Silt in the Markermeer/IJmeer

A study on the effectivity and efficiency of proposed approaches concerning the deterioration of the lake and its surroundings

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Preface

Since I was born in Lelystad, the capital of the county Flevoland in the Middle of the Netherlands, I lived near the Markermeer for about 18 years of my life. I still remember the time being on an airplane and my dad showing me the Markermeer and IJsselmeer below us. The difference in color (blue for the IJsselmeer, while green/brown for the Markermeer) was enormous, and I know now, this is mainly caused by the high amount of silt in the Markermeer. A couple of years later I was, again due to my father, at an information day about water, distributing ‘dropjes’, a typical Dutch candy, wearing a suit looking like a water drop, named ‘Droppie Water’. I think it were those two moments that raised my interest for water and even though I was not aware of it at that time, I never got rid of it.
Thanks to the Master track ‘Ecology and Natural Resources Management’ which I started in 2011, my interest for water was raised once, or actually thrice, again. After my first internship, which was about seed dispersal via lowland streams and arranging my second internship about heavily modified water bodies in Sweden (which I planned for the period between half of December 2012 and the end of July 2013) I wanted to specialize this master track in the direction of water. Since lakes were still missing, the choice to write about the Markermeer was, especially given the facts listed above, quite easily made. And I could not have been happier when this idea was approved by my supervisor Dr. Jos Dekker. I would like to thank him for being my supervisor, putting a lot of time and effort in guiding me through the, sometimes pretty rough, process of writing a thesis. Reminding me of how important it is to be precise in everything I wrote and challenging me to get the best out of this thesis and myself. Of course also a word of thanks to my parents and Roeland for their extreme, never ending support and to Lynn for being the best thesis-study-friend in the world, spending so many hours together in the library, writing and discussing our theses over and over again.

Hopefully you will enjoy reading this thesis about the silt problem in the Markermeer/IJmeer area, I personally was shocked to find out about the decline in numbers of certain species in the area. All I can add for now is that I hope that one day we can fly over the Markermeer and IJsselmeer, finding out the Markermeer turned more blue than it is at this moment. Probably meaning the water quality increased and a healthier lake is created, being more beautiful and species rich than it is nowadays.

Iris van Gogh

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Summary

This thesis will provide an answer to the question what the most effective and efficient approach is to solve the silt problem in the Markermeer/IJmeer area, in perspective of the EU Water Framework Directive (WFD) and Natura-2000. The Markermeer, with a surface of 750 km^2, was separated from the IJsselmeer in 1976 by the Houtribdijk and with its construction, the silt soils got isolated in this area. Since the Markermeer has a relatively limited depth, the wind waves have a free hand on the soil and a lot of re-suspension of silt is taking place. This creates difficulties for water plants to establish and negatively influences mussels, fish and birds. The amount of water plants has remained constant over the last decades, and the amount of zebra mussels, fish as well as birds have declined. Since the Markermeer/IJmeer area is listed as a Natura-2000 area and is also covered by the WFD, it should reach certain requirements, and if the area does not meet those requirements, as is the case for the Markermeer/IJmeer, it should be recovered. From 2007 until today, governments and social organizations are thinking about the future of the Markermeer/IJmeer area, and a plan for a 'Toekomst Bestendig Ecologisch Systeem' (TBES) was created. In 2012, an optimization report for the TBES followed, which led to an open-market-application for nature development plans. Those plans, in their turn, led to three approaches for possible measures, *The Marker Wadden, lee structures and Innovative TBES*. The first approach provides a plan for the creation of a large scale swamp area, the second focuses on lee structures in front of the coast of Noord-Holland and the last combines those plans with stepping stones and fish passages. From the Multi Criteria Analysis (MCA) performed on the approaches it can be concluded that the Marker Wadden project, proposing a large scale swamp area in the North-East of the Markermeer, is the most effective as well as efficient approach for solving the silt problem while reducing the costs as much as possible, taking Natura-2000, WFD and TBES requirements into account.

