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TNO report

An intercomparison of nutrient concentrations in surface water in agricultural and natural reserve peatlands in the Netherlands and pristine Scandinavian peatlands.

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Abstract

Eutrophication due to high nitrogen (N) and phosphorus (P) concentrations is associated with the poor ecological status in ecosystems, including peatlands. The EU Water Framework Directive (WFD) therefore requires adequate nutrient concentrations to achieve “good ecological status” in surface water bodies. Proper application of the WFD requires knowledge of the background loading of nutrients in surface water. Currently a systemic insight lacks in the variability of nutrient concentrations in natural reserve peatland and agriculturally used peatland in the Netherlands, and between Dutch natural reserve peatlands and international pristine peatlands. This insight in the variability of nutrient concentrations is indispensable in determining the nutrient background loading. This study compares nutrient concentrations in natural reserve peatlands with agricultural peatlands in the Netherlands and with pristine peatlands in Scandinavia between 1998 and 2018. Nitrogen concentrations were found to be lower in Dutch peatland surface water with a long history of natural conservation, and higher in agricultural peatland and natural reserve peatland with a more recent natural reserve designation. Phosphorus concentrations were found to be high in peatland with a recent natural reserve designation and rather similar in agricultural peatland and older natural reserve peatland. Nutrient concentrations in pristine Nordic peatland were generally lower than Dutch peatland. Suggested controls for nutrient concentration variability are historical land use, including fertilization; water level management, including inlet water and lowered groundwater tables; geochemistry of peat soils, including peat mineralisation; and atmospheric deposition of N.

Keywords: Nutrient concentrations, nitrogen, phosphorus, peat, Netherlands, Scandinavia, agricultural peatland, natural reserve peatland, background concentration

Contents

1 Introduction

1.1 Nutrients and eutrophication

Phosphorus (P) and nitrogen (N) are essential nutrients for all organisms. Both elements are found in every cell of every life form and are necessary for energy transport, growth, development and reproduction. Phosphorus and nitrogen are often limiting nutrients for biomass production in the natural environment, and as such, in agricultural production as well (Elser et al., 2007). For adequate yields in agricultural practices phosphorus and nitrogen are indispensable as a fertilizer (Higgs et al., 2000; Erisman et al., 2010).

Both phosphorus and nitrogen are available as synthetic and natural fertilizer, e.g. manure. In manure, nitrogen and phosphorus are found in high concentrations (Heathwaithe et al., 1998). Phosphorus and nitrogen are not only essential nutrients, their overabundance can be a polluting factor to aquatic and terrestrial ecosystems. Anthropogenic activity highly increased the input of P and N in the environment, especially around agricultural areas (Withers & Haygarth, 2007). Phosphorus and nitrogen loadings are known to cause eutrophication of water bodies. Eutrophication may cause cyanobacterial algal blooms, which can lead to hypoxia and disrupt the trophic system (Vaccari, 2009). These algal blooms can also result in toxic zones and a decrease in biodiversity.

Whereas N is generally known to be a limiting factor in oceans, freshwater systems tend to be P limited (Elser et al., 2007). While reality is more complex than this view – P can be a limiting factor in oceans as well – reducing P in freshwater systems is seen as an effective measure in eutrophication prevention (Elser et al., 2007; Burson et al., 2016), whereas reducing N input is seen as an effective measure against terrestrial biodiversity loss in temperate zones (Bobbink et al., 1998). Nitrogen and phosphorus input are a main cause of deterioration of wetlands through eutrophication. Wetland ecosystems are considered to be natural buffers for nutrient retention (Woltemade, 2000; Hefting et al., 2006). If nutrients accumulate in these ecosystems it could jeopardize their buffer capacity and biodiversity (Ibelings et al., 2007). Apart from eutrophication, nitrogen saturation is also a major cause of biodiversity loss in terrestrial ecosystems in Northwestern Europe (Schot & Pieber, 2012). Nitrogen saturation occurs in areas where nitrogen is deposited from the atmosphere in the form of NH_3 or NOx, or where it is introduced with the groundwater and runoff from agricultural areas (Kroeze et al., 2003).

High N and P concentrations in water and soils are commonly found in Northwestern Europe, an area with intensive human soil and water usage, both industrial and agricultural (EEA, 2015). High N and P concentrations are associated with the poor ecological status in many terrestrial and aquatic ecosystems in this region (EEA, 2015). In the Netherlands, the N and P surpluses increased from 1960 to 1985, while after this period a reduction occurred, because of the implementation of the Manure Law (Visser et al., 2007). However, there is still a surplus of approximately 132 kg N/ha/year and 18 kg P/ha/year in the Netherlands on agricultural soils (clo, 2019). In the Netherlands, the P and N concentrations are considered to be too high in 55% and 47% of the surface water bodies respectively according to Water Framework Directive (WFD) standards (Rozemeijer et al., 2014). The concentrations of N and P are higher in the Netherlands in groundwater, fresh surface waters, estuaries and coastal waters than elsewhere in Europe (Vermaat &

Hellman, 2012). This imperils the water and soil quality and threatens ecosystems through eutrophication.

1.2 Nutrient policies in the Netherlands

Agriculture in the Netherlands can be considered intensive with a high density of livestock, and hence, a large amount of nitrogen and phosphorus-rich manure. Since the second half of the 20th century, livestock population has multiplied several times; the number of pigs has grown from 2 million to 12.4 million between 1960 and 2018, the amount of cattle is 4.2 million, but has, due to manure laws, not grown since the 1980s (CBS, PBL, RIVM, WUR, 2019).

To counter the N and P load from agriculture into the environment, the Dutch government has introduced several policies. This started in 1985 with the so-called "*interim wet beperking varkens- en pluimveehouderijen*" – interim law on reduction of pig and poultry farms. Later followed by the *Meststoffenwet* (Fertilizer Law) in 1986. The EU commissioned the Nitrate Directive in 1993, demanding a decrease in nitrogen and phosphorus loading from agriculture. These policies, laws and directives resulted in a strong decrease of N and P emissions, mainly from point sources in industry and wastewater treatment plants (WWTP) (Grizetti, Bouraoui & Aloe, 2012). Another important incentive for the reduction of N and P enrichment in the aqueous environment came from the European Water Framework Directive (WFD) as introduced in 2000 (EU, 2000). The WFD emphasizes the importance of water quality within the European Union. EU member states are committed to achieve good water quality according to the WFD standards by 2027 (Hering et al., 2010). For the implementation of the WFD a reference of the natural background load (NBL) is necessary to identify contamination of specific surface water bodies. This NBL indicates the natural load of nutrients from, for instance, seepage.

To help implement the N and P reduction policies in the Netherlands, several monitoring systems were created. On the one hand these were – and are – systems to account for manure input and output at the farm level. On the other hand, there were – and are – monitoring networks for the state of the surface and ground water. One of these systems is the *mestboekhouding*, or manure accountancy; in 1998 replaced by MINAS, *Mineraal Aangifte Systeem* – mineral declaration system. This system is based on the farm gate balance of nitrogen and phosphate. MINAS was later replaced by the MAO, *mestafzetovereenkomst* or nutrient management plan system based on the usage standards in the EU's Nitrate Directive. The status of the soil was monitored by the National Soil Quality Monitoring Network (LMB) until 2010, whereas the Minerals Policy Monitoring Programme (LMM) continued. The latter is now the main monitoring programme for water quality around farms. The RIVM is responsible for both systems.

One of the programs set up by the Dutch government to reduce nitrogen deposition in nature conservation areas, called the PAS (programmatic nitrogen approach) was started in 2015. However, the highest court (Raad van State) in the Netherlands halted this approach and called it inadequate. The following, stricter, nitrogen policies led to tension between the agricultural sector and the Dutch government and its institutes, such as the RIVM. (Beunen & Turnhout, 2019)

1.3 Dutch peatlands

In the Netherlands, one of the soil types that is intensively used for agricultural is peat. It is one of the four major soil types in the Netherlands, together with clay, sand and loess. Whereas peatlands harbour some of the most valuable wetlands in Western Europe for birds and rare flora, and serve as a natural buffer, they have been cultivated intensively since the middle ages (Hefting et al., 2007). Most peatlands are currently still used as dairy cattle grasslands in the Netherlands. This requires a strict drainage management, i.e. low groundwater tables. A small fraction of the peatlands is used as nature conservation areas, managed by the Dutch government or NGOs such as Natuurmonumenten and the provincial landscapes.

In peatland, groundwater and surface water are closely linked due to the shallow groundwater table (Querner et al., 2012). With the current sea level rise, the hazard of land subsidence in peatlands increases further. Water boards are considering increasing groundwater tables to prevent further land subsidence due to peat compaction and oxidation. Another incentive for this increase is greenhouse gas reduction by preventing peat oxidation. Increasing the groundwater tables, however, is a controversial step, as farmers are generally against it because it is considered a cost increase (Querner et al., 2012). Improved drainage can impact groundwater regimes, resulting in peat mineralisation and subsidence, this then influences biodiversity in the peatland (Charman, 2002). The pattern of elongated stretches of land and ditches in Dutch peatlands form a dense network of littoral transitions between terrestrial and aquatic ecosystems (Vermaat et al., 2010). The narrow, linear wetlands in the Dutch peatlands are considered rich in unique biodiversity (Herzon & Helenius 2008), and are subject to intensive management (Van Beek et al., 2007). Due to their intensive usage and their high ecological value these peatlands are densely monitored for the compliance to the Nitrate Directive and Water Framework Directive. The dairy cattle farming is one of the reasons that the concentrations of N and P in the soil and surface waters of the peat areas are high. Compared to clay soils, the WFD Environmental quality standards (EQS) for N and P in surface water are exceeded for a larger fraction of locations in peatlands, but lower than in sand soils. Only 6 to 12% of the monitoring locations in the peat regions complied to the WFD standards, compared to 24 – 34% of the monitoring locations on clay soils (Rozemeijer, 2014). Nitrogen surpluses in peatlands were 200 kg/ha in 2017 and for phosphorus the surplus was around 1 – 5 kg/ha. It depends on the local circumstances how much nitrogen and phosphorus leach to the surface and groundwater. (Lukacs et al., 2019)

1.4 Nutrient chemistry in Dutch peatlands

Until now research on nutrient concentrations in Dutch peatlands has been carried out while either not discriminating between agricultural or natural peatlands (Vermaat et al., 2010), on specific agricultural peatland catchments (e.g. Van Beek et al., 2004; Van Beek at al, 2007; Van Gerven et al, 2011), or on a local scale in a specific naturally conserved peatland (Kooijman, 2012; Schot & Pieber, 2012; Cusell, 2014). On the national scale, research was done on the average nutrient concentration in Dutch surface waters, including peatlands (Rozemeijer et al., 2014). Griffioen et al. (2002; 2008) researched the NBL for groundwater of the Western clay and peat areas in the Netherlands. Several reports and studies were written on sulphur and phosphorus dynamics in peatland and how the species of S and P interact (e.g. Van Gerven et al, 2011; Vermaat et al., 2012). Griffioen et al., (2002) found that in the peat region, leaching is the principal background nutrient loading source, primarily explained in land use differences for nitrogen; and differences in land use, water management and P accumulation for phosphorus. Schot & Pieber (2012) found that in a relatively small naturally conserved peatland (Naardermeer) concentrations of N and P differed significantly spatially, and that the concentrations are dependent on factors as local thickness of peat layers and other geological characteristics; local polluting activities outside and at the margins of the wetland; differences in the quality of infiltrating water in the wetland; infiltration of polluted surface water under lakes and ditches; and local exfiltration of brackish groundwater. Van Beek et al., (2004; 2007) found that, apart from manure and fertilizer application (43 to 50% for N and 10 to 48% for P), peat mineralization (17 to 31% for N and 2 to 14% for P) and leaching from nutrient rich peat layers (8 to 27% for N and 33 to 82% for P) contributed considerable percentages to the N and P load of peatland ditches. The layers of eutrophic peat and marine clay present at shallow depth in peatlands, largely determined the composition of the soil solution and substantially contributed to the N and P concentration of surface water. Rising groundwater tables can suppress this contribution presumably for N, but this is still unclear for P. In the reports by Van Gerven et al., (2011) and Vermaat et al., (2012), SO_4 was found to have a considerable effect on P concentrations in peatland ditches in the Western Netherlands. Elaborating on Van Beek et al.'s research in a single polder, Vermaat & Hellman (2010) researched nutrient budgets in 13 peat polders in the lower part of the Netherlands (Figure 1.1). These budgets were found to be dominated mostly by agricultural sources. However, both in agricultural and natural reserve peatlands N and P input from peat mineralisation, atmospheric deposition (N) and reworking of ditch sediments was found to be not negligible either. Without the denitrification capacity of the peat soil, agricultural input and mineralisation would cause a large N surplus. Phosphorus budgets suggested a net annual surplus, which Vermaat & Hellman (2010) found to be in agreement with the known history of fertilization since the 1950s; the natural peat reserves studied by Vermaat & Hellman showed considerably lower amounts of P in the top 50 cm soil than agricultural peatlands– 600-800 kg/ha versus 1400 kg/ha respectively. P accumulation in the peat soil and ditch sediments was identified as the principal mechanisms of P retention in the polders.

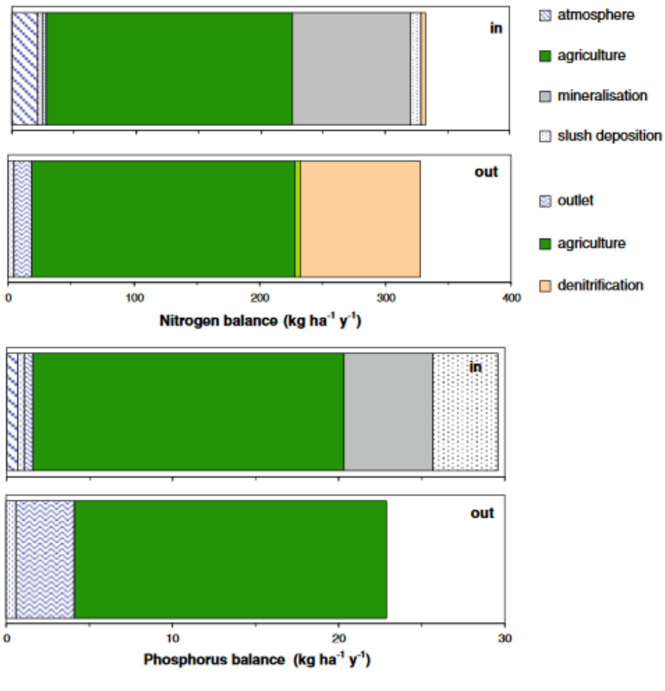


Figure 1.1 Mean nutrient balances of the 13 polders studied by Vermaat & Hellman (2010)

1.5 Knowledge gap

While the concentrations of N and P in agricultural peatlands and peatlands designated as natural areas have been thoroughly examined in the Netherlands, this is all research on specific study areas, and not a comparison at the national scale. Some of these researches have either investigated trends in agricultural or natural peatlands over longer periods of time (e.g. Schot & Pieber, 2012; Cusell, 2014; Veeken & Wassen, 2020) or have examined specific peatlands without considering temporal trends (e.g. Van Beek et al., 2004; Kooijman, 2012). While agricultural and naturally conserved peatlands have been the subject of nutrient budget research at national scale (Vermaat & Hellman, 2010), a comparison at a national scale between the N and P concentrations in agricultural and natural reserve peatlands has not been conducted. These natural reserves, however, are crucial to compare with the agricultural peatlands, since they are fundamental in determining the baseline nutrient concentrations in areas without agricultural land use. Determining natural reserve nutrient concentrations gives more insight in the variability of N and P concentrations in the Dutch peat region and hence the background loading. The concentration values found in natural reserve peatlands could act as a reference background nutrient concentration for the Dutch peat region.

Currently there is no systematic insight in what the typical nutrient concentrations in Dutch peat soils are for natural land use and how this compares to agricultural land use. This means that the degree of N and P contamination cannot be established correctly for the agricultural peat areas where soil chemical processes with respect to N and P are relevant in the fate of these nutrients in peat soils. More knowledge on the variability and controls helps distinguish between N and P concentrations as a result from atmospheric deposition, inlet water and peat mineralization in contrast to direct agricultural sources as manure application. As such this study will connect its results with previous researches and insights on the specific agricultural and naturally conserved Dutch peatlands.

A coherent comparison of nutrient data between Dutch naturally conserved peatlands and international pristine peatlands lacks as well. A comparison of Dutch nutrient data and data from foreign pristine peatlands, where anthropogenic influences are far smaller compared to the Netherlands, gives more knowledge on the non-agricultural nutrient concentration variability and controls. A comparative analysis between pristine and the intensively managed Dutch peatlands also broadens the perspective of the baseline nutrient concentrations in peatland. Examples of these controls are again soil chemical processes in peat, or the atmospheric deposition in less intensively used areas around the peatlands.

1.6 Research aim

This research aims at filling the knowledge gap of the variability in N and P concentrations between various land use types in peatlands in the Netherlands, by statistically characterizing this variability of N and P concentrations in these peatlands. It does so by comparing the variability of the N and P concentrations in agricultural peatlands to those in peatlands managed as nature. Furthermore, this study will discuss the variability in nutrient concentration in natural peatlands, e.g. in regard to historical land use, water management, and soil and water geochemistry by studying existing literature on the specific study areas. This study will also compare the Dutch natural peatlands to undisturbed peatlands in primarily northern Europe, i.e. boreal Sweden and Finland.

Two hypotheses have been formulated to help examine the differences in N and P concentration in natural reserve and agricultural peatlands in the Netherlands and pristine peatlands in Northern Europe:

1. There is spatial and temporal variability in N and P concentrations in surface water in Dutch natural reserve peatlands, with lower N and P concentrations in naturally conserved peatlands, compared to agricultural peatlands.
2. The typical N and P concentrations in surface water in naturally conserved peatlands in the Netherlands are higher than in international, pristine peatlands found in Northern Europe.

1.7 Societal relevance

In the EU's Water Framework Directive nutrient concentrations occupy a central role in acquiring good ecological status/potential in surface waters (GES for natural waters and GEP for modified water bodies). The WFD specifies that nutrient concentrations must "not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of values specified (for good status) for the biological quality elements" (European Commission, 2003). Knowledge of the variability and controls of nutrient concentrations is therefore indispensable. Using WFD standards, regional policy makers in the EU countries have been assigned to decide what N and P concentrations are "good" in a certain catchment; in the Netherlands these policy makers are the regional water boards. The policy makers base the GEP/GES on a baseline of nutrient concentration without direct agricultural input of the most similar natural water type and on the local modifications of a water body (Raadgever et al., 2009). Despite the policies attempting to prevent eutrophication in surface water, most water bodies in the Netherlands have still not acquired GES/GEP (Rozemeijer et al., 2014). For plenty of surface water bodies in the peat region acquiring "good" status has been challenging and for some peatlands deemed unachievable (Rost et al., 2020). Many natural reserve peatlands either were agriculturally used in recent years or lie close to intensively used agricultural areas (Kooijman, 2012; Cusell, 2014). Some natural peat reserves have high nutrient concentrations due to environmental controls, such as high P input from peat mineralization (Vermaat & Hellman, 2010; Van Gerven et al., 2011). A broad scope of the N and P concentration variability between natural reserve and agricultural peatlands provides a better understanding of the baseline and natural variation of nutrient concentrations in Dutch peatlands. Knowledge of the N and P concentration controls and baseline can help quantify the nutrient pollution and guide policy makers on whether the GEP/GES is achievable. The N and P concentrations found for nitrogen and phosphorus in this research could then be interpreted as a baseline reference for the whole Dutch peatland region. Combined with studies on the ecological status of peatlands, the nutrient concentrations standards according to the WFD could then be modified. A comparison with pristine peatlands in Scandinavia widens that scope further and places the nutrient concentrations in more anthropogenically influenced peatlands in the Netherlands in an international perspective with nutrient concentrations in an undisturbed peatland.

2 Nitrogen and phosphorus mechanisms in peatland

There are several factors that influence the nutrient load in peat soils. Peat soils can act both as source as well as sink of N and P, depending on peat type, drainage and other conditions. The source of N and P in peat soils may be: (synthetic) fertilizers, manure, cattle droppings, seepage, atmospheric deposition, peat mineralization and ditch sludge application (Vermaat & Hellman, 2010). However, it is difficult to quantify each source, since the discrimination of nutrients from the individual sources in the complex soil system in peat is still analytically challenging (Van Beek et al., 2007). Nevertheless, it is clear that there is a distinction between anthropogenic input of nutrients and available nutrients that are already contained in indigenous peat. Output of nutrients is influenced by natural and anthropogenic factors as well.

For the sake of the natural background load as a reference for the WFD, it is important to discriminate between the anthropogenic input and output and the natural input and output processes. This is described below for the situation that is typical for the Netherlands where agriculture is intensive.

Anthropogenic N and P inputs in peat soils are mineral application through fertilizers, atmospheric deposition, slurry application from ditches, dung and urine from grazing cattle. Natural inputs of N and P in peat soils are nutrient supply from the peat layer, groundwater exfiltration from the deeper subsurface and mineralization of soil organic matter, while a part of the atmospheric deposition has a natural origin. Peat mineralization and sedimentary organic matter in marine clay layers can result in nutrient-rich groundwater that reaches the soil or adjacent ditches under exfiltrating conditions. This may contribute up to 50% of the nutrient budget in a peat polder (Van Beek et al., 2004). The release of nutrients due to peat mineralization can either be anthropogenic or natural. If water management artificially keeps the groundwater table low enough for peat mineralization to become enhanced, the nutrient release has an anthropogenic cause. Anthropogenic outputs are the mowing of grass and exporting this from the field, and the grazing of cattle. Natural outputs are denitrification in the soil of N, fixation of P in Fe-rich ditches and drains, N-volatilization and groundwater recharge. Mixed outputs are runoff and leaching to surface water, since this is both a natural as well as an anthropogenic factor. An overview of inputs and outputs is presented in Table 2.1.

Farmers consider the nutrient release from the peat soil too uncertain, as a consequence, the inputs of N and P via fertilizers and animal manure are relatively high, albeit decreasing because of the aforementioned manure policies (Oenema et al., 2012).

Table 2.1: Overview of the input and output of nutrients in peat soils.

Natural inputs	Nutrient supply from peat layers and clay with marine deposits.
	Mineralisation of soil organic matter.
Natural outputs	Denitrification in the soil of N
	Fixation of P in Fe-rich ditches and drains
	N-volatilization and groundwater recharge
Anthropogenic inputs	Fertilizers, manure and cattle droppings
	Atmospheric deposition
	Slurry application from ditches
	Peat mineralisation due to artificial peat drainage
Anthropogenic outputs	Mowing of grass and exporting this from the field
	The grazing of cattle

Shallow soil layers in agricultural areas are commonly enriched with nutrients from agricultural inputs, and it is usually assumed that high groundwater table and subsequent drainage of these shallow, nutrient rich soil layers has a large impact on the N and P load of surface water. In peat soils however, a major part of the N surpluses at the soil surface is quickly denitrified and generally peat soils with a shallow groundwater table have a higher denitrification capacity (Van Beek et al., 2007). Yet peat soils with a lowered groundwater table may contribute significantly to the N and P concentration in surface water as indigenous peat layers may contain large amounts of nutrients (Heathwaite, 1991; Smolders et al., 2006). A schematic overview of the input and output mechanisms in a peat polder is visible in Figure 2.1.

