Master thesis

Temporal and spatial analysis of phosphate concentrations in surface waters in the 'Gelderse Vallei', the Netherlands

Simon van Dijk (3233782)
simonvandijk@live.nl
Ferguutplaats 50, 3813EN Amersfoort
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Master Sustainable Development – Global Change & Ecosystems
Cliënt: R. Gerritsen (Waterschap Vallei & Eem)
Supervisor Universiteit Utrecht: Prof. P.P. Schot
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Universiteit Utrecht

WATERSCHAP Vallei Eem

Abstract

High phosphate concentrations in surface waters are regarded as bad for the ecosystem integrity and leads to loss of aesthetic, ecological and economic value of the system. Therefore the European Union set targets for phosphate concentrations in the Water Framework Directive, which must be met by 2015 and ultimately by 2027. For the majority of the surface waters in the 'Gelderse Vallei' these targets are not met at the moment.

This study focuses on the temporal and spatial trends of phosphate concentrations in the 'Gelderse Vallei', with respect to the Water Framework Directive. An extensive dataset with phosphate concentrations is provided by water board 'Vallei & Eem' and is analyzed by using ordinary linear regressions and ANOVAs for the temporal trends. For the spatial analyses maps are made to provide quick visual output of spatial patterns.

For the temporal analyses no clear statistical trends are shown, however 70% of all ordinary linear regressions were negative, possibly indicating decreasing phosphate concentrations in the 'Gelderse Vallei'. From the spatial analyses phosphate concentrations tend to decrease in northern direction. The change in phosphate between time periods does not show a clear spatial pattern.

Considering the standards from the Water Framework Directive, respectively 60% and 50% of the studied surface waters will not meet the standards by 2015 and 2027. For water board 'Vallei & Eem' this means that measures should be taken to meet these standards. Furthermore, more attention should be given to the south of the 'Gelderse Vallei', for phosphate concentrations in the north are meeting the standards by 2015 and 2027 while in the south most surface waters do not meet the standards by 2015 and 2027.

Extending the dataset, extending the amount of analyzed surface waters and extending research on explanations of the trends can contribute to a better understanding of the trends and therefore to stronger conclusions and indicating possible measures.

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1. Introduction

Phosphorus (P) plays important roles in life. First of all it acts as a building block for the human and non-human body. One of the most important roles is that P is a key structural component of DNA and RNA. It also plays a role in ATP and phospholipids and P is a necessity for the formation and maintenance of bones and teeth in all vertebrates (Childers et al., 2011).

During the last 75 years the mobilization of phosphorus has quadrupled, mostly caused by human practices such as fertilizer application and consumption of P by industries, agriculture and animal wastes (Villalba et al., 2008). This altering of the global P cycle results in the accumulation of P in soils. This will increase the potential P runoff to aquatic ecosystems (Jeong et al., 2010; Vantarakis et al., 2008; Bennett et al., 2001). Eventually the runoff of P can result in eutrophication of surface waters, enhancing replication rates of bacteria and viruses and it can lead to excessive production of algae and plants in aquatic ecosystem**s** (Smith & Schindler, 2009; Bennett et al., 2001). Also loss of biodiversity and the presence of toxins are problems associated with eutrophication. Therefore, high concentrations of P in aquatic ecosystems are regarded as bad for the ecosystem integrity and leads to loss of aesthetic, ecological and economic value of the ecosystem (Bennett et al., 2001).

On an ecosystem level phosphorus also plays an important role, because it is present in all organisms, in the water and in the soil. Within an ecosystem a low amount of phosphorus act as a mechanism that decreases the competitive advantages of fast growing species, because they are limited by P (Wassen et al., 2005). Also species can avoid competition by exploiting different parts of the resource or by adaptation**s** that enable the use of normally unavailable nutrient sources (Verhoeven et al., 1996). In other words, there is room for different species to grow. In natural systems the main source of P comes from (chemical) weathering of rocks and is naturally low (Childers et al., 2011; Verhoeven et al., 1996). An increase in phosphorus can therefore cause a competitive advantage for some species, which will result in species loss through competitive exclusion (Wassen et al., 2005). High P concentrations in surface waters are therefore undesirable.

The P in surface waters is present in the form of phosphate (PO_4^{-3}). There are several sources of phosphate. First there is runoff from agricultural land, which can contribute significantly to high phosphate concentrations in surface waters (Adekunle et al., 2009). Extensive use of fertilizers, compost and manures can result in accumulation of P in the topsoil (Zhang et al., 2011; Jeong et al., 2010; Bennett et al., 2001). Because the majority of excess P (amount of P which lies above the concentration of P necessary for optimum plant growth (Jeong et al., 2010)) accumulates in the topsoil, the pool of transportable P, in the form of phosphate, increases and consequently the runoff of P from the field is increased (Jeong et al., 2010). Transport of dissolved phosphate and transport of particulate phosphate, caused by erosion of the soil, are the most important forms of runoff (Zhang et al., 2011).

Secondly, groundwater levels and large rain events play important roles in the runoff of phosphate. Starting with groundwater levels, when the groundwater levels are high, in winter season, the soil is wet and phosphate can be desorbed from particulate matter and will be dissolved in water (van Gerven et al., 2010). When the soil is dry, in summer season, the phosphate particles bond with particulate matter and are not available for runoff. The connection with large rain events lie in the fact that wet soils are quickly saturated, meaning that a rain event quickly saturates the soil and causes runoff. For dry soils it takes larger or longer rain showers before the soil is saturated with water and discharges to the brooks (Gerritsen, 2012). So in winter season a higher but steadier runoff of phosphate is expected, while in summer season low runoff of phosphate is expected but when an extensive rainfall event occurs high concentrations of phosphate are expected.

The major part of P runoff from agricultural fields occur due to large rain events (Sharply et al., 2008), see figure 1. In this figure it is shown that, with a delay, the phosphate concentration in surface waters increase when large rainfall events occur in agricultural areas. Due to the intensive use of fertilizer for agricultural purposes surface waters are affected by runoff of phosphate from agricultural fields (Young et al., 2010; Vantarakis et al., 2008).

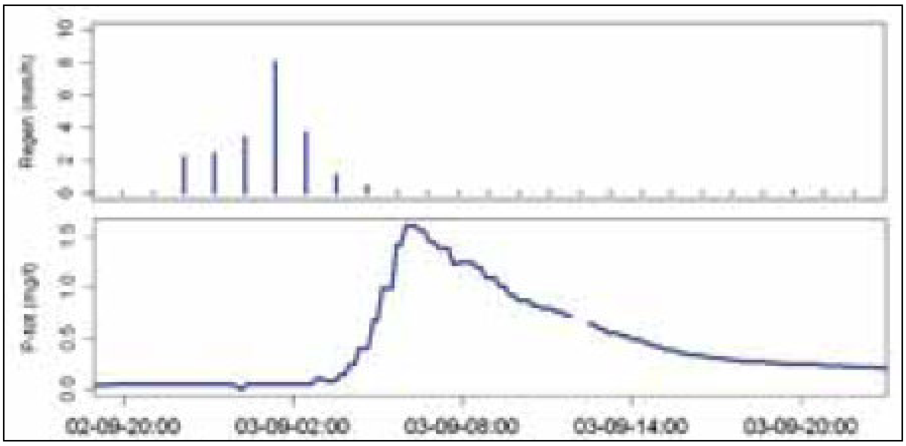

Figure 1: Typical relation between rainfall and phosphate concentrations in an agricultural area (Rozemeijer & van der Velde, 2008).

Another source of phosphate is phosphate from the sediment layer of the water bodies. The sediment layers contain phosphate adsorbed to iron and aluminium particles and phosphate bounded to organic matter. This phosphate is released in summer season when higher temperatures enhance the biochemical processes (van Gerven et al., 2011). The process can also be enhanced by an increase of the flow speed of a brook. When more water flows through at a given moment, sediment layers are under higher stress which can lead to more resuspension of phosphate-particles bonded to the sediment. These events can take place when a brook has to discharge a large rain event for example (Gerritsen, 2012).

In the Netherlands there has been a structural surplus of P (excessive P) in agricultural areas dating from at least 1980 (CBS, 2011). In other words, extensive use of fertilizers has taken place, which resulted in higher potential runoff of P from agricultural fields. In studies of Willems et al. (2005), Helming & Reinhard (2009) and van der Velde (2010) it is shown that for the majority of the surface waters of the Netherlands the concentrations of phosphate are above the target values set by the Water Framework Directive (WFD).

The WFD is an European Union directive considering achieving both a 'good ecological status' and a 'good chemical status' of all water bodies preferably by 2015 and ultimately by 2027 (Willems et al., 2005; van der Velde, 2010). The ecological goals are relating to preservation or enhancement of, for example, water plants. The goals for the chemical status are reducing or eliminating polluting substances and stopping water quality from deteriorating further (Helming & Reinhard, 2009).

Phosphate is one of the pollutants which is considered in the WFD and the WFD standard for phosphate in surface waters in the Netherlands is different for each WFD water type (Gerritsen, 2002; Willems et al., 2007). For the WFD standards the yearly summer average phosphate concentration is taken, because the ecology is more vulnerable in the summer (Faber et al., 2010).

Another standard in the Netherlands is the maximum acceptable risk or MTR (in Dutch: Maximaal Toelaatbaar Risico) introduced in the Vierde Nota Waterhuishouding, which was concerned with the water management objectives in the Netherlands between 1998 and 2006 and was replaced by the Nationaal Waterplan (MV&W, 2009). The MTR is based on ecotoxicological information and is based on the fact that 95% of the species survives if a certain value is breached. For phosphate the MTR is set to 0,15 mg/L (WVE, 2004).

Another Dutch law which is important when assessing phosphate concentrations is the 'Meststoffenwet'. As already mentioned a relation exists between fertilizer use and phosphate concentrations in surface waters. The 'Meststoffenwet' was introduced in 1986 and it states that fertilizer practices are limited to certain amounts of phosphate and nitrogen (Minister van LNV, 1986). In 2010 the maximum input of phosphate by fertilizers was set to 80 kg/ha. In 2011, 2012 and 2013 this will be respectively 75, 70 and 65 kg/ha (Minister van LNV, 1986). Because these norms are adjusted every year, variations in phosphate concentrations over time are expected.

For Water board Vallei & Eem (WVE), who's management area is located in the centre of the Netherlands (see figure 2), the standards from the WFD are also exceeded multiple times in the past (WVE, 1997; Gerritsen, 2002) and are probably still exceeded. Historically this area is associated with intensive agricultural practices and has high concentrations of phosphate in the aquatic systems. This together with expected variations in phosphate concentrations due to the 'Meststoffenwet' makes it important for WVE to monitor the phosphate concentrations and to interpret this data to increase knowledge in the current situation of their management area considering phosphate with respect to the WFD standards.

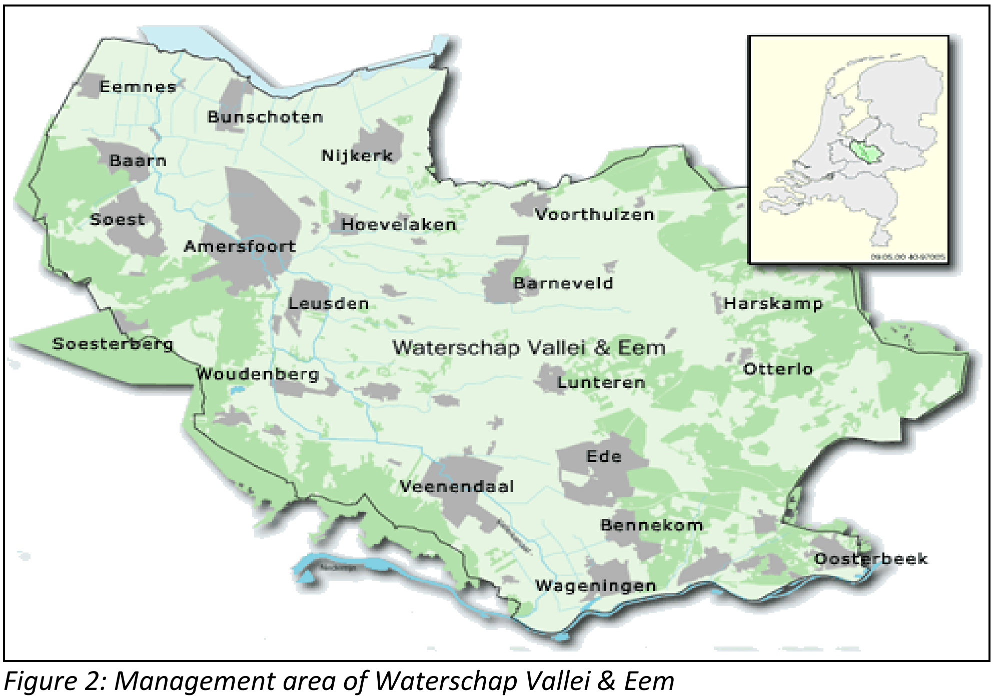

Figure 2: Management area of Waterschap Vallei & Eem

2. Problem description & Research questions

Because most brooks located in the WVE management area exceed the phosphate concentration standards, stated in the Water Framework Directive, it is necessary for WVE to evaluate the trends of phosphate in aquatic systems on a temporal scale and on a spatial scale. With trend analyses it can be determined whether the standards will be met in 2015 or 2027, or whether extra measures are needed. Because interest lies in the effect of agriculture and fertilizer use on phosphate concentrations, the 'Gelderse Vallei' was chosen as the research area for this study. In this area intensive agriculture is present and the phosphate concentrations are (almost) not influenced by point sources of phosphate. In 1995 the last point sources of phosphate (sewage treatments for example) were disconnected from the brooks in the 'Gelderse Vallei'. The year 2011 is also excluded for the trend analyses, because there is no year round data available. The trend analyses are therefore limited to the period 1995-2010.

This research has three aims. The first aim of this research is to gain knowledge in the occurring variations of phosphate concentrations in time and space. This knowledge may be of use when determining causes of high concentrations/low concentrations of phosphate and to analyze which areas need extra attention because of high phosphate concentrations. The second aim of this research is assessing whether the phosphate concentrations in the 'Gelderse Vallei' meet the WFD standards and the MTR standard. This information can be used to determine 'hotspots', spots where additional measures should be taken to live up to the WFD standards. The third aim is to determine possible explanations of the temporal and spatial trends. These explanations could be used to determine measures to decrease phosphate concentrations in the 'Gelderse Vallei'.

Resulting from the problem definition and research aims the following central research question is formulated:

How do phosphate concentrations in surface waters develop in time (from 1995-2010) and space within the 'Gelderse Vallei' and how may this affect meeting the WFD standards in 2015?

The sub-research questions drawn from the problem description and the main research question are:

1. How did the phosphate concentration in surface waters change over the period 1995-2010?
2. What are the implications of the observed trends for meeting the WFD requirements in 2015 (and 2027)?
3. How do the phosphate concentrations differ on a spatial scale?
4. What are the possible explanations for the spatial and temporal trends observed?

3. Methodology

In this section the data collection, the selection of brooks, the methods of the temporal and spatial analyses are presented.

3.1 Data collection

To be able to assess the development of phosphate concentrations in time and space WVE provided an extensive database with measurements of Total-Phosphate (Total-P) and orthophosphate (Ortho-P) for multiple locations from multiple years.

Total-Phosphate is the total amount of phosphate in a water sample. It encompasses all the forms of phosphate. These are orthophosphates, organic phosphate and condensed phosphate. Organic phosphate, primarily formed by biological processes, is a form of phosphate which is bound to plant or animal tissue, or which exists as loose fragments in solution (Murphy, 2007). Condensed phosphate consist of salt containing condensed phosphoric anions, which is a phosphoric anion including one or several P-O-P bonds (Averbuch-Pouchot & Durif, 1996). Orthophosphate is a group of specific compounds of phosphate which are available for plant uptake (Guan et al., 2005). It is derived from orthophosphoric acid (H_3PO_4). When this molecule losses all its H^+-atoms orthophosphate (PO_4^{3-}) is formed.

The dataset consist of 21988 measurements of Total-P and 21290 measurements of Ortho-P. These measurements were taken between January 1970 and August 2011. The dataset contains data for 724 measurement points in the WVE management area from which the data of 10 measurement points located in 10 different brooks is analyzed (see paragraph 3.2).

Besides the dataset, knowledge of the area under consideration is needed. This knowledge includes different land use practices, possible sources of point-pollution etcetera. This knowledge is in particular valuable to answer research question 4, concerning possible explanations of spatial and temporal variations of phosphate concentrations. This data is also provided by experts from WVE and is extracted from 'Balansstudies' made by employees of WVE. When more/extra specific knowledge about the area is needed, appointments have been made with experts from WVE to overcome gaps in knowledge.

Scientific articles are also regularly used to introduce new topics and to validate the results. Validating the research is done by comparing results and conclusions from other studies on the same subject. In the fourth research question scientific articles are used to back-up/add to the quality of the answers. The scientific articles are obtained by using the internet databases Omega, the database of the Utrecht University library, and Scopus. When assessing legislation the information is usually obtained from governmental websites.

3.2 Selection of brooks

In this research 10 surface waters are analyzed. These 10 measurement points are selected, together with an expert from WVE, because these surface waters are not influenced by point sources of phosphate, are located mostly in agricultural areas and are located in the 'Gelderse vallei'. In table 1 the 10 measurement points together with the name of the brook, the WFD water type and the number of measurements for Total-P and Ortho-P are shown (see figure 3 for map):

Measurement Point	Brook	WFD water type	# measurements Total-P	# measurements Ortho-P
28003	1. Lunterse beek	R5	193	194
28702	1a. Nederwoudsebeek	R4	89	89
28101	1b. Fliertsebeek	R4	42	42
29733	2. Nattegatsloot	R4	80	80
29853	3. Moorsterbeek	R4	167	167
28651	4. Modderbeek	R4	81	82
29738	5. Barneveldse beek	R6	196	199
27052	5a. Esvelderbeek	R5	187	190
27003	5b. Hoevenlakense beek	R5	63	63
26003	6. Brede beek	R4	119	121

Table 1: The ten selected measurement points with the name of the brooks, the WFD water type and the amount of data available for Total-P and Ortho-P.

The Nederwoudsebeek and the Fliertsebeek are branches of the Lunterse beek and the Esvelderbeek and the Hoevenlakense beek are branches of the Barneveldse beek and therefore ranked with a and b.

In the third column of table 1 the WFD water type for each brooks are presented. This information is needed when determining the phosphate standard for the brooks. The Modderbeek and Moorsterbeek are water type R4 (WVE, 2008). The Brede beek, Nederwoudsebeek, Fliertsebeek and the Nattegatsloot are also water type R4 (Gerritsen, 2012). The Lunterse beek, Esvelderbeek and the Hoevenlakense beek are water type R5 (WVE, 2008). The Barneveldse beek is classified as R6 (WVE, 2008). Water types R4, R5 and R6 are all slow flowing brooks on a sandy soil (in case of R6 it could also be a clay soil) (Stowa, 2007). The difference between the water types is based on the location of a stream and the location within a bigger system of streams. Type R4 is a slow flowing stream on sand and is located upstream. Type R5 is a slow flowing stream on sand and is located downstream or in the middle. And R6 is a small river on a sandy or clay soil (PIH, 2007).

For water type R4 different standards are used than for water types R5 and R6. The phosphate standards for water types R5 and R6 are the same. The WFD standards for water type R4 and for R5 and R6 are presented in table 2 (values are in mg P/L) (Stowa, 2007):

Water type	Status: High	Good	Moderate	Poor	Bad
R4	<0,05	<0,12	0,12-0,24	0,24-0,36	>0,36
R5 & R6	<0,06	<0,14	0,14-0,19	0,19-0,42	>0,42

Table 2: The Total-P standards formulated by the WFD for water types R4, R5 and R6 in mg P/L.

