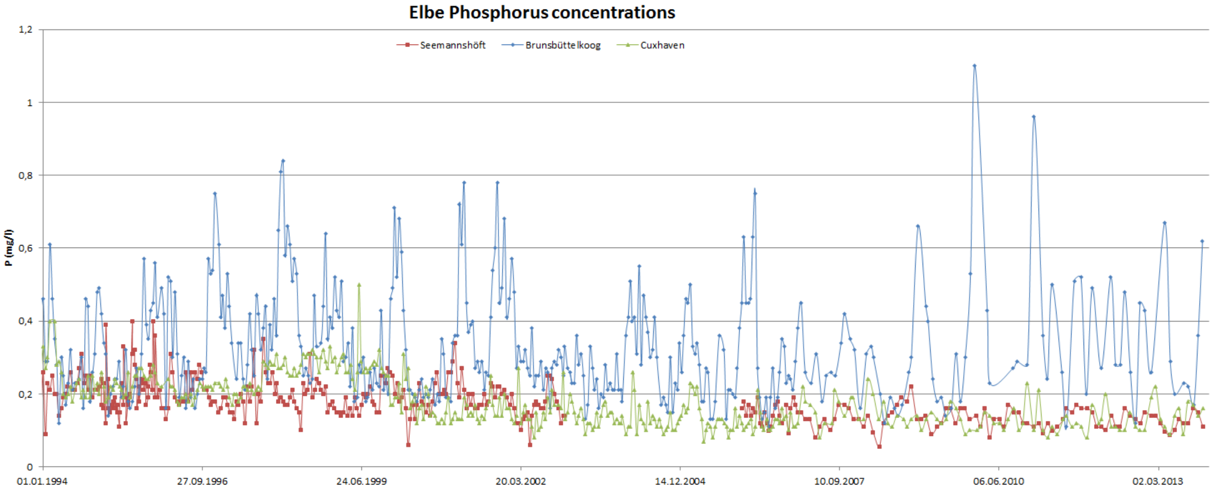

Figure 5.3 Elbe total phosphorus concentration at different measurement stations along the river (1980 – 2012).

