Options for improving the water quality of the polder Cromstrijen and the impact on ecosystem services

MSc Thesis of Jelle W.M. Gommans, March 2011

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Summary

The current European standards for water quality are recorded in the Water Framework Directive (WFD). Ditches are not strictly part of the WFD (Evers *et al.*, 2007), however, ditches discharge to lakes or rivers, which are indeed part of the WFD. Therefore, it seems reasonable that ditches should comply with the water quality standards of the WFD as well. The ditches of the polder Cromstrijen do not comply with the standards of the WFD related to phosphorus. The water quality is on average moderate (Waterschap Hollandse Delta, 2007) due to the current policy related to fertilizer use (Planbureau voor de leefomgeving, 2008). The present research focuses only on the chemical variable phosphorus. The question is how to improve the water quality of ditches through reducing the phosphorus levels in the surface waters of the polder by e.g. creating buffer zones, changing dredging and mowing regime. The objectives of the present research are:

- Identifying the phosphorus reduction capacities of different ditch management scenarios for the ditches in the polder Cromstrijen.
- Identifying the impact of the ditch management scenarios on the ecosystem services of the Cromstrijen polder.
- Making the used approach to evaluate the effect of the scenarios on the ecosystem services a blue print for other areas as well.

Four different ditch management scenarios have been selected to analyse their effects on the improvement of the water quality of the ditches. First, the current management scenario consists mainly of ditch cleaning and dredging. Ditch cleaning is mowing the aquatic and riparian vegetation and dredging is the removal of ditch sediment. Second, an alternative scenario with only dredging has been selected to identify whether ditch cleaning is effective for lowering the phosphorus levels of the polder. Thirdly, an alternative scenario with buffer zones of 5 m in combination with dredging has been selected because buffer zones reduce the amount of phosphorus entering the polder originating from agriculture. Finally, an alternative scenario with buffer zones of 25 m in combination with dredging has been selected. The efficiency of phosphorus removal increases with an increasing width of the buffer zones. Therefore the amount of phosphorus entering the polder from the agricultural fields declines further.

In the present research two different analyses have been preformed: water quality analysis and function analysis. The water quality analysis was performed by constructing phosphorus budgets that have been calculated through a mass balance approach. The mass balance considered the mass of phosphorus entering and leaving the polder. In order to apply the mass balance a water balance for the polder has been set-up. The water balance has been developed by assuming that the quantity of water entering the polder also leaves the polder on a yearly basis. The function analysis is performed to identify the ecosystem services present in the polder and to analyse the effect of the scenarios on the use of ecosystem services. This effect is used as a basis to rank the scenarios based on their effect on the ecosystem service through a multi-criteria analysis. The multi-criteria analysis is performed through scoring the effects of the scenarios on the ecosystem services and determining weights for the importance of the ecosystem services for the main stakeholders.

The results of the water quality analysis indicate that the water quality of the surface water remains stable for the current management scenario and the scenario with only dredging. A limited reduction of the phosphorus concentration in the ditch is achieved in the scenario with buffer zones of 5 m. In the scenario with buffer zones of 25 m the phosphorus concentration will presumably decline in a much larger extent. The phosphorus accumulation in the sediment is comparable for the current management scenario, the scenario with only dredging and the scenario with buffer zones of 5 m. The phosphorus accumulation in the sediment is reduced with 33% in the scenario with buffer zones of 25 m. The results of the function analysis indicate that the effect of the current management scenario on the use of ecosystem services is estimated at below neutral. A neutral score indicates that a scenario does not positively nor negatively affect the use of the selected ecosystem services. The effect of the scenario with buffer zones of 5 m is just above neutral. The scenario with buffer zones of 25 m and the scenario with only dredging both score an above neutral effect on the use ecosystem services. The difference between these two scenarios is small.

It can be concluded that the current management scenario, the scenario with only dredging and the scenario with buffer zones of 5 m do not appear to be sufficient to comply with the water quality standards of the WFD. In the scenario with buffer zones of 25 m the water quality will be improved to a large extent and the water quality standards of the WFD directive will be reached. The exact reduction of the phosphorus concentration in the surface water is currently unknown. Further research is therefore needed to quantify the effect of buffer zones on the phosphorus concentration in surface waters. Next to that it can be concluded that the ecosystem services are not used to their optimum in the current management scenario. The ecosystem services would be enhanced in all of the alternative management scenarios. It can be concluded that the best alternative scenario is the scenario with buffer zones of 25 m. A final conclusion is that the combination of water quality analysis and function analysis causes a more distinguished ranking of the ditch management scenarios. Especially the highest and lowest scoring scenarios are more clearly separated, however the distinction between the current management scenario, the scenario with only dredging and the scenario with buffer zones of 5 m remains limited.

Samenvatting

De huidige Europese normen voor de waterkwaliteit worden bepaald door de Kaderrichtlijn Water (KRW). Sloten zijn strikt genomen geen onderdeel van de KRW (Evers *et al.*, 2007). Echter, sloten voeren water af naar meren of rivieren, die wel onderdeel uitmaken van de KRW. Daarom lijkt het redelijk dat sloten ook moeten voldoen aan de waterkwaliteitsnormen van de KRW. De sloten van de polder Cromstrijen voldoen niet aan de normen van de KRW met betrekking tot fosfaat. De kwaliteit van het water is matig (Waterschap Hollandse Delta, 2007) als gevolg van het huidige beleid met betrekking tot het gebruik van meststoffen (Planbureau voor de Leefomgeving, 2008). Het huidige onderzoek richt zich alleen op de chemische variabele fosfaat. De vraag is hoe de waterkwaliteit van sloten te verbeteren is door het verminderen van de fosfaatconcentratie in het oppervlaktewater van de polder, bijvoorbeeld door het creëren van bufferzones, aanpassen van baggeren en maairegime. De doelstellingen van dit onderzoek zijn:

- Het identificeren van de fosfaat verminderingscapaciteit van de verschillende slootmanagementscenario's voor de sloten in de polder Cromstrijen.
- Het identificeren van de impact van de slootmanagementscenario’s op de ecosysteemdiensten van de polder Cromstrijen.
- Het maken van een blauwdruk voor andere gebieden die gebaseerd is op de gebruikte methoden om het effect van de scenario’s op de ecosysteemdiensten te bepalen.

Vier verschillende scenario’s voor het beheer van sloten zijn geselecteerd om de waterkwaliteit in de sloten te verbeteren. Ten eerste, het huidige beleid bestaat voornamelijk uit slootschonen en baggeren. Slootschonen is het maaien van de water en oevervegetatie en baggeren is de verwijdering van sediment uit de sloot. Ten tweede, een alternatief scenario met alleen baggeren is geselecteerd om te bepalen of slootschonen effectief is voor het verlagen van fosfaat op polderniveau. Ten derde, een alternatief scenario met bufferstroken van 5 m in combinatie met baggeren is geselecteerd. Bufferstroken verminderen de hoeveelheid landbouw grond en dus ook de hoeveelheid fosfaat die geïntroduceerd wordt in de polder door mest. Ten slotte, een alternatief scenario met bufferstroken van 25 m in combinatie met baggeren is geselecteerd. De efficiëntie van fosfaatverwijdering neemt toe naar mate breedte van de bufferstroken toeneemt. Daarom daalt de hoeveelheid fosfaat die de polder binnenkomt vanuit de landbouw verder.

In het huidige onderzoek zijn twee verschillende analyses gedaan: waterkwaliteitanalyse en functieanalyse. De waterkwaliteitanalyse werd uitgevoerd door het maken van fosfaatbalansen die zijn berekend door middel van een massabalans. De massabalans wordt bepaald door de hoeveelheid massa aan fosfaat die de polder binnenkomt en die de polder

verlaat. Om de massabalans toe te passen is een waterbalans voor de polder gemaakt. De waterbalans is gebaseerd op de veronderstelling dat de hoeveelheid water die de polder binnenkomt op jaarbasis ook de polder verlaat. De functieanalyse identificeert de ecosysteemdiensten die aanwezig zijn in de polder. Ook het effect van de scenario's op het gebruik van ecosysteemdiensten wordt bepaald. De multi-criteria analyse gebruikt dit effect als basis voor een classificatie van de scenario's. Dit is gedaan door het scoren van de effecten van de scenario's op de ecosysteemdiensten. Daarnaast worden gewichten bepaald voor het belang van de ecosysteemdiensten voor de belangrijkste betrokkenen.

Uit de resultaten van de waterkwaliteitsanalyse blijkt dat de waterkwaliteit van het oppervlaktewater stabiel blijft voor het huidige managementscenario en het scenario met alleen baggeren. Een beperkte vermindering van de fosfaatconcentratie in de sloten wordt bereikt in het scenario met bufferstroken van 5 m. In het scenario met de bufferzones van 25 m zal de fosfaatconcentratie vermoedelijk veel sterker afnemen. De fosfaataccumulatie in het sediment is vergelijkbaar voor het huidige managementscenario, het scenario met alleen baggeren en het scenario met bufferstroken van 5 m. De fosfaataccumulatie in het sediment wordt verlaagd met 33% in het scenario met bufferstroken van 25 m. Uit de resultaten van de functieanalyse blijkt dat het effect van het huidige managementscenario op het gebruik van ecosysteemdiensten als lager dan neutraal wordt beoordeeld. Een neutraal effect geeft aan dat een scenario geen positieve, noch negatieve invloed heeft op het gebruik van de geselecteerde ecosysteemdiensten. Het effect van het scenario met bufferstroken van 5 m is net boven neutraal beoordeeld. Het scenario met bufferstroken van 25 m en het scenario met alleen baggeren scoren het hoogst. Beiden hebben een boven gemiddeld effect op het gebruik van ecosysteemdiensten. Het verschil tussen deze twee scenario's is klein.

Geconcludeerd kan worden dat het huidige managementscenario, het scenario met alleen baggeren en het scenario met bufferstroken van 5 m niet in staat lijken om aan de waterkwaliteitsnormen van de KRW te voldoen. In het scenario met bufferstroken van 25 m zal de waterkwaliteit sterk worden verbeterd en de waterkwaliteit zal voldoen aan de normen van de KRW. De exacte verlaging van de concentratie van fosfaat in het oppervlaktewater is momenteel nog niet bekend. Dit houdt in dat verder onderzoek nodig is naar het effect van bufferstroken op de fosfaatconcentratie in het oppervlaktewater. Daarnaast kan geconcludeerd worden dat de ecosysteemdiensten niet optimaal benut worden in het huidige managementscenario. De ecosysteemdiensten worden beter gebruikt in alle alternatieve managementscenario's. Het beste alternatieve scenario is het scenario met bufferstroken van 25 m. Een laatste conclusie is dat de combinatie van functieanalyse en de analyse van de waterkwaliteit leiden tot een duidelijker onderscheid in the rangschikking van de slootmanagementscenario's. Er ontstaat vooral veel verschil tussen de hoogst en laagst scorende scenario's, echter het verschil tussen het huidige managementscenario, het scenario met alleen baggeren en het scenario met bufferstroken van 5 m blijft beperkt.

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1. Introduction

1.1 Background of the research

The Aquatic Ecology and Water Quality Management group of Wageningen University is executing the PLONS project. The aim of this project is amongst others to gain insight in the processes behind the self-cleaning capacity of ditches and the influence of ditch management on the ecological quality of ditches (Peeters *et al.*, 2007). The present research is related to the PLONS project as it deals with the regulation of nutrient levels in ditches and the influence of ditch management scenarios on the water quality.

The nutrient discharge to surface waters in the Netherlands is one of the highest in Europe. The first reason for this high discharge is the contribution of agriculture. Agricultural land receives fertilizer to increase crop production. Part of the phosphorus in the fertilizer enters the surface water. The second reason is that the Netherlands is located in the delta of rivers. Therefore, the river water entering the Netherlands consists of elevated loads of nutrients (Oenema *et al.*, 2004). Many of the Dutch surface waters do not comply with the standards because of these reasons. (Ligtvoet *et al.*, 2008). The Water Framework Directive (WFD) was implemented in 2000 and describes the current European standards related to the water quality. The WFD states that both water quality and aquatic ecology should comply with a good status at the latest in 2027 (Ligtvoet *et al.*, 2008). This appears to be a rather long time to achieve these goals. However, based on current management it is expected that a standstill is achieved in 2030. Nutrient concentrations need to decline further to comply with a good water quality and aquatic ecology status in 2030 (Ligtvoet *et al.*, 2006).

The present research focuses on the water quality of ditches. Ditches are defined as artificial constructions regulating the water quantity, by transporting water to an area or removing water from an area (De Klein *et al.,* 2006). Ditches belong to the so called category “heavily modified waters” which are not strictly part of the WFD (Evers *et al.*, 2007). However, ditches are connected to the rivers and/or lakes and these water systems are indeed part of the WFD. The discharge from ditches affects the nutrient concentration in rivers. Therefore it seems reasonable that ditches should also comply with the standards of the WFD.

Many ditches in the Netherlands face problems related to eutrophication due to high nutrient concentrations. It is decided to focus only on the nutrient phosphorus in the present research, because phosphorus is often the limiting factor for primary production in fresh water (Schindler, 1978; Vollenweider and Kerekes, 1980; Hecky and Kilham, 1988; Tomasky and Valiela, 1995; Phlips, 2002). Next to that, it is decided to focus on phosphorus because for nitrogen the atmospheric processes play a role. Eutrophication is in the present research defined as the enrichment of ditch water by phosphorus, possibly causing accelerated growth of duckweed floating on the water surface (Ærtebjerg *et al.*, 2003; Nijs *et al.*, 2007). Due to the duckweed layer, light penetration into the water will diminish and submerged vegetation will therefore receive less light and in the worst case not enough light to survive. Depending on the thickness of the duckweed layer the diffusion of oxygen from the atmosphere into the water column may be blocked. Meanwhile, the sediment uses oxygen to decompose organic matter. This may result in anaerobic conditions, which have a strong negative effect on the biodiversity (Ærtebjerg *et al.*, 2003; Scheffer *et al.*, 2003; Nijs *et al.*, 2007). Another problem of high phosphorus loads in the ditch water is the phosphorus accumulation in the ditch sediment. Under aerobic conditions phosphorus will be absorbed to the sediment when iron is available. However, under anaerobic conditions the binding between phosphorus and iron in the upper part of the sediment can be broken, resulting in a release of phosphorus from the sediment to the water column (Kim *et al.*, 2003).

1.2 Description of the study area

The study area of the present research is the polder Cromstrijen, located in the western part of the Netherlands near the city of Rotterdam (figure 1.1).

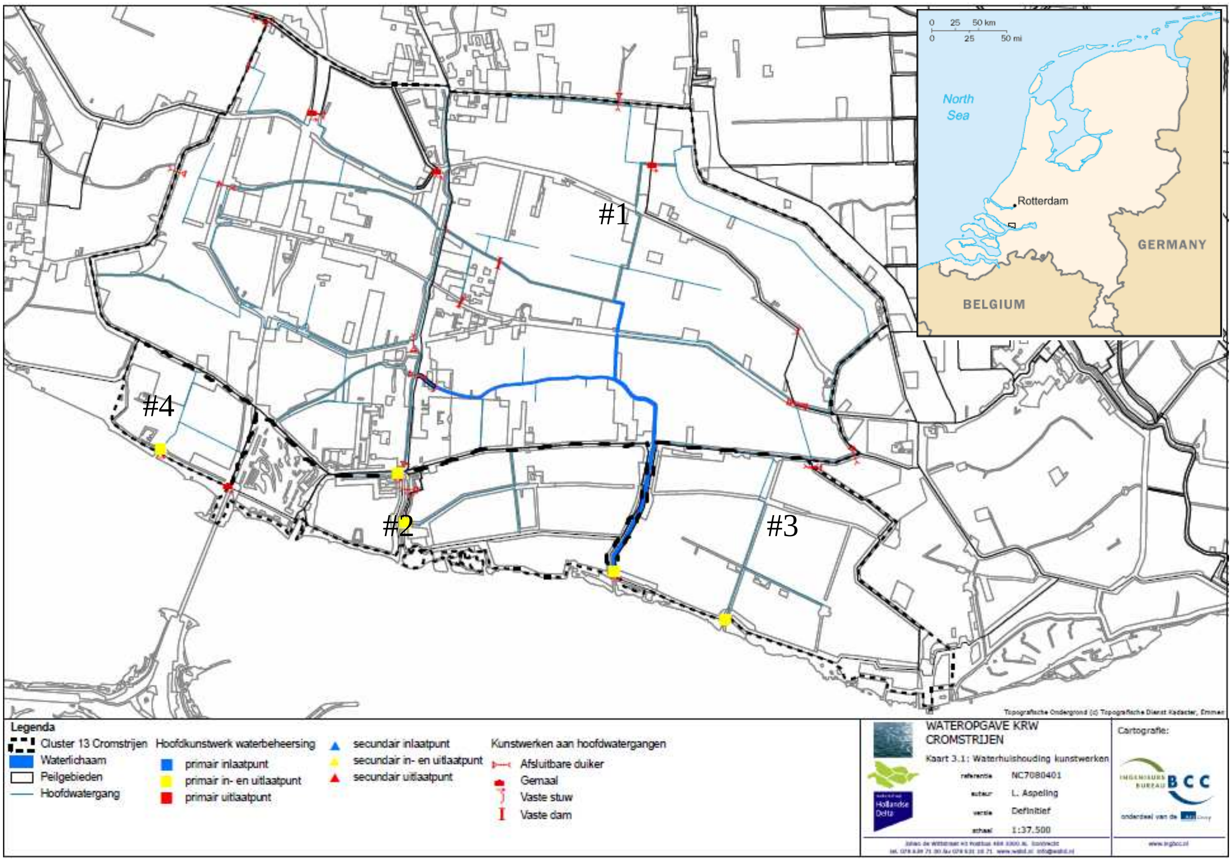

Figure 1.1: Right upper picture presents the location of the polder Cromstrijen in the Netherlands (black square). The other picture presents the study area and its sub polders (Waterschap Hollandse Delta, 2007), which are indicated by a number and are bordered with dashed lines. The locations of the pumps in the sub polder are indicated by a square.

A polder is mostly defined as a dry milled area, where the height of the water level is independent of the water level outside the polder. Pumping stations and dams regulate the water transport between inside and outside the polder (De Klein *et al.,* 2006). The polder Cromstrijen consists of several sub polders: area #1, Torenstee polder and Westerse polder (Eastern part) (#2), Hogezandse polder (#3) and Westerse polder (Western part) (#4). The Westerse polder is divided into the eastern and western part because the eastern part is a recreational area while the western part is an agricultural area. The pumps located in a sub polder are pumping water into and out of the polder independent of the other sub polder (figure 1.1) (Waterschap Hollandse Delta, 2007). The ditches in the polder seem to end mostly in the polder itself. Most of the water pumped into the polder therefore leaves the polder at the same place as it enters the polder (Waterschap Hollandse Delta, 2006). It is therefore assumed that the polder only receives or removes water at these pumps.

Land use affects the amount of nutrients entering the surface waters. Two main land use types of the polder are agricultural and urban areas, with agriculture being the most important one (85%). Important sources of nutrients for surface waters are agriculture, seepage and sewage water overflows (Waterschap Hollandse Delta, 2007).

A small part of the ditches of the polder Cromstrijen has to comply with the WFD standards. These ditches together are identified by the WFD as a water body, a waterway with a catchment of 1000 ha or bigger with an important ecological status (Waterschap Hollandse Delta, 2007). The water quality of this water body is good and therefore it complies with the standards of the WFD related to phosphorus. Not all ditches in the polder have a good status, some ditches in the Westerse polder have a bad status. The water quality for the polder scores on the Good Ecological Potential between 0.22-0.44 mg P l^{-1} and this complies with a moderate status (Stowa, 2007; Waterschap Hollandse Delta, 2007). This is due to the current policy related to fertilizer use (Planbureau voor de leefomgeving, 2008).

1.3 Objective and research questions

The present research has several objectives. The first objective is to indentify the phosphorus reduction capacities of different ditch management scenarios for the ditches in the polder Cromstrijen. The current ditch management is investigated and compared to different selected alternative scenarios. The scenarios are assembled through different management measures: mowing, dredging and buffer zones. The effect of these scenarios on the phosphorus concentration in the ditch and on the phosphorus accumulation in the sediment are investigated through phosphorus budgets.

