MASTER THESIS

Phosphorus release from the stream bed sediment in the management area of waterboard "Hoogheemraadschap De Stichtse Rijnlanden"

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English abstract

Several waters in the management area of waterboard "Hoogheemraadschap De Stichtse Rijnlanden" should meet the requirements for the Water Framework Directive but do not fulfil due to high phosphorus concentrations in the water column. These phosphorus concentrations were expected to be (partly) caused by high phosphorus release rates from the stream bed sediment to the water column, especially in non-urban ditches. Hence, phosphorus release rates were quantified in 57 non-urban ditches, divided over 11 sub-areas. This quantification was based on prior observed correlations of phosphorus release rates with interstitial phosphorus, the interstitial iron:phosphorus ratio and the sediment iron:sulphur ratio.

Also relations of phosphorus release with soil type, land use type, seepage/infiltration rate, nature management and chemical and non-chemical characteristics of the ditches were studied for more insight on phosphorus release (and mechanism behind it) and to define rules of thumbs about phosphorus release. These rules were based on easy determinable ditch characteristics (relative to interstitial phosphorus, interstitial iron:phosphorus and sediment iron:sulphur) and aimed to easily indicate ditches where phosphorus release is probably high or low.

Mean phosphorus release rates in the sub-areas vary between 0.0 and 2.0 mg P/m^2/day and the high release rates in some sub-areas might indeed explain high phosphorus concentrations in the water column.

Phosphorus release largely differs per soil type; the release is highest in peat areas and lowest in (sabulous) clay areas. Phosphorus release also seems to differ per land use and be lower by fruit cultivation than by crops/grasslands. However, this was not statistically verified. No effect of infiltration is found. Results, however, revealed that iron-rich seepage leads to lower release rates. Also nature management (e.g. decline of fertilizer use) can lead to lower phosphorus release rates. Phosphorus release correlates with variables that indicate organic decomposition, which emphasizes the important role of organic decomposition for phosphorus release. Furthermore, most locations with highly organic stream bed sediment also had low sediment phosphorus binding capacity, partly due to low iron concentrations.

The "Rules of thumbs" form a tool that can easily indicate the possibility of phosphorus release but not the height of phosphorus release. At locations with a possibility of phosphorus release, determined with this tool, water managers could decide to measure interstitial phosphorus concentrations to quantify the height of phosphorus release.

Keywords: phosphorus release, phosphate, iron, sulphate, organic decomposition, oxic sediment boundary, internal eutrophication, water quality.

Dutch abstract

Sommige wateren in het beheergebied van het waterschap "Hoogheemraadschap De Stichtse Rijnlanden" voldoen niet aan de eisen van de Kaderrichtlijn Water door te hoge fosfor concentraties in het oppervlakte water.

Deze hoge concentraties worden wellicht (deels) veroorzaakt door de nalevering van fosfor vanuit de waterbodem naar het oppervlakte water. Dit geldt vooral voor de landelijke sloten. Deze nalevering werd daarom gekwantificeerd in 57 landelijke sloten, verdeeld over 11 deelgebieden, aan de hand van gevonden correlaties van fosfor nalevering met bodemvocht fosfor, de bodemvocht ijzer:fosfor ratio en de waterbodem ijzer:zwavel ratio.

Ook werden relaties tussen fosfor nalevering en bodemtype, landgebruik, kwel/wegzijging, natuurbeheer en chemische en niet-chemische sloot karakteristieken onderzocht voor extra inzicht in fosfor nalevering (en achterliggende mechanismen) en om vuistregels op te stellen. Deze vuistregels, op basis van makkelijk bepaalbare sloot karakteristieken ten opzichte van bodemvocht fosfor, de bodemvocht ijzer:fosfor ratio en de waterbodem ijzer:zwavel ratio, moesten resulteren in een simpele tool om locaties met hoge of lage fosfor nalevering aan te geven.

De gemiddelde nalevering in de deelgebieden varieert tussen de 0,0 en 2,0 mg P/m^2/dag en de hoge fosfor nalevering snelheden in sommige deelgebieden kunnen waarschijnlijk hoge fosfor concentraties in het oppervlakte water verklaren.

De nalevering verschilt sterk per bodemtype: de nalevering was het hoogst in de veengebieden en het laagst in de zavel- en kleigebieden. Het lijkt erop dat de nalevering ook verschilt per landgebruik en lager is bij fruitteelt dan bij akkers en grasland. Dit kon echter niet statistisch worden bewezen. Geen effect van wegzijging op de nalevering was gevonden. IJzerrijk kwel zorgt echter wel voor een lage fosfor nalevering vanuit de waterbodem. Ook natuurbeheer (o.a. laag mestgebruik en hoge waterstanden) kan zorgen voor een verminderde nalevering.

Fosfaat nalevering correleert sterk met variabelen die duiden op organische decompositie. Dit benadrukt de belangrijke rol van organische afbraak voor de nalevering. De meeste sloten met veel organische afbraak hadden daarnaast ook een lage fosfor bindingscapaciteit in de waterbodem, deels door lage ijzerconcentraties in de waterbodem.

De resulterende vuistregels vormen een simpele tool om locaties aan te wijzen waar er wellicht sprake is van fosfor nalevering. De hoogte van de nalevering kan echter niet worden bepaald met deze vuistregels. In sloten waar nalevering voor kan komen kunnen de beheerders zelf bepalen om de hoogte van de nalevering te kwantificeren met fosfor gehaltes in het bodemvocht.

Preface

This thesis has been carried out as the final part of my Master program Sustainable Development at the Utrecht University. The research was conducted as an internship at Waterboard "Hoogheemraadschap De Stichtse Rijnlanden" and in cooperation with B-ware. B-ware is a research centre on biogeochemical water-management and applied ecosystems, a spin-off company of the department of aquatic ecology and environmental biology of the Radboud University Nijmegen.

I would like to thank the following people, without whose help and support this thesis would have been impossible.

First I want to show my gratitude to the people of waterboard "Hoogheemraadschap De Stichtse Rijnlanden". I would like to thank my supervisors Henk van Hardeveld and Bas Spanjers for giving me the opportunity to conduct a study of my own interest and to learn more about the waterboard. Besides that, their guidance and enthusiasm have always motivated me. I would also like to thank Peter Heuts and Joost Heijkers for their advice and help. Besides them, I would like thanks to the whole advisory department for giving me such a nice time. Especially the 30-minute lunch walks always gave me new energy and often led to interesting conversations. Lastly I thank the people from general services for their practical help.

I also want to show my gratitude to Fons Smolders, Mark van Mullekom, Rick Kuiperij and Paul van der Ven from B-ware for their advice, suggestions and help by the fieldwork and laboratory analysis. Also the advices of Bob Brederveld and Nico Jaarsma from Witteveen+Bos have helped me further.

I would like to thank my supervisor Paul Schot from the Utrecht University for his suggestions, guidance and talks. And Ewa van Kooten, Jan-Willem Moerman, Susy Rita Wanti, Vera Cortenraede and my mother for helping me during fieldwork.

I would also like to thank forester Nico de Bruin from Staatsbosbeheer for showing me the beautiful nature area "Broek and Blokland" and for giving me permission to sample the nature areas "Broek and Blokland" and "Schraallanden langs de Meije".

Last but not least, I would like to thank all the farmers, without their permission to enter their land this research would not have been possible

Contents

1. Introduction

1.1 Problem definition

Dutch waters should meet the requirements on their water quality for the Water Framework Directive in 2015 but currently several waters do not fulfil (Poelen et al., 2011). One problem is the high phosphorus (P) concentrations in the water column (Van de Kamp & Blom, 2011).

Phosphorus enters the water column as dissolved phosphate (PO_4^{3-}) or as a particulate form which can directly be deposited in the sediment. Due to the consumption of dissolved phosphate by primary producers also some dissolved phosphate is eventually deposited in the sediment as organic phosphorus (Søndergaard et al., 2001). Dissolved phosphate can also transform into a particulate form and deposit, for instance by the adsorption by iron hydroxides (Søndergaard et al., 2001).

Phosphorus can be permanently deposited in the sediment or released and returned to the water column via interstitial water ("bodemvocht" in Dutch). This transport occurs at the boundary between the sediment and water column (Søndergaard et al., 2001). Figure 1 gives a simplistic overview of the most important pathways and phosphorus-forms in the stream bed sediment. Stream bed sediment includes the softer, mostly organic, top layer (referenced to as "mud") and the solid underground.
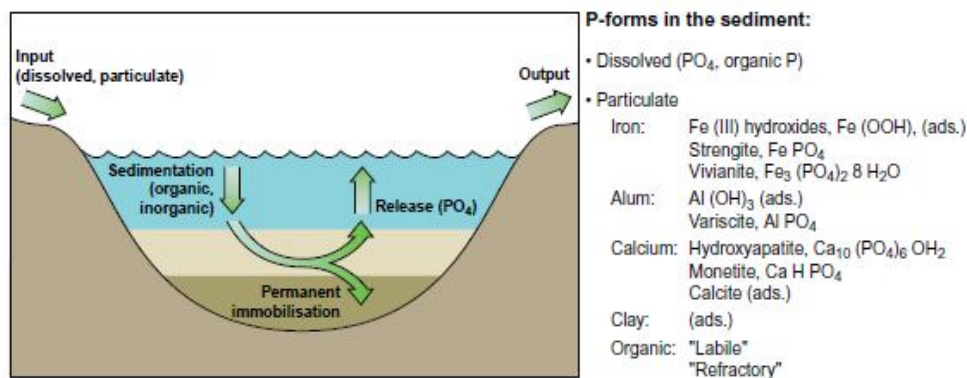
Figure 1: Input and output of phosphorus, important pathways and the phosphorus compounds in the sediment (Søndergaard et al., 2001). Examples of phosphorus inputs are input from surrounding soils (for instance by organic decomposition), inlet-water and point-sources (such as sewage treatments).

The release of phosphorus (in the form of phosphate) from the stream bed sediment to the water column can have a larger impact on the phosphorus concentrations in the water column than current fertilizer use (Poelen et al., 2011). Especially in the Netherlands as most Dutch waters are shallow, resulting in a small water volume per sediment area, and have large phosphorus pools in the sediment due to past fertilizer use (Poelen et al., 2011).

Also waterboard "Hoogheemraadschap De Stichtse Rijnlanden" expected high phosphorus release rates in their management area, especially in its non-urban ditches (B. Spanjers, personal communication, December 15, 2011). These ditches were defined as small water channels (width < 10 m) at least 10 m from urban features (e.g. houses, railways, paved streets and greenhouses). For better understanding of the effect of phosphorus release on the phosphorus concentrations in the water column the waterboard wanted to quantify the release of phosphorus in those ditches.

Extra attention has been given to the waterparels; water systems containing rare, endangered or international important species or/and have a good water quality (HDSR, 2008). Additional funding on phosphorus release in those areas was available as these areas have derived extra notice from the province of Utrecht and the waterboard. Furthermore, their phosphorus release from the stream bed also needed to be defined for a system analysis (see Van der Wijngaart, 2012).

Phosphorus release is highly complex; the release is affected by chemical, biological and physical conditions (in the sediment, interstitial water, water column and surrounding land) and (related) human interventions (Van Gerven et al., 2011a). All these variables can vary per location. Examples of these so-called "location variables" are fertilizer use, soil type and aquatic plant coverage. More research on relations between location variables and phosphorus release would give more insight on the mechanisms affecting the phosphorus release. More insight on phosphorus release by specific combinations of location variables can also help water managers with their decision making for measures to lower the phosphorus concentration in the water column. Results could suggest that by a certain combination of location variables the release of phosphorus from stream bed sediment to the water column is high. At these locations water managers should perhaps focus less on reducing the fertilizer use (external eutrophication) and more on measures to reduce the release of phosphorus from the stream bed sediment (internal eutrophication).

1.2 Research aim

Aim was (1) to quantify phosphorus release rates from the stream bed sediment in non-urban ditches within the management area of the waterboard "Hoogheemraadschap De Stichtse Rijnlanden" (including the waterparels) and (2) to relate phosphorus release to selected location variables to (2a) study phosphorus release and mechanisms behind it for more insight and to (2b) define rules of thumbs about phosphorus release. The rules of thumbs were aimed to result in a simple tool to indicate, based on easily determinable variables, ditches where phosphorus release is probably high or low.

1.3 Research question

How high is the release of phosphorus from stream bed sediment in non-urban ditches within the management area of the waterboard "Hoogheemraadschap De Stichtse Rijnlanden" and how is this release related to selected location variables?

2. Theoretical background

The most important relations between phosphorus release rates, the oxic conditions in the water column (and sediment) and several chemical/biological variables are shortly discussed (more in Smolders & Van Mullekom, 2011 and Van Gerven et al., 2011a).

The oxic boundary layer and iron
At high oxygen concentrations in the water column (an oxic water column) oxygen diffuses from the water column to the interstitial water of the stream bed sediment. This diffusion is limited, due to low oxygen penetration rates in sediment, so high oxygen concentrations in the sediment are generally restricted to the upper 10 mm of sediment (Smolders et al., 2006). This results in an oxygen-rich (oxic) boundary layer between the deeper anoxic sediment layers and the water column. This oxic layer hampers phosphorus release to the water column (figure 2). In the oxic boundary layer ferric iron (Fe^{3+}) immobilizes phosphate. The resulted compound, simplified as $Fe-PO_4$ in figure 2, is deposited in the deeper sediment. In this anoxic sediment iron functions as an electron acceptor and phosphate, which was bound to iron, is released. As the reduced ferrous iron (Fe^{2+}) has a low binding affinity for phosphate both chemicals separately diffuse to the oxic boundary layer. In this oxic layer ferric iron is formed which, again, immobilizes phosphate. This cycle hampers phosphorus release (figure 2). Absence of this oxic boundary layer leads to phosphorus mobilisation and a low sediment phosphorus binding capacity (figure 2).

As 1 mol phosphorus reacts with 1 mol iron an interstitial Fe:P-ratio in the anoxic sediment below 1.0 indicates that dissolved phosphorus exceeds dissolved iron. In that case, the iron amounts are insufficient to actually bind all phosphorus and phosphorus can still be released (Geurts et al., 2010).
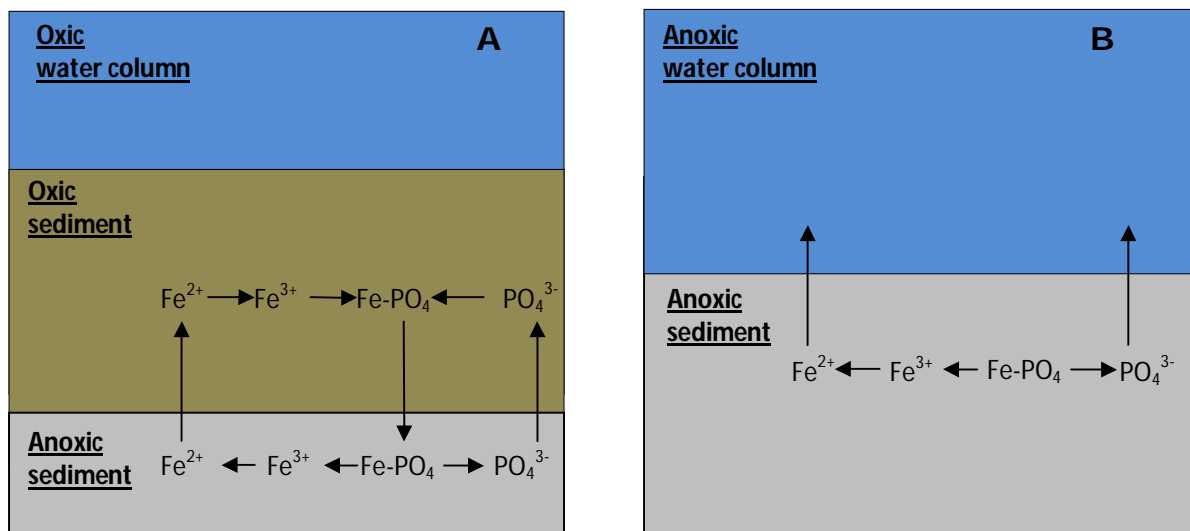
Figure 2: Functioning of the oxic boundary layer. A) With the oxic boundary layer and interstitial Fe:P>1 phosphate is bound to iron. B) Without the oxic boundary layer phosphate may be released from iron-bindings to the water column (based on Smolders & Van Mullekom, 2011).

Sulphur
Sulphur (S), from organic and pyrite (FeS) decomposition and from external inputs, can diffuse to the anoxic interstitial water, reduces and binds with ferrous iron (figure 3). The resulted highly insoluble iron-sulphur bindings (FeS_x) are buried in the anoxic sediment which limits the upward transport of iron (De Bruijne & Van de Weerd, 2009; Poelen et al., 2011). This could lead to iron deficiency in the oxic interstitial water and, consequently, to phosphorus release (Hupfer & Lewandowski, 2008; Smolders et al., 2011; figure 3).
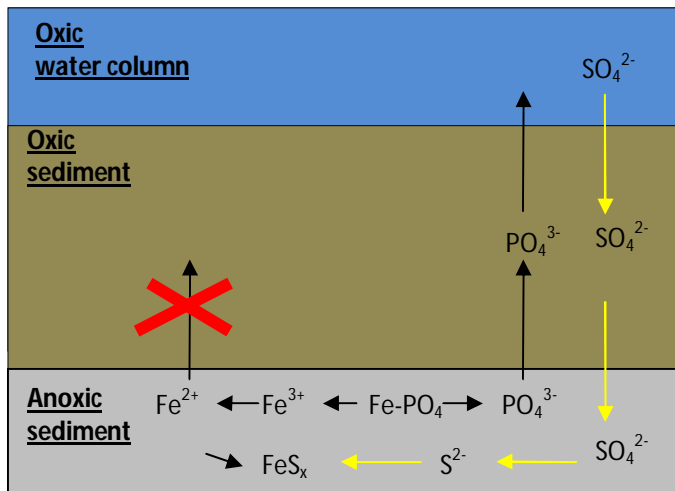
Figure 3: Effect of sulphur on the phosphorus from the stream bed sediment to the water column. Sulphide binds with reduced iron and limits the upward transport of iron. This can induce phosphorus release (based on Smolders & Van Mullekom, 2011).

The Fe:S ratio in the anoxic sediment indicates the sulphur-corrected iron that can potentially bind with phosphorus (by mobilization from the sediment). This availability decreases when the sediment Fe:S ratio is below 1.0 mol:mol (Geurts et al., 2010).

Nitrate and organic decomposition

Another important chemical is nitrate (NO_3^-). Nitrate, from organic decomposition or external input, is the most preferred electron acceptor when oxygen is depleted. Consumption of nitrate as electron acceptor could hamper phosphorus release from iron-bindings as iron is unconsumed as electron acceptor (De Bruijne & Van de Weerd, 2009). In a lake study indeed no phosphorus release was detected when nitrate or nitrite were present (Selig & Schlungbaum, 2003).

However, as electron acceptor, nitrate also stimulates organic decomposition and by organic decomposition chemicals are released that enhance phosphorus release (e.g. phosphate and sulphate) (De Bruijne & Van de Weerd, 2009).

Ammonium and alkalinity

Ammonium does not affect phosphorus release but can indicate high decomposition rates as ammonium is also released by organic decomposition (Van der Heide et al., 2010).

Alkalinity is also released by organic decomposition and enhances organic decomposition by buffering organic acids (Poelen et al., 2012). So, with this positive feedback, alkalinity increases decomposition and thereby also enhances phosphorus release (De Bruijne & Van de Weerd, 2009).

Calcium, aluminium and pH

Phosphorus also binds with aluminium and calcium. Contrary to iron-phosphorus bindings, these bindings are not affected by the sediment redox conditions (Hupfer & Lewandowski, 2008; De Bruijne & Van de Weerd, 2009). So, their phosphorus binding capacity does not decrease by absence of the oxic sediment boundary layer.

These bindings are, just as bindings with iron, affected by interstitial pH. Alkaline water (pH > 7.0) increases the binding capacity of calcium while acidic water (pH < 6.5) increases the binding capacity of aluminium and iron (Bostrom et al., 1988; Van Gerven et al., 2011a).

3. Method
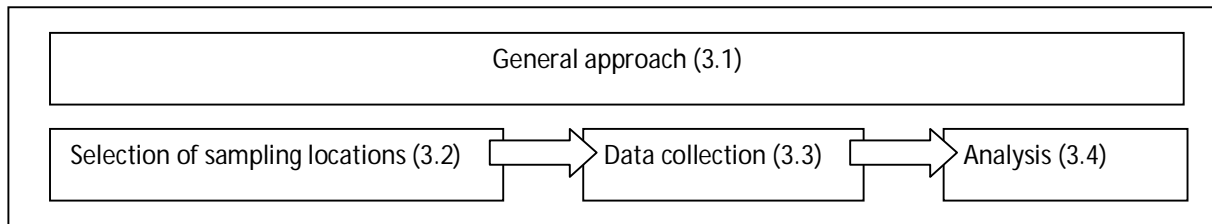
Figure 4: The methodological steps of this research.

Figure 4 shows the method. First, the general approach was defined which consisted of decisions on quantification method for phosphorus release (3.1.1), sampling strategy (3.1.2) and location variables (3.1.3). Afterwards the sampling locations in the strata (3.2.1) and in the waterparels (3.2.2) were selected. At the final locations (3.2.3) (mainly) water column and sediment samples were collected with fieldwork (3.3.1). Interstitial water was collected from the sediment and, together with the water column and sediment samples, analysed at the waterboard (3.3.2) and later on at the laboratory in Nijmegen (3.3.3). Finally, phosphorus release was quantified (3.4.1), relations with location variables were statistically analysed (3.4.2) and rules of thumbs were defined (3.4.3).

3.1 General approach

3.1.1 Quantification method

As traditional incubation methods were too costly, another method was needed to quantify phosphorus release. Phosphorus release was researched in various Dutch waters within the framework of Baggernut, a Water Framework Directive Innovation project (Poelen et al., 2012). Within this project, two consultancies (B-ware and Witteveen+Bos) developed a quick-scan to estimate phosphorus release from stream bed sediment in a relatively inexpensive way (Poelen et al., 2012). The quick-scan estimates phosphorus release based on a revealed correlation between phosphorus release and **interstitial phosphorus** in the anoxic sediment layer (figure 5).
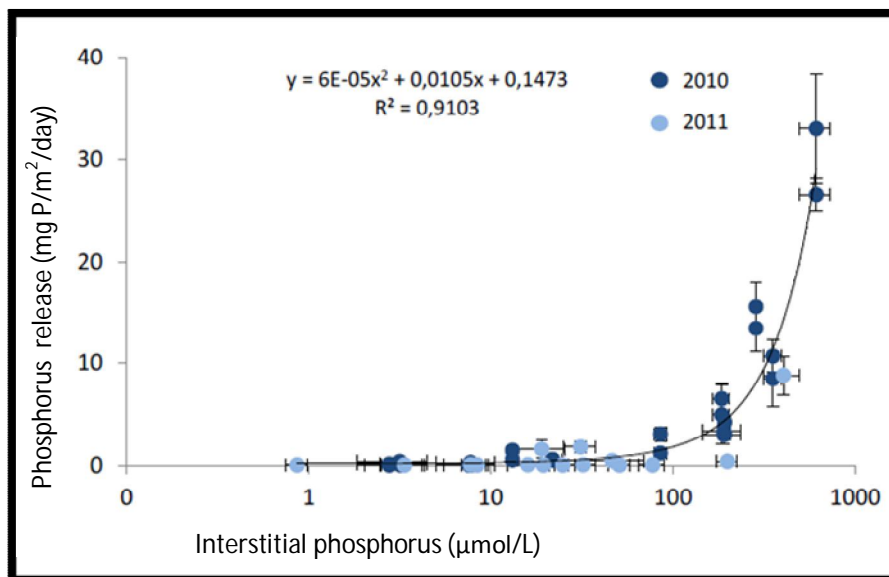
Figure 5: Correlation between interstitial phosphorus and measured phosphorus release with the resulted correlation formula, according to Poelen et al. (2012). Measurements were conducted in two years: 2010 and 2011.

Geurts et al. (2010) also measured phosphorus release rates by an oxic water column, so with the oxic boundary layer. However, they estimated (almost) no phosphorus release when **interstitial Fe:P** and/or **sediment Fe:S** in the anoxic stream bed sediment were above 1.0 (figure 6). Sediment Fe:S indicates iron in the sediment available for phosphorus binding (potential binding) while interstitial Fe:P indicates the actual binding of phosphorus with iron (Geurts et al., 2010; Chapter 2).
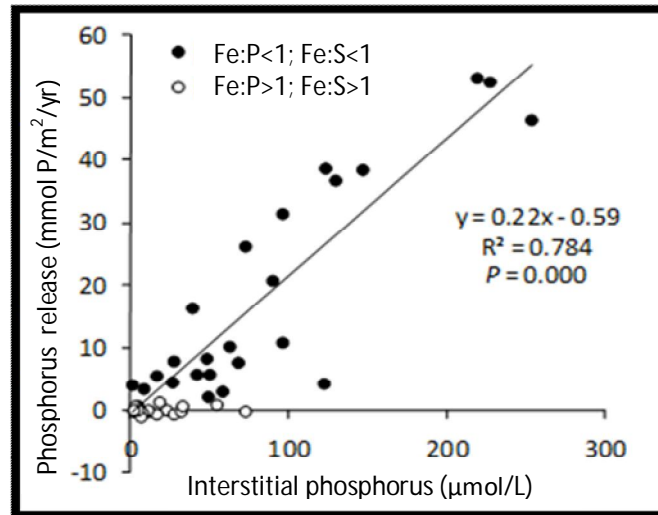
Figure 6: Correlation between interstitial phosphorus and measured phosphorus release with the resulted correlation formula, according to Geurts et al. (2010). Phosphorus release was always low by interstitial Fe:P and sediment Fe:S > 1.

Most common phosphorus form in anoxic interstitial water is phosphate. Measured interstitial phosphate should, therefore, almost equalled measured phosphorus. However, due to artefacts, this was untrue in Geurts et al. (2010) and this study (appendix A). Instead of measured phosphate, measured phosphorus was included in Geurts et al. (2010) and this study as it best approached actual phosphate and phosphorus (F. Smolders, personal communication, May 24, 2012).

Both quantification formulas were only partly similar (figure 7). As none of the formulas was better in advance, release rates were quantified based on both formulas and compared afterwards. So, the quantification of phosphorus release required information on interstitial phosphorus, interstitial Fe:P and sediment Fe:S.