As stated in the introduction the objective of the WFD is achieving both a ‘good ecological status’ and a ‘good chemical status’ of all water bodies preferably by 2015 and ultimately by 2027. This means that for R4 brooks a summer average phosphate concentration of less than 0,12 mg/L must be realized in 2015 or 2027 and for R5 and R6 brooks a summer average concentration of less than 0,14 mg/L must be achieved.

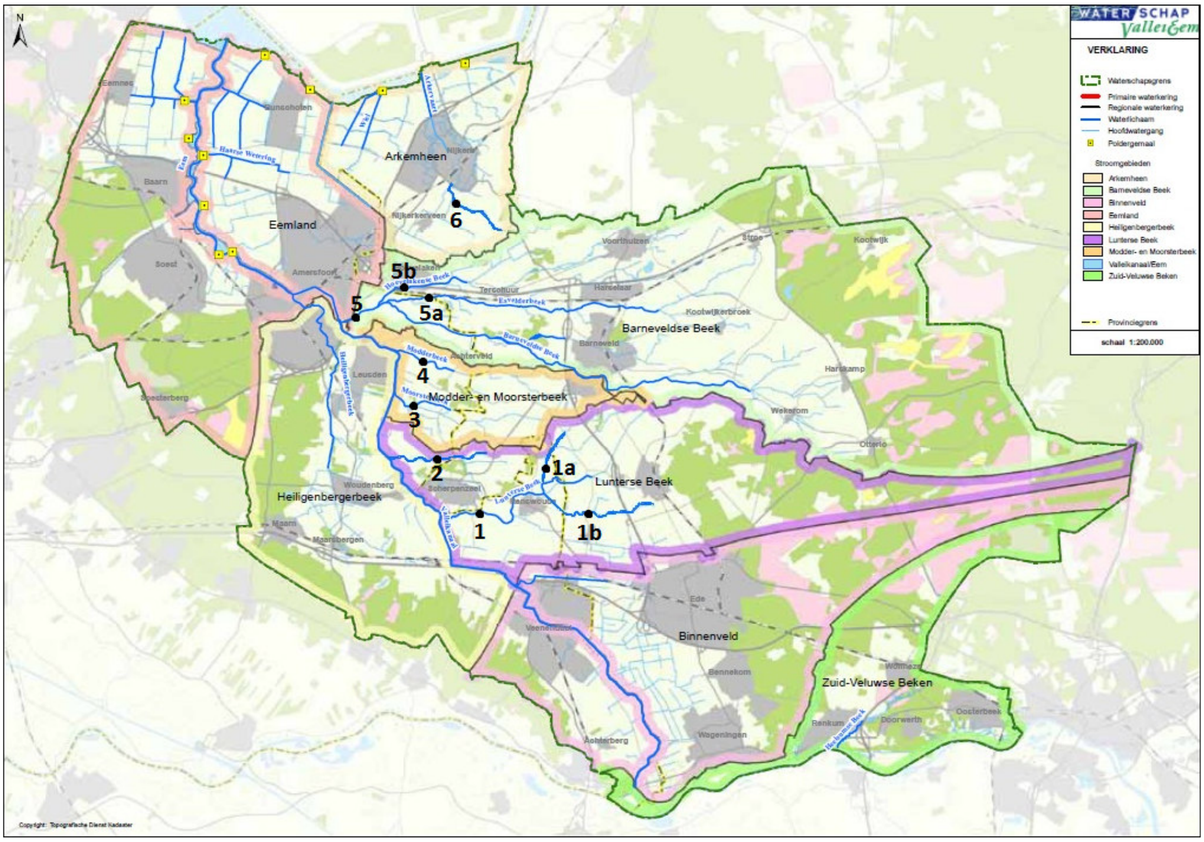

Figure 3: Locations of the 10 selected brooks in within the management area of WVE.

3.3 Temporal analysis

The first two research questions, considering temporal trends, are answered by means of trend analyses. In this paragraph the data preparation, the methods for answering the and second research question are handled.

Data preparation

To be able to statistically analyze the data for the 10 brooks the dataset is adjusted in the following way. First the 10 selected brooks are sorted and their values for Total-P and Ortho-P are separated. Secondly the data before 1995 and after 2010 is deleted, for this data will not be used in the analyses as already mentioned in chapter 2. Thirdly values stated as, for example, < 0,01 or < 0,04 are halved. This is done to be able to use them in the analysis, for the statistical tests will not include values with ‘smaller than’ signs. They are halved, in consultation with an expert from WVE, for then they resemble the reality in a better way.

Statistical analysis

After adjusting the dataset five statistical analyses are performed. These steps are listed below. The statistical analyses are done with the statistical tool pack of the program Excel. In step 1, 2 and 3 the same statistical tests are used, namely ordinary linear regressions (OLR) and ANOVAs (see below for explanation). The difference between the steps lies in the method of data analysis, in step 1 for each brook all data is used, in step 2 yearly average concentrations are used and in step 3 meteorological seasons (summer and winter season) are tested. These steps are done to assess the data from different angles and to compare the steps, which could lead to valuable information or extra information. In step 4 the Seasonal Kendall Tau test is done to compare it with step 1, to see whether seasonal influences and missing values have a significant influence on the results of step 1 and if the results of step 1, 2 and 3 are valuable or not.

So for step 1, 2 and 3 OLRs and ANOVAs are done for each brook for both Total-P and Ortho-P. The OLRs will result in a regression formula in the form of y=ax+b, where a is the x-variable. For all regressions x is in days since 1900, except for the yearly averages where x is time in years. The variable b is the intercept with the vertical axis when x=0. The tests will also results in R^2-values. R^2-values say something about the strength of the relation between phosphate concentrations and time. The higher the R^2-values the stronger the correlation is. The statistical significance of the regressions is tested by using ANOVAs. ANOVAs result in P-values. P-values say something about the significance of the regression formula and R^2-values. If the P-values of a and b from the regression formula are <0,05 the regression is significant at a 95% confidence interval. If the P-values are >0,05 there is no statistical significant trend between phosphate concentrations and time.

For step 1, 2 and 3 also figures are made in Excel to visually support the outcomes of the analyses. To limit the amount of figures three groups are made on the basis of the coefficient of the Total-P OLRs from step 1. For each group one brook is selected and for this brook 8 graphs are made, namely one graph for each column of table 3. For the Total-P OLR from step 1 also the middle 80% of all values are plotted. The top 10% of the highest values and also the lowest 10% of the values are deleted. By doing this the influence of outliers can be determined. So there will be 4 graphs of Total-P (all data, yearly averages, winter season and summer season). The same 4 graphs are made for Ortho-P. In addition to these 8 graphs, for each selected brook one extra graph is made with the share of Ortho-P in Total-P concentrations. These graph is used to check whether the data is correct (Ortho-P cannot be bigger than Total-P) and to see how Total-P and Ortho-P are connected with each other. In annex 2 the graphs with Total-P concentrations for all data and 80% of the data are presented for each brook.

All the steps are listed below:

- Step 1: All data
    - The statistical analysis is done for all Total-P values and for all Ortho-P values belonging to one of the ten brooks.
- Step 2: Yearly averages
    - In this step the data is adjusted so that yearly average concentrations are tested. This step is done to rule out monthly variations in phosphate concentrations, therefore making the trend clearer and making it easier to compare different years with each other.
- Step 3: Meteorological seasons
    - In this step the difference between meteorological winter and summer concentrations is analyzed, to be sure that the concentrations of phosphate are not dependent on the different groundwater levels and increased runoff of phosphate

due to precipitation and/or point sources of phosphate. The meteorological summer ranges from April up to and including September and the winter ranges from October up to and including March. Meteorological seasons are used to see the differences in phosphate concentrations between wet and dry periods, which could be valuable for answering research question 4.

- Step 4: Seasonal Kendall Tau test
  - In this step the dataset is analyzed by using the Seasonal Kendall Tau test, which determines the strength of the relation between two variables by means of a correlation coefficient. The dataset has to contain at least 5 years of data to be able to determine a trend. This test is particularly useful when there are seasonal influences present in the data set. Another advantage of the Seasonal Kendall Tau test is that it is not influenced by outliers and missing values (Roubos, 2009). Seasonal Kendall tau test tests on each season separately and then combining the results. So January is only compared with January and February only for February and so on (Helsel & Hirsch, 2002). The analysis is done by using an Excel-file provided by WVE.
- Step 5: Comparison of means
  - In this step a table is made, including each brook, where the mean value of 2005-2010 minus the mean value from 1995-2000 are represented. A negative value means that there is decrease in phosphate concentrations over the years and a positive value means that there has been an increase in phosphate concentrations. The higher the value the bigger the difference. These values can be used for answering research question 4. It also results in a quick overview of phosphate concentrations from two time periods and the difference between them.

To answer the second research question the regression formulas for yearly summer season Total-P concentrations are obtained from the dataset, which are needed because the WFD standards are considering yearly summer average concentrations. The obtained regression formulas can be extrapolated to 2015 to see if the phosphate values meet the required WFD standards. This is also done with extrapolating to 2027. It is also checked if the MTR is not exceeded. For this question only Total-P values are used, because the WFD is concerning only Total-P and does not set standards for Ortho-P.

3.4 Spatial analysis

To answer the third research question 4 maps are made and are analyzed from a spatial point of view. The first map contains the mean values of Total-P from the period 2005-2010 obtained in step 5 from the statistical analysis. The second map contains the mean values of Ortho-P from the period 2005-2010. For these figures a color scheme is made and for each brook the value with the color is presented in the maps. The mean values from 2005-2010 are chosen because they give a more accurate estimation of the concentrations on a spatial scale. The values are more accurate because seasonal influences in concentrations are of less importance when using averages over long time periods.

The third map contains the mean values of 2005-2010 minus the mean values for 1995-2000, calculated in step 5 of the temporal analyses. Those values are mapped on a spatial scale, to determine if there is a spatial trend in changing phosphate concentrations. For this map another color scheme is made, for the values lie in a different range of concentrations.

The fourth and last map contains the spatial information of research question 2. When a brook meets the WFD-standard by 2015 it scores a '+' and when a brook meets the WFD-standard by 2027 it scores a '(+)'. When a brook does not meet the WFD-standard by 2015 and 2027 it scores respectively a '-' or a '(-)'.

3.5 Possible explanations

The fourth research question focuses on explaining the results from the previous research questions. So in this section the possible explanations for temporal trends and for spatial trends are formulated. For the temporal trends this is done by looking at the processes that play a role in phosphate runoff to surface waters. Also dry and wet years and sudden changes in phosphate runoff are assessed by using the data from the previous research questions. The spatial trends are done by looking at the land use in the areas, which could explain the variations in phosphate concentrations. This paragraph could be of use for WVE to gain knowledge about causes of variations in phosphate concentrations and knowing these causes could create insight in possible measures to reduce phosphate concentrations.

4. Results

In this section the results are presented. This section starts with the results of the temporal analyses of the dataset. Then the results of the spatial analysis are presented. And last possible explanations for the temporal and spatial trends are given.

4.1 Temporal Analysis

In figure 4 all Total-P data from the 10 selected brooks are plotted. On the vertical axis the Total-P concentration in mg/L is given and on the horizontal axis the date is presented. From this figure it is shown that most data points lie between 0 and 0,5 mg/L (85%). A considerable amount of data points are found in the range 0,5-1 mg/L (10%). And 3% of the data points are located above 1 mg/L. For a quick statistical overview of the dataset which is used see the table in annex 1.

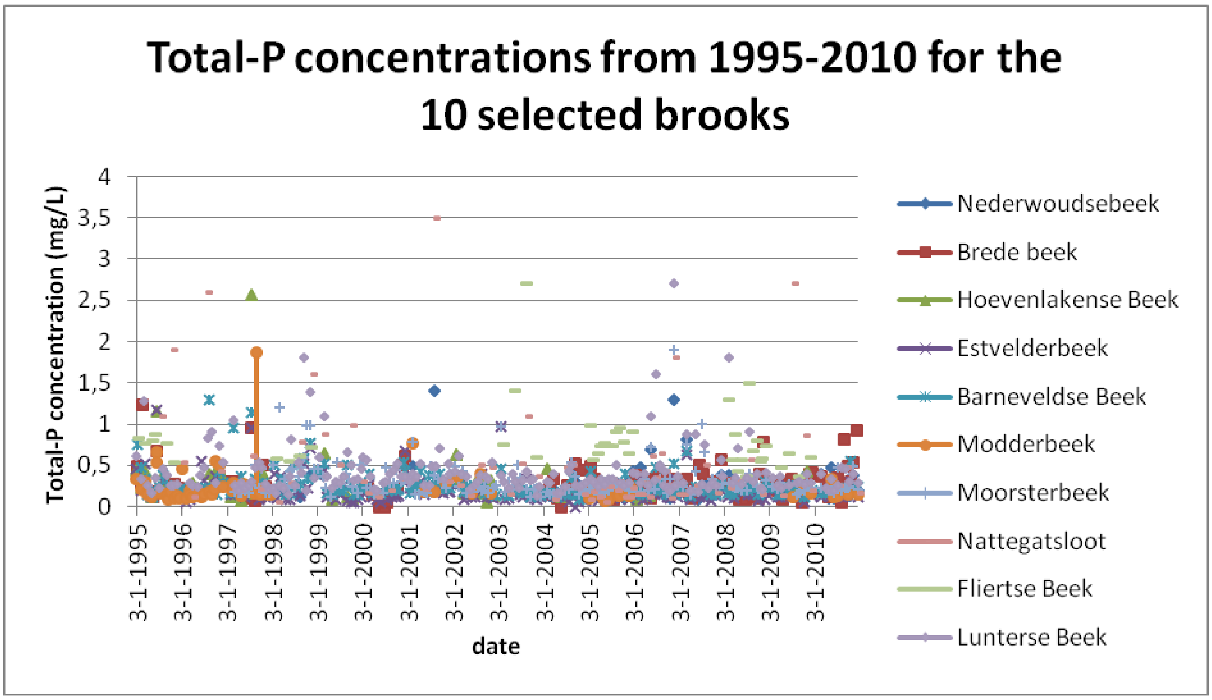

Figure 4: Total-P concentrations from 1995-2010 for the selected brooks.

OLRs and ANOVA (Step 1, 2 and 3)

In table 3 the ordinary linear regressions are shown for step 1 (All data) ,2 (Yearly averages) and 3 (meteorological seasons). Also the R^2-values for each regression are presented. The yellow columns represent the outcomes of step 1, the orange columns represent the outcomes of step 2 and the green columns represent the outcomes of step 3. The R^2-values marked with an asterisk (*) are statistically significant on a 95% confidence interval. If a regression formula has a negative coefficient this means that the phosphate concentrations will decrease in time. If a regression formula has a positive coefficient this means that for these regressions phosphate concentrations will increase in time.

From table 3 several statistical results can be extracted. First 15 of the 80 regressions (19%) are statistically significant (marked with a *). The Brede beek, Esvelderbeek and Barneveldse beek show respectively 2, 6 and 7 (out of 8) statistical significant OLRs, meaning that there is a statistical relation between the phosphate concentrations and time. For the Brede beek both regressions have a positive slope. All the other statistical significant OLRs have a negative slope, meaning a decrease in phosphate concentrations over time. The second results are the R^2-values. OLRs which are highlighted in black (**bold**) have a R^2-value of 0,1 or higher, this is the case for 16% of all OLRs but they are not necessarily statistical significant. The higher the R^2-value, the better the trend line fits the data. Especially in step 2 (yearly averages) high R^2-values were found, which was expected because the deviation from the trend line becomes smaller when averaging all the values.

Other data extracted from table 3 are the coefficients from the OLRs. In the table 70% of all OLRs show a negative coefficient. For step 1 all regressions of Total-P show a negative trend (100%) and for Ortho-P both positive (40%) and negative (60%) trends are shown, meaning that there is no clear direction of trends. For step 2, yearly averages, 90% of the OLRs for Total-P are negative and for Ortho-P 60% of the OLRs are negative. For step 3, meteorological seasons, 90% of the summer season Total-P tests have a negative trend. Here only the Nederwoudsebeek shows a positive trend.

For winter season Total-P, winter season Ortho-P and summer season Ortho-P no clear distinction between positive (14 out of 30) and negative (16 out of 30) trends can be made.

When looking at all steps together, for the Total-P tests 85% of the OLRs were negative, so a clear difference between positive and negative trends is present. Despite of the fact that most of the trends are not statistically significant this could be a sign of decreasing Total-P concentration in the selected brooks. For Ortho-P no distinction can be made, for 45% of the regressions are positive and 55% are negative.

Based on table 3 the ten selected brooks can be classified in three different groups. The x-coefficient of the Total-P regression from step 1 determines in which group the brooks can be stored. If the coefficient has a higher value than 2,0E-5 it is considered as a 'relatively strong negative' trend. Values between 1,0E-5 and 2,0E-5 are considered as a 'relatively weak negative' trend and values lower than 1,0E-5 are considered as 'no' trend. As a result group 1 consists of brooks with a 'relatively strong negative' trend. The Nattegatsloot, Hoevenlakense beek Esvelderbeek, Barneveldse beek and the Nederwoudsebeek are in this group and their rows are highlighted in blue. Group 2 consists of brooks with a 'relatively weak negative' trend. In this group the Moorsterbeek, Modderbeek and the Fliertsebeek are located and their rows are highlighted in green. Group 3 consists of brooks that show '(almost) no' trend. The Lunterse beek and Brede beek are located in this group and their rows are highlighted in yellow.

The data shown in table 3 is visualized in figures 5-11. For each group of brooks one brook is chosen to show the trends in phosphate concentrations over time. For group 1 the Esvelderbeek is chosen, for group 2 the Moorsterbeek is chosen and for group 3 the Lunterse beek is chosen. These brooks are selected because most data is available for these brooks (see table 1). The Esvelderbeek is chosen over the Barneveldse beek, because the x-coefficient is slightly higher. As stated in the chapter 3 eight graphs are made for the Esvelderbeek, Moorsterbeek and Lunterse beek (see figure 5-10) and one extra graph for each brook is presented in figure 11, concerning the relationship between Total-P and Ortho-P.