Secondly, the impact of the ditch management scenarios on the ecosystem services of the Cromstrijen polder is determined. The scenarios will influence the landscape and therefore they might also affect the ecosystem services. Ecosystem services are defined as benefits that humans derive from ecosystems (Millennium Ecosystem Assessment, 2005). Several studies combine different aspects of the influence of ditch management on ecosystem services (Meek *et al.*, 2002; Pywell *et al.*, 2006; Haaland *et al.*, 2010; Stowa, 2010). The present research presents these aspects into one approach and adds information to combine the different selected scenarios. This should lead to a better understanding about the influence of management scenarios on the ecosystem services of an area.

Thirdly, the present research is intended as a blueprint for other areas than the polder Cromstrijen as well. The method to evaluate the effect of ditch management scenarios on the water quality and ecosystem services can possibly also be applied to other areas. This is only possible if the data needed to apply this procedure is gathered.

Based on the objectives of the present research the following main research questions have been formulated:

1. What is the current phosphorus budget of the polder Cromstrijen?
2. What is the effectiveness of phosphorus removal of the selected ditch management scenarios?
3. What is the expected reduction of phosphorus in each ditch management scenario for the polder and which of the scenarios gives the best result related to the water quality?
4. What is the effect of the ditch management scenarios on a selection of ecosystem services?
5. What is the combined effect of water quality analysis and function analysis on the ditch management options?

2. Ditch management scenarios and phosphorus reduction

2.1 Current management

The current ditch management in the polder Cromstrijen consists mainly of ditch cleaning and dredging (table 2.1). Ditch cleaning is defined as the removal of aquatic and riparian vegetation. The aim is to prevent excessive aquatic plant growth, which increases the flow resistance of the ditch (Corporaal *et al.*, 1996; Orleans *et al.*, 1996; Spielman and Broodbakker, 2001). According to Orleans *et al.* (1996) ditch cleaning is in general performed twice a year in clay areas in the months July and October. It is in the present research assumed that each time 50% of the biomass is removed. The water board Hollandse Delta (water board) cleans ditches with a mowing bucket (pers. comm. F. Kuipers), which allows the cutting of submerged vegetation around 0.1 m above the sediment (Stowa, 1996; Spielman and Broodbakker, 2001; Heerdt, 2010). However, this is only the case if applied adequately, which is assumed in the present research. As a result the sediment is relatively undisturbed and unbound phosphorus is not reintroduced into the water column. The mowing bucket is quite animal friendly as the smaller animals can escape through the gaps of the bucket and organisms in the sediment are little disturbed (Stowa, 1996; Spielman and Broodbakker, 2001; Heerdt, 2010). The water board uses the method "klepelen[1]" to mow the riparian vegetation (pers. comm. F. Kuipers). The width of the riparian vegetation is assumed to be 1 m on both sides of the ditches. This method is not very animal friendly because it negatively affects the fauna (Heeswijk *et al.*, 2006). The water board leaves the mowed aquatic and riparian vegetation on the shore as the biomass is too little to gather (pers. comm. F. Kuipers). Part of the phosphorus from the mowed vegetation on the shore can re-enter the ditch. This might happen within two weeks after mowing (Stowa, 1996).

Sludge is removed from the ditches during dredging, with the aim to prevent that the ditch becomes dry land after tens of years (Corporaal *et al.*, 1996; Orleans *et al.*, 1996). A literature review indicated that ditches are dredged on average once every ten years (Orleans, 1996; Gemeente Vlist, 2010). The rate of sediment formation is on average 0.03 m yr^{-1} (Orleans, 1996; Gemeente Vlist, 2010). It is assumed that the sludge is removed from the polder and is not applied on the agricultural land. The water board removes sludge with hydraulic dredging (pers. comm. F. Kuipers). The amount of phosphorus in the sludge depends mainly on the ratio between the sources and sinks of phosphorus. A high input

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[1] "Klepelen" is the Dutch name for the method used for mowing the shore vegetation. The vegetation is smashed and therefore the vegetation is often not removed (Heerdt, 2010). Furthermore, the use of the shore vegetation for other purposes is probably declining.

compared to removal from sinks may cause nutrient accumulation of the sediment (Portielje and Lijklema, 1993).

2.2 Scenario I: only dredging

One alternative ditch management scenario is the scenario with only dredging (table 2.1), which should indicate whether ditch cleaning is effective in reducing the phosphorus levels from the polder. Orleans *et al.* (1996) state that the rate of sediment formation possibly increases as ditch cleaning is not performed. As a result a larger amount of none decomposing aquatic vegetation is present on the sediment. Dredging needs to be applied more frequent, through which presumably more nutrients will be removed. A negative aspect of this alternative scenario might be a lower drainage capacity of the ditches (pers. comm. F. Kuipers). An alternative scenario with only ditch cleaning is not considered because the ditches would become dry land at the long term (Corporaal *et al.*, 1996; Orleans *et al.*, 1996).

2.3 Scenario II: buffer zones of 5 m and dredging

Another alternative ditch management scenario is the scenario with buffer zones in combination with dredging (table 2.1). The water board has already implemented buffer zones of 3 m in the Hoeksche Waard at different locations (pers. comm. F. Kuipers). These buffer zones consist of wild flowers and grass mixtures. The aim of the buffer zones is to decrease the amount of nutrients entering the ditch from a particular source (Muscutt *et al.*, 1993). This source of phosphorus for the polder Cromstrijen is agriculture. The present research considers buffer zones of 5 m because the efficiency of phosphorus removal by buffer zones smaller than 5 m is limited (Klok *et al.*, 2003). In the present research it is assumed that the vegetation is mowed twice a year and that 50% of the biomass of the vegetation is cut per performance. Furthermore, it is assumed that the buffer zones are created directly next to the ditch and therefore replace the existing riparian vegetation. The creation of buffer zones next to both sides of the ditches in the agricultural area is not always possible, because of other land use types than crop production e.g. roads. It is assumed in the present research that the buffer zones are created at 40% of the ditches on one side and at 60% of the ditches on two sides of the ditches. Therefore the average total width of the buffer zones next to the ditches in the polder in the agricultural areas in the polder is 8 m.

The efficiency of phosphorus removal by the buffer zone depends on several factors: vegetation removal, slope of the surface, width of the buffer zone and soil type (Muscutt *et al.*, 1993; Klok *et al.*, 2003; Clevering and Visser, 2005; Stowa, 2010). In the polder Cromstrijen the efficiency of phosphorus removal through buffer zones might be low as the ground water does not flow through the root zone of the buffer zone vegetation (pers. comm. F. Kuipers). Furthermore, the flat landscape and small width of the buffer zones probably reduces the efficiency of the phosphorus removal. The travel time of the ground water is relatively short. Therefore, the chance for phosphorus to bind to the clay particles decreases. The width of the buffer zones also indirectly affects the amount of phosphorus removal. Less agricultural land remains and therefore less fertilizer is applied (Muscutt *et al.*, 1993; Klok *et al.*, 2003).

In this scenario the sediment production rate is probably higher than in the current management scenario, because ditch cleaning is not preformed. Buffer zones decrease the amount of nutrients entering the polder, possibly affecting the vegetation production. It is assumed in the present research that the rate of sediment formation is therefore lower compared to the scenario with only dredging. A negative aspect of this alternative scenario is a decline in drainage capacity because of the larger amount of aquatic plants present (pers. comm. F. Kuipers).

2.4 Scenario III: buffer zones of 25 m and dredging

The width of the buffer zone seems to be an important factor for the efficiency of phosphorus removal (Diepen *et al.,* 2002) and therefore a second scenario with buffer zones of 25 m has been developed (table 2.1). The efficiency of a buffer zone of 25 m is assumed to be close to the optimal reduction (Klok *et al.*, 2003) and therefore it has been chosen to apply buffer zones of 25 m. The buffer zones are created using the same assumptions as described in section 2.3. The average total width of the buffer zones on both sides of the ditches is 40 m.

The efficiency of phosphorus removal is presumably higher for the buffer zones of 25 m compared to the buffer zones of 5 m. Due to an increasing width of the buffer zone the travel time of the groundwater increases. Therefore, the possibility for phosphorus to bind to the clay particles increases. Next to that the indirect efficiency also increases because a larger amount of agricultural land is used to create the buffer zones (Muscutt *et al.*, 1993; Klok *et al.*, 2003), causing a decrease of the amount of applied fertilizer.

In this scenario the sediment production rate is probably higher than in the current management scenario, because ditch cleaning is not preformed. The rate of sediment formation is lower than the only dredging scenario (section 2.3). It is assumed in the present research that the sediment formation for the buffer zones of 25 m is comparable to the buffer zones of 5 m. A negative aspect of this alternative scenario is a decline in drainage capacity because of the larger amount of aquatic plants present (pers. comm. F. Kuipers).

Table 2.1: Overview of the different selected ditch management scenarios and the different measures included in these scenarios.

Scenario	Mowing	Dredging	Buffer zone 5 m	Buffer zone 25 m
Current management	Yes	Yes	No	No
Scenario I: Dredging	No	Yes	No	No
Scenario II: Buffer zones of 5 m and dredging	No	Yes	Yes	No
Scenario III: Buffer zones of 25 m and dredging	No	Yes	No	Yes

3. Methodology

3.1 Calculation of water balance

For a single year the water balance of the polder Cromstrijen was calculated to estimate the quantity of water entering and leaving the polder, which was later used to calculate the phosphorus budget. Water regulation is an important aspect of a polder. Therefore, water entering the polder should also leave the polder on a yearly basis, as storage of water in a polder is unwanted. The sources of water for the polder are precipitation, seepage, sewage overflow and water inlet from river, the losses of water are evapotranspiration and discharge to river.

The water quantity added by precipitation and lost by evapotranspiration was estimated using data of the KNMI. Three weather stations were selected to present a realistic value for the polder: Rotterdam, Wilhelminadorp and de Bilt. Precipitation and evapotranspiration data from January 2000 to December 2009 were used. The quantity of water added by precipitation and lost by evapotranspiration was calculated using the yearly precipitation surplus and evapotranspiration for the weather stations (appendix II). These values were calculated by determining whether there was a precipitation surplus or water shortage due to evapotranspiration for each month and summarising these months for each variable. These values were multiplied with the surface area of the polder to derive the quantities that were added to or lost from the polder.

The polder was originally wet and because of the reclamation, currently there is seepage flow. Therefore, seepage water is also a source of water in the polder. The rate of seepage was determined by the water board. The quantity of water added by seepage was calculated by multiplication of the rate with the surface area of the polder. It was assumed that villages and roads do not receive seepage water because they are paved. The resulting reduction of the surface area was estimated through data from the water board.

Also sewage water overflows cause input of water in the polder (Waterschap Hollandse Delta, 2007). The quantity of water added was determined through the water board. Since the sewage system only overflows during heavy rainfall events, it was assumed that the overflows occur in the months with a precipitation surplus.

Since water regulation is performed, on a yearly basis the total quantity of water entering the polder was the same as the water removed from the polder. The water is regulated by means of pumping. During wet periods, water is pumped out of the polder to compensate for the variables ‘Precipitation surplus’, ‘Seepage’ and ‘Sewage overflows’. The quantity of water pumped out at the different sub polders (figure 1.1) was determined based on their surface area, as it was assumed that precipitation, evapotranspiration and seepage are uniformly distributed over the area. During dry periods, water is pumped into the polder. This is needed, because seepage and precipitation cannot compensate the water leaving the polder through evapotranspiration. The river water pumped into the polder mainly originated from the Hollandsch Diep (Waterschap Hollandse Delta, 2007).

3.2 Phosphorus budget

A mass balance approach was used to determine the phosphorus budgets for the selected ditch management scenarios. The mass balance considers the quantities of phosphorus that are entering and leaving the polder Cromstrijen over time (Huet, 1992; Guangzhi, 2001) (figure 3.1). The general equation of the mass balance based on the current management is given by equation 1.

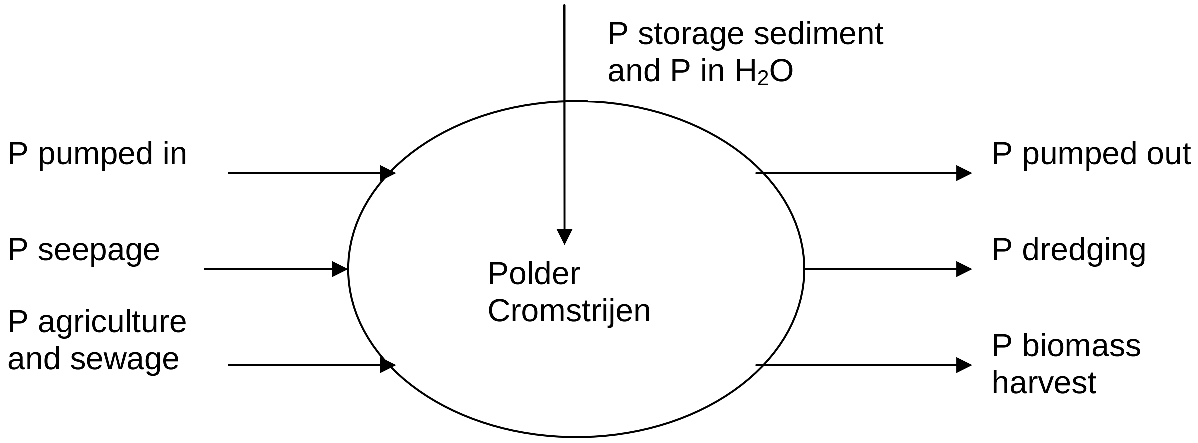

Figure 3.1: Schematisation of the most important sources and sinks of phosphorus for the polder Cromstrijen based on the current management.

$$\frac{\mathrm{dP}}{\mathrm{dt}} = \text{Pump in} - \text{Pump out} + \text{Sewage} + \text{Agriculture} + \text{Seepage} + \mathrm{H_2O} - \text{Dredging} - \text{Biomass} - \text{Capturing} \quad (1)$$

The contribution of the variable ‘Pump in’ to the mass balance was based on the quantity of water pumped into the polder and the phosphorus concentration in the water:

$$\text{Pump in} = Q_{\text{in, p}} \cdot P_{\text{in, p}} \quad (2)$$

With: $Q_{\text{in, p}}$ = quantity of water pumped into the polder (m^3 yr^{-1})

$P_{\text{in, p}}$ = concentration of phosphorus in water pumped into the polder (kg P m^{-3})

Information about the total phosphorus concentration of the incoming water was gathered from the water board. It was assumed that there is only one inlet point, as data of only one monitoring point was gathered for multiple years (appendix III). It was assumed that this monitoring point represents a realistic value for phosphorus for all the water pumped into the polder.

The calculation of the contribution of the variable ‘Pump out’ to the mass balance is comparable to the variable ‘Pump in’:

$$\text{Pump out} = Q_{\text{out, p}} \cdot P_{\text{out, p}} \tag{3}$$

With: $Q_{\text{out, p}}$ = quantity of water pumped out of the polder ($m^3\ yr^{-1}$)

$P_{\text{out, p}}$ = concentration of phosphorus in water pumped out of the polder ($kg\ P\ m^{-3}$)

The total phosphorus concentrations near the outlet points of the different sub polders were extracted from data of the water board. For one monitoring point data was available for multiple years and for the other monitoring points only a single year (appendix III). It was assumed that there is only one outlet point. The phosphorus concentration in the water pumped out at the single outlet point was determined through averaging the area size of the different sub polders (figure 1.1). As it was assumed that precipitation, evapotranspiration and seepage are uniformly distributed over the polder.

The calculation of the contribution of the variable ‘Sewage’ to the mass balance is comparable to the variable ‘Pump in’.

$$\text{Sewage} = Q_{\text{in, u}} \cdot P_{\text{out, u}} \tag{4}$$

With: $Q_{\text{in, u}}$ = quantity of water entering the ditch through sewage overflows ($m^3\ yr^{-1}$)

$P_{\text{in, u}}$ = concentration of phosphorus in water from sewage overflows ($kg\ P\ m^{-3}$)

The phosphorus concentration in the water of sewage overflows was gathered through a literature review.

The contribution of the variable ‘Agriculture’ was calculated based on the area for production, used fertilizer and the amount of phosphorus entering the ditch:

$$\text{Agriculture} = A \cdot F \cdot f \tag{5}$$

With: A = the surface area of the agricultural land (m^{-2})

F = amount of fertilizer applied on the agricultural land ($kg\ m^{-2}\ yr^{-1}$)

f = fraction of phosphorus from fertilizer entering the ditch (-)

The area for production, used fertilizer and the amount of phosphorus entering the ditch was gathered through a literature review.

The variable ‘Seepage’ consists of the quantity of seepage water and the phosphorus concentration in the seepage water:

$$\text{Seepage} = Q_{\text{in, s}} \cdot P_{\text{in, s}} \tag{6}$$

With: $Q_{\text{in, s}}$ = quantity of water flowing from the subsoil into the ditches ($m^3\ yr^{-1}$)

$P_{\text{in, s}}$ = concentration of phosphorus in water flowing from the subsoil into the ditches ($kg\ P\ m^{-3}$)

The phosphorus concentration in the seepage water was gathered from data of the water board. It is important to consider that the quantity of water entering the ditches is based on the surface area of the ditches in the polder. The length and the width of the ditches were estimated by using the outcome of the STONE model. This model is relevant as it estimates the amount of nutrients entering the ditch from the agricultural land. The hydrology of the Netherlands is modelled in detail in order to create this model. Therefore the lengths of different watercourses have been determined by using topographical maps of 1:10,000 (Top 10 vector maps). Each grid cell of 250 m by 250 m is automatically analysed in order to generate the length and width of a waterway per area. The model was validated by verifying the outcomes with field recordings for several locations (pers. comm. J. de Klein).

The contribution of the variable 'H_2O' was based on the water volume in the ditches and the phosphorus concentration in the water.

$$H_2O = V_{H2O} \cdot P_{H2O} \tag{7}$$

With: V_{H2O} = volume of water in the ditches (m^3 yr^{-1})

P_{H2O} = concentration of phosphorus in the surface water (kg P m^{-3})

The length and width of the ditches was determined based on the outcome of the STONE model (previous section). The depth of the water column was estimated by the water board. Due to limited data the phosphorus concentration in the water column was assumed to be equal to the concentration in the water pumped out of the polder.

The contribution of the variable 'Dredging' was based on the amount of sludge removed and the phosphorus concentration in sludge:

$$\text{Dredging} = V_d \cdot P_d \tag{8}$$

With: V_d = volume of sludge removed (m^3 yr^{-1})

P_d = concentration of phosphorus in the removed sludge (kg P m^{-3})

The amount of removed sludge was determined by the length, width and the depth of the ditches. The length and width of the ditches was determined based on the outcome of the STONE model (previous section). The depth of the removed sediment is estimated through literature. The phosphorus concentration in the sludge was obtained from the PLONS project. For this project the phosphorus concentration in the top layer of the sediment for different sediment types was determined. The sediment type of the polder is clay (Waterschap Hollandse Delta, 2007). The phosphorus concentrations in the sludge for clay sediments in the region of the polder were averaged. It is assumed that this concentration represents a realistic value of the phosphorus concentration in the top layer of the sediment of the polder and in the lower part of the sediment layer as well.

The contribution of the variable 'Biomass' was based on the amount of biomass removed per year and the phosphorus concentration in the removed material:

$$\text{Biomass} = B_v \cdot P_v \qquad (9)$$

With: B_v = the amount of biomass harvested (m^3 yr^{-1})

P_v = phosphorus concentration in the harvested plant biomass (kg P m^{-3})

Data for applying this formula was gathered based on a literature review, with which the growth curve of the submerged vegetation of the polder Cromstrijen was identified. The growth curve is used to estimate the amount of biomass which is removed. The growth curve is based on the maximum density of submerged vegetation in the Netherlands (Bloemendaal and Roelofs, 1988). It is assumed in the present research that 75% of this density is present in the polder. Literature states that the growth curve is created based on the month with maximum biomass, the moment of ditch cleaning and the biomass remaining in October (Serafy and Harrell, 1994; Asaeda *et al.*, 2006). The phosphorus concentration in the removed submerged vegetation is determined based on literature.