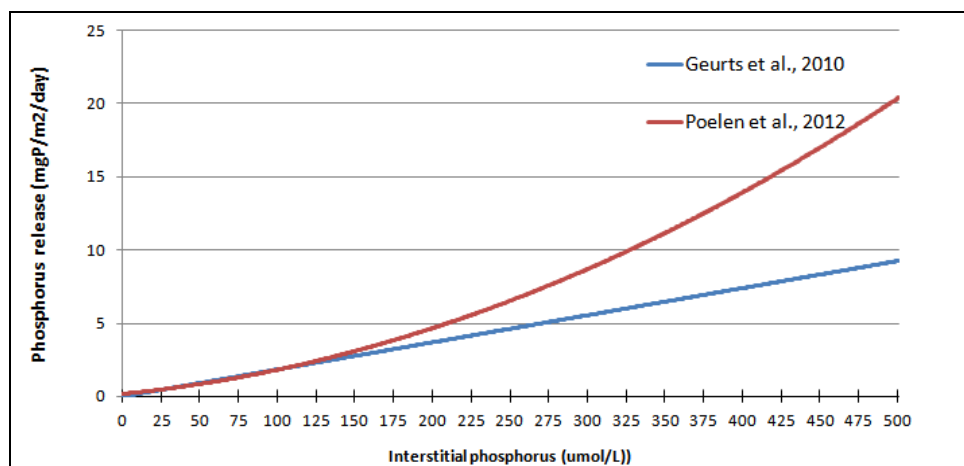*Figure 7: Relations between interstitial phosphorus and phosphorus release based on both formulas. Geurts et al. (2010) also included thresholds for interstitial Fe:P and sediment Fe:S. The formula of Geurts et al. (2010) was transformed to mg P/m^2/day by a division with 365 (day/yr) and a multiplication with the molar mass (30.97 mg P/mmol P).*

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3.1.2 Sampling strategy

As the sampling size was (financially) restricted to about 60 locations a smart sampling strategy was required to obtain representative samples of interstitial phosphorus, interstitial Fe:P and sediment Fe:P for the whole management area. The chosen strategy was stratified simple random sampling (with exception of the waterparels, more in 3.2.2). This could be more efficient than simple random sampling, particularly when the sub-areas (strata) are defined as homogeneous as possible (De Gruijter et al., 2005). To define homogenous sub-areas the stratification of the management area was based on variables that were thought to relate to interstitial phosphorus, interstitial Fe:P and sediment Fe:P and, besides that, were known for the whole management area. The following selected variables might relate to phosphorus release (B. Spanjers, personal communication, December 15, 2011; F. Smolders, personal communication, January 7, 2012; Chapter 2):

1. Soil type, for instance due to differences in organic decomposition between the soil types. Organic decomposition is expected to increase phosphorus release.
2. Land use type, for instance due to differences in fertilizer use between land use types. That may affect the water column phosphorus concentrations and indirectly phosphorus release.
3. Seepage/infiltration, for example by iron-rich groundwater seepage. That might affect the phosphorus binding capacity of the sediment and thereby indirectly phosphorus release,

3.1.3 Selection of location variables

Additional advantage of the stratified sampling strategy was that relations of the "location variables" **soil type, land use type** and **seepage/infiltration rate** with phosphorus release could be studied by comparisons of interstitial phosphorus, interstitial Fe:P and sediment Fe:P between the strata.

In the waterparels Schraallanden langs de Meije and Broek & Blokland various measures were implemented to protect their water quality/species (e.g. lowering water tables and declining fertilizer use). These measures **(nature management)** could have affected phosphorus release and their effect was, therefore, studied by comparing these two waterparels with agricultural strata.

These four variables were defined at the sampling locations in advance, so before fieldwork.

However, also correlations with other location variables - determined during fieldwork or afterwards - were studied. These location variables were called "**ditch characteristics**". If chemically and financially possible, the next chemical ditch characteristics were studied in the water column, stream bed sediment and interstitial water (all inter-connected by e.g. diffusion and adsorption): Phosphorus (P), phosphate (PO_4^{3-}), iron (Fe), sulphur (S), nitrate (NO_3^-), ammonium (NH_4^+), alkalinity (Alk), aluminium (Al), calcium (Ca) and pH. These variables may relate to phosphorus release (Chapter 2).

Also the following ditch characteristics were studied and might relate to phosphorus release as:

- Ditch width and depth (m, cm), for instance, affect the water column's volume. This affects chemical concentrations in the water column and may (indirectly) affect the chemical concentrations in interstitial water and phosphorus release.
- Water level (relative to soil surface) (cm) affects the decomposition rate at surrounding soils by altering oxic conditions. This could result in higher phosphorus and sulphur concentrations in the water column and (indirectly) in more interstitial phosphorus and phosphorus release (Zak et al., 2010).
- Organic sediment content (%) strongly relates with organic decomposition rate (Geurts et al., 2010) and organic decomposition is assumed to affect phosphorus release (Chapter 2).
- Mud depth (cm) (mainly) consists of organic matter and could, therefore, just as organic sediment, relate to phosphorus release (Geurts et al., 2010).
- Sediment density (kg/l) was also expected to correlate with organic sediment content, just like mud depth; low sediment densities were expected in highly organic sediments.
- Chemical ratios (P, PO_4^{3-}, Fe and S) in the three compartments (mol:mol) could correlate with phosphorus release, as found in Geurts et al. (2010) and De Bruijne & Van de Weerd (2009).

3.2 Sampling locations

3.2.1 Strata

The strata were defined in GIS by overlapping simplified versions of the land use map "LGN6_Monitoring", the soil map "Bodemkaart HDSR" and the seepage/infiltration map "Kwel en Wegzijging". In the end these simplified maps overlapped the line shape with all waters of the waterboard ("Kartering_OppervlakteWater_2010 Assen"). Appendix B shows all four original maps.

- Soil type

The soil map was simplified by combining light and heavy clay (Clay) and light and heavy sabulous clay (Sabulous Clay). The categories urban and other ("overig") and the small category marsh were excluded. Also the eastern sandy region "The Heuvelrug" was excluded due to low water column quantities. Lastly, also the floodplains along the river Rhine were excluded as their water quality is not managed by the waterboard but by Rijkswaterstaat, the national authority. Contrary to these simplifications peat was divided into Koopveen and Weideveen. Koopveen was expected to have higher phosphorus release rates as koopveen would contain more organic material (Giesen & Geurts, 2006). Final soil map consisted of six categories: Excluded, Koopveen, Weideveen, Clay, Clay on peat and Sabulous clay (figure 8).
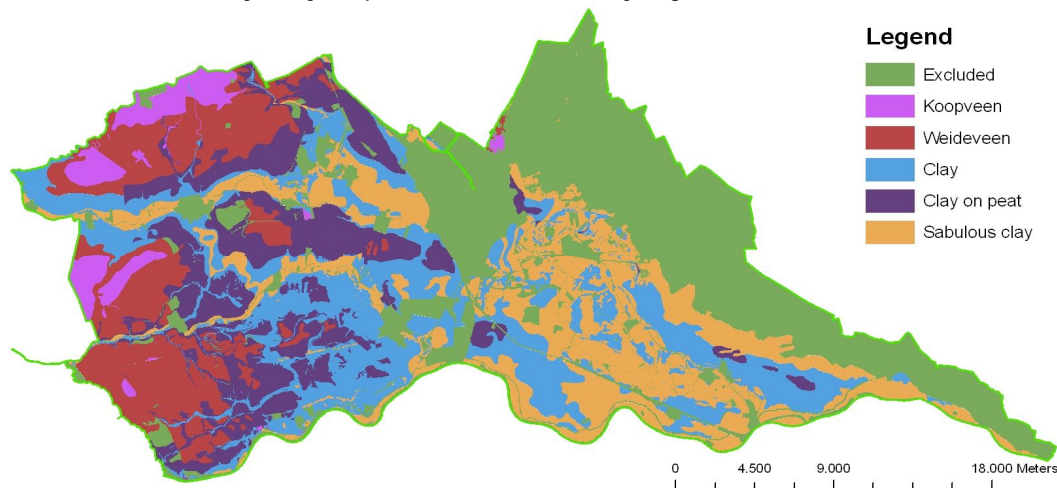
Figure 8: Simplified soil type map of the management area of the waterboard.

- Land use type

Greenhouses, infrastructure and urban area were excluded from the land use map. The category water mostly contained lakes and rivers (no non-urban ditches) and was, therefore, excluded. Furthermore, the small forest and nature areas were excluded. Fruit cultivation area was also small but included as more study in those areas was preferred by the waterboard. Furthermore, interstitial phosphorus concentration (and thereby phosphorus release) was expected to be lower by fruit cultivation as generally fewer fertilizers were used than by crops and grasslands (B. Spanjers, personal communication, December 15, 2011). No specific category for solely grassland and cropland was available; only the combined crops/grassland category existed. So, final land use map only consisted of three categories: Excluded, Crops/Grassland and Fruit (figure 9).
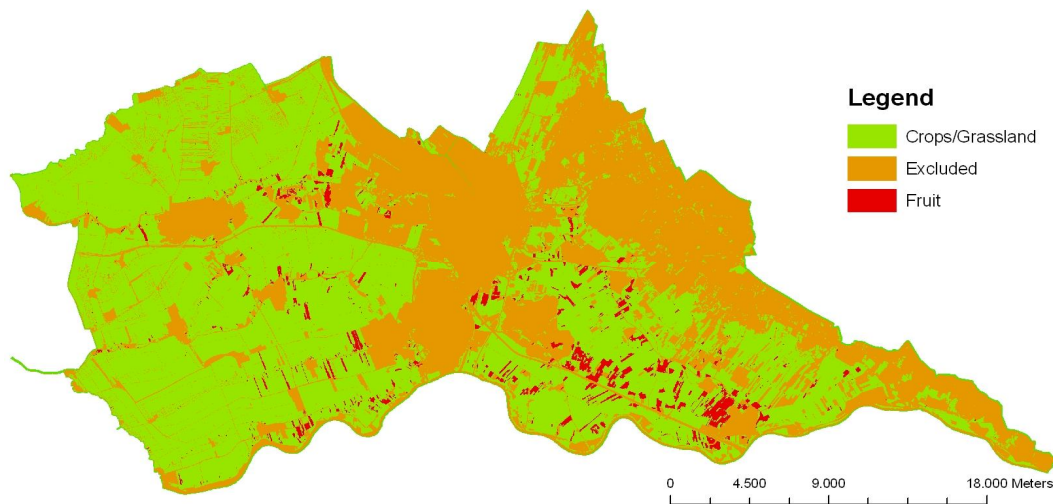
Figure 9: Simplified land use map of the management area of the waterboard.

- Seepage/infiltration rate

The ratio scale of the seepage/infiltration map was transformed into a categorical scale. Areas were defined seepage areas by more than 0.5 mm seepage per day and infiltration areas by more than 0.5 mm infiltration per day. Areas with less than 0.5 mm/day infiltration and less than 0.5 mm/day seepage were defined no seepage/infiltration areas. With these boundaries the vertical water flow was relatively high in the seepage and infiltration areas so significant differences in phosphorus release between the categories were expected to be revealed. The final map had three categories: Infiltration, No seepage/infiltration and Seepage (figure 10).
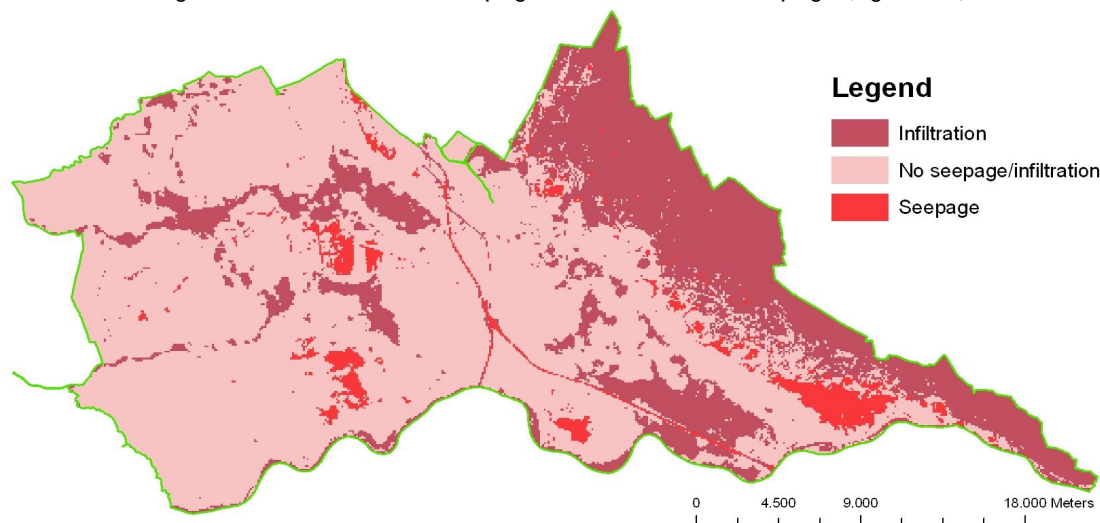
Figure 10: Simplified seepage/infiltration map of the management area of the waterboard.

Selection of strata and sample locations

The overlapping of the three maps (figure 8, 9 and 10) resulted in 30 strata with specific combinations of location variables. To limit the amount of strata only the largest strata were selected based on their surface water area (m^2). This water area was estimated with the "calculate area" GIS function on the map resulted from the overlap of the map with three location variables with the water surface map of the waterboard ("Kartering_OppervlakteWater_2010 Vlakken").

To compare the five soil types, all five soil categories were selected on the largest land use and seepage/infiltration category; on crop/grassland with no seepage/infiltration. To compare both land use types, the largest fruit stratum was selected on the largest seepage/infiltration category; this was

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the fruit stratum on clay with no seepage/infiltration. At last, to study the effect of seepage and infiltration, the largest seepage stratum and the largest infiltration stratum on grass/cropland (largest land use type) were selected. The resulting strata are shown in table 1 and figure 11.

Code	Soil type					Land use type		Seepage/infiltration rate		
	Koopveen	Weideveen	Clay on peat	Sabulous clay	Clay	Crops/ Grassland	Fruit	S	No S/I	I
1	■					■			■	
2		■				■			■	
3			■			■			■	
4			■			■		■		
5				■		■			■	
6				■		■				■
7				■			■			■
8					■		■		■	

Table 1: Strata codes and their categories for the location variables (S: Seepage; I: Infiltration).
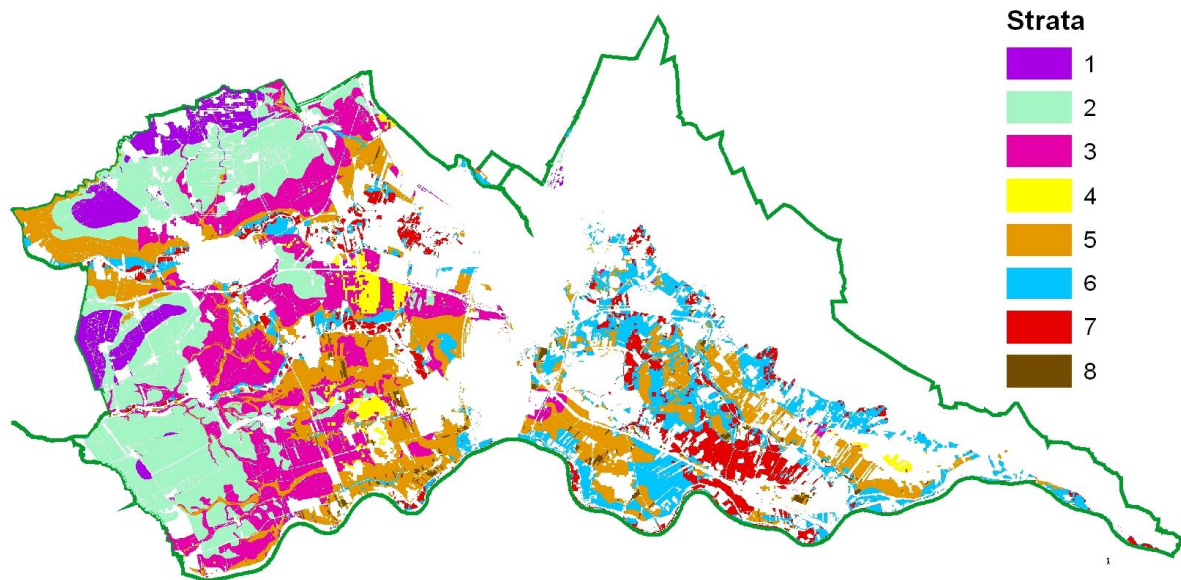
Figure 11: The management area of the waterboard with the selected strata codes. .

After the strata were selected, the map with the selected strata (figure 11) overlapped the line map with all waters of the waterboard (Kartering_OppervlakteWater_2010 Assen) (appendix B). Locations within the strata were randomly generated on this stratified line water map with the "Random Point Generator" in ArcView. The generation on the line map ensured that the random locations were situated in the middle of the ditch. Six locations were selected in each stratum (48 in total).

The locations were checked upon the criteria for a non-urban ditch (see section 1.1) and the criteria for the selected stratum (= valid combination of location variables, see table 1). These checks were needed as the original maps, in appendix B, contained flaws and/or were out-dated. Furthermore, it was impossible to include all criteria for non-urban ditches, such as all distances from urban features, in the final map (figure 11). For a selected non-urban ditch for the fruit stratum it was, for instance, checked whether the ditch was in fact situated in a fruit area and also not nearby urban features (<10 m.). This check was mostly based on recent aerial photographs. If a location did not fulfil the criteria another location was randomly generated. Later on, also five new locations were randomly selected as five earlier selected locations were inaccessible as land-owners refused us to enter their land.

3.2.2 Waterparels

The location selection within the waterparels was not random but directed by the aims of a system analysis study (Van der Wijngaart, 2012). This system analysis study needed the obtained data for other purposes. The location selection was, therefore, mostly based on the distance of the ditch from the inlet. Hydrological characteristics of the waterparels were studied first with literature (Van Diggelen et al., 2007a; HDSR, 2008) and discussed with forester N. de Bruin from Staatsbosbeheer and with N. Jaarsma and B. van Brederveld from Witteveen+Bos (similar consultancy as Van der Wijngaart, 2012). Due to financial restrictions, only three sampling locations were selected.

There were four waterparels within the management area of the waterboard (figure 12). The waterparel Binnenfortgracht Rhijnauwen was not studied as it had no non-urban ditches.
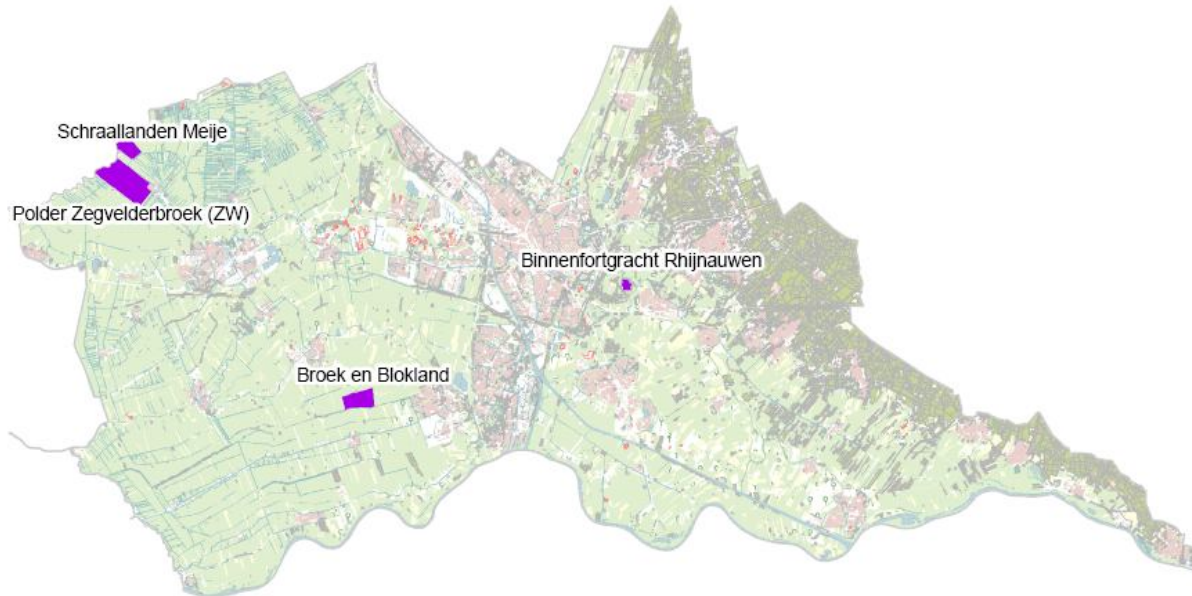
Figure 12: Locations of the waterparels within the management area of the waterboard (HDSR, 2008).

Schraallanden langs de Meije (S)

This waterparel is situated in the north-west of the management area. This koopveen/weideveen nature area with no seepage/infiltration is managed by Staatsbosbeheer. Four major measures were taken: 1) dephosphatation of inlet water, 2) rising of water tables, 3) banning of fertilizer and 4) introducing agricultural buffer zones around the waterparel (Van der Wijngaart, 2012). Selected locations varied in distance from the inlet (49: ± 100 m, 50: ± 2300 m, 51: ± 2750 m; figure 13).
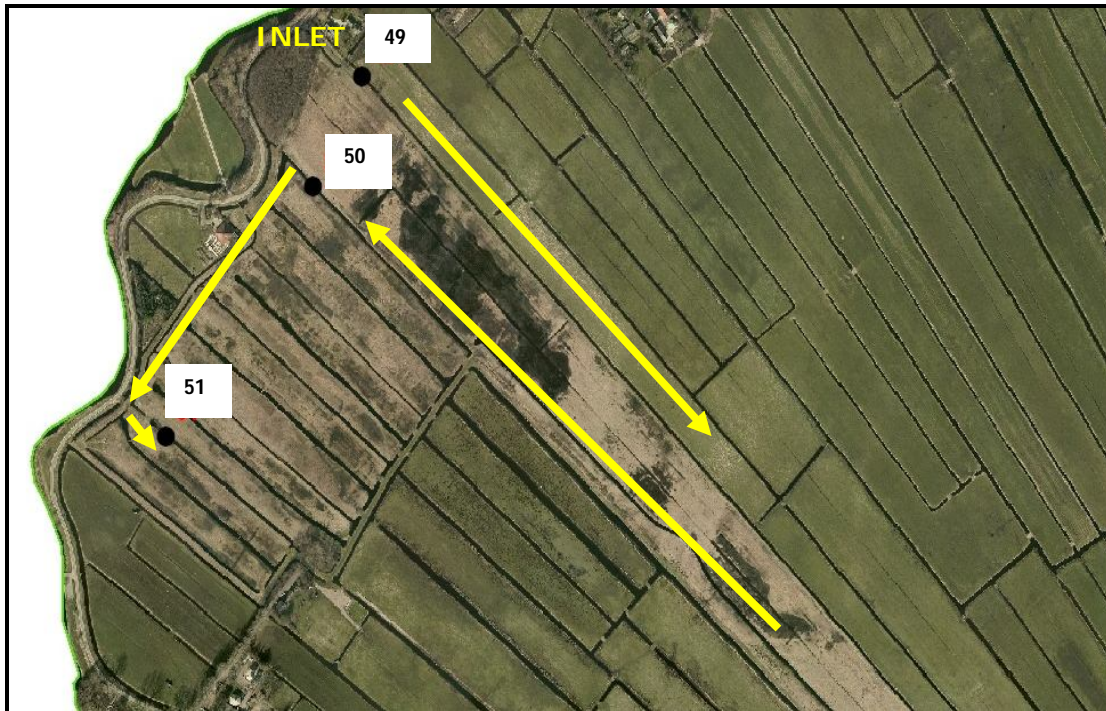
Figure 13: Sampling locations in "Schraallanden langs de Meije" with inlet location (arrows indicate water flow).

Polder Zegvelderbroek (Z)

"Polder Zegvelderbroek" is an agricultural weideveen area used for pastures without seepage/infiltration. It has a hydrological gradient from the south-eastern inlet to the north-western ditches. No measures have been taken to improve its surface water quality. The three sample locations were location in a long ditch in the middle of the polder at varying distances from the inlet (52: ± 150 m, 53: ± 700 m, 54: ± 1300 m; figure 14).
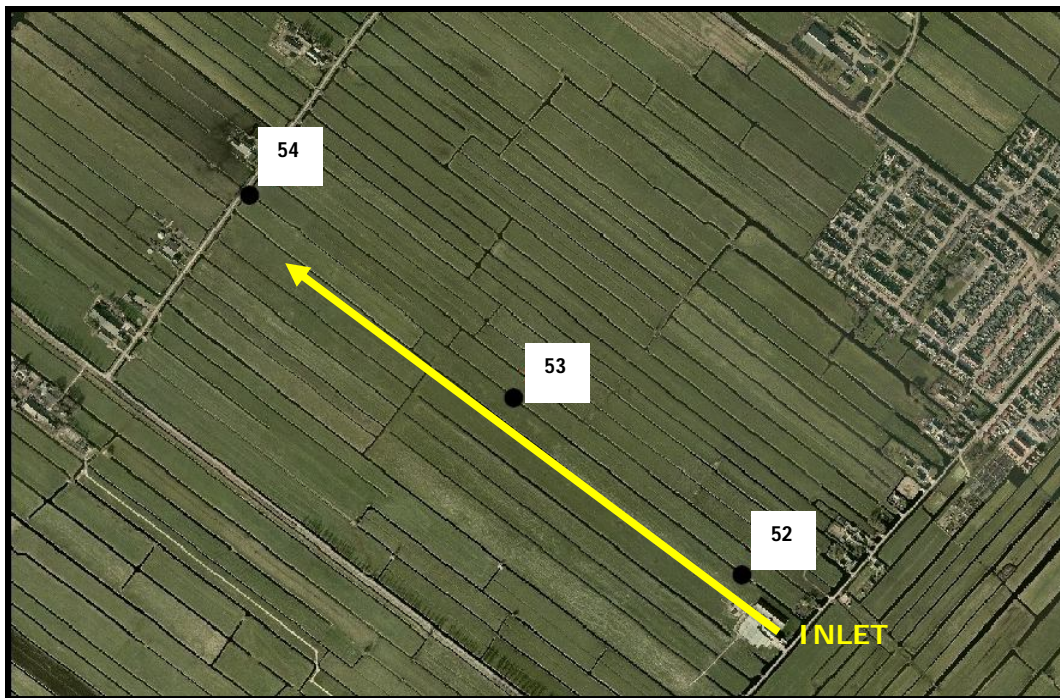
Figure 14: Sampling locations in "Polder Zegvelderbroek" with inlet location (arrow indicates water flow).

Broek & Blokland (B)

This Waterparel is managed by Staatsbosbeheer. Two main measures have been taken: 1) rising of the water tables and 2) lowering of fertilizer use (Van der Wijngaart, 2012). The area consists of four to five different hydrological areas with their own water regime. The least complex area is the northern clay area without seepage/infiltration which consists of one inlet and one outlet (Van der Wijngaart, 2012). In this hydrological area sampling locations were selected 10 m after the inlet (55) and 10 m before the outlet (56). The third sampling location was located in the isolated seepage (clay) area (57) which contained aquatic plants that indicated good water quality (N. de Bruin, personal communication, February 22, 2012). Figure 15 shows sampling locations.

Figure 15: Sampling locations in "Broek & Blokland" with inlet and outlet locations (arrows indicate water flow).