Brook		Step 1: All data		Step 2: Yearly averages		Step 3: Meteorological seasons			
		Total-P	**Ortho-P**	**Total-P**	**Ortho-P**	**Winter season Total-P**	**Summer season Total-P**	**Winter season Ortho-P**	**Summer season Ortho-P**
Nattegatsloot	OLR	-6,9E-5x+3,1	-2,2E-5x+1,0	**-2,7E-2x+55,4**	**-8,9E-3x+18,1**	-9,0E-5x+3,8	-5,1E-5x+2,5	-2,7E-5x+1,1	-1,9E-5x+0,9
	R^2	0,03	0,02	**0,17**	**0,14**	0,09	0,01	0,04	0,01
Hoevenlakense beek	OLR	-2,7E-5x+1,3	1,8E-7x+0,1	**-8,7E-3x+17,6**	6,1E-4x-1,1	6,8E-6x+0,0	-5,0E-5x+2,2	1,3E-5x-0,4	-8,8E-6x+0,4
	R^2	0,02	0,00	**0,39**	0,02	0,00	0,04	0,06	0,01
Esvelderbeek	OLR	-2,5E-5x+1,1	-6,9E-6x+0,3	**-8,9E-3x+18,1**	**-2,8E-3x+5,6**	-2,1E-5x+1,0	**-2,9E-5x+1,3**	-5,7E-6x+0,3	-7,9E-6x+0,4
	R^2	0,07*	0,02*	**0,60***	**0,29***	0,05*	**0,10***	0,03	0,02
Barneveldse beek	OLR	-2,5E-5x+1,2	-1,1E-5x+0,5	**-8,9E-3x+18,1**	**-4,3E-4x+8,7**	-2,5E-5x+1,2	-2,5E-5x+1,2	-9,9E-6x+0,5	-1,2E-5x+0,5
	R^2	0,07*	0,04*	**0,54***	**0,33***	0,07*	0,07*	0,07*	0,03
Nederwoudse-beek	OLR	-2,3E-5x+1,2	-5,6E-6x+0,3	**-1,2E-2x+23,4**	-3,2E-3x-6,5	1,0E-6x+0,2	4,7E-5x+2,1	1,2E-5x-0,4	-2,3E-5x+1,0
	R^2	0,01	0,00	**0,12**	0,03	0,00	0,05	0,02	0,03
Moorsterbeek	OLR	-1,8E-5x+1,0	-3,9E-6x+0,3	-5,8E-3x+11,9	-1,3E-3x+2,8	-3,4E-5x+1,6	-4,3E-6x+0,4	-1,4E-5x+0,7	4,3E-6x-0,0
	R^2	0,01	0,00	0,07	0,02	0,03	0,00	0,03	0,00
Modderbeek	OLR	-1,5E-5x+0,8	-6,2E-6x+0,3	**-6,1E-3x+12,4**	**-2,4E-3x+4,9**	-9,9E-6x+0,6	-1,9E-5x+0,9	7,8E-7x+0,0	-1,2E-5x+0,6
	R^2	0,02	0,01	**0,27**	**0,23**	0,02	0,02	0,00	0,01
Fliertsebeek	OLR	-1,2E-5x+1,2	3,2E-5x-0,7	-4,8E-3x+10,4	1,1E-2x-21,8	5,9E-6x+0,5	-3,4E-5x+2,1	3,4E-5x-0,9	2,2E-5x-0,2
	R^2	0,00	0,02	0,01	0,05	0,00	0,01	0,08	0,01
Lunterse beek	OLR	-7,9E-6x+0,7	6,1E-6x-0,0	-4,2E-3x+8,8	1,7E-3x-3,2	-1,4E-5x+1,0	-3,1E-6x+0,5	4,1E-6x+0,0	8,0E-6x-0,1
	R^2	0,00	0,00	0,05	0,03	0,00	0,00	0,00	0,01
Brede beek	OLR	-6,4E-7x+0,3	1,1E-5x-0,3	1,1E-3x-1,9	**4,3E-3x-8,5**	2,8E-6x+0,2	-4,0E-7x+0,2	**1,5E-5x-0,5**	8,1E-6x-0,2
	R^2	0,00	0,04	0,01	**0,51***	0,00	0,00	**0,10***	0,01

Table 3: Ordinary linear regressions (OLR) and R²-values of the 8 different tests for the 10 selected brooks. An asterisk (*) means that the R² and the OLR are statistically significant. When the OLR and R²-values are bold, a R²-value of >0,1 is present but it doesn't mean that it is statistically significant. The colors of the rows represent the different groups based on the x-coefficients. Blue has a coefficient >2,0E-5, green has a coefficient between 1,0 and 2,0E-5 and yellow has a coefficient <1,0E-5, indicating respectively a 'relatively strong' trend, a 'relatively weak' trend and 'no' trend.

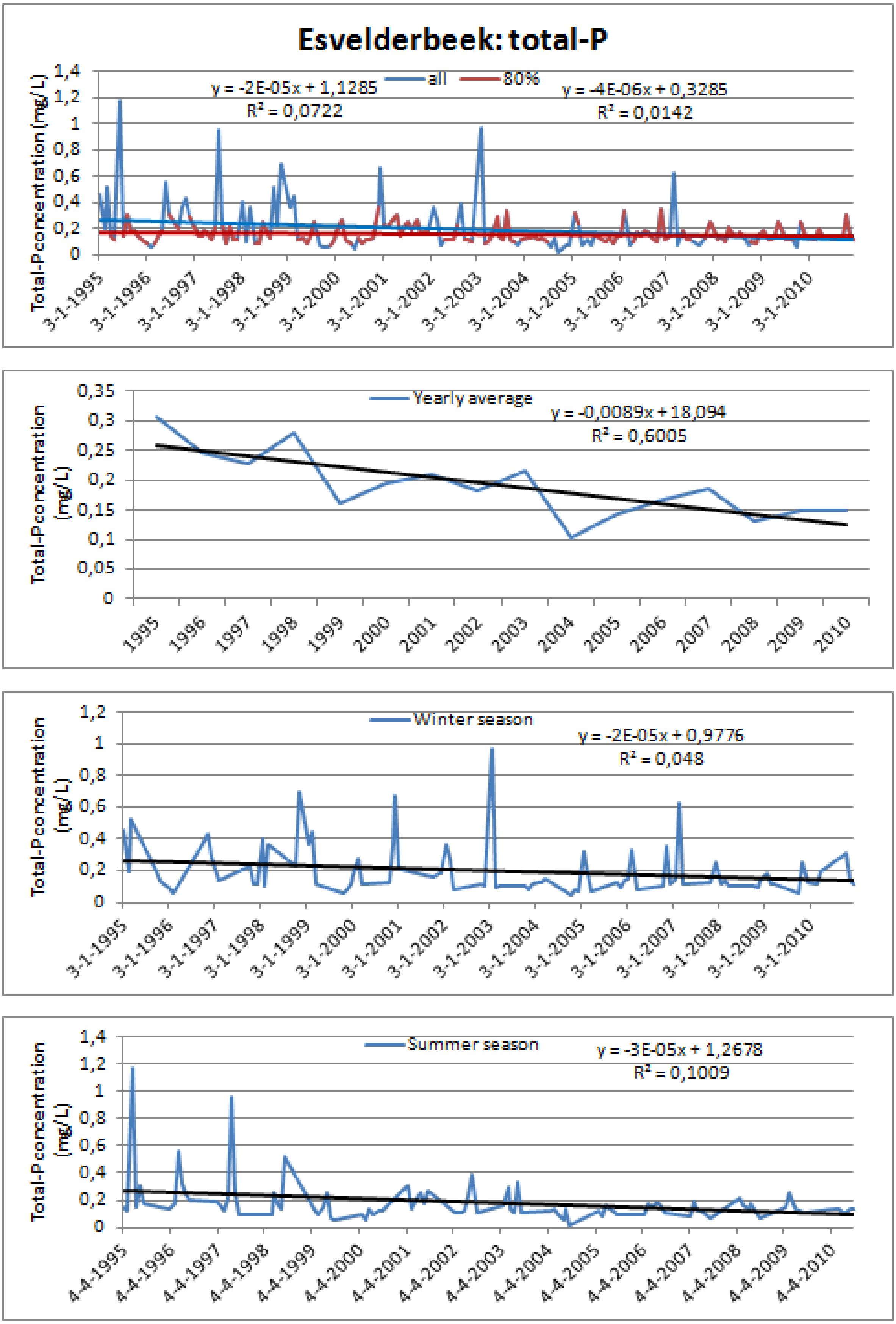

Figure 5: Total-P trend lines for the Esvelderbeek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

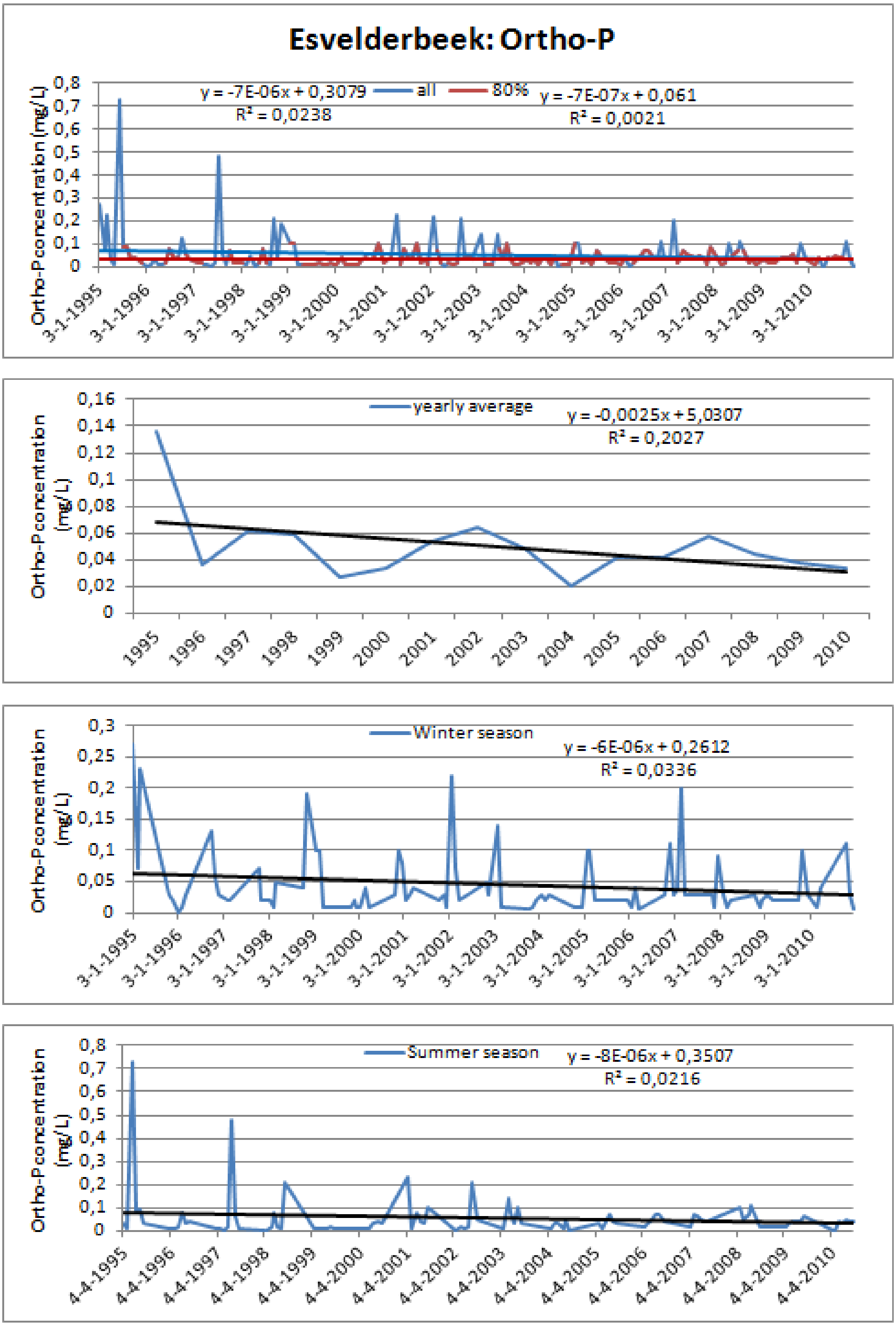

Figure 6: Ortho-P trend lines for the Esvelderbeek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

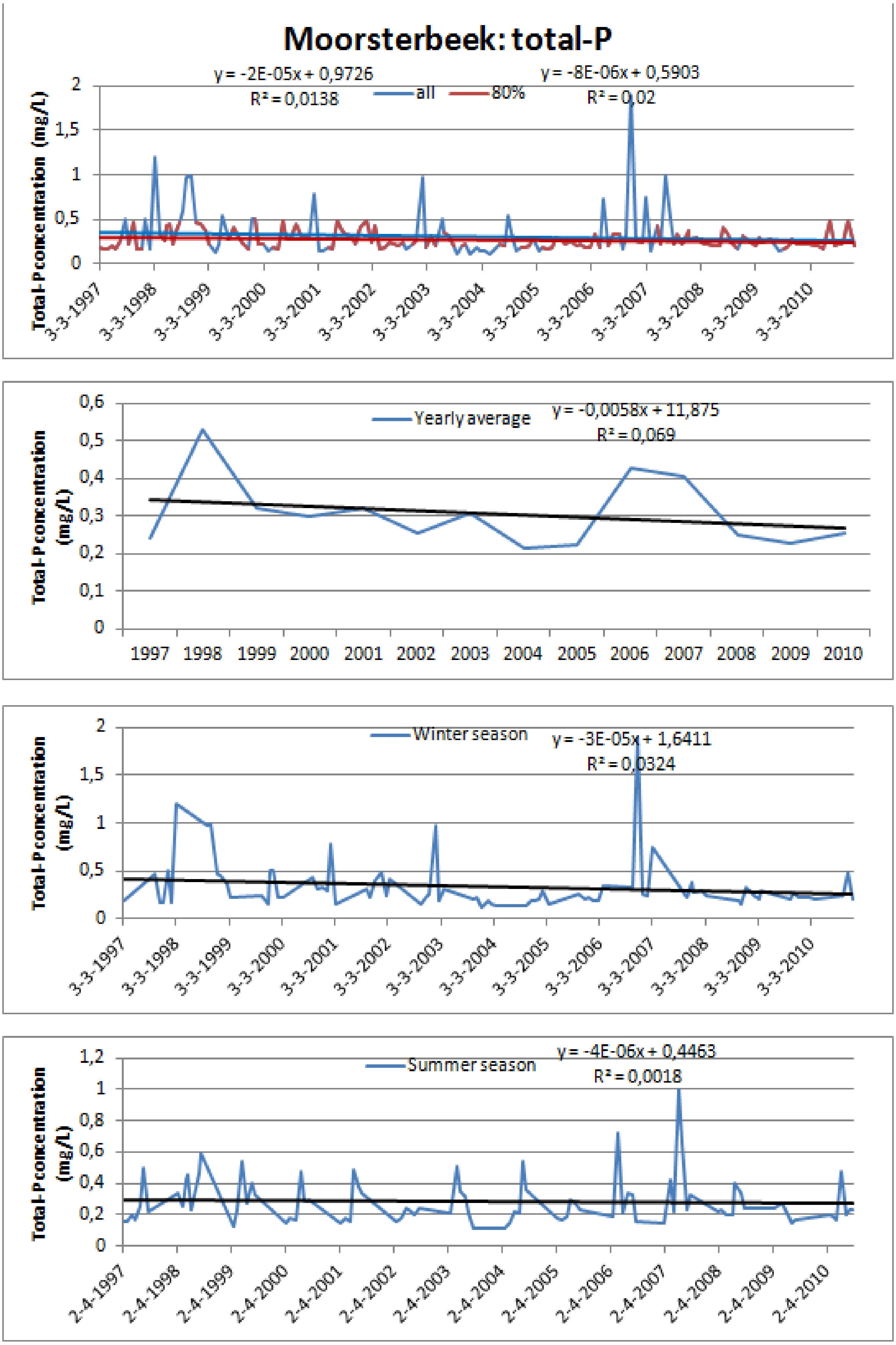

Figure 7: Total-P trend lines for the Moorsterbeek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

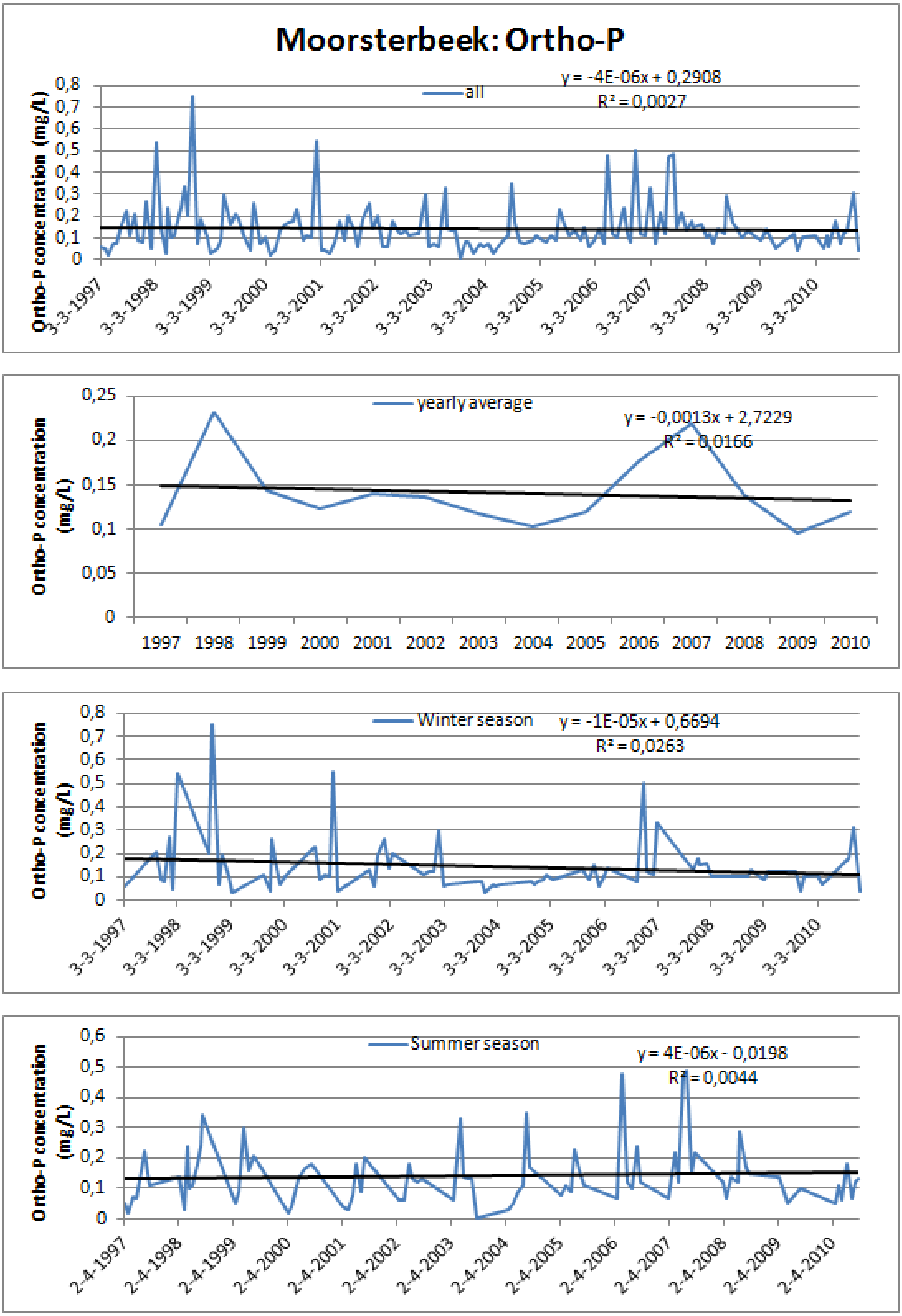

Figure 8: Ortho-P trend lines for the Moorsterbeek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