The degradation of sedimentary organic matter is a major source of P in lowland soils. Phosphorus is found in sedimentary organic matter and sedimentary marine depositions, not only in peat but also as part of sedimentary organic matter in clastic sediments (Griffioen, 2006). This degradation is an oxidation reaction called mineralisation. This reaction releases ortho-phosphate, which is soluble in (ground)water. SO_4 plays an important role in P concentration increase in peat ditches. When peat mineralises, it releases considerable amounts of SO_4. This sulphate is associated with high P concentrations as it helps desorb the P from Fe/Al-oxides (Van Gerven et al., 2011)

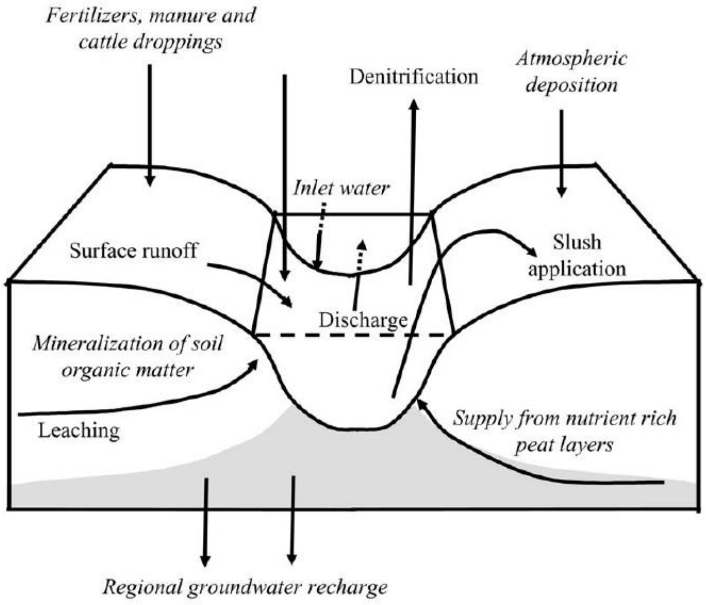


Figure 2.1 Schematic overview of N and P input and output mechanisms in a peat polder. (From Van Beek et al., 2004)

3 Study area

3.1 Peatlands in general

The geographical study areas this research focuses on are peatlands in the Netherlands, Sweden and Finland. These peatlands are mainly the types found in temperate regions, such as boreal, undisturbed sphagnum and *aapa (*sedge*)* peatlands in Northern Sweden and Finland to more cultivated peatlands with reed, sedge and alder in the Netherlands.

3.2 Dutch peatlands.

The peatlands in the Netherlands addressed in this research have in common that they are considered fens – opposed to the raised bogs in the Northeastern Netherlands and formerly in the Southern Netherlands. Dutch fens are commonly fed by minerotrophic surface or groundwater (Mettrop et al., 2014).

Geomorphologically, the Dutch peatland region is young, the formation of peat started during the Atlanticum, 8000 – 5000 BCE (Kooistra, 2003). Due to sea level rise the groundwater table rose. Lagoons formed between the sandy dunes and beach barriers and the moraine uplands. This induced wetland formation in the western Netherlands, peat formed on the areas where freshwater inflow was higher than that of salt water. Swamp vegetation occupied the lagoons and in areas where the plant decay is slower than plant growth and reproduction, peat started to form. This peatland area occupied a much larger area than it does nowadays. Approximately 15,000 km^2 were covered with peatlands. Due to the high groundwater table, peat decay occurs anaerobically and is therefore a slow process, until 2600 BCE peat formed faster than it degraded. After 2600 BCE peat formation ceased and large parts of the peatlands were calved, where lakes and ponds formed. Later much of the peatlands were flooded by sea or river and were buried under layers of clay and sand. Dependent on the formation circumstances, peat layers could grow up to several meters thick. Nutrient rich groundwater secured a steady inflow of nutrients for the peat vegetation, and thus controlled biomass production. Other than chemical groundwater composition, climate, and acidity and alkalinity steer peat, bog, or fen formation (Kooistra, 2003).

Peat has since the early Middle Ages been used as a fuel and large parts of peatland have been extracted. This process is still recognizable in the landscape as the typical peat lakes in the western Netherlands, examples are the Loosdrechtse and Reeuwijksche Plassen. At the same time peatlands were drained and reclaimed by digging ditches and canals, the peatlands then became available for agricultural practices. This resulted in subsidence of the peat soils, as the lack of water enhances oxidation and decay of peat. Due to the peat subsidence virtually all fen peatlands in the Netherlands now lie below sea level and require drainage for the maintenance of intensive dairy cattle farming (Vermaat & Hellman, 2010). Drainage of peat soils is required for intensive agricultural management, but also enhances peat soil subsidence (Schothorst, 1977). Subsidence of the surface necessitates the further lowering of surface water levels and these intimately linked processes may continue until all peat has been oxidized. Subsidence contributes to several side effects, including damage of infrastructure and increased risks for saltwater intrusion and flooding (Van Beek et al., 2007). Water boards are currently exploring options to raise surface water levels and groundwater table to slow down subsidence, without Wetland vegetation development, such as those found in peatlands, is determined by

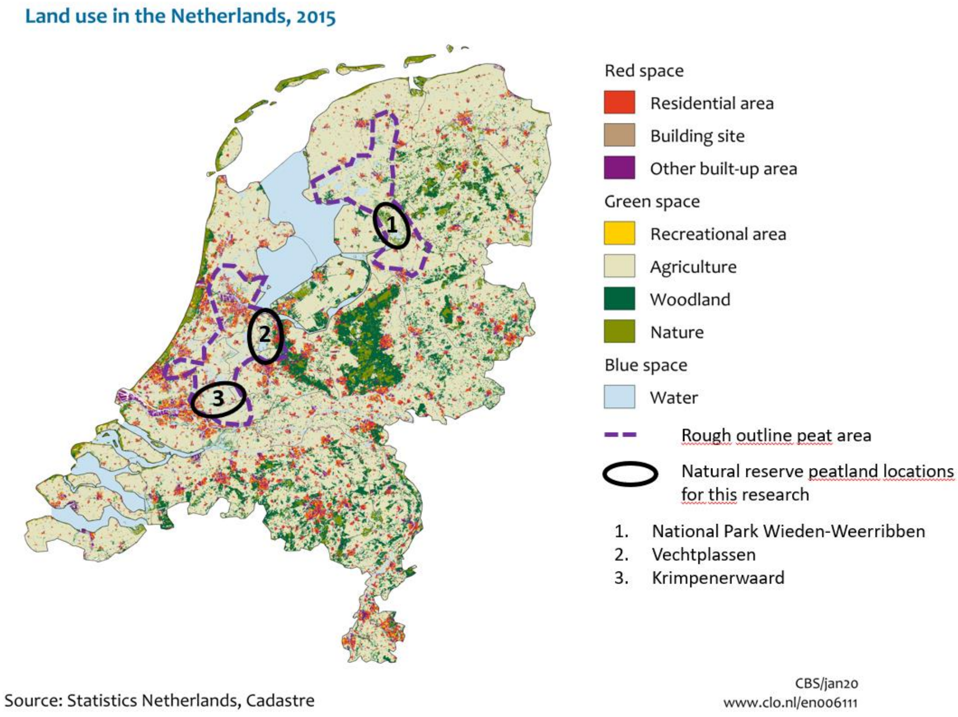


Figure 3.1 Map of land use in the Netherlands. Indicated are the locations of the naturally conserved peatlands used in this research (black numbered ellipses), and the rough outline of the Dutch peat region (dashed purple line). (Adapted from clo, 2015)

relatively stable factors like climate and soil type, and on more dynamic factors like drainage regime and water levels, and on the chemical composition of water (Schot & Pieber, 2012). Intensive agriculture and industry can significantly change both the chemical composition of groundwater as well as drainage regime. For terrestrial wetland vegetation this occurs due to changes in groundwater table, e.g. because of agricultural demand for low groundwater tables, or nutrient pollution from agricultural sources. These environmental changes affect biodiversity in wetlands by eutrophic algal blooms or changes in vegetation type. (Schot & Pieber, 2012). The conservation of wetlands is thus for a large part dependent on spatial and temporal changes in the composition of groundwater. Especially, abundant nutrients such as N and P need to be monitored well to prevent eutrophication of these ecosystems. (Schot & Pieber, 2012).

The naturally conserved peatlands in this research are monitored and managed by the Dutch Waterboards – or *waterschappen* in Dutch. The waterboards involved in this research are Waternet, Hoogheemraadschap Schieland Krimpenerwaard (HHSK) and Waterschap Drentsch Overijsselse Delta (WDOD). A map of the locations for the natural peatlands used in this research is visible in Figure 3.1.

A short description of the natural reserve peatlands is given below, a more extensive description is given in the data collection and description part of the Methodology Sections 4.1 and 4.2, where every water board region has its own sub section.

The main nature area of Waternet is the Vechtplassen, around the Vecht river. This area consists of vast fenland with small shallow lakes and ditches. Most of the area is in use as nature conservation area or for water recreation. It is a Natura2000 area, therefore protection and conservation of flora and fauna is required by the EU. The lakes' origin is the extraction of peat in this area until the 19th century.

The main natural peatland in the management area of WDOD are the Wieden-Weerribben. Like the Vechtplassen this is a Natura2000 fenland, with shallow lakes, ditches and swamps. This area was also extensively used for peat extraction but has been a natural conservation area since the first half of the 20th century.

The natural reserve peatlands in the HHSK region have a more recent natural conservation purpose. Most of the natural conservation areas in this peatland have only been designated as such in the last 30 years. This means that they were in use for agricultural purposes until recently, compared to the natural peatlands in the Waternet and WDOD area. The Krimpenerwaard peatland polder is managed by the HHSK water board. About 20% of the Krimpenerwaard is designated as nature conservation area. Some areas have only been assigned as nature since 2015.

The Dutch peatlands are considered valuable ecosystems. They support several rare species, especially for birds, certain insects and marsh plants that require open wetland landscapes (Cusell, 2014). It is a landscape type with a high ecological value due to its richness in species and food for animals, that is quite rare in Europe. Apart from the ecological value, the peatlands are attractive for recreation and tourism. Another important ecosystem service the peatlands provide is carbon storage. If the peatlands are drained however, they can be a considerable source of greenhouse gases, especially CO_2 and methane (Couwenberg et al., 2011).

3.3 Peatlands in Sweden and Finland.

The monitoring locations of the peatlands in Sweden and Finland have been specifically selected on their pristine states. This means the locations are mostly undisturbed, e.g. not drained for agricultural usage or extracted for peat fuel usage. Locations of peatlands in Sweden and Finland are visible in Figure 3.2. The peatlands of which the data has been collected in Sweden and Finland are considered *aapa* mires. These peatlands are considered fens – as opposed to raised bogs – and are fed by groundwater. Aapa mires are commonly found in lowlands or valleys and have a characteristically flat landscape with small, elongated and elevated parts on which larger plants and trees grow (Pakarinen, 1995). The main vegetation types are reed and sedge. Due to this morphology they are better suited for comparison with the Dutch fens as both Dutch fens and aapa mires are fed by minerotrophic groundwater and generally occupy the lowest parts of the landscape.

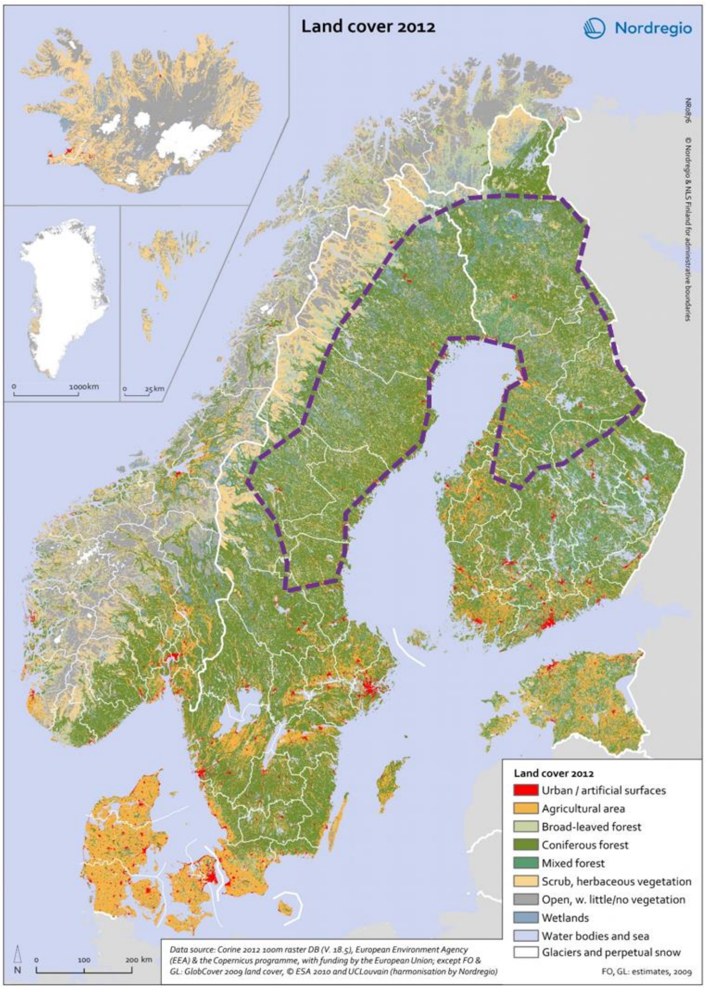


Figure 3.2 Land cover map of Scandinavia. Indicated with the dashed, purple line is the aapa mire region. Roughly 20% of this region is covered with fens (adapted from Nordregio.org).

4 Methodology

The methodology of this research contains three components. The first part consisted of data collection, while gaining some insight in the areas studied. The second part consisted of restructuring, cleaning and preparing the data for analysis. The third part was a data analysis to compare the different data sets of nutrients in peatlands.

4.1 Data collection and description

The necessary data was collected from a myriad of sources. Like the study areas, this methodology chapter is divided between the data collection process from sources in the Netherlands and that from sources in Sweden and Finland

The data from the Netherlands can be divided in water analysis data from agricultural peatlands and that from peatlands that are managed as nature. All the data from Sweden and Finland are from pristine undrained, natural peatlands.

The water quality data for agricultural peatlands is provided by the Dutch Institute for Public Health and Environment, RIVM. Their aforementioned LMM programme monitors several water types in the vicinity of farms. The locations of the monitoring points of the Landelijk Meetnet Mestbeleid are anonymized, hence they have no specific location on the map and are only visible as either Veen Noord (Northern peat) or Veen West (Western peat), visible in Figure 4.1. The monitoring points of the LMM represent the agricultural peatlands in this research. They cover the Northern and Western peatlands. The naturally conserved peatlands in this research are monitored and managed by the Dutch Waterboards – or *waterschappen* in Dutch. The waterboards involved in this research are Waternet, Hoogheemraadschap Schieland Krimpenerwaard (HHSK) and Waterschap Drentsch Overijsselse Delta (WDOD). A map of the locations for the natural peatlands used in this research is visible in Figure 3.1.

Figure 4.1 Soil type map of the Netherlands by RIVM. The pink and purple areas indicated as Northern peat and Western peat are the areas where the LMM measurements in this research were taken. (Spijker, 2012)

4.1.1 LMM

In the LMM monitoring programme, water chemistry is surveyed in ditch water, groundwater and drain water, all in the vicinity of farms. The reason for this strict monitoring is the EU derogation policy of the Nitrate Directive. In short, this policy applies to countries with intensive livestock farming and soils with large nitrogen losses, due to their wetness and precipitation surpluses. The policy excepts these countries or regions from the maximum yearly nitrogen application of 170 kg/ha, as ordered by the Nitrate Directive. In the derogation regions, the maximum allowed quantity of nitrogen allowed per ha is 250 kg. To assure this maximum amount is not exceeded, the EU demands the strict monitoring of water quality, to prevent eutrophication and a decrease in water quality.

The data that was provided by the RIVM-LMM consists of geochemical data of ditches, drains and groundwater in the areas marked as peat in the national soil type map of the RIVM (Figure 4.1). The peat area is divided into a northern and western region. In the most recent LMM reports (e.g. Lukacs et al., 2020), the areas were updated and this last version was used for this research. The RIVM map on soil type was, for instance, used as basis to determine whether the monitoring points of the water boards were in the peat region or outside of it.

The LMM data provides water analysis data of drain, ditch and groundwater with the following elements and substances: Ca, Cl, DOC, Fe, K, Kjeldahl N, Mg, Mn, Na, NH_4 (as ammonium), NO_3 (as nitrate), total-N (as N), PO_4 (ortho-P as P in solution), total-P (total-P as P in solution), SO_4 in mg/l; Al, As, Ba, Cd, Cr, Cu, Ni, Pb, Se, Sr, Zn in µg/l. Furthermore, electrical conductivity and pH were measured. The surface water samples were filtered using a 0.45 µm filter. To answer the research questions of this thesis, total-N and total-P were considered the most important components of the LMM data. Only monitoring points were selected where more than 80% of the soil consisted of peat, as there were several monitoring points in the peat region where clay or sand soils were present on a substantial part of the monitoring point's surface area (information on soil composition available in the LMM data). This selection resulted in 66 unique monitoring points. Not every point is represented in every researched year. The LMM data also provides information on type of agricultural land use for every monitoring location, cattle farming is the main agricultural practice for the peat region.

It is important to note that the LMM data provides no exact locations of the monitoring stations. This is to protect the farmers' privacy and to keep the goodwill of the agricultural sector while monitoring the water quality. Since last year the relation between the agricultural sector and the RIVM has decreased over the nitrogen verdict by the Raad van State and the consecutive unrests over potential policy changes, going as far as protests at the RIVM terrain. This situation affirms the importance of the anonymity of the partaking farmers.

4.1.2 WDOD

The data in the WDOD area encompasses National Park Wieden-Weerribben. This is a wetland of 105 km^2, being the largest contiguous fen wetland in western Europe. It is a national park since 1992, while the first steps of the transformation of the area into nature were set in the 1930s, when Natuurmonumenten bought the first fen parcels. In the 1960s, the area became a nature reservation. This is a European hotspot for endangered mosses, vascular plants, dragonflies and butterflies (Cusell, 2014)

The data of the WDOD was provided by Casper Cusell PhD. His research focused on the effects of surface water level fluctuations on biogeochemistry and ecology in Wieden-Weerribben National Park.

Cusell (2014), gives an extensive description of the water balance in the National Park: Considering the water balance in the Wieden-Weerribben, 35% of the input comes from precipitation, respectively 20% and 45% comes from the exterior waters of the Steenwijker Aa and adjacent agricultural polders (Cusell, 2014). Annual precipitation is 800 mm on average (KNMI, 2019). In summer water is pumped into the polder, while in the winter surplus water has to be pumped out. This means that during the summer N and P rich water flows into the polder. Dry conditions in summer are not the only reason for water inlet, the fenland also lacks base rich inflow, water inlet helps sustain base rich conditions. During the 20th century agricultural intensivation around the polder led to substantially increased N and P input (Cusell, 2014). Atmospheric deposition of N is approximately 19 kg/ha.year^{-1}; this is above the critical N-deposition for rich fens – i.e. 0-17 kg N/ha.year^{-1} (RIVM, 2012; Cusell, 2014).

4.1.3 *HHSK*

The HHSK monitors water quality as the water board in the Schieland-Krimpenerwaard region. Virtually all peatland in the HHSK region is situated in the Krimpenerwaard. Compared to the other two natural peatland regions examined for this research, the HHSK region knows a shorter history of nature conservation. The ecological main structure in the Krimpenerwaard has as of now been completed for 50%.

Since 1980 the water quality in several surface water bodies is analysed on a myriad of solutes and substances. The monitoring includes the nutrient concentrations in water.

The water balance of the Krimpenerwaard shows a precipitation surplus in general. water is pumped out of the polder in the winter, while water from the Lek and Hollandsche IJssel rivers is taken in in the summer to secure a decent polder water level in order to prevent the polder’s peat soils from degradation. As the area has known an intensive agricultural usage, the concentrations of nutrients associated with agriculture are high (Schipper et al., 2016). Inlet from rivers to sustain high water levels during dry periods accounts for a high inflow of nutrients as well. Other important factors influencing the concentration of mostly N and P in the water board region are wastewater treatment plants (WWTP), atmospheric deposition from industry and traffic, and degradation of the peat itself. A modelling study estimated the percentages of N and P sources in the Krimpenerwaard as follows: 40% from the N loading and 50% of the P loading is from agricultural sources, while 25% and 30% respectively is from inlet from the Lek and Hollandsche IJssel rivers, other sources are atmospheric deposition of N and point sources as WWTPs (Schipper et al., 2016).

Observations on water quality were retrieved from the HHSK database. This database includes monitoring points in natural reserve peatland as well as agricultural peatland. Selection of the natural reserve observations was based on information provided by the water board on natural areas and on a natural reserve map of the regional government. The latter contained a WMS file with spatial information on natural reserve terrains and reserve ownership. This map was combined with the monitoring points’ coordinates to select the correct measurements.

The naturally conserved peatlands are managed by either the provincial government, or the NGOs Landschap Zuid-Holland and Natuurmonumenten. Most of the region was only recently – 2017 – appointed as natural conservation area.

4.1.4 *Waternet*

Waternet is the executive water management organization of the municipality of Amsterdam and the water board Amstel, Gooi & Vecht. Waternet monitors water quality in the water board territory. This includes the peatlands around the Vecht river. East of this river is a large wetland, consisting of lakes, streams and marshes, originating from extensive peat extractions over the last few hundred years. Water quality data was provided by Ruth Heerdink, water system analyst at Waternet. To find the correct monitoring points, the RIVM soil type map was used together with Ruth’s knowledge on what parts of the water board territory were designated as peatland nature conservation areas. Waternet then provided a dataset of the water quality monitoring points in naturally conserved peatlands.

The hydrology of the area is influenced by groundwater seepage from the ice-pushed ridges of the Utrechtse Heuvelrug to the east. This seepage caused very slow or stagnant water on the Vecht floodplain, which enhanced peat formation. The groundwater flow from the ridge is rich in minerals, this helps develop the rich fens in the Vechtplassen. Several anthropogenic causes did decrease the groundwater flow from the ridge however (Grandiek et al., 2017). As the polder water levels in the area are now extensively managed, the surface water flow is complex due to the large numbers of water bodies and their controlled water level. Due to the decrease in groundwater flow, surface water is let into the area from the Vecht river. During the period 1930 -1975 this led to strong eutrophication. After this period the water quality improved slowly. Phosphate load has decreased until 2005 but has since then in most parts of the area either stagnated or even increased (Grandiek et al., 2017).

4.1.5 SLU

The SLU is the Swedish University of Agricultural Sciences. For the WFD, the SLU monitors surface water quality in many locations spread across Sweden. Contact with the SLU resulted in do-it-yourself data collection from their datasets. A map of all the monitoring points is available at their website, where one can download surface water analysis data of these points using search filters. For this research the total-N and total-P data were downloaded for a myriad of peatland sampling points. The SGU, the National Geological Survey of Sweden, monitors the range and natural value of peatlands . A map of these peatlands is available on their website and as a WMS package. This map was uploaded in ArcMap and then used to find the right monitoring points on the map of the SLU This amounted in a different number of locations in natural peatlands per year. As explained, most of the peatlands in Sweden examined in this research are considered aapa mires (Pakarinen, 1995), see also Figure 3.2. This is the most common peatland type in the regions where the monitoring stations were found. Other types of mires, such as raised bogs are also represented, albeit to a smaller extent.

The data from the SLU had to be prepared for usage in R, since every monitoring station had its own file, all the stations had to be combined in one spread sheet. After this task was carried out, the data was ready for analysis in R.

4.1.6 Luke

Luke is the National Resources Institute of Finland. This institute "*monitors natural resources, certify plant production, inspect control agents, store genetic resources, produce data on greenhouse gases, support natural resource policies and produce Finland's official food and natural resource statistics*". Luke is thus the main Finnish source for water quality data in peatlands. Researchers Sarkkola and Nieminen provided a large dataset of surface water quality data of undisturbed and undrained peatlands. Since Finland has a long tradition of using peat as fuel, many peatlands have lost their pristine state and are now used for silviculture. The data used for this research is of surface water flowing through pristine peatlands. Most of the locations are in aapa mires in nature reserves in Central and Northern Finland, as shown in Figure 3.2.