3.2.3 Final locations

There were 57 sampling locations: 48 locations in the strata (8*6) and 9 locations in the waterparels (3*3) (figure 16).
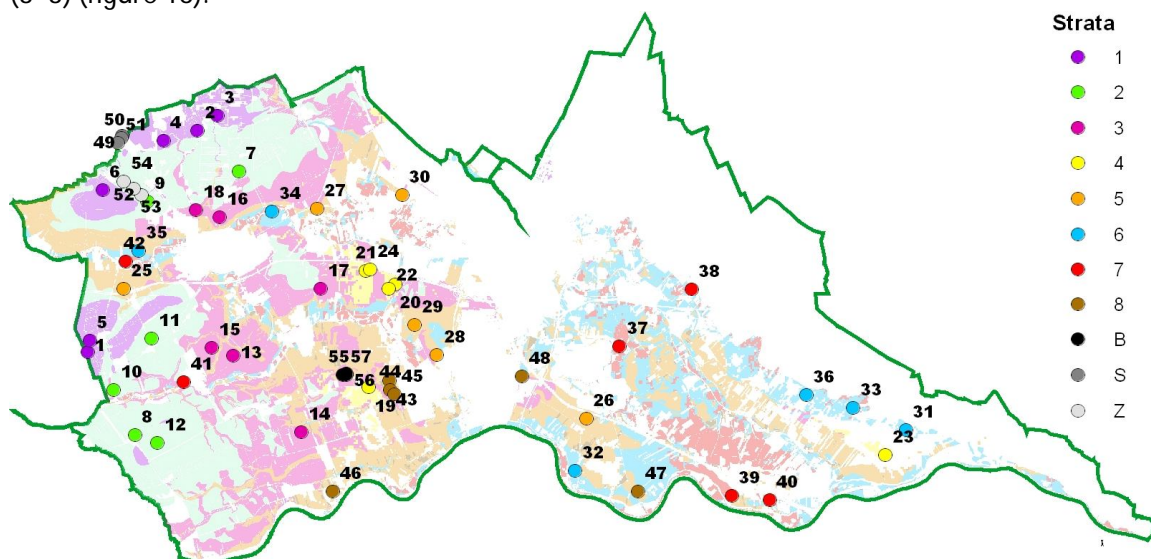
Figure 16: Final sampling locations with location numbers and codes for strata and waterparels. Coordinates of all locations can be found in appendix C.

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3.3 Data collection

3.3.1 Fieldwork

Samples were collected between 1 March and 21 March 2012. Exact locations were found with printed maps with coordinates and a GPS-meter. Permission was asked by the land-owner if needed. At each location width and water level (relative to soil surface) of the ditch were roughly estimated. Water from the water column was collected in the middle of each ditch and transported in 0.5 L polyethylene bottles. Water depth was measured in the middle of the ditch with a measuring rod (figure 17A and 17B). Same device was also used to measure the depth of the soft sediment (mud). To define this mud depth the measuring rod was forced into the sediment until movement stopped and the device arrived at the "solid sediment". Difference between upper boundary of soft sediment and solid sediment equalled mud depth. Finally the sediment grabber ("Van Veenhapper", figure 17C) collected the stream bed sediment. It collected approximately the upper 10 cm of sediment, including the mud layer (F. Smolders, personal communication, January 7, 2012). This was repeated once or until enough stream bed sediment (± 2 L) was collected. Collected sediment samples were rapidly mixed at each location and were transported in airtight plastic bags.

Figure 17: Fieldwork equipment: A) Measuring rod, B) Use of measuring rod and C) Sediment grabber.

3.3.2 PH, alkalinity and conservation

At the end of each day the plastic bottles with water from the water column were put in the dark by 4 degrees. At the same time, Rhizon soil moisture samples with vacuum syringes (60 ml) (Eijkelkamp, Agrisearch Equipment) were installed in the sediment bags to collect anoxic interstitial water. Same method was also used in Geurts et al. (2010).

After one or two nights enough interstitial water (± 50 ml) was collected and pH and alkalinity were determined. The pH and alkalinity in the interstitial water and water from the water column were measured with a calibrated pH-meter (Hach HQ40d). Alkalinity was estimated by titration to pH 4.2 with hydrochloric acid (HCl, 0.01mol/L). The sum of the multiplication of volume of added HCl (ml), concentration of HCl (mol/l) and 1000 (ml/l) was divided by sample volume (ml) to determine alkalinity. For the water column the sample volume was 20 ml whereas for the interstitial water the sample volume was 10 ml due to limited water quantities.

After the alkalinity was determined, remaining interstitial water and water from the water column were divided over two 20 ml polyethylene bottles (figure 18) for the analyses on the auto-analyser (AA) and on the inductively coupled plasma – optic emission spectrometer (ICP-OES). The 114 AA samples (57*2) were directly put in the dark in the fridge. For conservation, 0.2 ml of Nitric acid (HNO_3, 65%) was added to each ICP-OES sample. The 114 ICP-OES samples and 57 sediment samples were conserved in the dark by 4 degrees.

The samples were transported to the laboratory in Nijmegen (Gemeentelijk Instrumentarium, Radboud University) after the alkalinity and pH of all samples was determined.

3.3.3 Laboratory experiments

In the laboratory several analysis were conducted on the water (interstitial and water column) and sediment samples. These analyses are described below (in more detail in Geurts et al. (2010) and on http://www.ru.nl/fnwi/gi/faciliteiten-gi/element-aminozuur).

Figure 18: Water samples in polyethylene bottles and the trays for the AA.

Organic content and sediment density

To determine organic content the sediment samples were dried in pots for 24 hours at 70 ^{o}C. Organic content was determined after heating the dry sediment samples at 550 °C for four hours whereby mass loss approached organic matter content (Geurts et al., 2010). Fresh sediment density (kg fresh sediment/l) was determined by weighting the pots with sediment before heating (volume and weight of the pots were known).

Destruction of sediment samples

To measure total element/nutrient concentrations the sediment was destructed. Fine-grounded portions of 200 mg dry sediment were digested with four ml nitric acid (HNO_3, 65%) and one ml of hydrogen peroxide (H_2O_2, 30%) using an destruction magnetron (Milestone Microwave Type Mls 1200 Mega). After destruction and cooling down, samples were filled up until 100 ml with milli-Q water. Samples were conserved in polyethylene bottles by four degrees until further analysis on the ICP-OES.

ICP-OES and AA

Total Ca, Al, P and S of all 171 samples (3*57) were determined with the ICP-OES (Iris Intrepid 2, Thermo Fisher Scientific). Concentrations of NO_3^- (including NO_2^-), NH_4^+ and PO_4^{3-} (soluble reactive phosphorus) in the 114 water samples were measured colorimetrically with a Bran and Luebbe Auto-analyser 2 (figure 19), using a cadmium column and a sulphanilamide-NED colour reagent (for NO_3^-), sodiumsalicylate and dichloroisocyanurate acid (for NH_4^+) and ammonium molybdate and ascorbic acid (for PO_4^{3-}).

Figure 19: Auto-analyser including the tray with water samples

3.4 Analysis

3.4.1 Phosphorus release in the management area

As already discussed (3.1.1) phosphorus release rates (mg P/m^2/day) were quantified based on interstitial phosphorus (μmol/l) with the following formulas:

Poelen et al. (2012) phosphorus release =
0.00006(interstitial phosphorus)^2 + 0.0105(interstitial phosphorus) + 0.1473

Geurts et al. (2010) phosphorus release *(interstitial Fe:P < 1.0; sediment Fe:S < 1.0)* =
(0.22(interstitial phosphorus) – 0.59)/365 x 30.97

Both studies measured phosphorus release rates with incubation experiments. However, the water column phosphorus concentrations within the experiments differed. Poelen et al. (2012) measured phosphorus release rates with similar phosphorus concentrations in the water column as observed at the sampling locations, while Geurts et al. (2010) measured phosphorus release with demineralised water in the water column. Still, no correction in release rates for a change in diffusion resistance, due to other phosphorus water column concentrations, was assumed to be needed (following Poelen et al., 2012). Likewise, also no corrections in release rates, for varying observed phosphorus concentrations in the water column, were made in this study.

Phosphorus release rates were also visualized in maps by adding the mean release rates (n=6) in the map with the strata (figure 11). To better compare both quantification methods, the difference in phosphorus release between both methods was also visualized in a map.

3.4.2 Relations of location variables with phosphorus release

The relations between the location variables and phosphorus release were analysed statistically using SPSS for Windows (version 17.0). The statistical analysis consisted of Mann-Whitney U tests and Spearman rank correlation tests.

Mann-Whitney U tests were conducted to analyse relations of soil type, land-use type, seepage/infiltration rate and nature management with interstitial P, interstitial Fe:P and sediment Fe:S (phosphorus release). These non-parametric tests were used as student's t-tests were inappropriate and student's t-tests do require normal distributed data (De Vocht, 2008) and interstitial P, interstitial Fe:P and sediment Fe:S were not normally distributed (p<0.001). This was tested with Kolmorov-Smirnov and Shapiro-Wilk tests of normality.
Table 2 shows all the comparisons that were statistically analysed with Mann-Whitney U tests.

Location variables	Strata/Waterparels	Comparisons
Soil type	1, 2, 3, 5, 6	1 - 2; 1 - 3; 1 - 5; 1 - 6; 2 - 3... until 5 - 6 1,2,3 - 5,6 1,2 - 3,5,6
Land use	5, 8	5 - 8
Seepage/Infiltration	3, 4, 6, 7	3 - 4;6 - 7
Nature management	S, B, 1, 2, 5	S - 1,2; B - 5

Table 2: Mann Whitney U comparisons between the strata and waterparels (shown in codes) on their phosphorus release (interstitial phosphorus, interstitial Fe:P and sediment Fe:S).
To study the relation of soil type with phosphorus release, all different soil types (1,2,3,5,6) were compared pair-wise on their means for interstitial phosphorus, interstitial Fe:P and sediment Fe:S. Also the combined peat strata, with or without clay on peat (1,2,3; 1,2), was compared with the other soil type strata (5,6; 3,5,6). To study the effect of soil type, the crops/grassland clay stratum (5) was compared with the fruit clay stratum (8). The seepage and infiltration stratum (4,7) were compared with the no seepage/infiltration strata by similar soil and land use type (3,6). Lastly, to study the relation of nature management with phosphorus release, the two waterparels (S,B) were compared with crops/grassland strata with similar soil type and seepage/infiltration rate (1,2 & 5).

Similar Mann-Whitney U tests were conducted to reveal differences in means of the ditch characteristics. These comparisons were only used to elucidate observed differences in interstitial P, interstitial Fe:P and sediment Fe:S between the strata and waterparels.

Non-parametric Spearman rank correlation tests were conducted to reveal relations of the ditch characteristics with interstitial P, interstitial Fe:P and sediment Fe:S. All sampling locations were bundled as one group. The non-random Waterparel locations were, however, not included to limit statistical bias. Significant correlations (p<0.01) were defined strong by spearman's rho (r_s) > 0.8 and moderately strong by $0.6 < r_s < 0.8$. The (moderately) strong correlations were visualized with scatter-plots for more detailed analysis.
For extra insight all these correlations were also studied *within* the peat strata (1,2,3 and 1,2) and non-peat strata (3,5,6 and 5,6). These correlations, however, did not reveal new insights on phosphorus release and were, therefore, excluded.

3.4.3 Rules of thumbs

Aim of these rules of thumbs was to determine indicators for phosphorus release based on easy determinable ditch characteristics. Compared to the variables currently used to quantify phosphorus release (interstitial phosphorus, interstitial Fe:P and sediment Fe:S), water column characteristics and "non-chemical" sediment characteristics (e.g. organic content) are relatively easy to determine. Furthermore, chemical concentrations in the water column are sometimes already determined for the monitoring of the surface water quality. So, only these ditch characteristics were used to define rules of thumbs. To limit uncertainties, these rules of thumbs were only defined for ditch characteristics which correlated (moderately) strong with interstitial phosphorus, interstitial Fe:P and/or sediment Fe:S (see 3.4.2).

According to the method of Geurts et al. (2010), phosphorus release is only possible if both interstitial Fe:P and/or sediment Fe:S are below 1.0. Hence, the rules of thumbs needed to locate ditches where interstitial Fe:P is probably either below or above 1.0. Figure 20 explains the method.
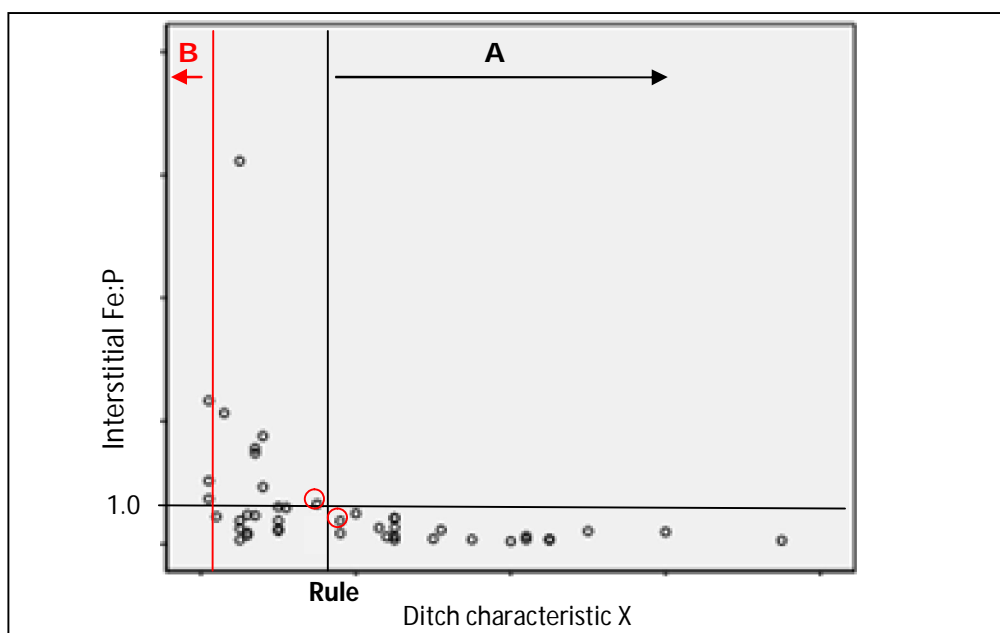
Figure 20: Explanation of the method to define rules of thumbs for interstitial Fe:P above or below 1.0 with a correlation between ditch characteristic X and interstitial Fe:P (horizontal line by Fe:P = 1.0). The same method was applied for the rules for sediment Fe:S above or below 1.0.
A rule, based on ditch characteristic X, could be made to indicate locations where interstitial Fe:P is probably below 1.0 as right from the vertical black line (area A) all locations had a Fe:P ratio below 1.0. So, the value for ditch characteristic X at this vertical line defined the rule; also at other locations with a value for ditch characteristic X above this rule interstitial Fe:P was probably below 1.0. This vertical line was situated in the middle of the first value above and below Fe:P = 1.0 (shown with red dots). To limit uncertainty, at least five locations needed to be below and above such vertical line. Therefore, no rule was defined to indicate locations with Fe:P above 1.0 as below the red line, in area B, only three locations were found.
A few exceptions were made; these locations in the scatter-plots did not correspond with the defined rule. However, these locations only had a small deviation (interstitial Fe:P or sediment Fe:S ratio was maximal 0.1 above or below 1.0) and exclusion of these small exceptions would have led to the disappearance of valuable rules. Exceptions are given in the results.

No rules of thumbs were defined for interstitial phosphorus as no (moderately) strong correlations were found between interstitial phosphorus and the water column and "non-chemical" sediment ditch characteristics (appendix F).

4. Results

This chapter shows the main results from the data analysis (3.3). First the phosphorus release rates in the management area are shown in a table and in maps (4.1). Afterwards, the results of the analysis of the relations of the location variables with phosphorus release are shown (4.2). Lastly, values for the rules of thumbs, based on the method described in figure 20, are revealed and visualized in graphs and tables (4.3).

4.1 Phosphorus release in the management area

Strata or Waterparel Code	P IW (µmol/l)	*Range (µmol/l)*	P IW (mg/l)	Fe:P IW mol:mol	*Range mol:mol*	Fe:S SED mol:mol	*Range mol:mol*	Geurts P release mg P/m^2/day	Poelen P release mg P/m^2/day
1	52.32	*25-65*	1.62	0.52	*0.02-2.09*	0.42	*0.30-0.73*	0.9	0.9
2	65.09	*20-195*	2.02	0.22	*0.02-0.63*	0.41	*0.24-0.65*	1.1	1.1
3	110.56	*35-329*	3.42	1.30	*0.14-3.03*	0.90	*0.42-2.13*	2.0	2.0
4	23.71	*12-39*	0.73	16.67	*4.09-48.0*	2.41	*0.99-7.78*	0.0	0.4
5	101.35	*46-176*	3.14	5.84	*0.61-15.9*	3.00	*1.22-7.38*	0.0	1.8
6	52.38	*12-121*	1.62	3.84	*0.39-9.45*	4.01	*0.93-12.0*	0.0	0.9
7	49.67	*9.8-170*	1.54	17.62	*0.14-50.0*	9.50	*1.10-31.2*	0.0	0.8
8	39.44	*15-73*	1.22	26.31	*7.40-92.0*	2.51	*0.89-5.14*	0.0	0.7
S	7.90	*4.4-14*	0.24	3.25	*0.38-8.17*	0.42	*0.34-0.45*	0.1	0.2
Z	35.82	*17-46*	1.11	1.83	*0.24-4.92*	0.47	*0.30-0.67*	0.6	0.6
B	24.89	*15-36*	0.77	12.84	*1.75-28.9*	1.40	*1.09-1.80*	0.0	0.4

Table 3: Means and ranges of interstitial P (in µmol/l and mg/l), interstitial Fe:P and sediment Fe:S and the phosphorus release according to Geurts et al. (2010) and Poelen et al. (2012) for the strata (n=6) and waterparels (n=3). Grey areas indicate chemical ratios below 1.0 which is, according to Geurts et al. (2010), indicative for strata/waterparels where oxic phosphorus release is possible.

Mean phosphorus release varied from 0.0 to 2.0 mg/m2/day (table 3). Highest release rates (6.1-10.1 mg P/m^2/day) were quantified for location 14 (appendix D shows all release rates).
Both correlation formulas estimated (almost) the same phosphorus release rates for peats (1, 2, S, Z; table 3) but different rates for the other strata and Broek & Blokland (3, 4, 5, 6, 7, 8, B; table 3). This is also shown in figure 21, 22 and 23.
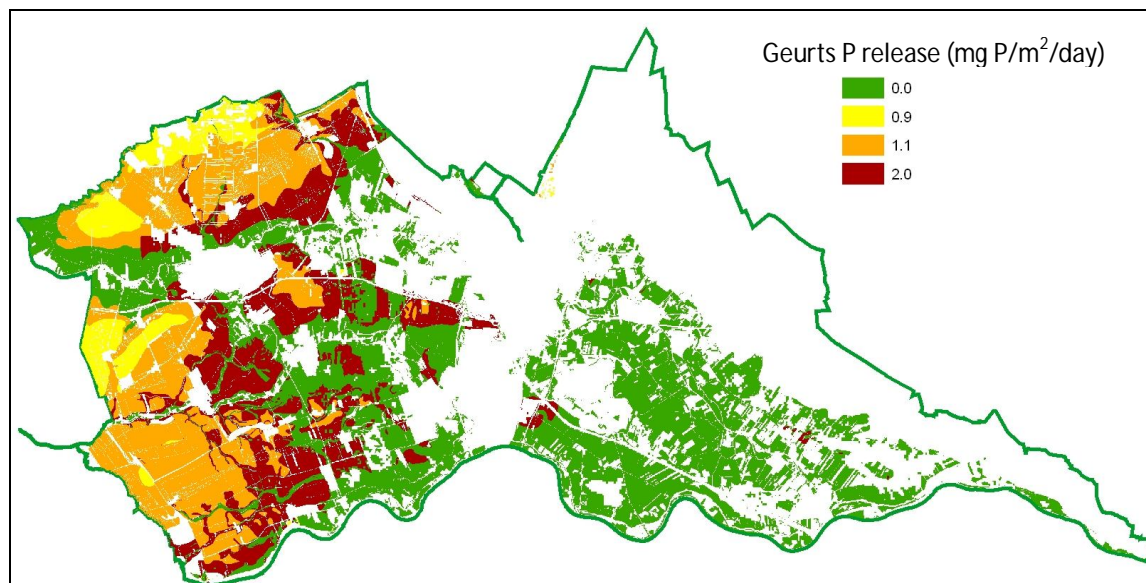
Figure 21: Phosphorus (P) release in the management area of the waterboard, according to the method of Geurts et al. (2010).
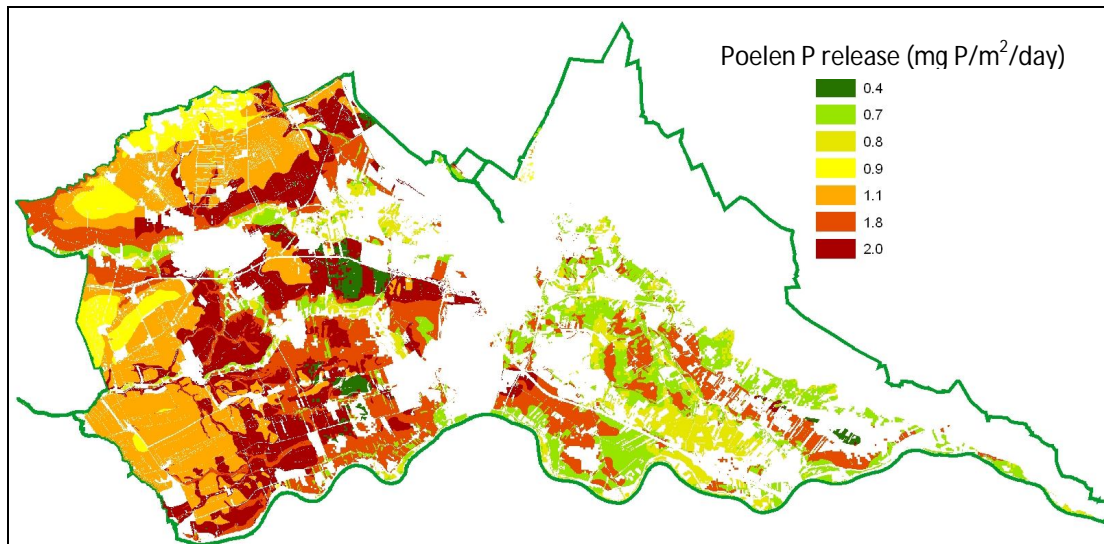
Figure 22: Phosphorus (P) release in the management area of the waterboard, according to the method of Poelen et al. (2012).
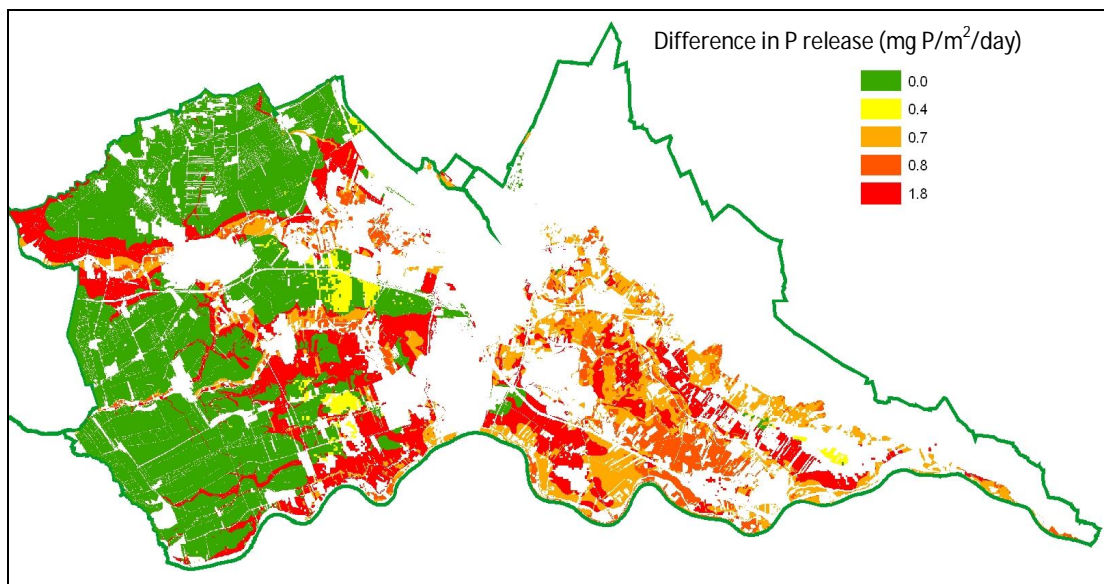
Figure 23: Difference in phosphorus (P) release in the management area of the waterboard (Poelen P release - Geurts P release).

4.2 Relations of location variables with phosphorus release

Table 4 reveals relations of interstitial phosphorus, interstitial Fe:P and sediment Fe:S with the location variables soil type, land use type, seepage/infiltration rate and nature management. Relations with ditch characteristics are discussed afterwards.

Strata/Waterparels	Comparisons	P IW	Fe:P IW	Fe:S SED
1 – 2	Koopveen - Weideveen	0.937	0.485	0.699
1 – 3	Koopveen - Clay on peat	0.132	0.093	**0.041**
1 – 5	Koopveen - Clay	0.394	**0.015**	**0.002**
1 – 6	Koopveen - Sabulous clay	0.818	**0.015**	**0.002**
2 – 3	Weideveen - Clay on peat	0.180	**0.026**	**0.041**
2 – 5	Weideveen - Clay	0.180	**0.004**	**0.002**
2 – 6	Weideveen – Sabulous clay	0.699	**0.004**	**0.002**
3 – 5	Clay on peat - Clay	0.937	0.132	**0.009**
3 – 6	Clay on peat – Sabulous clay	0.310	0.310	**0.026**
5 – 6	Clay – Sabulous clay	0.093	0.589	0.937
1,2,3 – 5,6	Koopveen, Weideveen & Clay on peat - Sabulous clay and clay	0.884	**0.000**	**0.000**
1,2 - 3,5,6	Koopveen, Weideveen - Clay on peat, Sabulous clay and clay	0.232	**0.000**	**0.000**
5 – 8	Crops/grassland - Fruit	0.065	0.065	0.699
3 – 4	Seepage - No seepage/infiltration	**0.004**	**<u>0.002</u>**	0.065
6 – 7	Infiltration - No seepage/infiltration	0.818	0.310	0.485
S - 1,2	Schraallanden - Crops/grassland; koopveen, weideveen	**0.004**	**<u>0.031</u>**	0.840
B – 5	Broek & Blokland - Crops/grassland; Clay	**0.024**	0.381	0.167

Table 4: P-values of the Mann-Whitney U tests for differences in interstitial P ($\mu mol/L$), interstitial Fe:P (mol:mol) and sediment Fe:S (mol:mol) between soil type (brown), land use type (purple), seepage/infiltration rate (orange) and nature management (green) (bold: significant ($p<0.05$); underlined: mean of first stratum/group was highest). Results of other Mann-Whitney U tests are found in appendix E. Table 3 already showed mean values.