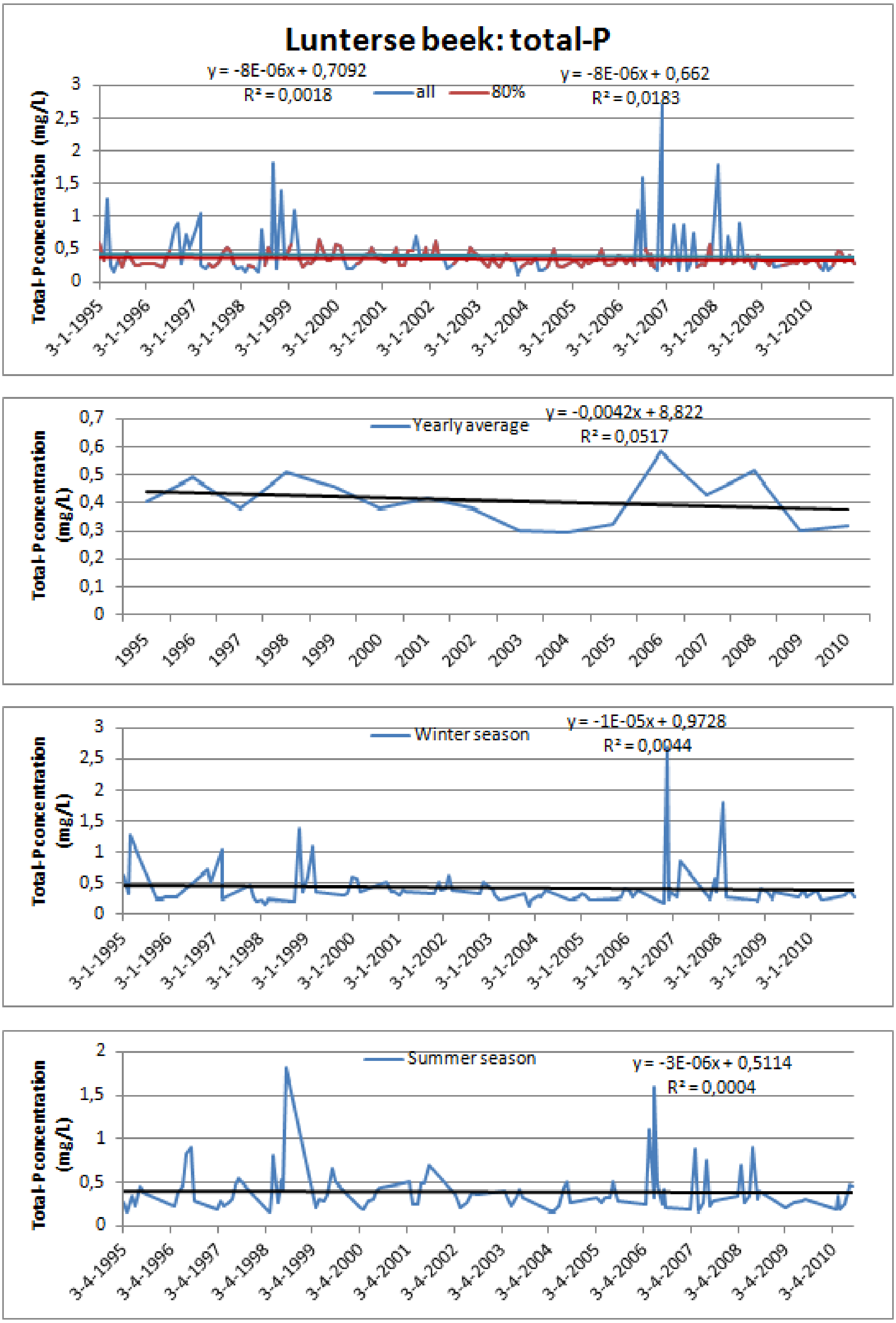

Figure 9: Total-P trend lines for the Lunterse beek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

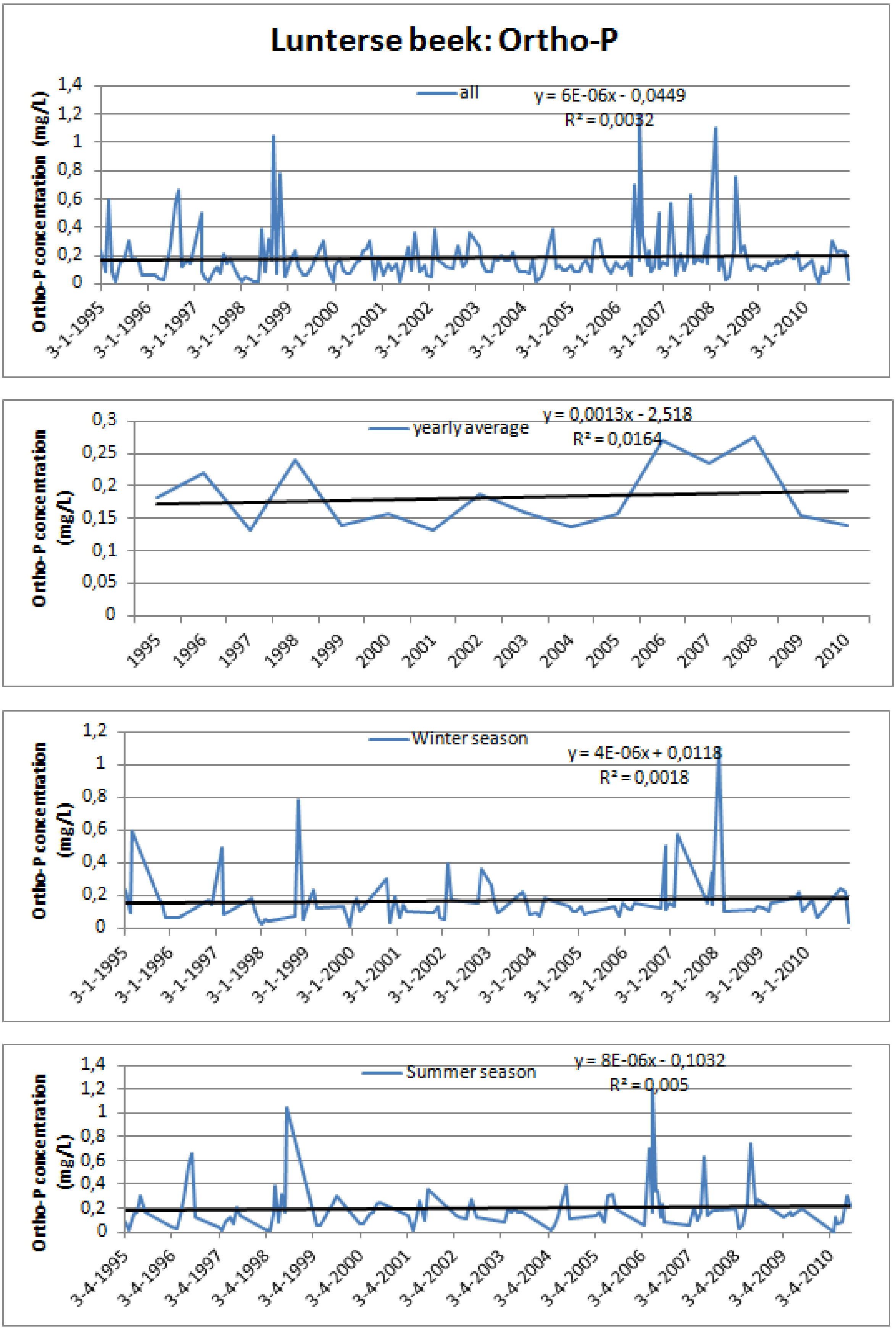

Figure 10: Ortho-P trend lines for the Lunterse beek for a) all data and middle 80% of the data, b) yearly averages, c) winter season and d) summer season.

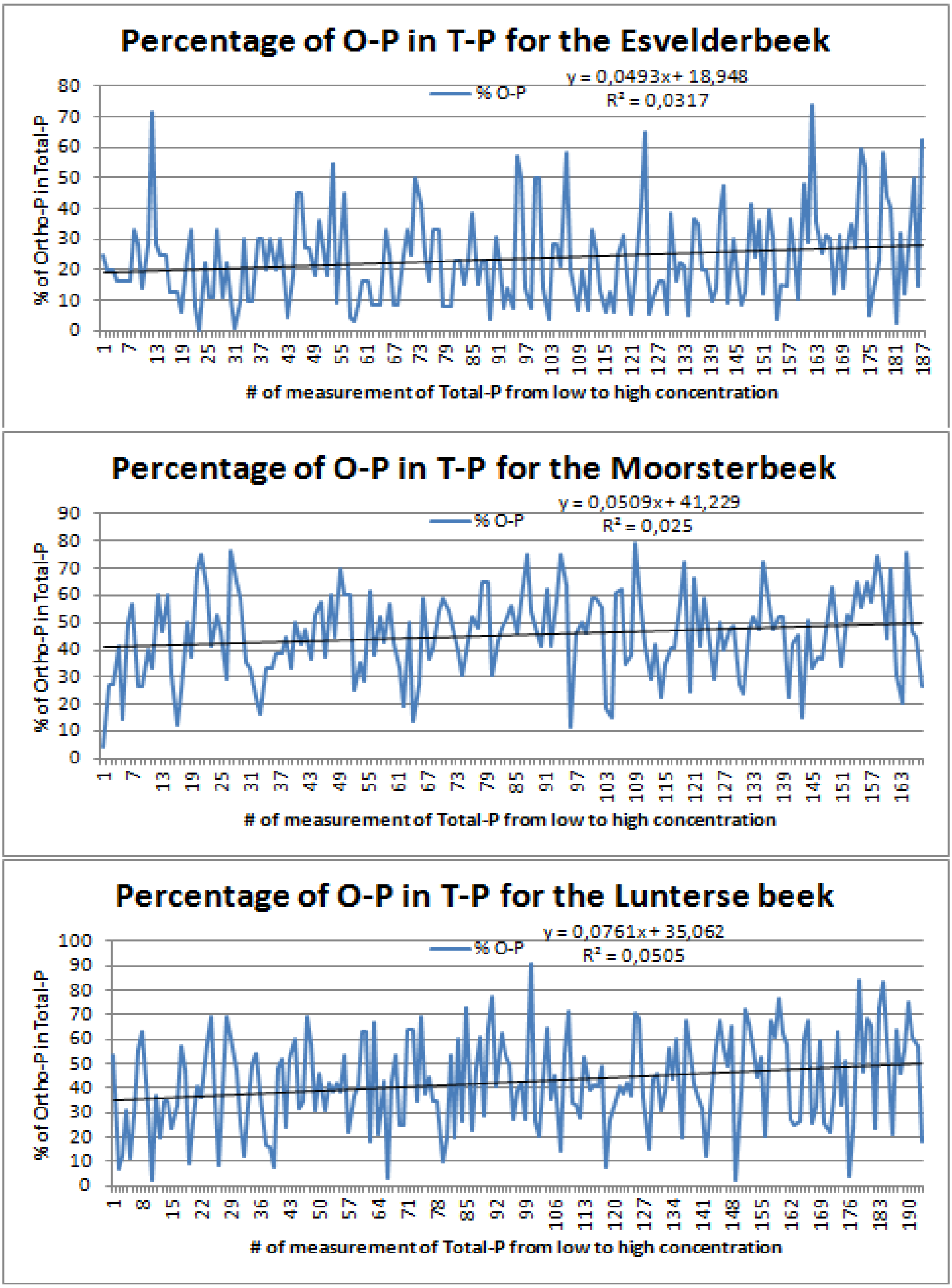

Figure 11: Percentage of Ortho-P in Total-P for a) Esvelderbeek, b) Moorsterbeek and c) Lunterse beek. On the x-axis the number of the measurement of Total-P from low to high concentrations are shown. So 1 is the lowest measured Total-P concentration and 187, 163 and 190 are the highest Total-P concentrations measured for respectively the Esvelderbeek, Moorsterbeek and Lunterse beek.

Visual results group 1
When considering the Esvelderbeek from group 1 several results are shown.

1) Graph 1 from figure 5 shows that both the trend for all data and 80% of the data is negative. The plot for all data has a higher R^2-value than the R^2-value from the 80% trend line, meaning that the trend line for all data fits the data better. If the 80%-regression is still negative this could mean that the 'normal/background' (not influenced by 'outliers', defined as the values which were left out in the 80% OLRs) concentrations are decreasing. The trend for all data shows a stronger negative trend than the 80% trend, this could be evidence that there is a decrease of high phosphate concentrations, which were filtered out in the 80% trend.

2) In the second graph (Yearly average Total-P) also a negative trend is shown. The yearly average Total-P concentration shows a steep decrease in time and has a high R^2-value, meaning that the data does not differ much from the trend line.

3) The winter en summer season for Total-P (figure 5, graph 3 and 4) both show a negative trend, consistent with graph 1. Generally higher concentrations are present in winter season. Also more values higher than 0,4 mg/L are present in winter season. So for the Esvelderbeek both the 'normal' concentrations and the 'outliers' are higher in winter season than in summer season.

4) When comparing Total-P with Ortho-P (figure 5 with figure 6) it is shown that Ortho-P trends show the same result as the Total-P trends. Ortho-P concentrations are always lower than the Total-P concentrations (see figure 11a). In figure 11a the trend line shows that the share of Ortho-P in Total-P tends to increase when Total-P increases. High concentrations in Total-P can therefore cause even higher concentrations of Ortho-P relatively to 'normal' concentrations.

Visual results group 2
For group 2 and therefore the Moorsterbeek (figure 7, 8, 11b) the following results are drawn.

1) From the first graph also both trend lines are negative. In this case the 80% trend generates a better fit than plotting all data, however only with a difference of 0,6%. From the two lines the same conclusion can be drawn as for the Esvelderbeek, namely decreasing 'normal' concentrations and a decrease in 'outliers'.

2) For the yearly average concentrations the trend line is still negative, but does not fit the data as good as by the Esvelderbeek. This trend line is influenced by the high values in the years 1998, 2006 and 2007.

3) Considering the meteorological seasons the summer concentrations show roughly the same amount of values above a concentration of 0,4 mg/L. Furthermore the winter concentrations are generally higher than summer concentration. Both graphs show a negative trend, meaning that concentrations decrease in time.

4) When comparing Total-P with Ortho-P (figure 7 with figure 8) Ortho-P concentrations are following Total-P concentration again. Interesting to see is that the Ortho-P trend line for the summer season is positive, whilst it was negative for the summer season Total-P trend. Where the trend line for all the data (figure 8 graph 1) contain both summer and winter season concentrations, they are split in graph 3 and 4 and the high concentrations in the period 1997-2002 were mainly measured in winter

season and the high concentrations between 2003-2008 are mainly measured in summer season. These 'outliers' influenced the trend lines and therefore a positive trend line was shown in summer season and a negative trend line was shown in winter season. It is strange that this is shown only for Ortho-P and not for Total-P, because they were measured at the same time. This might be explained by figure 11b, were a positive trend is shown for the percentage of Ortho-P in Total-P when Total-P increases. This could cause that the 'outliers' for Ortho-P become relatively bigger than the 'normal' concentrations, leading to a higher influence of the 'outliers' and therefore to different results.

Visual results group 3

1) When considering the Lunterse beek (group 3) all the Total-P trend lines are weak and negative, despite of the 'outliers' between 2006 and 2009, possibly due to the presence of 'outliers' between 1995 and 2000, but also due to decreasing 'normal/background' concentrations. The same holds for the other Total-P graphs.

2) When looking at figure 10 (Ortho-P trends) all regressions show a positive trend, in contradiction to the Total-P trends. Here the 'outliers' between 2006 and 2009 are of more influence and/or less dampened by the 'outliers' in earlier years, which is in line with figure 11c where the share of Ortho-P in Total-P increases with increasing Total-P concentrations (see also explanation for group 2). This effect is especially shown in the second graph (yearly averages) where the concentrations between 2006 and 2009 are relatively higher to the concentrations between the years 1995-2000 than for the Total-P concentrations.

Comparison between groups

1) When comparing the Esvelderbeek, Moorsterbeek and the Lunterse beek, besides the differences in trends, the Lunterse beek has higher 'normal' concentrations. This makes it harder to compare 'outliers' for the three groups, however it is clearly shown that the Esvelderbeek has a lower amount of values above 0,4 mg/L than the Moorsterbeek and the Lunterse beek. Furthermore, for the Esvelderbeek less 'outliers' are present in summer season than in winter season, while for the other brooks no clear difference is present.

2) Where all Total-P trends are negative in case of the Moorsterbeek the summer season Ortho-P trend is positive and for the Lunterse beek all the Ortho-P trends are positive. This is possibly caused by bigger shares of Ortho-P when Total-P increases. Brooks with a weak trend line are more vulnerable to this process than brooks with stronger trend lines.

3) When comparing the three graphs of figure 11, all graphs show that the Total-P concentration is always bigger than the Ortho-P concentrations and all graph show a positive trend. However for the Esvelderbeek the trend line lays around 20% and 30%, where for the other two brooks it lays between 35% and 50%.

4) All in all, the processes between the three brooks are the same. The Ortho-P concentrations follow the Total-P concentrations. For all Total-P graphs the trend is negative for Ortho-P graphs this varies due to changing shares of Ortho-P in Total-P.

Seasonal Kendall Tau test (Step 4)

In this step the Seasonal Kendall Tau test is used to compare the results with the results of step 1, 2 and 3. For each of the ten brooks the Seasonal Kendall Tau test is done and table 4 shows the outcomes for the test for the Esvelderbeek and the Lunterse beek. Only the outcomes from these two brooks are shown, because there are only two outcomes possible. Namely 1) there is a trend present shown on the left side of the table and 2) there is no trend present, shown on the right side of the table.

The Esvelderbeek, on the left, has a significant trend with a slope of -0,004 mg/L per year. The Lunterse beek, on the right, has no significant trend. The amount of seasons in this case are months (January-December) and the amount of years are years between the years 1995-2010.

For two brooks a trend is present, namely for the Barneveldse beek and the Esvelderbeek, for the other brooks no significant trend is possible. To relate this results to the results presented in table 3, when looking at table 3 step 1 also the regressions of the Esvelderbeek and the Barneveldse beek are statistical significant and the other show no statistical significance. The results from the Seasonal Kendall Tau test are therefore in line with the results shown in table 3 and also contribute to the credibility of the results from step 1, 2 and 3.

Seasonal Kendall Test	Esvelderbeek	Seasonal Kendall Test	Lunterse beek
Amount of seasons [m]	12	Amount of seasons [m]	12
Amount of years [n]	16	Amount of years [n]	16
Amount of values	179	Amount of values	175
Amount of missing values	13	Amount of missing values	17
Testvariabele Sk	-224	Testvariabele Sk	-107
LSA-testvar ZSk	-3,20	LSA-testvar ZSk	-1,56
p-value	0,001	p-value	0,119
alpha	0,050	alpha	0,050
Testresult with alpha	Trend present	Testresult with alpha	No trend present
Change per year	-0,004	Change per year	-

Table 4: Results of the Seasonal Kendall Tau test for the Esvelderbeek and the Lunterse beek.

From table 4 no further conclusions can be drawn, for there is no value which shows the strength of the correlation. The change per year is also only valuable when an intercept with the x-axis is present, because then a regression formula can be made and hard conclusions can be drawn.

Comparing means (Step 5)

In figure 12 and 13 the results of step 5 are shown. Figure 12 shows the difference between average Total-P concentrations in 2005-2010 and 1995-2000. In this figure it is shown that for all brooks the ‘difference’ column (green) is negative, except for the Brede beek. Negative values suggest that the Total-P concentrations between the years 2005-2010 are lower than those of 1995-2000, meaning that there is a decrease in Total-P in time. Positive values mean that there is an increase in Total-P concentration in time. In this figure the Nattegatsloot and the Nederwoudsebeek show the highest difference in time. For the Lunterse beek, Fliertsebeek and the Brede beek almost no difference is shown.

Figure 13 shows the difference between average Ortho-P concentrations in 2005-2010 and 1995-2000. In this table 40% of the values are positive and 60% of the values are negative. So for some brooks the Ortho-P concentrations increased in time and for other Ortho-P concentrations decreased in time.

Especially for the Fliertsebeek an increase in Ortho-P concentrations over the years is shown. For the Lunterse beek, Hoevenlakense beek and the Brede beek also an increase in concentrations is shown. For the Moorsterbeek, Barneveldse beek and Esvelderbeek a small decrease in concentrations is shown compared to the decrease in the Nederwoudsebeek, Nattegatsloot and the Modderbeek.

When comparing figure 12 and 13 it is remarkable that for the Lunterse beek, Fliertse beek and the Hoevenlakense beek the difference in Ortho-P is positive while for Total-P they are negative. For the other brooks, except for the Modderbeek, the relative difference is smaller for Ortho-P than for Total-P, meaning that the change over time is relatively lower. So for Ortho-P it is difficult to draw conclusions for they are not comparable with Total-P concentrations and are probably affected by other processes.