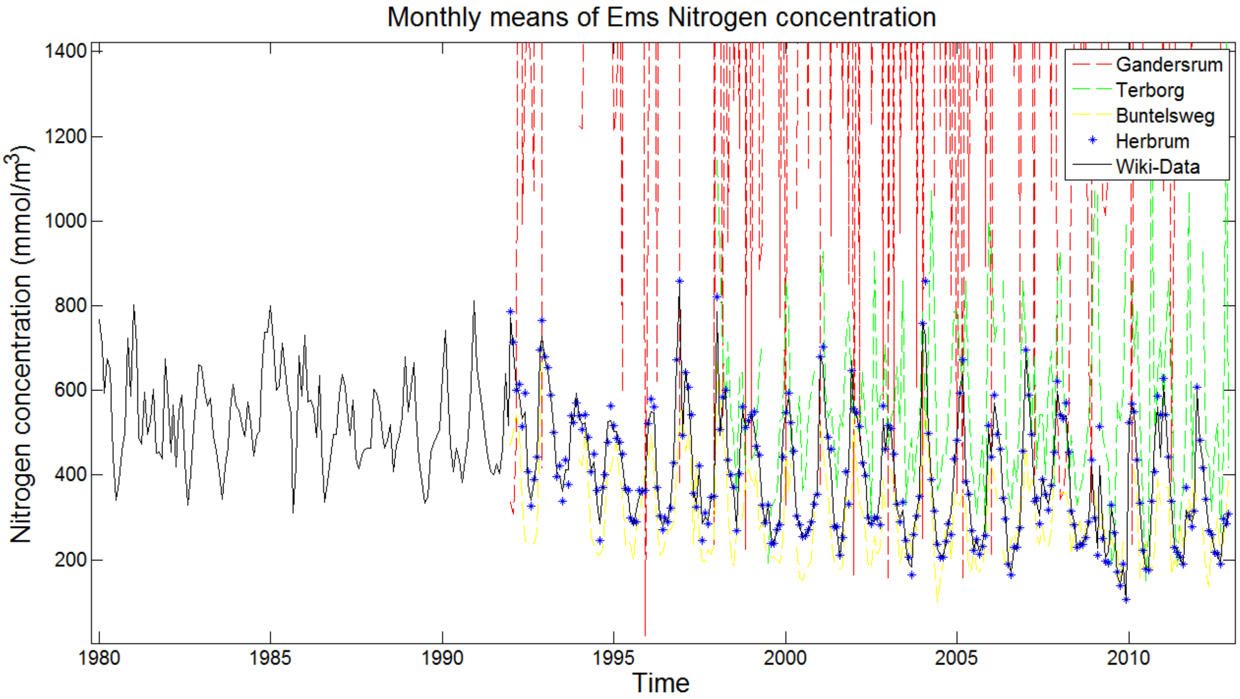

Figure 5.4 Monthly means of Ems total nitrogen concentration at different measurement stations along the river (1980 – 2012).

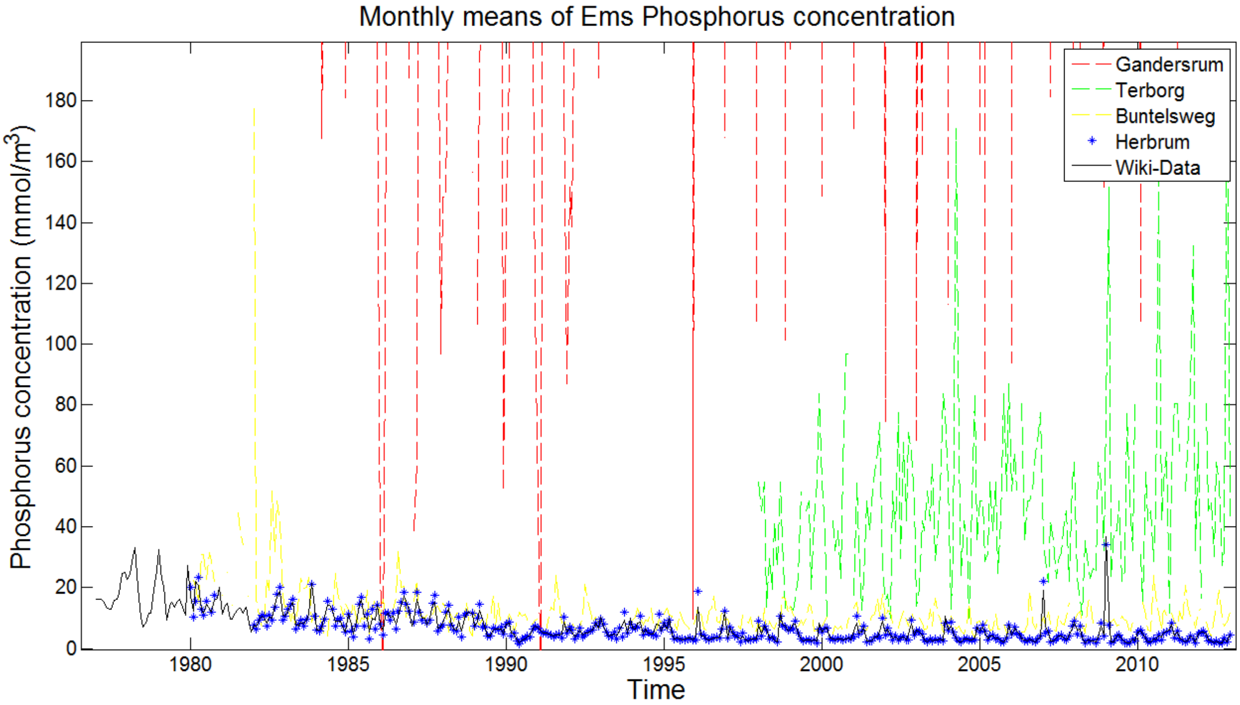

Figure 5.5 Monthly means of Ems total phosphorus concentration at different measurement stations along the river (1980 – 2012).