4.2 Data preparation

All datasets required their own data preparation as there was no uniform data or spreadsheet type or style. For usage in R, data needs to be sorted in columns, with every column containing data for just one variable, such as specific substance, location code, date or water type. Apart from the LMM and Luke data, none of the datafiles were sorted in the style readable for R. All the files were thus prepared in Excel to be ready to use for data analysis. In some cases, this required transformation using R. Because 2018 was the year with the most recent available data, 2018 was chosen as the most recent year in the data analysis. Per step of five years data was prepared. This meant data was extracted from every file for 2018, 2013, 2008, 2003, 1998. From every file, the N total and P total data were either retrieved as they were given with the data or calculated using other N and P species; this calculation is done by summing the mg N/l of Kjeldahl N and NO_3/NO_2. Important to note is that due to seasonality N and P concentrations can vary significantly, therefore the winter months – i.e. January, February, March, October, November and December – were chosen. Especially P concentrations show less fluctuation during winter. Prior to the statistical analysis, the data set was also prepared by changing the censored data. Censored data is the data with values below a detection limit: they were set at a value half the detection limit (Reimann et al., 2011). In cases where more than 25% of the values of a variable were below the detection limit, the variable was not used in the comparative data analysis.

Two types of spreadsheets were created to make the analysis in R more streamlined for every year and per nutrient. In the first file, every individual dataset had its own spreadsheet with the total-N and total-P data per year with information on the sample data, unit and monitoring location. This file was used for the median and percentile calculation, and for the Wilcoxon rank sum test. Then there was a file where all data of the individual datasets was combined for a given year. This last file was used for the Kruskal-Wallis test and boxplots.

4.3 Data analysis

The last phase of the research consisted of data analysis, which took place in several steps. A schematic overview of the data analysis methodology is presented in Table 4.1. The first step (Goal A) was a cluster analysis (CA) and a robust factor analysis (RFA) on the anonymized LMM data, to gain more information on the relation between the monitoring locations. The second step (Goal B) was a calculation and interpretation of the confidence intervals of the median and 90th percentile for every dataset, in which data was also compared to each other. The median was chosen over the mean because the median was found to be a more informative central value for the non-normal data collected for this research. The 90th percentile was chosen as it represents a high value but presumably avoids outliers. The third step (Goal C) was a Kruskal Wallis test, followed by Wilcoxon rank sum tests, to compare the nutrient data from the different study areas. The last step was to examine if the median and 90th percentile exceeded WFD Good Ecological Potential (GEP) standards for surface water (Goal D). The different phases are described below in more detail. All the data was prepared in Excel and in R, where RStudio was used for the data analysis. The specific functions or scripts used in R, are given below per analysis description.

Table 4.1 Schematic overview of the different goals described in the data analysis section and their respective methods. Indicated is if the goal/method applies to the dataset type; agriculture (NL) indicates LMM, Nature (NL) indicates WDOD/Waternet/HHSK, and Nature (FI/SE) indicates Luke/SLU. WFD standards for Luke/SLU were not yet retrieved by the publication of this thesis.

Goal	Method	Agriculture (NL)	Nature (NL)	Nature (FI/SE)
A.	Exploratory data analysis (CA/RFA)	X		
B.	Determine medians and percentiles	X	X	X
C.	Identify differences between areas	X	X	X
D.	Examine exceeding of WFD standards	(X)	X	(X)

4.3.1 Cluster analysis of LMM data

As the data of the LMM was anonymized and only the region of the monitoring locations was known, a cluster analysis was used to gain more information on the LMM dataset. Cluster analysis was used as it does not use a priori knowledge and serves as an exploratory data analysis method (Reimann et al., 2008).

The *Mclust* function in R provides the most reliable and best interpretable results when a dataset consists of a high number of observations and variables. For the cluster analysis the values of the substances analysed were selected. For the LMM data these substances were: Ca, Cl, DOC, Fe, K, Mg, Mn, Na, NH_4, NO_3 (as nitrate), PO_4 (ortho-P as P in solution), SO_4 in mg/l; As, Ba, Cd, Cr, Cu, Ni, Pb, Sr, Zn in µg/l. From the original data Se was omitted due to a large absence of values in considerable parts of the dataset – i.e. not available (NA) or because they had more than 25% of the values below the detection limit. The data was checked on extreme outliers. As the outliers that were found were not considered to be extreme, e.g. 2000 mg/l for Cl, they were not removed. In fact, most outliers were found in the Cl and Na measurements, which points at salinity. Because the substances can vary considerably in value, the data was log transformed and scaled to make both the major and trace elements better visible. The log transformed data was then inserted into the *Mclust* function of the *Mclust* package of R. The Expectation Maximisation algorithm of this function is used to select the cluster models, spherical or elliptical, and determines to which cluster a sample belongs.

4.3.2 RFA of LMM data

Based on the clusters gained in the cluster analysis, a robust factor analysis (RFA) was carried out. The main aim of robust factor analysis (FA), is to explain the variation in a multivariate dataset by as few factors as possible and to detect hidden data structures (Reimann et al., 2011). It is similar to a principal component analysis (PCA), but the number of axes does not equal the number of variables. The axes are limited to a smaller number of factors that explain most of the data variability (Reimann et al., 2011). In this research, RFA is used to explain the variation within a selected cluster of observations, as based on the clusters from the LMM dataset, and to discover relations between several monitoring points within that cluster (Reimann et al., 2011, as cited in Pit et al., 2016). As the LMM data is anonymized and no exact locations are known, this will further help to gain more insight in the dataset by explaining the relation between monitoring points in a cluster.

The script for the RFA returns factor loadings and scores. The loadings indicate how each of the variables used in the analysis is associated with the factors. The scores of the RFA indicate what the magnitude of association of every variable is to the factor loading. The scores are scaled between -1 to +1. How far away from 0 a variable score is, indicates whether a variable is strongly associated or dissociated with a factor (Pit et al., 2016). A hypothetical example of the RFA on a given cluster could be a factor with high values for Na and Cl, suggesting a cluster with monitoring points related to salinity

4.3.3 *Confidence interval for the median and the 90th percentile*

After finishing the exploratory analysis on the LMM dataset, the next step was the comparison of the several study areas and their respective nutrient data. The prepared spreadsheets of the data sources were imported in R. From Helsel and Hirsch (2020), their method of computing the confidence interval for the median and the 90th percentile was used. As confidence interval, 95% was chosen as this is the most common range for statistical analyses. Comparing the median and the 90th percentile were considered a basic first step of the data analysis. These two typical values provide information on the central and upper reaches of the dataset. Using the confidence interval for both values can disclose if these values differ significantly among the various datasets. If for instance the confidence interval of the medians between to datasets do not overlap, it tells us that the central values of the dataset are significantly different. This method, however, is highly dependent on the number of samples in a dataset. Therefore, in some years and for some datasets with a small number of samples, the confidence interval of the median and 90th percentile is informative but should not be used to draw conclusions on significance. The minimum number of samples required for this research is 30, as this means that there are still 3 higher sample values beyond the 90th percentile. For the visualisation, the *StatDA* package and *ggpubr* package were used in RStudio to create cumulative probability plots, while the functions of Helsel and Hirsch (2020), were used to calculate the confidence intervals and their plots.

4.3.4 *Kruskal-Wallis test*

To compare and test the differences between the medians of every dataset for a given years the Kruskal-Wallis test was used. This is a non-parametric one-way analysis of variance. This test does require independent samples but does not require the data to be normally distributed. Kruskal-Wallis was preferred over the parametric ANOVA with geochemical data as: "[the] non-parametric test is more reliable because it is dependent on fewer assumptions, and thus more trust should be placed on its results than a parametric test" (Reimann et al., 2011). An example of what hypothesis is tested using Kruskal-Wallis is as follows:

> Null hypothesis: *The central values of the Ptot groups of 2018 are equal*
> Alternative hypothesis*: At least two groups of the Ptot dataset of 2018 have different central values*

The Kruskal-Wallis test thus tests if one of the datasets has a significantly different value for a variable. If the outcome of the test is larger than 0.05, the null hypothesis cannot be rejected, if the p-value of the test is smaller than 0.05, the null hypothesis can be rejected.

4.3.5 *Wilcoxon Rank sum test*

If the Kruskal-Wallis test returned significant values, a Wilcoxon rank sum test was used to test if the groups have equal medians. Where Kruskal-Wallis compares the complete dataset and does not indicate between which two groups the difference in median lies, a Wilcoxon rank sum test can compare the individual groups with each other. The Wilcoxon rank sum test is non-parametric. An example of what hypothesis is tested using Wilcoxon rank sum test:

> Null hypothesis: *the underlying distributions of variable Ptot in group 1 (LMM) and group 2 (WDOD) are equal in 2018*
>
> Alternative hypothesis: *the underlying distributions of the variable Ptot of group 1 (LMM) and group 2 (WDOD) are shifted in 2018 (i.e. they have different medians).*

As these datasets are not normally distributed, it is justified to use the Wilcoxon rank sum test.

4.3.6 *Examination of WFD GEP exceedance*

The last goal was to check whether the median and 90^{th} percentile of the individual datasets exceed the WFD standards for surface water in the respective study area. Every water board (in the Netherlands) or water management organization (Finland and Sweden) decides the Good Ecological Potential for surface water. This is based on norms for nutrients (Raadgever et al., 2009). Thus, the exceedance of the WFD standards is based on this GEP for individual study areas. Because the LMM data is anonymized and exact water bodies are not known, no examination of the exceedance can be made.

5 Results and Discussion

In this chapter the results from the data analysis will be presented and explained. Per section, the results are followed by their discussion. The sequence of the analyses is the same as in the methodology. First the cluster analysis and the subsequent factor analysis will be discussed, then the median and 90th percentiles of total-N and total-P, then the differences in total-N and P between the areas using Kruskal-Wallis and Wilcoxon rank sum tests, and lastly the exceedance of WFD standards will be examined for every area.

5.1 Cluster analysis on LMM measurements

The exploratory cluster analysis (CA) and robust factor analysis (RFA) were both carried out on the LMM data. The data was split in surface water and groundwater data, as these have different hydrological and geochemical properties. The surface water data had a total of 2050 measures, while groundwater had 606; the substances measured are mentioned in the methods chapter. As the only spatial information on the LMM data was the distinction between the northern and western peat area, this was used as main discriminating factor. The cluster analysis resulted in seven clusters for the surface water measurements and four clusters for the groundwater measurements.

5.1.1 Cluster analysis on surface water measurements of the LMM

Table 5.1 Northern and southern peat cluster division of the LMM 2008-2018 surface water data

		Cluster						
Area	n	1	2	3	4	5	6	7
Peat North	900	1	46	0	237	0	229	387
Peat West	1150	449	76	325	78	205	0	17

Regarding the division of clusters between the northern and western peat areas in Table 5.1, some interesting observations can be made. Cluster 2 is shared between both peat regions. Clusters 6 and 7, and to a lesser degree cluster 4, lean towards the northern peat area. Clusters 1, 3 and 5 lean towards the western peat area. Every cluster has different cluster Mclust means for each variable. Table 5.2 is an extensive collection of the median, standard deviation, maximum value and Mclust means. Higher or lower Mclust means for an element suggest high influence of this variable on the cluster. High or low was considered $\mu > 0.5$ or $\mu < -0.5$ respectively. Notable values for the Mclust means will be discussed here. Cluster 1 has negative means for Cl and Na, associated with saline seepage. Cluster 3 has only positive means for a large group of elements: As, Al, Cl, Cu, K, Mg, Na C, PO_4, SO_4, Sr and Zn. Cluster 4 shows almost the opposite with only negative means for As, Al, Cu, Fe, K, Mg, NO_3, DOC, Ni, Pb, PO_4, SO_4 and Zn. The elements in both clusters 3 and 4 are associated with Al/Fe-oxides, heavy metals and elements found in peatlands where peat mineralisation or agricultural runoff occurs (Vermaat et al., 2012); cluster 3 also has positive means for Na and Cl, suggesting saline seepage. Cluster 5 has positive means for As, K, PO_4 and Sr, while negative means for Al, Cr, Fe, Na, Cl, Ni and Zn;

both positive and negative means are associated with saline seepage whereas the negative means are also associated with Al/Fe-oxides. Cluster 6 has positive means for Fe and Mn, associated with Fe/Mn oxides, negative means for As, Al and SO_4, associated with Al-oxides for Al and either deposition or peat mineralisation for SO_4. Cluster 7 has positive means for Cr, Fe, NO_3 and Zn, associated with oxic conditions and Fe-oxides and negative means for Ba, Ca and Sr, associated with carbonates.

Table 5.2 Median, standard deviation, maximum values with Ca, Cl, DOC, Fe, K, Mg, Mn, Na, NH_4, NO_3 (as nitrate), PO_4 (ortho-P as P in solution), SO_4 in mg/l; Al, As, Ba, Cd, Cr, Cu, Ni, Pb, Sr, Zn in µg/l, for the analysed variables in every cluster for the surface water data of the LMM years 2008-2018.

	Cluster 1			Cluster 2			Cluster 3			Cluster 4			Cluster 5			Cluster 6			Cluster 7		
	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max
As	1.77	0.51	4.10	1.90	1.58	10.70	2.70	0.74	5.92	0.90	0.57	3.50	2.30	0.42	3.60	1.10	0.38	3.43	1.32	0.46	3.51
Al	70.00	47.61	390.00	50.00	219.62	1130.00	140.00	132.06	710.00	10.00	31.04	220.00	30.00	15.50	90.00	31.00	48.81	339.00	222.4	256.07	1340.00
Ba	65.00	18.84	128.00	53.00	24.82	126.20	52.00	26.55	173.00	54.29	20.19	122.00	54.00	10.41	99.00	49.90	12.68	87.68	27.10	11.35	80.80
Ca	72.90	25.31	162.54	74.31	30.42	180.72	77.92	24.90	189.48	75.92	25.64	158.97	73.95	11.31	116.64	68.60	17.00	128.70	40.80	22.89	171.51
Cl	35.48	19.81	194.81	46.59	130.75	687.54	199.67	132.00	923.06	56.62	28.00	243.14	40.66	15.65	112.73	56.33	20.63	130.04	57.06	44.57	343.25
Cr	1.00	0.34	2.30	0.60	1.07	6.00	1.40	0.57	3.30	0.70	0.36	1.60	0.50	0.16	1.00	1.00	0.34	2.63	1.57	0.70	4.08
Cu	2.20	1.91	13.50	1.50	48.24	533.80	2.90	2.05	12.46	0.60	1.21	7.93	1.13	0.79	4.60	1.50	1.87	10.19	2.20	1.65	8.70
Fe	0.93	1.36	8.29	0.63	4.28	38.46	1.55	1.12	6.83	0.38	1.40	12.58	0.15	0.08	0.43	1.84	1.10	6.63	1.68	1.53	13.40
K	8.20	3.07	31.90	10.25	18.46	120.33	12.59	6.93	48.39	6.60	3.85	27.24	13.00	2.32	23.30	7.40	3.21	20.90	7.81	5.26	40.20
Mg	11.14	3.36	31.75	13.00	13.55	73.14	29.62	12.51	73.38	10.60	6.53	34.85	10.81	1.49	15.49	12.24	4.31	25.97	16.14	8.66	77.04
Mn	0.30	0.27	1.63	0.31	0.36	1.50	0.46	0.19	1.22	0.41	0.36	2.04	0.10	0.09	0.57	0.67	0.41	2.02	0.35	0.21	1.39
Na	22.00	10.06	88.30	29.35	79.85	399.60	121.42	74.75	495.50	33.89	23.36	170.38	26.50	8.72	66.67	43.70	18.52	103.40	41.80	29.84	222.66
NH_4	1.93	2.35	12.52	1.33	3.72	32.34	2.46	1.75	10.77	1.27	2.24	11.74	1.11	1.55	7.23	2.46	1.11	6.08	2.28	2.12	16.10
NO_3	2.19	2.36	17.88	0.68	12.73	106.88	1.99	2.70	21.78	0.41	4.63	55.64	2.92	2.92	15.99	1.29	1.59	22.87	3.92	10.21	76.19
Ni	5.20	1.81	12.10	3.65	5.51	33.00	6.10	2.74	19.41	1.50	1.54	11.55	2.10	0.48	3.75	2.70	0.29	10.19	4.31	3.49	18.82
Pb	0.56	0.52	4.30	0.40	1.10	7.60	1.40	1.20	6.80	0.06	0.26	1.70	0.30	0.17	1.00	0.24	0.06	1.81	0.60	0.55	3.10
PO_4	0.08	0.08	0.44	0.08	0.70	6.82	0.24	0.31	2.85	0.01	0.06	0.41	0.49	0.25	1.13	0.06	0.08	0.31	0.06	0.09	0.72
DOC	40.80	8.38	71.90	41.22	39.79	408.87	57.40	20.96	192.90	26.20	12.53	58.20	35.83	7.09	50.40	33.78	3.20	54.80	48.32	15.92	104.30
SO_4	75.48	62.88	395.37	70.61	87.55	480.77	97.56	56.48	371.58	30.82	41.83	287.72	54.77	22.23	150.95	28.56	30.98	242.84	78.72	74.88	602.33
Sr	390.00	124.48	851.20	391.45	183.84	1011.00	452.20	132.80	833.00	319.00	129.80	817.00	421.00	63.82	626.00	282.30	78.72	559.30	216.4	118.58	989.20
Zn	4.00	3.78	26.62	4.47	28.36	160.00	8.00	8.40	55.00	2.00	3.26	42.26	2.36	1.91	12.00	4.00	3.50	21.20	11.00	10.91	72.00

Table 5.3 Mclust means for surface water cluster analysis. High and low Mclust mean values are bold.

	Cluster 1	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**	**Cluster 6**	**Cluster 7**
As	0.27	0.11	**1.01**	**-1.13**	**0.73**	**-0.60**	-0.29
Al	0.03	-0.04	**0.64**	**-1.11**	**-0.75**	**-0.52**	0.01
Ba	**0.69**	-0.14	0.05	0.04	0.3	0.02	**-0.96**
Ca	0.29	-0.03	0.36	0.35	0.3	-0.04	**-1**
Cl	**-0.7**	0.02	**1.55**	-0.14	-0.45	-0.14	-0.07
Cr	0.13	**-1.83**	0.44	-0.33	**-0.56**	0.17	**0.5**
Cu	0.33	0.03	**0.6**	**-1.02**	-0.43	-0.09	0.21
Fe	0.12	-0.34	0.42	**-0.66**	**-1.5**	**0.6**	**0.57**
K	-0.12	0.27	**0.66**	**-0.71**	**0.68**	-0.28	-0.12
Mg	-0.41	-0.03	**1.3**	**-0.53**	-0.47	-0.36	0.27
Mn	-0.12	-0.24	0.32	0.18	**-1.31**	**0.85**	-0.01
Na	**-0.77**	-0.16	**1.45**	-0.13	-0.48	0.04	0.05
NH_4	0.08	-0.4	0.27	-0.42	-0.43	0.37	0.16
NO_3	0.21	**-1.03**	0.19	**-1**	0.34	0.03	**0.51**
Ni	**0.53**	0.01	0.77	**-1.11**	**-0.8**	-0.37	0.26
Pb	0.31	-0.16	**0.83**	**-1.48**	-0.06	-0.16	0.31
PO_4	0.01	-0.04	**0.66**	**-1.12**	**1.08**	-0.07	-0.17
DOC	0.1	0.05	**0.78**	**-1.14**	-0.29	-0.31	0.45
SO_4	0.37	0.31	**0.59**	**-0.97**	-0.05	**-0.8**	0.34
Sr	0.35	-0.01	**0.6**	-0.14	**0.52**	-0.4	**-0.79**
Zn	-0.11	-0.01	**0.55**	**-0.87**	**-0.62**	-0.18	**0.78**

Table 5.4 Median, standard deviation, maximum values with Ca, Cl, DOC, Fe, K, Mg, Mn, Na, NH_4, NO_3 (as nitrate), PO_4 (ortho-P as P in solution), SO_4 in mg/l; Al,As, Ba, Cd, Cr, Cu, Ni, Pb, Sr, Zn in µg/l, for the analysed variables in every cluster for the groundwater data of the LMM years 2008-2018.

	Cluster 1			Cluster 2			Cluster 3			Cluster 4		
	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max	Median	Sd	Max
As	3.50	3.78	23.2	2.16	1.80	13.1	2.80	1.02	7.4	2.70	1.27	7.3
Al	398.80	427.60	2550	230.00	626.27	6240	167.65	162.02	860	780.00	678.14	4450
Ba	93.00	31.63	184.0	43.27	38.48	304.0	128.50	29.39	222.1	44.40	15.69	85.8
Ca	114.90	46.64	268.2	67.49	53.94	315.0	134.70	35.64	234.4	50.09	21.00	134.5
Cl	35.23	37.69	202.2	45.91	130.71	872.2	31.42	11.80	76.9	27.30	9.20	47.1
Cr	2.10	1.48	7.8	1.54	1.55	15.9	1.20	0.66	3.8	2.22	0.82	5.7
Cu	2.60	4.04	20.6	1.20	2.59	11.7	0.89	2.71	14.7	3.30	3.53	22.2
Fe	7.87	5.78	27.6	4.44	8.72	72.0	2.78	2.35	14.2	3.91	3.97	20.8
K	4.90	2.98	18.2	7.10	13.24	114.1	5.60	4.45	27.4	7.10	3.84	21.6
Mg	22.76	10.83	69.0	18.90	26.14	125.3	16.21	5.19	33.9	21.23	7.33	34.3
Mn	1.09	0.44	2.5	0.80	0.71	3.8	0.83	0.29	1.7	0.67	0.37	1.9
Na	25.4	22.5	118.7	32.7	97.1	667.2	22.1	7.96	57.1	19.7	8.5	52.2
NH_4	4.47	2.73	18.7	5.50	3.90	27.4	8.18	6.34	34.8	2.77	1.57	9.0
NO_3	0.18	7.75	70.2	0.34	12.13	99.2	0.10	2.46	18.8	3.56	24.12	157.0
Ni	12.20	9.90	54.3	3.34	10.71	69.0	5.95	4.32	19.9	5.40	3.73	17.6
Pb	0.50	2.62	18.9	0.20	0.84	5.3	0.20	0.92	5.6	0.50	1.13	7.4
PO_4	0.26	0.19	1.1	0.17	0.56	3.9	0.53	0.34	2.4	0.08	0.15	1.2
DOC	93.01	34.72	221.2	65.05	24.01	140.3	72.90	17.51	138.0	84.50	25.47	194.6
SO_4	208.54	134.76	727.5	90.38	179.42	937.4	168.81	78.58	414.8	125.80	56.01	328.2
Sr	678.0	234.7	1366	319.3	298.8	1631	738.5	205.3	1412	299.9	84.4	696
Zn	22.00	32.32	214.2	15.19	57.38	500.0	7.00	11.69	63.2	29.00	44.19	266.8

Table 5.5 Mclust means for groundater cluster analysis. High and low Mclust mean values are bold.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
As	**0.65**	-0.41	0.01	-0.03
Al	0.30	-0.16	**-0.61**	**0.88**
Ba	0.41	**-0.63**	**0.96**	**-0.81**
Ca	0.46	-0.45	**0.69**	**-0.77**
Cl	0.08	**0.50**	-0.25	**-0.60**
Cr	**0.53**	-0.19	**-0.51**	**0.51**
Cu	0.43	-0.25	-0.37	**0.52**
Fe	**0.58**	0.03	-0.48	0.01
K	-0.41	0.34	-0.18	0.13
Mg	0.33	0.15	-0.32	-0.15
Mn	0.48	-0.09	-0.07	-0.28
Na	0.02	**0.50**	-0.30	-0.47
NH_4	-0.19	0.10	**0.66**	**-0.97**
NO_3	-0.17	-0.01	-0.39	**0.81**
Ni	**0.74**	-0.43	-0.02	-0.05
Pb	0.47	-0.16	-0.42	0.39
PO_4	0.11	-0.12	**0.72**	**-1.02**
DOC	**0.70**	**-0.52**	-0.12	0.31
SO_4	0.41	**-0.53**	0.30	0.03
Sr	0.43	**-0.51**	**0.73**	**-0.72**
Zn	0.32	-0.01	**-0.60**	**0.58**

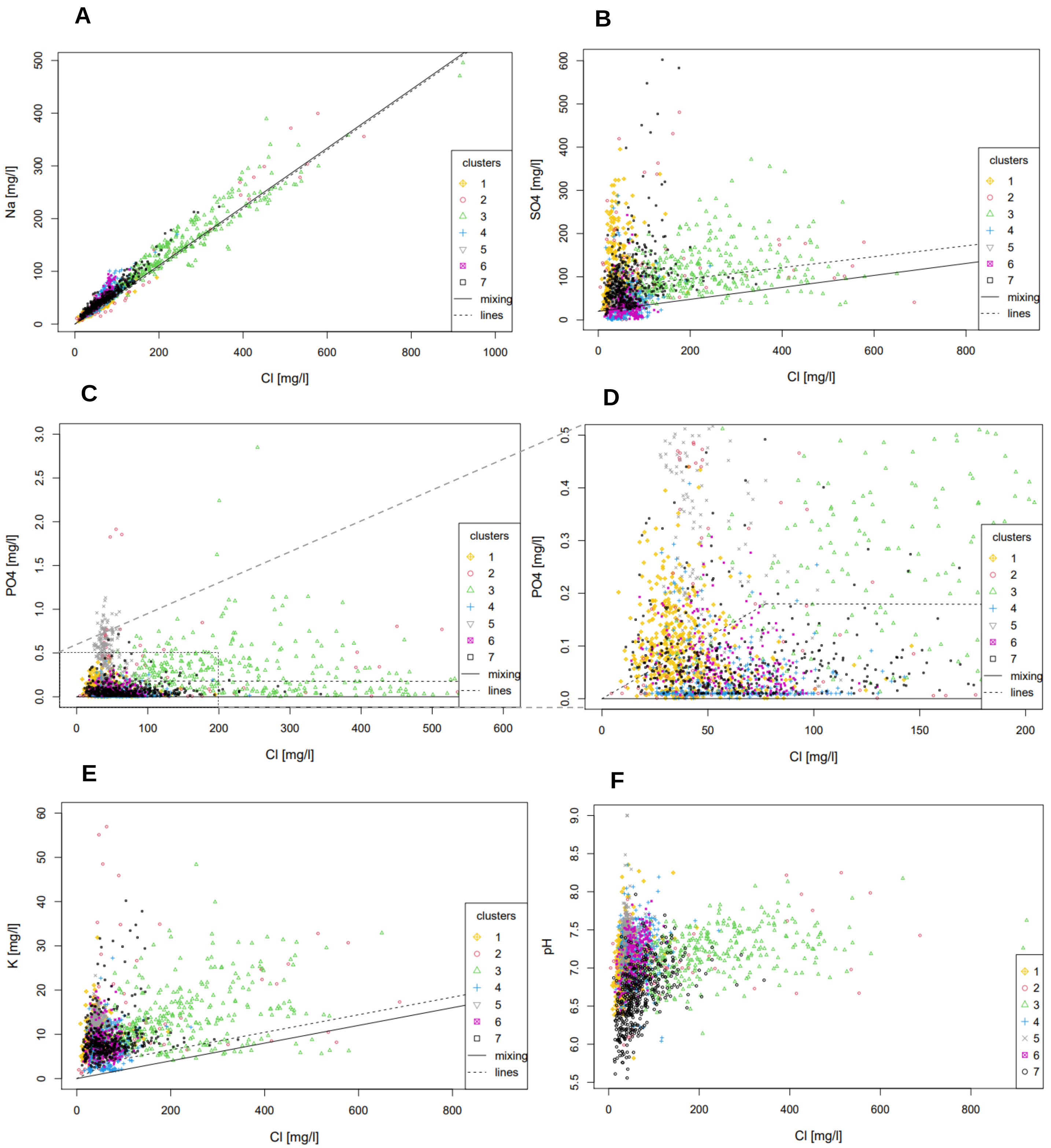


Figure 5.1 Scatter plots of the LMM surface water data with the clusters visible. Plot D zooms in on a section of plot C to provide more detail. The dotted line indicates the mixing line for specified substances from rainwater to Lek river water and from Lek river water to sea water; the straight line indicates mixing line from rain water to sea water.