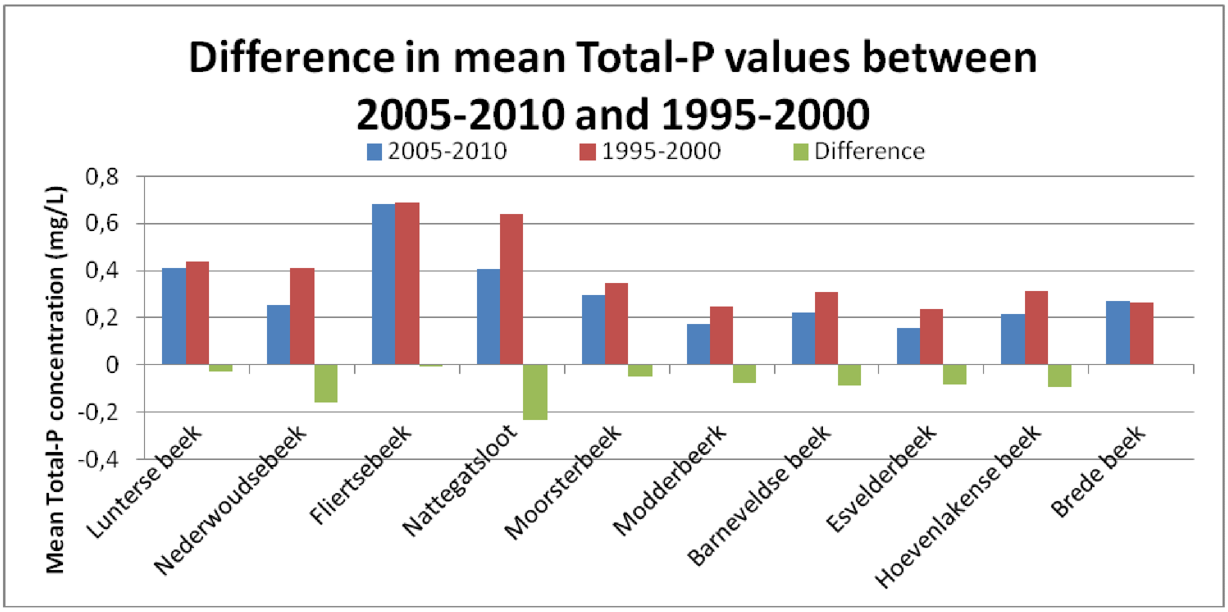

Figure 12: Difference in mean Total-P values between 2005-2010 and 1995-2000.

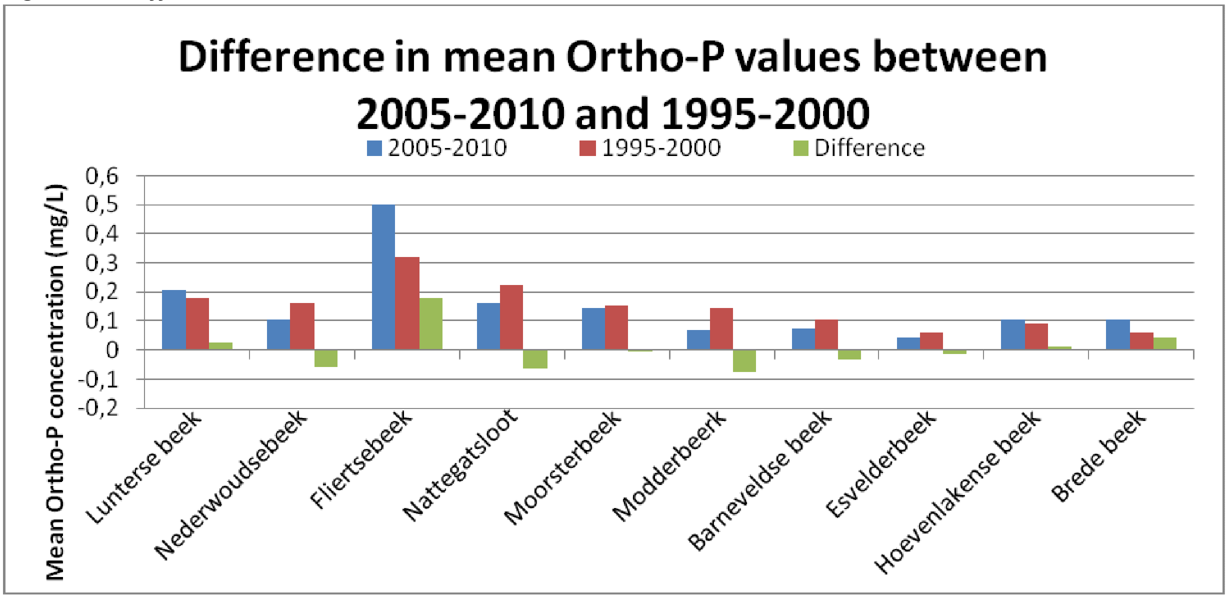

Figure 13: Difference in mean Ortho-P values between 2005-2010 and 1995-2000.

WFD standards and MTR

For the second research question it is necessary to calculate OLRs for the yearly average summer Total-P concentrations for each brook. It is necessary because the WFD standards are considering summer averages of Total-P concentrations. When the OLRs are obtained the OLR can be extrapolated to 2015 and 2027 to check if the selected brooks meet the WFD requirements by 2015 and ultimately by 2027. This is done as follows. As an example the OLR for the Lunterse beek is y=-0,0028x + 5,9881, where x represents the time in years. So by filling in x=2015 and x=2017 the Total-P concentrations in 2015 and 2027 for the Lunterse beek are calculated.

In table 5 the OLRs are shown together with the R^2-values. Furthermore the MTR and WFD standard are stated for each brook. And last the results of the extrapolations to 2015 and 2027 are shown.

Brook	OLR – yearly summer average Total-P concentration (mg/L)	R^2	MTR-standard (mg P/L)	WFD standard (mg P/L)	Total-P concentration in 2015 (mg P/L)	Total-P concentration in 2027 (mg P/L)
1. Lunterse beek	Y = -0,0028x + 6,0	0,02	0,15	0,14	0,346	0,313
1a. Nederwoudsebeek	Y = -0,0212x + 42,7	0,16	0,15	0,14	-0,008	-0,262
1b. Fliertsebeek	Y = -0,0067x + 14,3	0,00	0,15	0,14	0,797	0,716
2. Nattegatsloot	Y = -0,015x + 30,8	0,02	0,15	0,12	0,536	0,356
3. Moorsterbeek	Y = -0,0021x + 4,5	0,02	0,15	0,12	0,315	0,289
4. Modderbeek	Y = -0,0073x + 14,9	0,26	0,15	0,12	0,167	0,079
5. Barneveldse beek	Y = -0,0092x + 18,6	0,40*	0,15	0,14	0,038	-0,072
5a. Esvelderbeek	Y = -0,0106x + 21,5	0,49*	0,15	0,14	0,121	-0,006
5b. Hoevenlakense beek	Y = -0,0157 + 31,6	0,30	0,15	0,14	-0,033	-0,221
6. Brede beek	Y = 0,0005x – 0,8	0,00	0,15	0,14	0,246	0,252

Table 5: OLRs and R^2-values for the yearly summer average Total-P concentrations, the MTR and WFD standards and the Total-P concentrations in 2015 and 2027 when extrapolating the OLR for the 10 selected brooks. When a value is highlighted in 'green' the WFD standard is met and when highlighted in 'orange' the WFD standard is not met. When a R^2-value is marked with an asterisk (*) the trend OLR is statistically significant.

In table 5 the green values meet the WFD standard of either 0,12 mg P/L or 0,14 mg P/L. In 2015 40% of the brooks meet the required WFD standard. By 2027 this increases to 50%. For the Nederwoudsebeek, Barneveldse beek, Esvelderbeek and Hoevenlakense beek the WFD-standard is met in 2015. For the other brooks the WFD-standard is not met, meaning that additional measures have to take place to meet the WFD-standard by 2015. For 2027 only the Modderbeek shifts from orange to green. This means that five brooks still do not meet the WFD-standard and additional measures are necessary. In table 5 also negative concentrations are observed. In real life this is not possible, for there is always a background concentration present. In this case the values are present because when extrapolating an OLR can become negative. In the spatial analysis the information from table 5 is also presented on a spatial scale in a map. For the MTR the same holds as for the WFD standards. In 2015 40% meets its value and in 2027 this increases to 50%.

4.2 Spatial analysis

In this paragraph the data is analyzed from a spatial point of view. This is done by using maps and different colors for different concentrations.

Total-P and Ortho-P concentrations over 2005-2010

In figure 14 the mean Total-P value for each brook from 2005-2010 is shown. In this figure the different water basins are also shown for the management area of WVE. In this figure the Total-P concentrations in mg/L are present, these values are highlighted by different colors depending on the values. The color scheme for this graph is stated below.

0-0,1 mg/L	0,1-0,2 mg/L	0,2-0,3 mg/L	0,3-0,4 mg/L	0,4-0,5 mg/L	> 0,5 mg/L

From figure 14 it is shown that high Total-P concentrations are measured in the water basin 'Lunterse beek' located in the south (purple water basin). In the other three water basins concentrations are lower. In the water basin 'Modder en Moorsterbeek' the Moorsterbeek has a relatively high phosphate concentration compared to the Modderbeek. Further north, in the water basin 'Barneveldse beek', phosphate concentrations are even lower. They are varying between 0,154-0,219 mg/L. In this case phosphate concentrations tend to decrease when moving in eastern direction, possibly because they are located upstream. The Brede beek (brook 6) has a slightly higher concentration than the brooks 4, 5, 5a and 5b possibly because it is located in a different water basin and other processes play a role. All in all concentrations tend to increase when moving south.

In figure 15 the same figure is shown only the values for Ortho-P are now presented. The same color scheme is used for this figure as for figure 14. In this figure the same pattern is shown as in figure 14. Only the difference between Total-P and Ortho-P in the Barneveldse beek and the Nattegatsloot seems bigger than the differences for the other brooks. But because Total-P and Ortho-P are closely related here also a decline in concentrations can be found when going north. And there's also a slight decrease in Ortho-P concentration for the water basin 'Barneveldse beek' when moving in eastern direction.

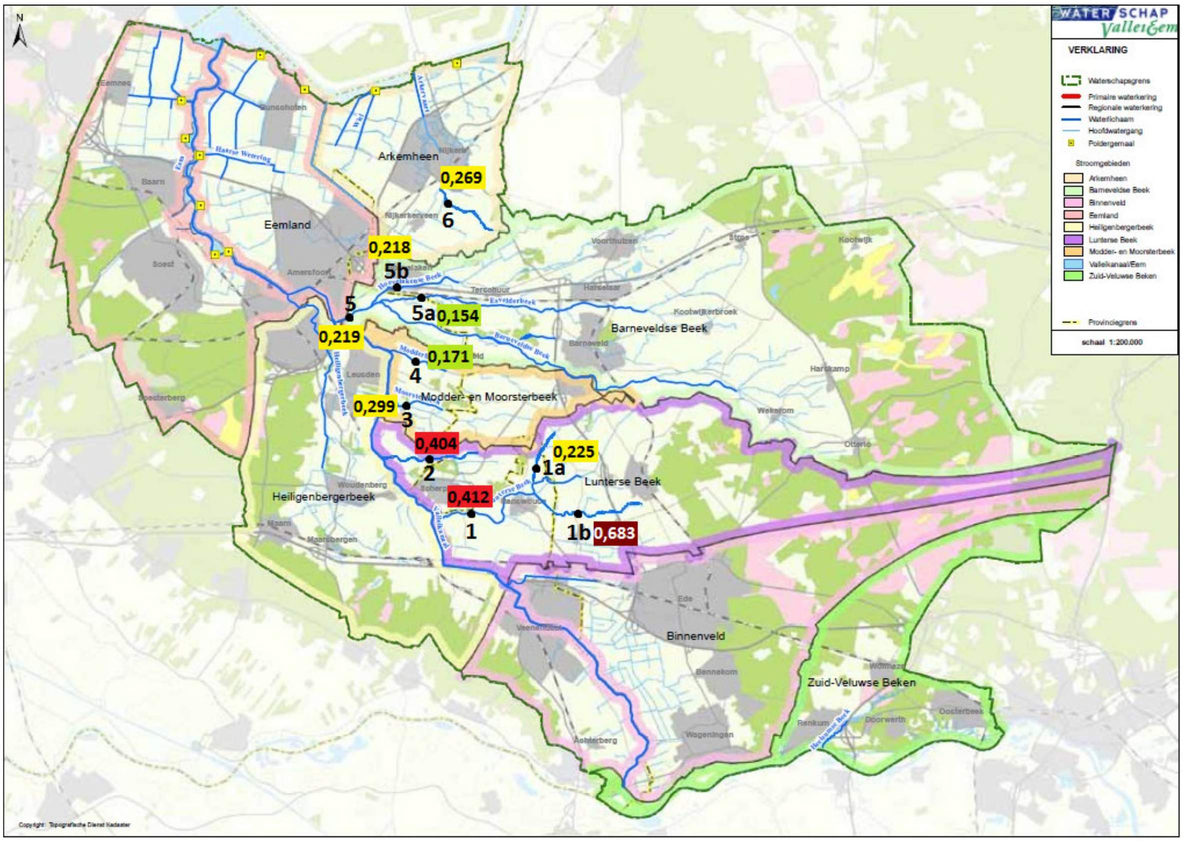

Figure 14: Spatial distribution of the mean Total-P values in mg/L over the period 2005-2010.

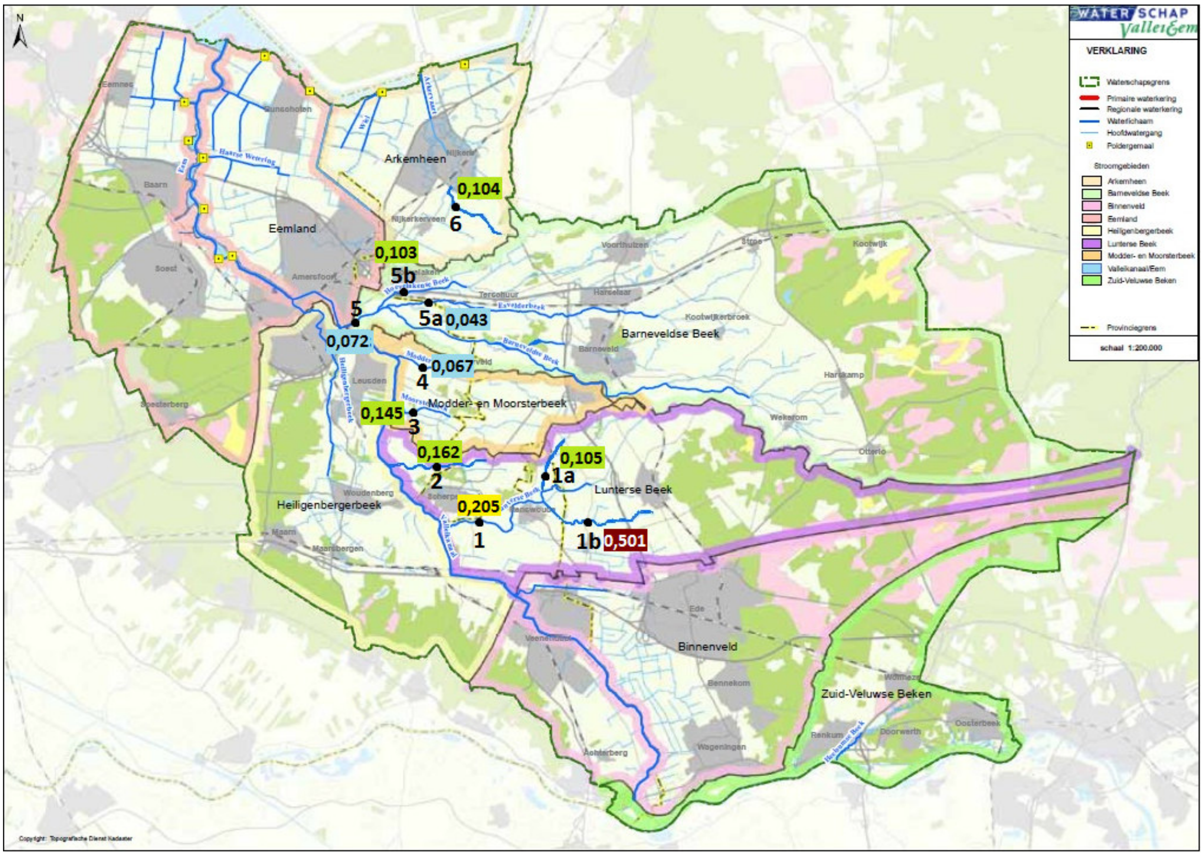

Figure 15: Spatial distribution of the mean Ortho-P values in mg/L over the period 2005-2010.

Difference between 2005-2010 and 1995-2000

In figure 16 the difference between the mean concentration of Total-P concentrations from 2005-2010 and 1995-2000 is presented (from chapter 4,1 step 5). A negative value means that there is a decrease of Total-P concentration over time and a positive number means that there is an increase over time. For this figure the following color scheme is used to be able to see spatial differences quickly.

< -0,15 mg/L	-0,1 - -0,15 mg/L	-0,05 - -0,1 mg/L	0- -0,05 mg/L	> 0 mg/L

In figure 16 it is shown that only for the Brede beek this value is positive. For the rest of the brooks this value is negative. In water basin ‘Barneveldse beek’ (including 5, 5a and 5b) there is a decrease of phosphate concentrations between 0,05-0,1 mg/L. In water basin ‘Lunterse beek’ (including 1, 1a, 1b and 2) the results are more deviated. There is almost no decrease in the Lunterse beek and the Fliertsebeek, while there is a large decrease in the Nederwoudsebeek and the Nattegatsloot. For the Moorsterbeek and Modderbeek the values lay between the values of the other water basins. In this case no clear spatial pattern is present, the biggest decrease concentration and smallest decrease of phosphate concentrations are located in the same water basin. This together with the contrast in the north with an increase in concentration in the Brede beek and decreases in the water basin ‘Barneveldse beek’ makes it impossible to determine a spatial pattern.

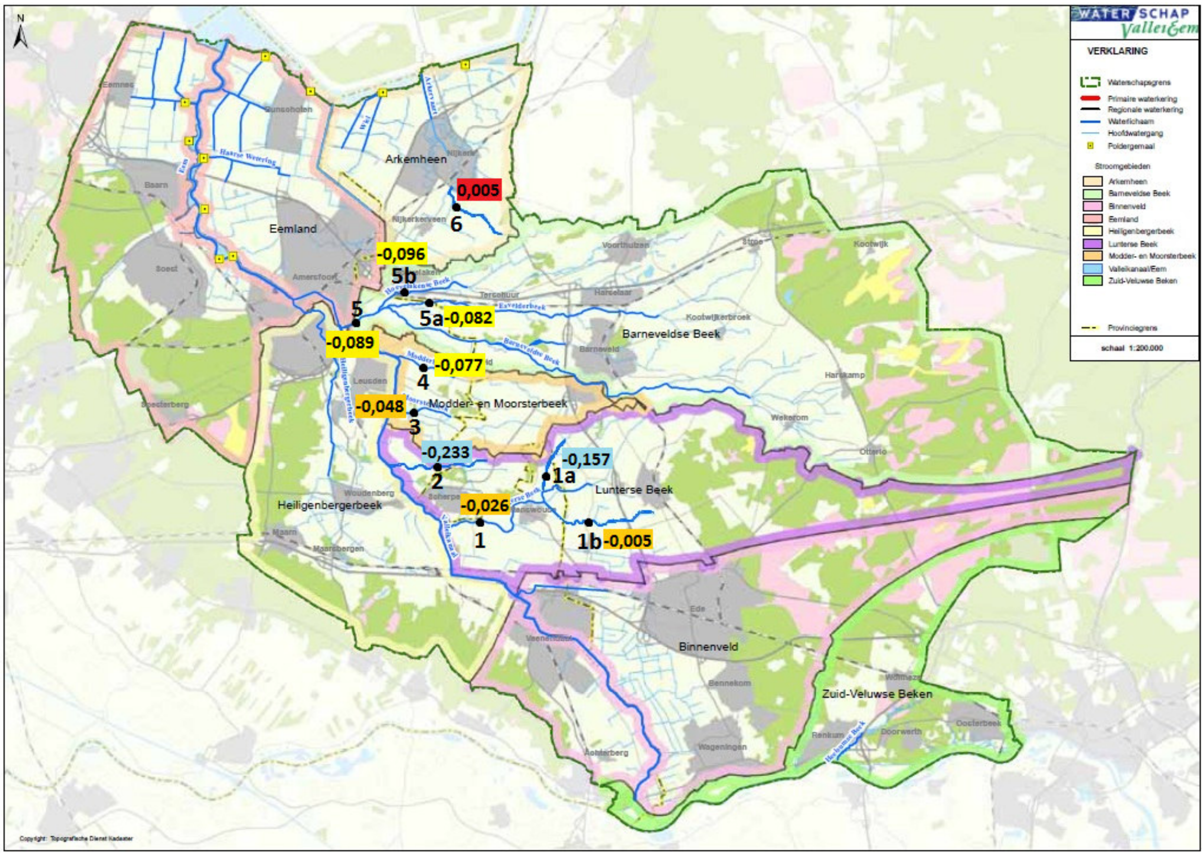

Figure 16: Change in mean Total-P concentrations between 2005-2010 and 1995-2000.