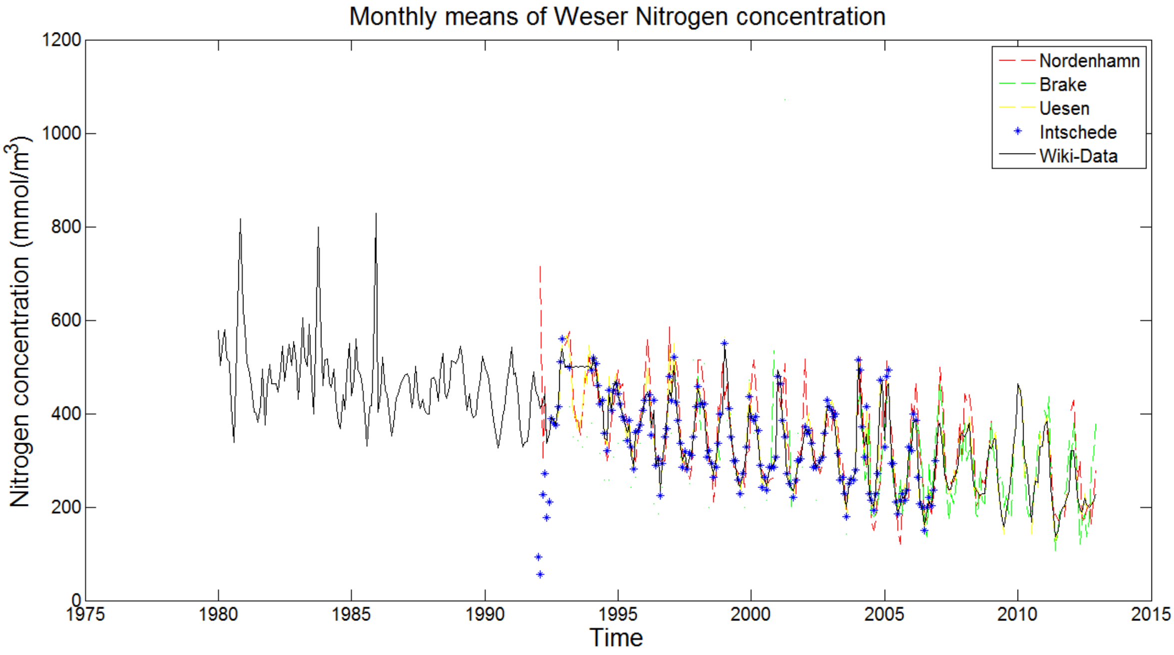

Figure 5.6 Monthly means of Weser total nitrogen concentration at different measurement stations along the river (1980 – 2012).