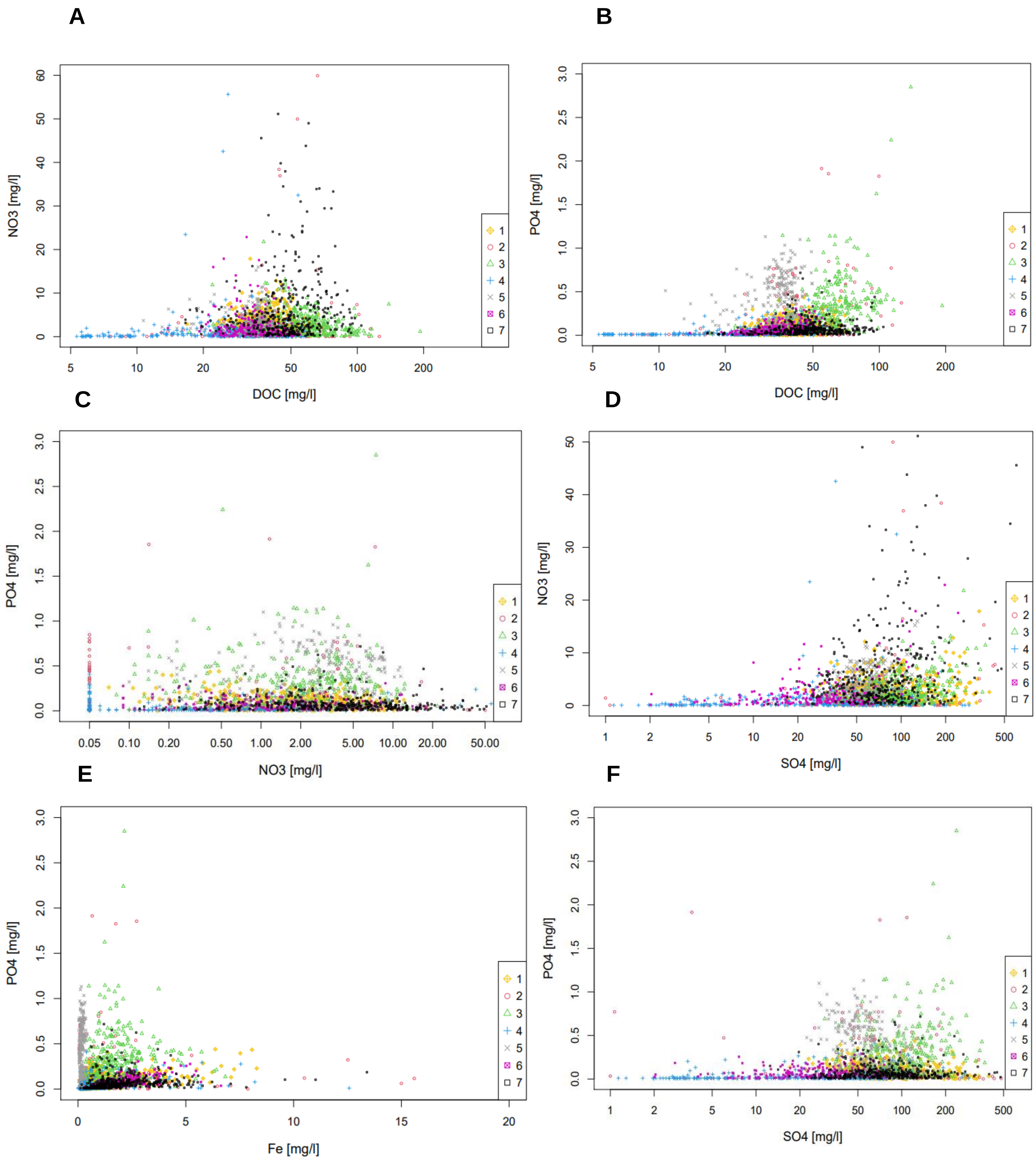


Figure 5.2 Scatter plots of the LMM surface water data with the clusters visible. Note that some x-axes have a log scale instead of a linear one.

Scatter plots of the measurements used for the cluster analysis in with the appointed clusters visible, provide a more detailed insight in the geochemical characteristics of the clusters. Figures 5.1A – 5.2F are the visualisations of several elements that may show coupled behaviour; a brief interpretation is given per plot. In Figures 5.1.A to 5.1F chloride concentrations are plotted against Na, SO_4, PO_4, K and pH. The plots contain a mixing line for rainwater and seawater and rainwater with Lek river water for the given substances (concentrations from Appelo, 1994; RIWA-Rijn, 2020). The water from the Lek River (a branch of the Rhine River) was chosen as this is a main inlet for the western peat region.

Plot 5.1A shows that most of the surface water samples remain under the 150 mg/l chloride threshold of freshwater. Only cluster 3 clearly contains brackish samples (150 – 1000 mg/l Cl). Chloride plotted against SO_4 in Figure 5.1B reveals that clusters 4 and 6 have both low values for chloride and sulphate and cluster 5 is slightly above the seawater mixing line, suggesting that there is no saline groundwater seepage and that atmospheric deposition or peat mineralisation could be the source of the SO_4. Note that both clusters 4 and 6 are mainly found in the northern peat area. Sulphate is increasing from clusters 1 via 2 to 7 while Cl remains relatively low, this does suggest peat mineralisation if additional SO_4 originates from oxidation of pyrite and organic sulphur (Vermaat, 2012). Clusters 1 and 2 are mainly found in the western peat region, while cluster 7 in the northern peat region. Cluster 3 contains shows higher values for both chloride and sulphate, which could be due to seepage from saline groundwater.

The plot for phosphate versus chloride in Figure 5.1C, and more detailed in Figure 5.1D, reveals high PO_4 values for clusters 1, 3 and 5. Cluster 5 does not have high chloride or SO_4 values, thus suggesting this is due to agricultural runoff. The K-Cl plot in 5.1E suggests roughly the same as Figure 5.1B and 5.1C; since all clusters apart from cluster 3 have chloride values below 150 mg/l, K is probably not originating from saline seepage. Clusters 4, 6 and 7 show similar values for K, while cluster 5, and to a lesser degree cluster 1, contain slightly higher concentrations.

The plot in Figure 5.1F with pH versus chloride reveals that cluster 7 is slightly more acidic than the other clusters, whereas clusters 5, 4 and 6 are slightly more alkaline. The other clusters remain mostly between pH 7.0 and 7.5. As the pH does not differ much it is hard to draw conclusions based in this data.

Figure 5.2A and 5.2B contain plots of NO_3 and PO_4 against DOC. Cluster 4 is in both plots relatively low, Clusters 3 and 5 show relatively high PO_4 concentrations with DOC values similar to clusters 2, 4, 6 and 7. NO_3 is somewhat higher in clusters 1 and 7, albeit hard to see as most observations seem quite similar. DOC is highest in clusters 1, 3 and 7; high DOC is associated with peat mineralisation, although this process is very complex and related to oxic/anoxic conditions and salinity (Van Gerven et al., 2011; Brouns & Verhoeven, 2013). NO_3 and PO_4 are highest in clusters 1, 3 and 5 (Figure 5.2C), all in the western peat area, while cluster 7 has low PO_4 and high NO_3. The high NO_3 values in cluster 7 could be due to the relatively thin peat layer in the northern peat area or due to a low groundwater Table; peat with a high groundwater Table is known to quickly denitrify nitrogen in solution. Both high NO_3 and PO_4 are associated with peat mineralisation. The highest SO_4 and NO_3 - concentrations in Figure 5.2D can be seen in clusters 1, 3, 5 and 7, of which only 7 is mainly northern peatland.

PO_4 concentrations are mainly dependent on the availability of Fe in the water. In aerobic conditions Fe(III)-oxide adsorbs PO_4, in anaerobic conditions this occurs vice versa. However, in water with higher SO_4 concentrations, S^{2-} can bind Fe(II)-ions and hence there is less Fe available to bind PO_4. This is visible in Figures 5.2E and 5.2F.

Concluding the CA of surface water data: peat mineralisation seems less prevalent in clusters 4 and 6, and more prevalent in 1, 3, 5 and 7. Higher chloride concentrations are prevalent in cluster 3, while some measurements in clusters 2 and 7 suggest saline seepage.

5.1.2 *Cluster analysis on groundwater measurements of the LMM*

The division of the groundwater analysis clusters between the northern and western peat areas is presented in Table 5.6. Like the surface water data, the groundwater clusters are split according to the northern and western peat region. Clusters 2 and 4 lean towards the northern peat area; clusters 1 and 3 towards the western peat area.

Table 5.3 summarizes the groundwater data CA. Cluster 1 has positive means for As, Cr, Fe, Ni and DOC, these elements are associated with Fe-oxides. Cluster 2 has positive means for Cl and Na, associated with saline seepage; negative means for Ba, DOC, SO_4 and Sr, associated with carbonates and peat mineralisation. Cluster 3 has positive means for Ba, Ca, NH_4, PO_4 and Sr, associated with carbonates and peat mineralisation; negative means for Al, Cr and Zn, associated with Fe and Al-oxides. Cluster 4 has positive means for Al, Ba, Cr, Cu, NO_3 and Zn, associated with Al, and oxic conditions; negative means for Ca, Cl, NH_4, PO_4 and Sr, associated with carbonates and also peat mineralisation and/or agricultural runoff. The means show similarities to those of the surface water cluster analysis. Clusters 2, 3 and 4 are associated with carbonates and with peat mineralisation. Saline seepage seems to be less of a factor in the groundwater means

Table 5.6 Northern and southern peat cluster division of the LMM 2008-2018 groundwater data

		Cluster			
Area	n	1	2	3	4
Peat North	270	20	145	0	105
Peat West	336	111	53	168	4

As with the surface water measurements, several elements of the LMM data were plotted against each other with the clusters visible. These plots are shown in Figures 5.3A 5.4D

Plots 5.3A – 5.3.F with chloride on the x-axis and the mixing lines of seawater and of the Lek River visible show similarities with the surface water plots. Figure 5.3.A is similar to 5.1.A, with only one cluster with brackish chloride concentrations. Clusters 1, 3 and 4 contain the lowest chloride concentrations and although cluster 2 leans towards the northern peat area, the measurements containing the highest chloride concentrations originate almost all from the western peat area. The SO_4, PO_4 and K plots in Figure 5.3D – 5.3E show that these values increase from cluster 1 via 3 to 4, while Cl remains below the 150 mg/l threshold for freshwater; cluster 3 shows a larger variance over the plots. This suggests that the source of SO_4, PO_4 and K is not saline seepage but from peat mineralisation and agricultural runoff in clusters 1, 3 and 4. The lowest PO_4 values can be observed in the norther peat region, in clusters 2 and 4.

Figures 5.4A and 5.4B contain plots of NO_3 and PO_4 against DOC. DOC concentrations are not clearly higher or lower in one cluster, the highest observed concentrations are in clusters 4 and 1. Absolute values of DOC are rather high for groundwater, this could be associated with peat mineralisation.

In Figure 5.4C the points seem to be quite evenly disitributed over all clusters, if the points on the detection limit are ignored. This is different in Figure 5.4D, where

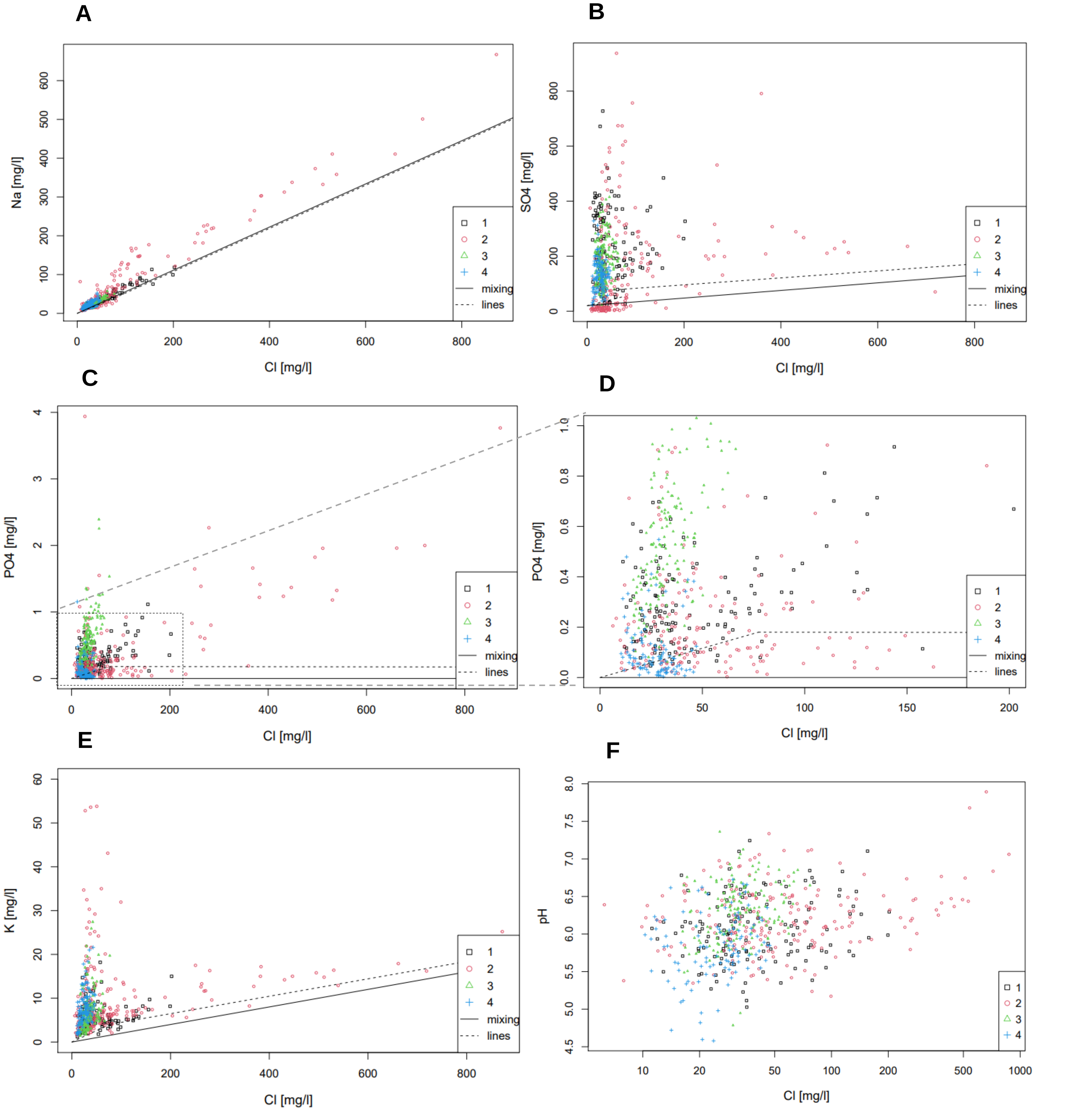


Figure 5.3 Scatter plots of the LMM surface water data with the clusters visible. Plot D zooms in on plot C to provide more detail. The dotted line indicates the mixing line for the substances from rainwater to Lek river water and from Lek river water to sea water; the straight line indicates mixing line from rain water to sea water.

cluster 4 shows both some higher values for NO_3 and SO_4, this could be related to agricultural inputs as well as a lower groundwater table, which enhances peat mineralisation and decreases the denitrification capacity of the peat soil.

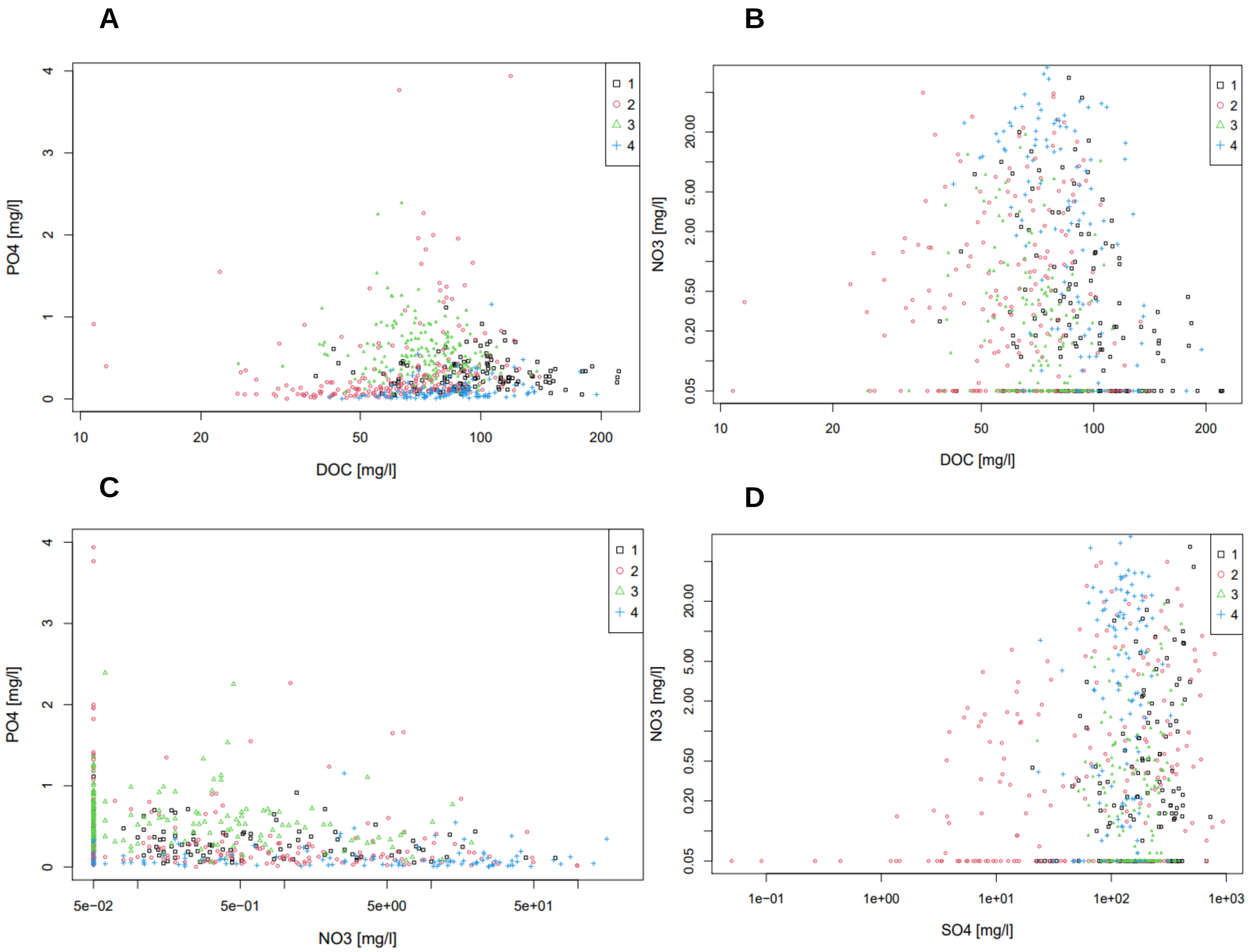


Figure 5.4 Scatter plots of the LMM ground water data with the clusters visible. Note that some axes have a log scale.

5.1.3 Evaluation of the cluster analysis

The results of the cluster analysis should be used as an exploratory data analysis. The purpose of the cluster analysis on the LMM data for 2008-2018 was to gain more insight in the anonymized data of the LMM monitoring points. The clustering is a welcome tool to discern the variance within the LMM data. The cluster analysis on both the surface and groundwater data of the LMM suggests that considering nutrients the monitored areas are associated with agricultural runoff and peat mineralisation. As the exact location of the sampling points is not known, it is hard to compare the cluster analysis with existing literature on specific peatland study areas in the Netherlands. However, it is possible to compare the outcome of the cluster analysis with studies on the western and northern peat region.

The higher chloride concentrations in cluster 3 of the western peatland region agree with the existing literature (De Louw, 2013). Saline seepage occurs mostly in deep clay polders, brackish surface water that is pumped from deep polders can end up in adjacent peat polders, another source of brackish water is inlet water from rivers. Saline seepage in the northern Netherlands is more situated in the clay region as well.

The higher SO_4 concentrations in the western peat region could have different reasons. SO_4 is associated with peat mineralisation due to oxidation of Fe sulphide as pyrite or organic S but also with former influence of the sea on groundwater and inlet of water from outside the peat area during dry periods. Vermaat et al. (2012) suggest that most of the SO_4 in peatlands has its source in the low groundwater table and subsequent peat oxidation. NH_4, NO_3 and PO_4 are associated with peat mineralisation as well but could also indicate agricultural leaching of nutrients. The relation between these elements is very complex and dependent on more factors than just nutrient and sulphate availability, the pH, aerobic/anaerobic conditions, organic matter and other elements as Al and $CaCO_3$.