Interstitial phosphorus only differed significantly between the seepage and no seepage/infiltration stratum and between the waterparels and agricultural strata ($p<0.05$; table 4).
Interstitial Fe:P differed significantly between 9 of the 17 comparisons ($p<0.05$; table 4). Interstitial Fe:P was significantly lower in the peat areas (1,2,3) than in the non-peat areas (5,7) ($p<0.05$; table 4). Besides that, interstitial Fe:P differed significantly between the seepage and no seepage/infiltration stratum and between the Schraallanden and the agricultural stratum ($p<0.05$; table 4).
Sediment Fe:S differed per soil type ($p<0.05$; table 4). Only between koopveen and weideveen and between sabulous clay and clay no significant differences in sediment Fe:S were revealed ($p>0.05$; table 4). No significant differences in sediment Fe:S were found between land use types, seepage/infiltration rates and nature management ($p>0.05$; table 4).

Relations between the ditch characteristics and interstitial phosphorus, interstitial Fe:P and sediment Fe:S were discussed in appendix F. Most important results were that:
1. Interstitial phosphorus correlated moderately strong positive with ammonium concentrations in the water column ($r_s=0.651$; $p<0.01$). Furthermore, interstitial phosphorus also correlated positively with sulphur concentration in the water column and interstitial alkalinity ($p<0.01$).
2. In general, interstitial Fe:P and sediment Fe:S correlated negatively with variables which are release by organic decomposition (e.g. PO_4^{3-} and S in the watercolumn and organic sediment content) and positively with several iron, aluminium, calcium concentrations ($p<0.01$).

4.3 Rules of thumbs

Figure 24, 25 and 26 show scatter-plots with the rules of thumbs, only for (moderately) strong correlations with interstitial Fe:P and sediment Fe:S. No (moderately) strong correlations were found between interstitial phosphorus and the water column concentrations and "non-chemical" sediment characteristics (r_s <0.6). All correlations (p-value and spearman's rho) are shown in appendix F.
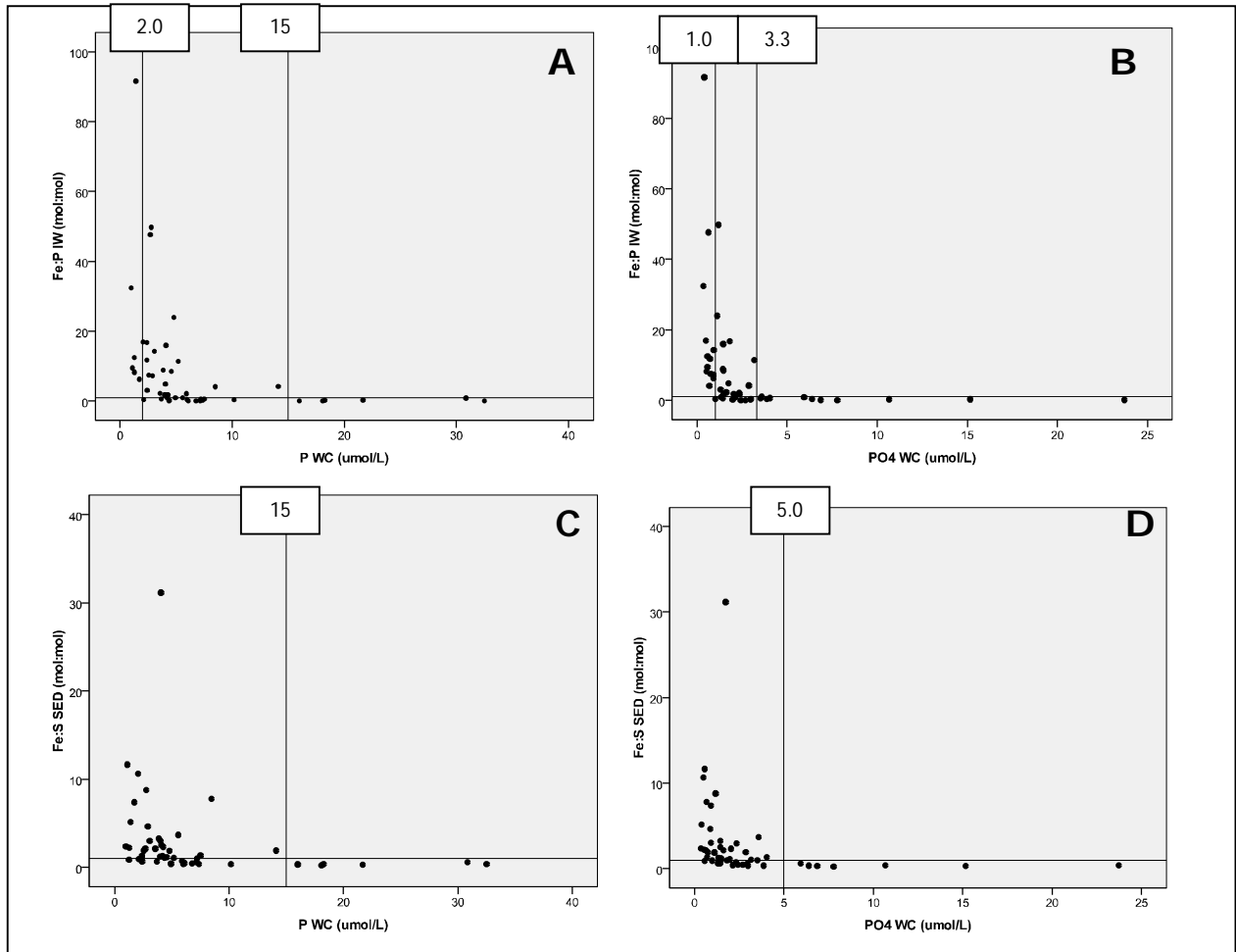
Figure 24: Relations of interstitial Fe:P and sediment Fe:S with phosphorus and phosphate concentrations in the water column, including the rules of thumbs and horizontal y= 1 line.

Both interstitial Fe:P and sediment Fe:S correlated moderately strongly with phosphorus and phosphate concentrations in the water column (figure 23). By water column phosphorus concentrations below 2.0 µmol/l and/or phosphate concentrations below 1.0 µmol/l only high interstitial Fe:P values (>1.0) were found (24A, 24B). By phosphorus concentrations above 15 µmol/l and/or phosphate concentration above 3.3 µmol/l in the water column only low interstitial Fe:P values (<1.0) were found (24A, 24B). All sediment Fe:S ratios were below 1.0 when phosphorus concentrations in the water column were above 15 µmol/l (24C) and/or when phosphate concentrations in the water column were above 5.0 µmol/l (24D).
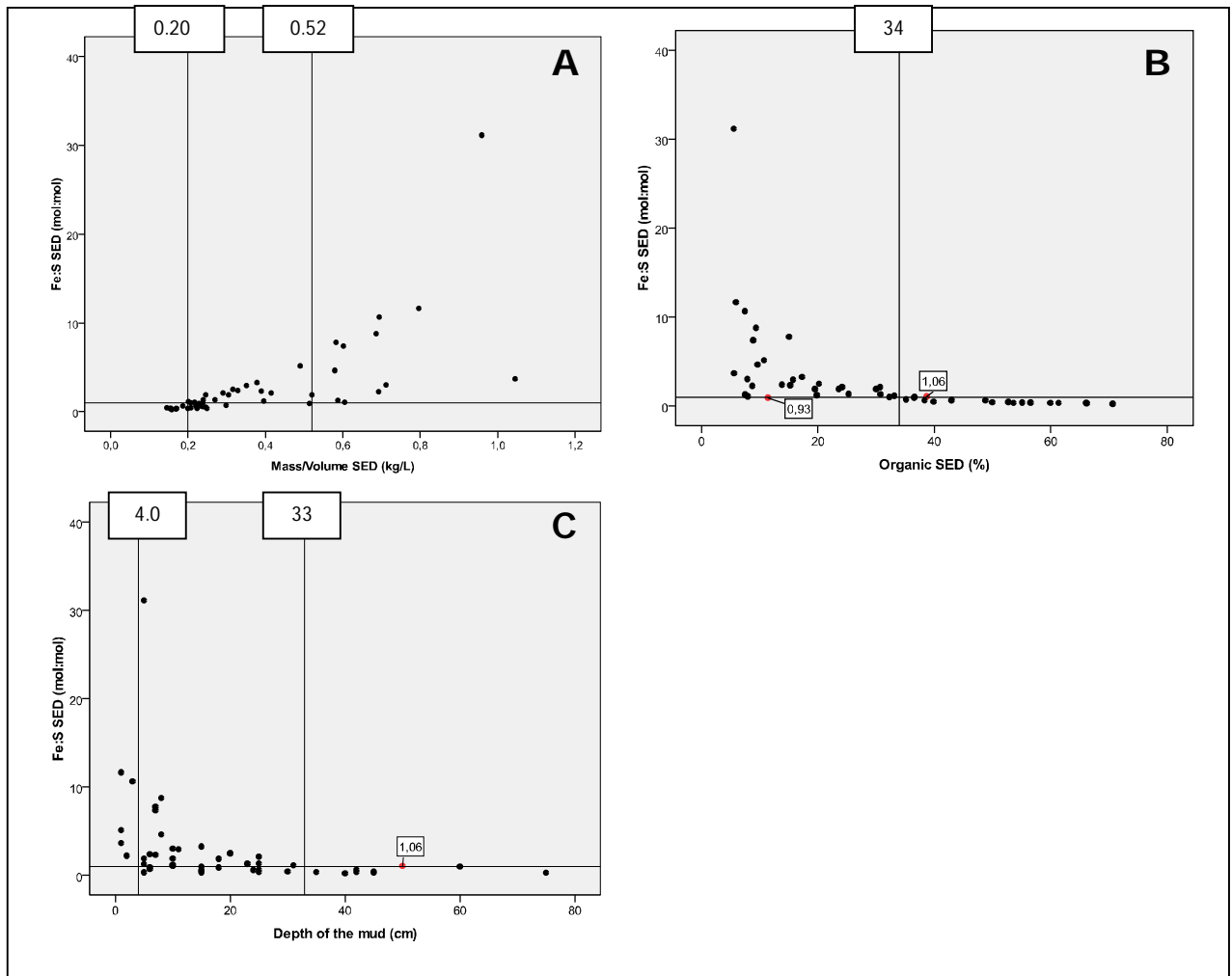
Figure 25: Relations between sediment Fe:S and three "non-chemical" ditch characteristics, including the rules of thumbs and horizontal y= 1 line. Exceptions are shown in red with their value for sediment Fe:S.

Sediment Fe:S correlated (moderately) strongly with mass density, organic sediment content and mud depth (figure 25). At locations with a mass density below 0.20 kg/l only low sediment Fe:S ratios (<1.0) were found, while high sediment Fe:S ratios (>1.0) were found at locations with a mass density above 0.52 kg/l (25A). The vertical line by an organic content of 34% separated all locations in locations with either high (>1.0) or low (<1.0) sediment Fe:S (25B). There were only two small exceptions (in red; 25B). All locations with small mud depths (<4.0 cm) had high sediment Fe:S ratio (>1.0), while locations with large mud depths (>33 cm) had low Fe:S ratios (<1.0) (25C). One exception was included (in red, 25C). Without this exception it was impossible to define a rule for low sediment Fe:S (< 1.0) based on the (easy determinable) mud depth.
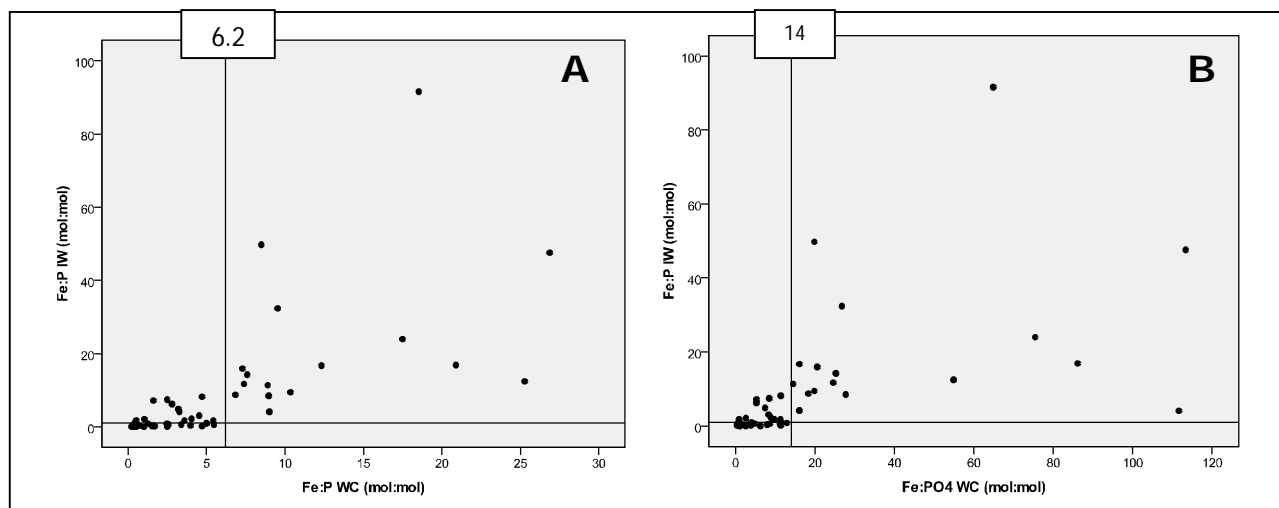
Figure 26: Relations between interstitial Fe:P and Fe:P and Fe:PO$_4^{3-}$ in the water column.

Interstitial Fe:P ratio also correlated moderately strong with the Fe:P and Fe:PO$_4^{3-}$ ratio in the water column. Figure 26 shows that at locations with a water column Fe:P ratio above 6.2 and/or a Fe:PO$_4^{3-}$ ratio above 14 only high interstitial Fe:P values (>1.0) were found.

Table 5 summarizes the rules of thumbs.

If	Was	Then it was only found by	See graph
Phosphorus in the water column	< 2.0 µmol/l	Interstitial Fe:P > 1	24A
Phosphorus in the water column	> 15 µmol/l	Interstitial Fe:P < 1	24A
Phosphate in the water column	< 1.0 µmol/l	Interstitial Fe:P > 1	24B
Phosphate in the water column	> 3.3 µmol/l	Interstitial Fe:P < 1	24B
Phosphorus in the water column	> 15 µmol/l	Sediment Fe:S < 1	24C
Phosphate in the water column	> 5.0 µmol/l	Sediment Fe:S < 1	24D
Sediment density	< 0.20 kg/l	Sediment Fe:S < 1	25A
Sediment density	> 0.52 kg/l	Sediment Fe:S > 1	25A
organic content	< 34 %	Sediment Fe:S > 1	25B
organic content	> 34 %	Sediment Fe:S < 1	25B
Mud depth	< 4.0 cm	Sediment Fe:S > 1	25C
Mud depth	> 33 cm	Sediment Fe:S < 1	25C
Fe:P in the water column	> 6.2 mol:mol	Interstitial Fe:P > 1	26A
Fe:PO$_4^{3-}$ in the water column	> 14 mol:mol	Interstitial Fe:P > 1	26B

Table 5: Revealed rules of thumbs for interstitial Fe:P and sediment Fe:S with graph numbers.

5. Discussion

This chapter discusses how the results met the aim of this study. Aim was to quantify phosphorus release rates from the stream bed sediment in the non-urban ditches (5.1) and to relate phosphorus release to selected location variables for more insight on phosphorus release and mechanisms behind it (5.2) and to define rules of thumbs on phosphorus release (5.3).
Afterwards, also recommendations for management and research were discussed (5.4).

5.1 Phosphorus release in the management area

First aim was to quantify the phosphorus release rates from the stream bed sediment in the non-urban ditches within the management area of the waterboard. This release was quantified with two correlation methods (Poelen et al., 2012; Geurts et al., 2010) as, prior to the study, it was unknown which of both methods best fitted the characteristics of the studied non-urban ditches. The two correlation formulas (Poelen et al., 2012; Geurts et al., 2010) estimated (almost) same phosphorus release rates for peats while formed independently. However, both methods measured different phosphorus release rates in the other strata and waterparels, mainly due to the use of interstitial Fe:P and sediment Fe:S thresholds in the method of Geurts et al. (2010).
Based on the following reasons, I prefer the method of Geurts et al. (2010):
1. Poelen et al. (2010) only sampled five locations with high interstitial iron concentrations (>200 µmol/l) while about half of the locations sampled in this study have high interstitial iron concentrations (>200 µmol/l; appendix G). Geurts et al. (2010) studied more locations with high interstitial iron concentrations (at least 8 locations; >200 µmol/l).
2. For locations with high interstitial iron concentrations (>200 µmol/l) Poelen et al. (2012) concluded that interstitial iron concentrations should be involved by the quantification of phosphorus release rates. However, how exactly is not cited. Geurts et al. (2010) did include those iron concentrations, namely as the interstitial Fe:P threshold for phosphorus release.
3. Lastly, the importance of iron for interstitial phosphorus concentrations (and indirectly for phosphorus release) is also shown in appendix A; at high interstitial iron concentrations (>200 µmol/l) most phosphorus in oxic water is bound to iron. This corresponds with the theory on the importance of iron for phosphorus immobilization (Chapter 2).

The mean phosphorus release rates are high in some strata and I expect that these high phosphorus release rates can largely affect the phosphorus water column concentrations. Similar conclusions were drawn by Poelen et al. (2011) and Van Gerven et al. (2011b). To give an impression of its magnitude, phosphorus release was compared with another phosphorus source in the weideveen area The Keulevaart. The other source was the direct phosphorus input to the water column by agricultural fertilization. With the estimated phosphorus release (1.1 mg P/m^2/day; table 3) and its surface water area (3.863.695 m^2; mainly non-urban ditches) the yearly phosphorus release in the Keulevaart is 1551 kg P/yr. This is about 40 times higher than the estimated direct phosphorus input by fertilization (365 kg P/yr; calculated by the waterboard based on data from emissieregistratie.nl).

The quantified phosphorus release rates are, of course, estimations of actual release rates. Uncertainties with these quantification methods are unavoidable as phosphorus release rates, and the mechanisms behind it, are complex. However, the correlations are, as far as the author knows, the best correlations available at this moment. Another method would make this research too expensive and, therefore, impossible. Also De Bruijne & Van de Weerd (2009), who reviewed quantification methods, favoured the use of indicators to estimate phosphorus release rates.

In correspondence with the method in Geurts et al. (2010) and besides interstitial phosphorus, also interstitial Fe:P and sediment Fe:S were involved in the following discussions on phosphorus release.

5.2 Relations of location variables with phosphorus release

Second aim was to relate phosphorus release to selected location variables for more insight on phosphorus release and mechanisms behind it. The relations between the locations variables (soil type, land use type, seepage/infiltration rate, nature management and the ditch characteristics) did lead to more insights. These relations are discussed below.

5.2.1 Soil type

Phosphorus release differs per soil types due to different organic decomposition rate and phosphorus binding capacity in the sediment. Most relations correspond with the expectations:

- In **weideveen and koopveen**, high phosphorus release rates due to low phosphorus binding and high decomposition rates were expected. Phosphorus binding is indeed low (interstitial Fe:P and sediment Fe:S <1) and high decomposition rates are also expected by the high values for decomposition-related variables (such as organic content; appendix E).
  Higher phosphorus release rates were expected in koopveen than in weideveen as koopveen should contain more organic material (Giesen & Geurts, 2006) but the soil types did not differ in organic sediment content (appendix E) and variables related to phosphorus release (interstitial phosphorus, interstitial Fe:P and sediment Fe:S).

- In **clay and sabulous clay**, low phosphorus release rates were expected due to high sediment phosphorus binding and low decomposition rates. The measured interstitial phosphorus concentrations are, however, unexpectedly high. These high concentrations probably relate to the observed large phosphorus pool in the sediment (appendix E); in the anoxic sediment large amounts of phosphorus can be released from this large phosphorus pool to the interstitial water. This large phosphorus pool exists due to the high phosphorus binding capacity of the sediment (interstitial Fe:P and sediment Fe:S>1). Nonetheless, according to the method of Geurts et al. (2010), the phosphorus release is, despite of the high interstitial phosphorus concentrations, still low due to this high binding capacity.
  Clays generally contain more aluminium and iron than sabulous clays (Velde, 2008; Horowitz & Elrick, 1987). Higher phosphorus binding was, therefore, expected in clays. Although iron and aluminium sediment concentrations are indeed higher in clay (appendix E) the soil types do not differ significantly in phosphorus binding (and release). The reason remains unclear.

- As expected, **Clay on peat** areas have intermediate values for phosphorus binding. For instance, mean sediment Fe:S ratio is lower than in koopveen and weideveen but higher than in clay and sabulous clay. It also has intermediate values for other variables, such as organic content (appendix E). Also the phosphorus release rates were assumed to be intermediate, so in between peats and (sabulous) clay. Nevertheless, their mean phosphorus release is higher than in all other strata. This is, however, mainly caused by the high phosphorus release rate at one location (location 14, appendix D).

5.2.2 Land use type

As expected, fruit cultivation areas seem to have lower phosphorus release than crops/grasslands areas as the mean interstitial phosphorus concentration is 2.5 times lower by fruit cultivation. So, fertilizer use on land might indeed affect phosphorus release as fruit cultivation generally uses less fertilizer (B. Spanjers, personal communication, December 15).

However, the difference in mean interstitial phosphorus between both land use types was not significant. This non-significance could be caused by the low numbers of samples (only six per stratum). Extra study with more sampling locations could perhaps reveal significant differences by increasing the power of the Mann-Whitney U tests. The power of these Mann-Whitney U tests could be estimated with power tests for Student's t-tests (Zimmerman, 2012). So, with the observed interstitial phosphorus concentrations (39.44 µmol/l ±SD 25 in fruit and 101.35 µmol/l ±SD 56 in crops/grassland), the power to reveal significant differences between the strata was about 75% ($p=0.05$; if observed means equal actual means; De Gruijter et al., 2005). Ten samples per stratum may already increase the power to 90% (if observed means equal actual means; De Gruijter et al., 2005).

5.2.3 Seepage/infiltration rate

As expected, iron-rich groundwater seepage might explain the low interstitial phosphorus concentrations and interstitial Fe:P rates (and indirectly phosphorus release) in the **seepage** area (Smolders & Roelofs, 1996). However, on the other hand, the vertical water movement by seepage could increase the diffusion of phosphorus from the interstitial water to the water column and could thereby increase the release of phosphorus (Van Gerven et al., 2011b). Nevertheless, this effect is assumed to be inferior to the effect of seepage on iron concentration and related phosphorus binding (F. Smolders, personal communication, January 7, 2012).

These low phosphorus release rates, among other processes, often lead to good water quality in seepage areas and make seepage areas optimal areas for nature conservation (Runhaar et al., 1996).

This study reveals no effects of **infiltration** on phosphorus release but the downward water flux might, however, hamper the diffusion of phosphorus from the interstitial water to the water column (Van Gerven et al., 2011b). Perhaps that the applied methodology with indicators is inappropriate to study the effect of this downward water flux on the phosphorus release rates and that this effect could better be analysed with laboratory experiments.

5.2.4 Nature management

Various long-lasting measures (dephosphatation of inlet water, rising of water tables, banning of fertilizer and introducing agricultural bufferzones) were implemented in the **Schraallanden langs de Meije.** These measures probably explain the low phosphorus release rates by lowering organic decomposition rates and external phosphorus input. For instance, the higher water tables could have led to lower decomposition rates in surrounding land and thereby decrease phosphorus and sulphur input to the water column and, indirectly, to the interstitial water. Also the measured ditch characteristics indicate low decomposition rates from sediment and surrounding land and low external phosphorus input (e.g. several low ammonium, sulphur and phosphorus concentrations; appendix E). So, as expected, nature management can lead to low phosphorus release rates.

Just as for the Schraallanden, measures (e.g. high water tables and low fertilizer use) can explain the low phosphorus release rates in **Broek & Blokland**. However, iron-rich groundwater seepage can also partly explain the low mean phosphorus release as particularly the seepage location had high phosphorus binding (interstitial Fe:P and sediment Fe:S) and low phosphorus release rates (location 57; appendix D). This made the effect of the implemented measures on phosphorus release in Broek & Blokland less evident than in the Schraallanden.

5.2.5 Ditch characteristics

Several correlations between interstitial phosphorus and the ditch characteristics also lead to extra understanding of phosphorus release and the mechanism behind it. For instance, the positive correlations of interstitial phosphorus with interstitial ammonium and alkalinity emphasize the important role of organic decomposition for phosphorus release; all three variables increase by organic decomposition (Chapter 2).

Organic decomposition was also expected to (partly) explain the positive correlation between interstitial phosphorus and sulphur in the water column. To verify this, the relation between sulphur in the water column and organic decomposition (as organic content) was studied. Unlike interstitial phosphorus, sulphur in the water column did not correlate with organic content (Spearman correlation test; $r_s=0.237$; $p=0.106$). So, iron immobilization in the sediment by sulphur more likely explains the revealed correlation between sulphur in the water column and interstitial phosphorus (and indirectly phosphorus release). Sulphur in the water column must, therefore, be seen as a potential threat for the water quality. This negative effect of sulphur on the water quality is even exacerbated by the toxicity of sulphide for aquatic plants (Smolders et al., 2006). As sulphate and sulphide were difficult to estimate only total sulphur concentrations were determined but especially sulphide leads to iron immobilisation in the sediment (Smolders et al., 2006). However, both chemicals can potentially stimulate phosphorus release as sulphate might as well be reduced to sulphide.

Also non-significant relations between interstitial phosphorus and the ditch characteristics gave valuable insights on phosphorus release and the mechanism behind it. The non-significance of correlations between interstitial phosphorus and water column and interstitial iron concentrations might, for instance, be explained by two contrasting relations:

- High iron concentration leads, via high phosphorus binding in the sediment, to a large phosphorus sediment pool. This is also indicated by the positive correlations of sediment phosphorus binding (interstitial Fe:P and sediment Fe:S) with iron and phosphorus sediment concentrations (appendix F). This results in high interstitial phosphorus concentrations, for instance due to sorption of phosphorus from the sediment. Figure 27 shows the positive correlation.

High iron concentrations	→	High phosphorus binding	→	High sediment phosphorus pool	→	High interstitial phosphorus
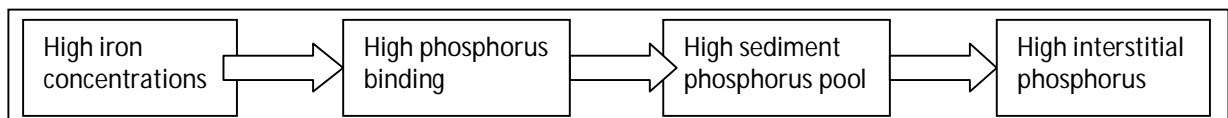
Figure 27: Positive correlation between iron concentrations and interstitial phosphorus.

- On the other hand, low phosphorus binding results in high interstitial phosphorus concentrations as phosphorus is not adsorped by iron in the sediment. Figure 28 shows this negative correlation. Furthermore, sediments with low iron concentrations are often highly organic which leads to organic decomposition and release of phosphorus.