WFD standards

In figure 17 a map is shown which contain plusses (+) and minuses (-) which state whether the WFD standards is met or not. From a spatial point of view a somewhat clear trend can be seen. The results tend to be positive in northern direction, except for the Brede beek. In water basin 'Lunterse beek' the brooks do not meet the WFD standard, except for the Nederwoudsebeek, which is located more to the north-east of the water basin. Considering water basin 'Modder en Moorsterbeek', the Moorsterbeek also does not meet the WFD standards. For the Modderbeek the minus from 2015 changed into a plus by 2027. In the water basin 'Barneveldse beek' all brooks meet the WFD standards. The Brede beek will not meet the WFD standards by 2015 and 2027 and is not following the trend in northern direction.

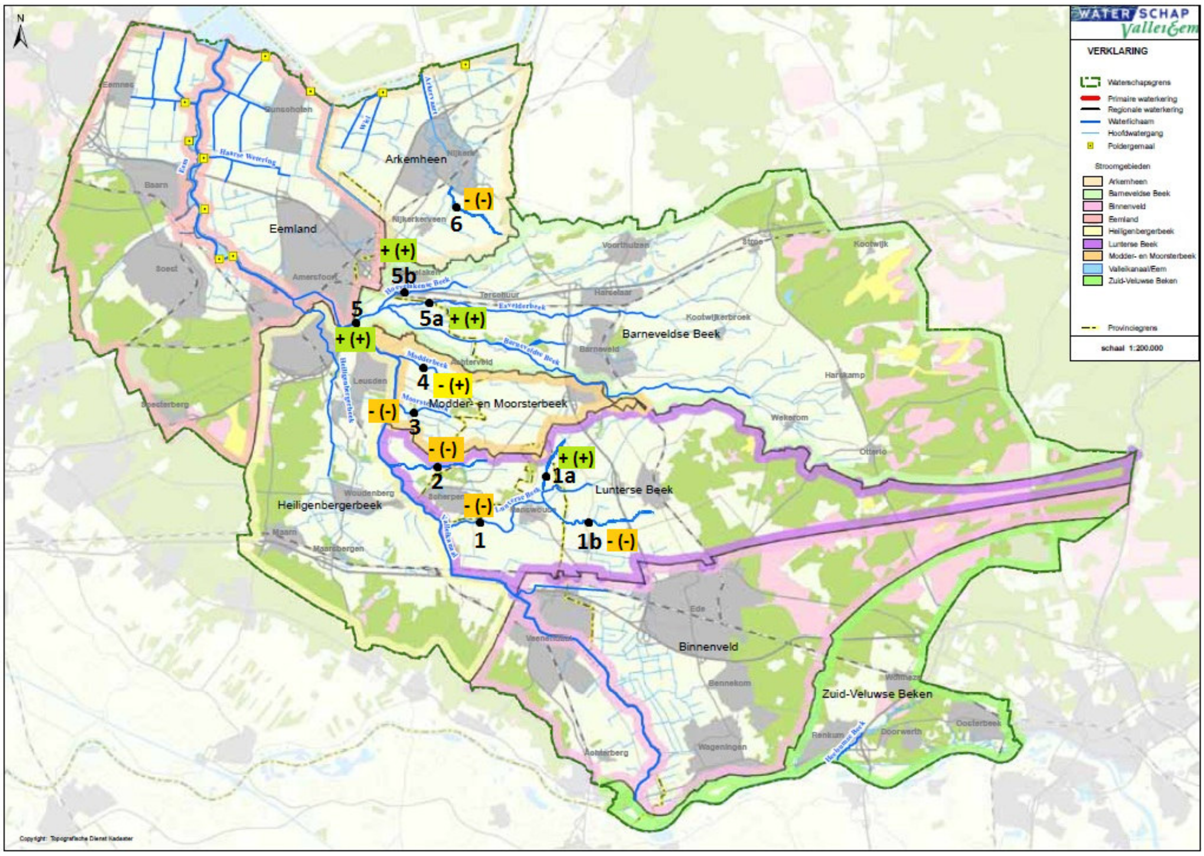

Figure 17: Spatial visualization of meeting/not meeting the WFD-standards for the years 2015 and 2027 (those plusses or minuses are between brackets).

To summarize figures 14-17 in short, it is observed that the phosphate concentrations for the Barneveldse beek, Esvelderbeek and Hoevenlakense beek show the best results/the lowest concentrations. Moving south the results are different. For water basin 'Modder en Moorsterbeek' the Modderbeek shows better results than the Moorsterbeek. Further south the worst results are shown. In water basin 'Lunterse beek' all brooks, except the Nederwoudsebeek, will not meet the WFD standards. Lastly the Brede beek, located in the north, does not meet the WFD standard and almost no change of phosphate concentration is observed in time. All in all this information shows that the phosphate concentrations increase in southern direction, only the Brede beek, which is located the most to the north of the selected brooks, and the Nederwoudsebeek, deviate from this statement.

4.3 Possible explanations

This paragraph consists of three sub-paragraphs. It starts with the effect of groundwater levels and rain events on phosphate concentrations. Then the effect of fertilizer use is assessed and last the effect of land use on phosphate concentrations is assessed.

Effect of groundwater levels

In the introduction (Chapter 1) it was said that phosphate concentrations originate from agricultural land and are affected by groundwater levels and large rain events. To analyze whether groundwater levels are indeed of influence a dry year with a wet year are analyzed. In dry years the groundwater level will be lower than usual and in wet years higher.

From our dataset the data from the Moorsterbeek for the years 1998 (wet year) and 2003 (dry year) were plotted together with the monthly precipitation of those years, see figure 18. An average year has a total of 793 mm rain. The year 1998 was a wet year with a total of 1240 mm rain measured in De Bilt, the Netherlands (KNMI, 2004). The year 2003 was a dry year with in total of 613 mm of rain also measured in De Bilt, the Netherlands (KNMI, 2004).

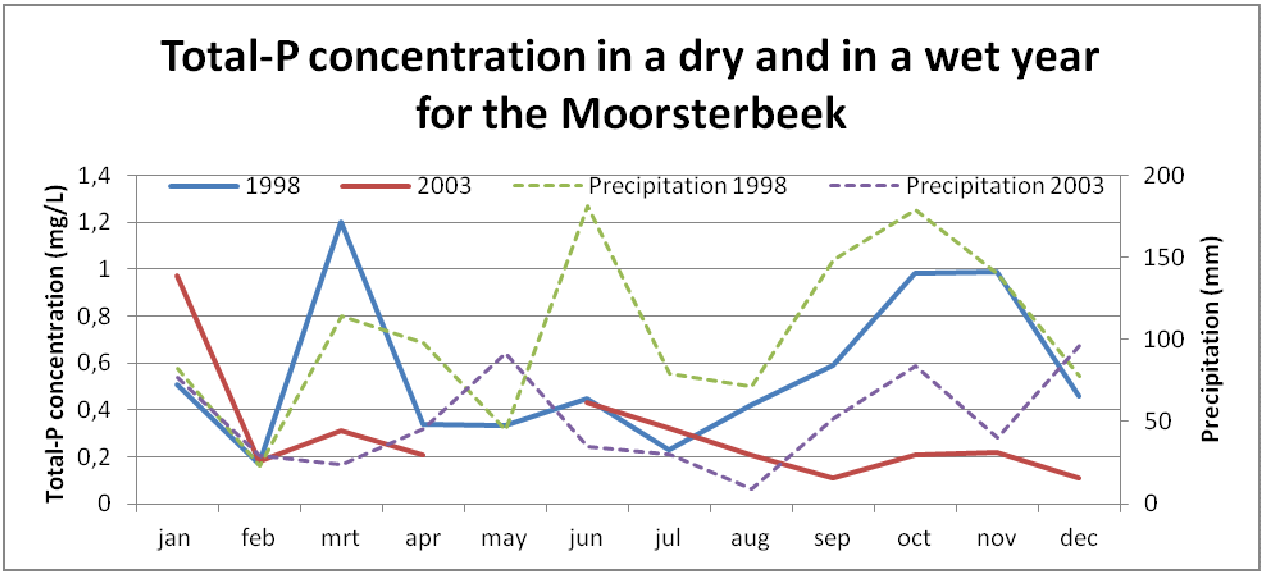

Figure 18: Total-P concentration in a dry and in a wet year for the Moorsterbeek, where 1998 is a wet year and 2003 is a dry year.

When comparing the Total-P concentration with the precipitation the Total-P concentrations generally increase when the precipitation increases. Also a difference between summer and winter season is shown. In March an increase in precipitation causes a large increase in Total-P concentration. In October and November this is also shown. In June however a large increase in precipitation does not affect the Total-P concentrations significantly. This difference between summer and winter season could be explained by changing groundwater levels. When looking at the dry year 2003, the reaction of Total-P to increases in precipitation is less extreme. This could indicate that the above mentioned expectation about low groundwater levels could be plausible. The precipitation infiltrates and stays in the soil because the soil is not quickly saturated, leading to less runoff and therefore lower Total-P concentrations. To be able to compare figure 18, the same figure for the Lunterse beek and the Barneveldse beek are presented in annex 3. From this figure the same results are shown, meaning that the results from figure 18 are validated and stronger conclusions can be drawn from it.

Effect of fertilizer use

Whether phosphate concentrations in surface waters decrease due to legislation on fertilizer use is difficult to analyze with this limited dataset (one measurement per month). The data is also influenced by groundwater levels and rain events, which makes it's hard to separate only the effect of changes in fertilizer use. However when looking at figure 7 the first graph high concentrations are shown in the year 2007. Despite of these high concentrations the regression (for all data) is still negative, which suggests that concentrations from 1997 till 2006 are higher than concentration from 2007 till 2010. When looking at the regression for 80% of the data also a negative trend is shown, also suggesting that concentrations decrease over time, not caused by high phosphate concentrations due to weather conditions. This holds for 8 out of 10 brooks (see annex 2). Only for the Modderbeek and the Nederwoudsebeek the trend for 80% of the data became positive, but for these brooks not all data for each year was present. The decrease in phosphate concentration of the 80%-regressions could be allocated to changing background concentrations and/or to less runoff from agricultural fields, which could be possibly allocated to changes in fertilizer use.

Furthermore, if sudden changes in fertilizer use can lead to lower concentrations, it could also be concluded that legislation on fertilizer use can be useful in decreasing phosphate concentrations in surface waters. Such a change was observed in the area of the Esvelderbeek in 2003, where lots of animals were killed because of a higher contagious animal decease (Gerritsen, 2012). In this year there was significantly less animal waste/manure present in the area, which could possibly lead to less runoff of phosphate from animal wastes/manure. In figure 19 the Total-P concentrations from the Esvelderbeek from 2001-2005 are shown.

From this figure it is shown that the years 2001 and 2002 show similar concentrations as the year 2003, except for the month January. A clear difference is shown between 2003 and 2004, where the concentrations in 2004 are generally lower than in 2003. In the year 2005 the concentration is similar to 2003 again. It could be possible that the low concentrations in 2004 are present due to a time lag in runoff, which could possibly mean that sudden changes in fertilizer use can contribute to lower phosphate concentrations. In annex 4 the same figures are shown for the Moorsterbeek and the Lunterse beek. In these areas no significant differences in fertilizer use was observed and in these figures there is no clear difference between 2003 and 2004. Because the phosphate runoff is highly dependent on groundwater levels and rain events, it is difficult to draw hard conclusions for this data, especially due to the fact that 2003 was a dry year.

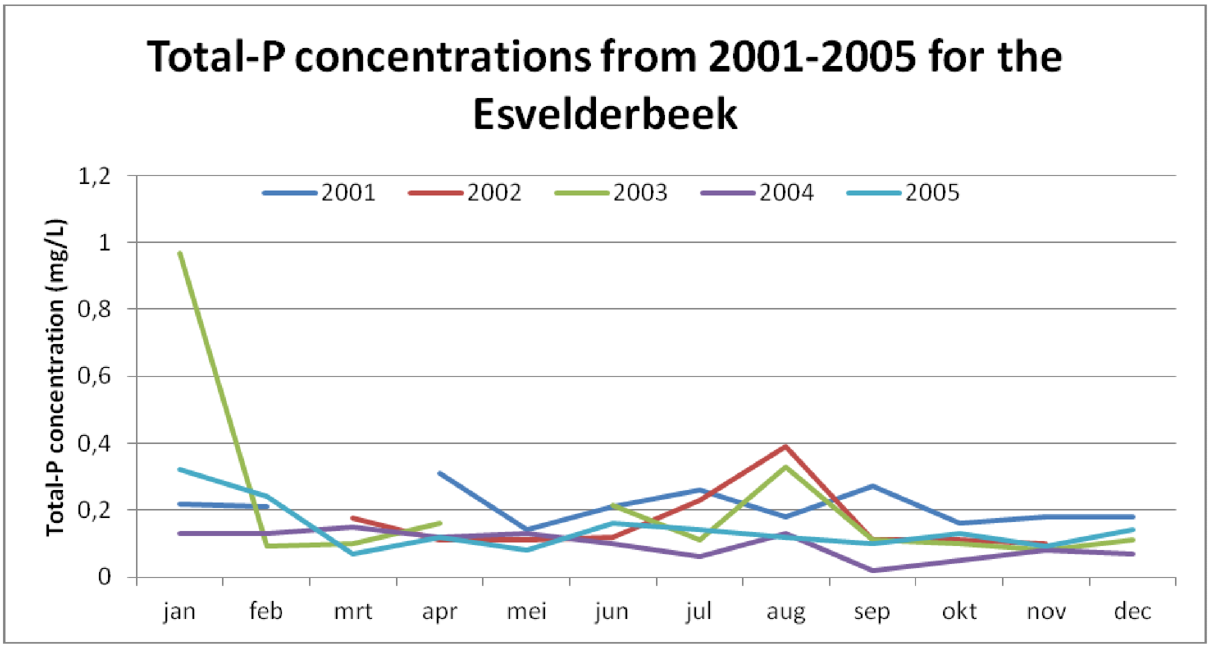

Figure 19: Comparison of Total-P concentrations for the years 2001-2005 for the Esvelderbeek

Effect of land use

In this section it is tried to explain variations in phosphate concentration on an area specific level. The processes stated in 4.3.1 are al of importance for the brooks, but in this section especially the land use in the areas play a role in explaining variations.

From the extra information of a study of Roubos (2009) it becomes clear that in the selected regions the phosphate concentrations mainly consist of phosphate originated from agricultural practices. For the Lunterse beek, Nederwoudsebeek, Fliertsebeek, Modderbeek and the Barneveldsebeek 93% of the phosphate concentrations comes from agricultural sources. For the Nattegatsloot this is 94% and for the Moorsterbeek this is 95%. For the other three brooks this information was not available, but similar shares are expected. With agriculture playing a very important role in phosphate concentrations in surface water, the differences in phosphate concentrations must be determined by different agricultural practices and/or by dilution because of seepage.

Differences in land use can be important, for example corn production is globally associated with high fertilizer use. Extensive rainfall can result to up to 70% loss of phosphate fertilizer and can result in high concentrations of phosphate/eutrophication in lakes and rivers (Mehnaz et al., 2010). Intensive livestock farming is also a source of phosphate in surface waters, the phosphate come from animal waste, so the more animals the more phosphate can end up in surface waters (Fadiran et al., 2008). From this information the conclusion can be drawn that areas with a lot of intensive livestock farming and corn production are vulnerable to high phosphate concentrations in surface waters. Areas with a lot of nature do not contribute much to phosphate concentrations, in these areas only decaying organic materials are a source of phosphate.

All areas under consideration are mainly used for agricultural activities. To start with the water basin 'Lunterse beek' the area mainly consists of grasslands, which are used for livestock farming. Furthermore, around 20% of the surface area is used to cultivate corn and intensive agriculture is also present in this water basin (WVE, 2005; Roubos, 2009). The agricultural grounds are phosphate saturated in this area, due to agricultural activities in the present and the past. Phosphate saturated soils have a high runoff potential and could cause high phosphate concentrations in the spring and winter due to leaching and runoff of phosphate (WVE, 2004). For the brooks within this water basin the conditions are relatively the same, only for the Fliertsebeek some houses which are not connected to the sewer system drain into the brook (Roubos, 2009), possibly leading to higher concentrations in the Fliertsebeek. Concentrations in the Lunterse beek are also dependent on the upstream located brooks, the Nederwoudsebeek and Fliertsebeek.

In water basin ‘Modder en Moorsterbeek’ the area is also mostly used as grasslands. Also some nature conservation areas are present, which do not contribute to phosphate runoff to surface waters (WVE, 2004). For this water basin also phosphate saturated soils still contribute to phosphate runoff to surface waters. For the Moorsterbeek and Modderbeek 10-30% of the area is used for corn production (Roubos, 2009).

For the water basin ‘Barneveldse beek’ intensive farming is present as well as grassland and patches of nature. In the east of this water basin seepage takes place, which dilutes the phosphate concentrations a bit (WVE, 2004). For the Barneveldse beek around 10-30% of the area is used for corn production and some nature. In the area of the Esvelderbeek grasslands have the upper hand, but also some corn production is present (WVE, 2005). For the Hoevenlakense beek the land use is dominated by grasslands, but also urban areas are present.

Finally, for the Brede beek, located in water basin ‘Arkemheen’, around 9% of the agricultural area is used for the cultivation of corn. Grasslands are also present in this area (WVE, 2005).

Because the information about the areas is limited it is hard to draw conclusions from them, however the information that is present could indicate why concentrations are varying on a spatial scale. For example, phosphate concentrations were highest in the water basin ‘Lunterse beek’ (see spatial analysis). Historical saturated grounds, intensive agriculture and the drainage of several households could be an explanation for high phosphate concentrations. For water basin ‘Modder and Moorsterbeek’ the comparable agricultural practices are present. Lower concentrations in this water basin could be explained by the presence of nature and because of the absence of households who drain into the brooks. For the water basin ‘Barneveldse beek’ the lowest concentrations were shown in the spatial analysis which can possibly be explained by dilution of the concentration due to seepage in the eastern region of the basin. For the Brede beek not much information was present so no clear conclusions can be drawn from the information.

All in all, this area specific information is too vague to draw conclusions and it can act merely as an indication for an explanation. To be able to draw hard conclusions further research is needed on the area specific sources of phosphate in surface waters.

5. Conclusions

Starting with the first research question, concerning trends in phosphate concentration over the period 1995-2010, the results are deviated. Only 19% of the regressions show a statistical significant relationship between phosphate concentrations and time, of which 16% show a negative trend and 3% show a positive trend. Furthermore, 70% of all regressions (80 regressions) show a negative trend, but are not necessarily statistical significant. Looking at all regressions for Total-P (40 regressions) 85% of the regressions is negative. For Ortho-P this value is lower, namely 55%.

From these results the conclusion can be drawn that however only 19% of the regressions are statistical significant, a clear difference is shown between negative and positive trends. Especially for Total-P most trends are negative, maybe pointing out that the phosphate concentrations are decreasing over time. The visualizations and the coefficient of the OLRs show that there is a difference in speed of the decrease per brook and in case of the Brede beek there even is an increase in phosphate concentration.

