The potentials to improve the macrophytes in polder ditches within the management area of water board “De Stichtse Rijnlanden”

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Master thesis

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HOOGHEEMRAADSCHAP
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RIJNLANDEN

English abstract

A number of water bodies in the management area of the Water board 'De Stichtse Rijnlanden' (HDSR) should meet the requirements of the Water Framework Directive (WFD). The WFD has determined that these water bodies must have a '*good ecological status'* by 2015. To assess ecological status, the WFD requires the definition of reference conditions using biological, physical and chemical indicators and an assignment of the water bodies to one of the five quality classes.

By focusing solely on the WFD water bodies, management options to increase the ecological status outside the WFD water bodies may be ignored. The water system in a polder is connected, whereby the WFD water bodies are heavily influenced by the rest of the water system. Eutrophication of polder ditches by over-fertilization and polder inlet water, with nitrogen and phosphorus, causes a shift from mainly submerged vegetation to a dominance of *Lemna* (Duckweed). While submerged vegetation is the desired status.

In this research, the main aim was to find catchment areas which show potential for improving the macrophyte status in the management area of Water board 'De Stichtse Rijnlanden'. Seven interesting catchment areas have been chosen to use as research areas. This is done on the basis of several criteria to have a diverse selection of areas and macrophyte statuses in order to be representative for the HDSR area.

The model PcDitch calculates the 'critical nutrient level' of the external nutrient loads above which shifts in vegetation are likely to occur. This model is used to determine the potential for macrophytes in two steps. First the actual nutrient load in a polder is compared to the critical nutrient load to determine the present status. Second the effect of implementation of dynamic water levels on the actual and critical nutrient load was determined. To what extent this measure was considered favourable for a catchment area depended on the reduction of the critical and nutrient load. The reduced nutrient load should be lower than the adapted critical nutrient load. This is a pre-condition for submerged plants to be able to recover. As a second precondition the recovery time calculated by PcDitch needed to be within 20 years of simulation.

Based on these steps the areas Zegveld, Haarrijn, Hekendorp, De Pleijt and De Koekoek show potential for improving the macrophyte status. The simulated reduction of nutrient loads in the areas Maartensdijk and Langbroekerwetering is not sufficient enough to create a shift towards dominance of submerged vegetation.

It is recommended to treat the used critical nutrient loads from PcDitch with caution due to several uncertainties and model simplifications. With this in mind the output and method can be used as a basis to develop a new tool to create an overall view of the critical and actual nutrient loads within HDSR.

Preface

First of all I would like to thank Henk van Hardeveld for giving me the opportunity to conduct my thesis at the water board 'De Stichtse Rijnlanden'. An internship is a great addition in the process of conducting a master thesis. It is highly motivating and I got the chance to learn more about the water board.

I would also like to greatly acknowledge the constructive feedback and patience of my two supervisors Paul Schot from the Utrecht University and Henk van Hardeveld from HDSR. I highly appreciated the time invested to supply me with great advice of how my thesis could be improved and structured better. Furthermore, I want to thank my colleagues from HDSR. My special thanks goes to Ciska Blom for helping set up my proposal. My other colleagues were always there for me to provide information, they were always in for coffee with cake breaks and provided a pleasant working environment.

Furthermore, I want to thank Luuk van Gerven from 'Nederlands Instituut voor Ecologie' in Wageningen. Thank you for helping me to understand the model PcDitch and to let me work with the model. Without you I would not have been able to include PcDitch in my thesis.

At last I would like to thank my family and friends for their faith, enthusiasm and support in these 10 months. In particular I want to thank, Sanne de Groot and Marjon Hendriks for helping me to improve my thesis.

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1. Introduction

1.1 Water Framework Directive

During the past decades there has been increasing concern about changes in the quality of surface waters of European lakes, rivers and ditches. The degradation is often attributed to excess nutrients, principally compounds containing nitrogen and phosphorus entering the water body (Janse and Van Puijenbroek, 1998). To improve and preserve the overall quality of water bodies in the European Community the Water Framework Directive (further referred to as WFD) was introduced in Europe in 2000. The WFD states: '*This Directive aims at maintaining and improving the aquatic environment in the Community. This purpose is primarily concerned with the quality of the waters concerned. Control of quantity is an ancillary element in securing good water quality and therefore measures on quantity, serving the objective of ensuring good quality, should also be established'* (European parliament and council, 2000 article 18).

The WFD covers all uses and types of water and the ultimate aims are prevention of further deterioration and most important achieving a 'good ecological status' of all European waters by 2015.

The Directive establishes a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. This means that:

- The aquatic environment will be protected and future deterioration prevented;
- Sustainable water use will be promoted, and will be based on long-term protection of available water resources;
- Protection of the aquatic environment will be enhanced and improved through reduction of discharges and emissions;
- The pollution of groundwater should stop;
- The effects of floods and droughts has to be reduced and controlled. (Project Environmental Risk Governance of the Baltic Sea, 2010).

The WFD regulations and ambitions are secured in a methodology for the Netherlands called 'Besluit Kwaliteitseisen en Monitoring Water' (further referred to as BKMW) (BKMW, 2009). All the Dutch water boards follow this methodology in order to fulfil the requirements of the WFD. This methodology is based on the WFD methodology and is specified for all water types in Netherlands, from small natural water bodies to large rivers. These types are specifically defined by the WFD as natural, heavily modified and artificial. Each type defines the environmental reference conditions of a water body. These reference conditions describe an undisturbed water body of this type and the standard to reach is the 'good ecological status' in a water body with respect to this reference level (Mostert, 2003). The BKMW methodology works with a classification method in order to determine an ecological status (*bad*, *inadequate*, *moderate*, *good*) of the water body. This is further explained in chapter 2.

The focus in the Netherlands is on WFD water bodies, the WFD has determined that these water bodies must be qualified *good* by 2015. The WFD water bodies are the larger waters in the Netherlands, which form only a small part of the Dutch water system. The definition from the WFD of a WFD water body is: *''Body of surface water' means a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or a stretch of coastal water'* (European parliament and council, 2000 article 2.10).

1.2 Water in the Netherlands

Most of the water bodies in the Netherlands are modified or artificial. Human activities, such as construction of dikes and normalization of water levels, caused the river to lose his naturalness and ecological integrity (Nienhuis et al., 2002). The water bodies in the Netherlands are characterized by a history of pollution (e.g. discharges of factories) and eutrophication (e.g. heavy discharges due to agricultural activities). In the last decades the external pollution (i.e. pollution from outside the water column) is reduced due to legislation but still runoff and seepage of nutrients from agricultural land and aerobic degradation of peat are present (Janse and Van Puijenbroek, 1998).

Ditches in the Netherlands cover a large and important part of all surface waters. They have been dug originally for the function of quantitative water management, primary for drainage and irrigation purposes from and to fields (Zuidam, van 2009; Arts and Leenders, 2006). In spite of this function, ditches can still be ecological valuable in the sense that they are able to support a high biodiversity (Williams et al., 2004) and they create diversity in the agricultural landscape (Zuidam, van 2009). Other functions of ditches are provision of habitat space for plants and to provide a drinking source for animals and cattle (Liere et al., 2007; Janse, 2005).

The vegetation composition in low to moderately eutrophic ditches is characterized by a dominance of slow-growing and diverse submerged vegetation and helophytes. An enrichment of the nutrients causes a dominance of one or two submerged species. In highly eutrophicated ditches become dominated by fast-growing floating plants such as *Lemna* (Duckweed) or *Azolla* (floating fern) (Janse and Van Puijenbroek, 1998; Scheffer, 2003; Lamers et al., 2012). This effect of nutrients is more extensively explained in chapter 2.3.

In the area of HDSR is currently a constant target water level kept which differs per polder. Water is drained when it exceeds the target level, or when the water gets below the target level, water is pumped in. Often in summer and winter a different target level is used. This water level management is particularly used for agricultural areas, whereby the winter water level is often kept lower than the summer level.

The research of Schep et al., (2012) showed that dynamic water levels reduces the external nutrient load entering a water body or catchment area. With this reduction the macrophyte status should improve. This reduction might be obtained by implementing the measure flexible water level management. If flexible water level management is applied in a polder no fixed water level is determined throughout the year. The water level can fluctuate in a more natural way between an upper and lower water level limit. The range between these levels can vary from five centimeters till 0.5 meters, depending mainly on the land use in the polder. In winter the water level will most of the time meet the upper limit, if the water exceeds this limit water will be drained. If in spring the evaporation increases, the water level will drop. In summer the water level can drop until the lower limit. The measure leads to less inlet of water from outside a catchment area, water will only be pumped in when the level gets below the lower limit. Between the extremes the water level can freely fluctuate, depending among other factors on the distribution of precipitation during the year (Schep et al., 2012).

1.3 Problem description

The WFD water bodies constitute only a small part of the water systems in a catchment area. Their physical characteristics, such as proportions, nutrient load and hydraulic load, differ from the rest of the water system, which mainly consists of ditches. Yet the Dutch BKMW only aims at improving the WFD water bodies (BKMW, 2009). First assumption behind this policy is that the WFD water bodies are representative for the entire water system. Secondly it is assumed that in order to improve the WFD water bodies improvement of the rest of the system is required, since the WFD water bodies are heavily influenced by the rest of the water system. Both assumptions are debatable. As the physical characteristics of WFD water bodies differ from the rest of the water system, the potentials to achieve a good ecological status differ as well. Moreover, by focusing solely on the WFD water bodies, management options to increase the ecological status outside the WFD water bodies may be ignored. If a good ecological status in the WFD water body proves to be unfeasible, the risk is that one writes off the rest of the water system as well. Or if a good ecological status in the WFD water body is achieved, no further measures are taken to improve the status outside the water body, even if this can relatively easily be achieved. Therefore Water boards may profit from knowledge on the potentials to improve the ecological status outside the WFD water bodies. This knowledge will help to constitute a management strategy that will improve the ecology status in the largest possible part of the water system. Yet it is still not sufficiently known what the variability in ecology status in the ditches is and how this variability can be explained. In addition it is unknown where the potentials to improve the water quality in a more effective way lie.

The Dutch water board 'De Stichtse Rijnlanden' (further referred to as HDSR) has initiated research to study the above mentioned potentials of improving the macrophyte status of ditches outside the WFD water bodies. The area of HDSR is situated in the middle of the Netherlands and covers almost the whole province of Utrecht (figure 1) (HDSR, 2009).

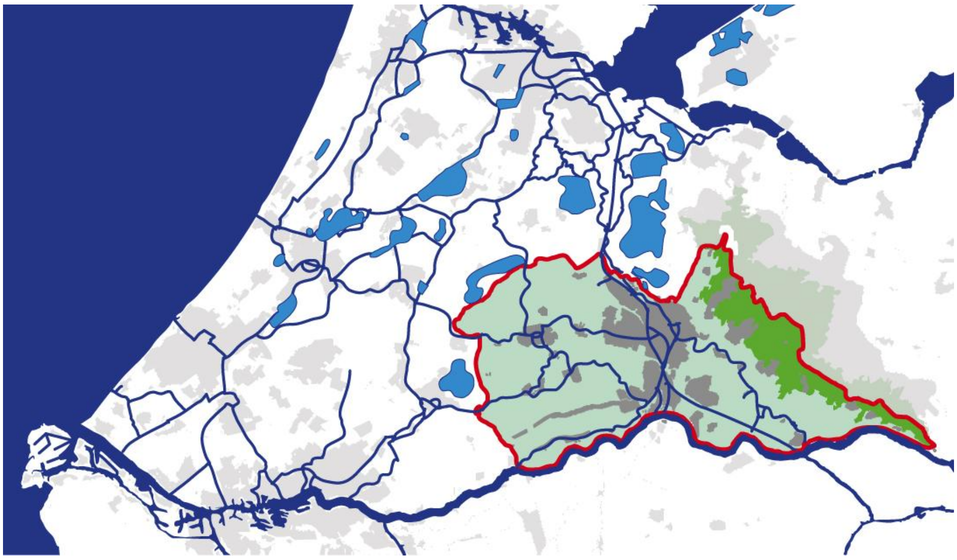


Figure 1: *The HDSR area within the Netherlands.*

The water system of HDSR consists of main watercourses the so called 'boezem' waters. HDSR consists of catchment areas of which the water level is lower than the 'boezem' water level; without all the pumps these areas would be permanently filled with water. HDSR is a divers area; the North-West of the management area is a peat meadow area. To the South-West peat soil is gradually replaced by clay deposits from rivers. The most southern border is the river Lek. In the middle part urban areas dominate notably the city Utrecht.

The altitude of the eastern area with the sandy hill ridge 'Utrechtse Heuvelrug' is a about 50 meters higher than the peat meadow area and has less surface water than the western part. Moreover levees from former rivers are present alternated with fluvial clay from the present rivers and clear seepage water comes from the 'Utrechtse Heuvelrug'. The land use is divers in this part, pastures, orchards and country estates alternate. The water in the area is controlled by weirs and by pumps. Weirs extend the residence time of the water in the area (HDSR, 2013).

Each catchment area is a closed-off system with his own water level and is regulated by pumps and inlet devices. HDSR is divided in 63 catchment areas, each area his own water system and associated water level. Figure 2 presents one of the 63 catchment areas within the HDSR, called Zegveld. It shows the difference between the many ditches and the WFD water body; this is representative for the other catchment areas. It is clear that a major part of the HDSR water system consists of ditches. The whole HDSR area contains 31 WFD water bodies.

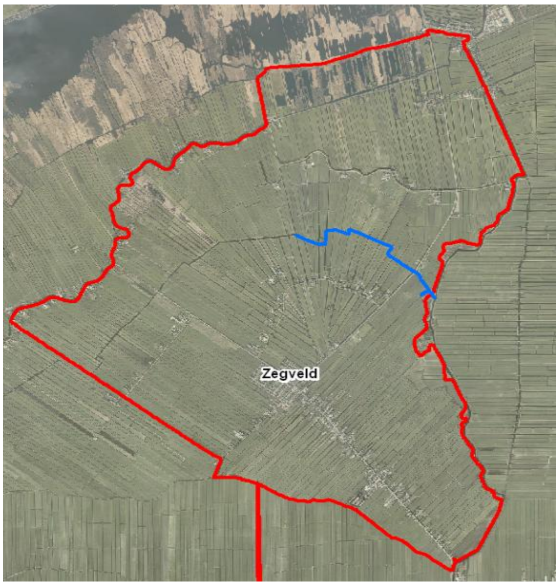


Figure 2: Catchment area Zegveld within HDSR. The blue line represents the WFD water body; (HDSR, air photo, 2011).

1.4 Objective and research questions

Improving the status of the ditches is necessary because the WFD aims at improving all the surface water and not only the WFD water bodies. Moreover the water from the ditches form input to the WFD water bodies. Thus the status of the water bodies are heavily influenced by that of the ditches. Improving the ditches will thus presumably have a positive effect on the water and ecological quality of the WFD water bodies. It is not yet known what management strategy is the most effective for improving the ecology status in the ditches. Flexible water level management is seen as a potential effective strategy.

The macrophyte status will be used as a general indicator of ecological status because the functioning and the overall biodiversity in a ditch is for a large part determined by the species composition of macrophytes (Zuidam, 2012). The presence of submerged macrophytes and Nympheaids has a positive effect on the faunal diversity (Janse and Van Puijenbroek, 1998) and is therefore seen as an indicator of a good macrophyte status. One of the greatest threats in the ecological value of a ditch is the dominance of floating plants such as *Lemna* (Duckweed). The mats of *Lemna* cause the disappearance of submerged and Nympheaids plants. This results in a very low diversity and biomass of aquatic fauna (Zuidam, 2012). As a result of the high nutrient load in ditches dense mats of floating plants are quite common (Zuidam, 2012). This makes macrophytes good bio indicators for eutrophication (Khan and Ansari, 2010).

The main objective of this research is to find locations with potential for improving the macrophyte status in the polder ditches within the management district of HDSR. To achieve this objective the following research question needs to be answered:

Which locations in the management area of water board 'De Stichtse Rijnlanden' show potential for improving the macrophyte status?

Nutrients are of major influence for the macrophyte status of a ditch (Liere et al., 2007) Reduction of the nutrient load is therefore an important first step towards clean and healthy conditions (Lamers et al., 2012, Liere et al., 2007). As a result the potential locations for improving the macrophyte status will be primarily linked to the nutrient load. Since with the measure of a flexible water level in a catchment area the influence of nutrient rich inlet water will be highly reduced. It will be examined to what extent this measure is favorable to apply in catchment areas. Depending on the catchment characteristics flexible water level management is a promising measure to improve the macrophyte status (Schep et al., 2012).

The main research question will be answered by the following sub-questions:

1. Which catchment areas within HDSR are the most interesting ones for this research?
2. What is the actual nutrient load compared to the critical nutrient load within the interesting catchment areas?
3. To what extent may flexible water level management lead to improvement of the nutrient load and macrophyte status in a catchment area of HDSR?

1.5 Outline of this research

Chapter 2 gives background information on the classification of ditches and the theory of stables states in water columns. Chapter 3 gives an outline of the available data and gives a description of the methods used to define the potential for improving macrophytes in ditches. Chapter 4 shows the results. Chapter 5 is the discussion and in chapter 6 the conclusion and recommendations are formulated.

2 Theoretical framework

2.1 Macrophyte classification of ditches by the WFD

Research from the research institute 'Stichting Toegepast Onderzoek Waterbeheer' formulated scientific criteria for the chemical status and the ecological status for a water body for the BKMW regulation. It determines environmental quality standards for the chemical substances in the water, it describes in which case a water body has a good chemical and ecological status (InfoMil, 2013; Stowa, 2013a).

This part explains the BKMW method of classification of WFD water bodies and ditches is explained. The purpose of the WFD is to reach a 'good status' in all surface water bodies in Europe. The good status is divided in a good chemical status and a good ecological status of the water. The good ecological status is divided in a good biological status and several requirements with respect to hydromorphology and physical-chemical. The biological status is tested on the basis of four quality elements (classifications): phytoplankton, macrophytes, marcofauna and fishes (Berg, van den and Pot, 2007; Mostert, 2003). Beside these quality elements all water bodies are of a particular type, each type defines the environmental conditions of a water body. Within the HDSR area there are no natural water bodies only artificial or modified ones. The ditches of HDSR are divided in the types M8 (peat soil ditches) and M1a (buffered freshwater ditches). This typology is based on environmental conditions which are determined by the climate, geology and geography (size, location, etc.) (Mostert, 2003; Verdonschot et al., 2003) and the human pressures in a water body, such as hydro morphological adaptations in the water body for shipping (Elbersen et al., 2002). For every type the natural or undisturbed reference condition is described, moreover the classifications for the different quality elements are set up. These reference conditions will serve as a basis for determining the status of the water (Mostert, 2003). The chemical status is explained below the table 1.