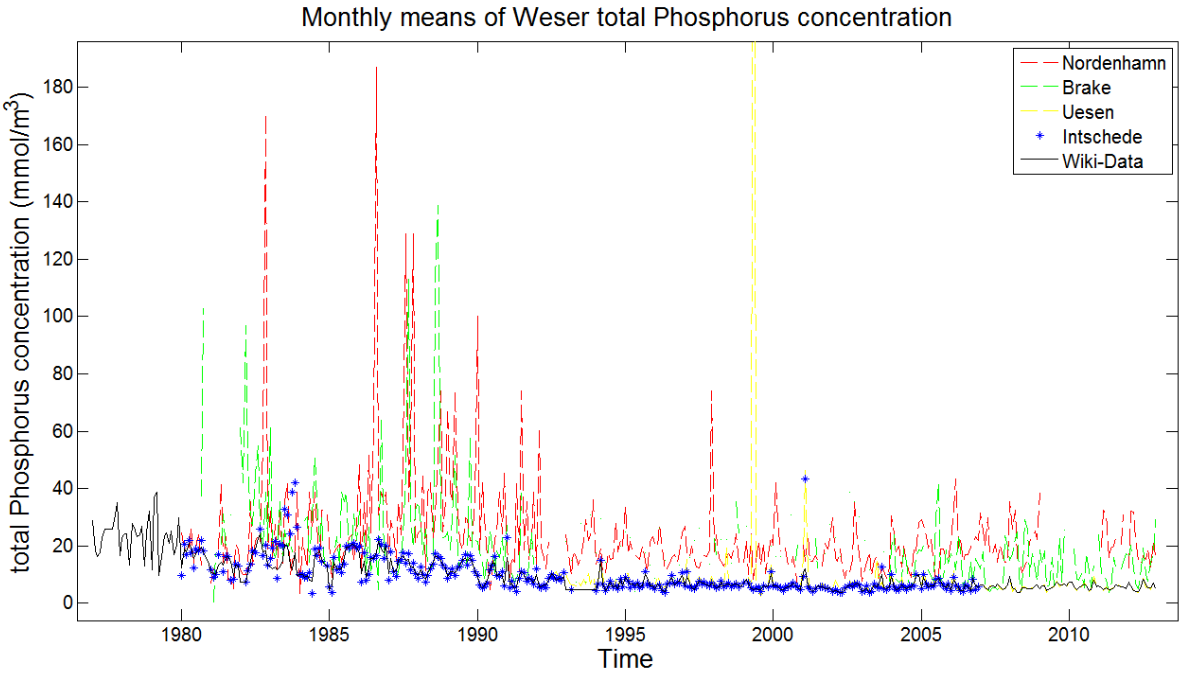

Figure 5.7 Monthly means of Weser total phosphorus concentration at different measurement stations along the river (1980 – 2012).

Table 8 River discharge in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River discharge (m^3/s)	Discharge (1)	Discharge (2)	Discharge (3)	Discharge (4)	Relative error (1)	Relative error (2)
Elbe	707	706,9	716,2	707	0,0001	-0,0131
Ems	84	83,9	83	83,9	0,0013	0,0111
Weser	332	331,8	327,3	331,8	0,0006	0,0134
Issel	577	575,1	567	575	0,0034	0,0104
Schelde	137	135	134,1	135	0,0147	0,0066
Nzkanaal	93	93,3	93,3	93,3	-0,0030	-0,0004
Nwaterway	1441	1439,7	1432,8	1439,6	0,0010	0,0047
Haringvliet	765	769,7	746,5	769,7	-0,0062	0,0302

Table 9 River concentrations for total nitrogen (totN) and nitrate (NO3) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River concentrations (mg/l)	totN (1)	totN (2)	totN(3)	totN(4)	NO3 (1)	NO3 (2)	NO3(3)	NO3(4)
Elbe	5,990	5,595	5,424	5,424	3,730	3,610	3,551	3,551
Ems	6,090	6,390	6,256	6,256	4,770	4,918	4,816	4,816
Weser	5,440	5,511	5,339	5,339	4,330	4,413	4,292	4,292
Issel	3,620	3,654	3,572	3,572	1,940	2,020	1,964	1,964
Schelde	6,560	6,579	6,373	6,373	4,260	4,273	4,189	4,189
Nzkanaal	4,550	4,232	4,178	4,178	2,560	2,469	2,443	2,443
Nwaterway	4,340	4,361	4,232	4,232	3,320	3,337	3,247	3,247
Haringvliet	4,220	4,163	4,058	4,058	3,300	3,263	3,188	3,188