After implementation of the equations in the mass balance the equation for the selected ditch management scenarios becomes:

$$\frac{dP}{dt} = Q_{in,p} \cdot P_{in,p} - Q_{out,p} \cdot P_{out,p} + Q_{in,u} \cdot P_{in,u} + A \cdot F \cdot f + Q_{in,s} \cdot P_{in,s} + V_{H2O} \cdot P_{H2O} - V_d \cdot P_d - B_v \cdot P_v - \text{Capturing} \qquad (10)$$

A list with the explanation of the used symbols can be found in appendix I. The equations for the alternative scenarios are comparable. The differences are that the variable ‘Biomass’ is left out of equations 9 and the height of the variables possibly changes.

3.3 Function analysis

Ecosystem functions are in the present research defined as the capacity of natural processes and components to provide goods and services that directly or indirectly are a benefit for humankind (Costanza and McMichael, 1998; De Groot, 2006). Four different ecosystem functions were distinguished. In each category different ecosystem services are present (De Groot, 2006; Millennium Ecosystem Assessment, 2005):

- Provisioning service: Primary production creates a large variety of carbohydrates. Humans use this broad variety of carbohydrate structures amongst others as food and energy sources.
- Regulation services: An ecosystem regulates essential ecological processes and life support systems through biochemical cycles and other biosphere processes. This results amongst others in clean water, air and soil.
- Habitat services: An ecosystem protects the existence of animals and plants by providing habitat for refuge and reproduction. In this way the ecosystem conserves biological and genetic diversity and evolutionary processes.
- Cultural services: An ecosystem contributes to the maintenance of human health by amongst others providing recreation and aesthetic experience.

Ecosystem services are benefits humans derive from ecosystems (Millennium Ecosystem Assessment, 2005). Dependent on the location in the polder several ecosystem functions and services are present. Based on the literature review a list of ecosystem services for agricultural areas were determined. In the present research a limited number of ecosystem services were selected from the derived list because of limited time. The ecosystem services will be selected based on the following criteria:

- The ecosystem services are at least affected by the one of the ditch management scenarios. This allows quantification of effect of the scenario on the ecosystem service(s).
- Ecosystem services will be selected from different categories of ecosystem functions because a landscape is used in diverse ways. This prevents that the selected ecosystem services are being selected from a limited number of ecosystem functions.

The second part of the function analysis is the quantification of the selected ecosystem services. The effect of the different theoretically implemented scenarios on the ecosystem services is different and was determined by “best professional judgement” based on literature. The effect is based on the expected increase or decrease of the use of ecosystem services, because of a changed landscape. For the aesthetic valuation a questionnaire was created to identify the landscape appreciation for different landscapes (Appendix V). The pictures in the questionnaire had different zones next to the ditch: crops, grasses, flowers and grasses, mowed and unmowed zones. Three series were made of different states of the water: turbid water, duckweed cover and clear water. It was asked to score each picture with a score from 1-5. Ten people were selected of which eight without an environmental background and two with environmental background. Important was that the participants identified which pictures were most appreciated and which ones the least and by which score.

3.4 Multi-criteria analysis

A multi-criteria analysis is a tool for making decisions in problems which are complex, have different important criteria and large amounts of quantitative and/or qualitative data available (Department for Communities and Local Governments, 2009). In the present research different ditch management scenarios were suggested to improve the water quality. However, it is unknown what the effects of these scenarios are on the ecosystem services, making it hard to decide which scenario is favourite. The multi-criteria analysis uses criteria that represent the most important factors regarded to making a decision for a scenario. The criteria were represented by the selected ecosystem services. Indicators for the ecosystem services were determined to quantify the effect of a scenario on an ecosystem service. The indicators for the ecosystem services were determined through a literature review.

Determinations of the scores

A score indicates the effect of a scenario on the use of an ecosystem service. The scores were based on the outcome of the function analysis and “best professional judgement” (table 3.1).The quantification of the effects and scores need to be determined as objectively as possible, otherwise the final outcome of the multi-criteria analysis does not represent what the decision maker desires (Department for Communities and Local Governments, 2009).

Table 3.1: Meaning of scoring options in the multi-criteria analysis. The scores (0-5) relate to the use of ecosystem services in the polder Cromstrijen.

Score	Description of score
0	An ecosystem service is not (anymore) available.
1	Very Negative effect on the use of ecosystem service.
2	Negative effect on the use of ecosystem service.
3	Neutral effect on the use of ecosystem service.
4	Positive effect on the use of ecosystem service.
5	Very positive effect on the use of ecosystem service.

Determination of the weights

The weights are usually more subjective compared to the scores as they depend on opinions of the stakeholders and might differ over time (Department for Communities and Local Governments, 2009). The weights indicate the importance of the ecosystem services for different stakeholders. The main stakeholders of the polder were determined through literature. For each stakeholder the weights have been determined by water scientists of Wageningen University. Three different scientists have distributed 100 points for each stakeholder perspective over the different criteria. The opinions of the three scientists have been averaged to gain the final weights, which were used in the present research. However, these weights may therefore not be completely objective. It is assumed that in this way the views of the different main stakeholders are represented.

Outcome of the multi-criteria analysis

The outcome of the multi-criteria analysis for a single management scenario is derived based on equation 11 (Department for Communities and Local Governments, 2009):

$$S = s_1 w_{A1} + s_2 w_{A2} + \ldots + s_n w_{An} = \Sigma s w_A \tag{11}$$

` S = final average outcome based on the view of the stakeholders.

$S_{1,2,\ldots 5}$ = scores for the effect of scenarios on ecosystem service

$w_{A1,2,\ldots n}$ = average weights for the importance of ecosystem services for stakeholders.

The scores are multiplied with the weights derived for the different stakeholders. This results in an average outcome for the different scenarios based on the different perspectives of the main stakeholders.

Sensitivity analysis

The last part of the present research is the sensitivity analysis that aims to check whether there is uncertainty in the derived outcome due to incorrect weights and scores for the ecosystem services. The sensitivity analysis is performed by changing the derived weights randomly with up to + or - 30%. These values are chosen because the highest weight is 63% (table 5.2), which makes the maximum achievable weight 93%. The present research assumes that not one single ecosystem service is the most important for the selected main stakeholders. Because of this reason and because of the uncertainty in the other criteria, a value of 30% is chosen.

These randomly changed weights are used to calculate a 100 different average outcomes of which 90% intervals are created. If there is large overlap of these intervals between the scenarios, there is little difference between the effects of the scenario. If there is little overlap, the difference in effects is large.

Also the sensitivity of the scores indicating the effect of the scenarios on the use of an ecosystem service is investigated. The scores may not be valid, because they are based on "best professional judgment". Therefore, the effect on changing the scores on the ranking of the scenarios is considered. Not all scores are validated: a few are selected based on the relative uncertainty of the scores. Large changes in the ranking of the scenarios indicate that the results are very sensitive and the difference between the different scenarios is small. Little or no change in the ranking of the scenarios indicates that the outcome is more or less stable and the difference between the different scenarios is large.

4. Phosphorus budgets of the ditch management scenarios

4.1 Water balance for the polder Cromstrijen

Table 4.1: Elements of the water balance for the polder Cromstrijen for a single year. The quantities of water from sources and losses were calculated based on the rate and area size.

Variable	**Rate** (mm yr $^{-1}$)	**Area** (10^6 m^2)	**Quantity of water added/ lost** (10^6 m^3 yr $^{-1}$)	
IN				
Precipitation surplus	430	49.2	21.2	
Seepage	237	44.3	10.5	
Sewage overflows	-	-	0.02	
Water inlet from river	97	49.2	4.8 +	
Total				*36.5*
OUT				
Shortage due to evapotranspiration	168	49.2	-8.3	
Discharge to river	573	49.2	-28.2 +	
Total				*-36.5*
				0

A water balance for the polder Cromstrijen is calculated for a single year by estimating the quantity of water entering through sources and lost through sinks (table 4.1). The total quantity of water entering and leaving is assumed to be equal, which indicates that there is no recharge or withdrawal of water in the polder on a yearly basis.

During wet periods the precipitation surplus is a source of water for the polder. The quantity of water added to the polder is based on the data of three selected weather stations. It is assumed that the precipitation is equally distributed over the total surface area of the polder. The average rate of the precipitation surplus is 430 mm yr $^{-1}$ (appendix II), an estimated quantity of 21.2*10^6 m^3 yr $^{-1}$. This means that the variable 'Precipitation surplus' is the most important source of the water balance.

Seepage occurs in the polder at an average rate of 237 mm yr $^{-1}$ (Waterschap Hollandse Delta, 2007). It is assumed that not all parts of the polder receive water from seepage, as there are paved areas like villages and roads. The area receiving seepage water is estimated at 4432 ha (Waterschap Hollandse Delta, 2007), an estimated quantity of 10.5*10^6 m^3 yr $^{-1}$.

Sewage water overflow occurs in the polder (Waterschap Hollandse Delta, 2007), presumably in the months with a precipitation surplus. The total quantity of sewage water entering the ditches is estimated at 0.02*10^6 m^3 yr $^{-1}$ (pers. comm. F. Kuipers). The quantity indicates that the contribution of the sewage overflow to the water balance is very small.

During dry periods the evapotranspiration is a sink, which is calculated on the same basis as the precipitation surplus. The average rate of the shortage due to evapotranspiration is 168 mm yr^{-1} (appendix II), an estimated quantity of $8.3*10^6$ m^3 yr^{-1}. During the period of shortage due to evapotranspiration water is introduced to the polder to prevent decreasing water levels. The quantity of water lost is partly compensated through seepage water. On average there are four months per year with a shortage due to evapotranspiration for the three weather stations (appendix II), a quantity of $3.5*10^6$ m^3 yr^{-1}. This indicates that only seepage is not enough to maintain the water levels in the ditches during dry periods and in the absence of pumping, water scarcity might occur in the polder. Therefore, water levels are regulated by pumping water into the polder, the quantity is estimated as $4.8*10^6$ m^3 yr^{-1}.

During wet periods water levels are regulated by pumping water out of the polder. The quantity of water pumped out of the polder is determined by the quantity of water added through the precipitation surplus, seepage (during periods with precipitation surplus (appendix II)) and sewage overflows. This is estimated at $28.2*10^6$ m^3 yr^{-1}. This quantity indicates that most of the water entering the polder is removed by pumping. Regulation of water levels is very important to prevent local flooding of the polder.

4.2 Phosphorus budget of the current management scenario

Table 4.2: Sources and losses of phosphorus in polder Cromstrijen for the current management scenario. The contribution of the variables to the budget is calculated by different parameters, for details see text.

Variable	**Area** ($*10^6$ m^2)	**Quantity of water** ($*10^6$ m^3 yr^{-1})	**Phosphorus concentration** (g P m^{-3}, g P kg dw^{-1}, g P m^{-2})	**Amount of phosphorus** (kg P yr^{-1})
IN				
Agriculture	35.6	-	0.23	8182*
Seepage	-	10.5	1.7	269
Sewage overflows	-	0.018	5.0	91
Water in ditches	-	0.59	0.22	130
Water inlet from river	-	4.8	0.12	574 +
Total in				9247
OUT				
Discharge to river	-	28.2	0.22	-6256
Dredging	7.3	-	0.8	-739
Ditch cleaning	7.3	-	3.0	-264 +
Total out				-7259
P capturing sediment (21.5% of sources)	-	-	-	-1988
Grand total				0

*** These numbers are rounded and are therefore not always consistent with the summation.**

A phosphorus budget based on the current management scenario for the polder Cromstrijen is calculated for a single year (table 4.2). Based on data from the water board of five of their monitoring points in the polder Cromstrijen it became clear that the water quality of the ditches in the polder has been stable in the last five to ten years (appendix III). It is assumed that this is the case for the water quality of all the ditches in the polder. This indicates that the total quantity of phosphorus added through sources and lost through sinks is presumably equal. As a result the amount of phosphorus in the water column and a small part of the sediment remains constant.

Fertilizer is applied on agricultural land to increase the crop production in the polder. The average fertilizer use by farmers in the polder is estimated through a literature review (Reenen, 2004; Smit *et al.*, 2006; Bakker, 2007) (appendix III). The crops use part of the phosphorus in the fertilizer for growth, the part that is not used is called soil surplus. For the polder the soil surplus is also estimated using literature (Bakker, 2007; Ham *et al.*, 2007; Hooijboer *et al*., 2007) (appendix III). The soil surplus ends up binding to the clay soil particles or being transported to the surface water through direct runoff or groundwater transport (Clevering and Visser, 2005; Ham *et al.*, 2007; Antheunisse *et al.,* 2008). On average 6% of the phosphorus in the applied fertilizer ends up in the surface waters (Schoumans *et al.*, 2004; Sharpley *et al.*, 1995; Bakker 2007), which equals 2.3 kg P ha^{-1} yr^{-1}. The STONE model also estimates the amount of phosphorus from fertilizer entering the ditches, an estimation of 1.97 kg P ha^{-1} yr^{-1} for wet clay soils (Schoumans *et al.*, 2008). The value of 2.3 kg P ha^{-1} yr^{-1} seems reasonable compared to the outcome of the STONE model. The agricultural area used for crop production is estimated to be 3558 ha (CBS, 2004a; Waterschap Hollandse Delta, 2007). The contribution of agriculture to the mass balance is 8182 kg P yr^{-1}. This variable can be considered as the most important source of the phosphorus budget.

The quantity of water entering the polder through seepage is estimated at $10.5*10^6$ m^3 yr^{-1}. Not all of the seepage water and the amount of phosphorus in this water enter the ditches, this is determined by the surface area of the ditches in the polder. The surface area receiving seepage is almost 1.5% of the total surface area of the polder (appendix III). The phosphorus concentration of the seepage water was measured at a few monitoring points by the water board. The phosphorus concentration is estimated at 1.7 g P m^{-3} (appendix III), a contribution to the mass balance of 269 kg P yr^{-1}.

The quantity of sewage water entering the ditch through overflows is estimated at $0.02*10^6$ m^3 yr^{-1}. The phosphorus concentration in the sewage water is estimated through literature at 5 g P m^{-3} (wRw and wWw, 2002; Civiele gezondsheidstechniek, 2010), a contribution to the mass balance of 91 kg P yr^{-1}. This is approximately 1% of the contribution of the variable ‘Agriculture’.

The quantity of water that is pumped into the polder during dry periods is estimated at $4.8*10^6$ m^3 yr^{-1}. The phosphorus concentration of the river water is estimated using a few monitoring points of the water board as 0.12 g P m^{-3} (appendix III), a contribution to the mass balance of 574 kg P yr^{-1}.

The quantity of water pumped out of the polder during wet periods is $28.2*10^6$ m^3 yr^{-1}. This quantity is pumped out at the different sub polders (figure 1.1). The phosphorus concentration in the water pumped out at these different sub polders is different. The phosphorus concentrations at the outlet points of the different sub polders are: #1 0.10 mg P l^{-1} (appendix III), #2 0.23 mg P l^{-1}, #3 0.31 mg P l^{-1} and #4 1.59 mg P l^{-1}. As a result the averaged phosphorus concentration pumped out at the single outlet point of the polder is estimated at 0.22 g P m^{-3} (appendix III). The contribution to the mass balance is 6256 kg P yr^{-1}, which is the largest sink of the phosphorus budget. The phosphorus concentration of the water pumped out of the polder is higher than the phosphorus concentration of the water pumped into the polder. This indicates that phosphorus is removed from the polder.

Phosphorus is also removed for the polder through dredging, which is applied on 10% of the ditches each year. The amount of sludge removed is therefore 13205 m^3 yr^{-1} (appendix III). Based on the literature it was identified that 1 m^3 of sludge is estimated to be equal to 70 kg dw (Stowa, 1994). The sludge phosphorus concentration is calculated based on a few monitoring points of the PLONS project and is estimated at 0.8 g P kg dw^{-1} (pers. comm. J. Zuidam), a contribution to the mass balance of 739 kg P yr^{-1}.

Phosphorus is also removed by mowing the submerged vegetation. The amount of duckweed covering the surface water is limited (pers. comm. F. Kuipers) and is therefore neglected. The total surface area being mowed is assumed to be comparable in size to the area of dredging (appendix III). The amount of vegetation density removed per year is estimated at 0.4 kg dw m^{-2} (figure 4.1). The mowed material is left on the shore. It is assumed in the present research that 50% of the phosphorus in the mowed vegetation (submerged and riparian vegetation) re-enters the ditch through ground water transport and wind. The vegetation is decomposed on the shore and the phosphorus is taken up by the soil and partly transported through ground water transport to the ditch. The wind will blow a part of the mowed vegetation into the ditches. The vegetation will be taken up into the sediment. The phosphorus content in the aquatic vegetation is estimated at 0.3% of the dry weight (Droef and Breukers, 1996), a contribution to the phosphorus budget of 264 kg P yr^{-1}. The amount of phosphorus removed with ditch cleaning indicates that ditch cleaning seems to be less important for phosphorus removal than dredging is. Important to consider is that the amount of phosphorus removed through ditch cleaning is based on general assumptions and this might influence the phosphorus reduction. Next to that the phosphorus reduction can further increase by removing the mowed aquatic and riparian vegetation from the polder.

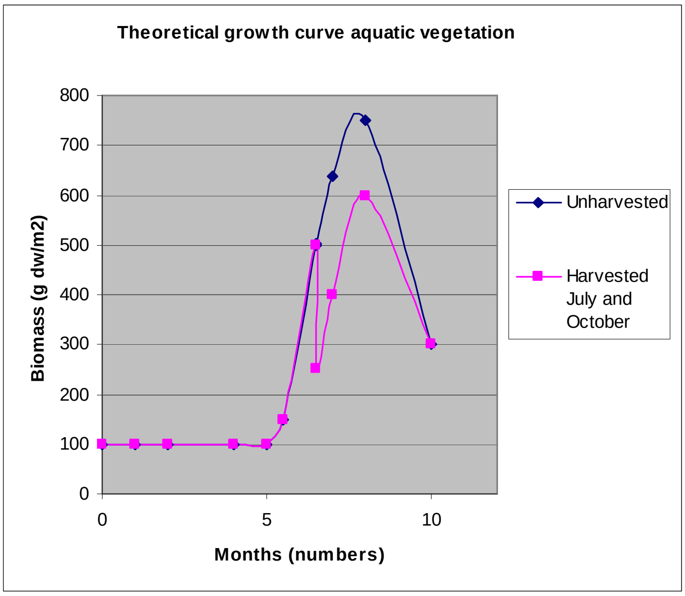

Figure 4.1: Calculated growth curves for the aquatic vegetation of the polder Cromstrijen. The blue line indicates an unharvested population. The pink line indicates a harvested population and amount of biomass removed (50% of the biomass is removed in July and October).

The phosphorus present in the water of the ditches is also a source of phosphorus. The total volume of water in the ditches is based on the wetted perimeter that is estimated at $0.59*10^6$ m^3 (appendix III). The phosphorus concentration in the ditches is assumed to be equal to the phosphorus concentration in the water pumped out of the polder. The contribution to the phosphorus budget is 130 kg P yr^{-1}.

Another important sink is capturing of phosphorus in the sediment. According to De Klein (2008) the retention of nutrients for small ditches is more or less 30% (0.25-0.35) of the incoming sources. A part of the phosphorus that enters the ditch is captured in the sediment each year. For the mass balance it is assumed that of the amount of nutrients entering the ditch and a small part of the sediment also leave the system. The total incoming amount of phosphorus is 9247 kg P yr^{-1} and the amount of phosphorus lost is 7259 kg P yr^{-1}. The phosphorus retention is therefore 1988 kg P yr^{-1}. This amount of phosphorus represents approximately 21.5% of the incoming phosphorus through water inlet from river, agriculture, sewage overflows, seepage and water in ditches.

As stated before, the water quality related to phosphorus remains presumably stable based on the current management scenario (appendix III). However, phosphorus accumulation in the sediment occurs because the amount of phosphorus entering the sediment is higher than the amount of phosphorus removed through ditch cleaning and dredging each year. The phosphorus accumulation is estimated at 984 kg P yr^{-1}.