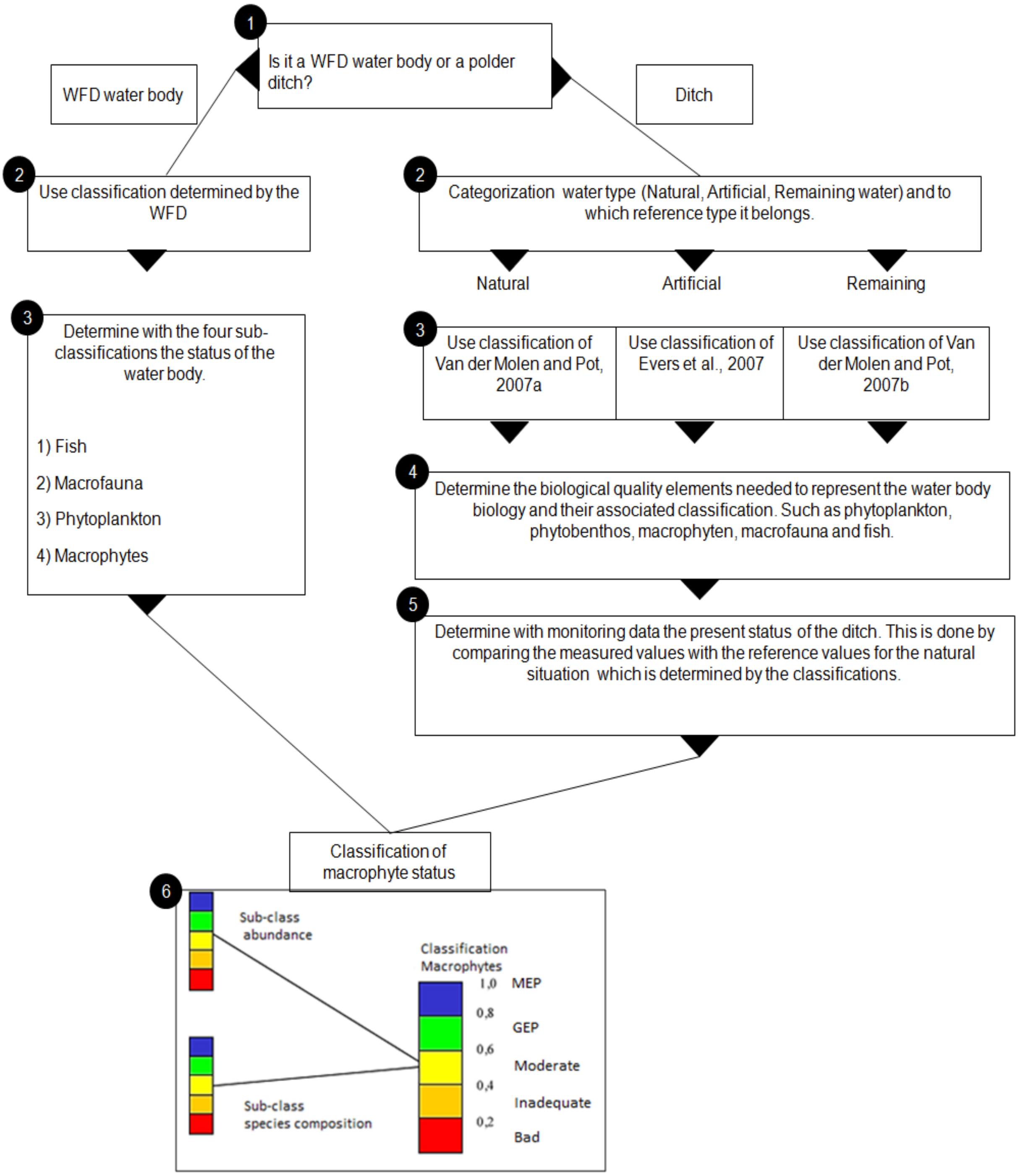
The steps which are taken in order to determine an ecological status are shown in the figure3 below and are explained here. The left part of the flow diagram represents the classification of a WFD water body, the right part of a ditch.

1. The first step is to define if the water body is a WFD water body or a ditch. The official classification by the WFD can be used for the WFD water bodies. For the ditches the nationwide concept classifications can be used to assess the ditches. These classifications are based on the official ones and recognized as concept classification.
2. The second step for the WFD water bodies is to follow the official classification method determined by the WFD. For the ditches the second step is a general categorization of the ditch. They can be divided into three categories: natural, artificial or remaining water.
3. In the third step the associated concept classification can be coupled with the categories. The following classifications can be used: for the natural ditches the classification determined by Van der Molen and Pot, 2007; for the artificial ditches the classification by Evers et al., 2007 and for the remaining waters the classification of Van der Molen and Pot, 2007.
4. The fourth step is to determine the type of ditch and to choose which biological quality elements are relevant to take into account by the various ditch types. The elements need to cover the human pressures on the ditch and need to represent the actual situation of a ditch. The four biological quality elements which can be used are: phytoplankton, macrophytes, marcofauna and fishes.
5. In the last step the measured data in the field is compared with the reference values for the natural situation which are determined by the classifications. The outcome of the comparison is a score, it represents the deviation relative to the reference state. As an example for the score the classification of macrophytes is shown below the flow diagram. The phytobenthos classification has not been taken into account, they are not important for the determination of the macrophytes (Vlieger et al., 2011).

In this research the focus is on the status of the macrophytes. In figure 3 can be seen that this element is split in two sub-elements/classifications: the coverage rate of the species and the species composition in the water. The coverage rate of macrophytes is used as indicator in the sub-classification 'abundance'. For the species composition all water plants, submerged and emerged vegetation within a water body are taken into account: floating plants, weed/FLAB and *Lemna* (Berg, van den and Pot, 2007). The maximum boundary for water plants taken into account isthe average high water mark. In figure 4 a ditch with a natural side bank is presented (Berg, van den and Pot, 2007) which gives an overview where the various plants are mostly situated in a ditch. At the sides the helophytes with their roots in the ditch sediment. The nympheaids, such as water lily with their roots in the sediment and their leaves floating on the water, are situated in the middle part of the ditch. These are mostly mixed with floating plants, they are submerged and are not rooted in the sediment.

All components have the same outcome from the classification, see the macrophyte example in the flow diagram. Every classification has a calculated score between 0-1 that expresses the distance to the MEP-score. This score is evenly divided in ranges of 'Maximal Ecological Potential'; 'Good Ecological potential'; 'moderate'; 'inadequate' and 'bad' combined with a colour from blue to red (Evers et al., 2007). The 'Good Ecological State (GET)' is the ambition for the natural water bodies. For all the water bodies within HDSR the ambition is a 'Good Ecological potential (GEP)' because they all are artificial (created by human activity) or heavily modified (influenced by human activity) water bodies.

Figure 3: *Flow diagram representing the WFD classification steps in order to determine macrophyte statuses of WFD water bodies and ditches (Evers et al, 2007).*



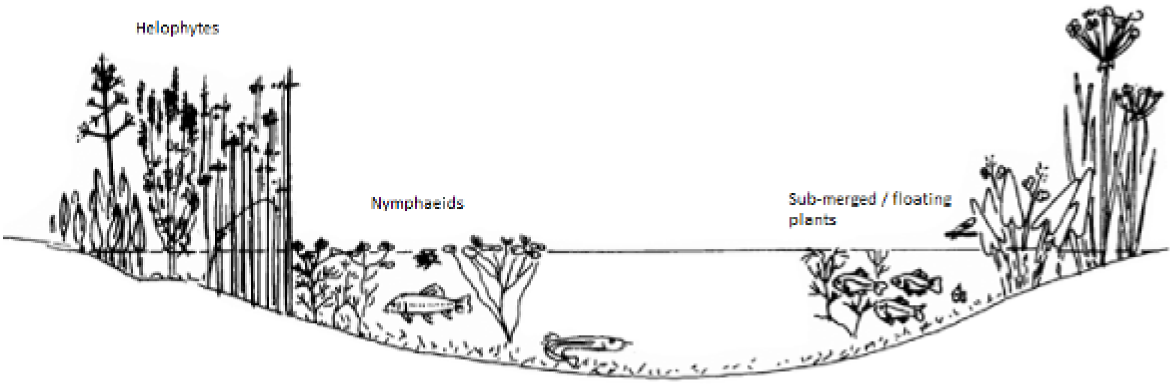


Figure 4: *Schematic figure of a ditch with natural banks. The helophytes are situated on the sides and rise above the water with their roots in the water. The Nymphaeids, such as lilies, are rooted in the sediment and have floating leaves. The sub-merged free floating plants are non-rooted and free floating in the water column (Liere et al, 2007; Berg, van den and Pot, 2007).*

2.2. Nitrogen and phosphorus classification of ditches by the WFD

For the chemical part of the WFD classification, physical chemical values are parameterized for various types of water bodies (Evers et al., 2007). For the ditches within HDSR two ditch types are used: M8 (peat soil ditches) and M1a (buffered freshwater ditches). In table 1 an example for the ditch type M8 is presented. It only represents the descriptors total-P (mg P/l) and total-N (mg N/l) since this is the focus of this research. The concentrations of nitrogen and phosphorus shown are the basis for the classification divided in MEP; GEP; moderate; inadequate and bad. All other water body types have their own specific physical chemical values.

Parameter	Descriptor	Unit	MEP	GEP	Moderate	Inadequate	Bad
Nutrients	Total-P	mg P/l	≤0.03	≤0.22	0.22-0.44	0.44-1.10	≥1.10
	Total-N	mg N/l	≤0.99	≤2.4	2.4-4.8	4.8-12.0	≥12.0

Table 1: *Requirements for peat ditches (m8)(Evers et al., 2007).*

2.3 Stable macrophyte states as a function of nutrient loads

The usual pristine state of water bodies is one of clear water with an affluent of submerged and floating vegetation (Scheffer, 2001). The overall biodiversity and the ecological functioning of a ditch is for a large part determined by the presence and the composition of vegetation in a ditch. It is of natural, human and economic importance that the biodiversity remains or increases. An invasion of free-floating plants like algae or *Lemna* is one of the greatest threats to the functioning and biodiversity in freshwater ecosystems like ditches. Such an invasion creates anoxic and dark conditions due to a thick layer of floating plants on the water column, leaving very little possibility for animal or plant species to flourish (Scheffer et al., 2003). On the other hand the presence of submerged macrophytes benefits the faunal diversity (Janse and Van Puijenbroek, 1998). It provides a habitat and shelter for the fauna (Mitsch and Gosselink, 1993). Therefore dominance of submerged over floating plants is favorable for the ecological status of a ditch.

Beside the importance of the presence diversity of vegetation types, the effects of nutrient loading is important.

Scheffer et al (2003) found three stable states of a water column (fig. 5). The parameter values, F=floating plants and N=nutrient concentration, are set to a default which mimic certain field situations to give an idea. The first stable state is when a low nutrient concentration is present in the water column, an equilibrium occurs with submerged plants. The second stable state occurs as the nutrient load increases, causing the emergence of floating plants (critical point X_m in fig. 5) and consists of a stable mix of floating and submerged plants. The last stable state appears when the nutrient load increases further (critical point F_m in fig. 5). The floating plants amplify gradually and the mixed equilibrium moves towards an equilibrium with a monoculture of floating plants (fig. 5, double arrow upward).

The reverse path from floating plants to submerged plants is different than the described path. When the nutrient concentration is reduced, the system will not return to the mixed equilibrium. It stays at the floating plant equilibrium until the *critical nutrient load* X_f is reached (fig. 5). From this critical point the system switches back to the equilibrium with submerged plants (fig. 5, double arrow downwards). The figure also shows a dashed line, this equilibrium is an unstable state, when this state occurs it will immediately shift to one of the stable states. The small arrows indicate which state, above this dashed line there will be a shift to the floating plants and under this dashed line it will shift to a mixed state. (Scheffer et al., 2003). This effect is called the 'hysteresis effect' due to the different critical loads for switching to alternative stable states. The critical load is influenced by several factors: depth of the water body, the length of the open water surface, soil type, conductivity, Biological Oxygen Demand (BOD), pH, hydraulic loading, measures and the fishing pressure (Janse, 2005; Jaarsma et al., 2008). So, several factors co-influence the ecosystem's response to nutrient loading, and the probability of the occurrence of a shift from predominantly submerged to a floating vegetation depends on the ditch characteristics (Janse, 2005).

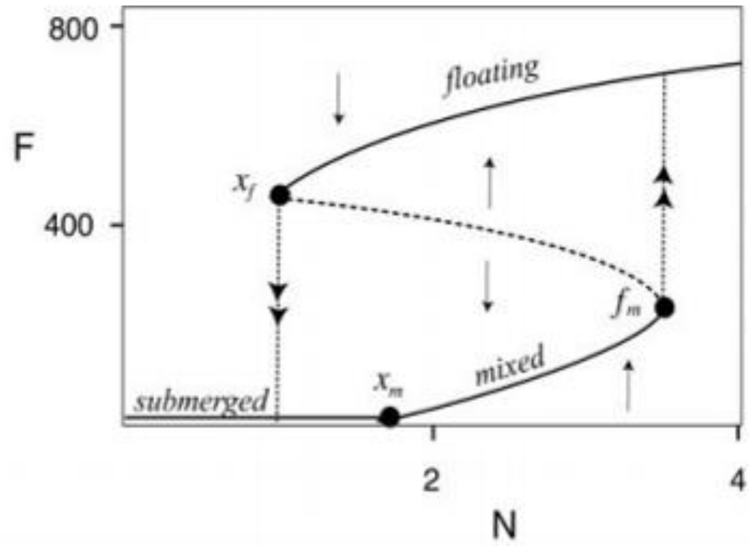


Figure 5: *The effect of nutrient loading (N) on the equilibrium biomass of floating plants (F) and submerged plants. The direction of change when the system is out of equilibrium is indicated by the arrows. They illustrate that the dashed equilibrium is unstable. The double arrows represent the catastrophic shifts to alternative stable states. These occur at the points xf and fm which are called critical nutrient loads. The parameter values are a default, which seems likely to mimic certain field situations (Scheffer et al., 2003).*

3. Method

In order to answer the research and sub-questions a step by step approach was followed. Every step in the process was directed to solve one sub-question and is defined by an action in combination with a methodology. The flow model of the research outline is summarized in figure 6.

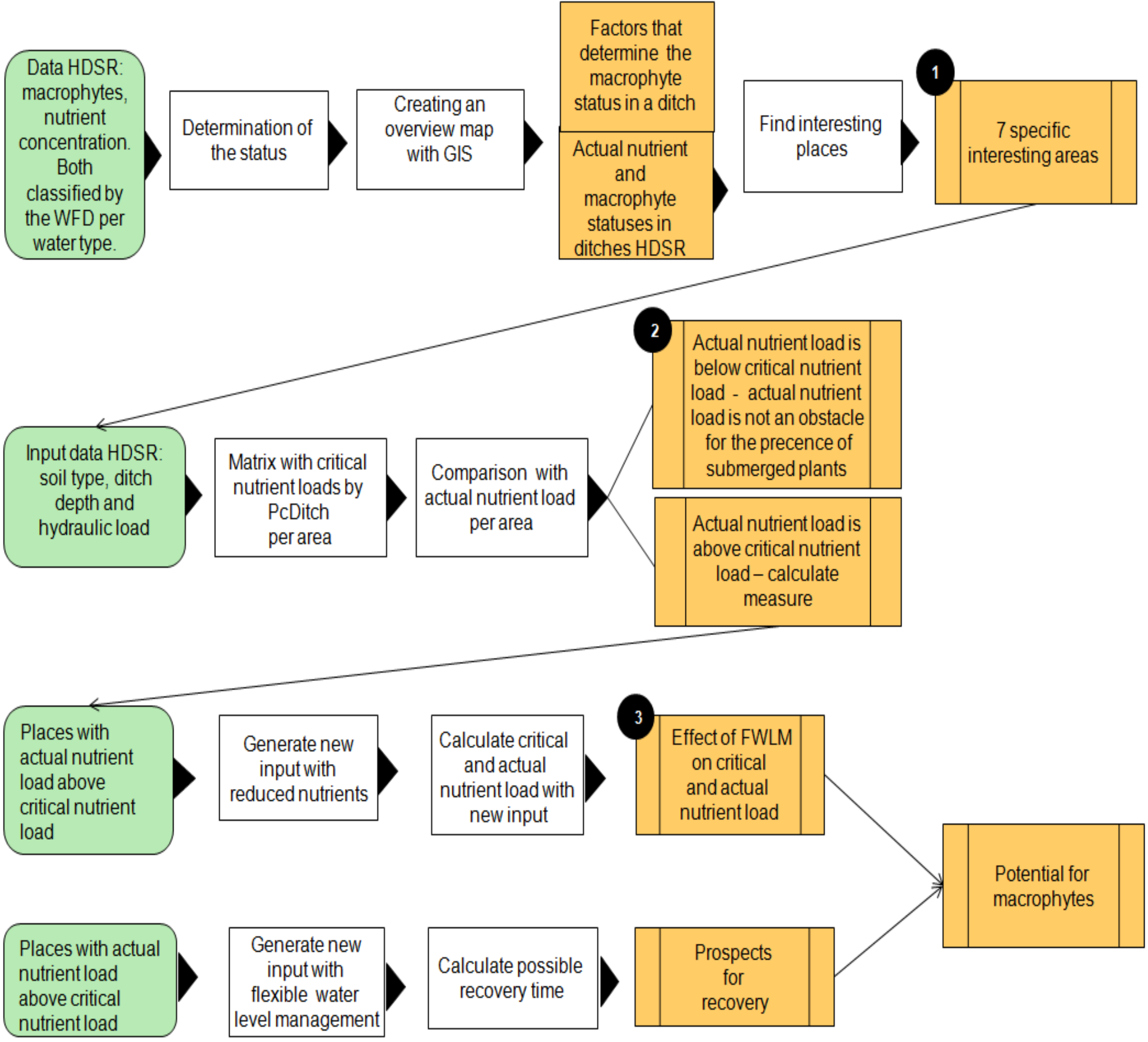


Figure 6: *Scheme of the structure of the methods used. The green boxes are the input data, white boxes are methods and the orange box are results.*

3.1 Selection of catchment areas by determination of actual nutrient and macrophyte statuses

This step will answer the first sub-question, shown in figure 7.

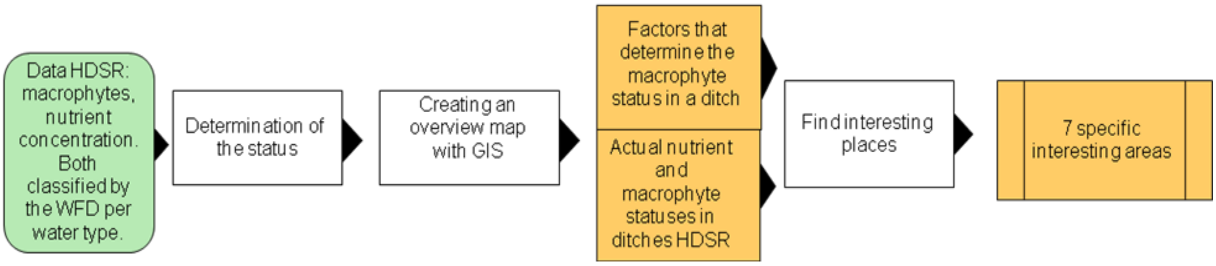


Figure 7: *Scheme of method used to chose seven specific areas. The green box refers to the input data. The white boxes to the methods used and the orange boxes to the results. This scheme corresponds with number 1 in figure 6.*

On the basis of the data, explained below, seven areas have been chosen as basis for further analyses due to time limits. It was considered important by HDSR to have a diverse selection of areas and ditch statuses in order to be representative for the complete management area of HDSR. The following criteria were taken into account;

- Diversity in distribution of the areas within HDSR;
- Diversity in soil type; clay, peat, sand;
- Areas where the status of the ditches is *moderate*, *inadequate* or *bad;*
- Diversity of ditch macrophyte statuses within a catchment area;
- Areas with contrasting statuses between ditches and WFD water bodies.