Low iron concentrations	→	Low phosphorus binding	→	Low sediment phosphorus pool	→	High interstitial phosphorus
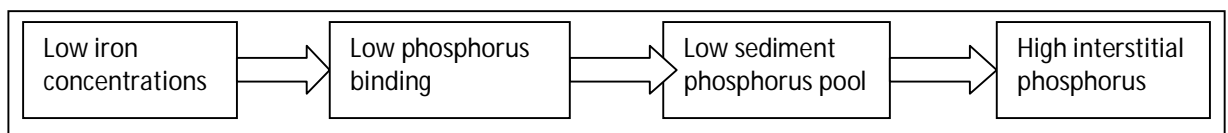
Figure 28: Negative correlation between iron concentrations and interstitial phosphorus.

Other studies stressed the important role of nitrate for the redox potential and (related) phosphorus release (Chapter 2; appendix H). However, most measured interstitial nitrate concentrations are low (< 4 µmol/l; appendix G). Reason for this is that, in the anoxic sediment, nitrate can be quickly transformed to ammonium or nitrogen gas (N_2) (Poelen et al., 2012). The measured interstitial nitrate concentrations might, therefore, underestimate the actual role of nitrate for the redox potential in the sediment. As also nitrate concentrations in the water column did not correlate with phosphorus release, the effect of nitrate on phosphorus release still remains unclear.

In addition, significant correlations for interstitial Fe:P and sediment Fe:S also lead to extra understanding of phosphorus release and the mechanisms behind it. The negative correlations of interstitial Fe:P and sediment Fe:S with variables indicating decomposition (e.g. P and PO_4^{3-} in the water column, S and NH_4^+ in the watercolumn and organic sediment content) emphasize the importance of organic decomposition for phosphorus release. On the other hand, the positive correlations of interstitial Fe:P and sediment Fe:S with several iron, aluminium and calcium concentrations emphasize the importance of inorganic sediments for phosphorus binding.

For these correlations, all sampling locations in the strata were combined and tested as one group. The correlation tests were, therefore, not based on an entirely random selection of samples as each stratum had the same amount of samples (=power) while some stratum had larger water surface areas than others. The amount of samples per stratum should have been relative to the surface water area of each stratum. At the start of this project it was not aimed to study these correlations in depth so the sampling strategy was not defined as such. Nevertheless, the location selection within each stratum was random and the correlations still lead to extra insights on phosphorus release.

5.3 Rules of thumbs

Last aim of this study was to define rules of thumbs for phosphorus release. These rules aimed to create a simple tool to indicate ditches where phosphorus release is probably high or low based on easily determinable ditch characteristics, compared to the current indicators (interstitial phosphorus, interstitial Fe:P and sediment Fe:S).

Results revealed rules of thumbs for interstitial Fe:P and sediment Fe:S. These rules can indicate the possibility of phosphorus release as, according to the method of Geurts et al. (2010), phosphorus release is only possibly if interstitial Fe:P and/or sediment Fe:S ratio is below 1.0.
It was not possible to include rules of thumbs for interstitial phosphorus concentrations due to the lack of (moderately) strong correlations between interstitial phosphorus and the easily determinable ditch characteristics. This made it impossible to define rules of thumbs for the height of phosphorus release (as the height is determined with interstitial phosphorus).
If the rules of thumbs reveal a possibility of phosphorus release, based on interstitial Fe:P and/or sediment Fe:S, water managers could decide to determine interstitial phosphorus concentrations to quantify the height of phosphorus release. These rules make the labour intensive collection of interstitial water at some locations, therefore, unnecessary.

Prudency is obviously needed as these rules are only based on the studied dataset. However, all rules were based on (moderately) strong correlations. Uncertainties also decrease when more rules are used at once to define the phosphorus release possibility for a location. Hence, I assume that these rules of thumbs resulted in a simple and proper tool to indicate the possibility of phosphorus release.

Note that only winter water column concentrations should be used for the rules of thumbs as fieldwork was conducted in March, after a cold winter period in February. Almost no plant activity was noted in the water column which indicated that plant growth still needed to start.
Contrary to these water column concentrations, interstitial and sediment concentrations are rather stable over the year (Geurts et al., 2008; Smolders et al., 2011).

Studies on the effect of the other location variables (Section 5.2) also resulted in "rules of thumbs" (table 3). Based on these "rules" the phosphorus release was roughly defined for the largest part of the management area (see figure 21). The variance in interstitial phosphorus, interstitial Fe:P and sediment Fe:S within each stratum was, however, high. The case-study in the Keulevaart even revealed that these variances are even high within the same drainage area (appendix H). So, these rules, based on the other location variables, are less suitable to define the possibility of phosphorus release for a ditch instead of a whole management area. For more local assessment of the possibility of phosphorus release (e.g. per ditch), use of the rules of thumbs based on the ditch characteristics is, therefore, preferred.

5.4 Recommendations for management and research

Phosphorus release rates might largely affect the phosphorus concentrations in the water column (Section 5.1). So, for lower water column phosphorus concentrations, measures to reduce phosphorus release are probably needed in some areas. Recommendations on these measures, and other recommendations for management and research, are discussed below.

- Be prudent with traditional measures

Schraallanden langs de Meije and another nature peat area (Van Gerven et al., 2011b) reveal that traditional measures, such as rising water tables ("rewetting") and decreasing fertilizer use, could reduce phosphorus release. However, these measures often conflict with agricultural farming, do not show results on a short time scale and still contain uncertainties regarding the effects (Riens et al., 2002; De Bruijne & Van de Weerd, 2009; Zak et al., 2010). For instance, rewetting periods of probably several decades are necessary in severely degraded fens before their water quality corresponds with the water quality in their natural counterparts (Zak et al., 2010). Furthermore, rising of water tables can also lead to increased phosphorus release due to decrease of oxygen concentrations in the stream bed sediment (Zak et al., 2009). So, even by implementation of these common measures, prudency is needed as phosphorus release and the mechanisms behind it are complex.

- Consider a ditch experiment with iron addition

A more innovative measure to reduce phosphorus release from the stream bed sediment would be addition of iron into ditches. Iron addition could increase the sediment phosphorus binding and thereby reduce phosphorus release (F. Smolders, personal communication, May 24, 2012). The effect of iron addition is, however, limited to oxic phosphorus release as by an anoxic water column iron-bound phosphorus in the sediment might be released (Burley et al., 2001; Lucassen et al., 2008). Yet, Cooke et al. (1993) cited that inactivation of phosphorus in the sediment is an effective measure to lower phosphorus concentrations in the water column at locations where phosphorus release highly affects the phosphorus concentrations in the water column. A small ditch experiment with iron-waste from drink water companies could be considered to study the effect of iron addition on phosphorus release (F. Smolders, personal communication, May 24, 2012).

- Note the importance of inlet water

Inlet water can affect the phosphorus release from the stream bed sediment in the drainage areas. Calcium- and iron-rich inlet water could increase the phosphorus binding capacity in the stream bed sediment (De Nijs et al., 2007), while sulphate and alkaline-rich inlet water can increase the phosphorus release (Van Diggelen et al., 2007b; Chapter 2). Nitrate-rich inlet water might also increase the phosphorus binding capacity (De Nijs et al., 2007).

Besides the actual water quality, water managers should also look at the relative water quality of the inlet water, so relative to water within the drainage area (Van Gerven et al., 2011b). In drainage areas with high sulphur and phosphorus concentrations in the water column, additional drainage of inlet water with relatively low sulphur and phosphorus concentrations might decrease the release of phosphorus in that drainage area.

The water quality of inlet water and of water in the drainage areas is currently researched with nutrient balances (phosphorus and nitrogen) at the waterboard. Together with additional information on the calcium, iron, sulphate, nitrate concentrations and the alkalinity of those waters, these nutrient balances should be included in the decision making on the quantity and type of inlet water.

- Analyse deeper sediment layers before mud removal

The observed correlation between interstitial Fe:P and mud depth suggests that mud removal could decrease phosphorus release by increasing the phosphorus binding of the sediment. However, the effect of mud removal depends on chemical concentrations of deeper sediment layers (Lucassen et al., 2008). So, information on chemical concentrations of deeper sediment layers is probably required before mud removal is implemented as a measure to lower phosphorus release.

- Research seasonal effects and (related) anoxic phosphorus release

The phosphorus release rates in the experiments of Poelen et al. (2012) and Geurts et al. (2010) were measured by 15°C. It is challenging to translate these phosphorus release rates (and the estimated phosphorus release rates based on the resulted correlation formulas) to actual release rates over the year. Poelen et al. (2012) did measure phosphorus release rates by varying temperatures (4 to 25 °C). However, the seasonal effects of, for instance, algae bloom were not considered. Algae bloom can lead to an anoxic water column (loss of the oxic boundary layer) which can result in phosphorus mobilization from iron bindings (De Bruijne & Van de Weerd, 2009). This leads to anoxic phosphorus release.

No correlation, such as Poelen et al. (2012) and Geurts et al. (2010), was available to determine anoxic phosphorus release. As anoxic phosphorus release is diffusion-mediated (F. Smolders, personal communication, May 24, 2012), interstitial phosphorus concentrations might be indicative for anoxic phosphorus release. However, this diffusion rate to the water column depends on several factors, such as the abundance of plant roots and the seepage rate (De Bruijne en Weerd, 2009). This makes quantification of anoxic phosphorus release rates difficult.

Nevertheless, anoxic phosphorus can largely affect the phosphorus concentrations in the water column. In the study of Van Gerven et al. (2011b) the anoxic phosphorus release in peats was, for instance, two to five times higher than the oxic phosphorus release in peats (Van Gerven et al., 2011b). Also in the (sabulous) clay areas I expect high anoxic phosphorus release rates due to their large redox-sensitive iron-bound phosphorus pool in the stream bed sediment.

So, more study is needed to better understand the seasonal variation in (oxic and anoxic) phosphorus release. Year-round measures, similar as conducted in this study, with extra oxygen measurements and algae observations can give more insight into this seasonal variation.

- Research the effect of nitrate on phosphorus release

The effect of nitrate on phosphorus release remains unclear as no effects were found in this study and opposing effects of nitrate on phosphorus release were found in literature (Chapter 2). In literature, the conditions in which nitrate and phosphorus release were studied varied (e.g. different soil types and quantification methods). These conditions perhaps affected the relation between nitrate and phosphorus release. A critical literature review on these conditions might, therefore, already give more insight into the effect of nitrate on phosphorus release.

6. Conclusion

Mean phosphorus release rates in the management area of the waterboard vary between 0.0 to 2.0 mg P/m^2/day, according to the method of Geurts et al. (2010). The high release rates in some areas might indeed largely affect the water column phosphorus concentrations. The release was also quantified with the method of Poelen et al. (2012). However, I prefer the method of Geurts et al. (2010) as it included thresholds for phosphorus release based on sediment phosphorus binding, namely that phosphorus release is limited by interstitial Fe:P and/or sediment Fe:S above 1.0.

Several relations with phosphorus release are found:

- **Phosphorus release largely differs per soil type.** Phosphorus release is highest in peat areas due to high organic decomposition and low sediment phosphorus binding (interstitial Fe:P and/or sediment Fe:S < 1.0). In sabulous clay and clay areas the release is lowest due to high sediment phosphorus binding (interstitial Fe:P and/or sediment Fe:S > 1.0). In general, intermediate phosphorus release rates, and related variables, are found in clay on peat.
- **Fruit cultivation areas seem to have lower phosphorus release** than crops/grasslands areas due to lower fertilizer use on land. However, this needs extra study for verification.
- **Iron-rich seepage leads to low phosphorus release rates** due to better phosphorus binding in the stream bed sediment. No effect of infiltration on phosphorus release is found.
- **Nature management can lead to lower phosphorus release rates.** Several long-lasting measures probably explain the low phosphorus release rates in peat area "Schraallanden langs de Meije". In clay area "Broek & Blokland" the effect of the implemented measures on phosphorus release was less evident.
- **Interstitial phosphorus correlates positively with interstitial ammonium and alkalinity and with sulphur in the water column.** The first two correlations accentuate the important role of organic decomposition as phosphorus, ammonium and alkalinity all increase by decomposition. Iron immobilization in the sediment by sulphur probably explains the last correlation.
- Lastly, in general, **phosphorus binding correlates positively with inorganic sediments** (aluminium, iron and calcium concentrations) **and negatively with variables indicating organic decomposition** (such as organic content). This also accentuates the important role of organic decomposition (and inorganic sediment) for phosphorus binding.

The relations also resulted in "rules of thumbs" and formed a tool to indicate locations were phosphorus release is probably possible. At locations where the tool indicates a possibility of release water managers can decide to measure interstitial phosphorus to quantify the height of this release.

If	was	then it was only found by	so (probably)
Phosphorus in the water column	< 2.0 µmol/l	Interstitial Fe:P > 1	**No oxic phosphorus release**
Phosphorus in the water column	> 15 µmol/l	Interstitial Fe:P < 1	**Oxic phosphorus release**
Phosphate in the water column	< 1.0 µmol/l	Interstitial Fe:P > 1	**No oxic phosphorus release**
Phosphate in the water column	> 3.3 µmol/l	Interstitial Fe:P < 1	**Oxic phosphorus release**
Phosphorus in the water column	> 15 µmol/l	Sediment Fe:S < 1	**Oxic phosphorus release**
Phosphate in the water column	> 5.0 µmol/l	Sediment Fe:S < 1	**Oxic phosphorus release**
Sediment density	< 0.20 kg/l	Sediment Fe:S < 1	**Oxic phosphorus release**
Sediment density	> 0.52 kg/l	Sediment Fe:S > 1	**No oxic phosphorus release**
organic content	< 34 %	Sediment Fe:S > 1	**No oxic phosphorus release**
organic content	> 34 %	Sediment Fe:S < 1	**Oxic phosphorus release**
Mud depth	< 4.0 cm	Sediment Fe:S > 1	**No oxic phosphorus release**
Mud depth	> 33 cm	Sediment Fe:S < 1	**Oxic phosphorus release**
Fe:P in the water column	> 6.2 mol:mol	Interstitial Fe:P > 1	**No oxic phosphorus release**
Fe:PO$_4^{3-}$ in the water column	> 14 mol:mol	Interstitial Fe:P > 1	**No oxic phosphorus release**

Table 6: Rules of thumbs for the possibility of phosphorus release

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Appendix A: Analysis of measured interstitial phosphorus versus phosphate

In the study of Geurts et al. (2010) oxidation took place in the interstitial water samples. This small study was conducted to test if this oxidation also occurred in the samples of this study. The relations between measured interstitial phosphorus, phosphate and iron concentrations were, therefore, studied with a scatter-plot (figure A1).
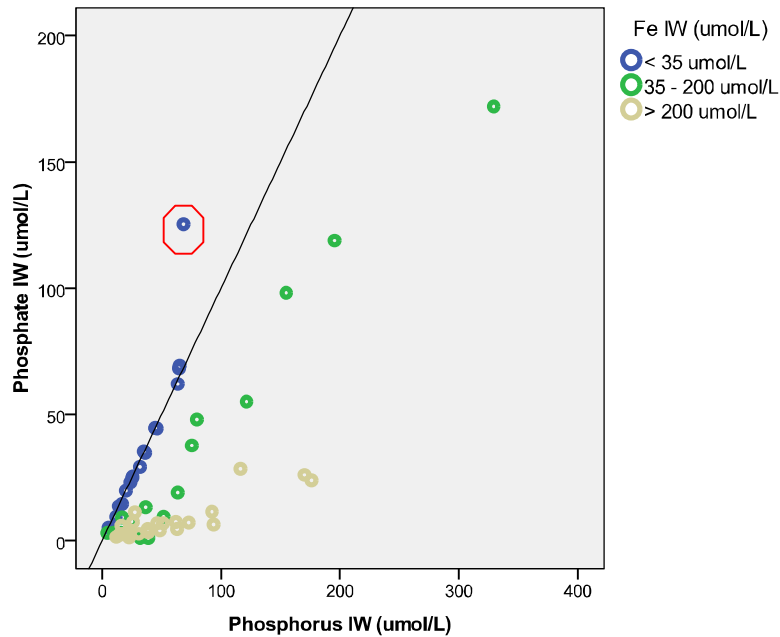
Figure A1: Interstitial phosphorus versus interstitial phosphate with the effect of interstitial iron (Fe) and a 1:1 line (IW: interstitial water). The sample indicated in red had an unknown artefact as its measured interstitial phosphate was higher than its measured interstitial phosphorus.

The anoxic interstitial water was collected with the Rhizon soil samplers and chemical concentrations in the interstitial water were measured afterwards. Anoxic interstitial water mainly contains phosphate as phosphorus-compound (F. Smolders, personal communication, January 7, 2012). Measured interstitial phosphorus and phosphate were, therefore, expected to be (nearly) similar.
This was, however, only valid at low interstitial iron concentrations (< 35 µmol/l; figure A1). At higher iron concentrations phosphate concentrations, relative to measured phosphorus, were lower. Binding of phosphate with iron during oxidation can explain these low phosphate concentrations. This oxidation probably occurred in the trays for the auto-analyser.

So, just as in the study of Geurts et al. (2010), oxidation probably occurred in the interstitial water samples. This oxidation, however, emphasized the importance role of oxic conditions and iron for phosphorus release. With oxidation and high interstitial iron concentrations (>200 µmol/l) all phosphorus is bound to iron and almost no dissolved phosphate existed. Within the stream bed sediments these conditions, an oxic boundary layer and high iron concentrations, will lead to low release rates of phosphorus (dissolved phosphate) to the water column. This corresponds with the theory on the oxic boundary layer and iron concentrations (Chapter 2).

Appendix B: Original maps of the management area of the waterboard

The four maps below were obtained from the waterboard.
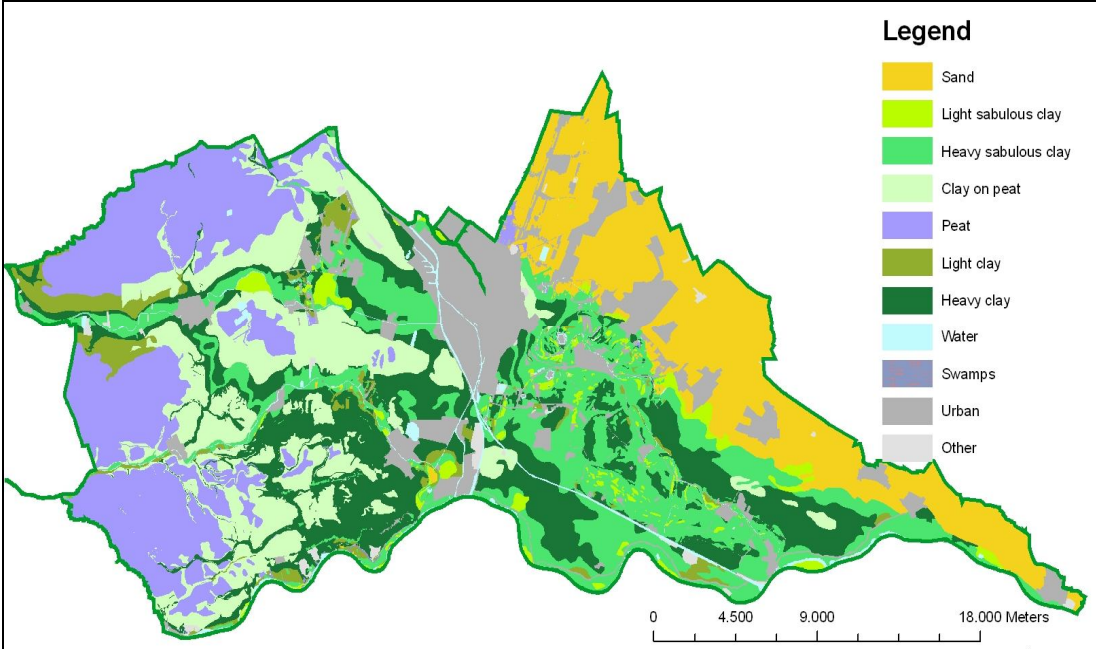
Figure B1: Soil map of the management area of the waterboard (Bodemkaart HDSR).
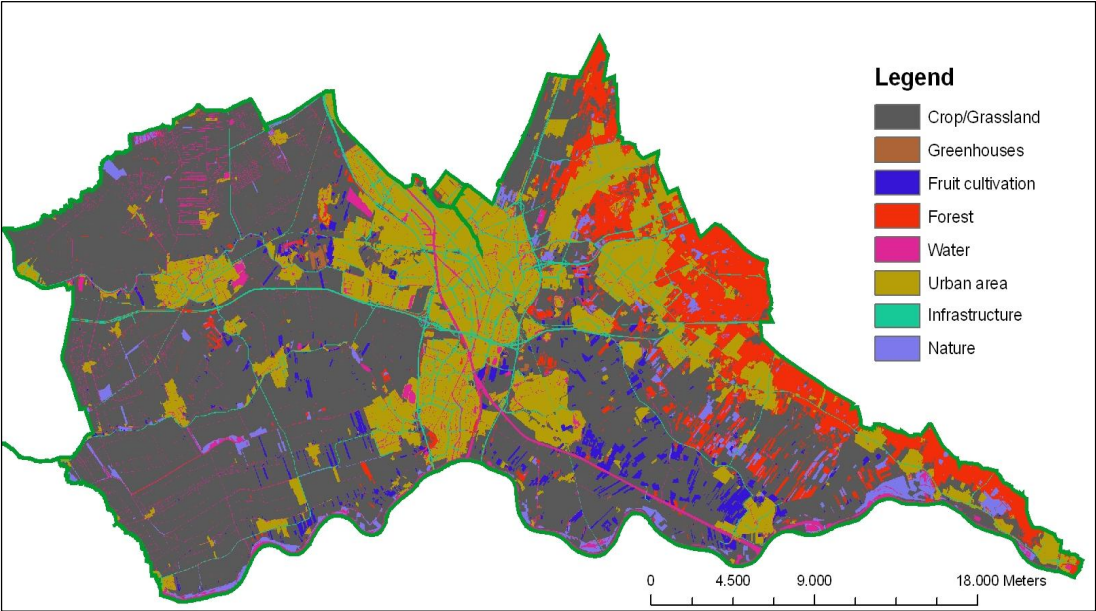
Figure B2: Land use map of the management area of the waterboard (LGN6_Monitoring).
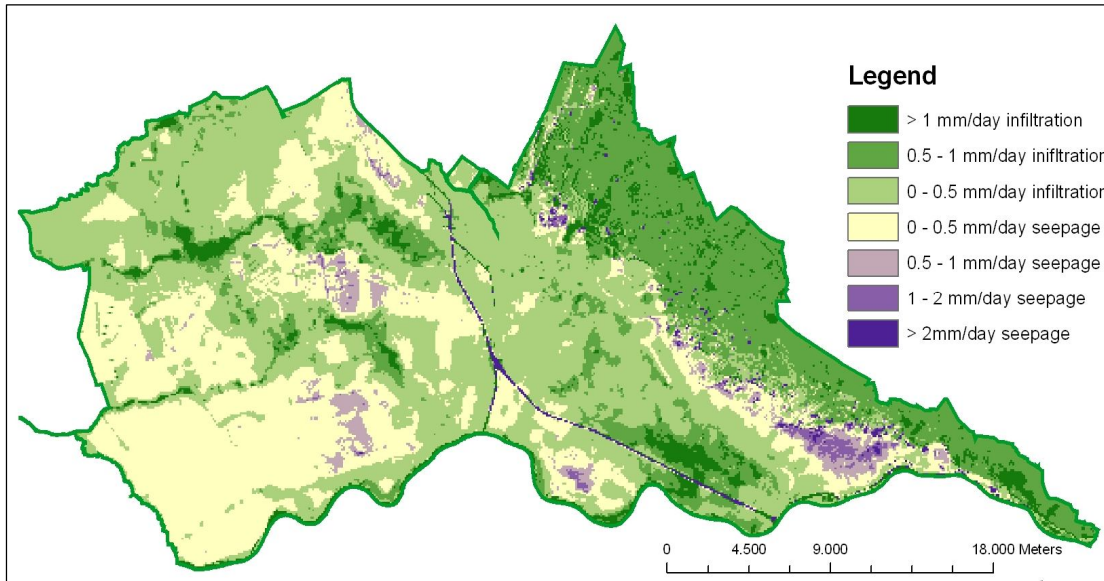
Figure B3: Seepage/infiltration map of the management area of the waterboard (Kwel/wegzijging).
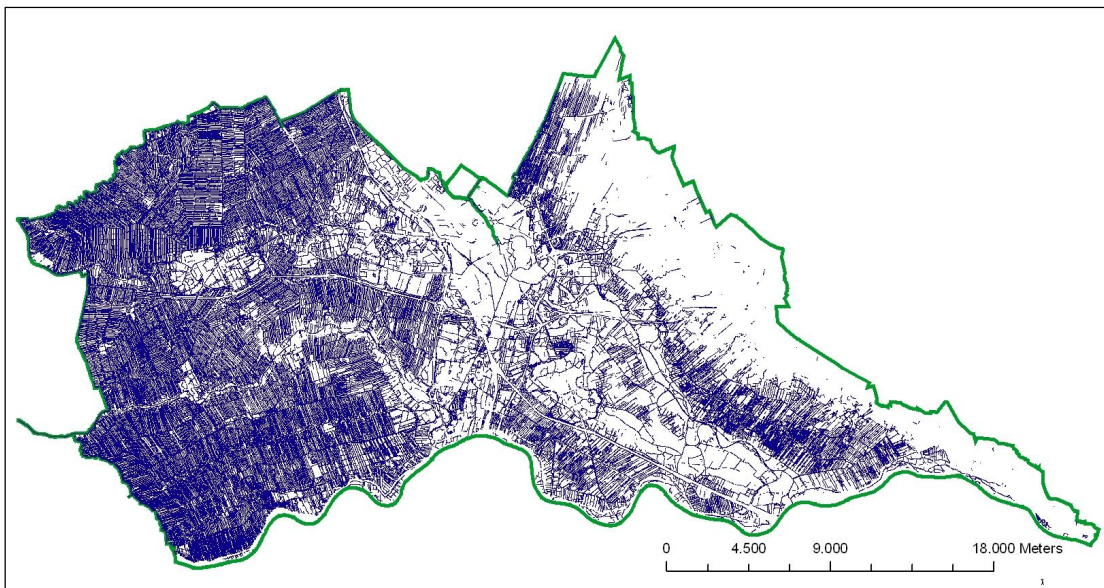
Figure B4: Water map of the management area of the waterboard (Kartering_OppervlakteWater_2010).