4.3 Phosphorus budgets of the alternative management scenarios

Table 4.3: Sources and sinks of the phosphorus budget for the selected scenarios for a single year. The current management is used as a reference for alternative management scenarios.

Variable	Current management	Scenario I	Scenario II	Scenario III
IN				
Agriculture	8182*	8182	7839	6038
Seepage	269	269	269	269
Sewage overflows	91	91	91	91
Water in ditches	130	130	130	130
Water inlet from river	574 +	574 +	574 +	574 +
Total in	9247	9247	8904	7103
OUT				
Discharge to river	-6256	-6256	-6256	-6256
Dredging	-739	-986	-863	-863
Ditch cleaning	-264 +	0 +	0 +	0 +
Total out	-7259	-7242	-7118	-7118
P capturing sediment (21.5%)	-1988	-1988	-1914	-1527
Grand total	0	18	-129	-1543

*** These numbers are rounded and are therefore not always consistent with the summation.**

In table 4.3 the phosphorus budgets for the selected ditch management scenarios are presented for a single year. The amount of phosphorus added by the source agriculture is not comparable for all ditch management scenarios. Scenario I has the same area of agricultural land as the current management scenario and the contribution is therefore 8182 kg P yr^{-1} as well. In the scenarios with buffer zones agricultural land is used to create the buffer zones. It is assumed that buffer zones are applied only on the sides of the ditches were crop production is present. For scenario II the total average width of the agricultural land that is lost is assumed to be 6 m (section 2.1 and 2.3). Furthermore it is assumed in the present research that 85% of the ditches are present in the agricultural area of the polder. This corresponds to an agricultural area of 149 ha (4.2% of the agricultural area). Therefore the contribution of agriculture to the phosphorus budget will be 7839 kg P yr^{-1}. For scenario III the total average width of the agricultural land that is lost is assumed to be 38 m (section 2.1 and 2.3) and 1% of the agricultural area is estimated to be lost based on topographical maps because of too small agricultural areas after construction of the buffer zones. This corresponds to a total area of 933 ha (26.2% of the agricultural area). Therefore the contribution of agriculture to the phosphorus budget will be 6038 kg P yr^{-1}. Due to the buffer zones the polder receives a lower input of phosphorus, resulting in lower phosphorus capturing of the sediment.

The amount of phosphorus introduced through seepage, sewage overflows and water inlet from river is comparable for all the scenarios. The phosphorus concentration and quantity of the water does not depend on the scenarios. The contribution to the mass balance for the different variables can be seen in table 4.3.

The alternative scenarios have a faster sediment formation rate because ditch cleaning is not performed (section 2.2, 2.3 and 2.4). Dredging needs to be preformed in a shorter time frame. It is also assumed that the phosphorus removal increases due to more frequent dredging. Scenario I has the fastest sediment formation. It is assumed in the present research that the sediment formation is 0.04 m yr^{-1}. The phosphorus removal is therefore 986 kg P yr^{-1}. For the buffer zones it is assumed that sediment formation is less fast as mentioned before. It is assumed in the present research that the sediment formation is 0.035 m yr^{-1}. The contribution to the mass balance is 863 kg P yr^{-1}.

Ditch cleaning is only performed in the current management scenario. Therefore, for the alternative scenario the phosphorus removed by mowing the submerged vegetation is 0 kg P yr^{-1}.

The phosphorus reduction through capturing by the sediment is based on the current management scenario, which is 21.5% of the incoming sources. This percentage is used as reference for the alternative scenarios. For scenario I the amount of phosphorus captured by the sediment is comparable to the current management scenario, but the buffer zones have a lower incoming load and therefore less phosphorus is captured by the sediment (table 4.3).

The phosphorus budgets of the alternative scenarios are not closed e.g. the amount of phosphorus removed in scenario III is much too large. To compensate for these differences, the phosphorus budgets need to be modified. This is done by changing the phosphorus concentration in the water of the ditches with the difference in input and output of the phosphorus budget. This needs to be performed several times to close the phosphorus budget because the change in the phosphorus concentration in the water leads to a different phosphorus budget. This is an iteration process. It is assumed that the sediment does not act as a source of phosphorus and only the variables ‘Discharge to river’ and ‘Water in ditches’ are changed. For scenario I and scenario II the phosphorus concentration in the ditches after iteration becomes 0.22 mg P l^{-1} (appendix III) (table 4.4). The water quality of the current management scenario and scenario I is probably not improving nor declining in the future. The input of phosphorus is higher for scenario I, but this is a very small difference. A limited improvement of the water quality will be achieved for scenario II, however the buffer relationship with the sediment might compensate the reduction in the phosphorus concentration. After iteration, for scenario III the phosphorus concentration in the ditches becomes 0.17 mg P l^{-1} (appendix III) (table 4.4). The water quality of scenario III will improve to quite an extent, despite the buffer relationship with the sediment.

The phosphorus accumulation in the sediment is calculated by subtracting the variables ‘Ditch cleaning’ and ‘Dredging’ from the variable ‘P capturing sediment’. The phosphorus concentration in the sediment in scenario I is comparable to the current management scenario. The estimated phosphorus accumulation is 1002 kg P yr $^{-1}$ (table 4.4). This indicates that ditch cleaning is probably not essential to prevent phosphorus accumulation of the sediment. The phosphorus accumulation in the sediment in scenario II is a bit higher than the current management scenario, an accumulation of 1051 kg P yr $^{-1}$. However, on the short term the lowered input from agriculture might be buffered by the sediment and this lowers the phosphorus accumulation in the sediment. Scenario III is effective to reduce the phosphorus accumulation in the sediment, and estimated phosphorus accumulation of 664 kg P yr $^{-1}$. This is a reduction of the phosphorus accumulation in the sediment compared to the current management scenario with 33%. This indicates that buffer zones might be effective to reduce the phosphorus accumulation in the sediment, as long as the width of the buffer zones is large enough.

Table 4.4: Estimated reduction of the phosphorus concentration in the surface waters of the ditches and the estimated phosphorus accumulation of the sediment.

Management scenario	**Phosphorus concentration in ditches** (mg P l $^{-1}$)	**Phosphorus accumulation of sediment** (kg P yr $^{-1}$)
Current management	0.22	984
Scenario I	0.22	1002
Scenario II	0.22	1051
Scenario III	0.17	664

5. Effect of ditch management scenarios on the use of ecosystem services

5.1 Selection of ecosystem services

Humans derive multiple benefits from agricultural landscapes. Ecosystem services present in these landscapes are: provisioning of food, provisioning of biomass, provisioning of water, pollination, soil retention, soil formation, gas regulation, climate regulation, disturbance prevention, water regulation, refugium service, recreation and aesthetic information (Dale and Polasky, 2007; Zhang *et al*., 2007; Herzon and Helenius, 2008; Noel, 2009). Of the above mentioned list of ecosystem services a selection has been made based on the criteria mentioned in the method section (section 3.3).

(1) Food provisioning is an important service in the polder Cromstrijen. Agriculture covers 85% of the surface area of the polder. The main category of agriculture is crop production, covering 72% of the surface area. The remaining 13% is covered by different types of agriculture, like fruit production and livestock (CBS, 2004a; Waterschap Hollandse Delta, 2007). In the present research crop production is considered as the only source for the food provisioning. The main cultivated crops in the polder are potatoes, sugar beet and cereals. Assumed is that these are the only crops produced in the polder. The spatial distribution of the agricultural crops in the polder is unknown. However, Geertsema *et al.* (2006) indicate that the spatial distribution for the Hoeksche Waard is: potatoes 25%, sugar beets 17% and cereals 25%. It is assumed that these percentages represent the crop production of the polder Cromstrijen as well, as it is a small part of the Hoeksche Waard. These percentages are scaled to a 100% in order to represent the spatial distribution of cultivated crops in the polder Cromstrijen. Therefore the distribution of crops in the polder is assumed to be: potatoes 37%, sugar beets 26% and cereals 37%. The food provisioning is not comparable for all ditch management scenarios because the buffer zones are causing a decline in the agricultural area.

(2) The provisioning of biomass is the removal of vegetation from the ditch and the riparian area (De Groot, 2006). The aquatic or riparian vegetation is mowed in several scenarios. In the scenarios where biomass is mowed it is not always removed because the amount of biomass may be too small (pers. comm. F. Kuipers). In order to use the biomass as an ecosystem service it should be gathered and made beneficial for humans e.g. by burning the biomass for electricity (Abbasi and Abbasi, 2010).

(3) The refugium service is the maintenance of genetic information of an area (De Groot, 2006). The genetic information of organisms living in the riparian area close to the ditch is considered in the present research. Studies have identified the effect of different land use types on groups of organisms (Meek *et al.*, 2002; Haaland *et al.*, 2010). The land use adjacent to the ditch is either crop production or a combination of buffer zones of 5 m or 25 m and crop production. In the present research only the groups of organisms are studied showing a clear and/or significant response based on the different types of land use selected. These organisms are butterflies and bumblebees (Meek *et al.*, 2002; Haaland *et al.*, 2010).

(4) The aspect of water regulation considered in the present research is the nutrient cycle. Ditches have the capacity to regulate nutrients by capturing them in the sediment and releasing them again at later moments in time. In the present research the outcome of the mass balance (section 4.2 and 4.3) is used to assess whether phosphorus is added to or removed from the ditch sediment. Phosphorus accumulation in the sediment hinders the use of the area for other purposes in the future, like nature.

(5) Aesthetic information deals with the scenery of landscapes. In the present research aesthetic information is researched through evaluating the landscape appreciation during the application of different scenarios. This is researched through a questionnaire. For the different scenarios the landscape appreciation might differ, due to different types of land use next to the ditch. Buffer zones with flowers might increase the landscape appreciation compared to only crop production (Stowa, 2010).

5.2 Effect of the current management on the landscape and its services

(1) The current management scenario has a positive effect on the food provisioning as the production is maximized. The available area for crop production in the polder is 3558 ha and is completely used by farmers. The total food provisioning is quantified using the amount of produced dry weight per year ($kg*10^3$ dw yr^{-1}). For the different cultivated crops the amount of produced dry weight differs. The average amount of dry weight is determined through the use of literature: potatoes produce on average 44.1 $kg*10^3$ dw ha^{-1} yr^{-1}, for sugar beets 60.0 $kg*10^3$ dw ha^{-1} yr^{-1} and for cereals is 7.8 $kg*10^3$ dw ha^{-1} yr^{-1} (appendix IV) (CBS, 2004b; Ministerie van Verkeer en Waterstaat, 2004; CBS, 2005; CBS, 2006; Rijk, 2008). The number of hectares for the cultivation of potato, sugar beet and cereal production is

calculated based on the percentage of the spatial distribution of crops in the polder. As a result the maximal provisioning of food is estimated at 129229 kg*10^3 dw yr $^{-1}$ (appendix IV).

(2) The provisioning of biomass causes changes in the landscape because the aquatic and riparian vegetation are being mowed. Mowing of aquatic vegetation affects the flow resistance of the ditches and the state of the shore vegetation. The amount of biomass is too low to gather (pers. comm. F. Kuipers) and is therefore left on the shore. However, the mowed aquatic biomass could be used as an ecosystem service. Based on the previous section it is possible to calculate the potential provisioning of biomass. The production in dry weight per year (kg*10^3 dw yr $^{-1}$) is used. The theoretical provisioning of biomass for the ditches of the polder is on a yearly basis estimated as 0.4 kg dw m^{-2} (figure 4.1). The total surface area of submerged vegetation growing in the ditches is 0.44 km^2 (section 4.2). The theoretical provisioning of biomass is therefore estimated at 176 kg*10^3 dw yr $^{-1}$. The amount of theoretical removed biomass could be enlarged if the mowed shore vegetation is also removed from the polder.

(3) The refugium service affects the landscape because the insect species numbers can increase or decrease over time. However, it is hard to come up with a single value for the effect of the current management scenario on the selected organisms in the polder. The population numbers differ from place to place depending mainly on the carrying capacity of the site. The carrying capacity is determined by several factors like the available food, available space for nursery determined by the width of the vegetation zone (Daily and Ehrlich, 1992). The total abundance and number of species of butterflies and bumblebees are used to qualify the effect of the current management scenario (Meek *et al.*, 2002; Pywell *et al.*, 2006). It is chosen to qualify the effect first because a single value cannot be derived and work with scores later in the multi-criteria analysis. Research indicates that the current management scenario causes a decrease in species number and abundance of species for both butterflies and bumblebees (Meek *et al.*, 2002; Pywell *et al.*, 2006).

(4) Water regulation also affects the landscape because the phosphorus concentration in the water column affects the state of the water: The phosphorus concentration in the water column might increase, decrease or stay stable over time causing the clearer, turbid or unchanged surface waters. However, the effect of the changed phosphorus concentration in the surface waters might not be visible. The phosphorus in the sediment is interacting as a buffer with the phosphorus in the water column (Portielje and Lijklema, 1993). The phosphorus accumulation in the sediment is expressed in the amount of phosphorus per year (kg P yr $^{-1}$). In the current management, phosphorus accumulation in the sediment

occurs to quite an extent: estimated 984 kg P yr^{-1}(section 4.2). This hinders the improvement the water quality of the polder. The current management has therefore a negative effect on the ecosystem service water regulation.

(5) The current management affects the landscape and therefore the aesthetic value of the landscape. For the current management the aesthetic value might differ over the year as management is performed in July and October (Orleans *et al.*, 1996). The ecosystem service aesthetics information is assessed by evaluating the landscape appreciation (appendix V). Different landscapes were visualised through pictures and assessed in a questionnaire. For the current management the outcome was average, which was indicated with a score of just above 3 (appendix VI). The clear water phase scored slightly lower in the questionnaire than the unclear water phase. This is remarkable because it was expected to be the other way around, as clear waters represent a good water quality. Why this occurred is not clear and may depend on several reasons. Furthermore it became clear that mowing the aquatic and riparian vegetation has a negative effect on the landscape appreciation for all water states (appendix VI).

5.3 Effect of the alternative scenarios on the landscape and its services

(1) The agricultural landscape is affected by the different alternative ditch management scenarios. For scenario I the food provisioning is comparable to the current management scenario because the amount of agricultural land is the same. As a result, the food provisioning is also estimated as 129229 kg*10^3 dw yr^{-1}. For the scenario with buffer zones the landscape will change because the amount of agricultural land declines and is replaced by the buffer zones. For scenario II the total average width of the agricultural land that is lost is assumed to be 6 m (section 2.1 and 2.3). Furthermore it is assumed in the present research that 85% of the ditches are present in the agricultural area of the polder. The agricultural land that is lost is therefore estimated at 149 ha, reducing the agricultural area to 3409 ha. The spatial distribution of the crops is assumed to be same as mentioned before (section 5.1), resulting in a total food provisioning of 123802 kg*10^3 dw yr^{-1}. The area used for the creation of buffer zones causes a loss of food provisioning of more or less 4.2%, indicating that the loss of food provisioning is relatively large. For scenario III the width of the agricultural land that is lost is assumed to be 38 m (section 2.1 and 2.3). The total agricultural land will decrease with 897 ha. Next to that some of the agricultural land becomes too small to produce crops after application of the buffer zones. Based on topographical maps it is assumed in the present research that 1% of the total agricultural area is lost in addition to the

area lost to the buffer zones. The total agricultural area available for production is therefore 2625 ha, the total food provisioning is 95356 kg*10^3 dw yr $^{-1}$. This means a loss of agricultural production of more or less 26.2%, indicating that the loss of food provisioning is large.

(2) Provisioning of biomass is not an ecosystem service of scenario I as no vegetation is mowed. The riparian vegetation in scenario II produces biomass, however, the amount of riparian biomass that is mowed is too low to gather (pers. comm. F. Kuipers). The riparian biomass is therefore left on the shore. As mentioned in the current management scenario it is possible to use the biomass as an ecosystem service. The theoretical provisioning of biomass is calculated based on mowing 50% of the vegetation in the buffer zones of 5 m twice a year. The total width of the buffer zones being mowed twice a year is 8 m (section 2.3), an estimated area of 200 ha. The total production of biomass of a buffer zone with grasses and flowers is estimated at 5.0 kg*10^3 dw ha^{-1} yr^{-1} (Meerburg and Korenvaren, 2009). The provisioning of biomass is estimated at 998 kg*10^3 dw yr $^{-1}$. The amount of biomass provided in this scenario is almost six times as high as in the current management scenario. For scenario III a larger amount of riparian vegetation can be mowed, which makes it more interesting to gather and use the mowed riparian vegetation. The total width of the buffer zones being mowed twice a year is 40 m (section 2.3), an estimated area of 998 ha. The amount of biomass provisioning is estimated here at 4989 kg*10^3 dw yr $^{-1}$.

(3) Scenario I affects the refugium service in more or less the same way as the current management scenario. However, no management is performed and therefore it is expected that the decrease in abundance and number of butterflies and bumblebees is less than in the current management scenario. There is more space for nursery and foraging for the butterflies and bumblebees in the polder. Scenario II has a positive effect on the refugium services. A wider vegetation zone increases the species number and abundance of butterflies and bumblebees (Meek *et al.*, 2002; Pywell *et al.*, 2006) and causes a decrease of the disturbance by agriculture. Next to that there is a larger area for foraging and nursery as well, which probably increases the carrying capacity for the organisms. For scenario III the above mentioned effects will probably be larger. This can be interpreted as a further increase of the species number and abundance in butterflies and bumblebees in the polder.

(4) For water regulation the effect of scenario I is comparable to the current management scenario. This is because the phosphorus accumulation in the sediment increases to 1002 kg P yr $^{-1}$. This indicates that ditch cleaning appears not to be very effective to prevent phosphorus accumulation in the sediment. The effect of scenario II on the water regulation is also comparable to the current management scenario, a phosphorus

accumulation of 1051 kg P yr^{-1}. For scenario III the phosphorus accumulation in the sediment is reduced with 33% (section 4.3), a phosphorus loading of 664 kg P yr^{-1}. This indicates that large buffer zones have a positive effect on the reduction of phosphorus accumulation in the sediment.

(5) In scenario I there is limited visual change in the landscape due to management. This has a positive effect on the aesthetic value of the landscape compared to the current management scenario, an average score of 4 (appendix VI). The unclear water state scored higher than the clear water state. This outcome is not as it was expected to be because a clear water state represents clean water. In scenario II the aesthetic value is comparable to the current management scenario. In the outcome of the questionnaire they both have an average score of 3 (appendix VI). The clear water state scored the highest, followed by the unclear water state and the duckweed cover. This outcome is as it was expected because clear water has presumably a higher aesthetic value. For scenario III the outcome of the aesthetic value is also comparable to the current management scenario, an average score of 3 (appendix VI). Furthermore, the buffer zones of 25 m scored the highest in the clear water phase (above 3.5), followed by the unclear water state and the duckweed cover. It is also remarkable that the buffer zones of 25 m do not score higher than the buffer zones of 5 m at all water states (appendix VI). There is probably an optimum width of the buffer zones. Wider buffer zones might lower the landscape appreciation because the agricultural landscapes are too much dominated by the buffer zones. Furthermore, the outcome of the present research does not comply with literature (Stowa, 2010) because the aesthetic value does not increase with the buffer zones.

5.4 Scoring of the ditch management scenarios

Scoring is an important aspect of the multi-criteria analysis, which needs to be done as objectively as possible. Sections 5.2 and 5.3 are used as a basis to derive the scores for the different ditch management scenarios. The meaning of the scores is indicated by table 3.1. An overview of all derived scores is shown in table 5.1.

Table 5.1: Overview of the derived scores for the different ditch management scenarios. The scores indicate the effect of the scenarios on the ecosystem services for the polder Cromstrijen. The scores are derived through literature and "best professional judgement".