Firstly the actual nutrient statuses *in WFD water bodies* were determined using measurements of 2011 as input data and the method of classification by the WFD to determine the nutrient statuses. This method is described in chapter 2 (Evers et al., 2007). HDSR uses their regular measurement network to check the chemical concentration in their region. These measurement locations are located in WFD water bodies near in- and outlets of the catchment areas. The nitrogen and phosphorus concentrations for the year 2011 have been used because these were the most recent measurements. For each of the 108 chemical measurement points the nutrient concentration is compared to the norms of the BKMW classification for nitrogen and phosphorus in order to determine a nutrient status. In table 2 example norms for the nutrients are given for the M8 type (peat soil ditches).

Quality element	Descriptor	Unit	MEP	GEP	Moderate	Inadequate	Bad
Nutrients	Total- P	mg P/l	≤0.03	≤0.22	0.22-0.44	0.44-1.10	>1.10
	Total- N	mg N/l	≤0.99	≤2.4	2.4-4.8	4.8-12.0	>12.0

Table 2*: Requirements for peat ditches (type M8) for the different statuses, where MEP is 'Maximum Ecological Potential' and GEP is 'Good Ecological Potential' (Evers et al., 2007).*

Secondly, the macrophyte statuses *in WFD water bodies* are used. For all the 31 WFD water bodies within the HDSR area the vegetation statuses were available for 5 successive years (2007-2011). The classification process developed by the WFD was followed for a WFD water body, this is explained in chapter 2 and figure 3 (Evers et al., 2007). As earlier discussed the macrophytes within a water body represent the status of the vegetation. Therefore, the final score was calculated based on the macrophyte classification. The total score for the whole water body is based on several measurement points within the water body (table 3). The amount of measurement points differs between the water bodies and increases when a water body is longer. In this research the total scores for 2011 (0.29 in table 3) have been used as macrophyte status in a

WFD water body. The total score is an aggregation of the individual vegetation recordings. The Macrophyte Ecological Quality Ratio is based on the abundance of species and the species composition of all the site together. The total vegetation composition is than classified in one of the five classes determined by the WFD. Due to the aggregation of the vegetation composition the total score is always higher than the individual scores (Evers et al., 2007).

Zegveld (M8)	**Macrophytes Ecological Quality Ratio**
	2011
NL14_28 1	**0.19**
NL14_28 2	**0.25**
NL14_28 3	**0.23**
NL14_28 4	**0.20**
NL14_28 Total	**0.29**

Table 3: *Example of the ecological quality ratio of macrophytes in the Zegveld WFD water body, it defines the quality of the ecology in a water body. In the whole water body at four locations the quality ratio was determined. The scores shown in the represent the statuses.*

Thirdly the ecological statuses in ditches were used. This includes the macrophyte status, additionally on the visited locations the plant coverage and several ditch characteristics have been measured. The sampling locations in the ditches were randomly selected, though spatially divers, and are not part of an official routine network. In total 638 locations have been visited in the summers of 2011 and 2012 by HDSR. It was not possible to measure the ecology in all the ditches within HDSR due to lack of time. Therefore 104 locations of these 638 locations have been specifically measured. The remaining 534 have been visited by HDSR but have not been specifically measured. Instead, based on an expert-judgement it is assessed that these locations were similar to a formal measurement location close by and so were given the same status.

The ditches that have been measured were divided in WFD types M8 (peat soil ditches) or M1a (buffered fresh water ditches) to be able to formally assess them according to the BKMW classification method, which is described in chapter 2 and figure 3 (Evers et al., 2007). The results of this data are presented in annex 3.

3.2 PcDitch analysis

3.2.1 The actual nutrient load compared to the critical nutrient load

In order to answer sub-question 2 the analysis was done with PcDitch (Janse and van Puijenbroek, 1998). A more specific description of the model is given in annex 1. The schematic overview of this step is shown in figure 8.

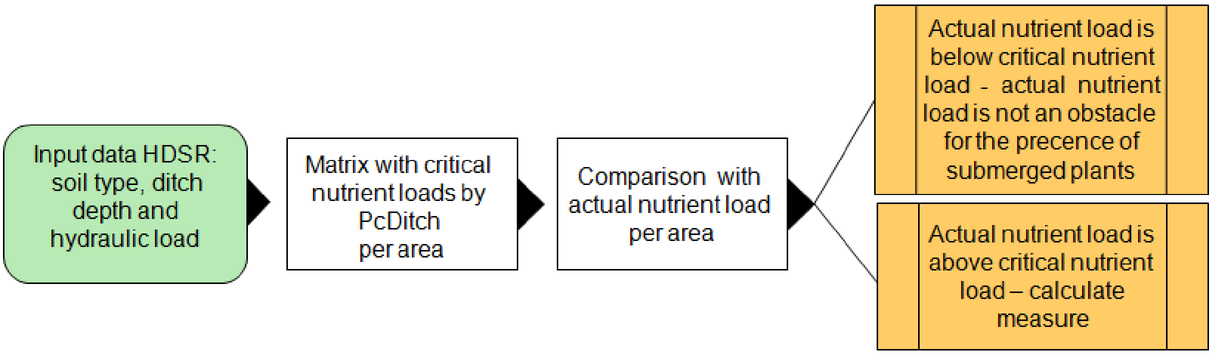


Figure 8: *Schematic overview of comparison between the actual nutrient loads and the critical nutrient loads given by PcDitch. The green box refers to the input data. The white boxes to the methods used and the orange boxes to the results. This scheme corresponds with number 2 in figure 6.*

PcDitch calculates the 'critical nutrient level' of the external nutrient loads above which shifts in vegetation are likely to occur. The 'hysteresis effect', as described by Scheffer et al., (2003) in chapter 2.3, is not included in the model PcDitch. This means the critical nutrient load is the same for the shift from submerged to *lemna* and for the backwards shift. The external loads are the nutrients entering a water body, this is specified in water balances. The critical nutrient load is important to know for management strategies to create a healthy ecosystem. PcDitch is a model build in excel, due to complexity of the model the model is controlled using R (see annex 2 for the whole script).

The advantage of using the nutrient loads instead of nutrient concentrations is such that in the latter case an important part of the nutrients is present in primary producers and sediment. Besides transport of nutrients, the external load and processes in a ditch such as nutrient retention and nutrient release from the soil (the internal load) are included in the concentration. The use of the external nutrient load is more reliable, because these processes are excluded. However, the disadvantage of nutrient loads is that they can only be modelled, or measured in experimental systems. Load cannot be measured in uncontrolled field situations, though with the increasing knowledge of the nutrient emission pathways from point and diffuse sources it is possible to give a good estimation what the nutrient load inputs into a water body will be (Behler and Opitz, 2000; Liere et al., 2007). In this study the nutrient load is used because PcDitch uses the nutrient load in the simulations and the nutrient load is quantifiable with for instance nutrient balances. The nutrient load is in contrast to the nutrient concentration a pure independent variable. The nutrient concentration is strongly influenced by aquatic vegetation, so this concentration is not able to explain the state of the aquatic vegetation because it is by itself a result of the state of the aquatic vegetation.

The input for the PcDitch model is the soil type (peat, sand, clay), average ditch depth for a catchment area (meters) and the hydraulic load (inflow) in mm/day. These input combinations are specified per selected area, so the ditch depth, soil and the hydraulic load are based on the available data per area. In this way the critical levels of PcDitch are specific for the chosen areas. The water system within the catchment areas was schematized in a hydrological balances for the flow of water in and out a catchment area. A nutrient balance of the in- and outflows was based on this schematization.

The hydraulic load is the volume of water which flows into an area or specific water column. It consists of: precipitation, inlet, surface runoff, seepage, drainage and sewer overflow. The unit used for the hydraulic load is mm/day. The hydraulic load was derived from the water balance of the catchment area, which was calculated by HDSR for this research with a spreadsheet model consisting of four interconnected volumes. Two volumes represent the soil in the catchment area, a third represents the sewer system and the forth represents the water system. Daily measurements of precipitation and evaporation were the main inputs. The amount of seepage was based on the results of MODFLOW a regional groundwater model. The connections between the four volumes (surface runoff, drainage and sewer overflow) were calculated by HDSR in the spreadsheet with the use of known properties of soil type, land use and sewer system dimensions. All these flows were instantaneously mixed in each volume for every time step of three hours. The resulting water balance was calibrated with the use of measurements of surface water levels, groundwater levels and the discharge of pumping stations. The inlet water was estimated to match the calculated and measured discharge.

The hydraulic load was further differentiated within the catchment area by distinguishing between an urban sub catchment (which receives the sewage overflow) and one or two rural sub catchments. For each sub catchment drainage and surface runoff were calculated based on the water levels, the elevations, the soil properties and the land use within the spreadsheet. A further distinction was made for all sub catchments based on the flow pattern of inlet water within the catchment areas. Using user knowledge of the way the water system is managed, in combination with known locations of inlets, pumping stations and main water arteries, a distinction was made. Areas with a high influence of the inlet water (Y inlet+) and places with less (Y inlet average and Y inlet -50%) or no (Y inlet -100%) influence of the inlet water. For each of these four categories of the spread of inlet water it was estimated in percentages to what extent these influence 'zones' were present in a catchment area. In this way each catchment area has been subdivided in up to twelve areas with different hydraulic loads (table 4).

Zegveld	***Estimated percentages***	***Hydraulic load (mm/day)***
Peat soil	Year Inlet+ (20%) Year average (45%) Year Inlet -50 (15%) Year Inlet -100% (20%)	63 52 48 44

Table 4: *The peat sub catchment of the Zegveld results for the average hydraulic load for the years 2007-2011. The urban sub catchment has been left out of consideration.*

With these specifications the PcDitch model calculated, for each hydraulic load as a function of the depth, the critical value for nitrogen and phosphorus load. These critical nutrient loads have been compared with the actual nutrient loads in a catchment area in order to determine if the actual load exceeds the critical load and if so whether theoretically floating plants like *Lemna* or submerged plants will be present.

The actual nutrient load refers to the total amount of nitrogen or phosphorus entering an area or specific water column during a given time. It is calculated with the same spreadsheet that is used for the water balance. All the considered water flows are multiplied by measured or calculated concentrations. In addition nutrient sources such as point discharges, manure and release from the stream bed are considered. Also processes such as denitrification and retention in the soil column are taken into account. Point discharges and manure application are based on measurements or estimations. Based on measurements in several Dutch ditches denitrification is estimated to remove on average around 30% of the total yearly nitrogen input (Veraart, 2012). Release from stream bed sediment is based on measurements (Dijkstra et al., 2013). The concentration of drainage and surface runoff is calculated by estimating the retention in the soil column, aiming for an equilibrium between in- and outflows.

The total nutrient load entering an area or specific water column (i.e. total inflow) consists of: precipitation, inlet of nutrients by the inlet water, surface runoff, drainage, seepage, sewer overflow, point discharges and release from stream bed sediment. The actual nutrient loads (g/m^2/year) in the ditches have also been subdivided in sub catchments and areas with more or less influence of the inlet water, in the same manner as the hydraulic load (table 5).

Both the hydraulic load and the actual nutrient loads are calculated each year for the years 2007-2011. The average value of these five years has been used as actual nutrient loads for the comparison with the critical nutrient loads calculated by PCDitch. As a condition for the results, the actual nutrient load should be below the critical nutrient load for submerged plants to be able to dominate, and the actual nutrient load should be similar or above the critical nutrient load for *Lemna* to dominate.

Zegveld	***Estimated percentages***	***Nitrogen (g/m^2/year)***
Peat soil	Year inlet+ (20%)	80.3
	Year average (45%)	71.2
	Year inlet -50 (15%)	67.9
	Year inlet -100% (20%)	64.6

Table 5: *The calculated average nitrogen load for the years 2007-2011 in Zegveld (HDSR, 2013). Within the areas a division is made for locations which are more (Y inlet+) or which are average (Y average), less (Y inlet -50) or not at all (Y inlet-100%) influenced by the inlet water.*

This comparison showed how much the phosphorus and nitrogen load exceeds the critical phosphorus and nitrogen load at which locations. Conclusions can be drawn to what extent a relation exists between the macrophytes in the ditches and the actual nutrient load in a ditch. When the actual nutrient load is below the critical nutrient load in a ditch stated as *bad* or *inadequate*, theoretically something else than the nutrients could be the problem. Moreover if the actual nutrient load exceeds the critical nutrient load the measure flexible water level management was simulated in PcDitch to determine if the nutrients loads were lowered enough to improve the macrophyte status. This is explained in the next paragraph.

3.3 Potential for improvement of the macrophyte status

A possibility to decrease the amount of actual nutrient load is to apply a flexible water level in the polder ditches. In this step it is examined to what extent this measure is favorable to apply and sub-question 3 will be answered. Figure 9 shows the scheme of this step.

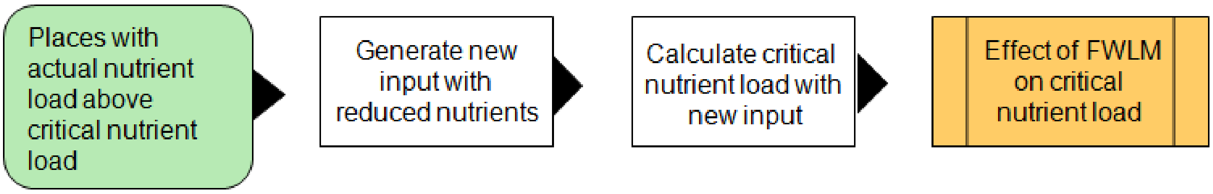


Figure 9: *Scheme of method used to determine the effect of flexible water level management. The green box refers to input data, the white boxes to methods and the orange box to the result. This scheme corresponds with number 3 in figure 6.*

By the application of flexible water level management the hydraulic load in a catchment area was reduced. The difference in the water balance with the original balance was that the flushing is zero (no extra water from outside the catchment area) and the inlet and drainage are reduced. The other parameters; precipitation, runoff, seepage and sewer overflow stay similar. The water level will regulate itself, intervention (e.g. pumping) is only needed when the maximum or minimum level is reached.

The average ditch depth is adapted with generally an increase of 0.05 meters or no increase, because the depth will fluctuate with a flexible water level.

Based on the adapted hydraulic load the actual nutrient loads were calculated in the same way as the original actual loads (3.2.1).

The critical nutrient load in a ditch was also changed due to the reduced hydraulic load and changed depth, and the associated adapted critical nutrient loads were calculated with PcDitch.

To what extent this measure was considered favourable for a catchment area depended on two conditions: the first one was that this measure needed to result in reduction of the external nutrient load which is beneath the newly calculated nutrient load. This is a pre-condition for submerged plants to be able to recover. The external load is not an obstacle anymore. The second pre-condition is described in the next section.

3.3.1 Recovery

Recovery of submerged vegetation following nutrient reduction is a very slow process, which involves the replacement of fast growing for slow growing vegetation (Duarte, 1995)

As a second precondition for flexible water level management to be considered favourable, the recovery time calculated by PcDitch needed to be within 20 years of simulation. If the ditch did not recover within these 20 years the reduction was not enough to break the *Lemna* dominance and thereby probably the inlet water was not the most important external load source. In figure 10 the scheme of this step is shown.

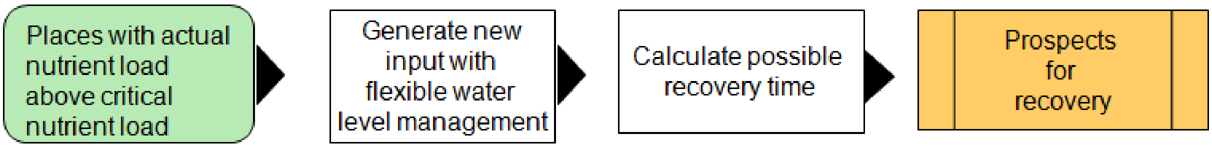


Figure 10: *Scheme of the methods used to calculate the prospects for recovery.The green box refers to the input data, the white boxes to the methods used and the orange box to the result.*

4. Results

This chapter shows the results of the different steps explained in chapter 3. The first section will focus on the chosen catchment areas within HDSR (4.1). Thereafter the result is shown of the PcDitch analysis (4.2). Next the implementation of flexible water level management is analyzed (4.3). Lastly the recovery time is shown when flexible water management in a catchment area is implemented (4.4).

4.1 Selection of areas within HDSR

Figure 11 shows the seven selected areas for this research; Zegveld, Maartensdijk, Langbroekerwetering, Hekendorp, Haarrijn, De Pleijt and De Koekoek. These seven catchment areas meet the criteria of the selection method: the areas are evenly distributed across the HDSR region, the soil types sand, peat and clay are present and a variety of nutrient and macrophyte statuses are within these areas (table 6).

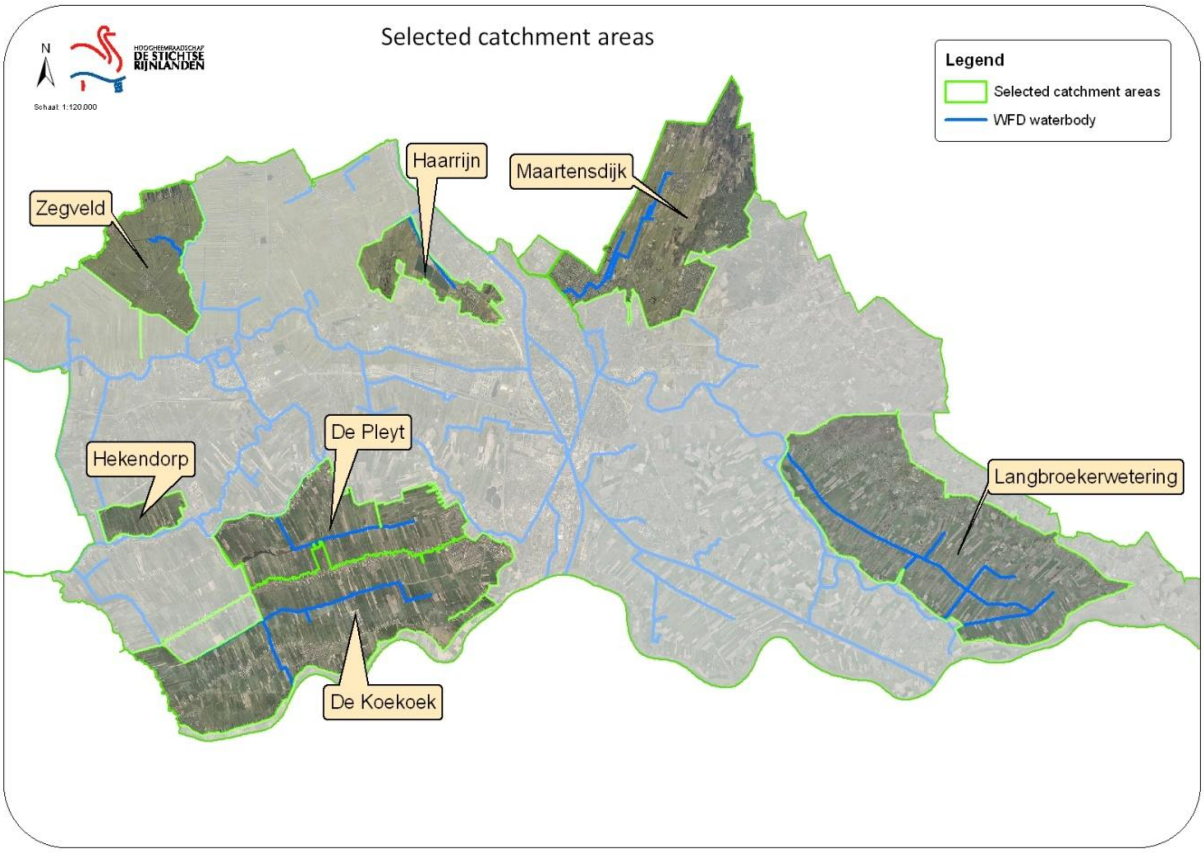


Figure 11: *Map of HDSR with the selected catchment areas.*

The nutrient and macrophyte statuses determined according to the BKMW classification are shown in table 6 for each catchment area. These statuses are also presented in a map per catchment area in annex 3. These areas are used for further analyses in the next paragraph in order to determine the potential for improving the macrophytes. A more detailed description of the areas can be found in annex 3.