A research in the Krimpenerwaard peatland found that internal eutrophication plays a large role in the nutrient loading of a peat polder (Van Gerven et al., 2011). 90% of the N in surface water is from the land system, of which manure and peat mineralisation both contribute 48% of this land system N to the surface water load. For P in surface water, 90% originated from the land system. Here the manure accounts for 60% of the P and peat mineralisation for 40%. Van Gerven et al. (2011) state that the Krimpenerwaard is comparable to other Dutch peat polders, both in the western and northern peat region.

The cluster analysis would have provided more useful information for this research if the naturally conserved peatlands had also been analysed using CA. However, the nature of the data for the naturally conserved peatlands made CA too complex in the time frame of this research. More knowledge on data tidying and transformation are strongly recommended to make further use of this exploratory type of data analysis. The clusters of the LMM data could then be compared to clusters of the naturally conserved peatland data and hence identify similarities or dissimilarities between the land use types in peatlands.

5.2 Robust factor analysis on LMM measurements

The results of the Robust Factor Analysis (RFA) help interpret the variance within each cluster from the CA. As with CA, the data is split in a surface water part and a groundwater part. The results of the RFA help with identifying the geochemical characteristics of every cluster and hence, when compared to the cluster analysis tell something about the distinction between the northern and western peatlands in the LMM.

5.2.1 Robust factor analysis of surface water measurements of the LMM

The results of the RFA for surface water are presented in Table 5.5. All clusters except cluster 5 show various degrees of explained variance by salinity with positive significant loadings for Na and Cl.

Elements related to peat mineralisation or agricultural land use also occur in every cluster. The clusters where these elements are represented with the highest loadings are 1, 2, 3, and 5. This agrees with the cluster analysis and the plots in the section above. Cluster 4 has a myriad of elements in the first factor and is therefore less evident in its explained variance. All clusters show significant positive values for elements associated with carbonate minerals. It is most likely that the carbonates are from dissolved lime, a legacy of floods in the peat region. (Van der Veer, 2006)

Fe-oxides are associated with the mobilization of PO_4 as PO_4 may be selectively bound by Fe oxides in surface water (Van der Grift, 2017), and they both have significant positive loadings in clusters 2, 3 and 5. Interestingly, but less relevant for this research, many clusters show significant positive loadings for Al-, Fe- or Mn-oxides with heavy metals. It is an open question where these heavy metals originate from but it was not investigated how the concentrations observed compare to environmental standards. It is thus not ascertained whether these concentrations refer to anthropogenic contamination or can be assumed as natural.

5.2.2 Robust factor analysis on groundwater measurements of the LMM

The RFA results for groundwater are visible in Table 5.6. Salinity seems less prevalent in the RFA of the groundwater LMM data; only cluster 2 has explained variance for Na and Cl in the first factor. Carbonate minerals, peat mineralisation and Al/Fe-oxides are more frequent among the clusters.

The RFA for the groundwater data shows more similarities with the groundwater cluster analysis than the surface water CA Agricultural land use and peat mineralisation have higher explained variance in clusters 1, 2 and 3; cluster 4 does not have peat mineralisation related elements in its explained variance. Just as the surface water data in the CA, species associated with peat mineralisation are present in in the western region’s clusters. In groundwater, Al/Fe/Mn in the groundwater solution, where Al is non-soluble in neutral pH. Heavy metals occur in many clusters.

5.2.3 Evaluation of the robust factor analysis

As there are no large differences between the explained variances in the RFA for surface water, with 30% being the highest explained variance for a single factor, there is not a very clear distinction between clusters. Species associated with salinity (Na and Cl) are present in clusters all clusters except 5, species associated with nutrients are present in all clusters, the same holds for carbonates and Al/Fe-oxides. Therefore, the interpretations from the cluster analysis and the plots in Figures 5.1 – 5.4 provide a better method for the exploratory analysis of the LMM data.

Like for the RFA of surface water, no clear differences among the factors distinguished can be recognised among the several clusters, and the factors in all the clusters show no striking hierarchy. For the individual clusters the RFA provides an interpretation in which elements explain most of the variance, but for a comparison among the clusters the differences of explained variance and interpretation of substances are not notable enough. Thus, the CA seems more suitable for the exploratory analysis of the groundwater data as well.

Table 5.7 Results of the robust factor analysis of the surface water LMM data 2008-2018 for the seven factors with the interpretation of the first four factors representing the variables with a significant positive loading (r larger than 0.7 and 0.5) as well as the variables with a significant negative loading (r lower than -0.7 and -0.5).

Cluster	Factor	% of explained variance	Significant positive loadings		Significant negative loadings		Interpretation
Cl_1	1	26%	r>0.7	Ba, Ca, Mg, SO_4, Sr	r>-0.7		Positive: Salinity, carbonate minerals, peat mineralisation
			r>0.5	Cl, Na, Mn	r>-0.5	Cu	Negative:
	2	20%	r>0.7	Al, Cr, Ni	r>-0.7		Positive: Al-oxides
			r>0.5	Cu, Pb, Zn	r>-0.5	Cl, Na	Negative: Salinity
	3	13%	r>0.7	Fe, NH_4	r>-0.7		Positive: Nutrients
			r>0.5	Mn	r>-0.5		Negative:
	4	11%	r>0.7	As	r>-0.7		Positive:
			r>0.5	DOC	r>-0.5		Negative:
Cl_2	1	27%	r>0.7	Al, Fe, Mn, Ni, Zn	r>-0.7		Positive: Al/Fe-oxides, peat mineralisation
			r>0.5	Cu, Pb, SO_4	r>-0.5		Negative:
	2	17%	r>0.7	Cl, Mg, Na	r>-0.7		Positive: Salinity
			r>0.5		r>-0.5	NO_3	Negative: Oxic conditions
	3	14%	r>0.7	Ca, Sr	r>-0.7		Positive: Carbonate minerals
			r>0.5	Ba, SO_4	r>-0.5		Negative:
	4	13%	r>0.7	As, PO_4	r>-0.7		Positive: Nutrients
			r>0.5	K, DOC	r>-0.5		Negative:
Cl_3	1	30%	r>0.7	Cl, Mg, Na, Mn, SO_4, Sr	r>-0.7		Positive: Salinity, carbonate minerals, peat mineralisation
			r>0.5	Ca	r>-0.5	Al, Cu, Pb	Negative:
	2	21%	r>0.7	Al, Cr, Fe, Ni	r>-0.7		Positive: Al/Fe/Mn-oxides
			r>0.5	Mn, DOC	r>-0.5		Negative:
	3	16%	r>0.7	As, NH_4	r>-0.7	Zn	Positive: Peat mineralisation, nutrients
			r>0.5	PO_4, C	r>-0.5	Cu, NO_3	Negative: Oxic conditions
	4	13%	r>0.7	Ba, Ca	r>-0.7		Positive: Carbonate minerals
			r>0.5		r>-0.5	PO_4	Negative:
Cl_4	1	35%	r>0.7	Ba, Ca, Cl, Cr, Mg, Na, NH_4, DOC, SO_4, Sr	r>-0.7		Positive: Salinity, carbonate minerals, peat mineralisation, nutrients
			r>0.5	Mn	r>-0.5		Negative:
	2	25%	r>0.7	Al, Cu, K, Ni, Pb, PO_4	r>-0.7		Positive: Al-oxides, heavy metals, feldspar
			r>0.5	As, Zn	r>-0.5		Negative:
	3	8%	r>0.7		r>-0.7		Positive: Saline seepage
			r>0.5	As, K, Na, Cl	r>-0.5		Negative:
	4	6%	r>0.7	Fe	r>-0.7		Positive:
			r>0.5		r>-0.5		Negative:
Cl_5	1	27%	r>0.7	Al, Cu, Fe, Pb	r>-0.7	Cl, Na	Positive: Al/Fe-oxides, heavy metals
			r>0.5	Cr, Ni	r>-0.5		Negative: Salinity
	2	23%	r>0.7	Ba, Ca, Mg, SO_4, Sr	r>-0.7		Positive: Carbonate minerals, peat mineralisation
			r>0.5	C	r>-0.5		Negative
	3	12%	r>0.7	Mn, NH_4, PO_4	r>-0.7		Positive: Peat mineralisation, nutrients
			r>0.5		r>-0.5		Negative:
	4	9%	r>0.7		r>-0.7	As	Positive:
			r>0.5	Zn	r>-0.5		Negative:
Cl_6	1	26%	r>0.7	As, Al, Cr, Ni, Pb, PO_4, DOC	r>-0.7		Positive: Heavy metals, Al-oxides, nutrients
			r>0.5	Cu	r>-0.5		Negative:
	2	24%	r>0.7	Ba, Ca, Mg, Mn, SO_4, Sr	r>-0.7		Positive: Carbonate minerals, peat mineralisation
			r>0.5		r>-0.5		Negative:
	3	16%	r>0.7	Cl, Na	r>-0.7		Positive: Salinity
			r>0.5		r>-0.5	Cu, Zn	Negative:
	4	9%	r>0.7	NO_3	r>-0.7		Positive:
			r>0.5		r>-0.5	Fe	Negative:
Cl_7	1	24%	r>0.7	Al, As, Cr, Cu, Ni, Pb, DOC	r>-0.7		Positive: Al-oxides
			r>0.5	Zn	r>-0.5	Ca	Negative:
	2	20%	r>0.7	Ca, Mg, Mn, SO_4, Sr	r>-0.7		Positive: Carbonate minerals, peat mineralisation
			r>0.5		r>-0.5		Negative:
	3	15%	r>0.7	Na, Cl	r>-0.7		Positive: Salinity
			r>0.5		r>-0.5	Al, DOC	Negative:
	4	14%	r>0.7	Fe	r>-0.7		Positive: Fe-oxides
			r>0.5	Ba, NH_4	r>-0.5	Cu, NO_3	Negative: Oxic conditions

Table 5.8 Results of the robust factor analysis of the groundwater LMM data 2008-2018 for the seven factors with the interpretation of the first four factors representing the variables with a significant positive loading (r larger than 0.7 and 0.5) as well as the variables with a significant negative loading (r lower than -0.7 and -0.5).

Cluster	Factor	% of explained variance	Significant positive loadings		Significant negative loadings		Interpretation
Cl_1	1	23%	r>0.7	Ba, Ca, Mn, SO_4, Sr	r<-0.7		Positive: Carbonate minerals
			r>0.5		r<-0.5		Negative:
	2	21%	r>0.7	Cu, Ni, Zn, Pb	r<-0.7		Positive: Al, heavy metals
			r>0.5	Al, Cr	r<-0.5	NH_4, PO_4	Negative Nutrients
	3	18%	r>0.7	As, DOC	r<-0.7		Positive:
			r>0.5	Al	r<-0.5	NO_3	Negative: Oxic conditions
	4	17%	r>0.7	Cl, Na, Mg	r<-0.7		Positive: Salinity
			r>0.5	PO4	r<-0.5		Negative:
Cl_2	1	29%	r>0.7	Na, Cl, K, Mg, NH4, PO4	r<-0.7		Positive: Saline seepage, nutrients
			r>0.5	Sr, SO4, DOC	r<-0.5		Negative:
	2	20%	r>0.7	Ca, Fe, Mn, Sr	r<-0.7		Positive: Carbonate minerals
			r>0.5	Zn	r<-0.5		Negative:
	3	16%	r>0.7	Al, Cr	r<-0.7		Positive: Al, heavy metals
			r>0.5	Ni, Pb, Zn	r<-0.5		Negative:
	4	10%	r>0.7		r<-0.7		Positive: Heavy metals
			r>0.5	Cu, Pb, Ni	r<-0.5		Negative:
Cl_3	1	26%	r>0.7	Ba, Ca, Mg, Mn, SO_4, Sr	r<-0.7		Positive: Carbonate minerals,
			r>0.5	Na	r<-0.5		Negative:
	2	21%	r>0.7	Fe	r<-0.7	NH_4	Positive: Al/Fe, heavy metals
			r>0.5	Cr, Ni, DOC, Al	r<-0.5	Cl, Na, PO4	Negative: Nutrients, salinity
	3	20%	r>0.7	Cu, Pb, Zn	r<-0.7		Positive: Al, heavy metals
			r>0.5	Al	r<-0.5	NH4, PO4	Negative: Nutrients
	4	6%	r>0.7		r<-0.7		Positive:
			r>0.5	Ni	r<-0.5		Negative:
Cl_4	1	19%	r>0.7	Ba, Ca, Sr	r<-0.7	Al	Positive: Carbonate minerals
			r>0.5	Mn, NH4	r<-0.5	Cr	Negative: Al, heavy metals
	2	15%	r>0.7	DOC	r<-0.7		Positive: Fe, heavy metals
			r>0.5	As, Cr, Fe	r<-0.5	Cu, NO3	Negative: Oxic conditions
	3	14%	r>0.7	Ni, Pb	r<-0.7	Cl	Positive: Heavy metals
			r>0.5	Cu, Zn	r<-0.5		Negative: Salinity
	4	14%	r>0.7	Mg, Na, SO4	r<-0.7		Positive: Salinity
			r>0.5	K	r<-0.5		Negative:

5.3 Median and 90th percentile and their confidence intervals

For the determination of the medians and the 90th percentiles, both these values as well as their confidence intervals (CI) were calculated. The medians and 90th percentiles are visible for total-N in Table 5.9 and Fig. 5.5 and those for total-P in Table 5.10 and Fig. 5.8. The interpretation for both species follows below.

5.3.1 Total-N

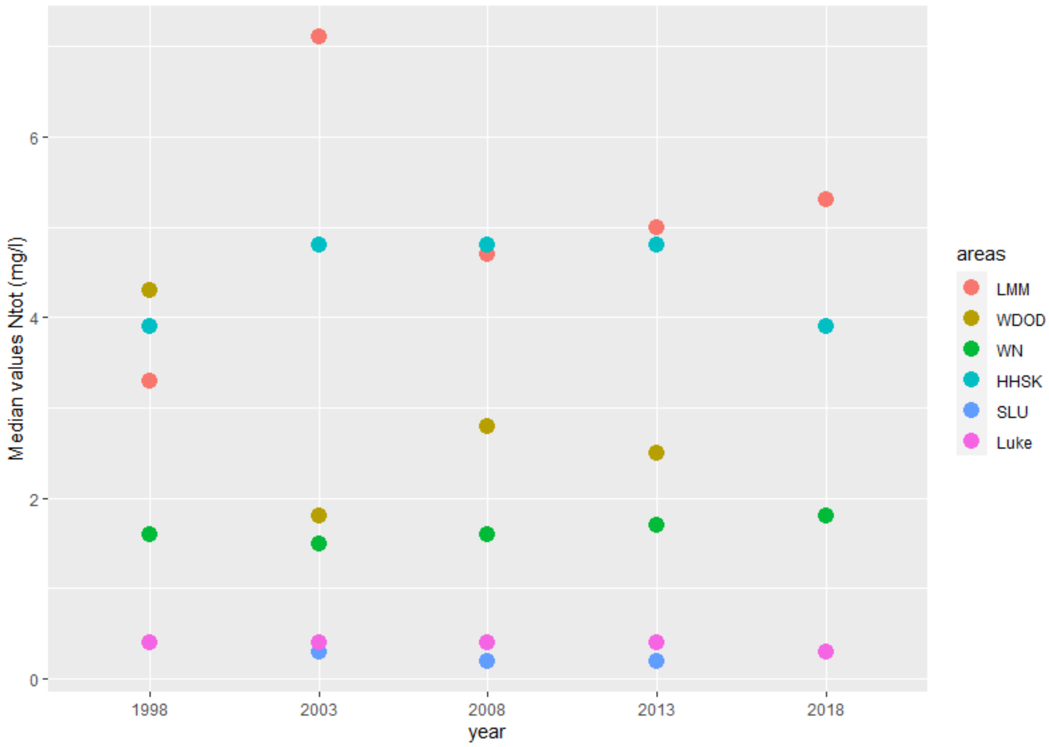
Figure 5.5 and Table 5.9 for total-N reveal that there are considerable differences between the study areas in every year. The median and 90th percentile values of the LMM data are among the highest values in every year. In 1998, the values for WDOD and HHSK are high as well, in later years the WDOD values are more comparable to those of Waternet, albeit somewhat higher. The HHSK values remain high and are comparable with LMM total-N. The values of SLU and Luke are noteworthy because their values are substantially lower than the values for the Netherlands, regardless of the year.

Table 5.9 Median and 90th percentile values for total-N per year for every study area.

	1998		2003		2008		2013		2018	
	median	90th	median	90th	median	90th	median	90th	median	90th
LMM	3.3	6.4	7.1	9.7	4.7	7.5	5.0	7.4	5.3	10.4
WDOD	4.3	7.3	1.8	4.0	2.8	4.5	2.5	4.2	~	~
WN	1.6	2.8	1.5	3.1	1.6	3.1	1.7	3.5	1.8	3.5
HHSK	3.9	5.8	4.8	7.6	4.8	7.3	4.8	6.9	3.9	5.5
SLU	0.4	0.6	0.3	0.5	0.2	0.3	0.2	0.5	0.3	1.0
Luke	0.4	0.7	0.4	1.0	0.4	1.0	0.4	1.4	0.3	1.1

Due to the differing density of measurements per year and study area, plotting a confidence interval of the median and 90th percentile, and a cumulative probability plot gives more information on overlap or dissimilarities between study areas. All graphs of the confidence intervals and the cumulative probability plots are available in appendix I for all years. These graphs give a proper image of the median and 90th percentile values of every dataset for the given years. To easily intercompare the values the y-axes of all the CI-plots are the same. Shown in this section are two examples of total-N confidence interval and cumulative probability plot of every dataset in the Figures 5.6 and 5.7.

Regarding the total-N data of 2003 in Figure 5.6, the large CI of the LMM dataset is visible. The reason for this is the small number of observations in 2003 for surface water in the LMM data (n = 20). As at least 30 observations were set to be required, the large confidence interval does not allow to draw any conclusions. However, it is still interesting to observe how the observations of the LMM are positioned compared to the other datasets. Important to note is that 2003 was the only year for which the amount of observations in a dataset was too small to compare, the other datasets do meet the minimum of required observations. The Luke and SLU values are considerably lower than those for the Dutch peatlands. The WDOD and WN values are rather comparable, with WDOD higher in 2003, 2008 and 2013. The HHSK total-N values are in between the naturally conserved peatlands of the WDOD and WN areas and the agriculturally used LMM peatlands. The cumulative probability plot helps visualise the variance of the datasets. The more similar the values of the datasets are, the closer together they will lie in the CP-plot. Here we see that the WDOD and Waternet values are quite similar across the entire range. The Scandinavian total-N data from SLU and Luke show similar values in the lower range while the higher values of both datasets become distinctively different.



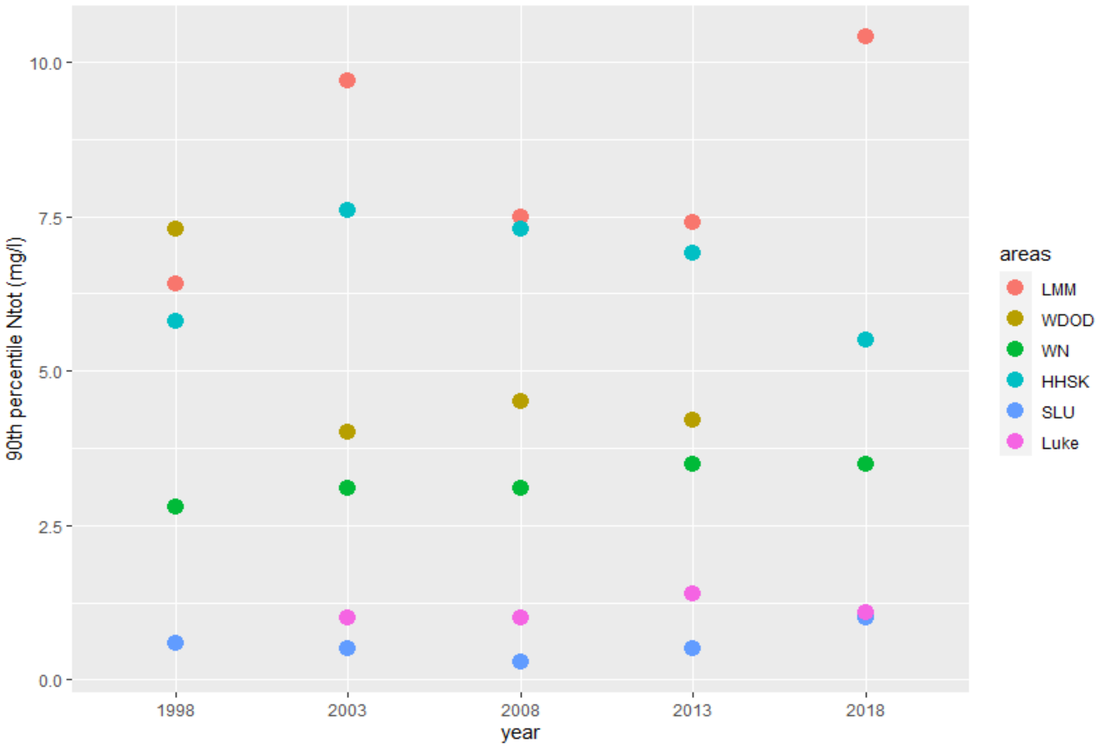


Figure 5.5 Median (top) and 90th percentile (bottom) values of all study areas for total-N. Note that some study areas are not visible due to overlap in the values. WDOD data was not available for 2018.

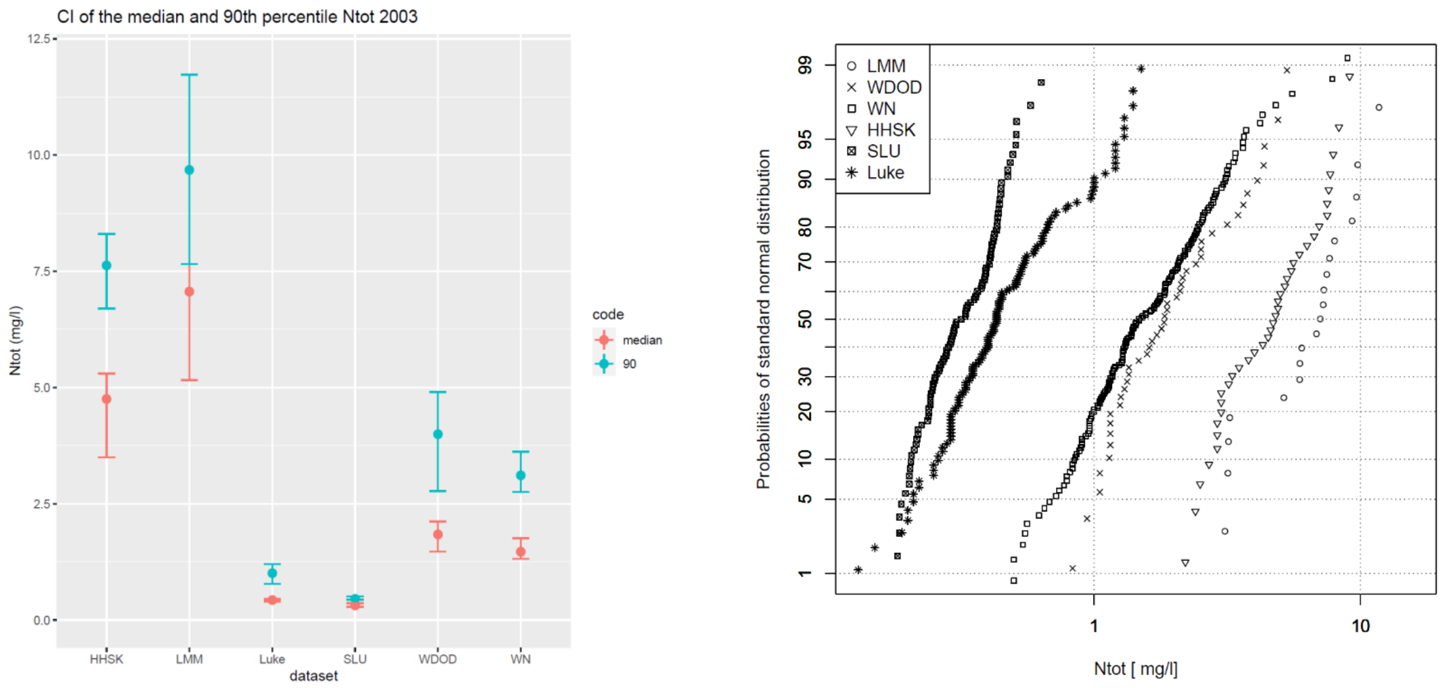


Figure 5.6 CI and CP plots of the total-N data of the LMM (n = 20), WDOD (n = 44), WN (n = 179), HHSK (n = 38), SLU (n = 99) and Luke (n = 137) in 2003.