Ecosystem service	Current management	Scenario I	Scenario II	Scenario III
Food provisioning	5	5	4	2
Biomass provisioning	0	0	0	3
Refugium service	1	2	4	5
Water regulation	2	2	2	4
Aesthetic information	3	4	3	3

(1) For the ecosystem service food provisioning the current management scenario maximizes the agricultural production. However, it might be possible to innovate the agricultural system of the polder Cromstrijen to increase the crop production. Innovation of agriculture in the polder is not considered in the present research. Therefore the production in the current management scenario is assumed to be maximal, a score of 5. Scenario I has a comparable food provisioning as the current management scenario because the same amount of fertilizer is applied and the same amount of agricultural area is used. The score is a 5 as well. In scenario II the provisioning of food reduces because agricultural land is lost for the creation of the buffer zones. Farming is an important function of the polder. A loss of 4.2% of the food provisioning has consequences for the income of the farmers. Next to that a lower amount of food production possibly might affects the inhabitants because less local food might be available for the polder. It is assumed that the combined consequences are relatively large. The derived score is therefore a 4. For scenario III a larger decline in the agricultural area occurs. The food provisioning decreases with 26.2%, this has a much larger negative impact on the income of the farmers and possibly on the food availability for the polder. The derived score is therefore a 2.

(2) The provisioning of biomass is available for the current management scenario. However, the water board leaves the mowed aquatic and riparian vegetation on the shore, therefore it receives a score of 0. The provisioning of biomass is not available in scenario I, therefore the derived score is a 0. In scenario II the amount of biomass being mowed is still too little to be used, a score of 0 as well. The provisioning of biomass in scenario III is profitable to consider. The expected costs of gathering the mowed riparian vegetation are presumably to a large extent comparable to the expected benefits (pers. comm. F. Kuipers). Therefore the derived score is a 3.

(3) The current management scenario has a very negative effect on the refugium services. Due to mowing of the riparian vegetation the foraging and nursery area for butterflies and bumblebees becomes very small. The riparian vegetation of 2 m tall is reduced to 1 m during ditch management twice a year. As a result the score for the current management is a 1. Scenario I has a slightly better effect on the refugium service. Due to the absence of mowing the foraging and nursery area becomes almost twice a much during summers, a derived score of 2. However, it is unknown to what extent the abundance and species number of butterflies and bumblebees in the polder is increased. For scenario II a positive effect on the refugium service was identified (Meek *et al.*, 2002; Pywell *et al.*, 2006). Due to the wider buffer zones an increase in the abundance and species number of butterflies and bumblebees is expected. The derived score is 4. For scenario III it is expected that the refugium service increases compared to scenario II, a score of 5.

(4) The current management scenario has a negative effect on phosphorus accumulation in the sediment, however the phosphorus accumulation in the sediment can further increase due to delayed management. The current management therefore scores a 2. Scenario I and scenario II have a comparable effect on the phosphorus accumulation in the sediment, a score of 2 as well for these scenarios. For scenario III the phosphorus accumulation in the sediment is reduced with 33% (section 4.3). In order to achieve this reduction a lot of effort is needed because a lot of agricultural area is lost (26.2%). As a result the use of water regulation is at least positively affected by this scenario. The reduction in phosphorus accumulation in the sediment is not optimal because it can be further reduced by using more or other measures. The derived score is therefore a 4.

(5) The current management scenario has an average effect on the aesthetic value of the landscape according to the outcome of the questionnaire, a score of 3. Scenario I has a positive effect on the aesthetic value of the landscape. This is due to the absence of mowing and as a result the landscape does hardly change due to management during the year. This results in a score of 4. Scenario II has a comparable effect on the aesthetic value of the landscape as the current management scenario, a score of 3. Scenario III does not have a comparable aesthetic value for every water state. It is expected that the water quality does not improve a lot in the short term due to a buffer reaction with the sediment. As a result the ditches are presumably most comparable to the turbid water state. Therefore the derived score is a 3.

5.5 Derivation of weights for the main stakeholders

In the multi-criteria analysis weights play an important role as well. The weights in the present research represent the subjective view of the most important stakeholders. For the polder Cromstrijen these are the water board, the farmers and the recreationist (Steingröver *et al.*, 2010). The opinion of the different stakeholder groups is determined based on expert view (section 3.4). The outcome can be seen in table 5.2.

Table 5.2: Derived weights for the importance of ecosystem service for the main stakeholders; water board, framers and recreationist. Also the relative importance of an ecosystem service is given by the summed value. Weights are derived based on expert views.

Ecosystem service	Water board	Farmers	recreationist	Sum of weights
Aesthetic information	0.25	0.12	**0.63**	**1.00**
Food provisioning	0.03	**0.63**	0.07	0.73
Water regulation	0.25	0.07	**0.27**	0.59
Refugium service	**0.30**	0.07	0.03	0.40
Biomass provisioning	**0.17**	0.12	0.00	0.29

*** The bold numbers indicate the highest weight for an ecosystem service.**

Table 5.2 shows that the different main stakeholders value an ecosystem service differently. Each stakeholder group has a number of ecosystem services which they value as most important. For the water board the refugium services, water regulation and aesthetic information are the most important ecosystem services. The water board mainly deals with the regulation of water, water quality and aquatic ecology. Next to that they also pay attention to the surrounding landscape (pers. comm. F. Kuipers). Food provisioning is not valued as important for the water board. For the farmers, obviously the food provisioning is valued as the most important ecosystem service. The other ecosystem services are of minor importance. For the recreationist the aesthetic information is valued as most important and the water regulation as quite important. The other ecosystem services are of minor importance.

Table 5.2 further indicates that overall, aesthetic information is valued as the most important ecosystem service. The sum of the weights of the three stakeholder perspectives for this ecosystem service is estimated at 1.00. This ecosystem service therefore has the largest influence on the outcome of the multi-criteria analysis. The food provisioning is valued as second most important, a sum of 0.73. This summed weight is mainly caused by the opinion of the farmers. The third most important is the water regulation, a summed weight of 0.59. The fourth most important is the refuguim service with a summed weight of 0.40. The height of this weight is mainly caused by the opinion of the water board. The least important ecosystem service for the outcome of the multi-criteria analysis is the service biomass provisioning. The summed score is estimated at 0.29.

5.6 Outcome of the multi-criteria analysis

The outcome of the multi-criteria analysis is determined by the derived scores and weights (formula 11). The weights of the different perspectives are averaged in order to derive a final score (table 5.3). The interpretation of the effects of the ditch management scenarios on the ecosystem services is based on table 3.1.

Table 5.3: Outcome of the multi-criteria analysis based on the derived scores and weights. The scores are multiplied with the derived weights for every main stakeholder, which results in an average outcome.

Management scenario	Water board	Farmers	Recreationist	Average outcome
Scenario III	**3.77***	2.57	**3.50**	**3.28**
Scenario I	2.27	**3.90**	3.46	3.21
Scenario II	2.48	3.28	3.30	3.02
Current management	1.77	3.72	2.57	2.68

*** The bold numbers indicate the highest score of a scenario for a stakeholder perspective.**

For the water board scenario III scores the highest, an estimated score of 3.77. Scenario II scores below averaged, an estimated 2.48. The current management scenario and scenario I score both low; the current management scenario is estimated at 1.77 and scenario I is estimated at 2.27. For the farmers scenario I scores the highest, an estimated score of 3.90. The difference between the current management scenario is relatively small, an estimated score of 3.72. Scenario II also scores quite well, an estimated score of 3.28. The lowest score is for scenario III, because a lot of agricultural land is lost to create the buffer zones. The outcome is still average, an estimated score of 2.57. For the recreationist scenario III scores the highest, an estimated score of 3.50. The difference with scenario I and scenario II is very small. The lowest score is for the current management scenario, an estimated score of 2.57.

The last column of table 5.3 shows the average outcome of the multi-criteria analysis, which indicates that scenario III scores the highest, an estimated score of 3.28. This indicates that this scenario is ranked as best with an effect on the ecosystem services of above neutral (table 3.1). Despites, this scenario does not score the highest on the most important ecosystem services (table 5.2), a score for aesthetic information of 3 and for food provisioning of 2 (table 5.1). The outcome is explained through the other derived scores (table 5.1). The second highest scored scenario I, an estimated score of 3.21. The effect of this scenario on the ecosystem service is therefore also above neutral and close to score of scenario III. The outcome can be explained by the high scores for the aesthetic information and food provisioning, which are the most important ecosystem services (table 5.1 and 5.2). The third highest scored scenario II, an estimated score of 3.02. The difference with scenario III and scenario II is still relatively small. The effect on the ecosystem services is just above neutral. The lowest scored the current management scenario, an estimated score of 2.68. This effect is lower than a neutral score. The outcome indicates that the ecosystem services can be used more optimal in the alternative scenarios than in the current management scenario.

5.7 Sensitivity analysis

In order to evaluate the above mentioned outcomes of the multi-criteria analysis, a sensitivity analysis is performed. The sensitivity analysis consists of two parts. First, the creation of 90% intervals, made out of the average outcomes of the three stakeholder perspectives.

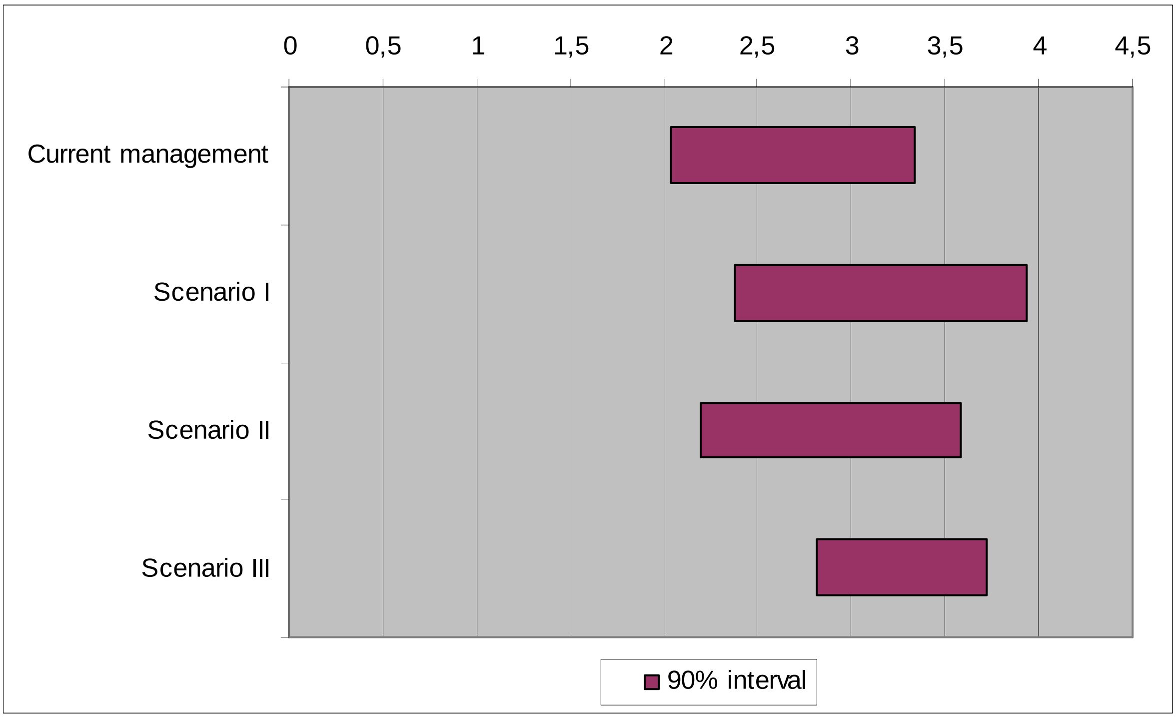

Figure 5.1: 90% intervals for all ditch management scenarios. The intervals are calculated by randomly changing the derived weight with up to + or - 30%.

The 90% interval of the current management scenario ranges from 2.04-3.34. The effect of this scenario on the ecosystem services can be interpreted as negative to neutral (table 3.1). For scenario I the 90% interval is 2.38-3.93. The effect of this scenario on the ecosystem service is negative to positive. For scenario II the interval ranges from 2.20-3.58 and the effect on the ecosystem services is between negative to positive. For scenario III the interval ranges from 2.81-3.72, therefore the effect on the ecosystem services is below neutral to below positive. The size of this interval is much smaller compared to the other management scenarios. This is probably explained by the smaller range of the outcome of the multi-criteria analysis for the three stakeholders perspectives.

The results of the 90% interval indicate that the 90% intervals of the current management scenario and scenario III differ quite a lot. The use of ecosystem services differs in these scenarios therefore quite a lot and scenario III distinguished itself from the current management scenario. Scenario I and scenario II have relatively comparable 90% intervals. The use of ecosystem services differs not much in these scenarios. These scenarios also have a lot of overlap with on one side the current management scenario and on the other side scenario III. The use of the ecosystem services is therefore hard to distinguish in the different scenarios.

Secondly it is assed whether changing the scores has an influence on the ranking of the scenarios. The scores are objectively determined; however it is possible that scores are not completely correct (section 3.4). In the present research the loss in food provisioning is rated as important. Scenario II has a score of 4 for food provisioning and scenario III a score of 2 (table 5.1). However, the effect may be underestimated. The score for food provisioning for scenario II may become a 5 and the score for scenario III a 3. The average outcome for scenario II would become 3.26, which is higher than the outcome for scenario I. The outcome of scenario III becomes 3.52. Another score which might differ is the score for the refugium service for scenario I. The decrease in the insect population may be underestimated and scenario I might therefore score comparable to the current management scenario, a score of 1. This results in an average outcome to 3.02, which is comparable to the outcome of scenario II.

Changing the scores can lead to a change in the ranking of the scenarios: scenario I and scenario II could switch places. However, the change seems to be limited to these scenarios. This small change in the ranking of the scenarios indicates that scoring should be done as objectively as possible to present a realistic outcome of the multi-criteria analysis.

6. Evaluation of ditch management scenarios

Based on the water quality analysis, scenario III is the best ditch management scenario. The water quality will improve in the future and the phosphorus accumulation in the sediment is the lowest. The phosphorus accumulation is reduced with 33% compared to the current management scenario. The current management scenario, scenario I and scenario II are scored lower then scenario III and these scenarios are more difficult to distinguish from each other. The differences in water quality and phosphorus accumulation in the sediment are limited between these scenarios. The water quality might improve in scenario II. However, the reduction in phosphorus concentration is limited. Presumably the water quality will not improve in the current management scenario and scenario I. The phosphorus accumulation in the sediment is lower in the current management scenario compared to scenario I and scenario II.

In the function analysis scenario III scored the highest. The effect of this scenario on the use of ecosystem services is above neutral. A neutral score indicates that a scenario does not positively nor negatively affect the use of the selected ecosystem services. The derived score indicates that the ecosystem services are probably used most optimal in this scenario. Scenario I is close to the outcome of scenario III. The effect of this scenario on the use of ecosystem services is also above neutral. Scenario II has a lower outcome, an effect on the use of ecosystem service of just above neutral. The score is still quite close to the outcome of scenario I and scenario III. The lowest scoring scenario, with a clear difference, is the current management scenario. The effect of this scenario on the use of ecosystem services is below neutral.

The combined effect of water quality analysis and function analysis creates a more distinguished ranking of the selected scenarios. This is valid for the highest and least highest scoring scenario. The second and third scoring scenarios are less easy to distinguish and are relatively close to the lowest scoring scenario. Scenario III scores the highest in both the water quality analysis and function analysis. This scenario is therefore ranked as the highest scoring scenario in the present research. However, this scenario is unlikely to be implemented by the water board because it has great consequences for the farmers in the polder (table 6.1). The agricultural land needs to be bought from the farmers and therefore the farmers lose their income. Next to that the costs for the creation of the buffer zones are large. Also, the storage capacity and flow resistance of the ditch might be negatively affected because of the absence of ditch cleaning (pers. comm. F. Kuipers). As a result the pumps might need a higher pumping capacity during wet periods in autumn to regulate the water levels. Scenario II and scenario I are ranked quite close to each other in the present research based on the water quality and the function analysis. This makes it difficult to distinguish these two scenarios from each other. Both scenarios might also negatively affect the storage capacity of the ditch (pers. comm. F. Kuipers) (table 6.1). Therefore the pumps might need a higher pumping capacity during wet periods. Another negative aspect of scenario II is the higher involved costs. Land need to be bought from the farmers, a lower agricultural production is achieved and the buffer zones need to be constructed. The current management scenario is the lowest scoring scenario in the present research. This scenario scored as one of the least optimal for the water quality and the lowest on the use of ecosystem services. A positive aspect is that the costs are relatively low because no agricultural land has to be bought from the farmers and the agricultural production is maintained (table 6.1).

Table 6.1: Overview of the expected consequence after the implementation of the management scenarios. Consequences have been determined based on information of the water board and "best professional judgement".

Scenario	High construction costs	Decrease of agricultural production	Increased pumping capacity needed
Current management	No	No	No
Scenario I	No	No	Yes
Scenario II	Yes	Yes	Yes
Scenario III	Yes	Yes	Yes

7. Discussion

7.1 Discussion of the used methods

Assumptions made for the water balance due to limited data

The data available to calculate the water balance was limited. Therefore, it was assumed that the quantity of water entering the polder Cromstrijen also leaves the polder on a yearly basis. Based on this assumption it was possible to calculate a water balance for the polder. The correctness of the values for the variables and the amount of used variables in the water balance determines whether the water balance is accurate.

The quantity of water entering the polder through seepage was estimated by using an average rate. In reality the quantity of seepage added to the polder could be lower or higher. The maximum change in the quantity added through seepage was estimated as $2*10^6$ m^3 yr^{-1}. This quantity equals an uncertainty of 20% of the calculated quantity of seepage. It is also assumed that 10% of the area does not receive seepage water, because of a paved surface. However, seepage water from below the paved areas may enter the polder at other locations. The maximum change in the calculated quantity of seepage was estimated at $1*10^6$ m^3 yr^{-1}, which equals an uncertainty of 10% of the calculated quantity of seepage. Furthermore, it is uncertain to what extent the data from the KNMI represented the precipitation surplus and water lost through evapotranspiration of the polder Cromstrijen. The polder is located on an island near the North Sea, while two of the weather stations are not. The surrounding water bodies may influence the weather and therefore the precipitation and evapotranspiration in the polder. This can be proved by comparing the precipitation and evapotranspiration data from the weather station Wilhelminadorp with the average precipitation surplus and evapotranspiration of the three weather stations. The quantity of water added through the precipitation surplus decreases at most with $2*10^6$ m^3 yr^{-1}, which equals an uncertainty of 11% compared to the average precipitation surplus. The quantity lost through evapotranspiration increased at most with $0.6*10^6$ m^3 yr^{-1}, which equals an uncertainty of 8% compared with the average quantity lost through evapotranspiration. The uncertainty of the variables ‘Seepage’ and ‘Precipitation surplus’ also caused uncertainty in the quantity of water pumped out of the polder. However, limited data from pumps for the polder was available.

Assumptions made to calculated the phosphorus budgets due to limited data

There is probably also uncertainty in the outcome of the phosphorus budget, as data for calculation of the variables was limited. The effect of the uncertainty on the phosphorus budget depends on the relative importance of the variables. Agriculture appeared to be the most important source of phosphorus. In the present research the contribution of agriculture was determined based on a literature review. It is unclear to what extent the derived value represents the actual contribution of agriculture to the phosphorus budget. Furthermore, it was assumed that the ditches end in the polder and therefore water can only enter the polder through pumping water from the Hollandsch Diep into the polder. However, water could enter the polder through neighbouring polders as well. The phosphorus concentration in the water entering the polder through other polders is presumably higher than the river water due to phosphorus input by agriculture. As a result more phosphorus is introduced to the polder than was calculated.

Ditch management is under responsibility of the water board and it is assumed that it is performed on regular time frames. However, delayed ditch management might occur in reality. With dredging a constant amount of sludge is removed in a time period. Dredging might be performed in a longer time period in reality than was scheduled. As a result less sludge is removed from the ditch and the phosphorus removal decreases. Moreover, the contribution of other variables to the phosphorus budget could be calculated more accurately. Pumping is the most important loss of phosphorus. The phosphorus concentration of the water leaving the polder can be calculated more accurately by using the measured phosphorus concentrations of the monitoring points for multiple years instead of a single year. The contribution of seepage is also uncertain as data from a few monitoring points have been used. By increasing the amount of monitoring points a more realistic value may be derived. The amount of aquatic biomass harvested from the ditches in the current management is not determined very objectively. The derived aquatic biomass is based on general numbers about maximum growth and grows curves. This is also the case for the derived phosphorus concentration in the harvested aquatic vegetation. Next to that by removing the mowed aquatic vegetation from the polder would benefit the phosphorus removal. Phosphorus entering the ditch from the mowed aquatic biomass is in this case prevented. This would lower the phosphorus loading of the ditch. The exact reduction of phosphorus depends on the time frame of removing the mowed aquatic vegetation (Stowa, 1996) and the ratio between the amount of phosphorus captured by the soil and the amount entering the surface water of the ditch.