Introduction

The Markermeer, including the IJmeer, is an important freshwater ecosystem of about 750 km^2, situated in a central part of the Netherlands between the provinces Noord-Holland, Flevoland and the IJsselmeer (Provincie Flevoland, 2012; Rijkswaterstaat, 2012). The Ministerie of EL&I (2012b) states that the Markermeer/IJmeer area is an important breeding area for fish eating-, mussel eating- and water plant eating water birds and it contains the largest amount of starry stonewort (*Nitellopsis obtusa)* in the Netherlands, which is an important food source for birds. Furthermore, some of the birds are of high national and international value and they need to have a favorable conservation status. It is thus important to keep the ecosystem in a healthy state, providing good living opportunities for the species occurring there. Besides the importance of the plants, fish and birds living in and around the Markermeer/IJmeer, it is also an area where ten thousands of Dutch people come on a yearly basis for leisure activities such as sailing, angling and bird spotting (Provincie Flevoland, 2012). In December 2009, the area was designated as a Natura-2000 area by the ministry of EL&I (Ministerie van EL&I, 2012b).

The Markermeer/IJmeer was cut off from the IJsselmeer due to the development of the Houtribdijk between Enkhuizen en Lelystad, which negatively influenced the water quality of the Markermeer/IJmeer. Nowadays, this water contains a lot of silt and low amounts of food. Due to that, populations of birds, fish and mussels show a decreasing trend over time (van Eerden, 2012). The Flora & Fauna act demands good conditions of the protected species in the area. Nevertheless these conditions are insufficient at this moment (Ministerie van EL&I, 2012b). Since the requirements set by the Water Framework Directive (WFD) and Natura-2000 are not obtained, this is a problem that needs to be solved (Provincie Flevoland, 2012). To deal with these problems, the first issue to tackle is the water quality in terms of silt content, which should improve in the next couple of years to provide a start for a livable and healthy lake system.

High amounts of silt influence the establishment and occurrence of water plants as well as the occurrence of mussels, fish and birds in a negative way. Different measures can be taken to improve the current situation, in which the Markermeer/IJmeer contains too much silt, and proposals have been drafted concerning the improvement of the silt quantity in the lake (Van der Vegt, 2012). However, there are some uncertainties concerning those improvements since the effects of the measures are yet unknown because the implementation can be done in a lot of ways. That is why this thesis questions:

What is the most effective and efficient solution for solving the silt problem in the Markermeer/IJmeer area, in perspective of the EU Water Framework Directive and Natura-2000?

The approach of this thesis will be to assess the main solutions that were drafted on effectivity and efficiency by a literature study and using a Multiple Criteria Analysis (MCA). The focus of this thesis is on the Markermeer area, including the IJmeer. The IJsselmeer area will not be discussed. Since the Houtribdijk cut of the connection with the IJssel, the water residence time is, with 12 – 15 months, relatively high (Bonte, 2009). Due to this fact the silt content of the Markermeer will be seen as invariable when discussed in this thesis. When relationships between species and their habitats as well as inter-species relationships are discussed, it is assumed that a change in a certain factor/species has a linear effect on the species it influences. Because it is difficult to predict the exact impact of changes in another species or the environment and possible important thresholds were not included, these simplified relationships had to be assumed.

Chapter 1 will give an introduction to the Markermeer/IJmeer area in which the development of the area will be discussed from the birth of the Markermeer/IJmeer towards the current status in terms of water quality and impacts on fish, water plants and birds. In chapter 2 the quality challenges of the Markermeer/IJmeer area will be discussed. The requirements set by the Water Framework Directive (WFD) and Natura-2000 will be listed and explained. Furthermore the most important habitat type of the Markermeer, the Characeae water, is discussed as well as some specific plant eating-, mussel eating- and fish eating birds concerning their status and requirements in terms of the Natura-2000. Furthermore, the plans concerning the improvement of the Markermeer/IJmeer area are discussed. Chapter 3 will continue with the assignment for the plans that are developed to reach the quality requirements for the Markermeer. The contents of these plans will be talked over, and an overview of the three resulting developed approaches, *The Marker Wadden, lee measures along the coast of Noord-Holland and the Innovative TBES,* will be given. Of those three approaches, the effectivity, as well as efficiency, will be determined in chapter 4. A broad overview of the approaches and their impact on the silt content of the lake, as well as improvements concerning water plants, mussels, fish, birds, tourism and leisure will be given. By performing a Multi Criteria Analysis (MCA) with the available information, the most effective and efficient approach can be pointed out. The discussion after the last chapter will aim at the assumptions and demarcations that were made during this thesis, combined with what has not be found and a review on the best approach. Finally, conclusions and recommendations will be given to complete this thesis.