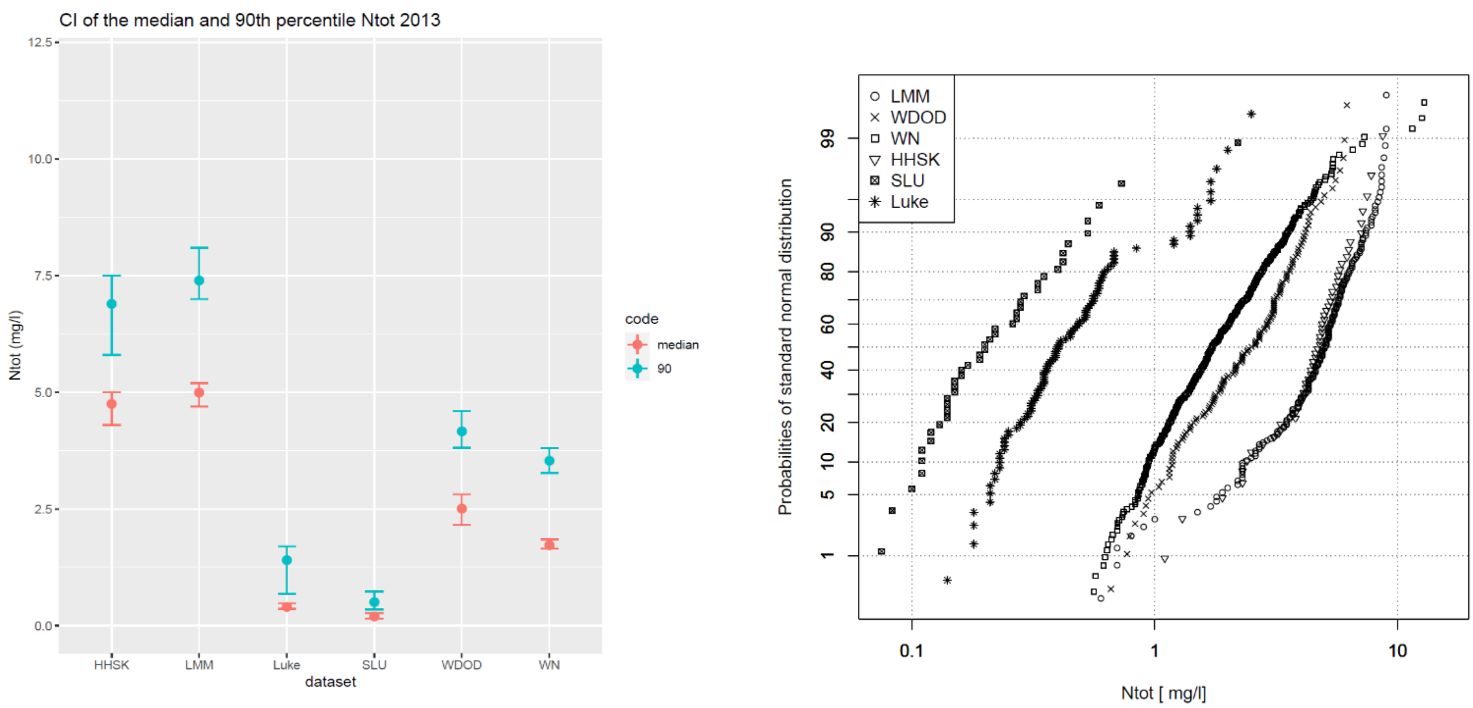


Figure 5.7 CI and CP plots of the total-N data of the LMM (n = 200), WDOD (n = 143), WN (n = 468), HHSK (n = 54), SLU (n = 44) and Luke (n = 107) in 2013.

Figure 5.7 shows the confidence interval and cumulative probability of the total-N data for 2013. For this year the amount of LMM observations was the largest (n = 200). This is visible in the smaller CI in the left plot in Figure 5.7 as the data density for the LMM data is much higher than for 2003. Because of the more accurate confidence intervals in this year, the three separate data clusters are better visible. The HHSK and LMM values are highest, as they are in most years. The WDOD and WN values compose the lowest values of the Dutch peatlands, whereas the bulk of SLU and Luke values are lower than the Dutch peatland total-N values, there is some slight overlap in the higher range of the Luke values around 1 mg N/l. The SLU values have a systematically lower range than the Luke values. The cumulative probability plot shows that there is substantial overlap between the LMM and HHSK values, and a slight overlap between the Waternet and WDOD data.

5.3.2 Total-P

The median and 90th percentile values are summarized for total-P in Table 5.10 and visible in Figure 5.8. Similar to the values for total-N, the LMM data is consistently among the higher values in every year. For total-P, however, the median values of LMM and WDOD are similar in 2003, 2008 and 2013. The WN data has the lowest median of the Dutch peatlands in every year. The data from the HHSK are notable for being higher than every other dataset in every year: often 3 – 5 times larger than the LMM values. Just as for total-N, the Scandinavian datasets SLU and Luke show the lowest values in every year.

Table 5.10 Median and 90th percentile values for total-P per year for every study area.

	1998		**2003**		**2008**		**2013**		**2018**	
	median	90th	median	90th	median	90th	median	90th	median	90th
LMM	0.26	0.82	0.14	0.46	0.13	0.57	0.12	0.47	0.08	0.26
WDOD	0.22	0.42	0.12	0.28	0.12	0.36	0.14	0.31	~	~
WN	0.11	0.33	0.07	0.22	0.09	0.26	0.07	0.33	0.08	0.26
HHSK	0.89	1.49	0.62	1.01	0.69	1.13	0.75	1.4	0.43	0.54
SLU	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02
Luke	0.01	0.03	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02

The total-P confidence intervals and cumulative probability plots for 2003 and 2013 are visible in Figures 5.9 and 5.10, and available for all years in appendix I.

Regarding the CI of total-P in 2003 in Fig. 5.9 the high values for the HHSK data are notable. The medians of LMM and WDOD have overlapping confidence intervals. The 90th percentile CI of the LMM data, however, ranges higher. The range above the 90th percentile value of the LMM is very small. The reason for this is the same issue as the total-N data for 2003; this year has the lowest number of observations for the LMM data (n = 20). This is better visible in the CP-plot (Fig. 5.9), where the three highest LMM values share their total-P concentration. A slight clustering of areas is detectable in the CP-plot. The Scandinavian datasets overlap in the higher probability range, the LMM, WDOD and WN data lie rather close together. When looking at the HHSK data in the CP plot, the points for the HHSK data have higher values on the x-axis than the other data for any given probability, the difference in total-P concentrations with the other datasets is clearly visible.

For the total-P data of 2013,the HHSK total-P concentration values for the median and 90th percentile are much higher than those for the other data (Fig. 5.10). The CI of the LMM and WDOD medians seem to overlap again, just like the 90th percentile CI of WN and WDOD. The 90th percentile CI of the LMM data has a higher range than for both WDOD and WN. The Scandinavian data are lower than most the Dutch peatland study areas although some very low concentrations are observed for WN overlapping both the Luke and SLU data in the lower range.

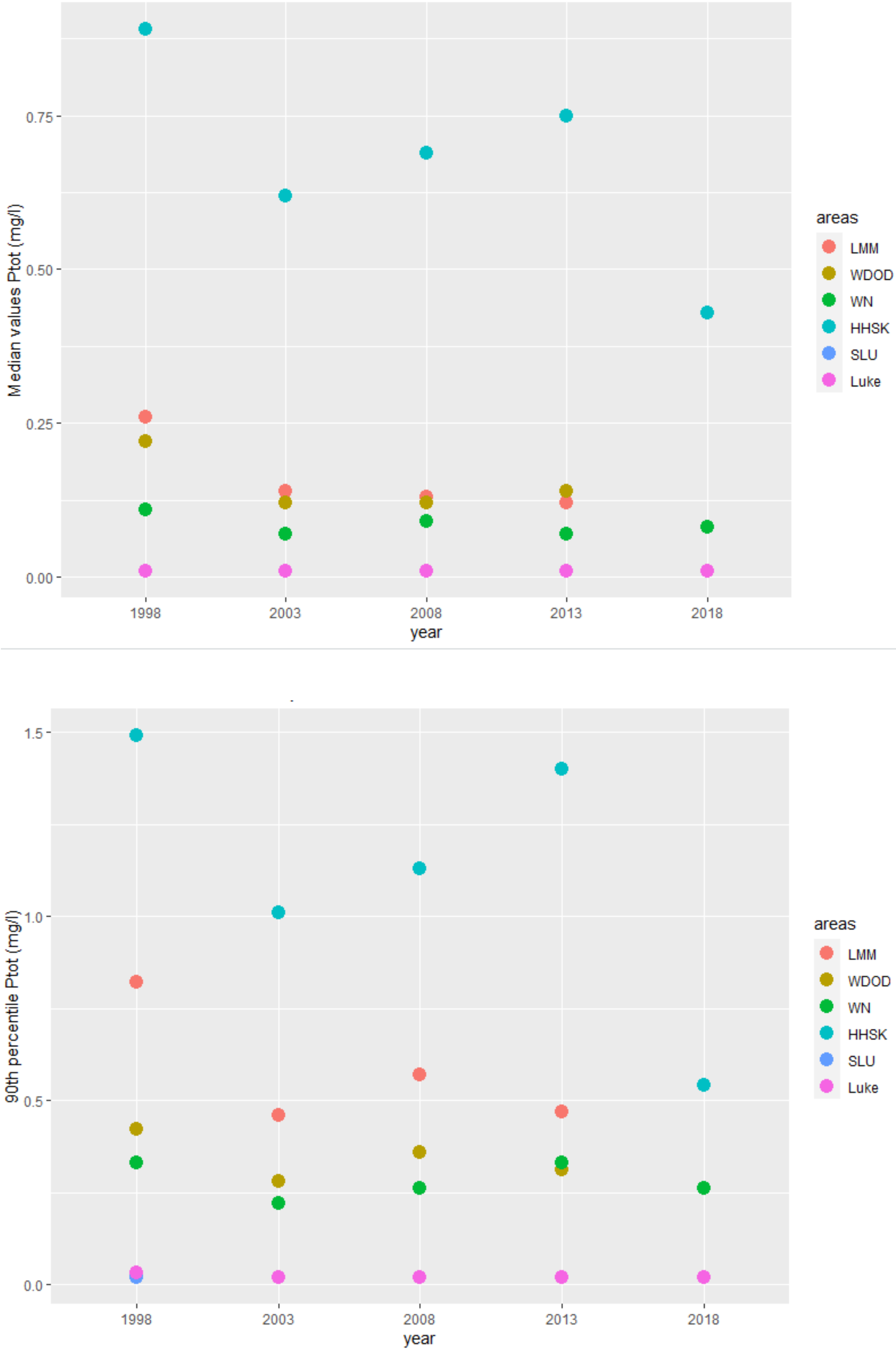


Figure 5.8 Median (top) and 90th percentile (bottom) values of all study areas for total-P. Note that some study areas are not visible due to overlap in the values. WDOD data was not available for 2018

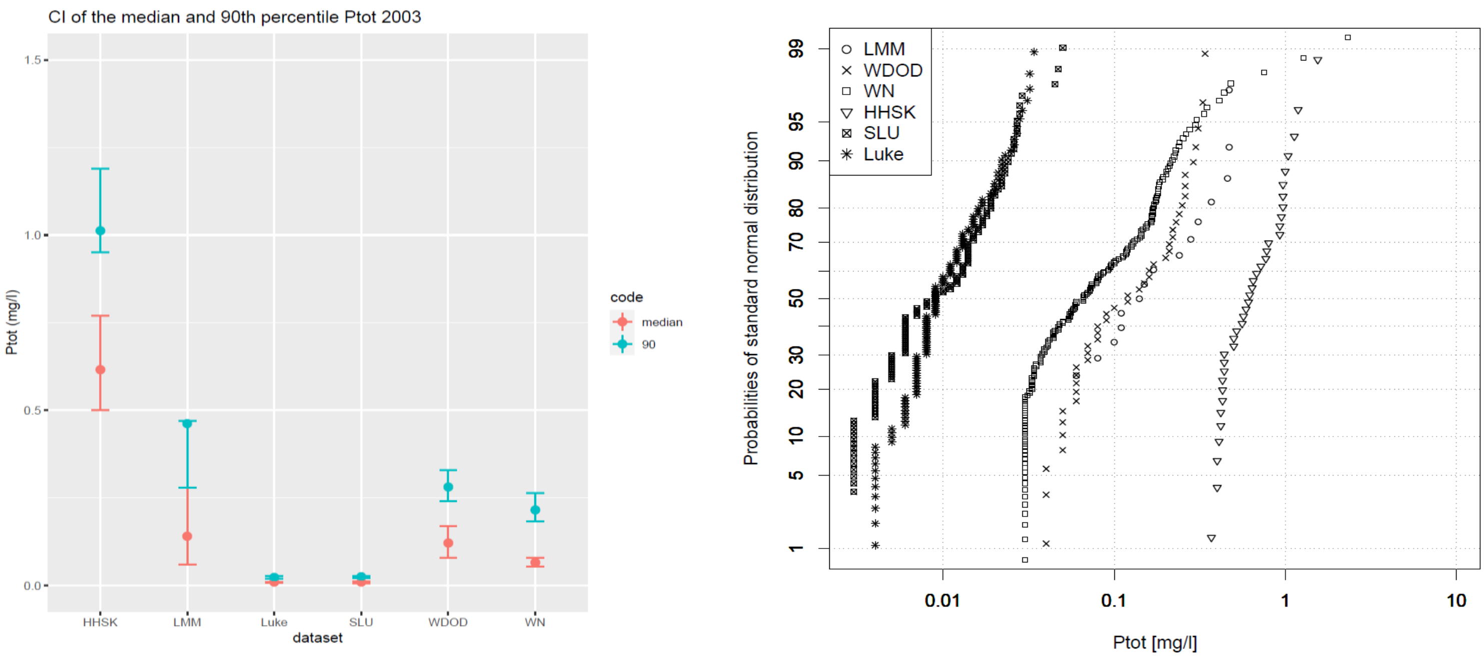


Figure 5.9 CI and CP plots of the total-P data of the LMM (n = 19), WDOD (n = 44), WN (n = 198), HHSK (n = 38), SLU (n = 152) and Luke (n = 137) in 2003

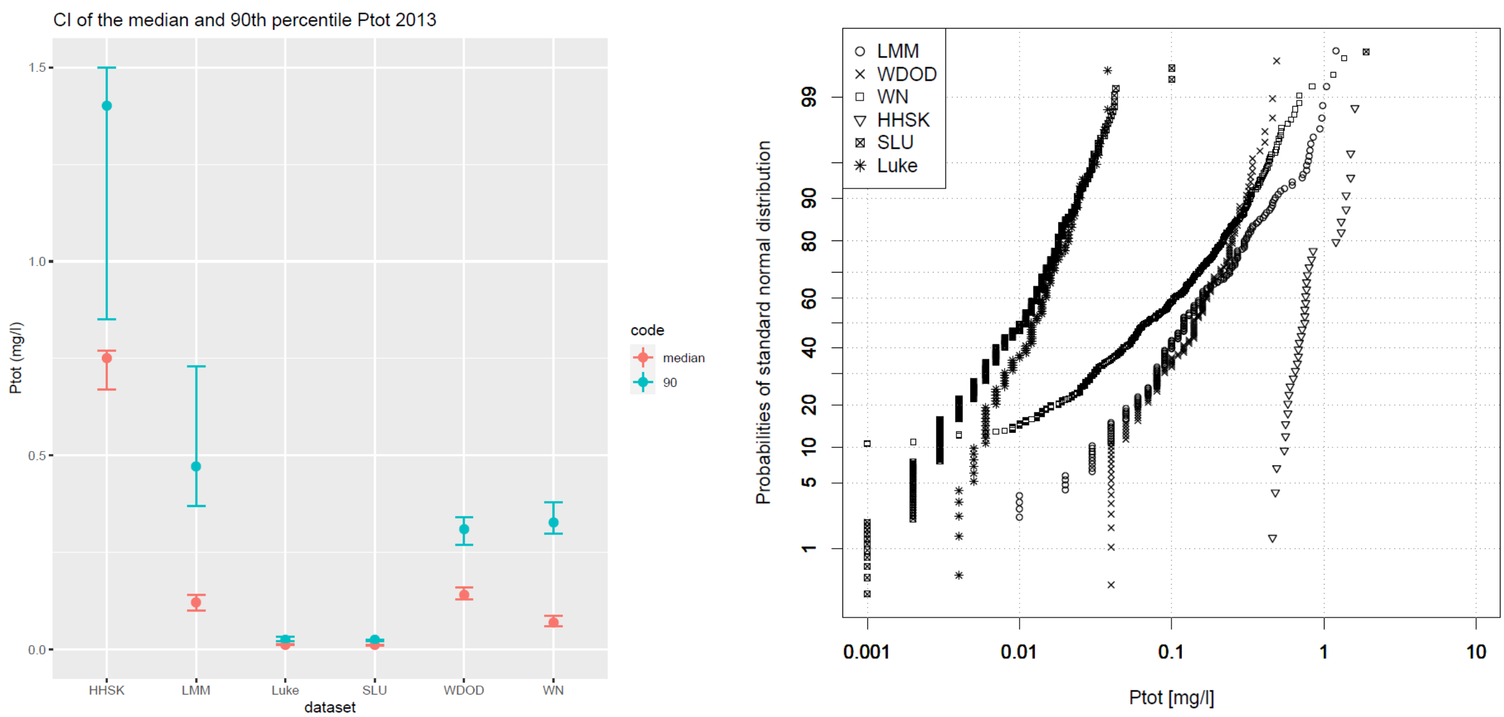


Figure 5.10 CI and CP plots of the total-P data of the LMM (n = 200), WDOD (n = 143), WN (n = 468), HHSK (n = 37), SLU (n = 572) and Luke (n = 107) in 2013.

5.4 Kruskal Wallis and Wilcoxon rank sum tests

The Kruskal Wallis p-value was significant for all datasets for every year. This means that in every analysed year at least one of the datasets had a significantly different median value than the others. The results of the Wilcoxon rank sum test, presented in Table 5.11, reveal between which of the datasets the median was significantly different and for which datasets the null hypothesis could not be rejected.

The results of the Wilcoxon rank sum tests show comparable results with the CI plots in the section above and in appendix I. Where medians clearly overlap, the Wilcoxon rank sum test shows non-significant p-values; e.g. between HHSK and LMM for total-N in 2008 and 2013, or for LMM and WDOD for total-P in 2008 and 2013.

Table 5.11 Overview of Wilcoxon rank sum test p-values between the study areas. Note that for 2003 the number of observations of LMM was too low for a correct analysis and for 2018 WDOD data was not available.

	Total-P					**Total-N**				
1998	LMM	WDOD	WN	HHSK	SLU	LMM	WDOD	WN	HHSK	SLU
WDOD	0.21					0.4				
WN	<0.01	<0.01				<0.01	<0.01			
HHSK	<0.01	<0.01	<0.01			<0.01	0.64	<0.01		
SLU	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	
Luke	<0.01	<0.01	<0.01	<0.01	0.5	<0.01	<0.01	<0.01	<0.01	0.57
2003	LMM	WDOD	WN	HHSK	SLU	LMM	WDOD	WN	HHSK	SLU
WDOD	0.58					<0.01				
WN	0.06	<0.01				<0.01	<0.05			
HHSK	<0.01	<0.01	<0.01			<0.01	<0.01	<0.01		
SLU	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	
Luke	<0.01	<0.01	<0.01	<0.01	0.13	<0.01	<0.01	<0.01	<0.01	<0.01
2008	LMM	WDOD	WN	HHSK	SLU	LMM	WDOD	WN	HHSK	SLU
WDOD	0.78					<0.01				
WN	<0.01	<0.01				<0.01	<0.01			
HHSK	<0.01	<0.01	<0.01			0.81	<0.01	<0.01		
SLU	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	
Luke	<0.01	<0.01	<0.01	<0.01	0.34	<0.01	<0.01	<0.01	<0.01	<0.01
2013	LMM	WDOD	WN	HHSK	SLU	LMM	WDOD	WN	HHSK	SLU
WDOD	0.68					<0.01				
WN	<0.01	<0.01				<0.01	<0.01			
HHSK	<0.01	<0.01	<0.01			0.27	<0.01	<0.01		
SLU	<0.01	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	<0.01	
Luke	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2018	LMM	WDOD	WN	HHSK	SLU	LMM	WDOD	WN	HHSK	SLU
WDOD	NA					NA				
WN	0.22	NA				<0.01	NA			
HHSK	<0.01	NA	<0.01			<0.01	NA	<0.01		
SLU	<0.01	NA	<0.01	<0.01		<0.01	NA	<0.01	<0.01	
Luke	<0.01	NA	<0.01	<0.01	<0.01	<0.01	NA	<0.01	<0.01	<0.01

5.5 Discussion and evaluation of the confidence intervals of the median & 90th percentile, and of the Kruskal-Wallis/Wilcoxon rank sum tests.

In this subsection the results presented in Sections 5.3 – 5.5 will be discussed. The hypotheses that were tested with the statistical analyses will be evaluated here. For all years except the LMM in 2003, there were enough observations for a correct analysis of the confidence intervals and the Kruskal-Wallis/Wilcoxon tests.

5.5.1 *Total-N in Dutch peatlands*

The calculated medians and 90th percentiles and their confidence intervals of the total-N in Figures 5.6 and 5.7 and in Appendix I, suggest that hypothesis 1 – “There is spatial and temporal variability in N and P concentrations in Dutch natural reserve peatlands, with lower N and P concentrations in naturally conserved peatlands, compared to agricultural peatlands” – is partly true for total-N. While in 1998 the LMM has a lower median than HHSK and WDOD, the LMM data contains the highest median value in 2003, 2008 and 2018, and the highest 90th percentile value in 2003, 2008, 2013 and 2018. The HHSK total-N median is higher than WN and WDOD in 2013 and is not significantly different from the LMM median in 2008 and 2013 (Table 5.11). WDOD has a particularly high total-N median and 90th percentile value in 1998, the median not significantly different than the LMM median. In 2003 and 2013 the WDOD and WN median values are rather comparable and the lowest of all Dutch peatland datasets. For 2018 the WDOD data lack but the WN data still has the lowest median and 90th percentile values of the Dutch datasets.

The results raise some questions about the statistical values for the study areas. What could cause that the total-N median and 90th percentile value for the WDOD are the highest in 1998 but lower in the other analysed years; what could cause total-N median and 90th percentile to be higher for HHSK than the other naturally conserved peatlands in 2003, 2008, 2013 and 2018; why are the Waternet total-N values the lowest in every year for the Dutch naturally conserved peatlands; and what explains the difference between the Scandinavian total-N values and that of Dutch peatlands?

The high N concentrations for the LMM data were expected, as this is data collected at farms where manure is applied and which lands are drained. In peatland, dairy cattle farming is the main agricultural practice. The concentrations are comparable to the concentrations mentioned in the *LMM derogation report 2018* (2020), i.e. 4.1 mg N/l in the 2017-2018 winter. The total-N concentration for the LMM data in 2018 is likely influenced by the drought that year. Drought can increase the NO_3 concentrations compared to normal or wet years (Lukacs et al., 2020). Atmospheric deposition of N (Table 5.12) has decreased until 2003 and has since then remained relatively stable (clo, 2019).