Table 10 River concentrations for total phosphorus (totP) and PO4 in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River concentrations (mg/l)	totP (1)	totP (2)	totP(3)	totP(4)	PO4 (1)	PO4 (2)	PO4(3)	PO4(4)
Elbe	0,330	0,300	0,288	0,288	0,150	0,130	0,122405	0,122
Ems	0,210	0,245	0,234	0,234	0,050	0,074	0,069418	0,069
Weser	0,310	0,319	0,307	0,307	0,130	0,146	0,137977	0,138
Issel	0,190	0,196	0,184	0,184	0,050	0,055	0,050608	0,051
Schelde	0,670	0,676	0,640	0,640	0,320	0,319	0,302483	0,302
Nzkanaal	0,490	0,437	0,430	0,430	0,370	0,333	0,327832	0,328
Nwaterway	0,340	0,348	0,328	0,328	0,210	0,216	0,203185	0,203
Haringvliet	0,230	0,228	0,218	0,218	0,160	0,153	0,145934	0,146

Table 11 River concentrations for silicate (SIOH4) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River concentrations (mg/l)	SiOH4 (1)	SiOH4 (2)	SiOH(3)	SiOH(4)
Elbe	2,680	2,926	2,965398	2,965
Ems	9,550	9,720	9,719969	9,72
Weser	7,410	7,371	7,370907	7,371
Issel	0,860	0,996	1,03393	1,034
Schelde	3,630	3,615	3,540423	3,54
Nzkanaal	2,200	2,285	2,310564	2,311
Nwaterway	2,130	2,129	2,125583	2,125
Haringvliet	1,950	2,037	2,066081	2,066

Table 12 Relative errors of river concentrations in (1) Radach and Pätsch (2011) compared to raw data for 1977 – 2009 and (2) raw data to NetCDF data for 1977 – 2012.

Relative error of river concentration	totN (1)	totN (2)	NO3 (1)	NO3 (2)	totP (1)	totP (2)	PO4 (1)	PO4 (2)	SiOH4 (1)
Elbe	0,0660	-0,0001	0,0321	-0,0001	0,0899	0,0003	0,1352	-0,0033	-0,0919
Ems	-0,0492	0,0001	-0,0311	-0,0001	-0,1648	-0,0000	-0,4743	-0,0061	-0,0178
Weser	-0,0131	0,0000	-0,0191	0,0000	-0,0286	0,0002	-0,1248	0,0002	0,0053
Issel	-0,0093	-0,0001	-0,0412	-0,0001	-0,0307	-0,0001	-0,0931	0,0077	-0,1582
Schelde	-0,0029	0,0000	-0,0031	0,0000	-0,0086	-0,0005	0,0040	-0,0016	0,0042
Nzkanaal	0,0699	0,0000	0,0356	0,0000	0,1088	0,0009	0,0996	0,0005	-0,0388
Nwaterway	-0,0047	0,0001	-0,0051	0,0001	-0,0235	-0,0003	-0,0286	-0,0009	0,0003
Haringvliet	0,0134	0,0000	0,0112	0,0000	0,0068	-0,0004	0,0452	0,0005	-0,0446

Table 13 River load for total nitrogen (totN) and nitrate (NO3) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River loads (t/d)	totN (1)	totN (2)	totN(3)	totN(4)	NO3 (1)	NO3 (2)	NO3(3)	NO3(4)
Elbe	353,100	364,133	357,689	357,689	244,000	243,979	243,684	243,690
Ems	51,500	53,003	51,613	51,612	40,700	40,674	39,615	39,615
Weser	156,600	169,519	163,344	163,343	135,300	135,268	131,069	131,074
Issel	200,900	200,926	194,433	203,550	119,300	119,308	114,541	119,912
Schelde	83,800	83,760	80,828	80,815	52,700	52,677	51,468	51,460
Nzkanaal	34,600	34,620	34,182	34,556	19,900	19,882	19,683	19,898
Nwaterway	552,600	552,584	536,035	539,856	422,300	422,318	410,946	413,882
Haringvliet	310,400	310,370	296,285	309,247	242,900	242,880	232,478	242,644