Appendix C: The coordinates of the sampling locations

Location	X-coordinate	Y-coordinate	Strata code
1	113889	449991	1
2	119596	461556	1
3	120625	462365	1
4	117837	461058	1
5	114005	450590	1
6	114656	458495	1
7	121740	459429	2
8	116346	445680	2
9	116988	457871	2
10	115217	448000	2
11	117194	450714	2
12	117493	445264	2
13	121431	449788	3
14	124978	445824	3
15	120332	450206	3
16	120725	457068	3
17	125998	453347	3
18	119521	457428	3
19	128483	448179	4
20	129846	453563	4
21	128334	454252	4
22	129514	453337	4
23	155317	444618	4
24	128549	454327	4
25	115759	453340	5
26	139777	446538	5
27	125793	457508	5
28	132014	449839	5
29	130864	451398	5
30	130210	458225	5
31	156378	445947	6
32	139198	443828	6
33	153643	447102	6
34	123463	457353	6
35	116530	455315	6
36	151210	447772	6
37	141513	450300	7
38	145251	453297	7
39	147332	442500	7
40	149305	442273	7
41	118876	448437	7
42	115853	454755	7
43	129542	448507	8
44	129608	448025	8
45	129814	447781	8
46	126611	442718	8
47	142480	442747	8
48	136444	448725	8
49	115679	461304	S
50	115625	461193	S
51	115460	460942	S
52	116677	458228	Z
53	116247	458555	Z
54	115748	458933	Z
55	127326	448809	B
56	127313	448858	B
57	127127	448784	B

Table C1: Coordinates of all sampling locations and their stratum/waterparel code.

Appendix D: The estimated phosphorus release rates of the sampling locations

Phosphorus release rates were quantified for all locations according to the method of Poelen et al. (2012) and Geurts et al. (2010).

Location	P IW (µmol/l)	Fe:P IW (mol:mol)	Fe:S SED (mol:mol)	Geurts et al. (2010) phosphorus release (mg P/m^2/day)	Poelen et al. (2012) phosphorus release (mg P/m^2/day)
1	65.06	0.05	0.33	1.2	1.1
2	63.48	2.09	0.73	1.1	1.1
3	63.64	0.27	0.30	1.1	1.1
4	25.14	0.37	0.35	0.4	0.4
5	31.89	0.33	0.35	0.5	0.5
6	64.68	0.02	0.44	1.2	1.1
7	20.16	0.24	0.38	0.3	0.4
8	68.58	0.04	0.24	1.2	1.1
9	25.62	0.02	0.48	0.4	0.5
10	195.4	0.63	0.65	3.6	4.5
11	36.13	0.30	0.35	0.6	0.6
12	44.66	0.09	0.38	0.8	0.7
13	79.53	0.82	0.61	1.4	1.4
14	329.4	0.61	1.00	6.1	10.1
15	75.49	0.96	0.42	1.4	1.3
16	92.38	2.23	2.13	0.0	1.6
17	35.07	0.14	0.61	0.6	0.6
18	51.53	3.03	0.64	0.9	0.8
19	26.05	8.47	1.15	0.0	0.5
20	11.84	47.6	2.12	0.0	0.3
21	16.25	16.7	0.99	0.3	0.3
22	22.09	11.7	1.32	0.0	0.4
23	38.65	4.09	7.78	0.0	0.6
24	27.39	11.4	1.06	0.0	0.5
25	176.3	1.71	1.22	0.0	3.9
26	116.4	1.74	2.33	0.0	2.2
27	63.06	15.9	2.49	0.0	1.0
28	46.14	8.79	3.26	0.0	0.8
29	154.8	0.61	1.34	2.8	3.2
30	51.40	6.23	7.38	0.9	0.8
31	16.87	0.39	0.93	0.3	0.3
32	38.49	9.45	11.7	0.0	0.6
33	11.64	0.94	3.68	0.2	0.3
34	121.4	0.90	1.27	2.2	2.3
35	93.83	7.20	4.64	0.0	1.7
36	32.02	4.15	1.90	0.0	0.5
37	24.67	4.82	31.2	0.0	0.4
38	38.65	49.8	8.77	0.0	0.6
39	9.80	16.9	10.6	0.0	0.3
40	30.65	32.4	2.39	0.0	0.5
41	170.4	1.78	2.96	0.0	3.7
42	23.92	0.14	1.08	0.4	0.4
43	72.94	8.18	2.24	0.0	1.2
44	21.98	24.0	1.89	0.0	0.4
45	16.61	12.4	0.89	0.3	0.3
46	62.06	14.3	3.02	0.0	1.0
47	14.61	91.6	5.14	0.0	0.3
48	48.43	7.45	1.90	0.0	0.8
49	13.94	0.38	0.34	0.2	0.3
50	4.38	8.17	0.45	0.0	0.2
51	5.39	1.20	0.42	0.1	0.2
52	44.53	0.25	0.43	0.8	0.7
53	46.08	0.32	0.31	0.8	0.8
54	16.86	4.93	0.67	0.3	0.3
55	36.42	1.75	1.09	0.0	0.6
56	15.44	7.88	1.31	0.0	0.3
57	22.80	28.9	1.80	0.0	0.4

Table D1: Interstitial phosphorus (P), interstitial Fe:P, sediment Fe:S and the phosphorus release rates for all locations (IW: interstitial water; grey areas indicate interstitial Fe:P or sediment Fe:S < 1.0).

Appendix E: Mann-Whitney U tests and means of location variables

Means and p-values of the Mann-Whitney U test are shown for soil type (table E1 and E2), land use type (E3), seepage/infiltration rate (E4) and nature management (E5).

Soil type

Ditch characteristics	Koop veen (1) Mean	Sd	Weide veen (2) Mean	Sd	Clay on peat (3) Mean	Sd	Clay (5) Mean	Sd	Sabulous clay (7) Mean	Sd
P WC (µmol/l)	11.1	6.46	14.3	11.0	9.35	10.7	4.24	1.86	5.00	4.73
PO_4^{3-} WC (µmol/l)	6.07	4.87	8.32	8.31	2.91	1.69	1.89	1.11	1.71	1.23
P SED (mmol/kg)	33.8	4.91	27.1	8.47	37.8	9.77	34.9	14.8	28.7	19.5
P SED L (mmol/l)	6.84	2.88	5.58	2.41	9.66	4.08	13.0	4.67	17.9	10.7
Fe IW (µmol/l)	29.1	51.0	24.3	48.5	117	81.7	388	321	217	260
Fe WC (µmol/l)	13.6	11.8	9.92	3.89	33.3	23.8	19.6	9.05	11.9	17.2
Fe SED (mmol/kg)	264	66.8	300	97.2	481	92.1	508	64.4	276	193
Fe SED L (mmol/l)	54.1	30.2	60.1	23.8	122	42.8	197	67.1	177	135
S IW (µmol/l)	331	273	528	540	283	189	131	88.3	280	289
S WC (µmol/l)	729	419	669	447	1257	377	617	382	447	156
S SED (mmol/kg)	652	75.4	758	224	673	246	234	119	117	108
S SED L (mmol/l)	126	22.8	147	38.0	155	42.6	82.4	39.7	67.5	60.3
NO_3^- IW (µmol/l)	2.32	0.96	3.13	2.20	2.96	1.76	8.90	16.4	4.25	5.19
NO_3^- WC (µmol/l)	16.6	15.7	18.9	21.8	8.66	7.39	17.2	23.7	119	158
NH_4^+ IW (µmol/l)	411	245	469	275	530	193	267	169	264	280
NH_4^+ WC (µmol/l)	19.0	6.88	46.9	31.2	60.6	108	20.0	19.7	47.5	49.2
Alk IW (µmol/l)	6.63	2.08	5.83	1.88	7.27	1.08	6.87	1.09	5.60	3.59
Alk WC (µmol/l)	4.22	0.82	4.79	2.08	3.98	0.83	4.56	1.58	5.45	3.15
AL IW (µmol/l)	2.58	1.58	2.52	1.27	3.32	2.02	1.75	0.50	1.76	1.38
Al WC (µmol/l)	5.33	1.16	4.51	1.57	11.6	12.1	13.5	8.56	2.29	1.91
Al SED (mmol/kg)	467	15.7	547	156	905	277	868	98.8	419	243
Al SED L(mmol/l)	93.4	30.6	111	42.4	241	141	334	97.8	270	183
Ca IW (µmol/l)	2329	462	2456	922	2762	549	2443	246	2841	671
Ca WC (µmol/l)	1776	595	2013	944	2314	441	1980	458	2303	690
Ca SED (mmol/kg)	513	55.6	597	176	480	151	366	109	333	331
Ca SED L (mmol/l)	102	32.0	115	28.1	117	35.8	140	61.3	202	190
pH IW	6.95	0.38	7.00	0.41	6.75	0.11	6.72	0.14	7.27	0.33
pH WC	7.81	0.28	7.66	0.44	7.35	0.34	7.50	0.40	7.44	0.37
Mass/Volume SED (kg/l)	0.20	0.06	0.20	0.04	0.25	0.08	0.39	0.12	0.67	0.21
Organic SED (%)	55.6	11.6	54.4	11.5	39.4	9.96	17.8	5.52	10.6	6.73
Depth of the ditch (cm)	39.0	9.32	50.0	17.3	27.8	18.9	29.2	13.3	17.3	13.8
Width of the ditch (m)	3.75	2.36	2.83	1.17	2.75	1.94	2.58	1.16	1.32	0.95
Waterlevel (m)	0.32	0.04	0.47	0.08	0.42	0.16	0.72	0.25	1.02	0.29
Depth of the mud (cm)	31.0	26.3	31.5	13.0	24.8	11.0	14.0	7.38	4.33	2.80
Fe:P SED (mol:mol)	7.83	1.51	11.2	2.80	12.9	1.44	15.8	3.83	9.90	6.85
Fe-S:P SED (mol:mol)	-11.9	4.73	-19.3	11.9	-6.21	8.28	8.71	5.77	5.18	5.96
Fe:P WC (mol:mol)	1.40	1.32	1.40	1.33	4.37	1.04	4.75	2.05	2.94	3.77
Fe:S WC (mol:mol)	0.03	0.04	0.02	0.01	0.03	0.01	0.05	0.05	0.04	0.07
Fe-S:P WC (mol:mol)	-92.8	82.0	-63.5	39.4	-223	141	-174	138	-166	119
$Fe:PO_4^{3-}$ WC (mol:mol)	2.85	2.63	3.30	3.49	10.7	1.73	11.7	6.57	7.90	8.07
$Fe-S:PO_4^{3-}$ WC (mol:mol)	-212	213	-144	107	-493	220	-382	270	-406	272
Fe:S IW (mol:mol)	0.09	0.10	0.18	0.41	0.63	0.51	4.15	4.30	4.36	6.04
Fe-S:P IW (mol:mol)	-7.19	9.02	-11.7	10.7	-3.88	7.30	4.02	5.59	-9.84	18.5

Table E1: Mean values (n=6) and standard deviations (sd) for soil types with strata codes (IW: interstitial water; WC: water column; SED: sediment; L: in l instead of kg).

Ditch characteristics	1-2	1-3	1-5	1-6	2-3	2-5	2-6	3-5	3-6	5-6	1,2,3-5,6	1,2-3,5,6
P WC (µmol/l)	.699	.394	.015	.026	.240	.093	.041	.485	.310	.937	.005	.004
PO_4^{3-} WC (µmol/l)	.818	.132	.015	.041	.180	.093	.026	.240	.180	.394	.002	.002
P SED (mmol/kg)	.132	.589	.589	.132	.065	.240	.818	.310	.093	.240	.285	.755
P SED L (mmol/l)	.485	.180	.026	.015	.093	.009	.002	.240	.093	.485	.000	.000
Fe IW (µmol/l)	.589	.065	.004	.093	.026	.004	.026	.026	.818	.310	.001	.000
Fe WC (µmol/l)	.937	.041	.485	.394	.026	.093	.240	.310	.065	.132	.491	.232
Fe SED (mmol/kg)	.818	.004	.002	.937	.015	.002	.937	.937	.065	.041	.346	.004
Fe SED L (mmol/l)	.485	.015	.004	.065	.015	.002	.132	.041	.818	.818	.002	.000
S IW (µmol/l)	.937	1.00	.093	.589	.937	.132	.310	.093	.589	.818	.048	.172
S WC (µmol/l)	.937	.041	.485	.310	.093	.818	.394	.026	.009	.589	.035	.884
S SED (mmol/kg)	.589	.310	.002	.002	.589	.002	.002	.015	.004	.132	.000	.003
S SED L (mmol/l)	.394	.240	.065	.065	.699	.041	.041	.015	.041	.394	.001	.104
NO_3^- IW (µmol/l)	.699	.818	.937	.310	.937	.937	.589	1.00	.699	.818	.573	.573
NO_3^- WC (µmol/l)	.699	.240	.589	.310	.310	.589	.310	.818	.093	.180	.439	.723
NH_4^+ IW (µmol/l)	.818	.485	.180	.394	.818	.180	.180	.093	.093	.937	.019	.285
NH_4^+ WC (µmol/l)	.093	.937	.180	.818	.240	.041	.818	.310	.937	.589	.215	.200
Alk IW (µmol/l)	.589	.589	.818	.240	.180	.394	.394	.485	.065	.065	.325	.819
Alk WC (µmol/l)	.394	.589	.937	.699	.240	.699	.699	.485	.394	.818	.723	.602
AL IW (µmol/l)	.818	.699	.394	.310	.699	.394	.132	.240	.093	.589	.043	.346
Al WC (µmol/l)	.394	.818	.009	.015	.394	.004	.041	.394	.015	.002	.884	.602
Al SED (mmol/kg)	.310	.026	.002	1.00	.041	.004	.310	.699	.026	.002	.662	.019
Al SED L(mmol/l)	.394	.015	.002	.026	.026	.002	.065	.180	.937	.310	.002	.000
Ca IW (µmol/l)	.485	.240	.818	.180	.818	.485	.818	.310	.937	.310	.950	.465
Ca WC (µmol/l)	.818	.180	.589	.310	.485	.937	.589	.240	.699	.589	.917	.249
Ca SED (mmol/kg)	.240	.394	.009	.394	.310	.026	.180	.394	.310	.394	.013	.013
Ca SED L (mmol/l)	.589	.699	.180	.699	.699	.699	.937	.818	.937	.937	.439	.518
pH IW	.818	.180	.240	.132	.394	.240	.240	.699	.004	.009	.518	.602
pH WC	.589	.026	.180	.093	.394	.699	.818	.394	.589	.937	.545	.059
Mass/Volume SED (kg/l)	.937	.240	.009	.002	.240	.004	.002	.041	.002	.026	.000	.000
Organic SED (%)	1.00	.026	.002	.002	.041	.002	.002	.004	.002	.093	.000	.000
Depth of the ditch (cm)	.180	.310	.240	.015	.093	.093	.002	.589	.394	.240	.022	.003
Width of the ditch (m)	.699	.485	.485	.065	.589	.589	.041	.937	.180	.093	.079	.079
Waterlevel (m)	.015	.310	.002	.002	.394	.093	.002	.026	.004	.093	.000	.004
Depth of the mud (cm)	.818	.699	.394	.026	.589	.041	.002	.093	.002	.009	.000	.015
Fe:P SED (mol:mol)	.026	.002	.004	.699	.132	.093	.394	.132	.394	.240	.346	.048
Fe-S:P SED (mol:mol)	.310	.180	.002	.002	.132	.002	.002	.015	.065	.310	.000	.000
Fe:P WC (mol:mol)	.818	.004	.015	.485	.009	.009	.485	.818	.093	.132	.185	.001
Fe:S WC (mol:mol)	.818	.485	.394	.937	.589	.394	.589	.818	.394	.240	.917	.518
Fe-S:P WC (mol:mol)	.589	.093	.394	.394	.026	.240	.240	.818	.818	.937	.325	.025
Fe:PO_4^{3-} WC (mol:mol)	.937	.002	.009	.310	.004	.026	.310	.937	.394	.310	.124	.000
Fe-S:PO_4^{3-} WC (mol:mol)	.937	.041	.310	.310	.004	.180	.132	.485	.699	.937	.305	.007
Fe:S IW (mol:mol)	.310	.093	.002	.180	.065	.004	.065	.015	.699	.394	.001	.000
Fe-S:P IW (mol:mol	.394	.065	.002	.818	.093	.004	.589	.015	.937	.310	.015	.006

Table E2: P-values from Mann-Whitney U comparisons for soil type, shown with strata codes (grey: p<0.05; underlined: mean of first group/stratum is higher; IW: interstitial water; WC: water column; SED: sediment; L: in l instead of kg).

Land use type

Ditch characteristics	Crops/Grassland (5)		Fruit (8)		p-value
	Mean	*Sd*	Mean	*Sd*	5-8
P WC (µmol/l)	4.24	*1.86*	2.40	*1.40*	.093
PO_4^{3-} WC (µmol/l)	1.89	*1.11*	0.72	*0.27*	.009
P SED (mmol/kg)	34.9	*14.8*	48.8	*28.9*	.485
P SED L (mmol/l)	13.0	*4.67*	18.1	*6.48*	310
Fe IW (µmol/l)	388	*321*	652	*407*	.180
Fe WC (µmol/l)	19.6	*9.05*	29.6	*28.7*	.589
Fe SED (mmol/kg)	508	*64.4*	586	*195*	.394
Fe SED L (mmol/l)	197	*67.1*	226	*49.6*	.485
S IW (µmol/l)	131	*88.3*	65.9	*42.2*	.180
S WC (µmol/l)	617	*382*	663	*463*	.818
S SED (mmol/kg)	234	*119*	330	*267*	.818
S SED L (mmol/l)	82.4	*39.7*	107	*42.2*	.180
NO_3^- IW (µmol/l)	8.90	*16.4*	0.91	*0.87*	.015
NO_3^- WC (µmol/l)	17.2	*23.7*	53.3	*60.7*	.240
NH_4^+ IW (µmol/l)	267	*169*	269	*244*	.818
NH_4^+ WC (µmol/l)	20.0	*19.7*	33.1	*36.5*	.310
Alk IW (µmol/l)	6.87	*1.09*	8.72	*3.12*	.310
Alk WC (µmol/l)	4.56	*1.58*	6.13	*1.59*	.132
AL IW (µmol/l)	1.75	*0.50*	6.32	*10.6*	.589
Al WC (µmol/l)	13.5	*8.56*	7.30	*6.56*	.240
Al SED (mmol/kg)	868	*98.8*	717	*275*	.310
Al SED L(mmol/l)	334	*97.8*	281	*76.4*	.310
Ca IW (µmol/l)	2443	*246*	3710	*1370*	.041
Ca WC (µmol/l)	1980	*458*	3003	*864*	.004
Ca SED (mmol/kg)	366	*109*	467	*336*	1.00
Ca SED L (mmol/l)	140	*61.3*	226	*269*	.937
pH IW	6.72	*0.14*	6.92	*0.21*	.132
pH WC	7.50	*0.40*	7.27	*0.34*	.180
Mass/Volume SED (kg/l)	0.39	*0.12*	0.45	*0.22*	.937
Organic SED (%)	17.8	*5.52*	18.9	*12.1*	.818
Depth of the ditch (cm)	29.2	*13.3*	28.2	*26.7*	.485
Width of the ditch (m)	2.58	*1.16*	1.67	*0.61*	.180
Waterlevel (m)	0.72	*0.25*	1.13	*0.43*	132
Depth of the mud (cm)	14.0	*7.38*	9.83	*7.39*	.485
Fe:P SED (mol:mol)	15.8	*3.83*	13.5	*3.65*	.240
Fe-S:P SED (mol:mol)	8.71	*5.77*	5.94	*4.57*	.485
Fe:P WC (mol:mol)	4.75	*2.05*	12.7	*9.05*	.180
Fe:S WC (mol:mol)	0.05	*0.05*	0.06	*0.06*	.818
Fe-S:P WC (mol:mol)	-174	*138*	-376	*417*	.310
$Fe:PO_4^{3-}$ WC (mol:mol)	11.7	*6.57*	40.1	*28.7*	.065
$Fe-S:PO_4^{3-}$ WC (mol:mol)	-382	*270*	-1065	*1001*	.180
Fe:S IW (mol:mol)	4.15	*4.30*	16.3	*19.9*	.065
Fe-S:P IW (mol:mol	4.02	*5.59*	24.5	*32.6*	.026

Table E3: Means (n=6), standard deviations (sd) and p-values from the Mann Whitney U comparisons for fruit versus crops/grassland, shown with strata codes (grey: Highest mean/p<0.05; IW: interstitial; WC: water column; SED: sediment; L: in l instead of kg).

Seepage/Infiltration rate

Ditch characteristics	No seepage (3)		Seepage (4)		p-value 3-4	No Infiltration (6)		Infiltration (7)		p-value 6-7
	Mean	Sd	Mean	Sd		Mean	sd	Mean	sd	
P WC (µmol/l)	9.35	10.7	4.28	2.37	.310	5.00	4.73	3.04	1.35	.485
PO_4^{3-} WC (µmol/l)	2.91	1.69	1.42	0.99	.093	1.71	1.23	1.35	0.81	.699
P SED (mmol/kg)	37.8	9.77	39.0	12.8	1.00	28.7	19.5	43.9	16.4	.240
P SED L (mmol/l)	9.66	4.08	10.5	3.16	.818	17.9	10.7	27.8	18.9	.310
Fe IW (µmol/l)	117	81.7	298	140	.009	217	260	584	744	.485
Fe WC (µmol/l)	33.3	23.8	47.1	23.3	.310	11.9	17.2	16.4	14.7	.394
Fe SED (mmol/kg)	481	92.1	581	125	.240	276	193	518	220	.041
Fe SED L (mmol/l)	122	42.8	162	50.9	.132	177	135	333	239	.240
S IW (µmol/l)	283	189	101	76.4	.026	280	289	136	90.0	.589
S WC (µmol/l)	1257	377	364	207	.004	447	156	334	224	.310
S SED (mmol/kg)	673	246	416	206	.065	117	108	113	74.7	.937
S SED L (mmol/l)	155	42.6	98.7	35.9	.041	67.5	60.3	56.1	28.9	.937
NO_3^- IW (µmol/l)	2.96	1.76	1.67	0.98	.180	4.25	5.19	5.39	9.30	.699
NO_3^- WC (µmol/l)	8.66	7.39	18.5	21.0	.589	119	158	18.3	26.5	.132
NH_4^+ IW (µmol/l)	530	193	180	77.0	.002	264	280	518	707	1.00
NH_4^+ WC (µmol/l)	60.6	108	24.0	12.3	.818	47.5	49.2	11.4	6.70	.180
Alk IW (µmol/l)	7.27	1.08	5.22	2.14	.093	5.60	3.59	8.28	4.36	.310
Alk WC (µmol/l)	3.97	0.83	5.52	1.94	.093	5.45	3.15	4.98	2.73	.699
AL IW (µmol/l)	3.32	2.02	5.28	10.6	.065	1.76	1.38	1.64	1.14	.937
Al WC (µmol/l)	11.6	12.1	11.4	13.0	.699	2.29	1.91	3.49	5.21	1.00
Al SED (mmol/kg)	905	277	874	151	.589	419	243	531	200	.394
Al SED L(mmol/l)	241	141	267	168	.937	270	183	326	213	.937
Ca IW (µmol/l)	2762	549	2300	722	.394	2841	671	3118	1420	1.00
Ca WC (µmol/l)	2314	441	2274	734	1.00	2303	690	2480	1003	.937
Ca SED (mmol/kg)	480	151	548	267	.818	333	331	348	297	.818
Ca SED L (mmol/l)	117	35.8	139	38.0	.240	202	190	164	72.1	.818
pH IW	6.75	0.11	6.88	0.12	.132	7.27	0.33	6.93	0.36	.093
pH WC	7.35	0.34	7.33	0.26	.818	7.44	0.37	7.52	0.53	.818
Mass/Volume SED (kg/l)	0.25	0.08	0.29	0.15	.818	0.67	0.21	0.60	0.24	.937
Organic SED (%)	39.4	9.96	30.8	8.35	.180	10.6	6.73	9.99	3.96	1.00
Depth of the ditch (cm)	27.8	18.9	27.3	12.8	.937	17.3	13.8	33.2	16.4	.132
Width of the ditch (m)	2.75	1.94	1.42	0.49	.240	1.32	0.95	2.33	1.08	.132
Waterlevel (m)	0.42	0.16	0.67	0.26	.065	1.02	0.29	0.78	0.20	.132
Depth of the mud (cm)	24.8	11.0	32.7	19.3	.485	4.33	2.80	7.17	3.06	.180
Fe:P SED (mol:mol)	12.9	1.44	15.5	2.73	.093	9.90	6.85	11.6	1.39	.394
Fe-S:P SED (mol:mol)	-6.21	8.28	5.20	6.48	.041	5.18	5.96	8.20	4.34	.240
Fe:P WC (mol:mol)	4.37	1.04	12.2	7.35	.002	2.94	3.77	7.39	7.55	.310
Fe:S WC (mol:mol)	0.03	0.01	0.19	0.18	.002	0.04	0.07	0.08	0.10	.310
Fe-S:P WC (mol:mol)	-223	141	-87.2	46.0	.041	-166	119	-102	41.4	.485
$Fe:PO_4^{3-}$ WC (mol:mol)	10.7	1.73	51.3	47.6	.002	7.90	8.07	24.2	31.9	.310
$Fe-S:PO_4^{3-}$ WC (mol:mol)	-493	220	-244	131	.065	-405	272	-251	92.8	.394
Fe:S IW (mol:mol)	0.63	0.51	5.23	4.53	.015	4.36	6.04	8.18	11.3	.699
Fe-S:P IW (mol:mol)	-3.88	7.30	12.7	16.3	.015	-9.84	18.5	11.8	21.4	.180

Table E4: Means (n=6), standard deviations (sd) and p-values from Mann Whitney U comparisons for seepage and infiltration, shown with strata codes (grey: significant highest mean/p<0.05; IW: interstitial; WC: water column; SED: sediment; L: in l instead of kg).