Area	Soil	Macrophyte status	Nutrient status
Zegveld	Peat	Bad - Moderate	Moderate - Good
Haarrijn	Clay	Bad - Good	Good
Maartensdijk	Sand & peat	Bad - Moderate	Moderate - Good
Langbroekerwetering	Sand & clay	Bad	Inadequate - Good
De Koekoek	Clay & peat	Bad	Moderate - Good
De Pleyt	Clay & peat	Inadequate - Moderate	Moderate - Good
Hekendorp	Peat	Inadequate	Inadequate - moderate

Table 6: *Overview of the soil, macrophyte and nutrient statuses in the chosen catchment areas.*

4.2 The actual and critical nutrient load in an average ditch

Table 7 shows the critical nutrient loads, derived by PcDitch and the actual nutrient loads, calculated by HDSR, for all selected catchment areas. The critical nutrient loads are derived with PcDitch based on the hydraulic load, soil type and depth. The actual nutrient loads are calculated for average ditches within a catchment area, based on the water levels over the years 2007-2011.

The distribution of the inlet water within the catchment areas is divided into zones with a minimum, average and maximum hydraulic load. The maximum influenced ditches are situated between the inlets and pumps in the main watercourses. Ditches situated close and directly connected to the main watercourses receive an average water flow. Ditches located further away receive a minimum water flow. This is explained in more detail per catchment area in annex 3.

The table indicates that both the critical and actual nutrient loads increase with the hydraulic load. This makes sense, because an increase in influx will automatically result in an increase of the actual nutrient load. The critical nutrient load increases as well because an increase of flow rate will result in a decrease in residence time, giving macrophytes less time to consume the nutrient load.

In four of the seven catchment areas the actual nutrient load exceeds the critical nutrient load in the 'maximum zone', which according to PcDitch analyses indicates *Lemna* dominance. Besides, in two catchment areas the critical nutrient load is exceeded in the 'average zone'. Only in Langbroekerwetering also in the 'minimum zone' exceeds the actual nutrient load the critical nutrient load.

Mostly the nitrogen load is well below the critical nutrient load. Only in Maartensdijk and Langbroekerwetering nitrogen is an obstacle for the presence of submerged vegetation in the maximum influenced ditches.

The phosphorus load exceeds, or is closer to, the critical phosphorus load than nitrogen load at more locations. This could mean that phosphorus load is the main factor for the occurrence of *Lemna*.

Table 7: *Overview of actual and critical nutrient load for the selected areas. A division is made in hydraulic loads (minimum, average, maximum) and soil type. The bold actual nutrient loads represent the ones which exceed the critical nutrient load.*

Catchment area	Hydraulic load (mm/d)	Soil		Minimum		Average		Maximum	
				P	N	P	N	P	N
				$g/m^2/year$		$g/m^2/year$		$g/m^2/year$	
Zegveld Depth: 0.45 m	Min: 44 Average: 52 Max: 63	Peat	Actual load	2.11	65	2.92	71	**4.34**	80
			Critical load	3.11	99	3.31	100	3.52	109
Maartensdijk Dept: 0.4 m	Min: 40 Average: 45 Max: 95	Peat	Actual load	2.74	66	**3.61**	84	**8.44**	**179**
			Critical load	3.03	98	3.12	100	4.34	125
	Min: 35 Average: 45 Max: 90	Sand	Actual load	2.37	35	2.81	52	**8.10**	**147**
			Critical load	4.07	92	4.07	97	4.54	120
Langbroeker-wetering Depth: 0.4 m	Min: 60 Average: 110 Max: 135	Clay	Actual load	**5.40**	84	**6.86**	128	**7.60**	**150**
			Critical load	2.76	104	5.22	131	5.71	143
	Min: 15 Average: 60 Max: 143	Sand	Actual load	1.90	29	3.36	73	**5.95**	**150**
			Critical load	3.37	78	4.08	104	5.27	148
Hekendorp Depth: 0.45 m	Min: 14 Average: 16 Max: 20	Peat	Actual load	0.95	28	1.46	25	2.04	21
			Critical load	1.98	69	2.15	73	2.36	79
Haarrijn Depth: 0.45 m	Min: 13 Average: 25 Max: 30	Clay	Actual load	0.41	12	1.01	22	2.42	27
			Critical load	2.34	66	2.92	83	3.31	88
De Pleijt Depth: 0.4 m	Min: 20 Average: 30 Max: 65	Peat	Actual load	1.20	40	1.75	51	3.43	82
			Critical load	2.45	88	2.79	93	3.54	110
	Min: 20 Average: 30 Max: 65	Clay	Actual load	1.20	37	1.72	48	3.36	79
			Critical load	2.99	88	3.34	90	4.08	107
De Koekoek Depth: 0.55 m	Min: 15 Average: 30 Max: 60	Peat	Actual load	0.83	27	1.32	32	**4.03**	66
			Critical load	2.63	62	2.63	81	3.52	102
	Min: 15 Average: 30 Max: 90	Clay	Actual load	0.66	24	1.14	30	**6.07**	91
			Critical load	2.92	60	3.20	79	4.53	112

4.3 Possibility of implementation flexible water level management

Table 8 shows the adapted critical nutrient loads (derived with PcDitch) and the adapted actual nutrient loads (calculated with MODFLOW by HDSR) when flexible water level management is applied. The critical nutrient loads are derived with PcDitch based on the hydraulic load, soil type and depth. The actual nutrient loads are calculated for average ditches within a catchment area, based on the water levels over the years 2007-2011.

The outcome shows that in all areas both actual and critical nutrient loads decrease. The decrease in actual nutrient load is mainly caused by a reduced inlet, but also by a decrease of the drainage flux from the surrounding fields. The decrease in critical nutrient load is caused by the decrease in the hydraulic load. In most areas the actual nutrient load decreases more than the critical nutrient load. This does not apply for the zones with a minimum hydraulic load, because the decrease in inlet water does not influence these zones.

Only for the clay soils in Langbroekerwetering the actual phosphorus load still exceeds the critical phosphorus load after implementation of the measure.

***Table 8:** Adapted actual and critical nutrient load when flexible water level management is applied in the catchment areas. The bold actual nutrient load represents the one which exceeds the critical nutrient load.*

Catchment area	Adapted hydraulic load (mm/d)	Soil		P	N
				g/m^2/year	
Zegveld Depth: 0.45 m	10	Peat	Actual load	0.73	11.68
			Critical load	1.77	65.05
Maartensdijk Dept: 0.4 m	32	Peat	Actual load	2.5	67
			Critical load	2.85	94
	27	Sand	Actual load	1.99	64
			Critical load	3.94	89
Langbroeker-wetering Depth: 0.5 m	63	Clay	Actual load	**5.26**	77
			Critical load	4.08	101
	10	Sand	Actual load	1.35	17
			Critical load	3.07	52
Hekendorp Depth 0.52 m	12	Peat	Actual load	1.2	24
			Critical load	2.52	59
Haarrijn Depth: 0.5 m	12	Clay	Actual load	0.7	11
			Critical load	2.47	65
De Pleijt Depth: 0.45 m	19	Peat	Actual load	1.31	36
			Critical load	2.81	67
	19	Clay	Actual load	1.28	34
			Critical load	2.77	65
De Koekoek Depth: 0.6 m	16	Peat	Actual load	0.66	22
			Critical load	4.27	63
	16	Clay	Actual load	0.55	24
			Critical load	4.75	61

4.4 Prospects after nutrient reduction

Several original actual nutrient loads exceeded the critical nutrient load (table 7) and thus are likely to be dominated by *Lemna*. The prospect for recovery from a *Lemna* dominance to a dominance of submerged vegetation in these locations has been calculated with PcDitch when flexible water level management is applied in the polders.

Annex 4 shows all the prospect results of the calculations with PcDitch. For the peaty area Zegveld (figure 12) submerged vegetation will still be dominant up till seven years after implementation of flexible water level management in the high influenced zones. For the sand area of Langbroekerwetering the prospect for recovery after reduction is 13.5 years in the high influenced zone. For the catchment area De Koekoek recovery time is nine years on peat for the zone with a high hydraulic load and respectively eight years on clay for the zones with an average hydraulic load (annex 4).

In the areas Maartensdijk (figure 13) and Langbroekerwetering (annex 4) there is no recovery of submerged vegetation within the 20 years of simulation. For the peat area of Maartensdijk both the phosphorus and nitrogen load are reduced in the high influenced zones. It can be seen in table 6 that the adapted actual phosphorus load of Maartensdijk is just below the critical phosphorus load. This is not a sufficient reduction to be able to switch to submerged vegetation. However the reduction of the nutrient loads does lead to reduction of the *Lemna* biomass with approximately 45%. This reduction of *Lemna* could be seen as positive.

The actual phosphorus load of Langbroekerwetering still exceeds the critical phosphorus load. In the graph of Langbroekerwetering (annex 4) it can be seen that the *Lemna* biomass has not decreased on the clay soil in the averaged influenced zone. This means flexible water level management does not have the desired effect in this catchment area.

For the catchment areas (Haarrijn, Hekendorp and De Pleijt) the original actual nutrient loads did not exceed the original critical nutrient loads. In general flexible water level management will improve the conditions for submerged vegetation in these areas as well. Since PcDitch predicts submerged vegetation to be dominant already, flexible water level management will not result in a vegetation type change (dominance by *Lemna* or submerged vegetation) in these areas.

Figure 12: *Simulated Lemna (Duckweed) biomass as a function of phosphorus load in the peat area. Starting with a pristine ditch the phosphorus load was increased to the actual phosphorus load (4.3 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (0.73 g/m²/year). The oscillations in the graph represent the seasons in light and temperature.*

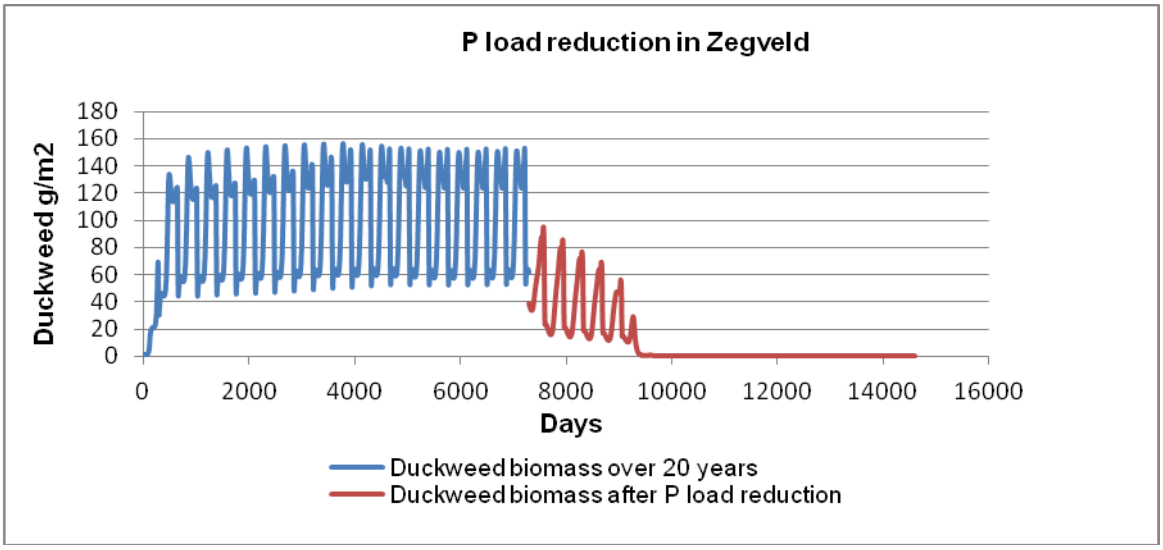
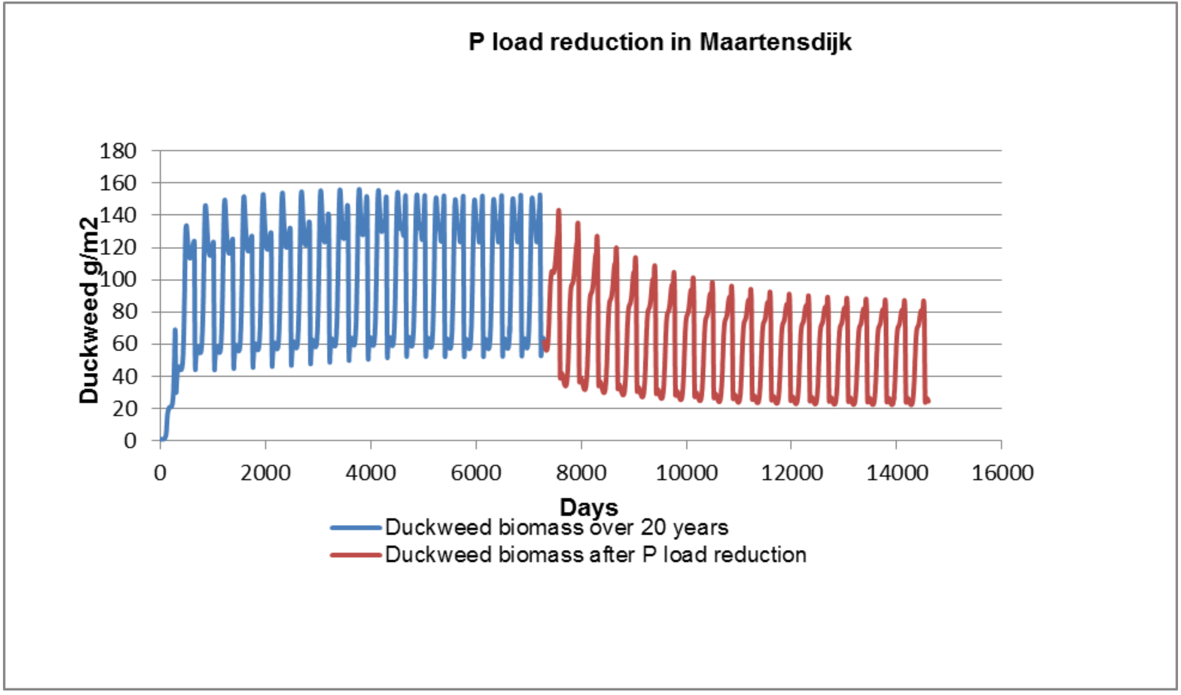


Figure 13: *Simulated Lemna biomass as a function of phosphorus load in the peat area. Starting with a pristine ditch the phosphorus load was increased to the actual phosphorus load (8.44 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (2.5 g/m²/year). The oscillations in the graph represent the seasons in light and temperature.*



5. Discussion

First the reliability of the method will be discussed (section 5.1). Second the reliability of the model will be discussed (section 5.2). The main results are discussed in section 5.3 and the value of the output of this research (section 5.4) will be discussed at the end of this chapter.

5.1 Reliability of the method used

The distribution of inlet water within sub catchments of the polders have been chosen on the basis of polder system knowledge (annex 3). The distribution was given in percentages in order to determine the influence of the inlet water. The chosen percentages influenced the hydraulic load and the actual nutrient load in an area. Especially the highest influenced ditches were dependent on the percentages.

These percentages for the distribution of inlet water (paragraph 3.2.1) have been estimated based on knowledge of the way the water system is managed, in combination with known locations of inlets, pumping stations and main water arteries. This method is acceptable because the knowledge of the water system is detailed and reliable.

Soils in PcDitch

The soils used in PcDitch is only clay, peat and sand. Within HDSR the soils are specified more detailed such as clay on peat. The different clay soils, light and heavy clay, are taken as clay. For the 'peaty clay soil' peat is chosen instead of clay in PcDitch to be sure the critical nutrient load is not overestimated. Moreover the 'clay on peat' soils are taken as peat in the model. This is done because the ditch soil is peat. The water table starts at 0.4 m beneath the surface level and the average ditch depth is between 0.4 and 0.5 m. The clay part above the peat is between 0.5 and 0.8 m from the surface level. This means that peat will be the soil of the ditch unless ditches are shallower than 0.4 m, than it is possible that the soil consist of clay or a mixture of peat and clay (Stouthamer et al., 2008).

The kind of soil selected in PcDitch has influence on the internal nutrient release calculated by PcDitch based on the soil type. This nutrient release is higher in peat soils than in clay and sand. The critical nutrient load will be lower on peat soils due to more internal nutrient load and so less external load is needed to exceed the critical nutrient load. This could be under- or overestimated by PcDitch for several ditch locations depending on the nutrient load within a soil. It is unknown for clay and sand if PcDitch under- or overestimated this release. For the peat soils within HDSR Dijkstra et al., (2013) indicated that the soils within HDSR are highly eutrophic. Because this is higher than an average ditch the internal nutrient load is probably underestimated in PcDitch. This can be improved by developing additional soil types within the model based on the HDSR soils.

Reliability of the model PcDitch

In PcDitch uses in calculations the yearly averages for hydraulic and nutrient loads. This is because the model is designed (Janse and van Puijenbroek, 1998) in such a way that it is questionable how accurate this is because the in- and outflow of hydraulic and nutrient load differ greatly per season. PcDitch might be improved by taking into account the seasonal variation of the nutrient load or by taking only the summer averages.

It is not sure that this will improve the model's prediction. Zuidam, van (2009) stated in his research results that his model with variable nutrient load gave very similar results as his model with constant nutrient load levels. So it seemed that ongoing nutrient load in ditches is important for the ditch vegetation development, but seasonal variable nutrient load has little effect on the ditch vegetation development.

Moreover the phenomenon hysteresis is not yet included in PcDitch. This means the critical nutrient load is the same for both the switch to *Lemna* dominance as backwards, the recovery to a clear state with submerged vegetation dominance. As Scheffer (2001) indicates the restoration of clear water happens at a substantially lower nutrient level than those at which the switch towards *Lemna* dominance occurs. This means for the results that depending on the present dominant vegetation the critical nutrient load is overestimated (switch toward submerged vegetation) or underestimated (switch towards *Lemna*). This means the critical nutrient loads as now calculated are not strict nutrient limits.

The model will most likely be improved with a seasonal variation in hydrology and nutrient load included and when hysteresis is implemented.

5.2 Reliability of the input data

Ditch ecology data

These data were gathered in the summers of 2011 and 2012, between May and September. The data were gathered by ecological experts. A disadvantage is that it is a 'snap shot' of the ditches. As the development of the vegetation changes in time mainly between spring and end of summer. The vegetation has not been developed yet in May and specifically *Lemna* has not grown. At the end of July and August *Lemna* is at the top in its growing season (Zuidam, van 2009). This could mean that in the same ditch in spring submerged vegetation is properly present while at the end of the summer *Lemna* dominates. Montfourt (2006) stated that the flora varies from year to year. The causes of this variation are uncertain. Due to this variation it is important to monitor the ditches over a number of years preferably in May and August. But mostly this is too intensive too carry out.