Chapter 1: An introduction to the Markermeer/IJmeer area, from the development until today

This chapter will describe the birth of the Markermeer/IJmeer area, starting with the impoldering of the Zuiderzee and the realization of Plan-Lely. Thereafter, a description of the development of the Markermeer/IJmeer will be given, in which characteristics of the lake and the water quality in terms of silt will be discussed. Furthermore, the effects of silt on water plants, fish and water birds are listed and explained into more detail.

1.1 The birth of the Markermeer/IJmeer area

Before the Markermeer/IJmeer area was created, the water was part of the Zuiderzee. For centuries, the Dutch were reclaiming land from water and the closure and reclamation of the Zuiderzee fits in this tradition (van Duin, 1984). For a long time, different plans were developed for the closure and reclamation of this Zuiderzee. The oldest known, a plan in which dams and sluices were supposed to be built between the different Frisian Islands and from Ameland to the Frisian coast, was made by Hendric Stevin and dates from 1667 (Tiesinga *et al.*, 1990). Van Duin (1984) explained that hereafter, many more plans followed and most of them were rejected until the creation of the Zuiderzee-Vereeniging (association) in 1886. This Vereeniging incorporated provinces, townships, polder boards and private investors, and the young engineer Lely was declared adviser. The original goals of the project he had to develop were to offer safety against floods and to improve the water discharge of the surrounding areas, as well as creating a fresh water basin and adding fertile farming land with lasting opportunities for employment.

1.2 Plan-Lely

Lely created a feasible plan, which was ready in 1891, and this Plan-Lely (Figure 1) formed the basis for the Zuiderzee-act (Act for closure and impoldering of the Zuiderzee) of the 14th of June, 1918. The Zuiderzee-Vereeniging was of a great importance for scientific research and the financial feasibility of Plan-Lely. The Vereeniging was also aware of the fact that, if it wanted to succeed, the public opinion had to be influenced. By use of propaganda they raised public support for the ideas and were very successful in fighting opponents. The opponents were people from the Royal Institute of Engineers as well as agricultural landowners, the polder

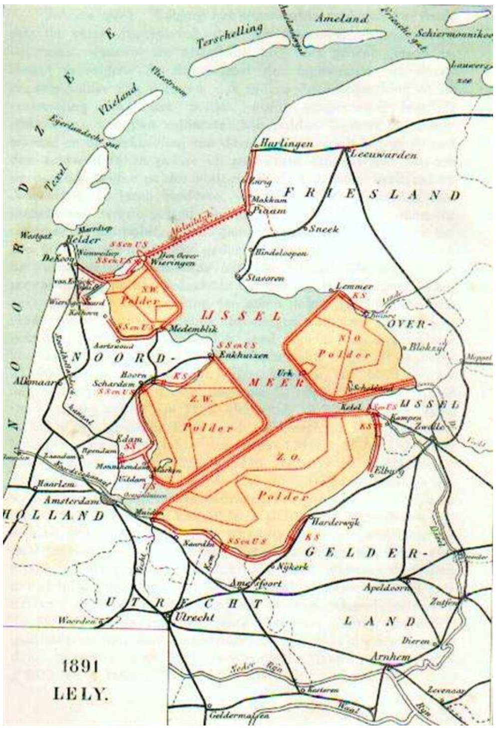


Figure 1.1 Plan-Lely (1891), with the four polders & the Afsluitdijk in red (source: nieuwlanderfgoed, 2012)

boards and the Zuiderzee-fisheries. Their resistance was caused by for example, their fear of an increase in floods because the water from the Ijssel could not be drained as easily anymore. The Afsluitdijk (IJsselmeer dike) was placed more to the north than in the original plans and, despite some other resistance, Plan-Lely was completed anyway. (Tiesinga *et al.*, 1990)

In table 1.1, the different stages of Plan-Lely are shown with the years it took to accomplish the building of the dikes and impoldering.