Table 14 River concentrations for total phosphorus (totP) and phosphate (PO4) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River loads (t/d)	totP (1)	totP (2)	totP(3)	totP(4)	PO4 (1)	PO4 (2)	PO4(3)	PO4(4)
Elbe	18,300	17,172	16,607	16,607	7,100	7,134	6,801	6,800
Ems	2,000	1,957	1,869	1,869	0,700	0,537	0,504	0,504
Weser	8,700	8,744	8,379	8,379	4,400	3,815	3,590	3,590
Issel	10,600	10,606	9,939	10,405	3,300	3,314	3,067	3,210
Schelde	8,000	7,999	7,556	7,555	3,400	3,355	3,180	3,180
Nzkanaal	3,500	3,530	3,474	3,512	2,700	2,666	2,626	2,654
Nwaterway	43,500	43,533	41,020	41,313	26,300	26,312	24,738	24,915
Haringvliet	16,700	16,655	15,611	16,297	10,400	10,423	9,785	10,215

Table 15 River load silicate (SIOH4) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River loads (t/d)	SiOH4 (1)	SiOH4 (2)	SiOH(3)	SiOH(4)
Elbe	136,800	201,620	210,7145	210,673
Ems	24,900	73,247	73,24704	73,247
Weser	36,900	296,771	296,7712	296,771
Issel	63,200	62,997	64,18745	67,118
Schelde	48,900	48,636	47,62964	47,615
Nzkanaal	17,300	18,695	18,94146	19,183
Nwaterway	279,900	281,098	280,6672	282,614
Haringvliet	186,100	184,324	178,8755	184,705

Table 16 River load of dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) in (1) Radach and Pätsch (2011) compared to raw data (2) for 1977 – 2009 and raw data (3) to NetCDF data (4) for 1977 – 2012.

River loads (t/d)	DIC (1)	DIC (2)	DIC(3)	DIC(4)	DOC (1)	DOC (2)	DOC(3)	DOC(4)
Elbe	134,100	134,0712	135,8345	1629,973	27,900	27,8526	28,21892	338,618
Ems	19,800	19,8445	19,62408	235,477	7,300	7,298574	7,217505	86,606
Weser		NaN	NaN	NaN		NaN	NaN	NaN
Issel		NaN	NaN	NaN		NaN	NaN	NaN
Schelde	46,300	46,31228	46,00622	551,942	6,000	5,971262	5,931798	71,164
Nzkanaal		NaN	NaN	NaN		NaN	NaN	NaN
Nwaterway	333,100	333,0954	331,5286	4006,76	28,600	28,60789	28,47333	344,12
Haringvliet	178,100	178,1009	172,7213	2163,124	15,300	15,29619	14,83416	----------

Table 17a Relative error of river concentrations in (1) Radach and Pätsch (2011) compared to raw data for 1977 – 2009 and (2) raw data to NetCDF data for 1977 – 2012.

Relative error of river load	totN (1)	totN (2)	NO3 (1)	NO3 (2)	totP (1)	totP (2)	PO4 (1)	PO4 (2)
Elbe	-0,0312	0,0000	0,0001	0,0000	0,0616	-0,0340	-0,0048	-0,0001
Ems	-0,0292	-0,0000	0,0007	0,0000	0,0216	-0,0470	0,2327	-0,0002
Weser	-0,0825	-0,0000	0,0002	0,0000	-0,0051	0,0436	0,1329	-0,0001
Issel	-0,0001	0,0448	-0,0001	0,0448	-0,0005	-0,0193	-0,042	0,0447

Schelde	0,0005	-0,0002	0,0004	-0,0002	0,0001	-0,0588	0,0131	0,0000
Nzkanaal	-0,0006	0,0108	0,0009	0,0108	-0,0085	-0,0051	0,0127	0,0107
Nwaterway	0,0000	0,0071	-0,0001	0,0071	-0,0008	-0,0537	-0,0005	0,0071
Haringvliet	0,0001	0,0419	0,0001	0,0419	0,0027	-0,0220	-0,0022	0,0421

Table 17b Relative error of river concentrations in (1) Radach and Pätsch (2011) compared to raw data for 1977 – 2009 and (2) raw data to NetCDF data for 1977 – 2012.