Assumptions made to carry out an multi-criteria analysis of changes in ecosystem services

The scores used in a multi-criteria analysis had a large influence on the outcome of the multi-criteria analysis. The identified scores were not derived by experts and their reliability is therefore not guarantied. The scores were quantified based on “best professional judgement” of the availability and importance of ecosystem services for the stakeholders. It was difficult to score the effect of the scenarios on the use of the ecosystem services. Therefore several assumptions had been made to quantify this effect.

First, the creation of buffer zones causes a decline in agricultural land. The exact surface area of the buffer zones of 25 m and 5 m is unknown, because the buffer zones cannot be applied next to every ditch in the polder. Buffer zones were theoretically applied only next to ditches that were located next to agricultural land. Also no buffer zones were constructed on the sides of the ditches were no crop production is present, for example orchards. As a result it is hard to quantify and score the provisioning of food.

Secondly, the (aquatic) biomass that is mowed in the different scenarios is not always removed, because the costs of removal are high. For the phosphorus removal however it would be beneficial to remove the mowed vegetation. In the future it might happen that the biomass is removed, for example if the use of aquatic and riparian biomass is made more beneficial. This affects the outcome of the multi-criteria analysis for the current management scenario and scenario II. The theoretical calculated biomass for these scenarios is both low (section 5.2 and section 5.3) compared to scenario III. Therefore the expected costs are much higher compared to the expected benefits and a score of 1 is given. The outcome of the multi-criteria analysis for the current management scenario and scenario II was estimated to increase with more than 3% compared to the derived outcome of the multi-criteria analysis. The ranking order of the scenarios does not change through this addition.

Thirdly, there is uncertainty in the outcome of the questionnaire. According to Stowa (2010) buffer zones have a positive contribution to the aesthetic value of landscapes. The outcome of the questionnaire confirmed this only partly (appendix VI). A possible explanation might be that the constructed pictures in the questionnaire were different from the real landscape, possibly resulting in a different assessment of a landscape by the participants.

Finally, it was hard to quantify the abundance and species number of butterflies and bumblebees for different scenarios for the polder. The assumption was that a larger area generates more species and a higher abundance of butterflies and bumblebees. It is questionable to what extent this is the case for the current management scenario and scenario I. The difference in width of the riparian vegetation zone was relatively small. The effect could have been underestimated, this would change the score for the refugium service from a 2 to a 1 in scenario I. As a result the outcome of the multi-criteria analysis decreased with 6% and the outcome is comparable to the outcome of scenario II (section 5.7).

The weights used in the multi-criteria analysis had a large influence on the outcome of the multi-criteria analysis. The derivation of the weights was done by experts of the department of Aquatic Ecology and Water Quality Management who stimulated stakeholder positions. These experts are competent to indicate the view of the different stakeholder groups. However, the view of the main stakeholders in the polder may not be represented because power relationships and other influencing factors are unknown.

7.2 Discussion of the results

Validate outcome of water quality analysis with existing knowledge

The current management scenario apparently does not lead to complying with the WFD standards (Ligtvoet *et al.*, 2006; Planbureau voor de leefomgeving, 2008). Furthermore, the ranking of the ditch management scenarios based on the outcome of the phosphorus budget was comparable as indicated by the water board. The phosphorus budget of scenario II is comparable to the budget of the current management scenario (pers. comm. F. Kuipers). The efficiency in phosphorus removal was larger for scenario III because the width of the buffer zones increases (Klok *et al.*, 2003). The efficiency of phosphorus removal increases mainly due to the indirect effect of the decreased amount of agricultural land. As a result less phosphorus was applied through fertilizer and a smaller amount of phosphorus entered the polder. Important to consider is that the sediment was not assessed as a source of phosphorus. Due to the reduction of the phosphorus concentration in the water column the sediment might become a source of phosphorus (Kim *et al.*, 2003). As a result the reduction in phosphorus concentration might be less than indicated in the present research. Nevertheless, the used methodology for the water balance and phosphorus budget in spite of all its assumptions has proven to be effective because the outcome complies with the opinion of the water board and with literature (Klok *et al.*, 2003; Ligtvoet *et al.*, 2006; Planbureau voor de leefomgeving, 2008).

Other relevant ditch management scenarios

In the present research alternative scenarios have been selected. However, based on the discussion with the water board it became clear that there were also other relevant scenarios not considered in the present research (pers. comm. F. Kuipers): reed beds and deepening the ditch through dredging. The effect of these scenarios on the phosphorus budget should be determined in order to evaluate all possible scenarios based on a water quality analysis. Weed beds filter phosphorus out of the water column. Deepening the ditch is effective as more sludge is removed and the phosphorus concentration in the surface water is diluted because of the larger perimeter. The ditches could be deepened with e.g. 0.3 m to a depth of 1.3 m. The effect of deeper ditches on the phosphorus concentration of the water volume has been calculated roughly in the present research based on the water volume in the ditch that was determined by its perimeter. It is unknown to what extent the ditch will be supplemented with water from precipitation or water from seepage and the phosphorus concentration in the seepage water entering the ditch. Therefore the concentration of phosphorus in the added water is unknown. In order to indicate the maximum and minimum effect on the phosphorus concentration it was assumed that the ditch is either filled completely with water originating from precipitation or with water originating from the river. It is assumed that the water originating from the river represented the phosphorus concentration of the additional seepage water that enters the ditch, because the phosphorus concentration in seepage water will be lowered due to longer travel times through the sediment. The total quantity of water in the ditches was estimated at 586890 m^3. The quantity of water introduced due to the deepening was estimated at 132050 m^3. The phosphorus concentration near the outlet points in the case with only precipitation water became 0.18 $g\ P\ m^{-3}$ and in the case with river water 0.20 $g\ P\ m^{-3}$. The reduction of the phosphorus concentration was estimated between 2 and 4 $g\ P\ m^{-3}$. This would mean that the water quality would comply with the WFD standards.

Validate outcome of function analysis with existing knowledge

The ranking of the scenarios based on the view of the water board seems logical. Scenario III scored the highest. The lowest score was for the current management because it scores the lowest on the refugium services, water regulation and aesthetic information (Hendriks *et al.*, 2010). The ranking of the scenarios in the perspective of the farmers was as it was expected. Scenario I and the current management scenario score the highest, because there is no loss in agricultural production. Scenarios II and scenario III scored lower because agricultural land is lost (Klok *et al.*, 2003). It is known that buffer zones can increase the recreational value of a landscape (Stowa, 2010). This is in accordance with the ranking of the outcome of the recreationist. Scenarios II and scenario III scored higher than the current management scenario. Next to that, an increase in the width of the buffer zone increased the recreational value. The used methodology in spite of all its assumptions is proven to be effective because the outcome appears to comply with literature (Klok *et al.*, 2003; Hendriks *et al.*, 2010; Stowa, 2010).

Interpretation of the outcome of the multi-criteria analysis

The outcome of the multi-criteria analysis should be interpreted carefully. First, it was assumed that all scenarios are functioning optimally from the start. However, the buffer zones need to be constructed first and it will take a few years before they perform optimally. This affects the availability of the ecosystem services negatively, e.g. the provisioning of biomass is lower and the aesthetic value might be lower.

Secondly, the effects of the scenarios on the ecosystem services of agricultural landscapes were assessed for a limited number of ecosystem services. According to Hendrik *et* al. (2010) more ecosystem services could have been selected for the polder Cromstrijen next to the used ecosystem services, e.g. natural pest control and gas regulation. Also a limited number of scenarios have been used. This may affect the outcome of the present research, because new scores and weights could be determined.

Finally, the choice for a ditch management scenario is not completely dependent on the effect of the scenario on the use of ecosystem services of the polder. There are more relevant criteria to consider, for example costs. These criteria are not considered in the present research and therefore it is only clear what the effect of the scenarios is on the selected ecosystem services.

8. Conclusions and recommendations

8.1 Conclusions

Phosphorus budget of the current management scenario

The phosphorus concentration in the surface water will not be reduced nor increased. The outcome of the present research therefore suggests that complying with the standards of the WFD is not reached by the current management scenario.

Effectiveness of the scenarios on phosphorus removal

The effectiveness of the current management scenario is based on phosphorus removal through ditch cleaning and dredging. The amount of phosphorus removed through dredging in scenario I is higher than in the current management scenario. Therefore, ditch cleaning appears to be not essential to reduce the phosphorus levels in the polder. The phosphorus removed through the buffer zones is based on the indirect effect of a decreasing total use of fertilizer. The efficiency of phosphorus removal increases in scenario III, due to wider buffer zones and thus less fertilizer use.

Effect of the scenarios on the phosphorus budgets

Based on the outcome of the present research it can be concluded that scenario I has an effect comparable to the current management scenario on the water quality. The water quality in scenario II might improve comparing to the current management scenario and scenario I depending on the buffer relation with the sediment. However, the water quality improvement is limited and does not appear to be sufficient to comply with the WFD standards. Scenario III is the best scenario: the water quality improves significantly due to wider buffer zones and the WFD standards are probably reached.

Effect of the scenarios on the selection of ecosystem services

The effect of the current management scenario on the use of ecosystem services scores below neutral. Scenario II scores higher, just above neutral. Scenario I and scenario III score a little higher, above neutral. It can be concluded that the ecosystem services could be used more optimal if the current management scenario is replaced by one of the alternative scenarios. The most optimal scenario, scenario III, has the highest implementation costs and consequences for the polder.

Value of water quality analysis and function analysis

The advantage of the combined analysis is a clearer ranking order of the selected ditch management scenarios than using the individual water quality analysis or function analysis. The ranking of the scenarios created using the water quality analysis does not change significantly by adding the function analysis. Scenario III remains the best scenario and the difference between the other scenarios remains limited.

8.2 Recommendations

Research on water quality analysis

The water balance might be improved by basing the calculations on the chloride mass balance (Vermaat and Hellmann, 2010). However, data from the water board is needed to calculate this balance. The chloride balance can be used to cross-check the water balance. Also the phosphorus concentration in the water column could be modelled dynamically (Dahl *et al.*, 2006). This could lead to a more accurate value for phosphorus. Next to the improvements on the phosphorus budgets it could also be interesting to study the effect of other relevant ditch management scenarios on the phosphorus budget, e.g. reed beds and deepening the ditch through dredging. Moreover, it is possible to calculate what needs to be done to comply with the standards of the WFD and to prevent phosphorus accumulation in the sediment.

Research on function analysis

The height of the scores could be validated by experts during further research. This results in more objective scores. Moreover, the derivation of weights could be determined by establishing a stakeholder panel with the relevant stakeholders of the polder. However, power relationships and representation of the view of the stakeholder should be taken into account during the creation of the panel. Further research could identify the ecosystem services affected by the different scenarios and quantify this effect. Due to the use of more ecosystem services the weights change and therefore also the average outcome of the multi-criteria analysis. Furthermore, an investigation could be made towards what affects the choice of the decision makers for applying a scenario. The effects of the scenarios on these criteria can be determined as well through a multi-criteria analysis. An important criterion is probably the costs. This can be researched also through a cost-benefit analysis that presents the relative costs of a scenario compared to its benefits related to the use of ecosystem services.

Management of ditches

It is important that the water board maintains the ditches on regular time frames. In this way delayed management is prevented. As a result the ditches maintained their planned depth and the pumps can have a lower pumping capacity because the storage capacity is higher. If delayed management occurs less phosphorus is removed because less sludge is removed and less aquatic biomass is removed. This also affects the water quality as the water is less diluted by rain water because the perimeter will be smaller.

The aquatic and riparian biomass that is mowed is not removed from the polder but left on the shores. It would be better to remove the mowed biomass from the polder, because re-entering of phosphorus in the soil and ditch is prevented. The current management scenario and scenario II would benefit from the removal of biomass.

References

Abbasi, T. and S.A. Abbasi (2010). Biomass energy and the environmental impacts associated with its production and utilization. *Renewable and sustainable energy reviews 14*(3), 919-937.

Ærtebjerg, G., J. H. Andersen and O.S. Hansen (eds) (2003). Nutrients and Eutrophication in Danish Marine Waters. A Challenge for Science and Management. Copenhagen, Ministry of the Environment.

Antheunisse, A.M., M.M. Hefting and E.J. Bos (2008). Moerasbufferstroken langs watergangen; haalbaarheid en functionaliteit in Nederland. Utrecht, Stowa, rapport 2008-07, ISBN 978.90.5773.413.7.

Asaeda T., L. Rajapakse, J. Manatunge and N. Sahara (2006). The effect of summer harvesting of Phragmites australis on growth characteristics and rhizome resource storage. *Hydrobiologia 553*(1), 327–335.

Bakker, D.W. (2007). Mest en Oppervlaktewater; Een terugblik 1985-2005; Deelrapportage ten behoeve van de Evaluatie Meststoffenwet 2007. Den Haag, Rijkswaterstaat, RWS RIZA-rapport 2007.002, ISBN: 9789036914299.

Bloemendaal, F.H.J.L. and J.G.M. Roelofs (1988). Waterplanten en waterkwaliteit. Utrecht, Koninklijke Nederlandse Natuurhistorische Vereniging (KNNV), ISSN 0169-5355.

CBS (2004a). Gemeente of Maat, Cromstrijen. Voorburg, Centraal Bureau voor de Statistiek, ISBN 90-357-2936-6.

CBS (2004b). Aardappelen: laagste opbrengst in tien jaar. Voorburg, Centraal Bureau voor de Statistiek, Persbericht PB04-101.

CBS (2005). Topoogst akkerbouwgewassen. Voorburg, Centraal Bureau voor de Statistiek, Persbericht PB05-012.

CBS (2006). Slechte oogst aardappelen en uien. Voorburg, Bureau voor de Statistiek, Persbericht PB06-097.

Civiele gezondsheidstechniek (2010). Afvalwaterbehandeling. Consulted on 16-12-2010 (http://ocw.tudelft.nl/fileadmin/ocw/courses/SanitaryEngineering/res00063/embedded/Afvalwaterbehandeling2008.pdf)

Clevering, O.A. and A.J. Visser (2005). Beheeradvies grasbufferstroken voor het project Actief Randenbeheer Brabant. Wageningen, Praktijkonderzoek Plant & Omgeving B.V., PPO nr. 500149.

Costanza, R. and A.J. McMichael (1998). Assessing ecosystem health. *Trends in Ecology and Evolution 13*(10), 397-402.

Corporaal, J., K.M. van Houweling and J.M. Verheul (1996). Slootschonen. Lelystad, Praktijkonderzoek Rundvee, Schapen en Paarden, ISSN 1385-0121.

Dahl, M., D.I. Wilson and L. Håkanson (2006). A combined suspended particle and phosphorus water quality model: Application to Lake Vänern. *Ecological Modelling 190*(1-2), 55–71

Daily, G.C. and P.R. Ehrlich (1992). Population, sustainability and earth's carrying capacity. *BioScience 42*(10), 761-771.

Dale, V.H., and S. Polasky (2007). Measures of the effects of agricultural practices on ecosystem services. *Ecologicaleconomics 64*(2), 286-296.

De Groot, R.S. (2006). Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. *Landscape and planning 75*(3-4), 175-186.

De Klein, J.J.M., M. Scheffer, S. van der Zee, S. van der Schaaf, P. Troch and J.P.M. Witte (2006). Bodem en water 1; Onderdeel water. Wageningen, Wageningen University.

De Klein, J. J. M. (2008). From Ditch to delta; Nutrient retention in running waters. Wageningen, Wageningen University, ISBN 978-90-8504-930-2.

Department for Communities and Local Governments (2009). Multi-criteria analysis: a manual. London, Department for Communities and Local Governments, ISBN: 978-1-4098-1023-0.

Diepen, C.A. van, G.H.P. Arts, J.W.H. van der kolk, A. Smit and J. Wolf (2002). Mogelijkheden voor verbetering van de waterkwaliteit door vermindering van de nutriëntenbelasting in Noord-Brabant; Deelrapport 4: Mogelijkheden voor toepassing van effectgerichte maatregelen op gebied van waterbeheer en waterzuivering. Wageningen, Alterra, Alterra-rapport 527.4.

Droef, R.W. and C.P.M. Breukers (1996). Waterplanten in de Binnenschelde 1988-1995. Lelystad, Ministerie van Verkeer en Waterstaat.

Evers, C.H.M., A.J.M. van der Broek, R. Buskens, A. van Leerdam and R.A.E. Knoben (2007). Omschrijving MEP en maatlatten voor sloten en kanalen voor de Kaderrichtlijn Water. Utrecht, Stowa, Stowa rapport 2007-32b, RWS-WD rapport 2007-019.

Geertsema, W., E. Steingröver, W. van Wingerden, J. Spijker and J. Dirksen (2006). Kwaliteitsimpuls groenblauwe dooradering voor natuurlijke plaagonderdrukking in de Hoeksche Waard. Wageningen, Alterra, Alterra-rapport 1334.

Gemeente Vlist (2010). Beheerplan baggeren Gemeente Vlist 2011-2015. Stolwijk, Gemeente Vlist.

Guangzhi, G. (2001). Mass balance and water quality in aquaculture tanks. China, Dalian Fishery University.

Haaland C., R. Naisbit and L. Bersier (2010). Sown wildflower strips for insect conservation: a review. *Insect Conservation and Diversity 4*(1), 60-80.

Ham, A. van den, C.H.G. Daatselaar, G.J. Doornewaard and D.W. de Hoop (2007). Bodemoverschotten op landbouwbedrijven; Deelrapportage in het kader van de Evaluatie Meststoffenwet 2007 (EMW 2007). Den Haag, Lei, Rapport 3.07.05; ISBN/EAN 9789086151769.

Hecky, R. E. and P. Kilham (1988). Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effect of enrichment. *Limnology and Oceanography 33*(4), 796–822.

Heerdt, G. ter (2010). Natuurvriendelijk onderhoud en ecologische kwaliteit. Literatuuronderzoek naar de ideale frequentie van schonen en onderbouwing van het nut van het afvoeren van maaisel. Amsterdam, Waternet, Rapportnummer 10.012104.

Heeswijk, R. van, S. Holtes and U. Vegter (2006). Een nieuw onderhoudsplan voor Waterschap Hunze & Aa's. *H2O 39*(4), 40-43.

Hendriks, K., I. Geijzendorffer, T. Hermans, C. Kwakernaak, P. Opdam and P. Vellinga (2010). Natuur voor iedereen: participeren, investeren en profiteren. Wageningen, Alterra, derde druk.

Herzon, I. and J. Helenius (2008). Agricultural drainage ditches, their biological importance and functioning. *Biological conservation 141*(5), 1171-1183.

Hooijboer, A.E.J., B. Fraters and L.J.M. Boumans (2007). Waterkwaliteit op landbouwbedrijven Evaluatie Meststoffenwet 2007. Bilthoven, RIVM, RIVM rapport 680130002/2007.

Huet, H.J.W.J. van (1992). Phosphorus eutrophication in the SW Frisian lake district; 1. Monitoring and assessment of a dynamic mass balance model. *Hydrobiologia 233*(1-3), 259-270.

Kim, L., E. Choi and M.K. Stenstrom (2003). Sediment characteristics, phosphorus types and phosphorus release rates between river and lake sediments. *Chemosphere 50*(1), 53-61.

Klok, C., P.F.A.M. Römkens, H.S.D. Naeff, G.H.P. Arts, J. Runhaar, C.A. van Diepen and I.G.A.M. Noij (2003). Gebiedsgerichte maatregelen voor de waterkwaliteit en natuur in reconstructiegebieden van Noord-Brabant. Wageningen, Alterra, Research Instituut voor de Groene Ruimte, Alterra-rapport 635.