Table 1.1 The different stages of Plan-Lely and the years in which the building of the dikes and impoldering were accomplished. * The test polder Andijk was created somewhere between 1925 and 1930, but the exact dates could not be found. ** The development of the Markerwaard was started and stopped at three different moments, the first two times within a very short time span. The last time the Houtribdijk, leading from Lelystad – Enhuizen was created, but the development of the 4th polder, the Markerwaard did not occur. (Source: van Duin, 1984)

Stage of Plan-Lely	Accomplished during the years
Amsteldiepdijk	1920 – 1925
Test polder Andijk	1925 – 1930*
Wieringermeer	1926 – 1930
Afsluitdijk	1926 – 1932
Noord-oost polder	1936 – 1942
Oost Flevoland	1950 – 1957
Zuid Flevoland	1959 – 1967
Markerwaard	1941, 1956, 1963-1975**

According to van Duin (1984), for a long time the question lingered if the Markerwaard area should remain water or whether it should be converted to green land. Several times the development of the Markerwaard started, but as many times it started, it also ended. The Houtribdijk was completed in 1976, separating the Markermeer from the IJsselmeer. The Markerwaard was never realized and until today the area exists as the Markermeer (van Duin, 1992).

1.3 The development of the Markermeer/IJmeer water

Before the creation of the Afsluitdijk, the salinity of the Zuiderzee was determined by saline tides and the supply of fresh river water (Noordhuis, 2010). From the moment the Afsluitdijk was completed, the enclosed water turned from saline- towards fresh water. In a period of about five years, a freshwater column developed above the ‘old salt’ storing soil (Rijkswaterstaat, 2010). According Rijkswaterstaat (2010), the Markermeer/IJmeer is thus derived from a major interruption, causing the sudden disappearance of the estuarine zone, which caused a permanent change in the system. Furthermore, since the creation of the Flevopolders, the area exists of quite uniform separate ‘reservoirs’, with the IJsselmeer in the north, and the Markermeer/IJmeer in the south. This induced the disappearance of the original gradients in bed elevation and soil composition, and the Markermeer/IJmeer as it exists nowadays has relatively few shallow waters. The construction of the Houtribdijk separated the Markermeer/IJmeer from the IJsselmeer (Fig. 1.2 on the next page) and the sand soils north of the Houtribdijk, got isolated from the silt soils south of the Houtribdijk. Rijkswaterstaat (2010) also stated that when the Afsluitdijk enclosed the water areas, a lot of this silt lagged behind in the southern area, which is nowadays known as the Markermeer/IJmeer. The silt, no longer influenced by tides, accumulated in the deeper eastern part of the lake. Moreover, the retrieving of 'old salt' from the silt caused slackening of the silt and wind waves re-suspended the silt quite easily. This has a negative impact on the transparency of the water and the existence of the zebra mussel (*Dreissena polymorpha)*, which both declined over time. Since the zebra mussel filters the water and covers the soil, decrease of their appearance makes the situation even worse.

1.4 Characteristics of the Markermeer/IJmeer

With a surface of 750 km^2, the Markermeer/IJmeer (fig. 1.2) is the second largest lake of the Netherlands (Sarink & Balkema, 2008). The minimum and maximum water temperature of respectively 2,9^{0}C and 21,1^{0}C were determined by measures from a real cold winter (in 1996-1997) and hot summer (in 2003). The lake only freezes partially in winter, providing good living opportunities for the wet vegetation and water birds. The salt content of the lake in 2009 fluctuated between 113 and 125 mg chloride/L. (Deltaprogramma, 2011)
The KWR (2009) states that the Markermeer is fed by water from the Gooi- and Eemmeer, the IJsselmeer and by precipitation and the discharge of the water takes place by evaporation and via the sluices to the Noordzeekanaal and IJsselmeer.