Table 5.12 Atmospheric N deposition in the Netherlands in researched years (clo, 2019)

Year	**1998**	**2003**	**2008**	**2013**	**2018**
mol N ha^{-1} $year^{-1}$	2398	1846	1771	1590	1730

The higher values in the Krimpenerwaard peatland could be related to several causes. Compared to the WDOD and WN naturally conserved peatlands, most of the observed peatland in the Krimpenerwaard has only recently been designated as nature, i.e., 2017. Several small parcels have been administered by the Zuid Hollands Landschap for 20-30 years. These small parcels have had their own water management policy, which means that less water from the agricultural areas flows into these naturally conserved peatlands. Since 2017 this policy is implied on the area used for this research, thus currently a much larger area has its own water level management. The land around a large number of the monitoring locations were thus in agricultural use during the studied years. As only 2018 is the year where all observation points were officially designated as nature, the observations of this year probably give the best insight in the effects of the land use management changes. One year, however, is too little to draw hard conclusions, because other effects may cause the N concentrations to vary. 2018 for instance had a severe drought in the Netherlands, influencing N concentrations due to lower groundwater table. It also takes years before all nutrients applied on the land during farming get leached from the soil. Van Gerven et al. (2011a) found that the ratio of sources of N in surface water in the Krimpenerwaard are manure application (40%), peat mineralisation (40%), followed by atmospheric deposition (8%) and inlet from the Lek and Hollandsche IJssel rivers (8%). Lowering of groundwater levels is a major driver of peat mineralisation in the Krimpenerwaard and could thus have influenced the N concentration values in the years before 2017 (Van Gerven et al., 2011a).

The Wieden-Weerribben and Vechtplassen – WDOD and WN in the graphs respectively – show the lowest total-N values for the Dutch peatlands. This is with the exception of the high total-N values for the WDOD study area in 1998. Reasons for this high median and 90th percentile could be a coincidental peak; the catchment area of the Wieden-Weerribben was afflicted by floods in 1998. Cusell (2014) mentions that the noticeable nutrient concentration improvements started 20 years ago. The high values could thus also be a legacy of the high nutrient concentrations before this year. The total-N median values for 1997 and 1999 however, are 2.1 and 2.2 mg N/l respectively and hence lower than 1998 (4.3 mg N/l).

In the Wieden-Weerribben and Vechtplassen inflow from exterior water and atmospheric deposition are the main sources of N input. While atmospheric deposition is higher in the Vechtplassen area than in the Wieden-Weerribben - 1558 mol/(ha.yr^{-1}) in versus 1338 mol/(ha.yr^{-1}), respectively – the total-N values observed in this research are lower in the Vechtplassen. The difference in N concentration due to inflow are explained by the sources of water in both areas.

Considering the ecological status of surface water, the situation in the WDOD and WN naturally conserved peatlands is somewhat more complex than just N and P concentrations. Both the Wieden-Weerribben and Vechtplassen lack steady base rich water inflow (Kooijman, 2012; Cusell, 2014). The ecologically valuable rich fen vegetation of these areas requires Ca and HCO_3 rich water to sustain their vulnerable ecosystems. The artificial water management and peat extraction decreased the base rich water inflow and jeopardized several rare rich fen species, such as *Stratiotes Aloides.* Base rich exterior water was therefore let into the naturally conserved peatlands. This water from outside the peatland, however, also contains higher nutrient concentrations as it originates from agricultural areas. Here, the N and P concentrations of this inflow water are higher for the Wieden-Weerribben than the inflow water of the Vechtplassen, and it is also more base rich. This is one of the reasons base-rich fen species have been declining in the Vechtplassen on a faster rate than in the Wieden-Weerribben in the period 1992-2012 (Kooijman, 2012).

5.5.2 Total-P in Dutch peatlands

Based on the results of the median and 90th percentile of the total-P in Figures 5.8, 5.9 and 5.10 and in Appendix I, hypothesis 1 does not seem true for total-P. The HHSK dataset contains higher values for both median and 90th percentile than all other datasets in every analysed year. The LMM values for the median are comparable to those for WDOD and Waternet in 2008 and 2013, WDOD and LMM median being not significantly different in 1998, 2008 and 2013 (Table 5.11). Due to inadequate LMM data 2003 is not considered. WDOD data lacks for 2018 but the LMM median value is comparable to the Waternet one. The 90th percentile values of the LMM data is higher than that of the WDOD and WN data in 2008 and 2013. In

2018, the LMM 90th percentile does not seem to differ much from the WN 90th percentile. Note as well that the median P concentration for the LMM dataset is 0.08 mg P/l in 2018 and 0.12 mg P/l in 2013, which is 0.18 mg/l and 0.14 mg/l lower than in 1998 respectively.

Like the total-N results, these results require further interpretation. Why is the median value of the HHSK data higher than in the other datasets in every year? And why are the LMM, WDOD and WN median P concentrations comparable in 2008, 2013 and 2018, whereas LMM represents agricultural areas?
The P concentrations in Krimpenerwaard are significantly higher than in the other study areas. These remarkable concentrations were noticed earlier by other researchers (e.g. Van Gerven et al., 2011a). Several probable causes for these concentrations were investigated, related to historical land use, soil composition and water management.

As with the cause for the higher total-N values, the total phosphorus statistical values might be higher because of the recent, ongoing land use change from agriculture to nature in much of the Krimpenerwaard, which causes the past agricultural practices still perceptible in recent P concentrations.

Additionally, the Krimpenerwaard differs from the WDOD and WN peatlands in its geochemical characteristics of the sublayers. The sulphate concentrations in the Krimpenerwaard's surface water are relatively high compared to those in the WDOD and WN peatlands. These high SO_4-concentrations are associated with the higher P concentrations (Smolders et al., 2006; Van Gerven et al., 2011a; Vermaat et al, 2012). The major source of this SO_4 is the peat itself. Peat in the southwestern peat area stores large amounts of pyrite. It is suggested that manure application – with NO_3 – enhances pyrite oxidation and subsequently causes high SO_4 concentrations (Smolders et al., 2010; Van Gerven et al., 2011b). The legacy storage in the ditch bottom of P from manure is significant and can deliver considerable amounts of P to the surface water under the right circumstances (Van Gerven et al., 2011b; Van der Grift, 2017). SO_4 concentrations seem to be related to the high P concentrations in ditch bottoms and are suggested to enhance desorb P from Fe/Al-oxides present in the ditch (Smolders et al., 2006).

Contact with HHSK led to interesting and important insights in the Krimpenerwaard P concentration. Four monitoring points used in this research area were indicated to have been designated as nature far longer than the bulk of the HHSK observations, i.e. 20-30 years. These four points could indicate the effects of long-term natural management in the Krimpenerwaard. As an indication: these points had a median value of 0.1 mg P/l in 2018. This is much lower than the 2018 HHSK median in this research of 0.43 mg P/l, which is based on the observations in more recent established naturally conserved peatland. The future should reveal if the P concentrations at the other areas in the Krimpenerwaard will become as low as these observations or that the older naturally conserved peatlands were designated as nature because of initial low P concentrations due to very local soil and water conditions.

While the high P concentrations of the Krimpenerwaard are interpreted above, the P concentrations in the LMM, WDOD and WN datasets deserve their own interpretation. The similarities of the median values for the P concentration for these three areas are notable and do seem to disagree with hypothesis 1 (lower total-P concentrations in natural reserve peatland than in agricultural peatland). The concentrations could be explained by the elements historical land use, water management, soil and water geochemistry. This includes the implications of improved water quality in agricultural areas due to the Manure law.

The P-concentrations in this research comply with the water quality results given in the LMM reports (Lukacs et al., 2020). Phosphorus concentrations have been decreasing since monitoring started and for the last years the concentrations were relatively stable between 0.1 and 0.2 mg P/l in ditches (Lukacs et al., 2020).

The Wieden-Weerribben and Vechtplassen show median values of the P concentration in the 0.1-0.2 mg P/l range as well, with the Vechtplassen somewhat lower than the Wieden in every year. The main cause for the P concentrations similar to agricultural areas are assumed to be the legacy stock of P from former agriculture and the base rich water inflow. In both naturally conserved peatlands the base rich water inflow is also rich in N and P (Wassen et al., 1996; Kooijman, 2012; Cusell, 2014). The polders surrounding these Natura2000 areas are still in use for dairy cattle farming and the inlets can be considered as point sources of P. To prevent a lack of base rich water and to sustain water levels that prevent peat oxidation this water inflow cannot be ceased, however. In the Vechtplassen P rich water from point sources – e.g. Bethunepolder – is now filtered and dephosphatised. This method is now being researched in the Wieden-Weerribben. The implications of the water inflow on the ecosystem are already mentioned in 5.5.1.

5.5.3 Total-N and total-P difference between Scandinavian and Dutch peatlands

For both total-N and total-P the values of the Scandinavian pristine peatlands are consistently lower in every year addressed in the data analysis. Research on pristine peatland nutrient concentrations confirms these values (Nieminen et al., 2017). This was expected according to hypothesis 2: the typical N and P concentrations in naturally conserved peatlands in the Netherlands are higher than in international, pristine peatlands found in Northern Europe.

An important general remark about the N and P concentrations in the Dutch peatlands compared to the Scandinavian peatlands relates to Dutch water management. The Dutch study areas can all be considered artificial wetlands, as they were heavily modified anthropogenically. The Wieden-Weerribben and Krimpenerwaard were agriculturally used peatlands before their designation as nature reserve and hence contain substantial stocks of N and P in their soil (Lamers et al., 2002; Mettrop, 2015). The alterations of the natural reserve peatland also mean they require intensive water management, although these areas are designated as nature areas. Often this results in inlet of water from water systems outside the naturally conserved peatlands, these waters having higher N and P concentrations than the water inside the natural conserved area (Cusell, 2014). Examples are water level management in the Wieden-Weerribben to sustain Ca and HCO_3 levels, or the remnants of high N and P input during the 1950s – 1980s from the Vecht river in the Waternet peatlands (Wassen et al., 1996; Kooijman, 2012; Cusell, 2014). Scandinavian pristine peatlands are mostly not surrounded by areas with intensive agriculture and water inflow originates from other naturally conserved areas being controlled by precipitation and groundwater fluctuations (Mattson et al., 2003; Baker et al., 2009). Peat mineralisation and the subsequent leaching of N and P to surface water are also suggested to be one of the higher N and P concentrations in Dutch natural reserve peatlands. Drained pristine peatlands in Scandinavia show similar issues with peat mineralisation to the Dutch peatlands (Lundin et al. 2017; Nieminen et al, 2017), for further details on this subject see Section 5.7.2. While atmospheric deposition of N is an acknowledged issue for natural areas in Scandinavia, the lower density of people and industry around the peatlands addressed is suggested to be the cause of much lower atmospheric N deposition than in the Netherlands, i.e., 314 mol

N/(ha.yr^{-1}) in boreal Sweden versus 1500 mol N/(ha.yr^{-1}) in the Netherlands (Sponseller et al., 2014; Gies, Kros & Voogd, 2019)

5.5.4 *Limitations and recommendations on the comparison*

The main limitations for the comparison between the study areas and their N and P concentrations were of a temporal and spatial nature. Comparing more years would have given more information on trends in N and P concentrations and would have given a more precise image of the N and P concentrations as coincidental events can have impacts on the data analysis, e.g. the median total-N value for the WDOD area in 1998. However, the primary scope of this research was to compare peatlands on a spatial scale based on land use; temporal changes were of secondary interest. The higher density of researched years would then have resulted in a subsequent higher temporal density . The restricted time for this study must then also be considered and the preparation and collection of data had cost a substantial amount of time.

The spatial scale was a more important limitation. The original aim was to collect vastly more data of naturally conserved peatlands both in the Netherlands as well as international peatlands. This turned out to be quite a bump. As set out in section 1.5, a large-scale comparative research on nutrient concentrations had not been carried out yet and data had to be collected from a large number of sources. Moreover, the data had to be detailed enough to intercompare the studied areas for the chosen years and needed to contain enough observations for a correct statistical data analysis. The LMM data of 2003 is a good example of a year with low density in data and this effect on the accuracy of the median and 90th percentile. While more data from different sources was collected, only the three Dutch naturally conserved peatlands mentioned in the research had sufficient data by the time data analysis was started. For international peatlands this was a limitation as well. As pristine peatlands are abundant in Eastern Europe as well as the boreal Northern Hemisphere, a large number of research institutes were contacted and asked for data on pristine peatlands. This resulted in data from Finland, Sweden and Poland. Where sadly the data from the Biebrza peatland in Poland could not be compared to the LMM data due to the data's restricted time range from 1987 to 1993. Data from Canadian peatlands is to be expected in November and could be used for future research.

A recommendation for expansion of this research would be to examine statistically what the major drivers behind the N and P concentrations in the researched study areas are. In Sections 5.5.1 – 5.5.3 several of these controls of N and P concentration variability are considered in previous research. An example of analysis that could be used to further study the sources of N and P concentrations could be a principal component analysis, similar to the research by Vermaat & Hellman (2010).

Another recommendation for further research regards the role of the inlet water and the seasonality of nutrient concentrations. This study focused primarily on winter concentrations of N and P. But as exterior water is mostly let in during the drier summer months, this inlet could influence the N and P concentrations during the summer. Comparing the chloride and nutrient concentrations in measurements within the peat polder with that of the exterior inlet water could indicate the extent of the role of inlet water in nutrient dynamics. Seasonal Cl, N and P concentration changes in measurements within the peatland and exterior water can be compared in a similar manner. Another spatial aspect of inlet water and seasonality that could be researched is the spatial variability of N and P concentrations in surface water in a study area; it is then hypothesized that the water closer to the inlet points has higher N and P concentrations than water further from the inlet points in a certain study area. The role of connectivity of the water bodies could then be investigated.

5.6 Exceedance Good Ecological Potential/Status

The WFD requires Good Ecological Potential (GEP) for anthropogenically altered water bodies and Good Ecological Status (GES) for natural water bodies. Water authorities administer and base their own local potential or status on national WFD standards based on the reference of the most similar natural water bodies, see also Sections 1.7 and 4.3.6 (Raadgever et al., 2009). This means that local effects on nutrient concentrations are considered. This is visible in Table 5.13 where the HHSK norms for P concentrations are some factors higher than the other study areas. The required N and P concentrations in Table 5.13 also imply that the lower N and P concentrations of the Vechtplassen and Wieden-Weerribben does not necessarily mean that the water quality is good. Both areas still exceed the WFD GEP standards in some water bodies. The GEP/GES N and P concentrations for Swedish and Finnish water bodies were searched for and requested but could not yet be retrieved, hopefully the norms will be received later this year.

Table 5.13 N and P standards for GEP/GES in water bodies present in the areas studied. As indicated, the Scandinavian GES values were not retrieved yet.

Area	**Water body**	**N (mg/l)**	**P (mg/l)**
WDOD	Wieden-Weerribben	1.3	0.09
HHSK	Nesse/Berkwoude	2.4	0.22
	Stolwijk/Kromme, Geer, Zijde/ Bergambacht	2.8	0.15
WN	Naardermeer	1.3	0.07
	Ankeveen	1.28	0.06
	Loosdrechtse Plassen	0.63	0.03
	Maarsseveen	0.12	0.03
	Wijde Blik	0.37	0.01
	Ster en Zodden	0.7	0.03
SLU	*General peatland*	NA	NA
Luke	*General peatland*	NA	NA

5.7 Embedding of findings in existing literature.

In this section the findings in this research will be placed in a context focused on nutrient dynamics in Dutch peatlands and in an international context of nutrient dynamics in peatlands.

5.7.1 Embedding of findings in literature on nutrient concentrations in Dutch peatland

Most of the relations between the findings in this research on the specific study areas and previous research have been described above in Section 5.5 (e.g. Van Gerven et al., 2011; Cusell, 2014). The findings are embedded in a more national Dutch peatland context as well. Vermaat & Hellman (2010) studied the nutrient budget in soil, groundwater and surface water of 13 peat polders, both naturally conserved and agricultural. This study found that in the Dutch peatlands agriculture is still the primary control of nutrient concentrations, not only in agriculturally used peat, but in natural reserve peatlands as well. In contrast to our research, Vermaat & Hellman found that there was a significantly lower P-concentration in natural reserve peatlands compared to agricultural, but nitrogen budgets showed no negative difference. The results in our study on surface water found more difference in the total-N concentration than for total-P between agricultural and natural peat reserves. The difference in the P surplus in Vermaat & Hellman's research with the surface water P concentration in our research could be due to P retention in the soil and ditch sediments. Vermaat & Hellman (2010) found that N did not accumulate in most polders and leaves the polder as it is pumped out. This could clarify the larger differences in the N concentrations in surface water between agricultural and natural reserve peatlands in this research, as surface water can be a temporary stock of N before it leaves the polder.

5.7.2 *Embedding of findings in international context*

The Dutch peatlands are rather unique in the sense that they were originally rich fens, intensively used for agriculture and peat extraction and moreover have a strict water management (Van Beek et al., 2007). There is, however, research on international peatlands which can be compared to the findings of this study. Regarding Section 5.5, it is suggested that internal eutrophication, water management, historical land use and atmospheric deposition play important roles in the surface water nutrient dynamics of peatlands besides agricultural inputs. Comparable to the Dutch peatland situation, Northern-German rich fens are used agriculturally. Other international fen peatlands are rarely used for agriculture but are often modified for other purposes as peat extraction or silviculture. Drainage is a common modification in these international peatlands. Nutrient dynamics in drained – and rewetted – peatlands have been the subject of research in Canada, Germany, Ireland, Sweden, USA and Finland (e.g. Prévost et al., 1999; Sündstrom et al., 2000; Zak et al., 2010; Richardson et al., 2011; Nieminen et al., 2017). Several researches on nutrient concentrations in international peatlands will be highlighted here to compare to the findings in this research.

In Germany two studies focused on the nutrient dynamics in surface water in rewetted natural reserve fens. The purpose of these researches was to study the nutrient retention in natural reserve rich fens that were formerly agricultural areas. In one study an isolated fen was found to have substantially lower nitrate concentrations and generally lower N and P concentrations than a fen that still received inflow from an agricultural area (Kieckbusch & Schrautzer, 2007). This is comparable to the situation in the Wieden-Weerribben and Krimpenerwaard, as both areas are former intensively used agricultural areas, where exterior water inflow from agriculture flows into the natural peat reserve. Both the isolated and connected fens in the study by Kieckbusch & Schrautzer (2007) retained about 1/3rd of the NO_3 input. Both areas had large fluctuations of N and P concentrations over the year, but the researchers state that the system will become more stable after more years of rewetted conditions.

Another study investigated the effects of flooding and water flow on a rewetted fen, formerly intensively used for agriculture and hence, fertilized (Zak et al., 2010). Large fluctuations in water level and stagnant water were found to be correlated with high N and P concentrations. The researchers recommend continuous water flow and stable, high water levels to prevent high nutrient concentrations and to retain nitrate. For an optimal result in biodiversity recovery and nutrient retention they recommend removing the upper layer before rewetting, as this layer contains large legacy stocks of N and P from the former agricultural use. Other research on restoration of rich fens through rewetting found similar results in other study areas (e.g. Lamers et al., 2002; Van Dijk et al., 2007). Uncoupling P rich streams adjacent to the peatland resulted in lower P concentrations in The Everglades National Park in the United States, similar to the findings in the Wieden-Weerribben National Park (Richardson et al., 2011; Cusell, 2014).

Drained peatlands used for forestry have been studied on nutrient dynamics on several timescales after drainage occurred. Nieminen et al. (2017) found that, concurrent to earlier research (Joensuu et al., 2001), the N and P concentrations in discharge water from pristine peatland in Finland were lower than for drained peatland, 412 μg l^{-1} and 847 μg l^{-1} respectively for total-N, and 14 μg l^{-1} and 31 μg l^{-1} respectively for total-P. The source of the enhanced P concentration was hypothesized to be from peat erosion and the source of the enhanced N concentration mineralization of N due to a lower groundwater table. The number of years since drainage was found to be significant in explaining the variation. A follow-up research by Nieminen et al. (2018) found that, other than drainage age, the management history, drainage proportion and geographical location were significant factors in N and P concentrations in peatland discharge water as well. Study areas with a history of fertilization showed higher P concentrations in surface water 1-5 years after drainage than pristine peatlands, 90 μg l^{-1} versus 10-15 μg l^{-1} respectively.

Although the results from Finland consider fens drained for silviculture, the mechanisms that control N and P concentration in surface water are comparable to the research Dutch peatlands. Legacy stocks of fertilization and lower groundwater tables seem to significantly affect the N and P concentration in modified peatlands.

5.8 Research implications

Most research on peatlands in the Netherlands and abroad tends to focus on specific study areas or restrict research to specific land use. Therefore, a comprehensive overview of the variability in N and P concentrations between agricultural and naturally conserved peatlands lacked within the Netherlands, as well as a comparison of Dutch peatlands with pristine, international peatlands.

This study attempted to fill this knowledge gap. The outcome highlights that the variability of N and P concentrations can differ significantly between study areas and land use types of peatland. The study broadened the scope of the variability of nutrient concentrations in peatlands. As these peatlands have their unique water management, historical land use and geochemical characteristics the differences were expected. However, the results reveal that the N and P concentrations in naturally conserved peatlands in the Netherlands are not necessarily lower than in agricultural peatlands. For total-N, land use type is suggested to be an important controlling factor, for total-P this relation seems more complex. The results and discussion in this research suggest that other controls than land use type are related to N and P concentrations.

The lowest N and P concentrations were found in pristine, naturally conserved peatlands in Scandinavia. In the Netherlands the lowest N concentrations were found to be in the peatlands administered by Waternet. The peatlands in the Waternet area and in Scandinavia have in common that they have been designated as nature for a long time and that inflow from exterior waters has relatively low N concentrations. Furthermore, the agricultural influence seems to be less prevalent in the Waternet peatlands than in the other Dutch peatlands, due to the relatively large hydrological system of the Vechtplassen and the inflow of water from the ice pushed ridge

Utrechtse Heuvelrug. The lowest P concentrations in the Netherlands were observed in the Waternet and WDOD study areas. The difference between median P concentrations in LMM observations and those from the WDOD and Waternet areas was relatively small. The highest N concentrations were found either in LMM peatlands or in the Krimpenerwaard peatlands, while the highest P concentrations were found in the Krimpenerwaard peatlands. The last example revealed the complex relation between nutrient concentrations in naturally conserved peatlands and historical land use, water management and geochemical characteristics of the soil and groundwater. Assessing water quality in peatlands in general, and nutrient concentrations specifically, should thus account for these complexities, and just a change of land use should not be expected to be the only factor in decreasing N and P concentrations.

6 Conclusions

In this study, nitrogen and phosphorus concentrations in surface water in natural reserve peatland and agricultural peatland in the Netherlands and pristine peatlands in Scandinavia were compared for the years 1998, 2003, 2008, 2013 and 2018. The aim of the study was to gain insight in the background concentration of nutrients in surface water in Dutch peatlands.

Two hypotheses were tested using an extensive data analysis:

1. There is spatial and temporal variability in N and P concentrations in Dutch natural reserve peatlands, with lower N and P concentrations in naturally conserved peatlands, compared to agricultural peatlands.
2. The typical N and P concentrations in naturally conserved peatlands in the Netherlands are higher than in international, pristine peatlands found in Northern Europe.

Spatial and temporal variability in N and P concentrations were found in Dutch peatlands. Nutrient concentrations, however, were not necessarily lower in natural reserve peatlands. Median phosphorus concentrations were highest in the Krimpenerwaard peatland. The lowest median concentrations in Dutch peatlands for both N and P were found in the Vechtplassen and Wieden-Weerribben. For phosphorus concentrations the median value of the agricultural peatland and the Vechtplassen and Wieden-Weerribben natural reserve peatlands in the Netherlands was similar, and in some cases not statistically different.

Several probable controls were suggested for the variability of nutrient concentrations in Dutch peatlands. Historical land use and the history of fertilization in a natural reserve were found in studies on specific peatlands to have caused high nutrient concentrations. Water management, including a lower water table and exterior water inlet, can result in increase of N and P concentrations due to peat mineralisation and inflow of nutrient rich water respectively.

The data from Scandinavian pristine peatlands contained the lowest medians for both N and P concentrations. This was expected as the anthropogenic influence in boreal pristine peatlands is less intensive than in the Netherlands.