Ligtvoet, W., G. Beugelink, R. van den Berg, L. Braat, P. Cleij, F. van Gaalen, H. van Grinsven, J. Janse, J. Kragt, W. Lammers, M. Kuijpers-Linde, L. van Liere, M. Van Veen, J. Willems, M. Witmer, R. Wortelboer and H. Van Zeijts (2006). Welke ruimte biedt de Kaderrichtlijn Water: een quick scan. Bilthoven, Milieu- en Natuurplanbureau, Publicatie nummer 5000072001, ISBN 90-6960-137-3.

Ligtvoet, W., G. Beugelink, C. Brink, R. Franken and F. Kragt (2008). Kwaliteit voor later. Ex ante evaluatie Kaderrichtlijn Water. Bilthoven, Milieu- en Natuurplanbureau, publicatienummer 500140001, ISBN 978-90-6960-203-5.

Meek, B., D. Loxton, T. Sparks, R. Pywell, H. Pickett and M. Nowakowski (2002). The effect of arable field margin composition on invertebrate biodiversity. *Biological conservation 106*(2), 259-271.

Meerburg, B.G. and H. Korevaar (2009). Ecologisch beheer van de publieke ruimte: mogelijkheden voor natuurtechnisch dijk-, slootkant- en wegbermbeheer, toegespitst of de Hoeksche Waard. Wageningen, Plant Research International B.V., rapport 280.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group (Millennium Ecosystem Assessment Series). Washington, Islands Press.

Ministerie van Verkeer en Waterstaat (2004). Prijzen en productiviteit van landbouwgewassen. Den Haag, Ministerie van Verkeer en Waterstaat.

Muscutt, A.D., G.L. Harris, S.W. Bailey, and D.B. Davies (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, ecosystems and environ*ment *45*(1-2), 59-77.

Nijs, A.C.M. de, B.J. Pieters, E. van der Grinten, A.M. Durand, R. Lieste and W. Verweij (2007). Afweging tussen generieke en regionale eutrofiëringsmaatregelen. Bilthoven, Rijksinstituut Voor Gezondheid en Milieu (RIVM), RIVM rapport 607800001.

Noel, J.E., E. Qenani-Petrela and T. Mastin (2009). A Benefit Transfer Estimation of Agro-Ecosystems Services. Western Economics Forum.

Oenema, O., L. van Liere and O. Schoumans (2005). Effects of lowering nitrogen and phosphorus surpluses in agriculture on the quality of ground water and surface water in the Netherlands. *Journal of hydrology 304*(1-4), 289-301.

Orleans, A.B.M., W. Twisk, and W.J. ter Keurs (1996). Minder vaak slootschonen. Provincie Noord-Holland, Dienst Ruimte en Groen, ISBN 90-72624-94-7.

Peeters, E.T.H.M., J.J.M. de Klein and M. Scheffer (2007). Onderzoek naar het ecologisch functioneren van sloten. *H20 40*(6), 30-31.

Phlips, E. J., S. Badylak and T. Grosskopf (2002). Factors affecting the abundance of phytoplankton in a restricted subtropical lagoon, the Indian River Lagoon, Florida, USA. *Estuarine, Coastal and Shelf Science 55*(3), 385–402.

Planbureau voor de leefomgeving (2008). Kwaliteit voor de leefomgeving: ex ante evaluatie Kaderrichtlijn Water. Bilthoven, Planbureau voor de leefomgeving, PBL publicatienummer 50014001/2008.

Portielje, R. and L. Lijklema (1993). Sorption of phosphate by sediments as a result of enhanced external loading. *Hydrobiologia 253*(1-3), 249-261.

Pywell, R.F., E.A. Warman, L. Hulmes, S. Hulmes, P. Nuttall, T.H. Sparks, C.N.R. Critchley and A. Sherwood (2006). Effectiveness of new agri-environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes. *Biological conservation 129*(2), 192-206.

Reenen, P. (2004). Ex ante analyse van het stelsel van gebruiksnormen voor mest en mineralen in de landbouw. Zetten, Van Reenen- Russel Consultancy.

Rijk, P. (2008). Landbouwgronden in Europa; Analyse van en visie op gewasopbrengsten, bevolking en milieu. Den Haag, LEI, Rapport 2008-004, ISBN/EAN 978-90-8615-218-6.

Scheffer, M., S. Szabó, A. Gragnani, E.H. van Nes, S. Rinaldi, N. Kautsky, J. Norberg, R.M.M. Roijackers and R.J.M. Franken (2003). Floating plant dominance as a stable state. *PNAS100*(7), 4040-4045.

Schindler, D. W. (1978). Factors regulating phytoplankton production and standing crops in the worlds freshwater. *Limnology and Oceanography 23*(3), 478–486.

Schoumans, O. F., R. Renaud, H.P. Oosterom and P. van Groenedijk (2004). Lot van het fosfaatoverschot. Wageningen, Alterra, Alterra-rapport 730.5.

Schoumans, O.F., P. Groenendijk, L. Renaud and F.J.E. van der Bolt (2008). Nutriëntenbelasting van het oppervlaktewater. Vergelijking tussen landbouw- en natuurgebieden. Wageningen, Alterra, Alterra-rapport 1700.

Serafy, J.E. and R.M. Harrell (1994). Mechanical removal of hydrilla in the Potomac River, Mary land: Local impacts on vegetation and associated fishes. Maryland, University of Maryland.

Sharpley A.N, M.J. Hedley, E. Sibbesen, A. Hillbricht, W.A House and L. Ryszkowski (1995). Phosphorus transfers from terrestrial to aquatic ecosystems. In: Tiessen H. (Ed) *Phosphorus and the Global Environment* (171–199). Chichester, UK: John Wiley and Sons.

Smit, A.L., J.F.F.P. Bos, A.M. van Dam, W. van Dijk, A.A. Pronk, F.J. de Ruijter, J.R. van der schoot and B. van der Sluis (2006). Kosteneffective maatregelen(pakketten) onder het nieuwe gebruiksnormenstelsel voor de sectoren akkerbouw, vollegrondsgroenten, bollen en bomen. Wageningen, Plant Research International B.V., Rapport 122.

Spielman, E. and N. Broodbakker (2001). Nota Natuurvriendelijk onderhoud, Richtlijnen voor natuurvriendelijk onderhoud van wateren, oevers en keringen (dijken). Amsterdam, AGV.

Steingröver, E.G., W. Geertsema and W.K.R.E. van Wingerden (2010). Designing agricultural landscapes for natural pest control: a transdisciplinary approach in the Hoeksche Waard (The Netherlands). *Landscape Ecology 25*(6), 825-838.

Stowa (1994). Verwijdering van fosfaat uit het oppervlaktewater. Utrecht, Stowa, rapport 94-15, ISBN 90-74476-15-5.

Stowa (1996). Onderhout of maat. Utrecht, Stowa, rapport 96-27.

Stowa (2010). Bufferstroken in Nederland. Utrecht, Stowa, rapport 2010 39.

Tomasky, G. and I. Valiela (1995). Nutrient limitation of phytoplankton growth in Waquoit Bay, Massachusetts. *Biological Bulletin 189*(2), 257–258.

Vermaat, J.E. and F. Hellmann (2010). Covariance in water- and nutrient budgets of Dutch peat polders: what governs nutrient retention? *Biogeochemistry 99*(1-3), 109-126.

Vollenweider, R. A. and J. Kerekes (1980). The loading concept as basis for controlling eutrophication, philosophy and preliminary results of the OECD program on eutrophication. *Progress in Water Technology 12*(2), 5–38.

Werkgroep Riolering West-Nederland (wRw) and Werkgroep Waterkwaliteit West-Nederland (wWw) (2002). De Tweede Rioleringsnota, Bijlagen. Werkgroep Riolering West-Nederland.

Waterschap Hollandse Delta (2006). Doelen, maatregelen en kosten ten gevolgen van de Europese Kaderrichtlijn Water; Globale verkenning voor de Zuid-Hollandse eilanden. Ridderkerk, Waterschap Hollandse Delta.

Waterschap Hollandse Delta (2007). Wateropgave waterkwaliteit cluster 13: Cromstrijen; Uitwerking van doelen, maatregelen en kosten in het gebied Hollandse Delta (KRW Fase 3). Ridderkerk, Waterschap Hollandse Delta.

Zhang W., T.H. Ricketts, C. Kremen, K. Carney and S.M. Swinton (2007). Ecosystem services and dis-services to agriculture. *Ecologicaleconomics 64*(2), 253-260.

Appendixes

I List of symbols used in the mass balance

A = the surface area of the agricultural land (m^{2})

B_v = the amount of biomass harvested (m^{3} yr^{-1})

F = amount of fertilizer applied on the agricultural land (kg m^{-2} yr^{-1})

f = fraction of phosphorus from fertilizer entering the ditch (-)

P = concentration of phosphorus in the polder (kg P m^{-3})

P_d = concentration of phosphorus in the removed sludge (kg P m^{-3})

P_{H2O} = concentration of phosphorus in the surface water (kg P m^{-3})

$P_{in, p}$ = concentration of phosphorus in water pumped into the polder (kg P m^{-3})

$P_{in, s}$ = concentration of phosphorus in water flowing from the subsoil into the ditches (kg P m^{-3})

$P_{in, u}$ = concentration of phosphorus in water from sewage overflows (kg P m^{-3})

$P_{out, p}$ = concentration of phosphorus in water pumped out of the polder (kg P m^{-3})

P_v = phosphorus concentration in the harvested plant biomass (kg P m^{-3})

$Q_{in, p}$ = quantity of water pumped into the polder (m^{3} yr^{-1})

$Q_{in, s}$ = quantity of water flowing from the subsoil into the ditches (m^{3} yr^{-1})

$Q_{in, u}$ = quantity of water entering the ditch during sewage overflows (m^{3} yr^{-1})

$Q_{out, p}$ = quantity of water pumped out of the polder (m^{3} yr^{-1})

t = selected time period (yr^{-1})

V_d = volume of sludge removed (m^{3} yr^{-1})

V_{H2O} = volume of water in the ditches (m^{3} yr^{-1})

II Precipitation and evapotranspiration of the weather stations

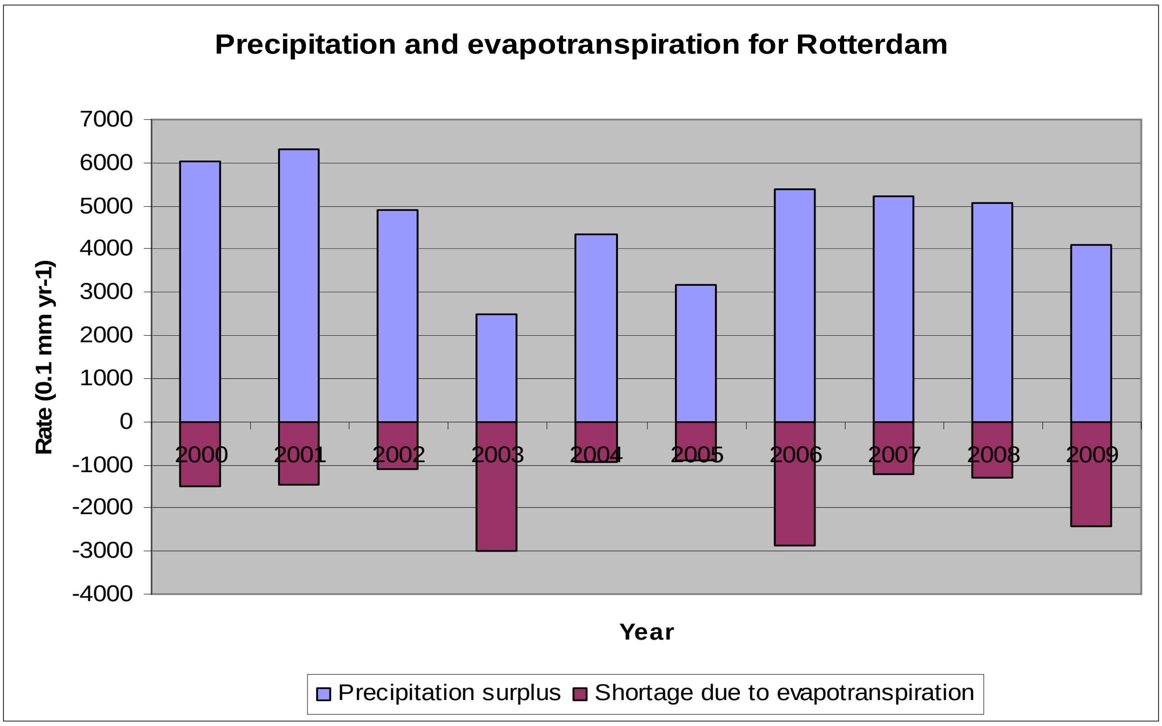

Figure I.1: Calculated precipitation surplus and shortage due to evapotranspiration for the KNMI weather station Rotterdam. The quantities added and lost were calculated by determining whether there was a precipitation surplus or shortage due to evapotranspiration for each month and sum the quantities of these months per year.

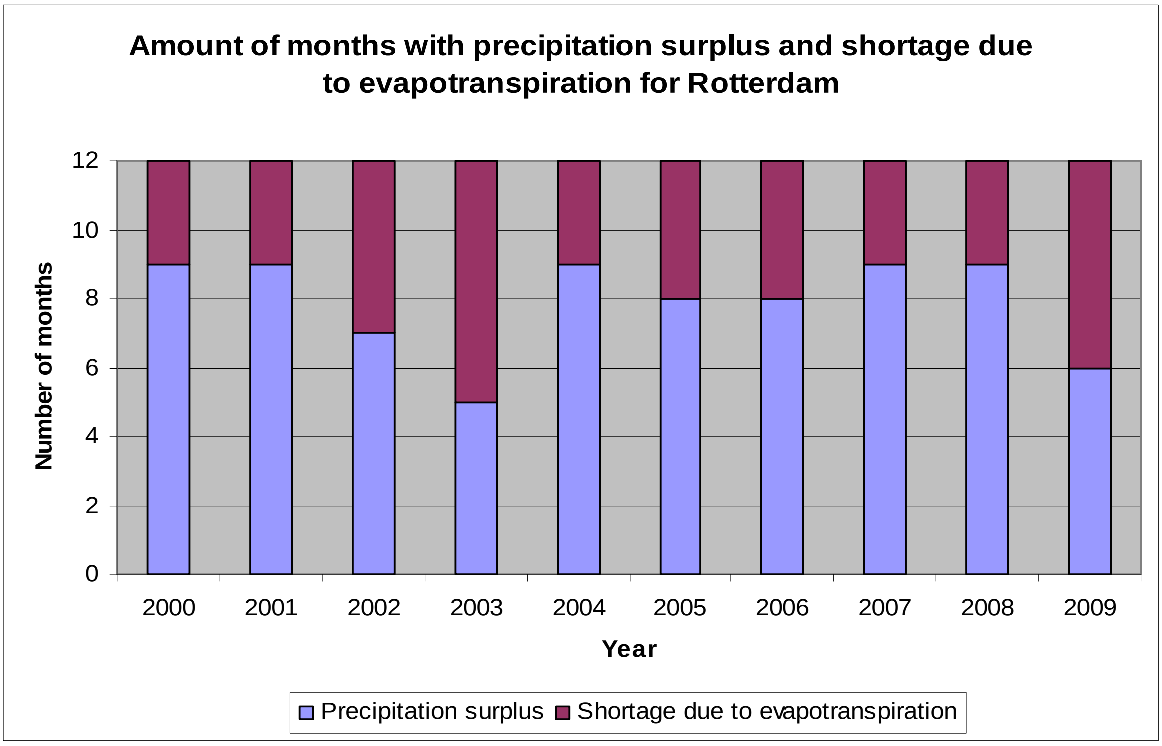

Figure I.2: Calculated number months with a precipitation surplus and shortage due to evapotranspiration for the KNMI weather station Rotterdam.

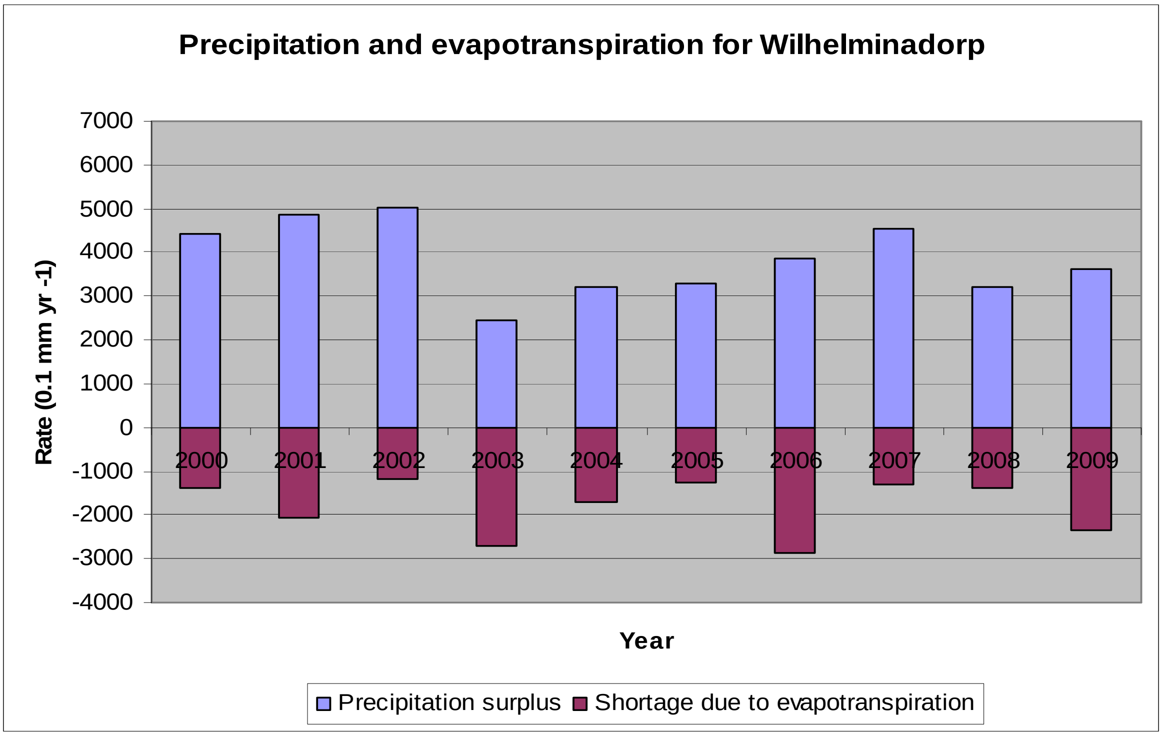

Figure I.3: Calculated precipitation surplus and shortage due to evapotranspiration for the KNMI weather station Wilhelminadorp. The quantities added and lost were calculated by determining whether there was a precipitation surplus or shortage due to evapotranspiration for each month and sum the quantities of these months per year.