Figure 1.2 Overview of the Markermeer/IJmeer area with the Houtribdijk separating the Markermeer/IJmeer from the Ijsselmeer. (Source: watersportbank, 2012)

However, the mean residence time of the water varies between 15 and 18 months. This is much longer than the 3 months the water stays in the IJsselmeer and for this thesis the residence time will thus be seen as non-variable. Because of that, the solutions concerning the improvement of the quality of the lake will only aim at the Markermeer/ IJmeer area itself and do not consider the limited input of silt from outside areas.
The lake has a mean depth of 3,9 meter. Compared with other lakes in the world this is a limited depth, and it does not contain many shallow zones of about half a meter or less (Noordhuis, 2010).

In figure 1.3 the bathymetry of the Markermeer is shown. This picture illustrates that the lake is the deepest in the eastern part (where silt is accumulating because of erosion by wind waves) and that it has a rather flat soil. This soil exists of (sandy) clay and silt. Because of the limited depth of the Markermeer as a whole, the wind has a free hand on the soil, which causes re-suspension of the sediment. The amount of suspended-matter is increases over time, causing a low transparency of the water. This is one of the main reasons for the deterioration of the Markermeer. (KWR, 2009)

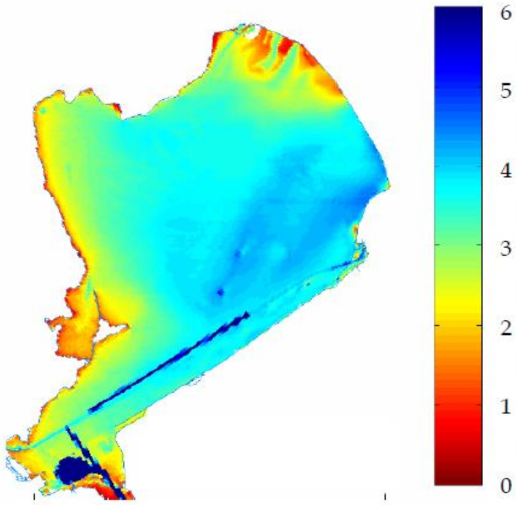


Figure 1.3 Bathymetry of the Markermeer (Kuiper *et al.*, 2008)

In figure 1.4, the amount of suspended matter in the Markermeer from 1982 until 2008 is shown (Noordhuis, 2010). The graph shows a slight decrease of the transparency which is associated with a slight increase in the amount of suspended matter.