When considering meeting the targets set by the Water Framework Directive by 2015 or 2027, the second research question, after extrapolation of the regressions for the summer average Total-P concentrations only 40% of the 10 selected brooks meet the WFD standard by 2015. In 2027 this has increased to 50%, but that means that still half of the brooks do not meet the WFD standard.

On a spatial scale, when considering Total-P and Ortho-P and the WFD standards, the results tend to improve when moving north, with an exception of the Brede beek. So, the highest concentrations are observed in water basin the 'Lunterse beek' and the lowest concentrations in water basin 'Barneveldse beek'. Considering changes in Total-P concentrations between 2005-2010 and 1995-2000 no clear spatial pattern is present.

Considering research question 4, differences in phosphate concentrations can be caused by differences in groundwater levels, differences in precipitation and due to differences in fertilizer use between the different brook and water basins. Also seepage and drainage of households in brooks can also influence phosphate concentrations in surface waters. However no solid conclusions about the possible explanations of the temporal and spatial trends can be drawn due to insufficient data on the specific areas.

Coming back to the central research question the phosphate concentrations tend to decrease in time, however not completely statistically proven. However by 2015 only 40% of the brooks meet the WFD standard and 50% by 2027. On a spatial scale the concentrations tend to increase in southern direction, with exception of the Brede beek. This spatial trend is also shown for meeting the WFD standards, only the Nederwoudsebeek and the Brede beek deviate from this statement.

6. Discussion

The usefulness of this study lies in the fact that the data is analyzed in several ways, on both a spatial and a temporal scale, but also three different analyses on a temporal scale (step 1, 2 and 3). By doing these different analyses more information about the trends is obtained than when only drawing conclusions from one analysis.

Step 1 is used to assess all the data available and to determine the temporal trend of phosphate over the years. Step 2 is introduced to compare the results with step 1, but also to make it easier to compare years and brooks with each other. Step 3 is introduced to analyze the difference between the meteorological seasons and how the results of step 1 are depending on the different seasons. The different tests also back each other up, which makes the results more credible although most of the regressions show no statistical significant regressions. When only one step was done, the results would be more sensible to unpredictable variations and would be less useable to base further research on for example.

It is up to the reader to decide whether the results are truly useful or not, because of the low amount of statistical significant trends. However, the fact that 70% of all regressions and 85% of the Total-P regressions are negative could be a indication that phosphate concentrations are decreasing in the Gelderse Vallei.

These results can become more valuable when assessing the data and methodology used in this study on a higher level. First there is difference in the number of measurements for the selected brooks. Where some brooks have 150 measurements or more, the Fliertsebeek has only 42 measurements, followed by the Hoevenlakense beek with 63 measurements. Respectively 42 and 63 measurements could be a too low amount of measurements to be able to draw validate conclusions about the trends from 1995-2010.

In a study of Rozemeijer (2010) it is shown that a sample frequency of once a month is generally insufficient to capture the concentration dynamics in surface water. For example, when it rains there is a short sudden increase in runoff of phosphate to surface waters (van der Velde, 2010) and the mean recovery time of phosphate concentrations after a rainfall is 6,1 hours. When a measurement is taken precisely in this peak event a high value could be the result and could influence the trend of phosphate. Together with uncertainties in measurements this results in large uncertainties in the estimates of average concentrations (Rozemeijer, 2010). This problem can be reduced by increasing the measurement frequency.

Also attention should be paid to the use of ordinary linear regressions. OLRs are merely used as a statistical tool to analyze the dataset. Using OLRs negative concentrations are possible, while in real life phosphate concentrations cannot become lower than the background concentration. So the OLRs are used to determine trends and do not resemble the natural situation. Carefulness is therefore needed when basing measures or legislation on the results.

Considering the results of this study especially the results of research question 2 are important for WVE. With respectively 60% and 50% of the brooks who do not meet the WFD standard by 2015 and 2027, extra measures should be taken by WVE to ensure that these brooks meet the required Total-P concentration by 2015 or 2027. Especially for the Lunterse beek, Fliertsebeek and Brede beek extra measures are needed, for these brooks are not even close to reaching the goal. If it is validated that decreasing fertilizer use leads to lower phosphate concentration in the brooks, this is the most effective measure for WVE to decrease the phosphate concentrations in surface waters. For the Fliertsebeek connecting households to the sewage system could possibly be a measure to decrease the phosphate concentrations in the brook. Not only the Fliertsebeek will show lower concentration, but because the Fliertsebeek is a branch of the Lunterse beek phosphate concentrations in the Lunterse beek will also decrease due to this measure.

Furthermore, the results of meeting the WFD standards are compared to the results from other water boards. For water board 'Hunze en Aa's', located in the North-East of the Netherlands, by 2009 already 80% of the measurement locations meet the WFD standard (Torenbeek, 2010). The same values are present in the management area of water board 'Groot Salland' located south of Hunze en Aa's and north of WVE (WGS, 2010). For water board 'De Stichtse Rijnlanden', located directly south of water board WVE, the results are comparable with the results of this study. Here 40% of the measurement locations meet the WFD standard by 2009 (HDSR, 2010). Precaution should be taken, for in both cases also other WFD water types are included, which could have different WFD standards for Total-Phosphate. However it is clear that some water boards perform better concerning WFD standards of Total-Phosphate and others show comparable results.

Because the WFD is only concerned with summer averages of Total-P and as stated before measuring once a month doesn't capture the concentration dynamics of phosphate, increasing the sample frequency in the summer months could be a valuable improvement. By doing this the data becomes more accurate and is less affected by peaks caused by sampling during rain events. It is however not possible to cut the measurements in the winter, because the management area of WVE drains into the Eemmeer, which has a year round WFD standard (Gerritsen, 2012).

Due to limitations in time only 10 different locations are analyzed. However WVE has a bigger regular grid containing more measurement points. Using the data of other measurement points enhances the knowledge of the phosphate trends in the area and makes it easier to derive spatial patterns in phosphate concentrations. Also further research can be done on explaining the temporal and spatial trend of the specific areas. From this study no solid conclusions can be drawn, but it could be a starting point of a study on explaining temporal and spatial differences in phosphate concentrations.

Furthermore phosphate is only one of the pollutant considered in the WFD, so if phosphate concentrations meet the WFD standards this will not automatically mean that a good chemical status is achieved for surface waters. The results in this study should therefore be linked to studies about other pollutants to assess whether the water quality of a surface water complies to all norms.

As a concluding remark, from this research it becomes clear that for WVE the most attention must be paid to the water basin 'Lunterse beek', to the Brede beek and to a lesser extend to the water basin 'Modder en Moorsterbeek'. In water basin 'Barneveldse beek' no extra attention is needed considering phosphate concentrations. From this research no clear measures to decrease phosphate concentrations can be drawn, but it can act as a stepping stone for further research.

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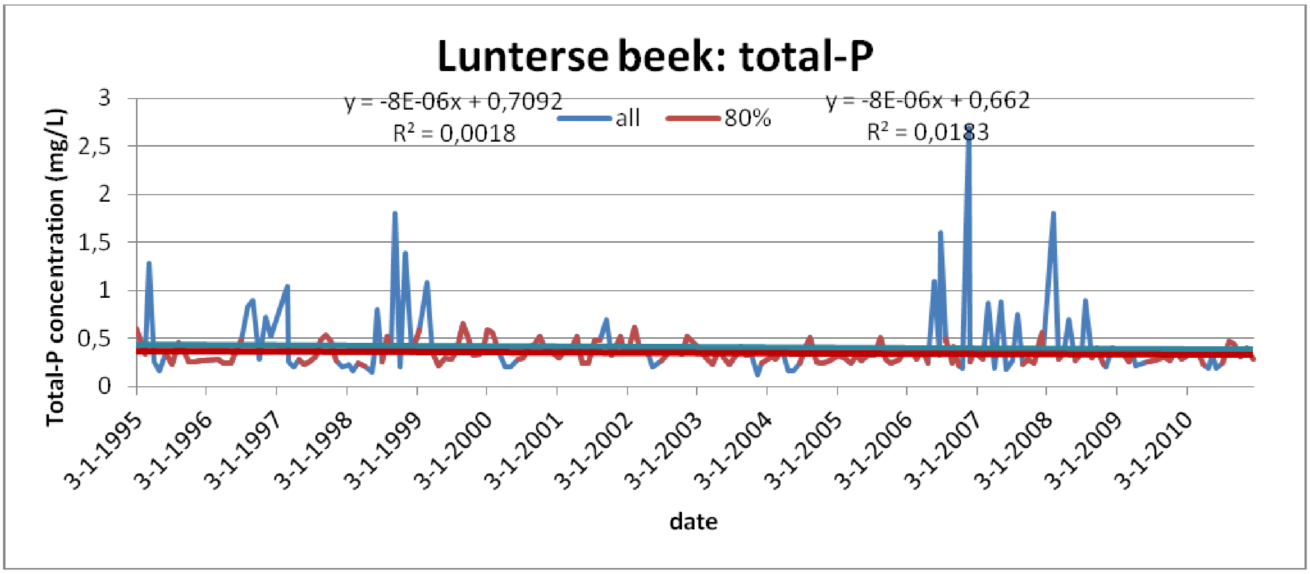
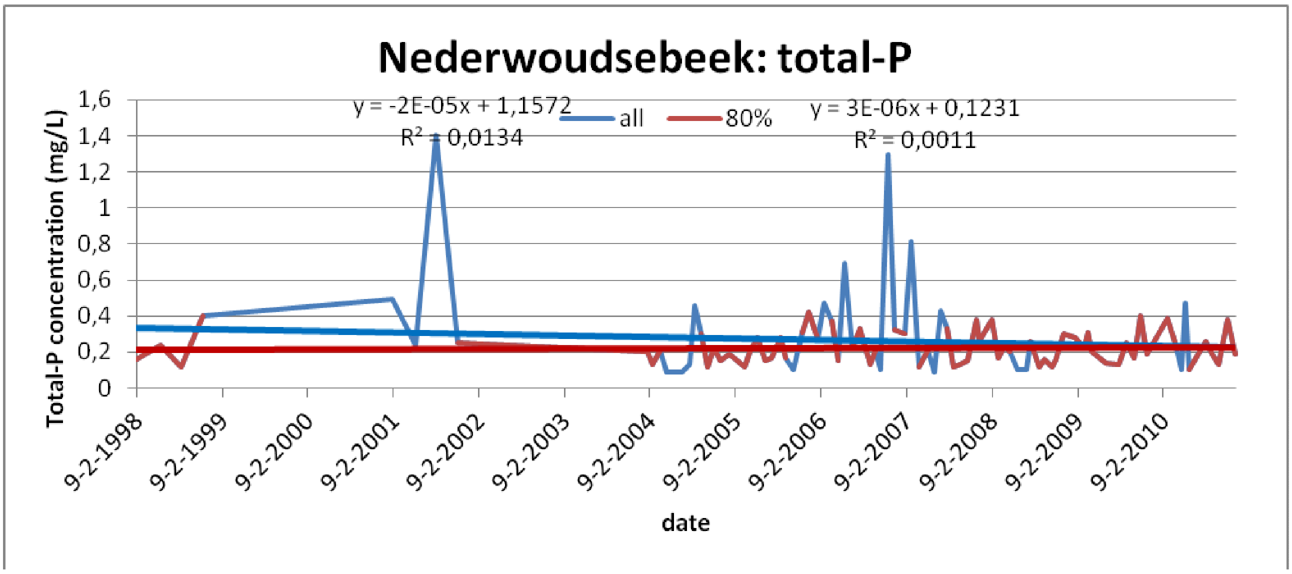
Annexes

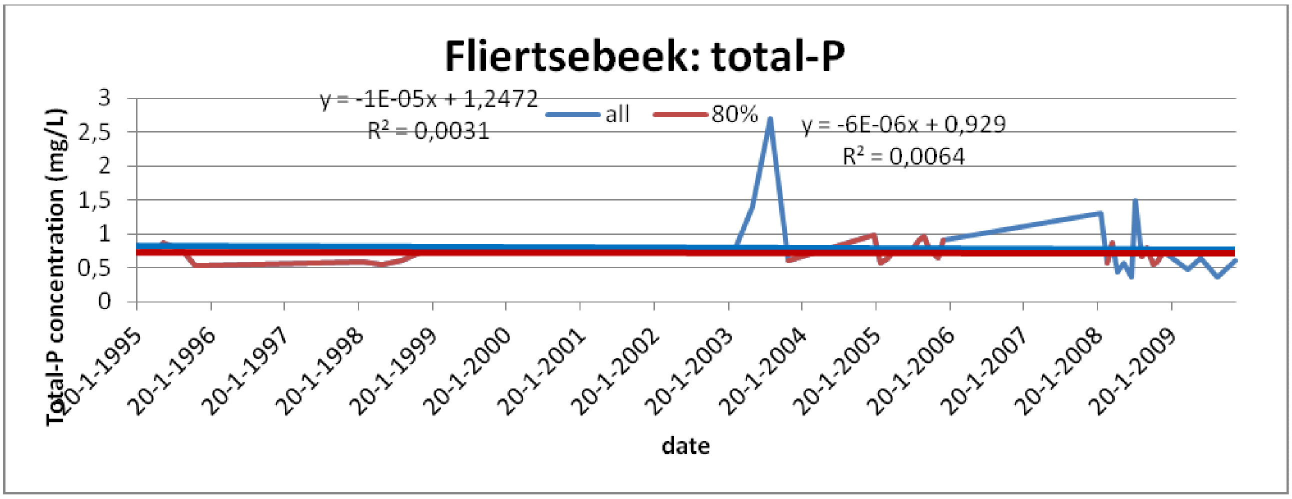
Annex 1: A statistical overview of the dataset used in this study.

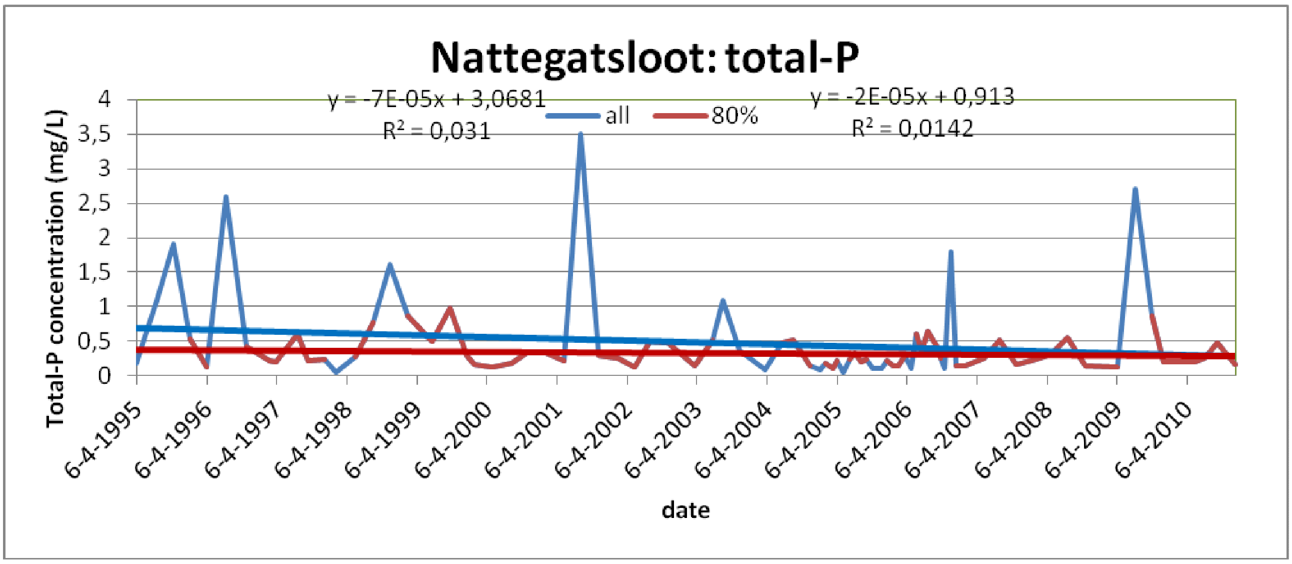
Brook		n	min	max	mean	median	mode
1. Lunterse beek	Total-P	193	0,13	2,7	0,41	0,33	0,26
	Ortho-P	194	0,01	1,2	0,18	0,14	0,12
1a. Nederwoudsebeek	Total-P	89	0,09	1,4	0,26	0,2	0,12
	Ortho-P	89	0,01	0,92	0,11	0,07	0,04
1b. Fliertsebeek	Total-P	42	0,36	2,7	0,78	0,73	0,87
	Ortho-P	42	0,11	2,2	0,54	0,44	0,43
2. Nattegatsloot	Total-P	80	0,06	3,5	0,48	0,25	0,15
	Ortho-P	80	0,02	1,6	0,19	0,09	0,03
3. Moorsterbeek	Total-P	167	0,11	1,9	0,31	0,23	0,23
	Ortho-P	167	0,01	0,75	0,14	0,11	0,07
4. Modderbeek	Total-P	81	0,07	1,87	0,23	0,17	0,13
	Ortho-P	82	0,00	1,49	0,09	0,06	0,04
5. Barneveldse beek	Total-P	40	0,11	0,96	0,24	0,19	0,18
	Ortho-P	40	0,01	0,62	0,10	0,08	0,04
5a. Esvelderbeek	Total-P	187	0,02	1,17	0,19	0,14	0,12
	Ortho-P	190	0	0,73	0,05	0,03	0,01
5b. Hoevenlakense beek	Total-P	63	0,06	2,57	0,30	0,2	0,16
	Ortho-P	63	0,01	0,76	0,10	0,06	0,02
6. Brede beek	Total-P	119	0,02	1,24	0,27	0,22	0,22
	Ortho-P	121	0,00	0,6	0,10	0,06	0,03

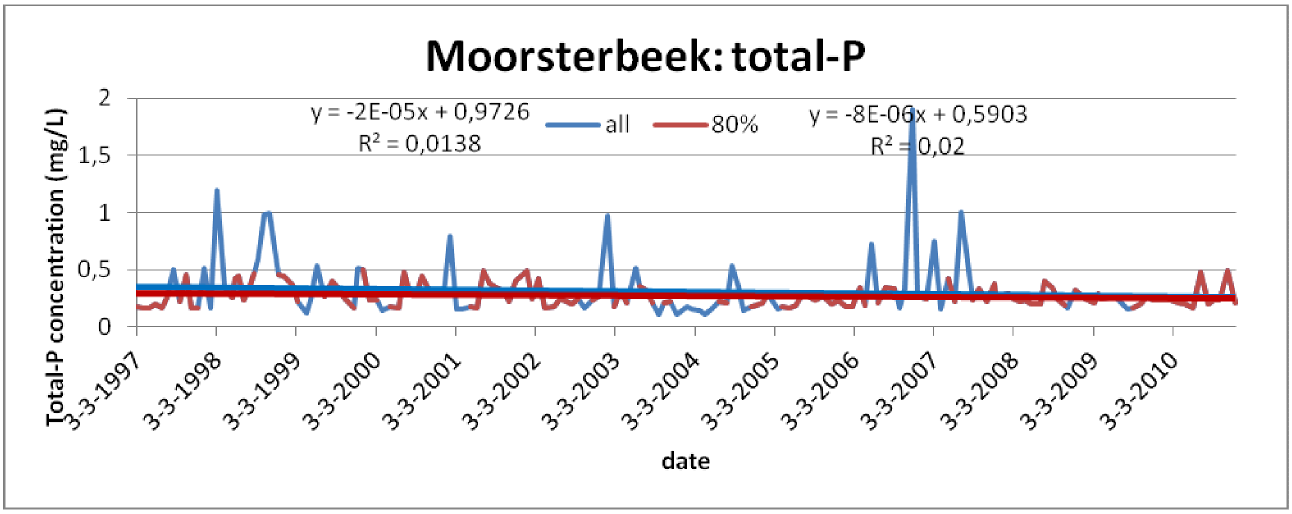
Annex 2: Total-P concentrations for all data and 80% of the data for all selected brooks.