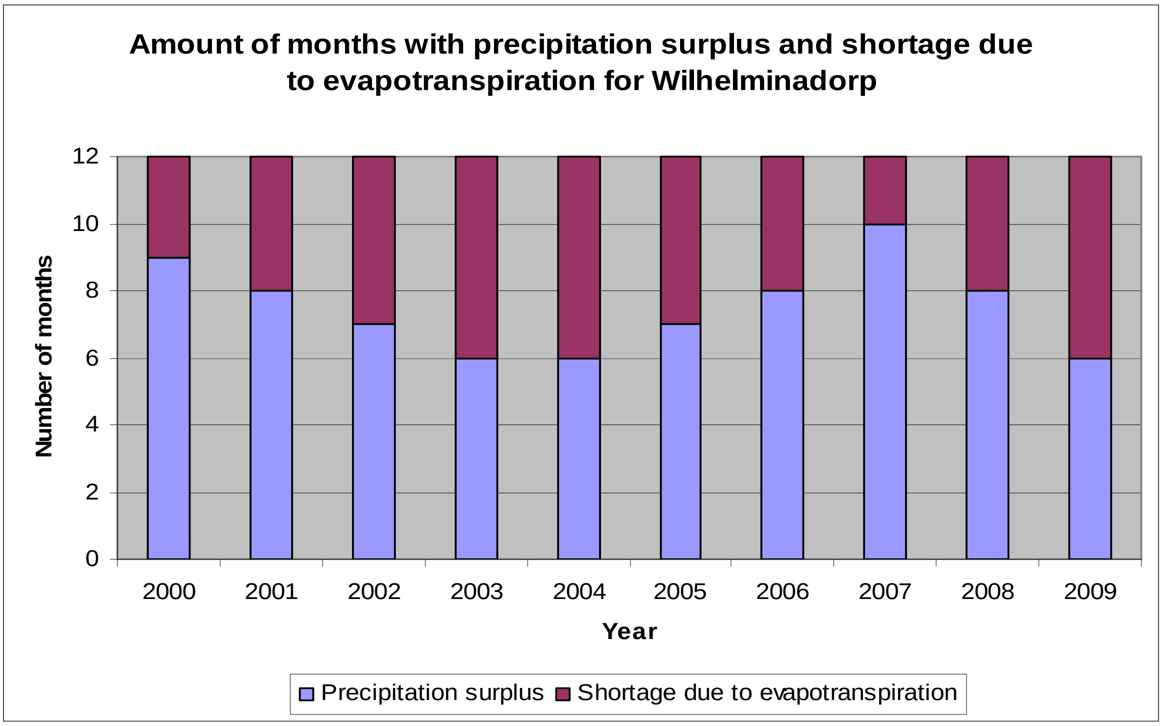

Figure I.4: Calculated number months with a precipitation surplus and shortage due to evapotranspiration for the KNMI weather station Wilhelminadorp.

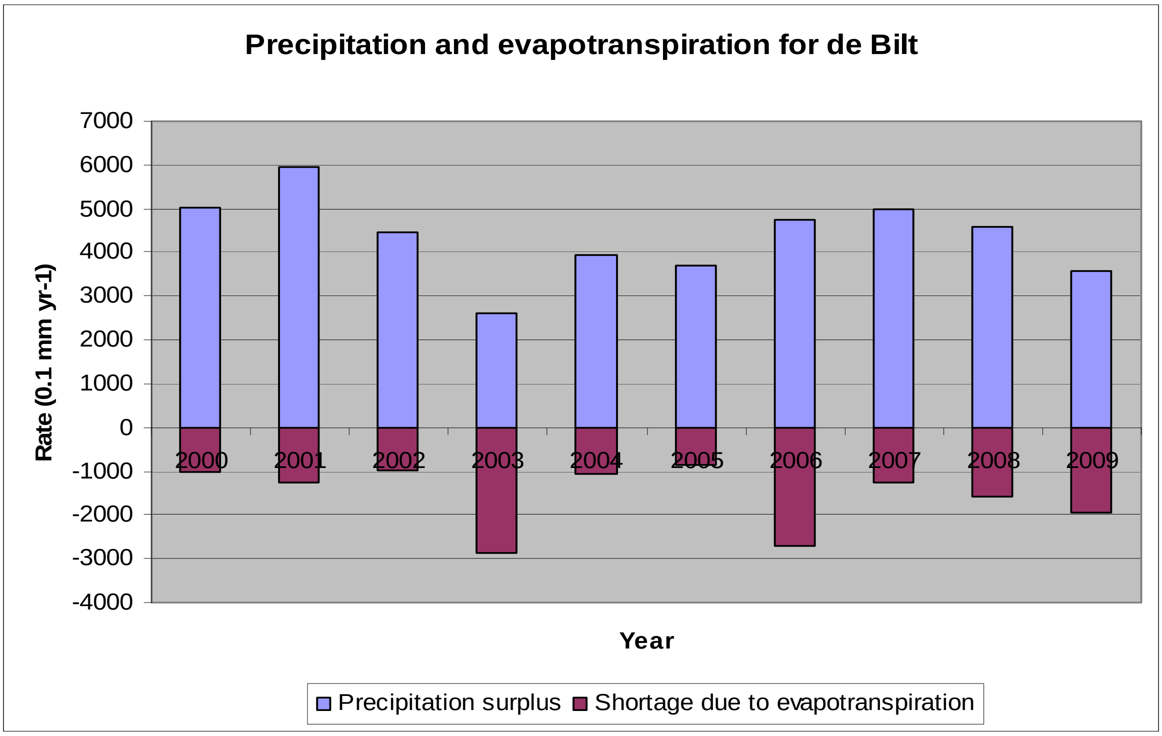

Figure I.5: Calculated precipitation surplus and shortage due to evapotranspiration for the KNMI weather station de Bilt. The quantities added and lost were calculated by determining whether there was a precipitation surplus or shortage due to evapotranspiration for each month and sum the quantities of these months per year.

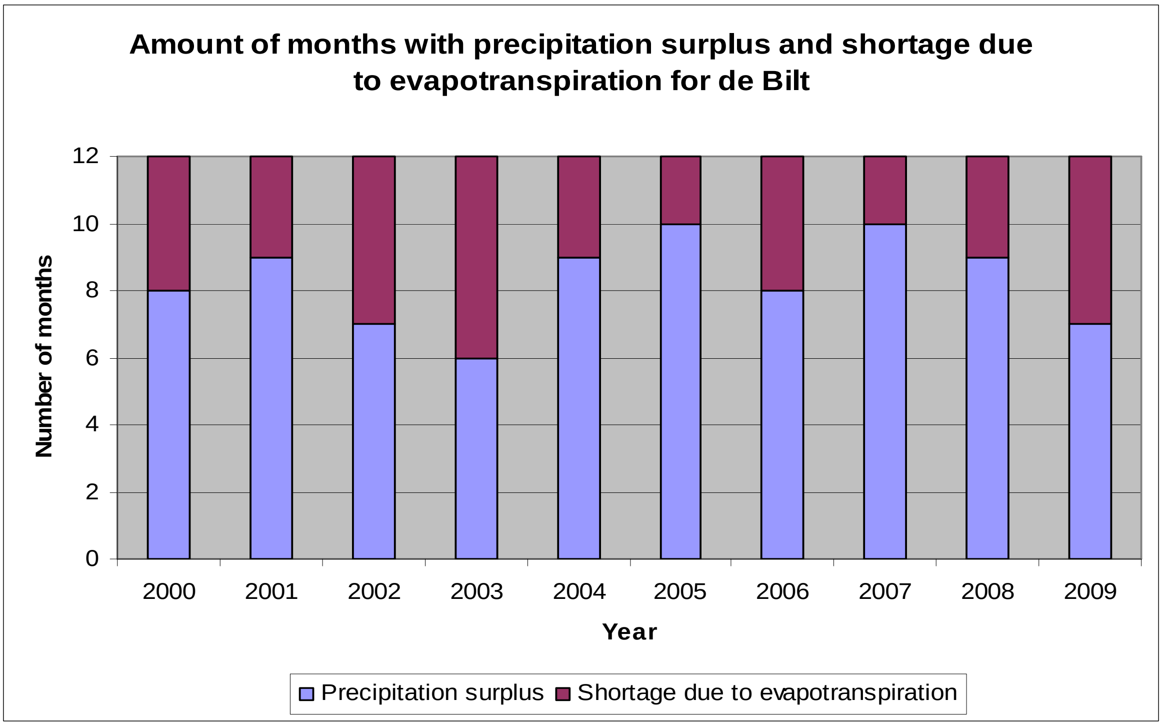

Figure I.6: Calculated number months with a precipitation surplus and shortage due to evapotranspiration for the KNMI weather station de Bilt.

III Detailed calculations of the phosphorus budgets

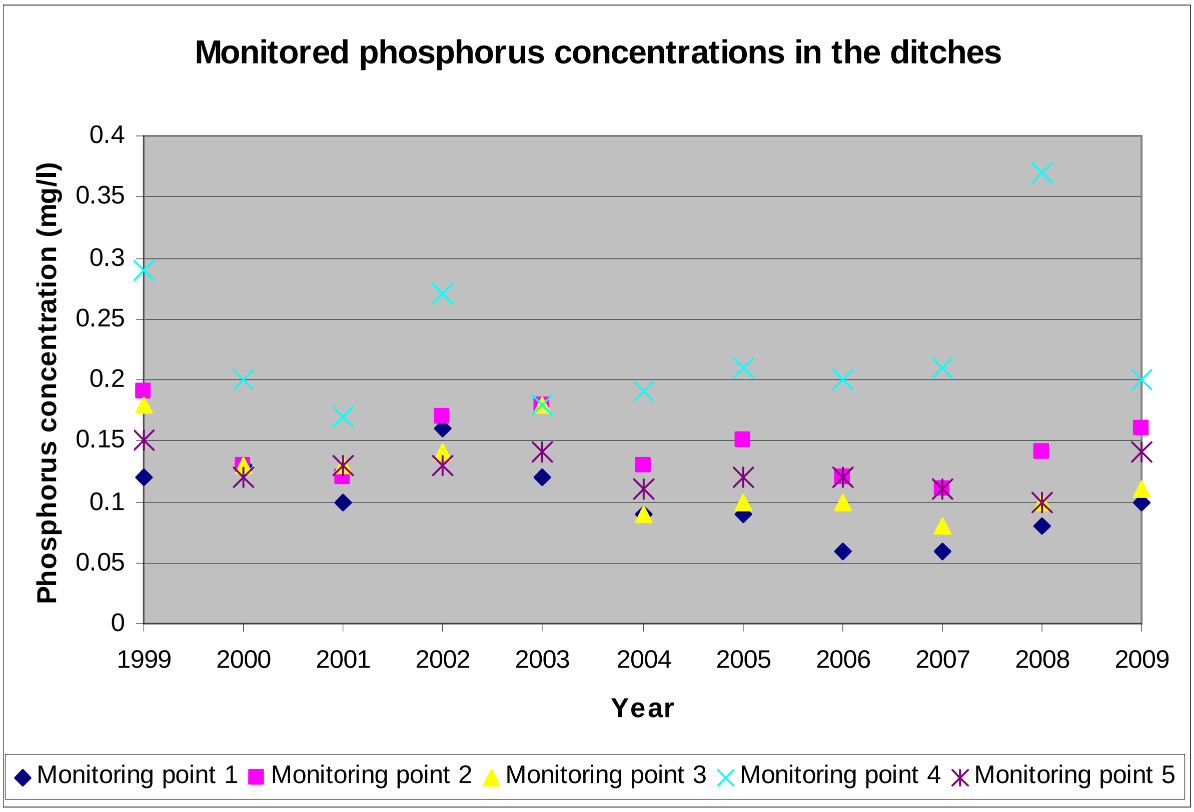

Figure I.7: Overview of the total phosphorus concentrations in the surface waters of a few monitoring points located in the polder Cromstrijen. The measured phosphorus concentrations are given for a time period of ten years. Data was gathered from water board Hollandse Delta.

Table I.1: Calculated fertilizer and soil surplus for different parts of the Netherlands. Numbers were gathered through a literature review. The average values were used in the present research.

Used fertilizer (kg P ha^{-1} yr^{-1})	**soil surplus** (kg P ha^{-1} yr^{-1})	**Source**
33.6	10.0	(Bakker, 2007)
41.5	-	(Reenen, 2004)
39.3	-	(Smit *et al.*, 2006)
-	17.5	(Ham *et al.*, 2007)
-	17.5	(Hooijboer *et al.*, 2007)
38.1	**16.5**	**Average**

Table I.2: Calculated percentage of the surface area of ditches compared to the surface area of the polder Cromstrijen. The length and width of the ditches are based on the STONE model and the surface area of the polder on data of the water board Hollandse Delta.

Element of polder	Area (ha)	% of ditches in surface area polder
Ditches	(293445 m * 2.5 m) 73.4	1.5%
Polder	4924	

Table I.3: Calculated total phosphorus concentration in seepage water. The calculations are based on a few monitoring points in the polder Cromstrijen. The data was gathered from water board Hollandse Delta.

Monitoring point and year	**Phosphorus concentration** (mg P l^{-1})	**Average phosphorus concentration** (mg P l^{-1})
I (2007)	3.3	1.7
I (2008)	2.9	
I (2009)	3.0	
II (2007)	1.3	
II (2008)	1.4	
II (2009)	1.2	
III (2007)	0.8	
III (2008)	0.8	
III (2009)	0.8	

Table I.4: Overview of the total phosphorus concentrations of a single monitoring point in the surface water of the river Hollandsch Diep. The measured phosphorus concentrations are given for a time period of nigh years. Data was gathered from water board Hollandse Delta.

Year	**Phosphorus concentration** (mg l^{-1})	**Average concentration** (mg l^{-1})
2000	0.13	0.12
2003	0.12	
2004	0.12	
2005	0.12	
2006	0.12	
2007	0.10	
2008	0.11	
2009	0.11	
2010	0.12	

Table I.5: Overview of the total phosphorus concentrations in the water pumped out of area #1 (figure 1.1). The measured phosphorus concentrations are given for a time period of ten years. Data was gathered from water board Hollandse Delta.

Year	**Phosphorus concentration** (mg l^{-1})	**Average concentration** (mg l^{-1})
1999	0.12	0.10
2000	0.13	
2001	0.10	
2002	0.16	
2003	0.12	
2004	0.09	
2005	0.09	
2006	0.06	
2007	0.06	
2008	0.08	

TableI.6: Overview of calculated total phosphorus concentration in the outlet water. The calculations are based the surface area of the sub polders in the polder and the phosphorus concentration near their outlet points. Data was gathered from water board Hollandse Delta.

Name polder	**Size** (ha)	**P-concentration** (mg P l^{-1})	**P-concentration polder** (mg P l^{-1})
Area #1	3443	0.10	0.22
Molense polder and Westerse polder (Eastern part)	557	0.31	
Hogezandse polder	660.4	0.23	
Westerse polder (Western part)	263.6	1.59	

Table I.7: Calculated amount of removed sludge per year. This depends on the area on the rate of sediment formation and the amount of ditches being dredged, which is based on literature.

Surface area (ha)	**Rate of sediment formation** (mm yr^{-1})	**% of ditches dredged per year**	**Amount of removed sludge** (m^3 yr^{-1})
(293445 m * 1.5 m) 44.0 ha	0.03	10	13205

Table I.8: Calculated volume of water based on the dimensions of the ditch. Data was gathered from the outcome of the PLONS model and the water board Hollandse Delta.

Variable	**Length** (m)	**Width** (m)	**Depth** (m)	**Volume of water** (*10^6 m^3)
Water in ditches	293445	2	1	0.59

Table I.9: Calculated effect of the scenario on the phosphorus concentration in the ditch waters, the phosphorus concentration present in the variable 'Discharge to the river' and "water in ditches' is comparable.

Scenario	**Quantity of water** (*10^6 m^3 yr^{-1})	**Variable discharge to river** (kg P yr^{-1})	**Variable water in ditches** (kg P yr^{-1})	**Grand total budgets** (kg P yr^{-1})	**New outcome** (kg P yr^{-1})	**Phosphorus concentration in ditches** (mg P l^{-1})
Current management	28.8	6256	130	0	6386	0.22
Scenario I	28.8	6256	130	18	6403	0.22
Scenario II	28.8	6256	130	-129	6257	0.22
Scenario III	28.8	6256	130	-1543	4843	0.17

IV Production of agricultural crops

Table I.10: Overview of the yearly production for potatoes, sugar beets and cereals for the Netherlands. Also the production for the polder Cromstrijen is calculated based on the average production of crops in the Netherlands and the area used in the polder to cultivate these crops.

Year data	**Potatoes** (kg*10^3 dw ha^{-1} yr^{-1})	**Sugar beets** (kg*10^3 dw ha^{-1} yr^{-1})	**Cereals** (kg*10^3 dw ha^{-1} yr^{-1})	**Source**
(2003)	41.9	60.7	7.9	(CBS, 2005)
(2004)	45.6	64.6	8.1	
(2002/2004)	43.7			(Rijk,2008)
(2005)	42			(CBS, 2006)
(2002)	44.8	58.2		(CBS, 2004b)
(2003)	40.8	60.7		
(2002)	50.7	56.6	7.5	(Ministerie van Verkeer en Waterstaat, 2004)
Average	**44.1**	**60.0**	**7.8**	
Area (ha)	1316	925	1316	
Total	**59234**	**60123**	**9872**	

V Landscape appreciation experiment

Options for improving the water quality of the polder Cromstrijen and the impact on ecosystem services

It is important for my research to get an indication of the appreciation of different landscapes. I want to ask you to give your opinion on three different series of pictures, independent from the other series. The series consist of 8 pictures, which need to be scored with a number from 1 to 5 (1 = very negative effect on landscape, … 5 = very positive effect on landscape). Two pictures of a series can receive the same score, as the effect can be equally negative or positive. The ratio between the given scores indicates which landscape is appreciated most and by how much compared to the other landscapes. Apply this method for every series.

Thank you for your cooperation!
Jelle Gommans

WAGENINGEN UNIVERSITEIT
WAGENINGEN UR

Serie1: Opportunities for the area next to unclear ditch (crops, grass and flowers).

Score:

Score (right side is mowed):

Score:

Score:

Score:

Score (right side is mowed):

Score:

Score (right side is mowed):

Serie2: Opportunities for the area next to ditch with duckweed cover (crops, grass and flowers).

Score:

Score (right side is mowed):

Score:

Score:

Score:

Score (right side is mowed):

Score:

Score (right side is mowed):

Serie3: Opportunities for the area next to clear ditch (crops, grass and flowers).

Score:

Score (right side is mowed):

Score:

Score:

Score:

Score (right side is mowed):

Score:

Score (right side is mowed):

VI Outcome of landscape appreciation experiment

Table I.11: Outcome of the landscape appreciation experiment. The scores were determined by the participants of the constructed questionnaire.

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	4	1	3	3	4	1	5	2	3	1	2	3	3	1	3	1	4	2	3	4	4	1	5	2
2	5	3	3	5	3	2	4	3	5	3	3	4	2	2	2	2	5	4	3	4	4	3	5	4
3	4	3	4	4	5	3	5	3	3	2	3	2	5	4	5	3	4	3	4	3	5	3	5	3
4	4	2	2	3	5	2	4	2	4	2	3	3	5	2	4	2	4	2	2	3	5	2	4	2
5	3	2	4	3	4	2	3	2	3	2	4	3	4	2	3	2	3	2	4	3	4	2	3	2
6	3	2	3	3	4	2	3	2	3	2	4	3	4	3	4	3	2	2	4	3	3	2	3	2
7	5	3	3	4	5	3	5	3	4	3	4	3	5	2	4	3	5	4	4	4	5	3	5	4
8	2	1	3	3	4	3	4	3	2	1	2	3	4	2	4	2	2	1	3	3	5	2	5	3
9	5	5	4	3	1	1	2	2	5	5	4	3	1	1	2	2	4	3	5	2	3	2	1	1
10	5	2	3	2	5	1	4	1	4	2	3	2	5	1	4	1	4	2	3	2	5	1	4	1
Average	**4**	**2.4**	**3.2**	**3.3**	**4**	**2**	**3.9**	**2.3**	**3.6**	**2.3**	**3.2**	**2.9**	**3.8**	**2**	**3.5**	**2.1**	**3.7**	**2.5**	**3.5**	**3.1**	**4.3**	**2.1**	**4**	**2.4**

Table I.12: Outcome of the landscape appreciation experiment for the different ditch management scenarios for different water states. The average scores of table I.11 were used to calculate the outcomes.

	Ditch with duckweed cover	**Ditch with turbid water**	**Ditch with clear water**
Management scenario			
Current management	3.17*	3.47	3.30
Scenario I	3.60	4.00	3.70
Scenario II	3.03	3.37	3.47
Scenario III	3.20	3.33	3.57

*** The pictures used for the current management are 1(0.67%), 2(0.33%), 9(0.67%), 10(0.33%), 17(0.67%), 18(0.33%). The pictures used for the scenario only dredging are 1,9,17. The pictures used for the scenario with buffer zones of 5 m are 7(0.67%), 8(0.33%), 15(0.67%), 16(0.33%), 23(0.67%), 24(0.33%). The pictures used for the scenario with buffer zones of 25 m are 5(0.67%), 6(0.33%), 13(0.67%), 14(0.33%), 21(0.67%), 22(0.33%).**