WFD water body nutrient and macrophyte statuses

These statuses and data in the WFD water bodies are very trustworthy because this is monitored each year by HDSR with the same method defined by the WFD.

Original hydraulic and nutrient load based on the water balance per catchment area

On the basis of the deviation between the measured and calculated nutrient concentrations, the reliability of the load is determined. The concentrations formed the basis of the nutrient load calculations in the hydraulic and nutrient balances.

For the catchment areas Zegveld and Maartensdijk the nutrient and hydraulic loads are reliable. The calculated nutrient concentration differed between one and nine percent from the measured concentration.

The data of the catchment area Hekendorp are from 2007. For this year the hydraulic load and the nitrogen load are reliable for these measurements. The calculated nutrient concentration differed between one and four percent from the measured concentration. The phosphorus load is questionable due to the overestimation of summer concentrations but underestimation of peaks in summer.

For the areas Haarrijn en Langbroekerwetering both the hydraulic and nitrogen load are reliable. The calculated nitrogen concentration only differed two and three percent from the measured concentration. The phosphorus load is in Haarrijn highly overestimated, namely by 55%. This is due to the unknown phosphorus concentration at the Haarrijnse Plas. For Langbroekerwetering the phosphorus load is underestimated due to the high phosphorus peaks within the area which are not simulated.

For the areas De Pleijt and de Koekoek the hydraulic load and the phosphorus load are reliable. The nitrogen loads are in both the areas overestimated with 15% higher than the nitrogen concentrations. This deviation is possibly due to the fact that the nitrogen concentrations in spring decrease faster in the ditch than does in the calculations. It is also possible that the drainage quantity is overestimated in the calculations. The last possibility is the retention of nitrogen by vegetation, this process is not taken into account in the simulations.

On the basis of the above mentioned discussion it can be seen that there are many inputs that effect the output of this research. To what extent this effect is cannot be said specifically, and therefore the output needs to be treated with caution.
For now it is assumed that the output is reliable. With the uncertainties kept in mind the main results will be discussed in the next paragraph.

5.3 Main results

PcDitch result

The result of PcDitch implies *Lemna* dominance at the zones with high hydraulic loads. In contrast the ecology fieldwork data (annex 3) imply *Lemna* to a lesser extent present at these zones than at the zones with a minimum hydraulic load. The difference can be explained firstly by the flow pattern of the water within a polder. The ditches with a stronger water flow are mostly deeper and wider than locations with less water flow. *Lemna* floats away easier in these ditches by wind and with the water flow. PcDitch does not take this into account.

Secondly this difference can be explained by the relation between the hydraulic and nutrient load. *Lemna* is able to develop better in stagnant ditches because the nutrient load entering this water body leads to a higher nutrient concentration in the ditches in contrast to ditches which are flushed. A flushed ditch needs a higher nutrient load than a stagnant ditch for the development of *Lemna*. PcDitch does take this into account with the calculations (Janse and van Puijenbroek, 1998) but these measurements suggest the model is not yet sufficient calibrated on this point.

Still PcDitch is in contrast with the fieldwork data. The actual loads also show a low nutrient load in these stagnant ditches. This in turn corresponds with PcDitch, this match is logical because both are based on the hydraulic load which is low in these stagnant ditches and high in the flushed ditches. Presumably the nutrient load is good in these ditches but not low enough to create a shift toward submerged vegetation dominance. This is also shown for instance in the prospects of Maartensdijk (figure 13). *Lemna* decrease in biomass but the submerged vegetation needs more time to recover or the nutrient loads need to be lowered.

The result that phosphorus seems to be more important over nitrogen is underlined by Mountfourd (2006); Lamers et al., (2012) and Zuidam, (2012). These state that the total available phosphorus should be taken as the most important criterion for determining which channels have the greatest potential for biodiversity improvement. Arts and Leenders (2006) and Lacoul and Freedman (2006) both stated that in hypereutrophic fresh water ditches nitrogen is limited due to denitrification.

Ditch status

The relation between the nutrient load, nutrient concentration and the status of ditches among the WFD method is discussed in annex 3.

It showed two important results. Firstly ditches were present where the actual nutrient load was lower than the critical nutrient load but still vegetation was present indicating eutrophication, such as a high coverage (above 60%) of *Elodea nuttalli* or *Ceratophyllum demersum*.

This could be due to a large network of interconnected ditches in the polder. Connectivity may facilitate vegetation distribution through the network by water flow and wind from locations where the actual nutrient load is higher than the critical nutrient load (Zuidam, 2012). Besides it is possible that the eutrophic species are still present from the past. The legislation for manure was less strict than they are now, whereby the actual nutrient load was higher about ten years ago. With the alternative stable states theory in mind (Scheffer et al. 2003) these ditches do not show a stable state. Because the nutrient load is now beneath the critical nutrient load the ditches are possibly not recovered yet. The prospects of Maartensdijk (figure 13) show this, the *lemna* biomass is decreasing, but the ditches need more time to recover.

Secondly ditches were present of which the actual nutrient load was close to or exceeded the critical nutrient load containing one or two submerged vegetation species with a coverage above 60% and with a moderate status.

Reflecting on the theory of Scheffer et al., (2003) this could imply the ditches show resilience. This would mean these ditches could switch to a duckweed dominated ditch. Within what time period this will be and if it will happen differs per ditch, if the nutrient load is increasing or decreasing and if measures are taken.

Moreover the soil (5.1) could play a role or the method used (5.2) is influencing the results.

Implementation of flexible water level management

In most of the catchment areas the implementation of flexible water level management is helpful for decreasing the nutrient load in the system. The actual load extremely decreases because the hydraulic load decreases. As a consequence the critical nutrient load decreases because the hydraulic load decreases and the depth increases in most of the areas. As long as the actual nutrient load decreases more than the critical nutrient load there is no exceedance of the critical nutrient load when this measure is implemented and the measure is therefore recommendable (Schep et al., 2012).

The results show that flexible water level management does not have the desired effect for recovery of the submerged vegetation in the catchment area Langbroekerwetering. The adapted actual phosphorus load still exceeds the adapted critical phosphorus load. It is known that in this area the nutrient drainage from agricultural fields is high. This source stays in the ditches due to longer residence time of the water. This means that this source highly influences the nutrient load in the ditches when flexible water level management is implemented and the water is not flushed away (Schep et al., 2012). Moreover the influence of seepage from the river Lek and from the Utrechtse Heuvelrug on the ditches in Langbroekerwetering increases, with this measure the seepage is exacerbated. The seepage from the river Lek contains a large amount of nutrients (C. Blom, personal communication, August 19, 2013), which negatively influences the water quality but seepage from the Utrechtse Heuvelrug is of good quality.

For the catchment area De Koekoek the implementation of flexible water level management was effective for the maximum and average by inlet water influenced locations. However it is not possible to implement this measure because the northern adjacent polder De Keulevaart needs water which is provided through the area De Koekoek from the river Lek.

For the area Maartensdijk the biomass of Lemna decreased when flexible water level management was applied but still dominated the ditches after 20 years of simulation. Reflecting on the theory of Scheffer et al., (2003) this means that the reduction in nutrient load is not sufficient enough to create a shift to dominance of submerged vegetation within two decades. When flexible water management will be applied it must be kept in mind that the northern part will be drier than it already is, because the water is not pumped anymore towards the north (annex 3). This might not be desirable for the land use in the north in the summer.

For the catchment areas where the original actual nutrient load did not exceed the critical nutrient loads the application of flexible water level management has a positive lowering effect for the maximum and average influenced locations, but for the locations with a minimum influence the actual nutrient load and the critical nutrient loads become higher, without exceeding the critical nutrient load. This can be explained by the increase of depth with 0.05 m after implementation of the measure. The other advantages of this measure will possibly outcompete this disadvantage after implementation.

So, overall implementation of flexible water level management is a good measure when the inlet water is a high contributor to the external load in a catchment area. Processes, such as nutrient retention, and the internal water quality in a ditch will play a major role when flexible water level management is applied. It is important to have a detailed knowledge at ecosystem level to determine if this is a good measure for a catchment area, this is also underlined by Schep et al., 2012.

5.4 Value of the output

For HDSR it is possible to create a new tool in order to get an overall view of the critical and actual nutrient loads within HDSR. The method used is applicable on all the catchment areas of HDSR. It can be chosen if on the basis of this method, it is used for a more specific and detailed research in a ditch or to generalize this method in order to create an overview of a polder. Moreover the recovery prospect can be used to determine whether flexible water level management is a good measure in a polder.
It must be taken into account in creating management that the critical nutrient loads as now calculated cannot be seen as strict limits of the nutrient load. To assure a dominance of submerged vegetation the actual nutrient load must be well beneath the critical

nutrient load. Moreover it must be determined how eutrophic the soil is to determine if the critical nutrient load is over- or underestimated.

The other water boards Amstel, Gooi and Vecht and Wetterskip Fryslân are already using PcDitch to predict the impacts of flexible water level management. They can compare this method with their method or integrate this method. The water boards who do not use PcDitch can learn from these three water boards and their findings.

6. Conclusion

In this research, the main aim is to find locations outside the WFD water bodies which show potential for improving the macrophyte status in the management area of Water board 'De Stichtse Rijnlanden'. Improvement of the macrophyte status has been defined as a decrease in actual nitrogen and phosphorus load within a polder with respect to the original actual nutrient load as a consequence of flexible water level management.

The method developed in this study is the first attempt to assess the macrophyte status of polder ditches within HDSR using the critical nutrient load of the model PcDitch. To achieve a better macrophyte status the nutrient load must be lower than the critical nutrient load at which submerged vegetation is dominant.

Based on the actual nutrient loads and the perceived effectiveness of flexible water level management the areas Zegveld, Haarrijn, Hekendorp, De Pleijt and De Koekoek show potential for improving the macrophyte status. The simulation showed a sufficiently reduced nutrient load with the application of water level fluctuations in these areas. In the areas Zegveld and De Koekoek, where *Lemna* (Duckweed) was dominant according to PcDitch, a recovery of submerged vegetation occurred within 20 years after implementation of flexible water level management.

The simulated reduction of nutrient loads in the areas Maartensdijk and Langbroekerwetering was not sufficient enough to create a shift towards dominance of submerged vegetation which is the target vegetation. This study shows that flexible water level management is an effective measure to improve the nutrient load in five out of the seven investigated areas in the management area of HDSR. Generally seen implementation of flexible water level management is a good measure when the inlet water is a high contributor to the external load in a catchment area.

6.1 Recommendations

- A next step in the approach of using PcDitch for simulating water management measures will be to analyse to what extent the internal calculated nutrient load by PcDitch corresponds to the actual internal nutrient load calculated by HDSR. In this way it can be seen whether PcDitch underestimates the internal nutrient load which can result in an overestimation of the submerged vegetation.

- It must be further researched if and how nutrient *load* plays a role in determining ecological quality of ditches, instead of nutrient *concentrations*. This might have consequences for the method of the WFD in the future as it now uses concentrations.

- In this study the seasonal change within a year has not been specified. It could be interesting for further research as an improvement of the model. Luuk van Gerven of NIOO is already working on this topic.

- The water boards Amstel, Gooi and Vecht and Wetterskip Frylân are also researching the possibilities of the implementation of flexible water level management. The impacts are predicted, among other methods, with PcDitch. It is recommended to get in touch with these water boards to exchange ideas on the subject.

- The implementation of flexible water level management is in this research only focussed on the nutrient load reduction in a catchment area. Before implementing this measure all advantages and disadvantages of flexible water management need to be investigated.

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Annex 1. The PcDitch model

The PcDitch model describes the relations between the external nutrient loading, the nutrient concentrations in the ditch and the dynamics of the dominant vegetation types in ditches. The water plants were divided into six functional groups and the definition of the plant group is primarily based on the layer(s) in which they grow and the layer(s) from which they take up nutrients. *Lemna*, algae and non-rooted submerged plants take their nutrients from the water column. Helophytes and floating-leaved plants are included for their role in the nutrient household and light interception. Helophytes take their nutrients from the sediment only while rooted submerged plants are able to use both the sediment and the water column as their source. Beside, *Lemna* hampers the growth of sub-merged plants by light interception at the water surface and it creates an anoxic condition underneath the *Lemna* (Janse, 2005; Zuidam, 2012).

The aim of the model is to assess the 'critical level' of nutrient loading above which shifts in vegetation are likely to occur, moreover the main influencing factors will be determined (Janse and van Puijenbroek, 1998; Janse, 2005).

The readily available data (chemical and physical) from HDSR will be used as input for the model. With the model calculations will be done for different soil types and depths in combination with water flow rate and nutrient loading to determine what the critical load is. In this way it is known at which locations the nutrient load exceeds the critical load and what consequences this has for the ecology. Moreover measures needed to reduce this load can be adopted.

The model may be regarded as a competition model between several water plants groups, coupled to a description of the nutrient cycles. The cycling of the four substances; dry weight (D), phosphorusus (P), nitrogen (N) and oxygen (O_2) are described by the model. The whole model structure is shown in figure 14. The main N, P and O_2 flows in the ditch system are described combined with the abovementioned vegetation groups. Respiration fluxes are not shown.

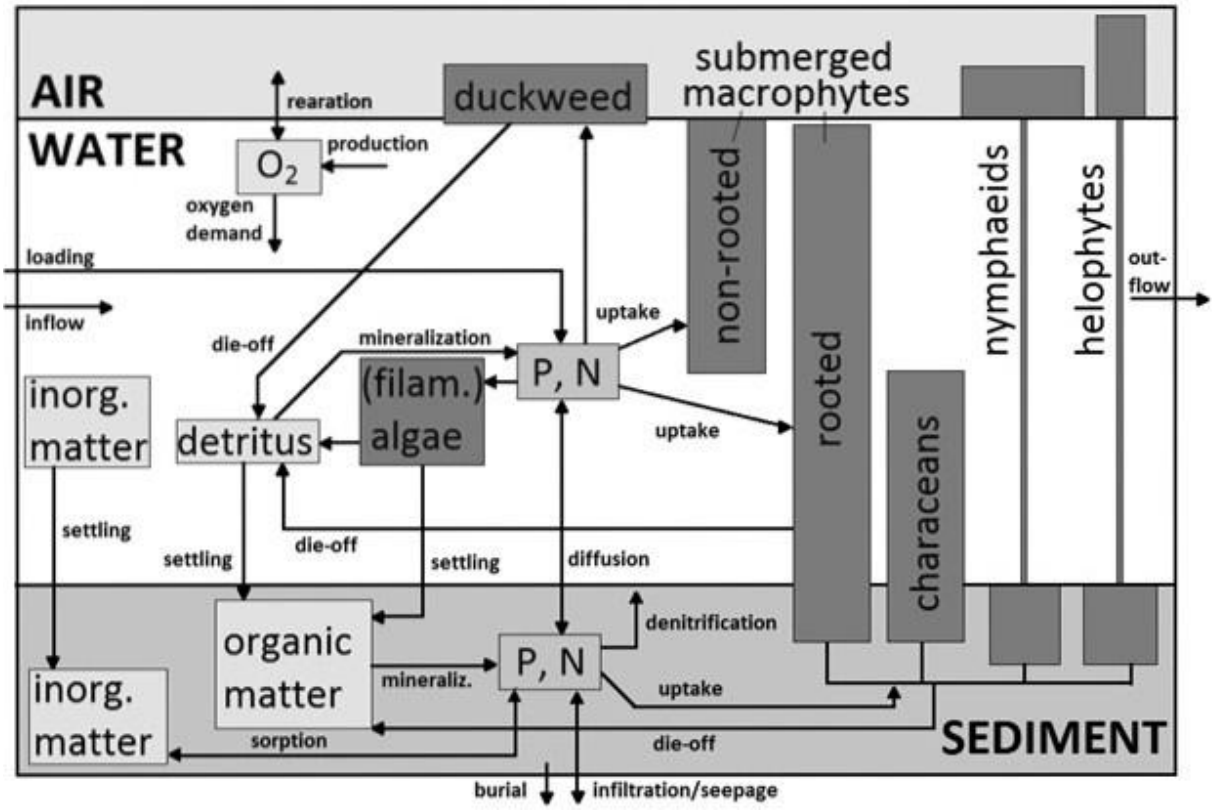

Figure 14. The PcDitch model structure. The vegetation groups are explained in the text. Shaded blocks denote components modeled in both dry-weight and nutrient units. Respiration fluxes are not shown (Janse, 2005).