Nature Management

Ditch characteristics	Broek & Blokland			p-value	Schraallanden langs de Meije			p-value
	55	56	57	5 - B	49	50	51	1,2-S
P WC (µmol/l)	1.82	2.09	2.31	.167	2.93	1.29	0.80	.004
PO_4^{3-} WC (µmol/l)	0.87	0.79	0.98	.048	1.36	0.55	0.47	.004
P SED (mmol/kg)	25.4	20.4	36.6	.548	21.4	25.0	23.4	.136
P SED L (mmol/l)	5.31	6.02	9.66	.095	3.51	3.87	2.75	.048
Fe IW (µmol/l)	63.8	122	660	.548	5.28	35.7	6.47	.633
Fe WC (µmol/l)	10.4	13.9	57.7	.905	7.40	9.68	4.47	.448
Fe SED (mmol/kg)	570	646	643	.048	242	430	360	.365
Fe SED L (mmol/l)	119	191	170	.262	39.8	66.5	42.3	.840
S IW (µmol/l)	82.5	62.5	48.9	.262	163	50.7	58.9	.031
S WC (µmol/l)	215	191	244	.048	520	216	119	.101
S SED (mmol/kg)	524	494	357	.048	707	960	860	.233
S SED L (mmol/l)	110	146	94.2	.167	116	148	101	.536
NO_3^- IW (µmol/l)	2.73	2.80	2.54	.714	0.43	1.59	0.97	.048
NO_3^- WC (µmol/l)	5.21	2.33	2.68	.714	0.32	5.75	1.34	.018
NH_4^+ IW (µmol/l)	111	51.6	242	.381	94.3	173	137	.048
NH_4^+ WC (µmol/l)	26.1	10.4	9.61	.714	9.93	15.6	9.09	.031
Alk IW (µmol/l)	5.10	2.60	4.90	.024	3.80	2.00	0.90	.009
Alk WC (µmol/l)	2.50	1.75	3.70	.048	2.00	0.25	0.30	.009
AL IW (µmol/l)	1.10	3.11	1.22	.905	1.76	5.38	8.97	.180
Al WC (µmol/l)	9.78	4.98	8.27	.548	2.16	6.98	9.09	.448
Al SED (mmol/kg)	974	1214	920	.095	654	724	610	.031
Al SED L(mmol/l)	204	359	243	.548	107	112	71.7	.840
Ca IW (µmol/l)	1979	974	2318	.095	1297	753	386	.009
Ca WC (µmol/l)	1030	798	1615	.095	1063	253	158	.018
Ca SED (mmol/kg)	511	314	316	.905	710	426	383	.448
Ca SED L (mmol/l)	107	92.6	83.2	.262	117	65.8	45.0	.136
pH IW	7.01	7.06	6.67	.262	6.61	6.59	6.59	.101
pH WC	7.46	7.26	7.41	.548	7.29	6.31	6.14	.009
Mass/Volume SED (kg/l)	0.21	0.30	0.26	.095	0.16	0.15	0.12	.101
Organic SED (%)	33.6	25.6	30.3	.024	65.4	55.7	66.9	.295
Depth of the ditch (cm)	55.0	73.0	28.0	.095	87.0	38.0	70.0	.136
Width of the ditch (m)	3.00	2.00	1.50	.714	3.00	2.25	2.50	.734
Waterlevel (m)	0.30	0.30	0.50	.048	0.30	0.30	0.30	.233
Depth of the mud (cm)	10.0	10.0	20.0	.905	5.00	40.0	42.0	.945
Fe:P SED (mol:mol)	22.5	31.7	17.5	.167	11.3	17.2	15.4	.018
Fe-S:P SED (mol:mol)	1.09	1.31	1.80	.167	0.34	0.45	0.42	.840
Fe:P WC (mol:mol)	1.80	7.42	7.79	.548	-21.7	-21.1	-21.4	.101
Fe:S WC (mol:mol)	5.68	6.67	25.0	.262	2.53	7.50	5.60	.018
Fe-S:P WC (mol:mol)	0.05	0.07	0.24	.262	0.01	0.04	0.04	.365
$Fe:PO_4^{3-}$ WC (mol:mol)	-112	-84.6	-80.8	1.00	-175	-160	-144	.031
$Fe-S:PO_4^{3-}$ WC (mol:mol)	11.9	17.6	58.7	.262	5.44	17.6	9.43	.031
Fe:S IW (mol:mol)	-235	-223	-190	1.00	-377	-376	-242	.070
Fe-S:P IW (mol:mol	1.75	7.88	28.9	.381	0.38	8.17	1.20	.031
Fe:S IW (mol:mol)	0.77	1.95	13.5	.905	0.03	0.70	0.11	.180
Fe-S:P IW (mol:mol	-0.51	3.83	26.8	.714	-11.3	-3.43	-9.72	.840

Table E5: Values and p-values from Mann Whitney U comparisons for the waterparels, shown with strata/waterparel codes (grey: p<0.05; underlined: lowest mean in the waterparel; IW: interstitial; WC: water column; SED: sediment; L: in l instead of kg).

Appendix F: Spearman tests of the ditch characteristics

In this appendix the studied correlations between interstitial phosphorus, interstitial Fe:P and sediment Fe:S and the ditch characteristics are shown (table 6) and discussed. (Moderately) strong correlations ($r_s > 0.6$) are also visualized in scatter-plots.

Ditch characteristics	P IW		Fe:P IW		Fe:S SED	
	r_s	p	r_s	p	r_s	p
P IW (µmol/l)	1.000	.	-0.317	0.028	-0.114	0.439
Fe:P IW (mol:mol)	-0.317	0.028	1.000	.	**0.710 B**	0.000
Fe:S SED (mol:mol)	-0.114	0.439	**0.710 B**	0.000	1.000	.
P WC (µmol/l)	0.223	0.128	**-0.714 ***	0.000	**-0.600 ***	0.000
PO_4^{3-} WC (µmol/l)	0.226	0.122	**-0.758 ***	0.000	**-0.678 ***	0.000
P SED (mmol/kg)	-0.045	0.763	**0.489**	0.000	0.188	0.201
P SED L (mmol/l)	-0.087	0.554	**0.694 C**	0.000	**0.834 J**	0.000
Fe IW (µmol/l)	-0.001	0.992	**0.907 D**	0.000	**0.718 K**	0.000
Fe WC (µmol/l)	-0.188	0.201	**0.373**	0.009	0.078	0.598
Fe SED (mmol/kg)	-0.100	0.501	**0.705 E**	0.000	**0.453**	0.001
Fe SED L (mmol/l)	-0.005	0.972	**0.742 F**	0.000	**0.842 L**	0.000
S IW (µmol/l)	0.076	0.610	**-0.582**	0.000	**-0.394**	0.006
S WC (µmol/l)	**0.451**	0.001	**-0.443**	0.002	**-0.397**	0.005
S SED (mmol/kg)	0.153	0.301	**-0.495**	0.000	**-0.908 M**	0.000
S SED L (mmol/l)	0.231	0.114	**-0.428**	0.002	**-0.794 N**	0.000
NO_3^- IW (µmol/l)	0.099	0.504	-0.218	0.137	-0.082	0.579
NO_3^- WC (µmol/l)	-0.054	0.717	-0.239	0.102	-0.132	0.370
NH_4^+ IW (µmol/l)	**0.651 A**	0.000	**-0.293**	0.043	-0.308	0.033
NH_4^+ WC (µmol/l)	-0.191	0.194	-0.140	0.342	-0.280	0.054
Alk IW (µmol/l)	**0.394**	0.006	0.238	0.103	0.125	0.398
Alk WC (µmol/l)	-0.082	0.578	**0.421**	0.003	0.024	0.874
AL IW (µmol/l)	0.220	0.133	-0.115	0.435	-0.143	0.332
Al WC (µmol/l)	0.301	0.038	-0.163	0.268	-0.092	0.534
Al SED (mmol/kg)	0.080	0.587	0.307	0.034	0.235	0.107
Al SED L(mmol/l)	0.057	0.699	**0.540**	0.000	**0.786 O**	0.000
Ca IW (µmol/l)	0.123	0.405	0.346	0.016	0.188	0.200
Ca WC (µmol/l)	-0.024	0.873	**0.446**	0.001	0.143	0.331
Ca SED (mmol/kg)	0.348	0.015	-0.172	0.244	**-0.500**	0.000
Ca SED L (mmol/l)	0.264	0.069	0.365	0.011	0.354	0.014
pH IW	-0.278	0.056	-0.186	0.206	-0.005	0.972
pH WC	0.298	0.040	-0.300	0.038	-0.262	0.072
Mass/Volume SED (kg/l)	-0.100	0.499	**0.443**	0.002	**0.845 ***	0.000
Organic SED (%)	0.113	0.444	**-0.527**	0.000	**-0.899 ***	0.000
Depth of the ditch (cm)	0.256	0.079	**-0.394**	0.006	-0.254	0.081
Width of the ditch (m)	0.282	0.052	**-0.381**	0.008	-0.315	0.029
Waterlevel (m)	-0.229	0.118	**0.566**	0.000	**0.584**	0.000
Depth of the mud (cm)	0.157	0.288	-0.286	0.049	**-0.635 ***	0.000
Fe:P SED (mol:mol)	0.131	0.374	0.331	0.022	0.306	0.034
Fe-S:P SED (mol:mol)	-0.039	0.793	**0.701 G**	0.000	**0.956 P**	0.000
Fe:P WC (mol:mol)	-0.319	0.027	**0.793 ***	0.000	**0.484**	0.000
Fe:S WC (mol:mol)	-0.359	0.012	**0.525**	0.000	0.254	0.081
Fe-S:P WC (mol:mol)	-0.192	0.191	-0.223	0.128	-0.187	0.202
$Fe:PO_4^{3-}$ WC (mol:mol)	-0.279	0.055	**0.798 ***	0.000	**0.504**	0.000
$Fe-S:PO_4^{3-}$ WC (mol:mol)	-0.180	0.222	**-0.330**	0.022	-0.273	0.061
Fe:S IW (mol:mol)	-0.010	0.946	**0.874 H**	0.000	**0.657 Q**	0.000
Fe-S:P IW (mol:mol)	-0.070	0.638	**0.862 I**	0.000	**0.556**	0.000

Table F1: Spearman correlation coefficients (r_s) and p-values (p) for the correlations between the ditch characteristics and interstitial phosphorus, interstitial Fe:P and sediment Fe:S (IW: interstitial water; WC: water column; SED: sediment; L: concentrations per L instead of per kg). Letters correspond with the graph numbers of figures F1, F2 and F3 (*: scatter-plots are shown in section 4.3 to define the rules of thumbs). Bold values show significant correlations (p<0.01) (pink: moderately strong, $0.6 < r_s < 0.8$; red: strong, $r_s > 0.8$).

Interstitial phosphorus

Interstitial phosphorus correlated moderately strong positive with ammonium concentrations in the water column ($r_s=0.651$; $p<0.01$; table F1). Figure F1 shows that the trend was, however, less clear.
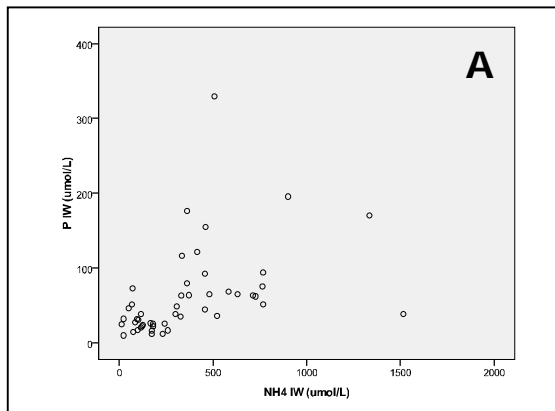
Figure F1: Correlation between interstitial ammonium and interstitial phosphorus (IW: interstitial water). Letter A corresponds with the location in table F1.

Furthermore, interstitial phosphorus correlated positively with sulphur concentration in the water column and interstitial alkalinity ($r_s<0.6$; $p<0.01$; table F1). No other significant correlations were found ($p>0.01$; table F1).

Interstitial Fe:P

Interstitial Fe:P correlated strongly positive with iron, Fe:S and (Fe-S):P in the interstitial water ($r_s>0.8$; $p<0.01$; table F1).

It also correlated moderately strong positive with phosphorus, iron, Fe:S and Fe-S:P in the sediment and with the Fe:P(O_4^{3-}) ratio in the water column ($r_s>0.6$; $p<0.01$; table F1). Interstitial Fe:P only correlated negative moderately strong with the phosphorus and phosphate concentrations in the water column ($r_s>0.6$; $p<0.01$; table F1).

Not all of these (moderately) strong correlations were clearly visible in the scatterplots (figure F2). Especially the correlations between interstitial Fe:P and sediment phosphorus and iron concentrations were affected by outliers (figure F2; letter C and F).
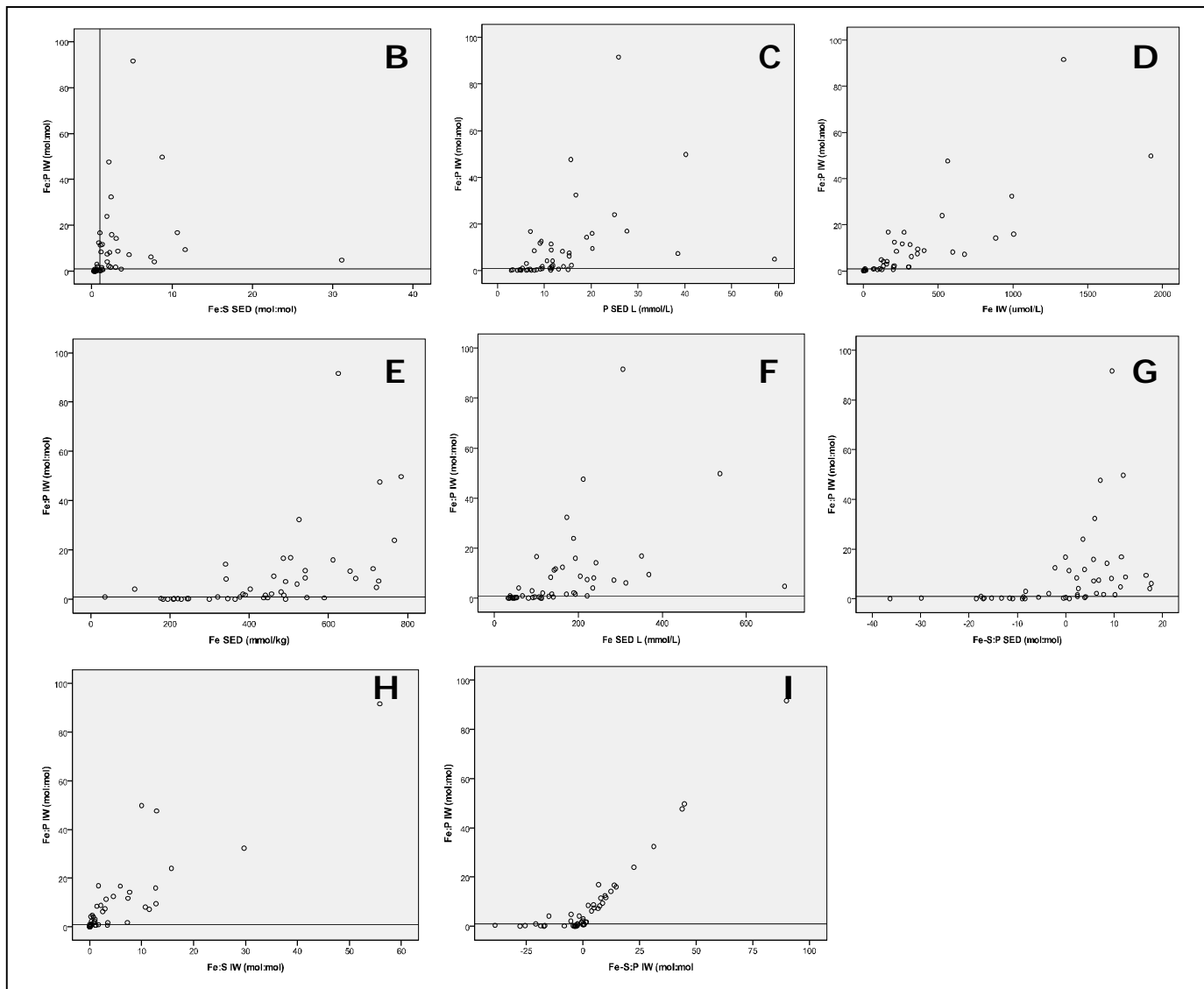
Figure F2: Correlations between interstitial Fe:P and various ditch characteristics (IW: interstitial water; SED: sediment) (horizontal and vertical lines show interstitial Fe:P or sediment Fe:S = 1.0). Letters correspond with the locations in table F1.

Other significant negative correlations with interstitial Fe:P were found for several sulphur and ammonium concentrations and ditch characteristics ($r_s < 0.6$; $p < 0.01$; table F1). Significant positive correlations with interstitial Fe:P were found for alkalinity and calcium in the water column, aluminium sediment concentrations, mass density, waterlevel and two ratios ($r_s < 0.6$; $p < 0.01$, table F1).

Sediment Fe:S

Sediment Fe:S correlated strongly with six ditch characteristics: positively with phosphorus and iron in the sediment (per l), mass sediment density and the sediment (Fe-S):P ratio and negatively with the sediment sulphur concentration and organic sediment content ($r_s > 0.8$; $p < 0.01$; table F1).

Positive moderately strong correlations with sediment Fe:S were found for interstitial iron, aluminium in the sediment and interstitial Fe:S. Negative moderately strong correlations with sediment Fe:S were found for phosphorus and phosphate concentrations in the water column, sulphur in the sediment (per l) and mud depth ($r_s > 0.6$; $p < 0.01$; table F1).

Most of these correlations were also clearly visible in scatter-plots (figure F3).
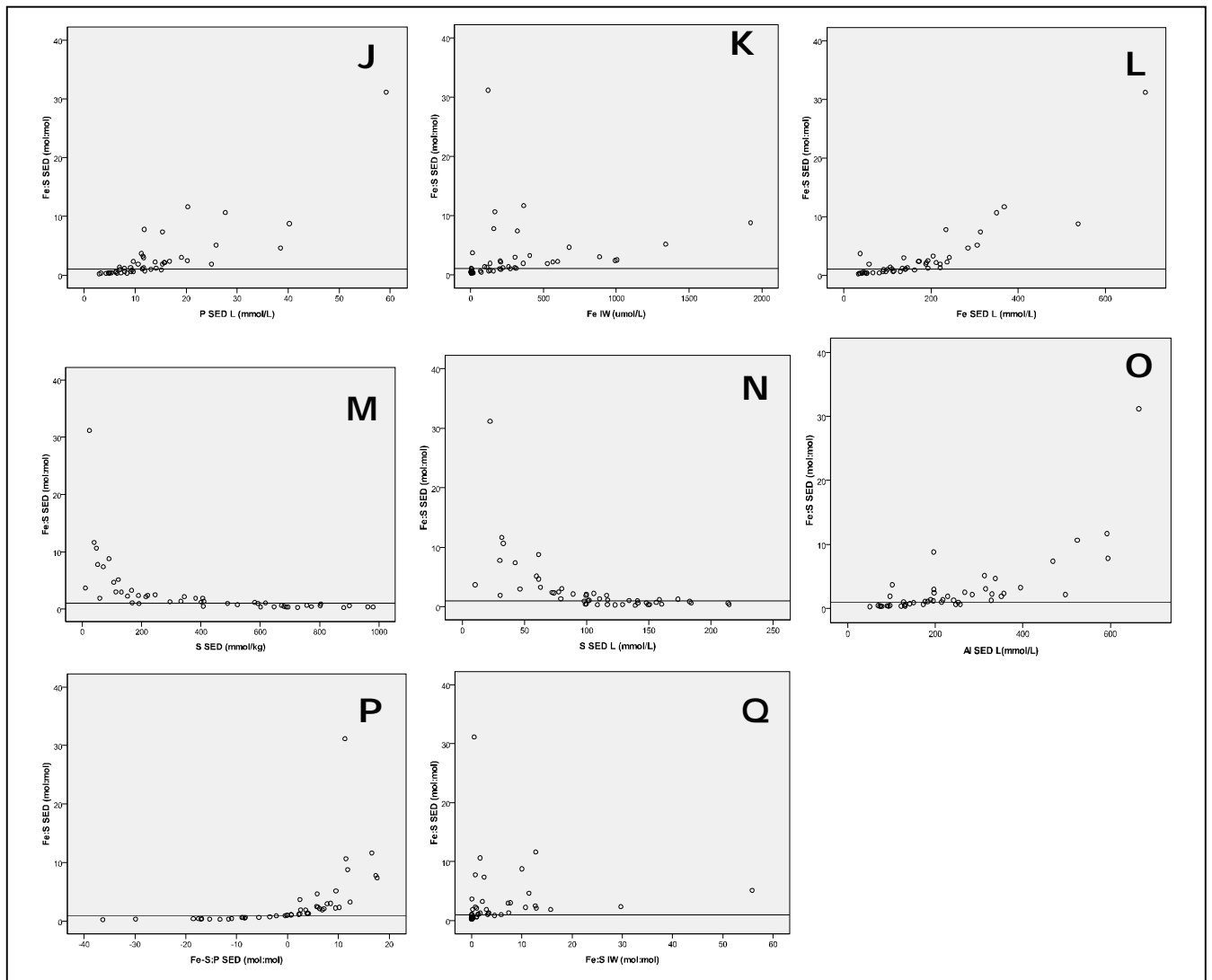
Figure F3: Correlations between sediment Fe:S and various ditch characteristics (IW: interstitial water; SED: sediment). Letters correspond with the location in table F1.

Also less strong correlations with sediment Fe:S were revealed ($r_s<0.6$; $p<0.01$; table F1). Negative correlations were found with other sulphur concentrations and sediment calcium concentrations (mmol/kg) while positive correlations were found with sediment iron concentrations, water level and some ratios ($r_s<0.6$; $p<0.01$; table F1).

Appendix G: Chemical and non-chemical databases of the locations

All data used in this study was split into four tables. Appendix D already revealed the interstitial phosphorus concentrations and the interstitial Fe:P and sediment Fe:S ratio per location.

Location	P WC µmol/l	PO_4^{3-} WC µmol/l	P SED mmol/kg	P SED L mmol/l	Fe IW µmol/l	Fe WC µmol/l	Fe SED mmol/kg	Fe SED L mmol/l
1	16.01	6.87	27.32	4.28	3.22	8.10	228.36	35.78
2	5.91	2.34	39.83	11.89	132.53	6.13	384.39	114.72
3	21.67	15.17	38.08	6.45	17.25	32.62	219.87	37.26
4	5.99	2.98	29.00	4.92	9.38	23.80	243.49	41.34
5	10.17	6.39	33.80	8.42	10.65	3.97	209.70	52.21
6	6.78	2.69	34.75	5.05	1.55	6.81	298.89	43.47
7	18.27	10.67	23.68	4.72	4.82	4.88	246.83	49.20
8	18.09	7.78	18.52	2.92	2.84	7.46	209.00	33.00
9	6.09	2.43	25.33	6.21	0.58	15.16	194.39	47.65
10	3.69	1.43	41.57	9.17	123.06	12.50	436.82	96.39
11	7.39	3.87	21.27	3.27	10.90	12.02	346.26	53.21
12	32.52	23.72	32.31	7.21	3.83	7.52	364.06	81.23
13	30.86	5.94	40.43	9.61	65.57	76.47	545.35	129.67
14	7.21	3.51	54.90	13.09	199.28	39.41	589.80	140.57
15	4.93	2.14	25.73	5.35	72.28	24.66	320.56	66.64
16	3.56	1.62	38.11	15.81	205.91	14.42	456.89	189.51
17	7.14	2.96	34.58	7.94	4.93	33.64	491.94	112.93
18	2.41	1.31	33.16	6.19	155.97	10.90	480.68	89.78
19	4.56	1.47	39.21	7.88	220.59	40.88	668.93	134.38
20	2.69	0.64	54.01	15.68	563.47	72.30	729.59	211.82
21	2.38	1.82	34.15	7.06	271.98	29.33	486.58	100.56
22	2.40	0.72	33.84	9.11	259.27	17.73	541.05	145.66
23	8.48	0.68	20.23	11.78	158.21	76.35	402.86	234.60
24	5.18	3.17	52.73	11.45	311.37	46.14	654.52	142.18
25	3.98	1.47	35.70	14.11	302.24	14.31	488.06	192.94
26	4.26	2.04	24.73	9.61	201.97	23.10	441.08	171.48
27	4.09	1.45	64.08	20.22	1005.01	29.81	611.58	192.99
28	3.86	1.44	30.44	11.50	405.37	26.41	541.68	204.69
29	7.51	4.04	29.11	6.95	94.65	19.37	446.23	106.55
30	1.72	0.92	25.49	15.34	320.14	4.82	520.77	313.45
31	2.12	1.00	29.37	15.10	6.65	1.54	177.69	91.35
32	1.10	0.58	25.49	20.28	363.65	11.43	462.55	368.03
33	5.57	3.60	10.72	11.20	10.99	2.33	35.85	37.46
34	4.18	1.33	19.83	11.65	109.38	5.31	376.65	221.18
35	2.91	0.89	66.45	38.49	675.92	4.68	491.75	284.89
36	14.12	2.87	20.32	10.58	132.80	46.27	111.05	57.82
37	4.05	1.74	61.73	59.18	118.98	12.95	721.53	691.70
38	2.77	1.18	58.61	40.22	1923.01	23.51	783.26	537.58
39	2.04	0.50	39.82	27.66	165.23	42.63	504.84	350.64
40	0.98	0.35	51.08	16.76	991.76	9.39	526.07	172.61
41	4.02	2.35	33.14	11.65	303.49	2.07	390.33	137.18
42	4.37	1.97	18.85	11.40	3.32	7.54	182.53	110.43
43	1.29	0.53	20.09	13.90	596.96	6.07	342.22	236.89
44	4.81	1.12	101.66	24.97	526.41	84.17	766.70	188.35
45	1.26	0.58	41.22	9.38	206.62	31.84	712.65	162.17
46	3.08	0.92	26.78	19.05	884.33	23.35	340.08	241.98
47	1.40	0.40	52.81	25.87	1338.59	26.02	624.78	306.01
48	2.56	0.75	50.41	15.34	360.79	6.36	726.62	221.05
49	2.93	1.36	21.39	3.51	5.28	7.40	242.14	39.79
50	1.29	0.55	25.03	3.87	35.74	9.68	430.41	66.48
51	0.80	0.47	23.39	2.75	6.47	4.47	360.16	42.30
52	4.78	2.76	37.32	5.46	11.10	12.72	342.94	50.15
53	7.12	2.05	29.84	4.47	14.80	10.43	209.36	31.38
54	6.44	2.58	39.10	10.01	83.06	9.90	260.36	66.65
55	1.82	0.87	25.39	5.31	63.80	10.36	569.97	119.25
56	2.09	0.79	20.38	6.02	121.65	13.94	645.53	190.58
57	2.31	0.98	36.64	9.66	659.98	57.67	642.67	169.45

Table G1: Phosphorus, phosphate and iron concentrations of the locations (IW: interstitial water; WC: water column; SED: sediment; L: concentrations per L instead of per kg).