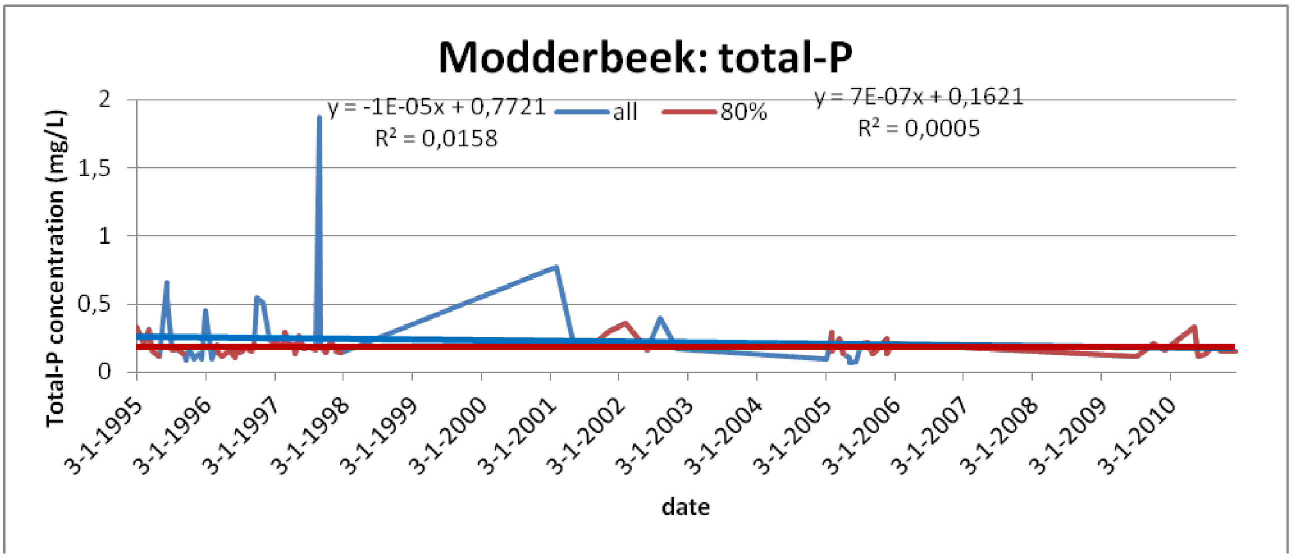


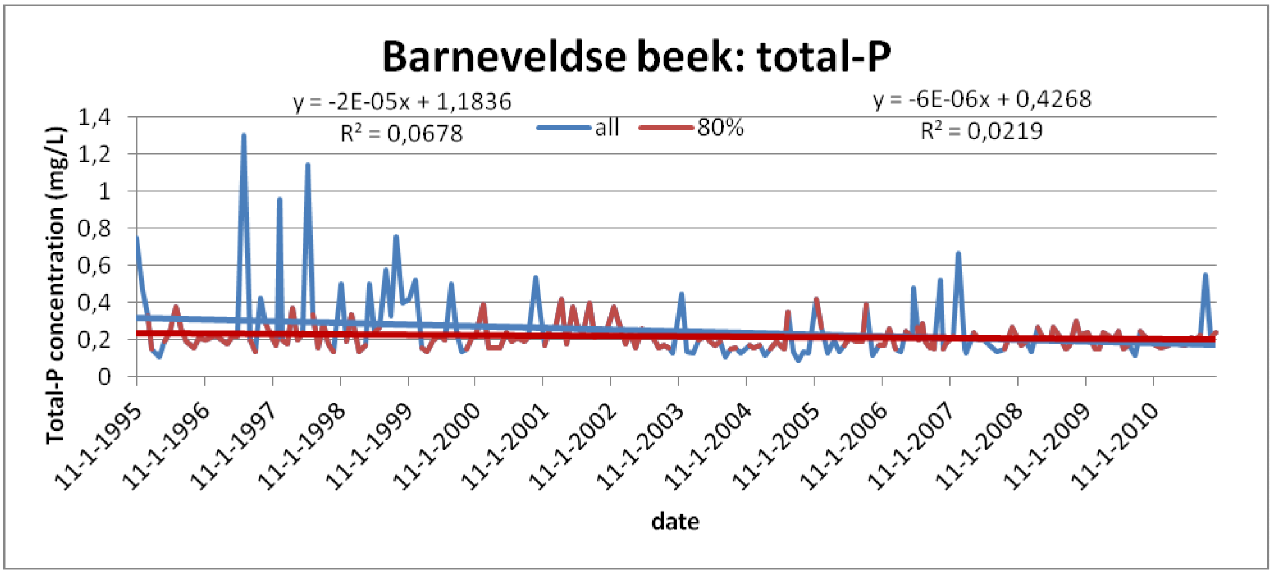


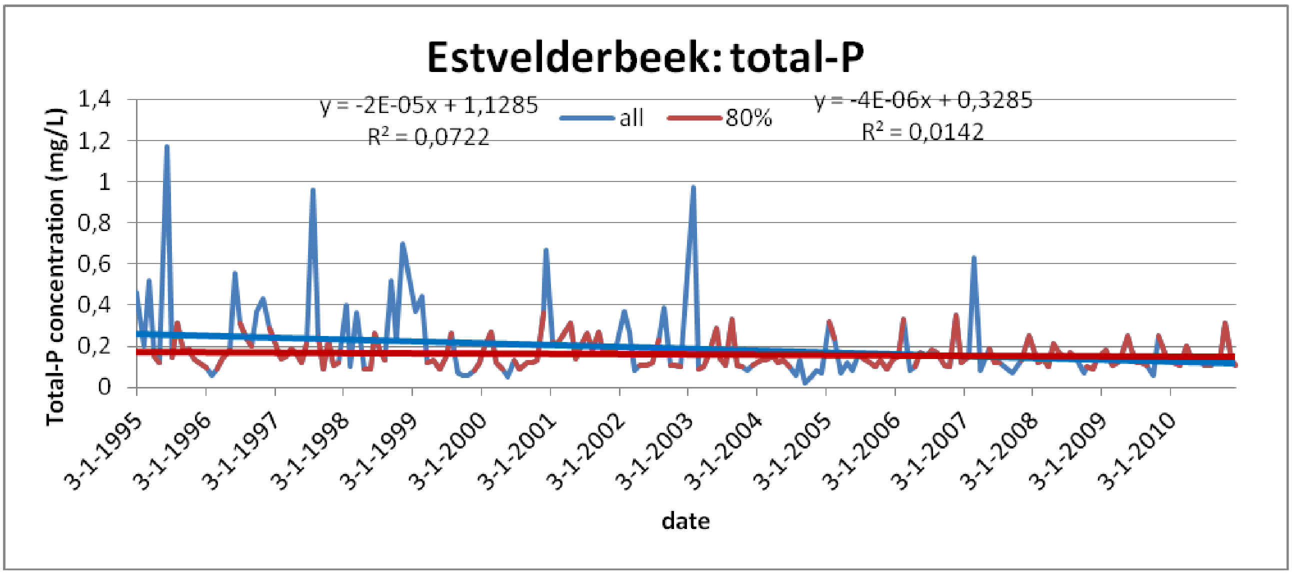



Nattegatsloot: total-P
y = -7E-05x + 3,0681
R² = 0,031
all
80%
y = -2E-05x + 0,913
R² = 0,0142
Total-P concentration (mg/L)
4
3,5
3
2,5
2
1,5
1
0,5
0
6-4-1995
6-4-1996
6-4-1997
6-4-1998
6-4-1999
6-4-2000
6-4-2001
6-4-2002
6-4-2003
6-4-2004
6-4-2005
6-4-2006
6-4-2007
6-4-2008
6-4-2009
6-4-2010
date


Moorsterbeek: total-P
y = -2E-05x + 0,9726
R² = 0,0138
all
80%
y = -8E-06x + 0,5903
R² = 0,02
Total-P concentration (mg/L)
2
1,5
1
0,5
0
3-3-1997
3-3-1998
3-3-1999
3-3-2000
3-3-2001
3-3-2002
3-3-2003
3-3-2004
3-3-2005
3-3-2006
3-3-2007
3-3-2008
3-3-2009
3-3-2010
date


Modderbeek: total-P
y = -1E-05x + 0,7721
R² = 0,0158
all
80%
y = 7E-07x + 0,1621
R² = 0,0005
Total-P concentration (mg/L)
2
1,5
1
0,5
0
3-1-1995
3-1-1996
3-1-1997
3-1-1998
3-1-1999
3-1-2000
3-1-2001
3-1-2002
3-1-2003
3-1-2004
3-1-2005
3-1-2006
3-1-2007
3-1-2008
3-1-2009
3-1-2010
date


Barneveldse beek: total-P
y = -2E-05x + 1,1836
R² = 0,0678
y = -6E-06x + 0,4268
R² = 0,0219
all
80%
Total-P concentration (mg/L)
1,4
1,2
1
0,8
0,6
0,4
0,2
0
11-1-1995
11-1-1996
11-1-1997
11-1-1998
11-1-1999
11-1-2000
11-1-2001
11-1-2002
11-1-2003
11-1-2004
11-1-2005
11-1-2006
11-1-2007
11-1-2008
11-1-2009
11-1-2010
date


Estvelderbeek: total-P
y = -2E-05x + 1,1285
R² = 0,0722
y = -4E-06x + 0,3285
R² = 0,0142
all
80%
Total-P concentration (mg/L)
1,4
1,2
1
0,8
0,6
0,4
0,2
0
3-1-1995
3-1-1996
3-1-1997
3-1-1998
3-1-1999
3-1-2000
3-1-2001
3-1-2002
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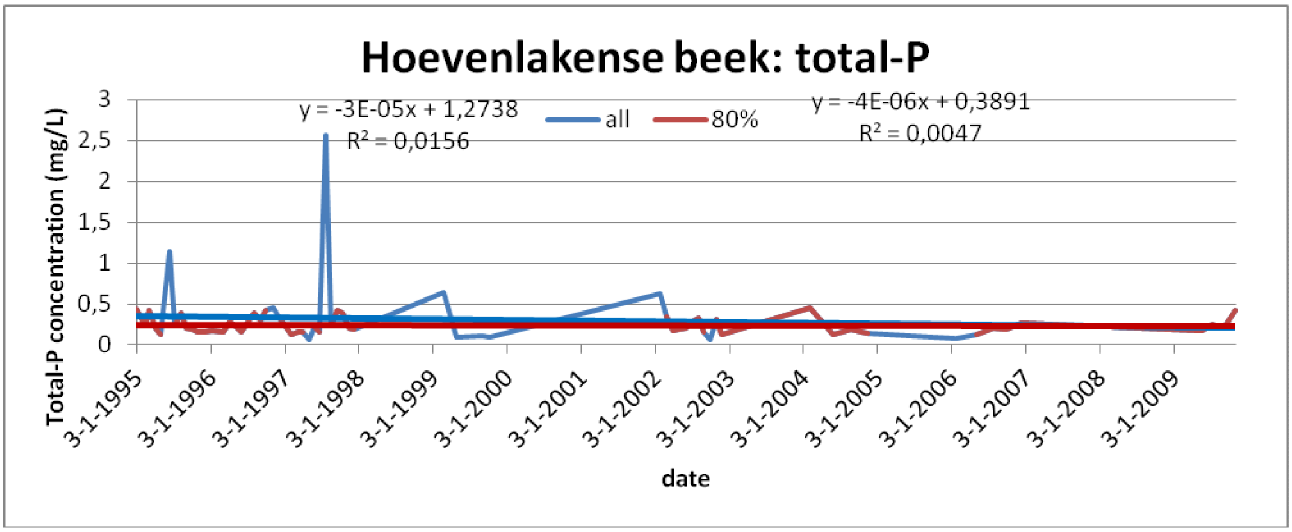
3-1-2005
3-1-2006
3-1-2007
3-1-2008
3-1-2009
3-1-2010
date


Hoevenlakense beek: total-P
y = -3E-05x + 1,2738
R² = 0,0156
y = -4E-06x + 0,3891
R² = 0,0047
all
80%
Total-P concentration (mg/L)
3
2,5
2
1,5
1
0,5
0
3-1-1995
3-1-1996
3-1-1997
3-1-1998
3-1-1999
3-1-2000
3-1-2001
3-1-2002
3-1-2003
3-1-2004
3-1-2005
3-1-2006
3-1-2007
3-1-2008
3-1-2009
date

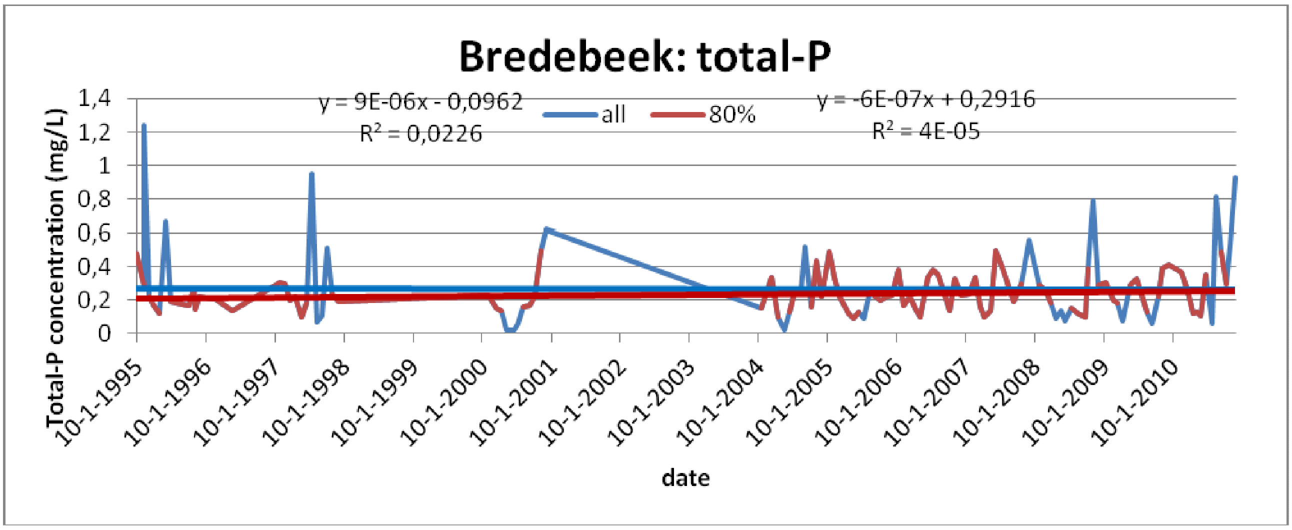
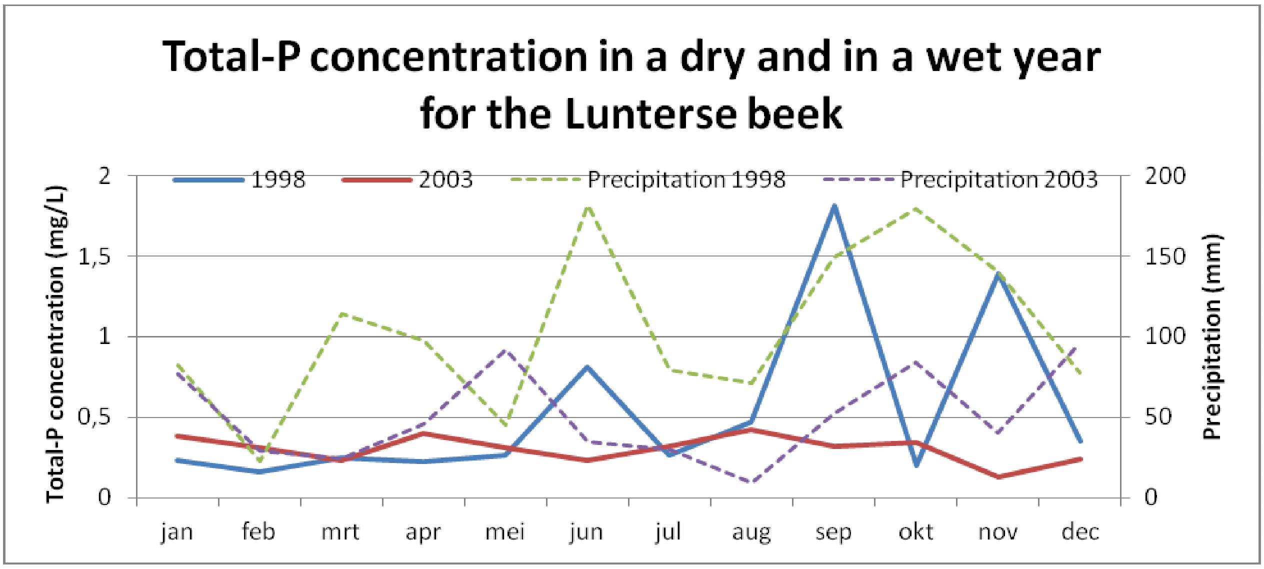
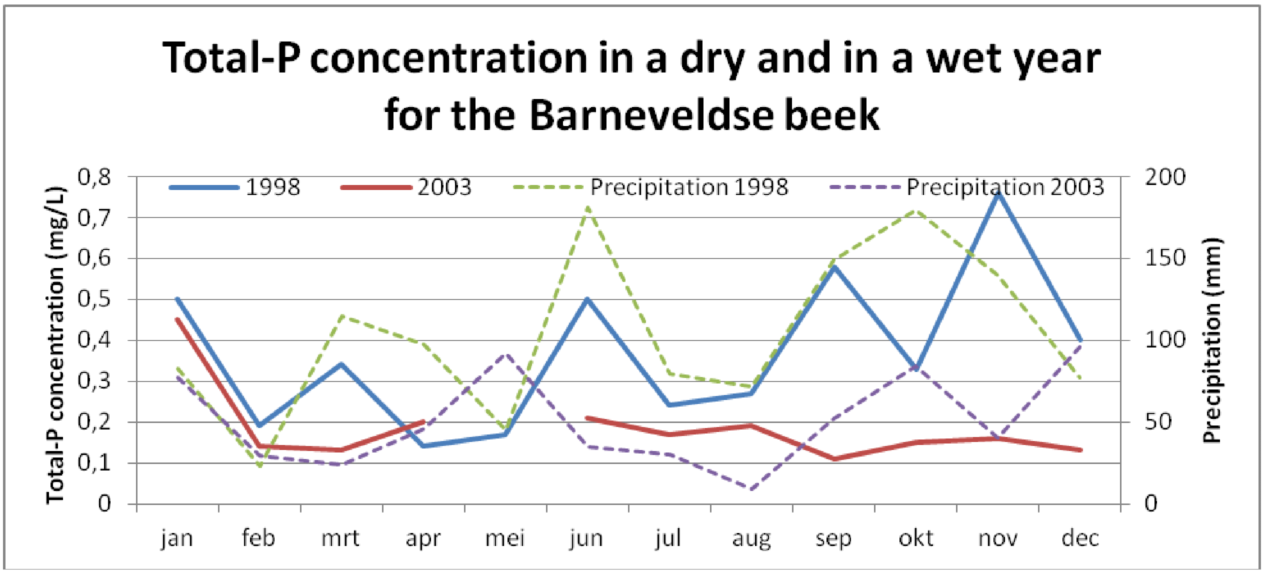


Figure 1: Total-P concentrations for all data and 80% of the data for a) Lunterse beek, b) Nederwoudsebeek, c)Fliertsebeek, d) Nattegatsloot, e) Moorsterbeek, f) Modderbeek, g)Barneveldese beek, h) Esvelderbeek, i) Hoevenlakense beek and j) Brede beek.

Annex 3: Total-P concentrations for the Lunterse beek and the Barneveldse beek in a dry year (2003) and in a wet year (1998).





Annex 4: Comparison of Total-P concentrations for 2001-2005 for the Moorsterbeek and the Lunterse beek.