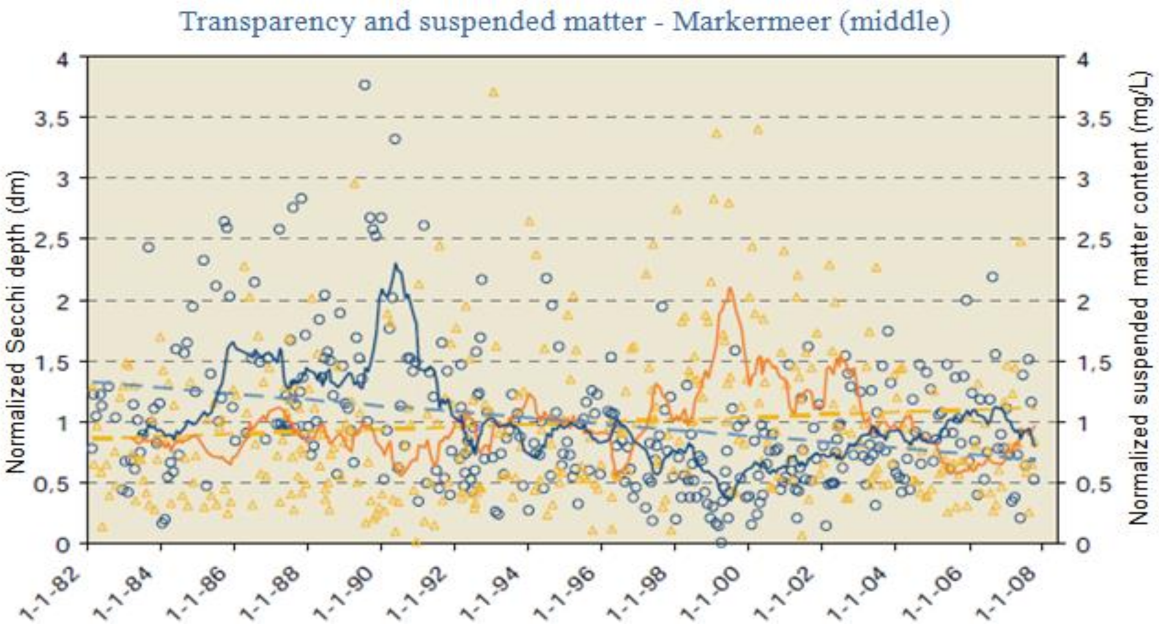


Figure 1.4 The transparency (Secchi depth in dm) in blue and the amount of suspended matter (in mg/L) in orange, of the middle part of the Markermeer from 1982 - 2008. The data is normalized for wind speed. The solid lines show the means and the dotted lines the linear trends. (Source: Noordhuis, 2010)

According to the KWR (2009), the suspended matter in the Markermeer creates problems for the zebra-mussel, fish, water plants and also birds, which will be explained in the next section, and because of the requirements of Natura-2000 and the WFD, measures should be taken to solve this silt problem. When the water becomes more fresh, erosion takes place more easily. Combined with fish digging the soil and waves created by boats, gradually more silt will get suspended in the system. However, the main cause of the amount of suspended matter that is shown in figure 1.4 is simply the wind, creating waves and water-flows that cause re-suspension of the silt (Noordhuis, 2010). The impact of the wind on the silt is, according to Noordhuis (2010), dependent on the season. It seems that during summer, by the same wind speed less silt gets re-suspended compared to the winter, when the water is colder. Note that the suspended matter content in figure 1.4 is normalized for wind speed. The measured, non-normalized amount of silt (or Total Suspended Matter), has a mean of 50mg/L and dependent on the wind, the TSM can even reach values of 300mg/L (van Kessel, *et al*., 2009).

Box 1 Silt in the Markermeer, a problem?

Whether the occurring silt in the Markermeer/IJmeer really is a problem can be questioned since there are no standards for the maximum allowed amount of silt in a lake. Those standards do not exist because the amount of suspended silt is variable and dependent on for example weather conditions, where windy conditions will cause an increased amount of free floating silt compared to windless conditions (Helpdesk water, 2012). The amount of silt in the Markermeer has not changed much since the moment of the creation of the lake, until today the silt has always been there. Indeed, the system has changed over the last couple of decades, as can be read in paragraph 1.5 and there is a slight increase in the amount of silt (fig. 1.4). However, the lake and its surroundings might be turning into a ‘natural’ state, considering the circumstances with relatively high amounts of silt compared to for example, the IJsselmeer. So the question remains why the amount of silt in the Markermeer/IJmeer nowadays is seen as a problem, when the situation has not changed much over the last decades.

The KWR (2009) states that the Markermeer water is of poor quality because of the mobility and nutrient richness of the silt. Given the unfavorable impacts of the amount of silt concerning certain animal and plant species currently living in the Markermeer, it could indeed be seen as a problem since some of the species should reach certain requirements set by Natura-2000. Similar statements and hypotheses about the unfavorable effects of the silt can be found in other literature (Molenaar, 2005 & Noordhuis, 2010) and the major cause of the arise of a ‘silt problem’ is due to rules set by Natura-2000 and the WFD. The WFD for example, requires a reduction of the silt amount in the IJmeer, which will improve the transparency of the water (Molenaar, 2005). Furthermore, the Markermeer is in relation to its (theoretical) natural state, classified as an M21 type (‘Large deep buffered lakes’) of lake. Since the transparency of the M21 type waters has to be two meters (van Nes, 2006), the silt problem is created. It is because of those requirements that in this thesis, the amount of silt in the Markermeer/IJmeer is seen as a problem that needs to be solved.