Annex 2. The R script for PcDitch

```
# script to calculate the critical nutrient load for different settings (depth and sediment
type of ditch, hydraulic loading (inflow rate))
# assumptions:
# - critical nutrient load = load where any type of vegetation dominance goes to a
dominance of duckweed/algae
# threshold        <- 1              # minimum duckweed biomass left after 20 years of
calculation, to define persistance [g/m2]
res                  <- 0.000001       # resolution of 'critical N load' to be found [g/m2/day]
For P this resolution is divided by 10
# PCShell computation
source(paste(dir_SCHIL,"scripts/R/functions_cpp.R",sep=""))           # Define functions
source(paste(dir_SCHIL,"scripts/R/initialisation_cpp.R",sep=""))       # Initialisation
(read user defined input + convert cpp files of model + compile model)

# function to search critical nutrient load
Compute_critical_load <- function(substance,loading,start_loading,res,threshold,parms,
init_states,times,forcings,aux_number,aux_names,integrator_method,state_names,times
_output,vegetation_type,runtime_years)   {
         if (substance == "N") {
                  N_loading <- loading
                  loading_start <- start_loading        # starting P load
                  resolution <- res/10  # resolution of 'critical P load' to be found [g/m3]    }
         if (substance == "P") {
                  P_loading <- loading
                   loading_start <- start_loading       # starting N load
                   resolution <- res/1      # resolution of 'critical N load' to be found [g/m3]  }
# search for critical loads
             i <- 0
             switch_down <- 0
         switch_up <- 0
         repeat {      i <- i + 1
 #change parameter settings ("parms")
           if (substance == "N") P_loading <- loading_start
           if (substance == "P") N_loading <- loading_start
           params_to_change <- c(N_loading,P_loading)
           names(params_to_change) <- c("cNLoad","cPLoad")
           for (j in 1:length(params_to_change)) {
id <- grep(paste("_",names(params_to_change[j]),"_",sep=""),paste("_",names(parms),
"_",sep=""),ignore.case=T)
parms[id] <- params_to_change[j]      }
# run model and compute biomass of selected vegetation_type at equilibrium
RunModel(init_states,times,parms,forcings,aux_number,aux_names,"vode",state_names,
times_output)
      if (nrow(outC) != (runtime_years*365+1))
RunModel(init_states,times,parms,forcings,aux_number,aux_names,"daspk",state_name
s,times_output)                  # try another integrator if model run crashed
if (nrow(outC) != (runtime_years*365+1)) {
    return("calculation failed")
{break}          }
           out_veg <- Compute_equilibrium_biomass(outC,vegetation_type,runtime_years)
 #determine new load
      if(out_veg[,4]>=threshold) { # check if mean target biomass > threshold
          if (i==1) {
                    loading_new <- loading_start/2
       } else if (direction=="-") {
           if (switch_up == 0) loading_new <- loading_start/2
```

```
      if (switch_up == 1) loading_new <- mean(c(loading_start,loading_min))
    } else if (direction=="+") {
           loading_new <- mean(c(loading_start,loading_min))
           switch_up <- 1    }
      loading_max <- loading_start
      direction <- "-"
      switch_down <- 0
   } else {
     if (i==1) {
           loading_new <- loading_start*2
   } else if (direction=="+") {
      if (switch_down == 0) loading_new <- loading_start*2
      if (switch_down == 1) loading_new <- mean(c(loading_start,loading_max))
   } else if (direction=="-") {
           loading_new <- mean(c(loading_start,loading_max))
           switch_down <- 1                }
           loading_min <- loading_start
           direction <- "+"
           switch_up <- 0      }
 # stop if convergence criterium is reached or if convergion takes too long
 if((abs(loading_start-loading_new) < resolution) || (i == 50)) {
     tmp <- cbind(data.frame(vegetation = vegetation_type, substance =
     substance, P_load = P_loading, N_load = N_loading, n = i),out_veg)
    return(tmp)
       {break}      }
   loading_start <- loading_new     }}
# function to compute the biomass of a vegetation type (mean, min and max) in last
summer half year of calculation period
Compute_equilibrium_biomass <- function(outC,vegetation_type,runtime_years) {
          # compute biomass at equilibrium
  outC <- as.data.frame(outC)      # model results
  out_veg <- outC[,c(1,grep(pattern=vegetation_type,names(outC)))]  # results, only
          for selected vegetation type
  names(out_veg) <- c("time","biomass")
  temp <- data.frame()
  for (index in c(1,2)) {
   tmp <- subset(out_veg, subset=(time %in% c(((runtime_years-index)*365+91):
((runtime_years-index)*365+272)))) #select last summer half year of run time
   tmp$dummy <- 0
   tmp_veg_stats <- summaryBy(biomass ~ dummy, data=tmp,
FUN=c(min,max,mean),na.rm=TRUE)      #calculate min, mean and maximal biomass
          (can be used to check if biomass is in equilibrium)
   tmp_veg_stats$year <- index
   temp <- rbind(temp,tmp_veg_stats)          }
out_veg_stats    <-    data.frame(biomass_min_diff_perc    =    (temp$biomass.min[1]-
temp$biomass.min[2])/temp$biomass.min[2],biomass_max_diff_perc                    =
(temp$biomass.max[1]-temp$biomass.max[2])/temp$biomass.max[2],
biomass_mean_diff_perc     =(temp$biomass.mean[1]     -     temp$biomass.mean[2])/
temp$biomass.mean[2],biomass_mean=temp$biomass.mean[2])
  return(out_veg_stats)             }
LoadPackage("doBy")
parms          <- ref_pars
init_states    <- states
nvar           <- 0
critical_loads <- data.frame()
for (target_vegetation_type in c("sDLemn","sDPhytW")) { # for Lemna (duckweed) and
     algae
```

```
for (sediment_type in c("clay","peat","sand")) {
# define sediment types
  if (sediment_type=="clay") { #clay
        FDTOTS0 = 0.3
        FDORGS0 = 0.08
        FDORGSOIL = 0.08
        FLUTUM = 0.4
  } else if (sediment_type=="peat") { #peat
        FDTOTS0 = 0.10
        FDORGS0 = 0.25
        FDORGSOIL = 0.25
        FLUTUM = 0.4
  } else if (sediment_type=="sand") { #sand
        FDTOTS0 = 0.5
        FDORGS0 = 0.08
        FDORGSOIL = 0.08
        FLUTUM = 0.03
}
  FFEDIM = 0.1 * FLUTUM  #[gFe/gD]
  FALDIM = 0.1 * FLUTUM  #[gAl/gD]
for (depth in c(0.3,0.4,0.45,0.5,0.6,0.7,0.8,0.9)) {                # sDepthW  in "states"
# change initial states (water depth) in "states"
        id <- grep("_sDepthW_",paste("_",names(init_states),"_",sep=""))
        init_states[id] <- depth
for (inflow in c(13,16,20,30,50)) {                              # _cQIn_  in "ref_pars"
                nvar <- nvar + 1
# change parameter settings ("ref_pars") (also set mowing day to 259 = 16 sept)
          params_to_change <-
c(FDTOTS0,FDORGS0,FDORGSOIL,FLUTUM,FFEDIM,FALDIM,inflow,259)
          names(params_to_change) <-
c("FDTOTS0","FDORGS0","FDORGSOIL","FLUTUM","FFEDIM","FALDIM","cQIn","cDayMan
Veg2")
for (i in 1:length(params_to_change)) {
id <- grep(paste("_",names(params_to_change[i]),"_",sep=""),paste("_",names(parms),
"_",sep=""),ignore.case=T)
        parms[id] <- params_to_change[i]        }
# calculate critical loading
          N_loading_start <- 10
          P_loading_start <- 1
# calculate critical P loading
tmp <-Compute_critical_load("N",N_loading_start,0.001,res,threshold,parms, init_states,
times,forcings,aux_number,aux_names,integrator_method,state_names,times_output,
target_vegetation_type,runtime_years)
tmp <-cbind(tmp,data.frame(depth=depth,sediment_type=sediment_type,inflow=inflow,
nvar=nvar))
if (length(tmp)>1) critical_loads <- rbind(critical_loads,tmp) # store results per run for
runs that do not fail (if run fails then tmp becomes "calculation failed" =>
length(tmp)=1)
# calculate critical N loading
tmp <- Compute_critical_load("P",P_loading_start,0.01,res,threshold,parms,init_states,
times,forcings,aux_number,aux_names,integrator_method,state_names,times_output,ta
rget_vegetation_type,runtime_years)
tmp <-cbind(tmp,data.frame(depth=depth,sediment_type=sediment_type,inflow=inflow,
nvar=nvar))
if (length(tmp)>1) critical_loads <- rbind(critical_loads,tmp) # store results per run for
runs that do not fail (if run fails then tmp becomes "calculation failed" =>length(tmp)=1)
```

```
# write to logfile about computation time
          if  ((nvar%%1)==0)  WriteLogFile(LogFile,ln=paste("computed  combination
",nvar," at: ",Sys.time(),sep=""))          }   }  } }
# write to file
write.table(x=critical_loads,file=paste(dir_SCHIL,work_case,"/results/critical_loads.csv",
sep=""),sep=',',row.names=FALSE, col.names = TRUE, quote = FALSE) #write all output
# write to logfile
end_time <- Sys.time()
WriteLogFile(LogFile,ln=paste("end of PCShell at: ",end_time,sep=""))
# plot results
# read data
#output<-read.csv(file=paste(dir_SCHIL,work_case,"/results/critical_loads.csv",sep=""))
output <- critical_loads
# rename values for inflow
output$inflow <- replace(output$inflow,output$inflow=="10","q (10 mm/day)")
output$inflow <- replace(output$inflow,output$inflow=="40","q (40 mm/day)")
output$inflow <- replace(output$inflow,output$inflow=="70","q (70 mm/day)")
# switch N and P...
output$substance <- as.character(output$substance)
output$substance <- replace(output$substance, output$substance=="N","phosphorus")
output$substance <- replace(output$substance, output$substance=="P","nitrogen")
output$substance <- replace(output$substance, output$substance=="phosphorus","P")
output$substance <- replace(output$substance, output$substance=="nitrogen","N")
# get critical load
output$critical_load <- 0
for (i in 1:nrow(output)) {
  if (output$substance[i]=="N") output$critical_load[i] <- output$N_load[i]
  if (output$substance[i]=="P") output$critical_load[i] <- output$P_load[i] }
# unit conversions
output$critical_load  <-  output$critical_load  *  365  #  converts  loads  for  g/m2/day  to
g/m2/year
output$depth <- output$depth * 100              # convert depth from m to cm
# select output data for duckweed and algae
duckweed <- subset(output,subset=(vegetation=="sDLemn"))
algae <- subset(output,subset=(vegetation=="sDPhytW"))

# make plot
for (property in c("N","P")) {
  tmp1 <- subset(duckweed,subset=(substance==property))
  tmp2 <- subset(algae,subset=(substance==property))
  G = ggplot(tmp1, aes(x=depth,y=critical_load))
  G = G + geom_line()
  G = G + geom_point()
  G = G + geom_line(data=tmp2,linetype=2)
  G = G + geom_point(data=tmp2)
  G = G + facet_grid(inflow ~ sediment_type ,
       scales="free")+scale_x_continuous(limits=c(0,125))
  G = G + scale_y_continuous(limits=c(0,1.1*max(tmp1$critical_load,na.rm = TRUE)))
  G = G + labs(y=paste("critical ",property," load (g/m2/year)",sep=""),x="depth (cm)")
  pdf(paste(dir_SCHIL,work_case,"/results/critical_",property,"_load.pdf",sep=""),6,4.5)
                # write plot to file
  print(G)
  dev.off()           }
```

Annex 3. Description of the catchment areas

In figure 15 the area Zegveld is depicted in a detailed map; inlets, waterways and nutrient and macrophyte statuses are shown. "Polder Zegveld" is an agricultural peat meadow area mostly used as pastures which is situated in the north-west of the HDSR region. The legend is the same for each map.

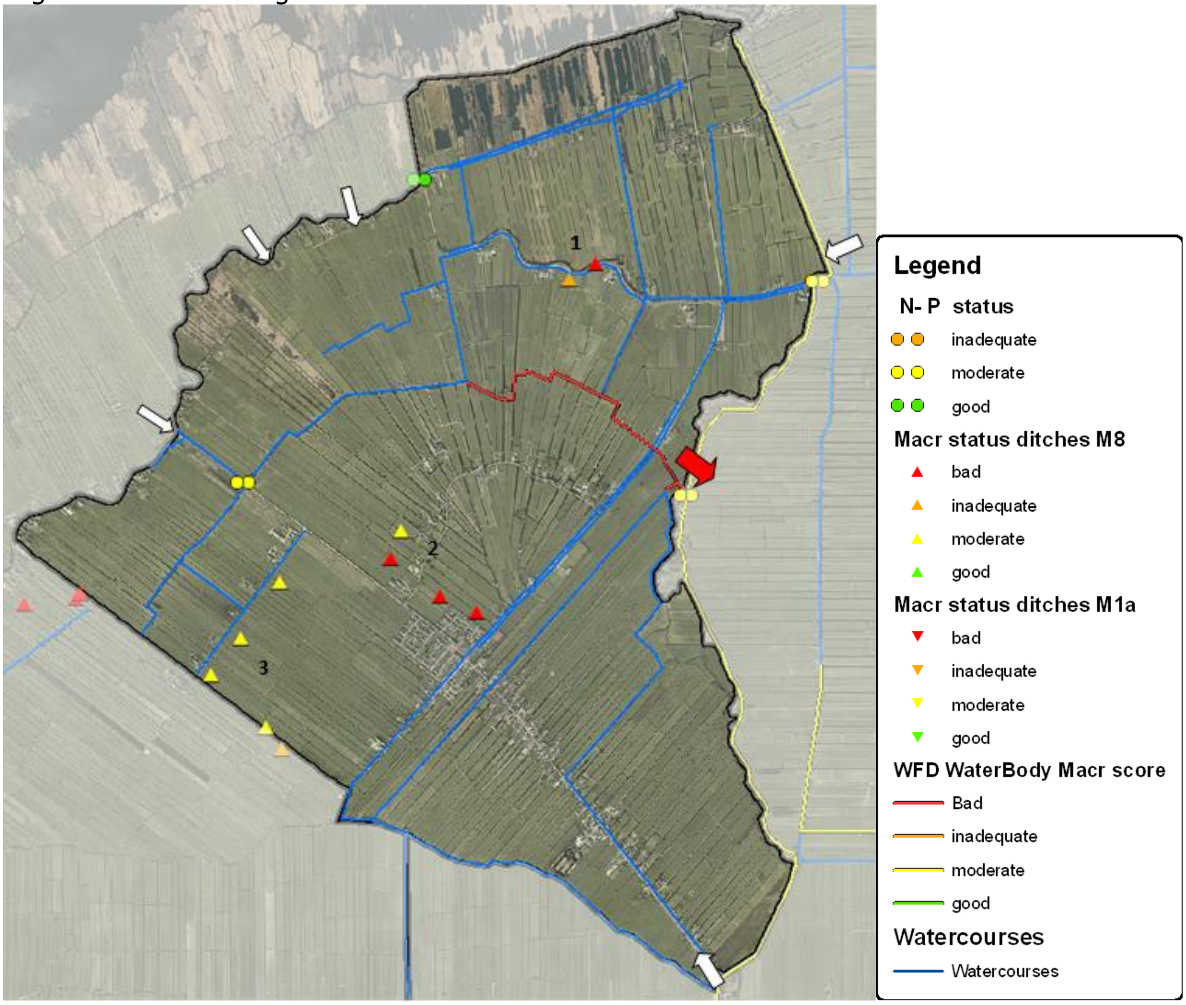

Figure 15: *WFD statuses of nutrients and macrophytes in WFD water body and ditches in the area Zegveld. The red arrow indicates a pumping station. The white arrows indicate inlet devices.*

The water supply for this area is regulated with inlet devices on several places (shown by the white arrows in figure XX). In the map the main watercourses are shown which includes the WFD water body. From the main inlets the water flows through the main watercourses towards the WFD water body. There the water is pumped out to the Grecht, this is the 'boezem' east of Zegveld (shown by the red arrow in figure 15). In between these inlets and pumps the inlet water is not evenly distributed among the watercourses. The main watercourses receive the strongest water flow, in between the main watercourses ditches are situated. Ditches close and directly connected to a main watercourse receive an average water flow. Ditches located further away or divided by a weir from the main watercourses receive less water than average up until a minimum flow.

The area is subdivided in a small urban sub catchment (5% of the area, representing the small village Zegveld in the middle of figure 15) and a large rural sub catchment with a peat soil (95% of the area). The distribution of inlet water in the area is as followed estimated: The main water system is largely influenced by the inlet water and it is estimated that it covers 20 percent of the total water surface area. The average influence, close around the large influenced watercourses, is estimated to be 40 percent. The lesser influence (inlet -50%) is estimated to cover 20 percent of the total water surface area and is situated in between the inlet average and no influence of inlet water. The uttermost places from the main watercourses are the places with no influence of the inlet water and with a minimum water flow (inlet -100%). This is estimated to be 20 percent of the surface water area and situated in the lower middle of the polder, around the *moderate* ditches and north of the two ditch measurement locations in the northern part.

The WFD water body

The distinction in the amount of water flow can also be seen in the macrophyte measurements. Starting with the strongest water flow locations; the macrophyte status of the WFD waterbody is *bad*. This status is not as good as the moderate nutrient status, which means something else than the nutrient concentration might be influencing the macrophyte status. The *bad* status is bad because the bank sides are quite steep causing helophytes to be able to evolve only on a small zone. Partly the water body is shaded by trees. More towards the polder the vegetation gets diverse than close to the pumping station, especially helophytes are more divers because of sloping bank sides. The water plants are diverse present but only cover about 15% or less of the water body, the ones which are present are general plants and indicators of eutrophic water such as Duckweed, Western Water-weed, wire whose. On the other hand also two red-list species, Water Soldier and Bluntleaf Pondweed, are present in this water body. Overall the vegetation has a low coverage and low diversity characteristic for this specific type of water body. Besides, the strong water flow, the water at this location has a high nutrient load entering with the water. The macrophytes respond on this load, to what extent they respond is described in the next paragraph with the results of PcDitch.

The other macrophyte measurement locations are situated in ditches disseminated in the catchment area. The statuses spatially vary between the ditches.

The measured ditches in the North (1)

The ecological statuses of the ditches north (1) of the WFD water body are stated as *bad* and *inadequate* which is remarkable because of the *good* nutrient statuses in the west and moderate in the east. Both ditches are dominated by duckweed and free floating algae, both covering 60% of the water surface. Besides, the coverage of 40% of the submerged vegetation is favourable. The location with a *bad* status is situated in the main watercourse. The location with the *inadequate* status has a less or minimum water flow, because it is closed off from the main watercourse by a weir.

The measured ditches in the middle (2)

Also in the lower middle (2) of the polder several ditches have a *bad* status. The ditches were physically the same as the *moderate* location close by but more duckweed was present. The two ditches in the east are averaged influence by the inlet water, the other two less than average.

The measured ditches in the South (3)

Several *moderate* ditches are present more to the south (3). Here the helophytes are highly present with a coverage of 40% though the diversity is not high. The red-list specie 'water Soldier' is present with a high coverage of 80% and Duckweed has only a coverage of 10% which is positive. The submerged vegetation is a slightly low present with 20% coverage. These ditches are less influenced by the inlet water. The minimum water flow in the ditches gives the chance for 'Water Soldier' (*Stratiotes aloides*) to grow.

“Maartensdijk’’ is situated in the north-east of HDSR and the soil is sand with a small area of peat in the South-Western part. A detailed map of Maartensdijk is shown in figure 16.

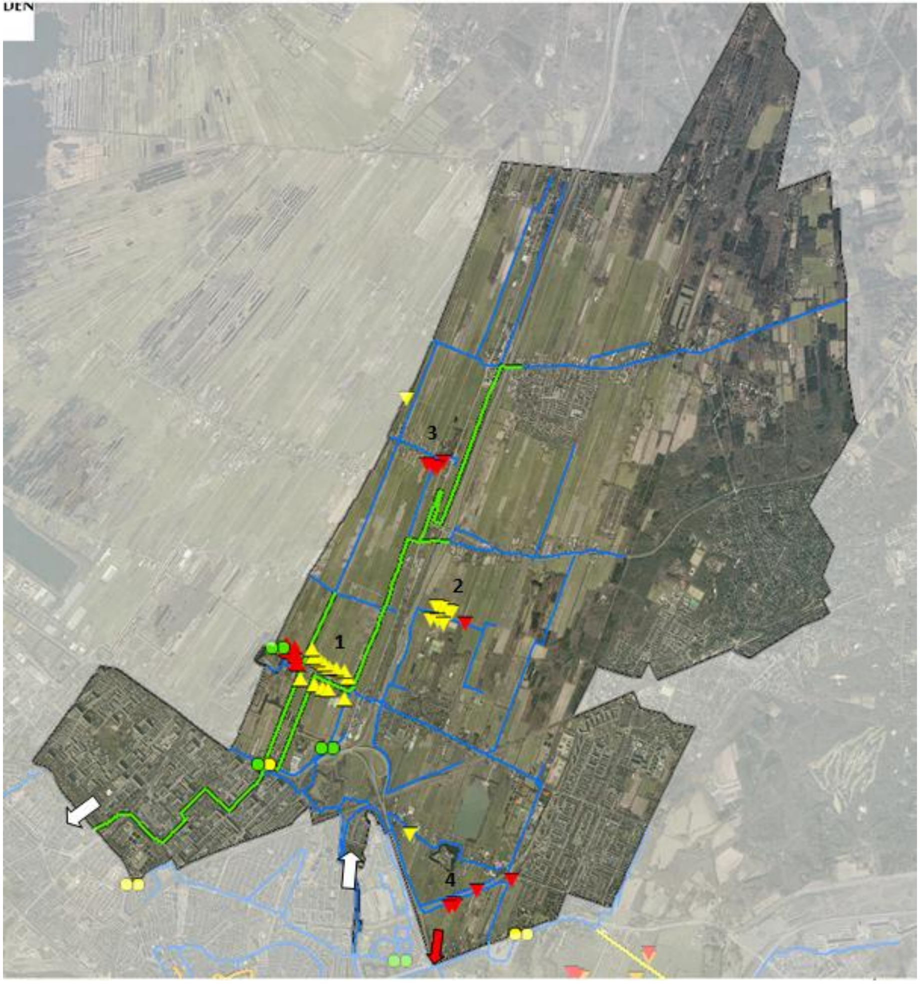

Figure 16: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area Maartensdijk. The red arrow indicates a pumping station. The white arrows indicate inlet devices.*

The water supply in this area is regulated with inlet device in the south. Here the water enters the catchment area after which several pumps in the catchment area pump the water further north following the WFD water body and the main watercourses. These pumps are needed because the altitude is higher in the north of Maartensdijk due to the ‘Utrechtse Heuvelrug’, a sandy hill ridge. Several watercourses in the north are dry in the summer months. The drainage water in this area is drained from the north mainly through the WFD water body to the South-West, where a weir is situated. Moreover the water is drained through the main watercourses towards the pumping station in the South-East. Within the area the inlet water is not evenly distributed, in the map (figure 16) the main watercourses can be seen. These main watercourses receive the strongest water flow, with the exception of the branches leading up to a dead end in the North or East, which receive less inlet water as the distance to the inlet increases. The ditches situated close and directly connected to a main watercourse receive an average water flow. Further away from these watercourses the amount of inlet water decreases, until a minimum flow is reached.