Further research is recommended to determine the controls of N and P concentration variability. Examples of these are the effects of inlet water in natural reserve peatland or a principal component analysis on different nutrient concentration controls.

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9 Appendix

Appendix I contains the confidence intervals of the median and 90th percentile and the CP-plots. 2003 and 2013 are both given for total-N and total-P in Section 5.3.

9.1 Appendix I

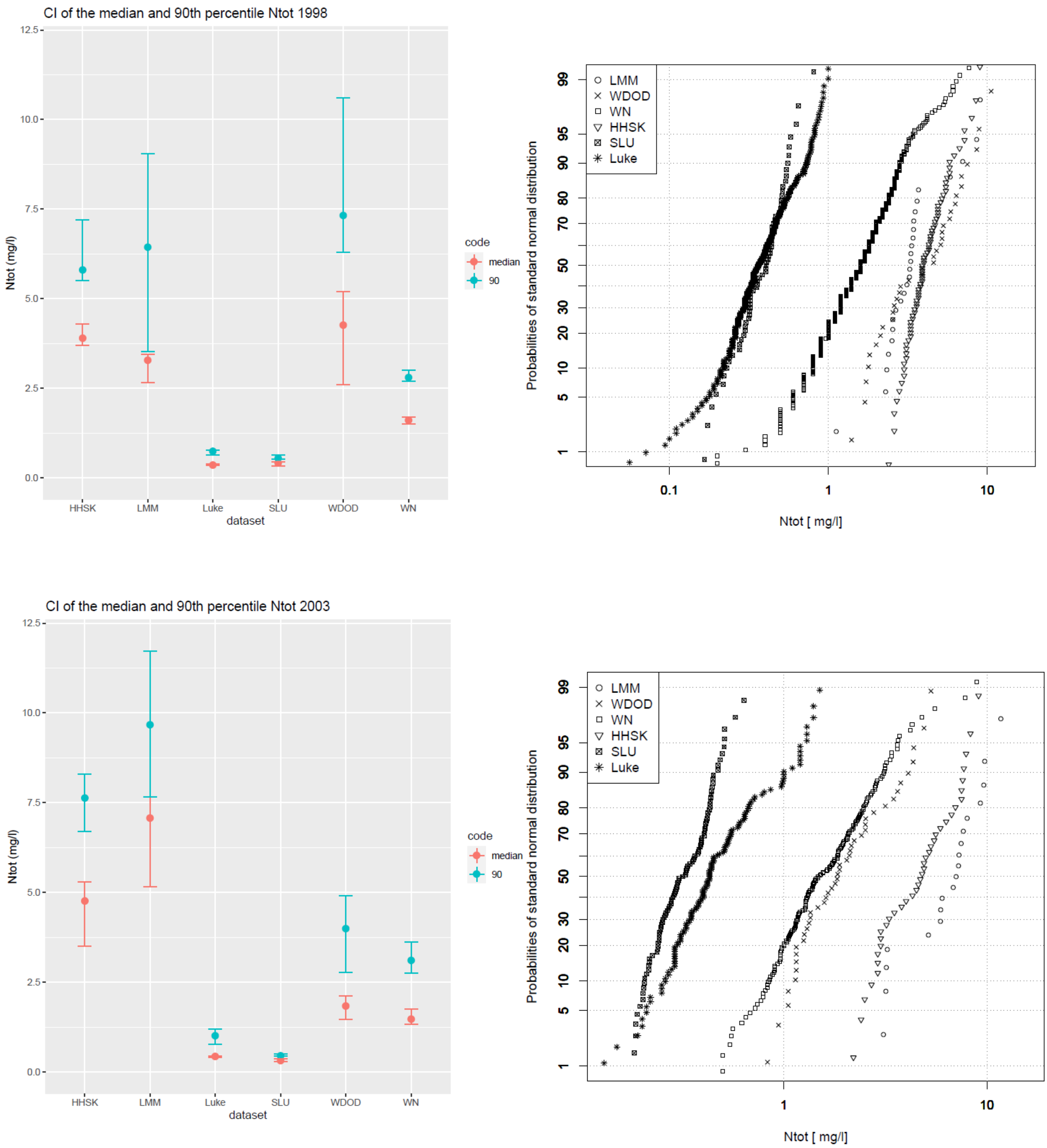

Figure 9.1 Plotted median and 90th percentiles of total-N in 1998 (top) and 2003 (bottom) with confidence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plots is on a log scale. Study areas: **1998:** LMM (n = 26), WDOD (n = 34), WN (n = 515), HHSK (n = 77), SLU (n = 65) and Luke (n = 360); **2003:** LMM (n = 20), WDOD (n = 44), WN (n = 179), HHSK (n = 38), SLU (n = 99) and Luke (n = 137

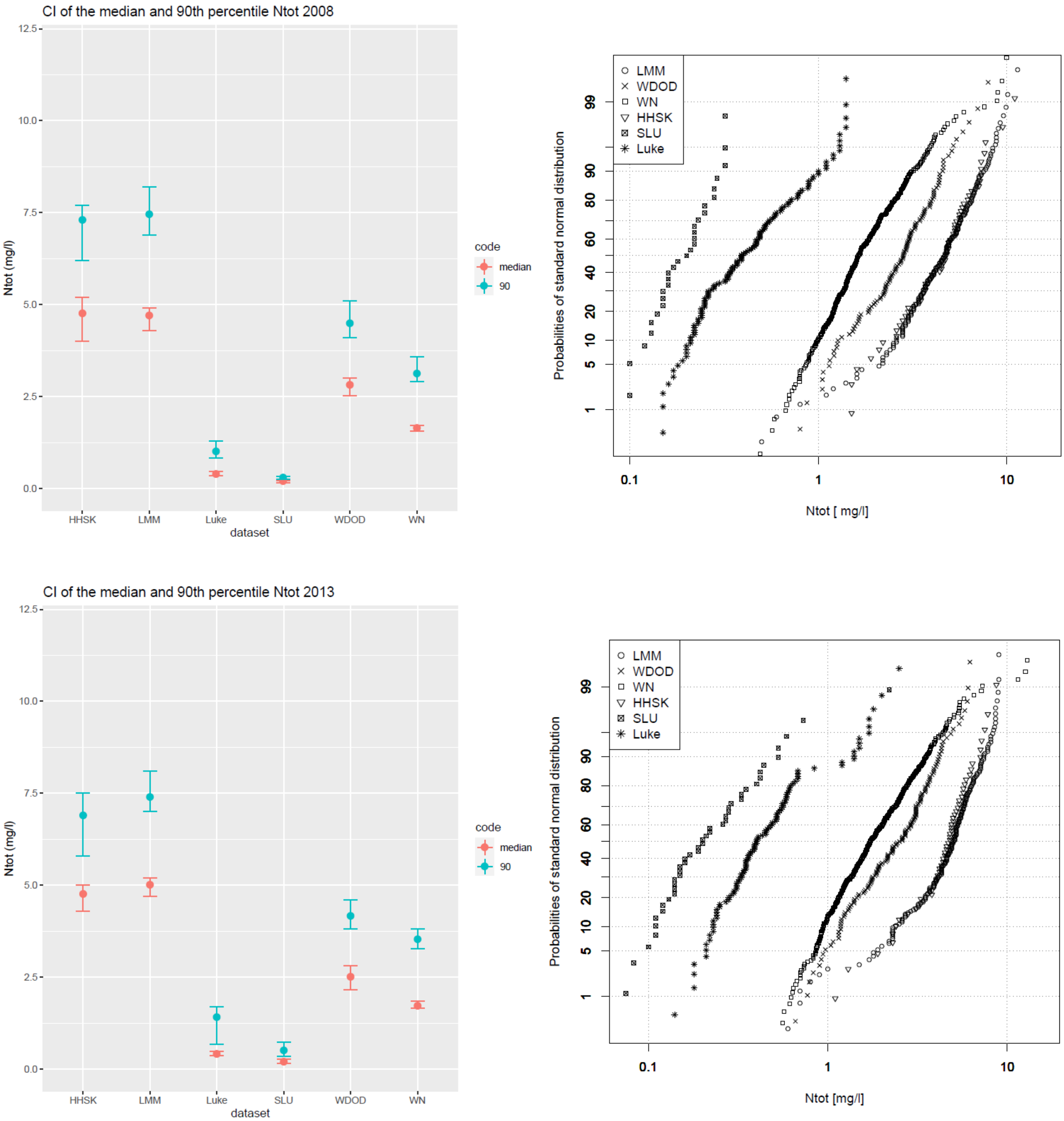

Figure 9.2 Plotted median and 90th percentiles of total-N in 2008 (top) and 2013 (bottom) with confidence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plots are on a log scale. Study areas: 2008: the LMM (n = 203), WDOD (n = 115), WN (n = 370), HHSK (n = 58), SLU (n = 29) and Luke (n = 134). 2013 LMM (n = 200), WDOD (n = 143), WN (n = 468), HHSK (n = 54), SLU (n = 44) and Luke (n = 107)

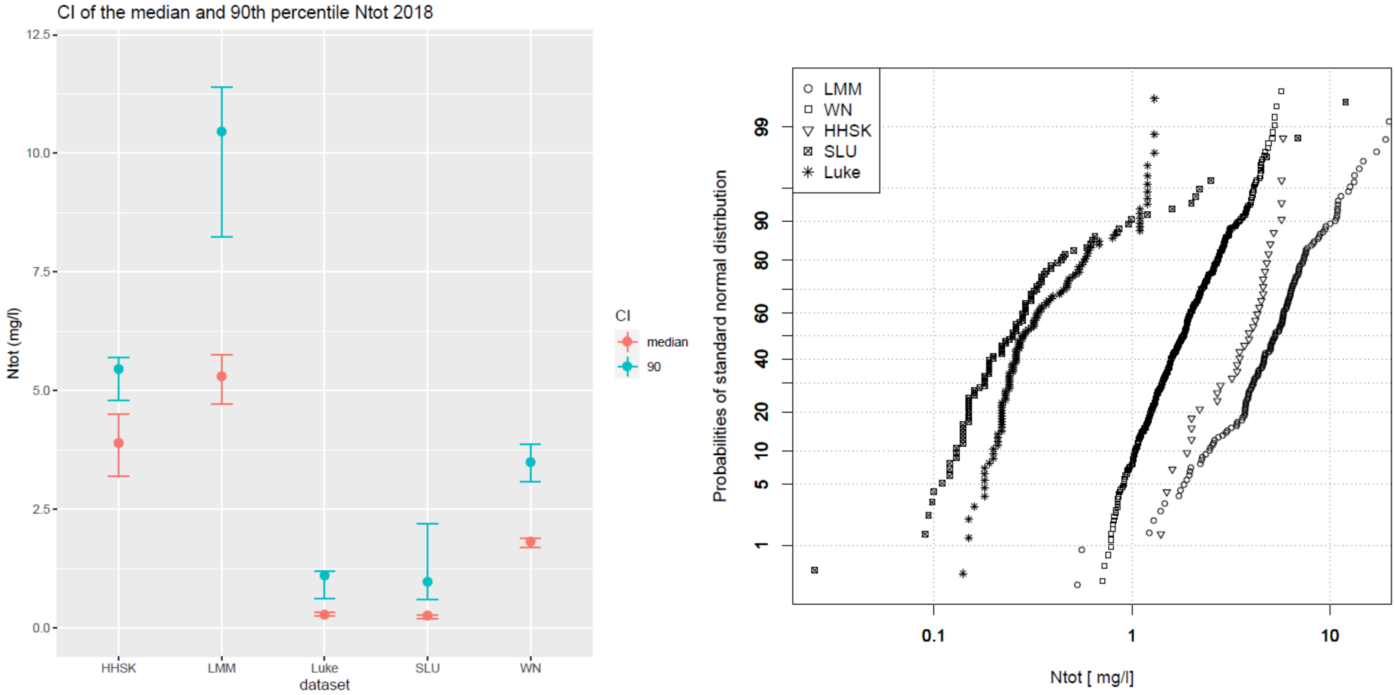

Figure 9.3 Plotted median and 90th percentiles of total-N in 2018 with confidence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plot is on a log scale. Study areas: 2018: the LMM (n = 174), WN (n = 468), HHSK (n = 36), SLU (n = 108) and Luke (n = 120)

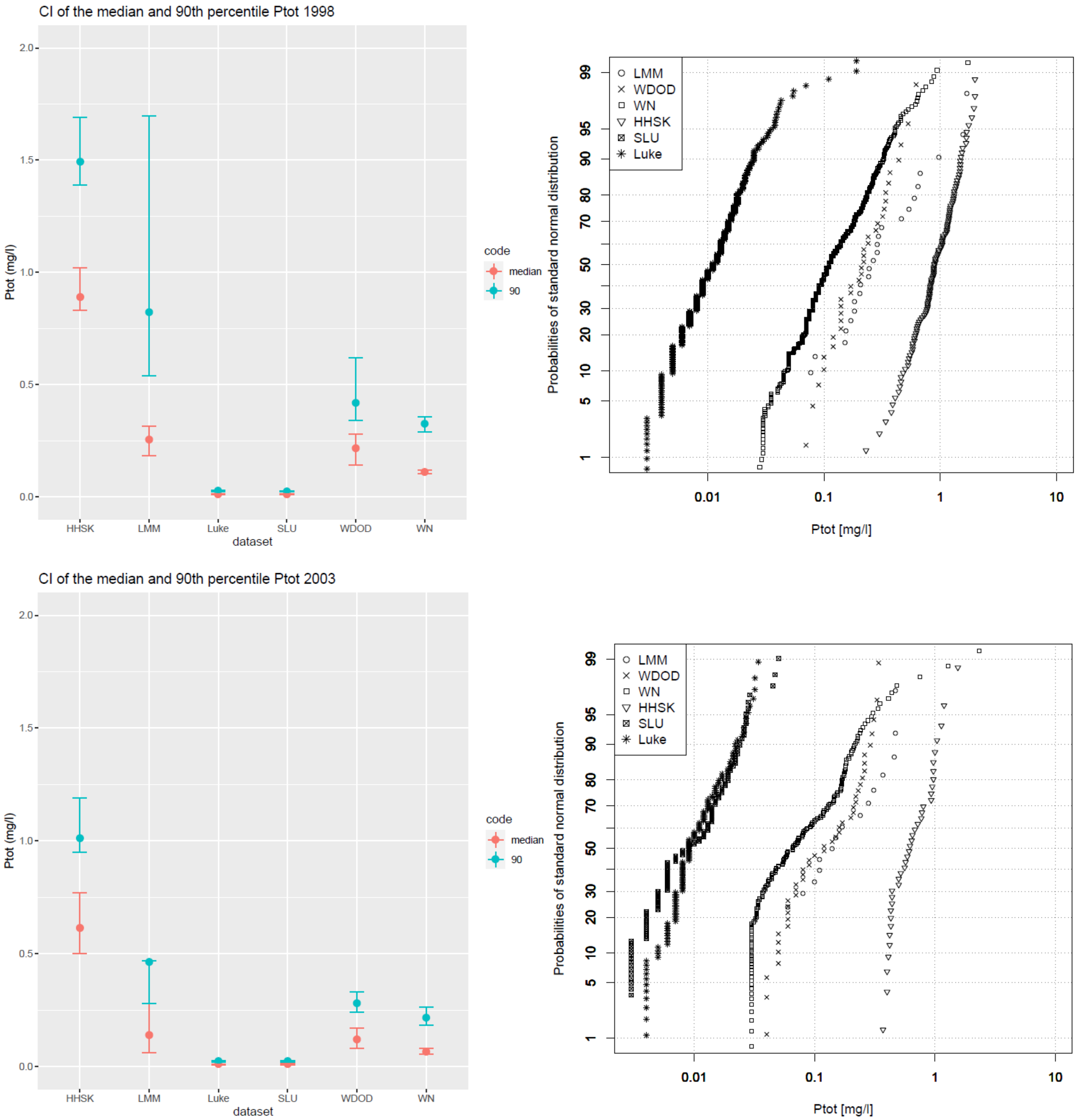

Figure 9.4 Plotted median and 90th percentiles of total-P in 1998 (top) and 2003 (bottom) with confidence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plot are on a log scale. Study areas: 1998: the LMM (n = 26), WDOD (n = 34), WN (n = 480), HHSK (n = 120), SLU (n = 160) and Luke (n = 363). 2003: LMM (n = 19), WDOD (n = 44), WN (n = 198), HHSK (n = 38), SLU (n = 152) and Luke (n = 137)

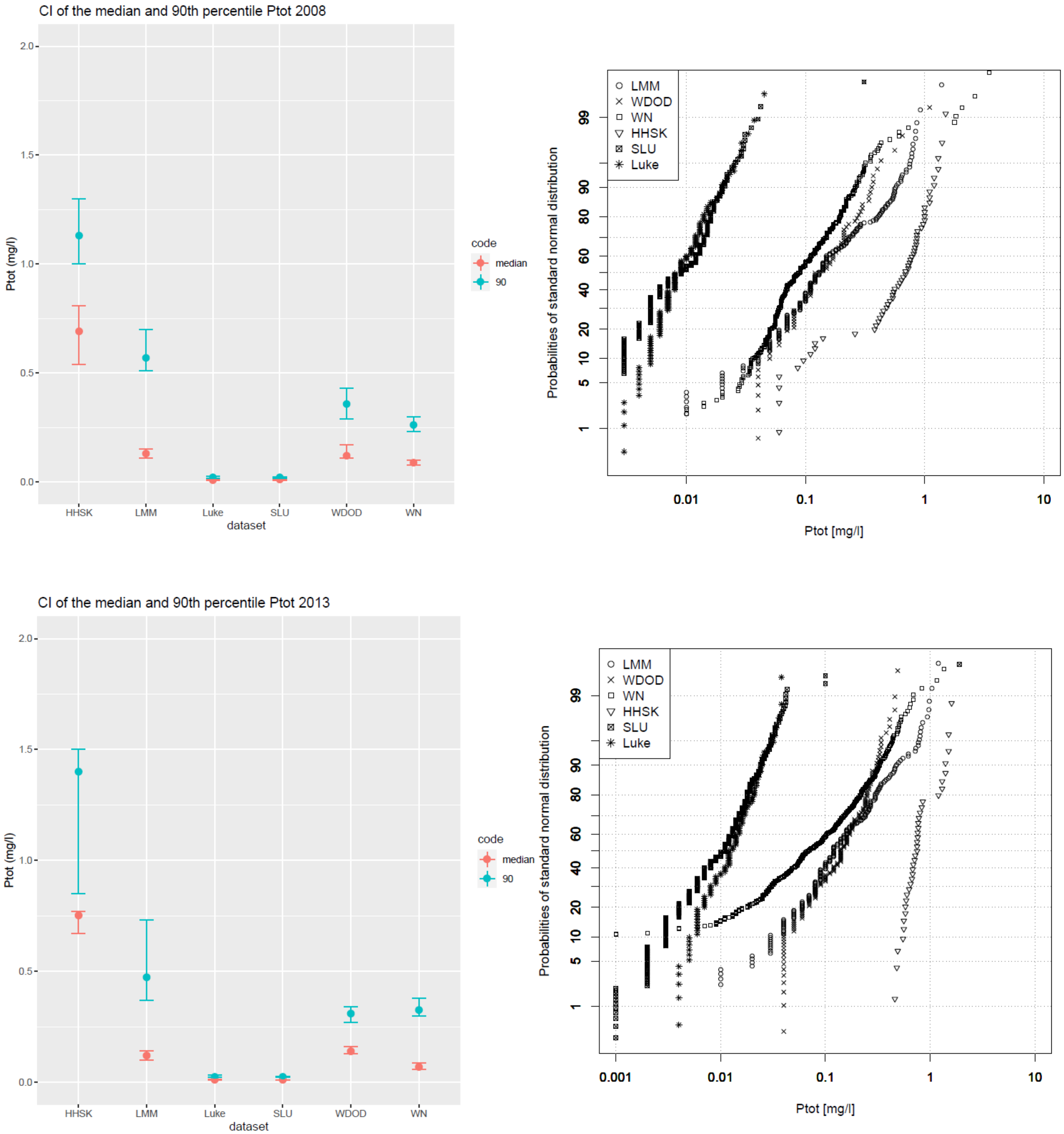

Figure 9.5 Plotted median and 90th percentiles of total-P in 2008 (top) and 2013 (bottom) with confidence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plots are on a log scale. Study areas: 2008: the LMM (n = 203), WDOD (n = 75), WN (n = 370), HHSK (n = 58), SLU (n = 234) and Luke (n = 134). 2013: LMM (n=200), WDOD (n=143), WN (n=468), HHSK (n=37), SLU (n=572) and Luke (n=107)

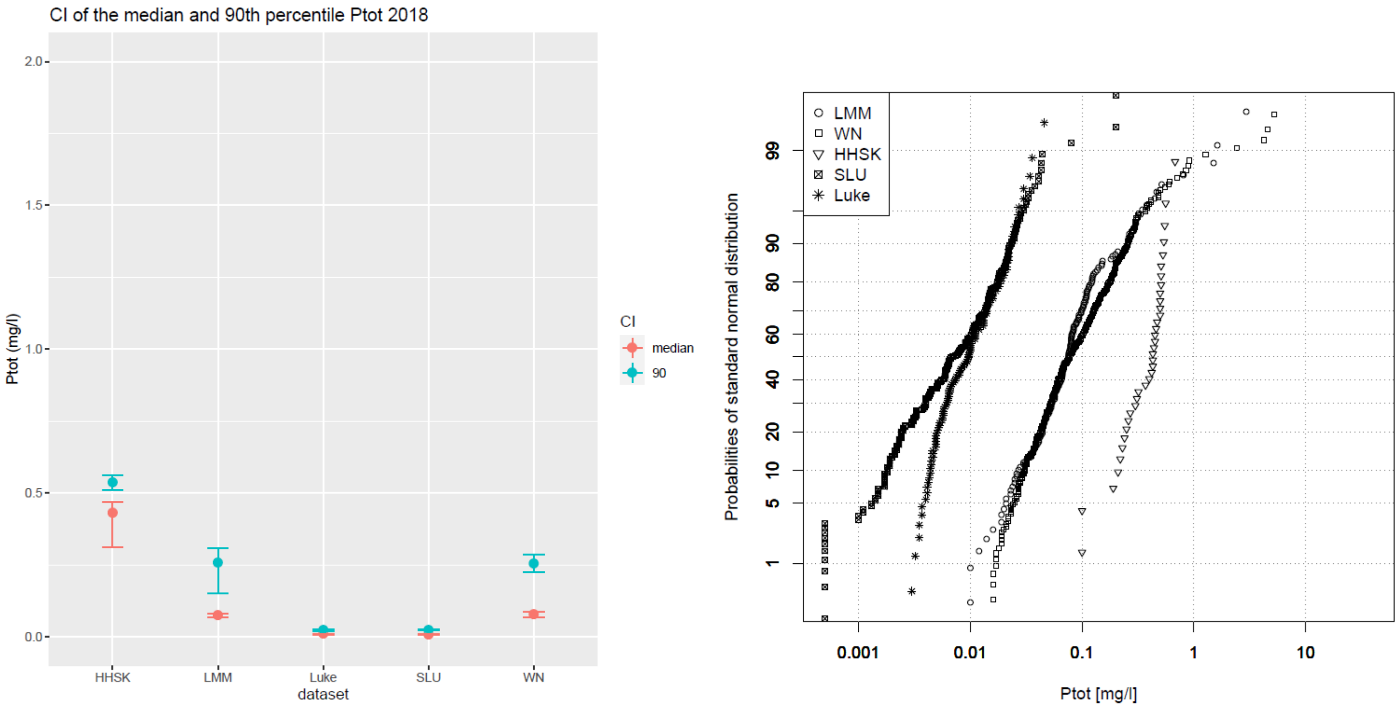

Figure 9.6 Plotted median and 90th percentiles of total-P in 2018 with conficence interval of the median and 90th percentile. Cumulative probability plots of the measurements per study area on the right, note that the x-axis of the CP-plot is on a log scale. Study areas: 2018: the LMM (n = 174), WN (n = 482), HHSK (n = 36), SLU (n = 313) and Luke (n = 120)