Location	S IW µmol/l	S WC µmol/l	S SED mmol/kg	S SEDL mmol/l	NO_3^- IW µmol/l	NO_3^- WC µmol/l	NH_4^+ IW µmol/l	NH_4^+ WC µmol/l	ALK IW meq/l	ALK WC meq/l	pH IW	pH WC
1	230.65	480.82	693.67	108.68	2.43	3.84	630.31	20.47	7.60	5.25	6.85	8.06
2	473.03	1410.98	523.06	156.10	2.73	21.41	713.62	15.80	9.80	4.75	6.93	8.15
3	172.87	310.04	725.45	122.92	2.81	9.96	370.82	20.59	5.50	3.25	6.58	7.41
4	95.29	382.91	687.39	116.70	3.13	8.33	177.93	13.78	4.70	4.10	6.87	7.86
5	823.82	921.42	600.99	149.65	2.36	9.58	94.66	31.09	4.50	4.65	7.68	7.76
6	191.61	866.54	680.40	98.96	0.43	46.30	479.38	12.05	7.70	3.30	6.81	7.62
7	347.05	423.14	646.45	128.86	7.26	9.27	114.06	84.50	4.50	4.35	7.16	7.43
8	1187.40	1552.85	881.32	139.15	2.72	60.72	583.26	84.14	6.00	6.50	7.70	8.31
9	99.66	340.51	407.16	99.80	0.62	24.69	242.59	22.68	3.20	1.15	7.06	7.18
10	120.61	463.67	670.94	148.05	2.56	2.49	899.33	12.15	8.30	5.75	6.66	8.08
11	170.13	577.80	980.97	150.74	2.60	8.08	520.42	47.54	7.50	4.20	6.82	7.44
12	1243.84	657.31	962.30	214.70	3.03	8.01	456.57	30.38	5.50	6.80	6.58	7.52
13	268.35	1521.98	900.08	214.02	3.05	6.33	361.30	281.15	7.40	4.95	6.74	6.78
14	163.33	1584.66	591.65	141.01	2.16	1.01	506.44	11.53	6.20	2.55	6.88	7.38
15	256.44	1317.43	771.75	160.44	2.67	18.21	762.43	26.00	8.00	4.60	6.67	7.48
16	202.65	558.47	214.89	89.13	6.19	2.90	456.78	17.30	6.10	3.75	6.79	7.59
17	655.75	1420.95	802.31	184.17	0.89	6.04	326.21	16.27	8.90	3.90	6.83	7.15
18	150.89	1140.32	756.33	141.27	2.80	17.50	767.53	11.55	7.00	4.10	6.57	7.71
19	160.71	695.35	581.39	116.79	2.81	57.58	165.89	13.58	3.60	4.90	6.99	7.57
20	43.84	246.99	343.68	99.78	0.69	1.27	231.41	35.42	8.10	7.50	6.76	6.96
21	46.27	290.43	489.48	101.16	0.29	13.41	174.02	25.78	5.50	6.20	6.78	7.50
22	35.20	261.24	409.75	110.32	2.24	2.14	122.00	13.41	6.90	7.20	6.90	7.35
23	223.64	150.58	51.76	30.14	2.19	11.79	299.43	14.29	2.20	2.20	7.06	7.07
24	98.04	537.26	617.55	134.14	1.80	24.61	84.48	41.63	5.00	5.10	6.80	7.53
25	87.90	855.94	401.02	158.54	2.37	23.12	361.89	11.90	5.80	4.70	6.82	7.85
26	273.43	1233.55	189.37	73.62	42.35	8.71	334.42	59.73	7.20	4.00	6.72	6.81
27	79.23	227.94	245.45	77.45	2.73	2.21	331.48	11.14	7.30	7.25	6.69	7.74
28	190.05	275.74	166.31	62.85	2.82	4.10	48.00	11.03	5.50	3.90	6.54	7.34
29	27.84	458.68	331.83	79.23	0.91	62.94	459.92	18.43	8.50	2.50	6.62	7.44
30	127.03	650.45	70.56	42.47	2.21	2.26	67.64	8.02	6.90	5.00	6.94	7.83
31	661.99	593.70	190.86	98.13	3.20	376.90	98.32	6.72	2.80	3.80	7.50	7.60
32	28.49	344.87	39.70	31.59	0.70	16.59	116.09	125.16	3.87	5.05	7.20	6.88
33	253.10	327.41	9.75	10.19	14.45	257.22	172.03	89.64	5.40	2.65	7.50	7.59
34	64.52	511.07	295.43	173.48	0.26	20.89	413.72	13.98	5.40	3.95	6.91	7.89
35	59.09	640.47	105.95	61.38	3.45	41.27	765.46	39.83	12.60	11.50	6.87	7.56
36	615.22	264.17	58.31	30.36	3.44	2.48	20.87	9.45	3.50	5.75	7.64	7.11
37	246.59	298.41	23.16	22.20	1.83	38.42	10.90	5.92	3.00	2.40	7.29	8.30
38	192.61	321.48	89.27	61.27	2.53	4.57	1516.35	5.56	14.00	3.00	6.91	7.70
39	98.57	153.54	47.44	32.95	24.30	0.81	21.00	22.54	7.20	8.35	6.66	6.70
40	33.40	129.65	220.39	72.31	0.53	0.58	100.07	9.63	12.30	8.50	6.61	7.27
41	41.85	351.73	131.70	46.29	2.31	1.94	1333.47	8.56	9.00	4.00	6.67	7.72
42	201.87	751.48	168.33	101.84	0.84	63.25	124.12	16.38	4.20	3.60	7.46	7.44
43	55.66	1527.28	152.86	105.81	0.74	46.05	69.69	5.70	12.00	8.00	7.08	7.29
44	33.49	500.47	405.63	99.65	0.40	108.28	180.73	20.49	4.50	5.15	6.85	7.41
45	45.15	266.29	804.05	182.97	0.52	9.45	258.32	105.65	5.70	7.25	7.10	7.38
46	115.00	717.18	112.52	80.07	0.50	146.61	727.18	29.96	12.00	6.00	6.69	7.18
47	23.98	677.27	121.66	59.59	0.61	6.90	73.75	23.70	9.30	3.60	6.66	6.66
48	122.01	290.08	381.87	116.17	2.66	2.55	305.74	13.34	8.80	6.80	7.12	7.69
49	162.99	520.11	706.51	116.10	0.43	0.32	94.28	9.93	3.80	2.00	6.61	7.29
50	50.73	216.37	959.56	148.20	1.59	5.75	172.68	15.58	2.00	0.25	6.59	6.31
51	58.90	119.27	859.53	100.95	0.97	1.34	136.82	9.09	0.90	0.30	6.59	6.14
52	153.20	773.62	806.40	117.91	0.86	0.71	548.71	22.17	5.00	2.70	6.86	7.31
53	226.04	744.93	679.49	101.85	0.74	0.71	369.86	16.40	3.70	1.90	6.86	7.70
54	83.04	673.21	389.06	99.60	1.12	5.89	335.58	17.18	3.50	2.00	6.63	7.32
55	82.51	215.03	524.19	109.67	2.73	5.21	111.23	26.05	5.10	2.50	7.01	7.46
56	62.46	190.68	494.29	145.92	2.80	2.33	51.55	10.39	2.60	1.75	7.06	7.26
57	48.89	244.40	357.16	94.17	2.54	2.68	241.83	9.61	4.90	3.70	6.67	7.41

Table G2: Sulphur, nitrate and ammonium concentrations, alkalinity and pH of the locations (IW: interstitial water; WC: water column; SED: sediment; L: concentrations per L instead of per kg).

Location	AL IW µmol/l	AL WC µmol/l	Al SED mmol/kg	AL SEDL mmol/l	Ca IW µmol/l	Ca WC µmol/l	Ca SED mmol/kg	Ca SEDL mmol/l	SED Mass Volume kg/l	SED Organic %
1	2.28	6.22	470.18	73.66	2524.95	2000.50	475.37	74.47	0.16	59.94
2	2.14	4.94	474.88	141.73	2916.67	2514.97	481.49	143.70	0.30	35.13
3	4.22	5.48	459.75	77.90	2285.43	1034.18	599.72	101.62	0.17	66.14
4	4.76	6.14	445.32	75.61	1532.93	1088.82	449.35	76.29	0.17	66.04
5	0.83	3.17	490.37	122.10	2205.84	2155.69	551.21	137.25	0.25	53.61
6	1.26	6.02	478.60	69.61	2507.49	1863.77	518.79	75.45	0.15	52.72
7	1.59	4.77	451.82	90.06	1661.43	1677.64	475.93	94.87	0.20	55.10
8	1.40	5.63	320.14	50.59	3295.91	3320.86	748.14	118.12	0.16	70.64
9	2.47	5.06	530.14	129.94	1013.47	533.18	305.64	74.92	0.25	39.87
10	1.80	2.83	782.72	172.72	2766.97	2038.67	611.80	135.00	0.22	43.01
11	4.78	6.37	607.63	93.37	2734.53	1847.06	749.64	115.19	0.15	61.35
12	3.05	2.41	589.15	131.45	3265.97	2659.68	690.28	154.01	0.22	56.53
13	4.69	34.60	1037.77	246.76	2784.43	2747.01	476.65	113.34	0.24	42.90
14	1.37	12.31	899.98	214.49	2702.10	2349.30	743.56	177.22	0.24	32.28
15	1.69	3.05	463.87	96.43	3043.91	2781.94	547.50	113.82	0.21	49.95
16	3.66	3.91	1198.25	497.01	2035.43	1678.14	319.58	132.55	0.41	24.16
17	2.01	12.59	1119.90	257.08	3627.74	2402.45	402.57	92.41	0.23	38.32
18	6.53	3.34	710.43	132.69	2377.74	1922.65	392.46	73.30	0.19	48.77
19	0.73	22.55	974.90	195.85	1694.36	2123.75	465.82	93.58	0.20	33.11
20	1.24	3.40	980.03	284.54	3146.21	3103.79	475.66	138.10	0.29	30.66
21	1.07	1.00	617.44	127.60	2549.90	2312.62	986.44	203.86	0.21	36.58
22	0.72	1.96	808.13	217.57	2841.82	2739.52	434.04	116.85	0.27	30.75
23	26.88	32.45	1020.77	594.43	1221.81	952.10	212.76	123.90	0.58	15.06
24	1.07	7.12	841.70	182.84	2345.06	2412.43	711.40	154.53	0.22	38.69
25	2.00	6.06	828.64	327.59	2370.01	1973.80	406.06	160.53	0.40	19.80
26	2.15	14.03	917.21	356.59	2709.58	2544.91	224.19	87.16	0.39	15.24
27	2.09	6.53	847.35	267.39	2756.99	2313.12	452.91	142.92	0.32	20.18
28	1.34	24.24	1043.91	394.48	2123.25	1559.13	234.24	88.52	0.38	17.27
29	1.98	23.47	793.17	189.39	2285.93	1337.08	465.34	111.11	0.24	25.29
30	0.93	6.60	779.28	469.04	2413.17	2153.44	415.42	250.04	0.60	8.86
31	0.91	1.50	491.05	252.46	2559.88	2309.63	183.42	94.30	0.51	11.42
32	4.40	0.69	744.76	592.58	3021.46	2744.51	208.04	165.53	0.80	5.92
33	1.17	1.17	97.48	101.87	2412.18	1513.47	38.63	40.37	1.05	5.59
34	0.81	2.33	412.06	241.97	1983.78	1794.66	808.33	474.67	0.59	7.50
35	2.18	2.02	582.08	337.22	3894.71	3413.17	687.95	398.55	0.58	9.64
36	1.07	6.00	185.05	96.35	3173.65	2041.42	69.10	35.98	0.52	23.56
37	1.00	13.95	693.72	665.05	1609.03	1586.33	158.50	151.95	0.96	5.55
38	3.86	2.61	285.83	196.17	4765.47	2332.34	176.44	121.09	0.69	9.38
39	1.00	0.40	754.85	524.29	2766.97	3285.93	243.17	168.90	0.69	7.47
40	1.86	1.20	601.11	197.23	4920.16	4094.31	891.39	292.47	0.33	13.82
41	0.95	0.43	560.29	196.91	2799.40	1730.04	491.92	172.88	0.35	15.75
42	1.18	2.35	292.38	176.89	1847.06	1851.05	128.73	77.88	0.61	7.95
43	1.23	9.60	476.36	329.75	5903.19	4718.06	1115.81	772.39	0.69	8.74
44	1.06	16.24	929.45	228.34	2587.33	2397.95	340.36	83.62	0.25	30.02
45	3.23	1.35	662.09	150.66	2412.43	2574.85	478.96	108.99	0.23	36.53
46	1.92	13.05	442.99	315.21	4738.02	2976.55	215.33	153.22	0.71	7.89
47	2.66	1.20	638.17	312.56	3667.66	2552.40	216.43	106.00	0.49	10.72
48	27.81	2.34	1153.94	351.05	2954.09	2799.40	435.76	132.57	0.30	19.48
49	1.76	2.16	653.72	107.43	1297.41	1063.37	710.14	116.70	0.16	65.40
50	5.38	6.98	723.95	111.81	752.50	253.24	425.78	65.76	0.15	55.74
51	8.97	9.09	610.27	71.67	386.23	158.31	383.23	45.01	0.12	66.85
52	3.19	5.97	773.40	113.09	1669.41	1442.61	551.99	80.71	0.15	54.02
53	4.67	14.18	530.61	79.53	1331.59	1177.40	587.16	88.01	0.15	69.15
54	5.04	5.46	831.59	212.89	1175.65	1118.01	376.79	96.46	0.26	44.48
55	1.10	9.78	974.60	203.91	1979.04	1029.94	510.77	106.86	0.21	33.61
56	3.11	4.98	1214.38	358.51	973.80	797.90	313.56	92.57	0.30	25.57
57	1.22	8.27	919.99	242.57	2318.11	1614.77	315.70	83.24	0.26	30.33

Table G3: Aluminium and calcium concentrations, sediment mass density and organic content of the locations (IW: interstitial water; WC: water column; SED: sediment; L: concentrations per L instead of per kg).

Location	Depth	Width	Water level	Mud Depth	Fe/P SED	(Fe-S)/P SED	Fe/P WC	Fe/S WC	(Fe-S)/P WC	Fe/PO4 WC	(Fe-S)/PO4 WC	Fe/S IW	(Fe-S)/P IW
	cm	m	m	cm	mol: mol	mol: mol	mol: mol	mol: mol	mol: mol	mol: mol	mol: mol	mol: mol	mol: mol
1	35	4.0	0.3	45	8.36	-17.03	0.51	0.02	-29.53	1.18	-68.82	0.01	-3.50
2	29	2.0	0.3	6	9.65	-3.48	1.04	0.00	-237.71	2.62	-601.39	0.28	-5.36
3	44	2.5	0.3	75	5.77	-13.28	1.51	0.11	-12.80	2.15	-18.29	0.10	-2.45
4	55	1.0	0.3	25	8.40	-15.31	3.97	0.06	-59.96	7.97	-120.35	0.10	-3.42
5	33	7.0	0.3	5	6.20	-11.58	0.39	0.00	-90.20	0.62	-143.62	0.01	-25.50
6	38	6.0	0.4	30	8.60	-10.98	1.00	0.01	-126.85	2.53	-319.13	0.01	-2.94
7	35	3.0	0.5	42	10.43	-16.88	0.27	0.01	-22.90	0.46	-39.19	0.01	-16.97
8	45	2.5	0.5	40	11.28	-36.30	0.41	0.00	-85.42	0.96	-198.59	0.00	-17.27
9	80	5.0	0.3	15	7.68	-8.40	2.49	0.04	-53.45	6.24	-134.00	0.01	-3.87
10	35	1.5	0.5	42	10.51	-5.63	3.39	0.03	-122.35	8.75	-315.73	1.02	0.01
11	60	2.5	0.5	15	16.28	-29.85	1.63	0.02	-76.58	3.10	-146.08	0.06	-4.41
12	45	2.5	0.5	35	11.27	-18.52	0.23	0.01	-19.98	0.32	-27.39	0.00	-27.77
13	8	1.0	0.7	24	13.49	-8.77	2.48	0.05	-46.84	12.88	-243.52	0.24	-2.55
14	30	4.0	0.5	15	10.74	-0.03	5.47	0.02	-214.32	11.22	-439.99	1.22	0.11
15	45	6.0	0.4	45	12.46	-17.53	5.00	0.02	-262.23	11.53	-604.67	0.28	-2.44
16	55	2.0	0.3	25	11.99	6.35	4.05	0.03	-152.82	8.90	-336.04	1.02	0.04
17	14	1.0	0.3	15	14.23	-8.97	4.71	0.02	-194.30	11.38	-469.16	0.01	-18.56
18	15	2.5	0.3	25	14.50	-8.31	4.52	0.01	-468.64	8.35	-864.79	1.03	0.10
19	25	1.0	0.5	31	17.06	2.23	8.96	0.06	-143.53	27.77	-444.62	1.37	2.30
20	39	2.0	0.5	25	13.51	7.15	26.88	0.29	-64.94	113.32	-273.81	12.85	43.90
21	25	1.5	1.0	60	14.25	-0.08	12.32	0.10	-109.71	16.11	-143.38	5.88	13.89
22	40	1.0	1.0	23	15.99	3.88	7.39	0.07	-101.46	24.59	-337.75	7.36	10.14
23	30	1.0	0.5	7	19.91	17.36	9.00	0.51	-8.75	111.62	-108.52	0.71	-1.69
24	5	2.0	0.5	50	12.41	0.70	8.91	0.09	-94.81	14.55	-154.88	3.18	7.79
25	45	4.0	0.5	10	13.67	2.44	3.59	0.02	-211.47	9.76	-574.10	3.44	1.22
26	18	1.5	1.0	7	17.84	10.18	5.42	0.02	-284.14	11.34	-594.23	0.74	-0.61
27	20	2.5	1.0	20	9.54	5.71	7.29	0.13	-48.44	20.56	-136.64	12.68	14.68
28	25	1.5	0.5	15	17.79	12.33	6.84	0.10	-64.59	18.35	-173.27	2.13	4.67
29	20	4.0	0.8	25	15.33	3.93	2.58	0.04	-58.50	4.79	-108.69	3.40	0.43
30	47	2.0	0.5	7	20.43	17.66	2.80	0.01	-375.37	5.26	-704.07	2.52	3.76
31	9	1.0	1.0	6	6.05	-0.45	0.73	0.00	-278.71	1.54	-590.98	0.01	-38.84
32	20	2.5	1.0	1	18.15	16.59	10.35	0.03	-301.95	19.85	-578.89	12.77	8.71
33	4	0.5	1.0	1	3.34	2.43	0.42	0.01	-58.40	0.65	-90.43	0.04	-20.80
34	33	2.5	0.6	5	18.99	4.09	1.27	0.01	-121.05	3.99	-379.99	1.70	0.37
35	34	1.0	1.5	8	7.40	5.81	1.61	0.01	-218.78	5.28	-716.79	11.44	6.57
36	4	0.4	1.0	5	5.47	2.60	3.28	0.18	-15.44	16.10	-75.85	0.22	-15.06
37	57	4.0	1.0	5	11.69	11.31	3.20	0.04	-70.50	7.44	-163.87	0.48	-5.17
38	27	2.5	1.0	8	13.36	11.84	8.49	0.07	-107.57	19.86	-251.67	9.98	44.77
39	14	1.0	0.8	3	12.68	11.49	20.90	0.28	-54.37	86.13	-224.05	1.68	6.80
40	18	2.0	0.8	6	10.30	5.98	9.54	0.07	-122.11	26.77	-342.62	29.70	31.27
41	43	1.5	0.5	11	11.78	7.80	0.51	0.01	-86.98	0.88	-148.86	7.25	1.54
42	40	3.0	0.6	10	9.69	0.75	1.72	0.01	-170.16	3.82	-377.25	0.02	-8.30
43	25	1.0	1.5	2	17.04	9.43	4.71	0.00	-1180.75	11.41	-2859.43	10.73	7.42
44	8	1.5	1.5	18	7.54	3.55	17.50	0.17	-86.53	75.42	-373.02	15.72	22.42
45	12	1.0	1.5	18	17.29	-2.22	25.28	0.12	-186.18	54.89	-404.24	4.58	9.72
46	30	2.0	1.0	10	12.70	8.50	7.59	0.03	-225.48	25.27	-750.90	7.69	12.40
47	14	2.0	0.8	1	11.83	9.53	18.52	0.04	-463.66	64.88	-1624.07	55.82	89.95
48	80	2.5	0.5	10	14.41	6.84	2.49	0.02	-110.80	8.47	-377.79	2.96	4.93
49	87	3.0	0.3	5	11.32	-21.71	2.53	0.01	-175.07	5.44	-376.72	0.03	-11.31
50	38	2.3	0.3	40	17.20	-21.14	7.50	0.04	-160.03	17.61	-375.79	0.70	-3.43
51	70	2.5	0.3	42	15.40	-21.35	5.60	0.04	-143.94	9.43	-242.20	0.11	-9.72
52	50	2.3	0.5	50	9.19	-12.42	2.66	0.02	-159.12	4.61	-275.79	0.07	-3.19
53	60	2.3	0.3	40	7.02	-15.75	1.47	0.01	-103.16	5.08	-357.94	0.07	-4.58
54	40	2.0	0.2	30	6.66	-3.29	1.54	0.01	-102.92	3.84	-257.60	1.00	0.00
55	55	3.0	0.3	10	22.45	1.80	5.68	0.05	-112.19	11.89	-234.98	0.77	-0.51
56	73	2.0	0.3	10	31.67	7.42	6.67	0.07	-84.60	17.58	-222.87	1.95	3.83
57	28	1.5	0.5	20	17.54	7.79	24.95	0.24	-80.77	58.73	-190.15	13.50	26.80

Table G4: Various ditch characteristics and chemical ratios of the locations (IW: interstitial water; WC: water column; SED: sediment; L: concentrations per L instead of per kg).

Appendix H: Case the Keulevaart

The ditches within the weideveen area the Keulevaart do not fulfil the requirements for the Water Framework Directive (partly) due to high phosphorus (P) concentrations in the water column (Van de Kamp & Blom, 2011). These high phosphorus concentrations are perhaps caused by phosphorus release from the stream bed sediment. Therefore, the waterboard wanted a more detailed analysis of the phosphorus release in this area. This was done with a comparison of the results of this study with the results of Poelen et al. (2012). Poelen et al. (2012) only sampled the main drainage ditch while other ditches were sampled in this study (figure H1).
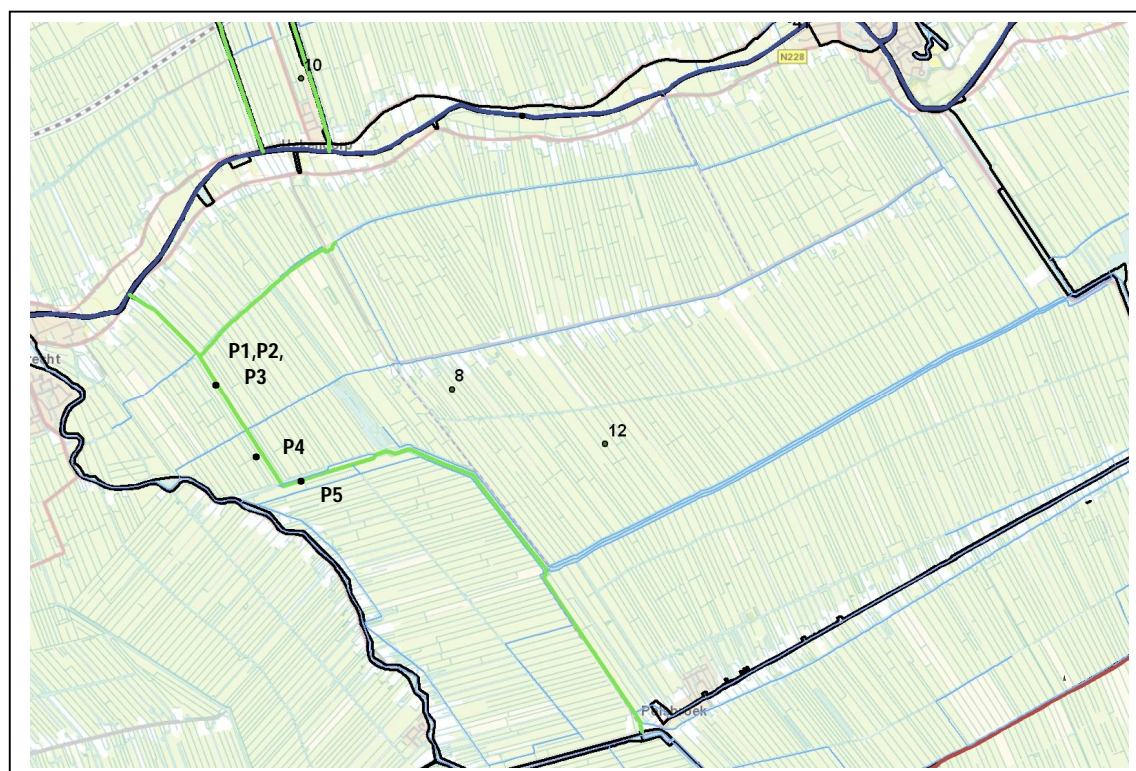

Figure H1: Sampling locations in the keulevaart of this study (8, 12) and of the study in Poelen et al. (2012) (P1, P2, P3, P4 ,P5). The green line shows the main drainage ditch.

Table H1 shows chemical concentrations at the locations.

Location	P IW	Fe:P IW	Fe:S SED	Fe IW	S IW	P SED	Fe SED	S SED	Fe WC	S WC	NO_3^- IW	NO_3^- WC	NH_4^+ WC	NH_4^+ IW
8	68.6	0.04	0.24	2.8	1187	2.9	33	139	7.5	1552	2.7	60.7	84	583,2
12	44.7	0.09	0.37	3.8	1243	7.2	81	214	7.5	657	3	8.0	30	456.6
P1, P2, P 3	46.4	1.4	0.7	31.7	879	4	67	101	0.9	640	2.4	28.0	9.8	508.1
P4	78.8	0.5	0.5	38	320	4	51	107	1.0	632	6.6	29.2	12.8	677.7
P5	26.2	0.8	0.7	21.7	594	4	75	103	1.0	604	2.2	23.15	9.9	386.0

Table H1: (Mean) chemical concentrations at the locations of this study and Poelen et al. (2012) (IW: interstitial water; WC: water column; SED: sediment; all in µmol/l or mol:mol).

Poelen et al. (2012) determined the phosphorus release rates with incubation experiments. These were, with a maximum release rate of 0.54 mg P/m^2/day, rather low. The measured release rates were also about twice as low as expected based on interstitial phosphorus and the correlation formula (Poelen et al., 2012; table H1). They suggested that the release rates remained low due to high nitrate concentrations in the water column which led to high redox potentials (Poelen et al., 2012). However, the effect of nitrate on phosphorus release is still uncertain and needs more research.

Consequently, Poelen et al. (2012) concluded that phosphorus release does not have a large effect on the phosphorus concentrations in the water column in the Keulevaart. It is, however, premature to conclude that phosphorus release does not affect the water quality in the Keulevaart for two reasons:

1. First, they only sampled locations in the main ditch. These locations had a higher phosphorus binding capacity (higher interstitial Fe:P and sediment Fe:S) than the locations sampled in this study (table H1). Higher phosphorus release rates are, therefore, expected in the ditches sampled in this study. Their phosphorus release still affects the water quality in the main ditch as water from those smaller ditches drains on the main ditch.

2. Furthermore, Poelen et al. (2012) and this study mainly focussed on the oxic phosphorus release. However, especially the anoxic phosphorus release is assumed to affect phosphorus concentrations in the water column of the Keulevaart. In summer, low sulphate concentrations and high phosphorus and ammonium concentrations are observed (Smolders et al., 2011). These observations indicate organic decomposition and (perhaps) iron immobilization by sulphate reduction and led to phosphorus release (Smolders et al., 2011; F. Smolders, personal communication, May 24, 2012). Sulphate reduction occurs by an anoxic water column and the absence of the oxic sediment layer (anoxic release).

So, although Poelen et al. (2012) estimated intermediate phosphorus release rates I expected that oxic phosphorus release can have a large effect on the water quality in the Keulevaart as phosphorus release is expected to be higher in the smaller ditches. Besides oxic phosphorus release, also anoxic phosphorus release might largely affect the water column's phosphorus concentrations. Nevertheless, this case-study also revealed uncertainties about phosphorus release, namely on the effect of nitrate on phosphorus release and correlation methods. Both uncertainties need more research.