Relative error of river load	SiOH4 (1)	SiOH4 (2)	DIC (1)	DIC(2)	DOC (1)	DOC(2)
Elbe	-0,0312	-0,0002	0,0001	0,9167	0,0017	0,9167
Ems	-0,0292	-0,0000	0,0007	0,9167	0,0002	0,9167
Weser	-0,0825	-0,0000	NaN	NaN	NaN	NaN
Issel	-0,0001	0,0437	NaN	NaN	NaN	NaN
Schelde	0,0005	-0,0003	0,0004	0,9166	0,0048	0,9166
Nzkanaal	-0,0006	0,0126	NaN	NaN	NaN	NaN
Nwaterway	0,0000	0,0069	-0,0001	0,9173	-0,0003	0,9173
Haringvliet	0,0001	0,0316	0,0001	0,9202	0,0002	NaN

7 Acknowledgment

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8 References

Fock, H. O. 2003. Changes in the seasonal cycles of inorganic nutrients in the coastal zone of the southeastern North Sea from 1960 to 1997: Effects of eutrophication and sensitivity to meteoclimatic factors. Marine Pollution Bulletin 46:1434–1449.

Leeuwen, Sonja van (personal communication, December 11, 2014). Centre for Environment, Fisheries and Aquaculture Science (CEFAS).

H.-J. Lenhart, D.K. Mills, H. Baretta-Bekker, S.M. van Leeuwen, J. van der Molen, J.W. Baretta, M. Blaas, X. Desmit, W. Kühn, H.J. Los, A. Menesguen, R. Neves, R. Proctor, P. Ruardij, M.D. Skogen, A. Vanhoutte-Brunier, M.T. Villars, S. Wakelin, Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea, Journal of Marine Systems, Vol. 81,pp 148-170, 2010, doi:10.1016/j.jmarsys.2009.12.014

Nixon, S. W., J. W. Ammerman, L. P. Atkinson, V. M. Berounsky, G. Billen, W. C. Boicourt, W. R. Boyton, T. M. Church, D.M. Ditoro, R. Elmgren, J. H. Garber, A. E. Giblin, R. A. Jahnke, N. J. P. Owens, M. E. Q. Pilson, and S. P. Seitzinger. (1996). The fate of nitrogen and phosphorus at the land-sea margin of the North Atlantic Ocean. Biogeochemistry 35:141–180.

OSPAR Convention for the Protection of the Marine Environment of the North – East Atlantic (2010). Summary of the 2009 OSPAR Eutrophication Modelling Workshop. Agenda Item 6 OSPAR 10/6/2 Add.1-E(L). Oslo and Paris Commissions.

Pätsch, J. and H.-J. Lenhart (2004). Daily loads of nutrients, total alkalinity, dissolved inorganic carbon and dissolved organic carbon of the European continental rivers for the years 1977 – 2002. Berichte aus dem Zentrum für Meeres- und Klimaforschung; Reihe B: Ozeanographie 48. Institut für Meereskunde, Hamburg, Germany.

Pätsch, J. and Lenhart, H.-J. (2011). Daily loads of nutrients, total alkalinity, dissolved inorganic carbon and dissolved organic carbon of the European continental rivers for the years 1977 – 2009. Technical report.

Pätsch, J. and Radach, G. (1997). Long-term simulation of the eutrophication of the North Sea: temporal and development of nutrients, chlorophyll and primary production in comparison to observations. Journal of Sea Research 38: 275–310.

Radach, G. (1992). Ecosystem functioning in the German Bight under continental nutrient inputs by rivers. Estuaries 15:477– 496.

Radach, G. and Pätsch, J. (2007). Variability of continental riverine freshwater and nutrient inputs into the North Sea for the years 1977-2000 and its consequences for the assessment of eutrophication. Estuaries and coasts, 30(1):66–81.

Seitzinger, S. P. and A. E. Giblin. (1996). Estimating denitrification in North Atlantic continental shelf sediments. Biochemistry 35: 235–260.

Wolf, Matthias (personal communication, December 11, 2014). FGG Elbe Datenportal