The area is subdivided in an urban catchment, covering 17% of the total catchment area, representing the suburbs of the town Utrecht shown in the South, as well as the small village ‘Maartensdijk’ shown in the north of figure 16. Moreover, in the South-West (in between the ditch cluster number (1) and the nutrient measurement points) a small rural sub catchment with a peat soil is located, covering 4% of the catchment area. And a large rural sub catchment with a sandy soil which covers 79% of the area. The peat area is small but has an important location where many macrophyte measurement points and a great part of the WFD water body are situated in this sub catchment.

The distribution of inlet water is as followed: the main water system is largely influenced by the inlet water and it is estimated that it covers 10 percent of the water surface area. The area with an average influence of inlet water close around the largely influenced areas is estimated to be 20 percent of the total water surface area. The lesser influence (inlet -50%) is estimated to be 30 percent and the minimum flow (inlet -100%) is estimated to cover 40 percent of the water surface.

The WFD water body

When looking at the link between the distribution of the water flow in the area and the macrophyte status of the WFD water body no clear correlation was found. Though a clear correlation can be seen between the macrophyte status of the WFD water body and statuses of nitrogen and phosphorus, both are *good*. There is one exception for phosphorus which is *moderate*.

The status of the WFD water body is *good.* Duckweed is limited present which is positive for the development of submerged vegetation. On average the water body has a diverse submerged vegetation. The coverage is with an average of 41% good developed and on several locations highly developed.

Overall mainly common helophytes are present in the water body which indicate a nutrient rich situation, only a small zone helophytes can develop because of the steep bank side. The helophytes indicate good quality seepage just above the ditch location in the water body. This could be due to the discharge of groundwater by a pumping station nearby, this water flows towards the WFD water body. Besides the general helophytes also some less general species are present here which creates diversity.

The other macrophyte measurement locations are situated in ditches disseminated in the catchment area. Spatial variation in macrophyte status between ditches was found. Ditches in this area are quite divers in size, depth and hydraulic load.

The measured ditches in the South-West (1)

The ecological status of the ditches in the South-West (1) close by the WFD water body are *moderate* with several *bad* locations in the west. The ditches with a *moderate* status have duckweed covering one percent of the ditch. The submerged vegetation is, with a coverage of 60%, very good. Though not very varied with just two Western Waterweed species, in contrast the helophytes species show more diversity with seven species present. The ditches north of the WFD water body receive an average water flow and the ditches south receive a less than average water flow. It must be kept in mind that these ditches could switch to a duckweed dominated ditch, in the next paragraph is the nutrient load is described. The ditches with a *bad* status are in contrast with the good nutrient concentration close by. These *'bad'* ditches have a plain stream bed and the biodiversity is very low. The ditches are 0.4m deep, which is the average depth of all the ditches in this area. The ditches are mainly covered by algae, while only 1% is covered with duckweed.

The measured ditches in the East (2)

For the cluster east (2) the WFD water body is found to be *moderate*. Duckweed is absent in these ditches which is positive for the ecological quality. The submerged plant Western Waterweed (*ElodeaNuttallii*) is highly present and dominates the water body with a coverage of 90%. Because the diversity and the presence of the helophytes are good, the ditches are stated as *moderate*. The locations on the north side receive less water, and the ones on the south side receive average amount of water flow.

The ditch at the east is stated as *bad*, this is because duckweed, floating algae and Frogbit are present. This result might be found because there is a small pool which is connected with the main water flow. This prevents the duckweed from flushing away and thus causes the bad status.

The measured ditches in the North (3)

The cluster in the north (3) stated as *bad* is not specifically determined in the fieldwork sessions. The ditches were physically the same as the *moderate* location. This location has a high water level, and is quite large (0.8m depth). The ditch has an average flow. The *bad* ditches in this northern area contain more duckweed than the *moderate* ditches, it are small ditches which are cut out deep with steep bank sides and little water. Three locations of the four measured have an average flow, the ones in the east receives less water.

The measured ditches in the South (4)

The four ditches in the south (4) are all stated as *bad*. The ditch on the right is not covered with helophytes and in the water only star duckweed (*Callitriche*) is present (cover 1%), moreover the soil looked like peat and is not covered with vegetation. The middle ditch is recently cleaned, is situated in the shadow of trees and does contain several plant species mainly drijvendfonteinkruid. The ditches at the left side are very shallow (0.2m) and do contain more diversity in plant species but still not divers.

All these ditches have an average water flow and receive mostly drainage water from the area. Possibly some inlet water will reach the ditches but this will not be much. Because the influence of inlet water is low, processes such as nutrient retention in the ditches are more important. These processes depend on physical environment of a ditch, such as depth, light availability and leaf litter. The middle ditch is shaded by trees and the ditches on the left are very shallow.

Figure 17 shows the area Langbroekerwetering in a map. The area is situated in the South-East of HDSR next to the 'Utrechtse Heuvelrug'. The soil consists of sand, sabulous clay and clay.

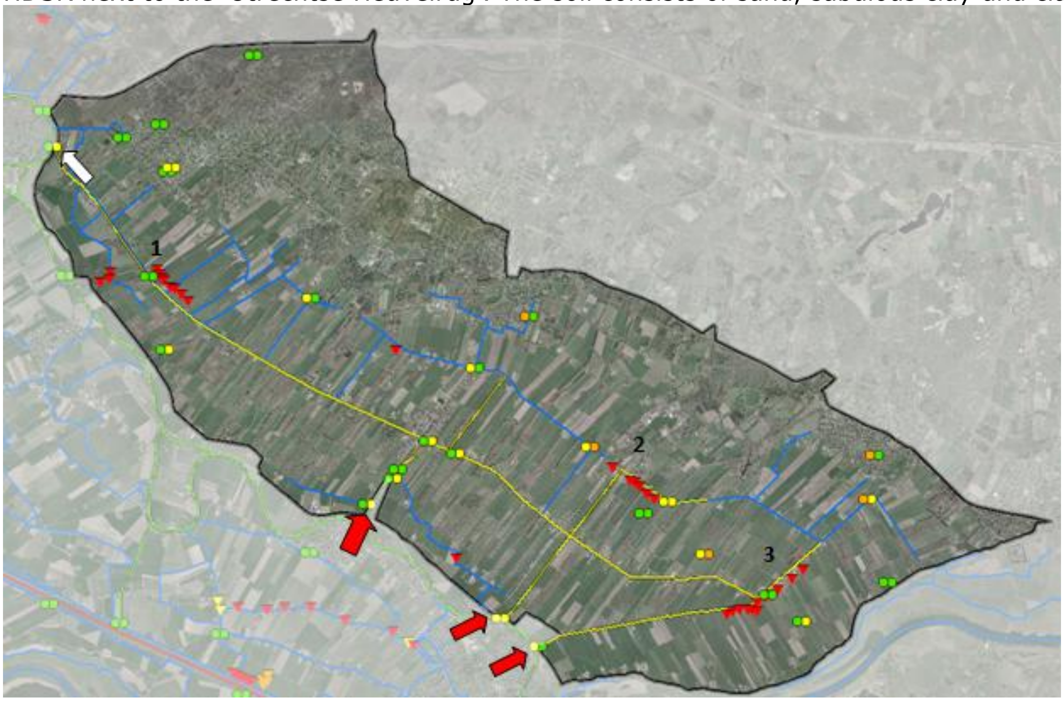

Figure 17: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area Langbroekerwetering. The red arrow indicates a pumping station. The white arrow indicates an outlet device.*

The water supply for this area is regulated by three pumping stations on the South-West side of the catchment area. From the pumps the water flows in the WFD water body. With several pumps in the area (not shown in figure 17) the water is pumped towards the 'Utrechtse Heuvelrug' through the main watercourses. The pumps are needed in order to provide ditches of water because the altitude towards the Heuvelrug is higher. The main flow direction is towards the north-west, where the discharge of water out of the catchment area is regulated by a weir. The main watercourses receive the strongest water flow. In between the main watercourses ditches are present which receive less water depending on their location with respect to the main watercourses.

The area is subdivided in an urban sub catchment (10% of the catchment area, representing the villages of Doorn, Driebergen en Langbroek, shown in the north of figure 17) and two rural sub catchments: one with a sandy soil (58% of the catchment area, located along the full length from west to east, north of the full length of the main watercourse) and one with a clay soil (32% of the area, located in the south along the full length of the area). The distribution of the inlet water is followed estimated. The main watercourses including the WFD water body receives the strongest water flow and it is estimated that it covers 30 percent of the total water surface area on clay and 20 percent on the sand soil. The average influence of the inlet water is estimated on 50 percent on clay and 30 percent on the sand soil. The less influence (inlet -50%) and the minimum influence (inlet -100%) is estimated on 10 percent both of clay and respectively 30 and 40 percent for the sand soil.

The nitrogen and phosphorus statuses differ spatially in this area. In the North-West they are stated as good with one exception for a *moderate* location. In the South-West, right after the left pumping station, several locations indicate a *good* nitrogen status and a *moderate* phosphorus status. Close to the 'Utrechtse Heuvelrug' in the South-Eastern part of this area the nitrogen is indicated as *inadequate* where the phosphorus is *good.* More towards the lower middle part both nutrients are *moderate* or *inadequate* with several strange *good* nutrient measurement locations.
The macrophyte status in the WFD water body within this area is moderate. This is in correlation with the mostly moderate nutrient statuses in the South-East, but this doesn't apply for the North-Western part where the nutrients are *good*. This is logical because the status of the WFD water body is less influenced by the inlet water in the north, because the inlets are in the south and the north is downstream.

<u>The measured ditches in the North-West (1)</u>
The cluster of ditches in the North-West (1) do not correlate with the *good* statuses of the nutrients at that point. The cluster west of the WFD water body are small shallow ditches with Lemna

(Duckweed), liesgras (*Lythrum salicaria*) and Bur-reed (*Sparganium*). The shallowness could be exacerbated by the leaf litter coming from the trees on the bank sides. This cluster has an average to high water flow, which would indicate a high nutrient load. On the North-East side of the WFD water body intensive agriculture is present, the ditches have steep bank sides and duckweed is highly present. The ditches have an average water flow with a high nutrient load.

The measured ditches in the middle (2)

The cluster of ditches in the middle of the polder (2) are stated as *bad.* They are situated close to the WFD water body but directly connected to the water body. What stands out is the intensive agriculture and the seepage membranes on the water (red rust colored sediment on the water which is iron). There are no seepage species present, only some dead stems under water are found and only the helophyte Branched Bur-reed (*Sparganium erectum*) were found. The ditches are shallow and have a low water flow.

The measured ditches in the middle (3)

The cluster of ditches in the South-East (3) are situated close by the WFD water body but the ditches are not directly connected to the water body. The nutrients in the WFD water body don't correlate with the macrophyte statuses in the ditches. Duckweed is highly present at these locations with several duckweed species. The helophytes are present with Reed sweetgrass and reed. The ditches are very shallow and agricultural and yard runoff are high due to the farms near the measurement locations. The clay soil is very wet (also on the agricultural land because of seepage of the 'Utrechtse Heuvelrug' and the river 'Rhine').

Figure 18 represents a detailed map of the catchment area Hekendorp. The area is situated in the west of the HDSR region. The soil consists of peat the difference with the peat area Zegveld is that this peat soil is mixed with clay.

Figure 18: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area Hekendorp. The red arrow indicates a pumping station. The white arrows indicate inlet devices*

The area receives water from the boezem 'Lange Weidsche boezem' by the pumping station in the west and flows through the main watercourse in the area. Next to this pumping station an outlet is situated, it depends on the water level which way the water flows in this area. Moreover two inlets are situated in the eastern part where the area receives water from the 'Hollandse IJssel'. This catchment area doesn't contain a WFD water body. The incoming water is not evenly distributed among the ditches between the inlets. The main watercourse, between the inlets and the pumping station, receives the strongest water flow. The more ditches are located further away from the main watercourse the lesser water flow they receive.

The area is subdivided in a small urban catchment which covers 3% of the area, representing the farms along the south border of the area. Besides a large rural area covering 97% of the area with a peat soil.

The distribution of inlet water is as followed estimated: For the large influence of inlet water it is estimated that this covers 20 percent of the total water surface in this area. The average inlet flow next to the large flow is estimated on 50 percent. The less (inlet -50%) and minimum (inlet-100%) flow are both estimated on 15 percent coverage.

The distribution of water flow partly be seen in the macrophyte measurements.

The macrophyte statuses in the ditches in Hekendorp are all *inadequate* due to the highly present submerged vegetation and floating algae. The presence of the helophytes is divers with eight different species. The coverage of the submerged plants is with 80% very high, with the general species Common Hornwort (*Ceratophyllum demersum*) and Western Waterweed (*Elodea nuttallii*), this is not divers and indicates fallowing. Moreover six different duckweed species are present, it depends on the ditch what the coverage is, but mostly it is present at the dead-end of ditches because it drift towards the dead-ends by wind. The ditches in the north are strong and averaged influenced by the inlet water. The ditches in the south are less influenced by the inlet water except for the several measurement locations close to the inlets, these are average to high influenced.

Figure 19 represents in detail the catchment area Haarrijn. The area is situated in the middle north of HDSR and the soil consists of clay.

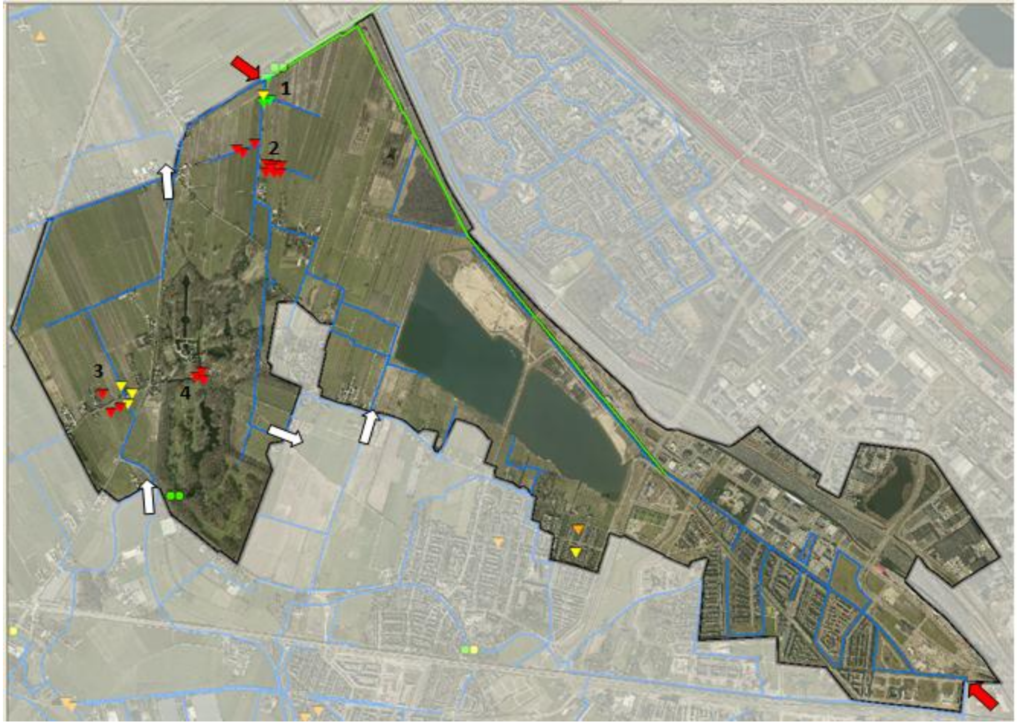

Figure 19: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area Haarrijn. The red arrow indicates a pumping station. The white arrows indicate in or outlet devices.*

The water supply is regulated by a pump and several small inlet devices. In the map the WFD water body is shown and is situated on the north border of the catchment area, also the main watercourses are shown. The main flow direction is towards the north where the discharge of the water is regulated by a pump. On the east side of the area the water is pumped into the area towards the Haarrijnse Plas and into the WFD water body. The lake is further left out the water system calculations because it is not a ditch but a small lake. This difference is hard to calculate in combination properly due to different water systems. On the south two inlet devices are situated and two small outlets. The water is not evenly distributed among the ditches in the catchment area. The WFD water body and the main watercourses receive the strongest water flow. The ditches situated close and directly connected to a main watercourse receive an average water flow. Further away from these watercourses the inlet water is in a lesser extent present until a minimum flow is reached.

The area is subdivided in urban catchment covering 20% of the area, representing the village Haarzuilens, in the east a small part of Utrecht Leidsche Rijn and several farms. Besides two rural sub catchments: one covering 55% of the area, located west of the Haarrijnse Plas, with a light clay soil and the other covering 26% of the area, located north and south of the Haarrijnse Plas, with a heavy clay soil.

The distribution of the inlet water is as followed estimated: The main watercourses including the WFD water body receives the strongest water flow and it is estimated that it covers 30 percent of the total water surface area on heavy clay and 40 percent on the light clay soil. The average influence of the inlet water is estimated on 40 percent on heavy clay and 30 percent on the light clay soil. The less influence (inlet -50%) and the minimum influence (inlet -100%) is estimated on 20 percent and 10 percent on both soils.

A clear correlation can be seen between the macrophyte status of the WFD water body and statuses of nitrogen and phosphorus, both are *good*. Moreover three macrophyte measurement locations in ditches close by are stated as *good,* because they are in connection with and so influenced by the water body it can be said that a correlation is present.

<u>The measured ditches in the North (1)</u>

The good ditches in the north have a depth of 0.5m, were recently cleaned. On the basis of the vegetation on the bank side (the rests of the cleaning) a divers vegetation composition has been determined. The submerged vegetation was about 80% present, several Nympeaieds were present and the emergent vegetation was about 5%. The ditches little to the south (2) are the same ditches as the ones in the north but contained more *Lemna*.

<u>The measured ditches in the South-West (3)</u>

Further south of these good ditches the statuses are getting poorer. The cluster of ditches in the South-West (3) are partly stated as *moderate* and *bad*, which is a great difference so close by each other. The helophyte composition is divers and the coverage of the submerged plants are high which indicates fallowing, 90%, with one species the 'Western Waterweed' (*Elodea nuttallii*).

<u>The measured ditches in the South-East (4)</u>

The cluster of ditches in the South-East are stated as *Bad*. Possibly more fertilization is present here because of the agriculture. These ditches were recently cleaned and before that duckweed was dominating.

Figure 20 shows a detailed map of the catchment area De Pleijt. Within the region of HDSR it is situated in the South-West and the soil consists of clay, clay on peat and peat.

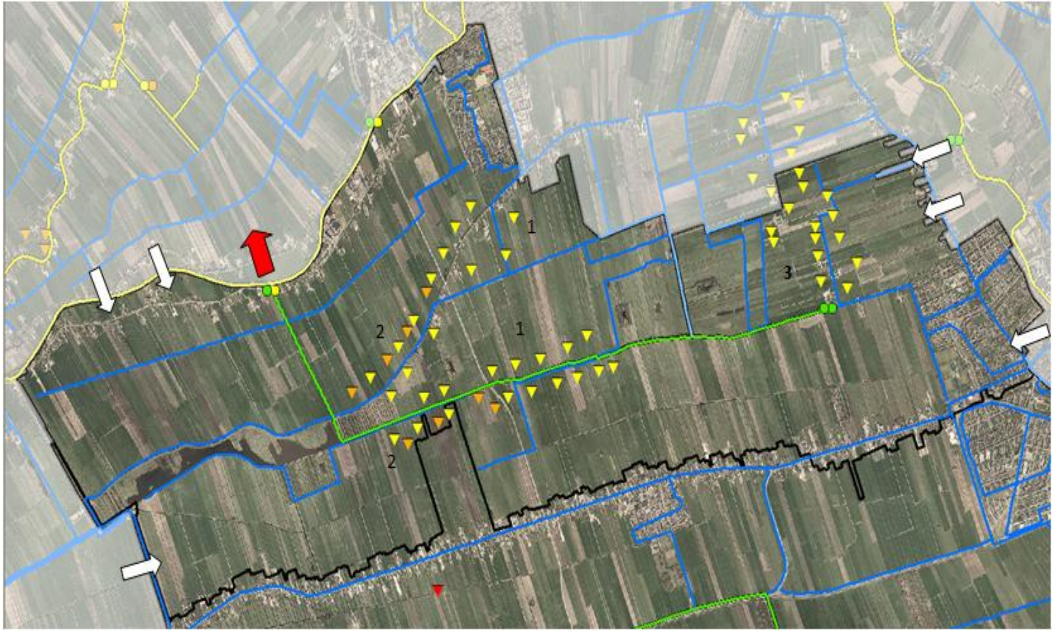

Figure 20: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area De Pleijt. The red arrow indicates a pumping station. The white arrows indicate inlet devices.*

The water supply is regulated by a pump and several small inlet devices. The water enters the catchment area mainly through an inlet next to the pump and by several small inlets in the east and west side. If the water is drained the water flows towards the pump. In between the pump and inlets several pumps are situated to distribute the water within the area, however the water is not evenly distributed. In figure 20 the WFD water body is shown situated in the middle of the catchment area, also the main watercourses are shown. These watercourses receive the strongest water flow. The ditches situated close and directly connected to a main watercourse receive an average water flow. Further away from these watercourses the inlet water is in a lesser extent present until a minimum flow is reached.

The area is subdivided in an urban catchment covering 5% of the area, representing the farms near the WFD water body and a part of the village Montfoort in the north and part of the village IJsselstein in the east. Besides two rural sub catchments: one covering 49% of the area, located the middle of the western part of the area, with a soil mixture of peat and light clay and the other covering 47% of the area, located near all the borders, with a clay soil.

The distribution of the inlet water is as followed estimated, both soils have the same distribution: The main watercourses including the WFD water body receive the strongest water flow and it is estimated that it covers 10 percent of the water surface area. The area with an average amount of influence of inlet water is estimated to be 50 percent of the surface water area. The less influence (inlet -50%) and the minimum influence (inlet -100%) are both estimated to cover 20 percent of the water surface area.

The distinction in the amount of water flow can also be seen in the macrophyte measurements. There is no clear spatial pattern/difference in the ditches recognizable, except that the ditches get worse more towards the west, the ditches are broader, more duckweed is present and the soil is more peaty. Most of the ditches have a *moderate* status with several *inadequate* statuses in between. The phosphorus concentration is moderate near the inlet but good at the end of the WFD water body, the nitrogen has a good status. A correlation can be seen between the macrophyte status of the WFD water body and the statuses of the nutrients, both are *good*.

All the ditches have a very high plant biodiversity, mainly helophytes. The *moderate* ditches (1) have a depth of about 0.7m. The submerged plants have a high coverage rate of 90%, but this also includes the underwater coverage of the floating-leaved plant Yellow water lily (*Nuphar lutea*). The Duckweed is present with three different species and covers 5 percent of the water surface. The helophytes have a coverage of 20 percent which is high, including a high biodiversity of 12 species.

The measured ditches in the middle (2)

More to the left the moderate ditches (2) are shallower than the outer right ditches, namely a depth of 0.30m. Duckweed is present with a coverage of 2 percent, and the submerged coverage is 90 percent. With only 3 different species. Also in these ditches 12 helophyte species are present, but with a lower coverage of 10 percent.

The measured ditches in the middle (2)

The *inadequate* ditches (2) are shallow with a depth of 0.3m with several ditches fully grown with Reed Bur-reed (*Sparganium*). Probably because of the shallowness the diversity and the coverage rate of 30 percent of the helophytes is high because the environment is perfect for settlement. Duckweed has only a coverage of 3 percent. The ditches near the WFD water body have probably a high water flow, and the ditches north, close to the main watercourse, have an average to high water flow.

The measured ditches in the East (3)

The *moderate* ditches (3) are situated in an ecological high potential are a ‘Waterparel’ of HDSR. The depth of the ditches is 1 meter and the soil can be seen. Duckweed and floating algae are minimal present, but the coverage of the submerged plants is 95 percent, with mainly Western water weed and veenwortel (*Polygonum amphibium*). The presence of helophytes is divers with eight different species. The ditches in this are mainly less to minimum influenced by the inlet water. Several ditches in the south will have a more average influence because they are closely to the main watercourses.

Figure 21 shows a detailed map of the catchment area De Koekoek; inlets, watercourses and nutrient and macrophyte statuses are shown. Within HDSR it is situated in the South-West and the soil consists of clay, clay on peat and peat.

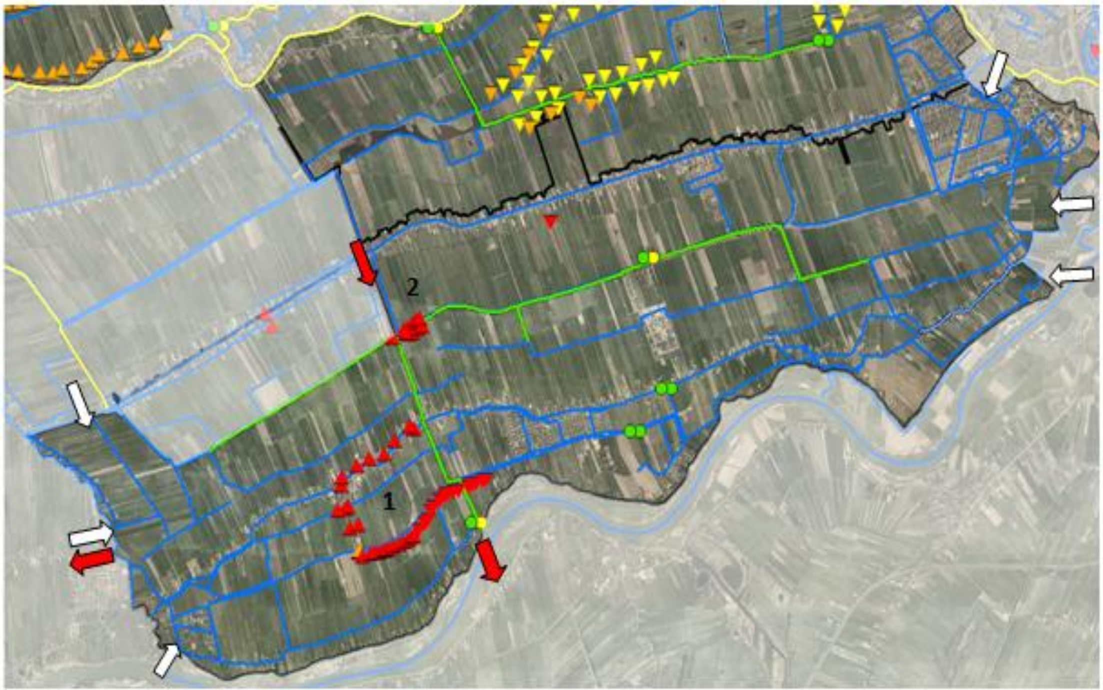

Figure 21: *WFD statuses of nutrients and macrophytes in WFD water bodies and ditches in the area Koekoek. The red arrows indicate pumping stations. The white arrows indicate inlet devices.*

The water supply is regulated by pumps and several small inlet devices. The water enters the catchment area mainly by the pump in the north of the area and by several small inlets in the west and east side. Also a weir is situated at the south next to the pump where the water is able to flow in. The discharge of the area is regulated by the pump in the south where it flows in the Lek boezem and a small part is drained in the west by a pump. The inlet water is not evenly distributed among the ditches in the area. In figure 21 the WFD water body and the main watercourses are shown. These watercourses receive the strongest water flow. The ditches situated close and directly connected to a main watercourse receive an average water flow. Further away from these watercourses the inlet water is in a lesser extent present until a minimum flow is reached.

The area is subdivided in urban catchment covering 7% of the area, representing the farms situated in the middle part, the villages Benschop, Lopik a small part of the village IJsselstein in the east. Besides, two rural sub catchments are present: one covering 57% of the area, located west of the WFD water body where the pumps are situated, with a soil mixture of peat and light clay and the other covering 36% of the area located at the east side with a heavy clay soil.

The distribution of the inlet water is as followed estimated: The main watercourses including the WFD water body receives the strongest water flow and it is estimated that it covers 10 percent of both soils. The average influence of the inlet water is estimated on 60 percent for the mixed soil and 30 percent for the heavy clay. The less influence (inlet -50%) and the minimum influence (inlet -100%) are both estimated on 20 percent for the mixed soil and 30 percent for the heavy clay soil.

The distinction in inlet water influences can also be seen in the macrophyte measurements. Starting with the strongest influenced location: the macrophyte status of the WFD water body is good. This status is the same as the nutrient status. The status depends on the location in the water body. The other macrophyte measurement locations are situated in ditches mainly measured near the WFD water body. The statuses are all *bad* with one place *inadequate* in between the others.

<u>The measured ditches in the South (1)</u>

The measured ditches in the south (1) are all dominated by Duckweed or floating algae. The diversity of the submerged and floating plants is high with four different duckweed species and three submerged species. But the submerged coverage is only 10 percent. This is similar for the helophytes with ten different species present but a coverage of only 2 percent. The helophytes are possibly able to develop with this diversity because the depth is only 0.3m. The ditches in the south and north are highly influenced by the inlet water and the ditches in de west are averaged influenced.

The measured ditches in the North (2)

At the cluster in the middle north (2) of the polder partly measurement locations are situated in the WFD water body. Here Duckweed is little present because due to the high flow rate of the water Duckweed gets flushed away. The submerged plant Western waterweed is highly present. These ditches are highly influenced by the inlet water because they are situated close by an in and outlet of the water for the polder.

Several other measurement locations in this cluster are situated next to the WFD water body. Here, Duckweed and floating algae are highly present. The helophytes are also divers present (opzoeken? Divers of veel?) the influence of the inlet water is high because the measured location are direct connected to the WFD water body and measured at the beginning of the ditch.

Annex 4. Prospects for recovery

Figure 22: *Simulated Lemna biomass as a function of phosphorus and nitrogen load on sand. Starting with a pristine ditch in the high influenced zone the phosphorus and nitrogen loads were increased to the actual phosphorus load (5.95 g/m²/year) and actual nitrogen load (150 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (1.28 g/m²/year) and to the adapted actual nitrogen load (17.15 g/m²/year). It was found that after this reduction of both phosphorus and nitrogen the system needs a recovery time of 13,5 years until the Lemna biomass is zero. The oscillations in the graph represent the seasons.*

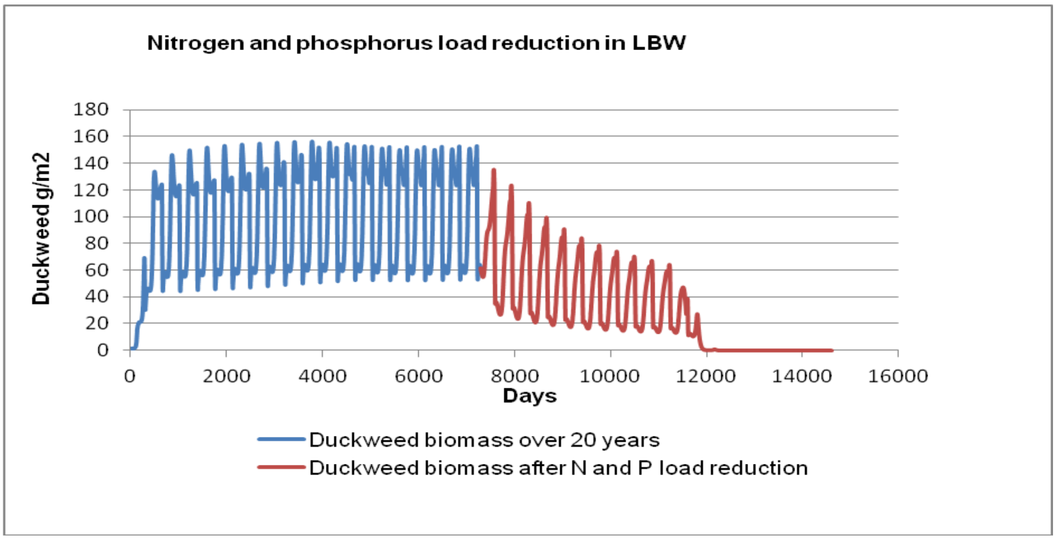

Figure 23: *Simulated Lemna biomass as a function of phosphorus and nitrogen load on clay. Starting with a pristine ditch in the averaged influenced zone the phosphorus and nitrogen loads were increased to the actual phosphorus load (6.86 g/m²/year) and actual nitrogen load (128 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (5.26 g/m²/year) and to the adapted actual nitrogen load (76,65 g/m²/year). The oscillations in the graph represent the seasons.*

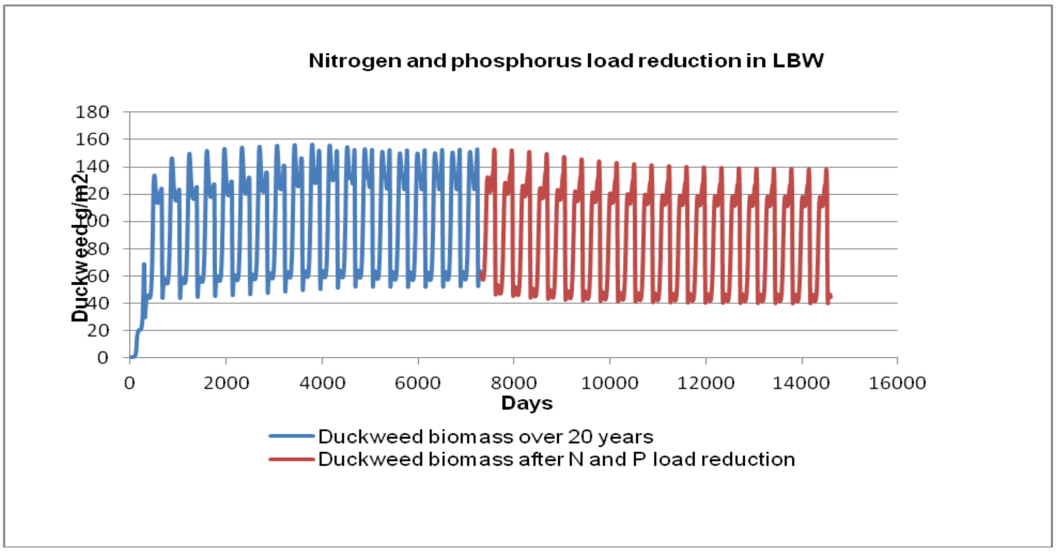

Figure 24: *Simulated Lemna biomass as a function of phosphorus load on peat. Starting with a pristine ditch in the high influenced zone the phosphorus and nitrogen loads were increased to the actual phosphorus load (4.03 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (0.65 g/m²/year). It was found that after this reduction of phosphorus the system needs a recovery time of nine years until the Lemna biomass is zero. The oscillations in the graph represent the seasons.*

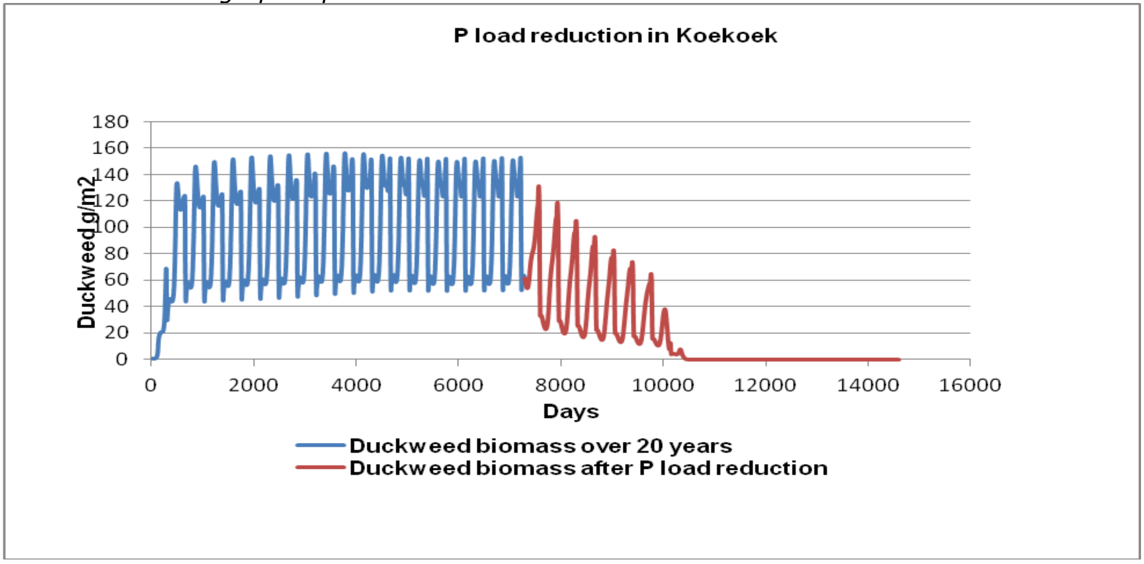

Figure 25: *Simulated Lemna biomass as a function of phosphorus load on clay. Starting with a pristine ditch in the averaged influenced zone the phosphorus and nitrogen loads were increased to the actual phosphorus load (6.07 g/m²/year) and after 20 years the loading was reduced to the adapted actual phosphorus load (4.75 g/m²/year). It was found that after this reduction of phosphorus the system needs a recovery time of eight years until the Lemna biomass is zero. The oscillations in the graph represent the seasons.*