1.5 The effects of the silt amount in the Markermeer

- Transparency

Suspended matter exists of two parts, an organic (algae and dead material) and inorganic (silt) part. The suspended matter in the Markermeer exists for 70% out of inorganic material, and silt thus creates the major problem concerning suspended matter (Noordhuis, 2010). Noordhuis (2010), states that the amount of suspended silt in the Markermeer influences the transparency of the water. When the suspended matter contains a major part of organic material, the transparency of the water is highly dependent on the nutrient richness of the water. When the amount of nutrients decreases, the transparency of the water will increase and vice versa. This is however not the case for suspended matter with high amounts of silt, such as in the Markermeer. Independent of the amount of nutrients, the system shows a decline in transparency with an increase in amount of silt. In the first years of the nineteen-nineties, the transparency of the water decreased, while the nutrient content decreased at the same time. The precise cause of the decline in transparency is still studied, but according to Noordhuis (2010) it is possible that it has a relation with the increase in amount of silt, combined with the decrease of the zebra mussel population, causing a decline in filtration of the water. Furthermore, climate change is also thought to influence the transparency of the water. In case of increasing southwestern winds and sun-hours, the re-suspension of the silt and amount of algae can both enlarge.

Figure 1.5 shows the food chain of the Markermeer/ IJmeer area, starting with Phytoplankton and ending with fisheries, water plant eating-, fish eating- and mussel eating birds. If something in this food chain changes negatively, it is supposed to affect all the directly or indirectly dependent species also in a negative way. By first looking into the effect of silt on phytoplankton, the further impact on the other species will be discussed.

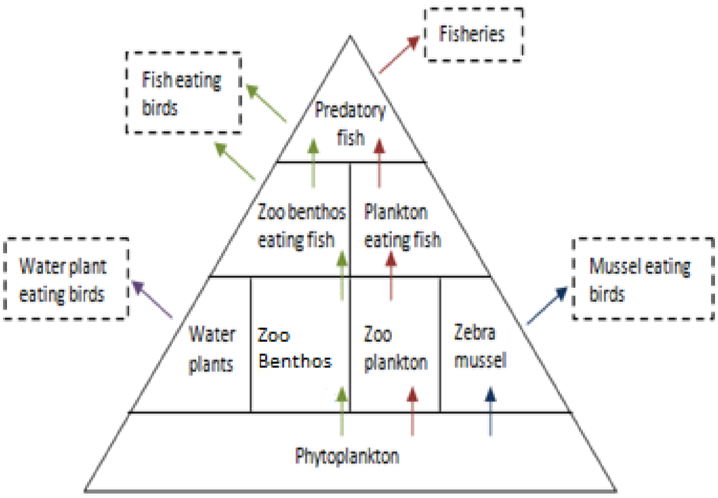


Figure 1.5 Food chain of the Markermeer/IJmeer area (Based on: Sarink & Balkema, 2008)

- Phytoplankton

As mentioned by Bijkerk (2010), the basis of the food chain in the Markermeer/IJmeer is formed by Phytoplankton, providing food for zooplankton and zoo-benthos. The amount of phytoplankton in a lake is influenced by the amount of nutrients and light availability. The poor light conditions in the

Markermeer, due to the suspended matter, cause a relatively low amount of phytoplankton compared to the adjacent IJsselmeer. During the last decade, the amount of small algae (<5 µm) has increased compared to the mid-nineties. According to Bijkerk (2010) this indicates a decrease of the zooplankton and zebra-mussel grazing pressure, since small algae are their main food source. The increased share of small algae reduces the water transparency even more by a larger effect of scattering. Because of this, the transparency problem of the Markermeer is further expanded.

- Zooplankton & zebra mussel

Not much is known about zooplankton in the Markermeer/IJmeer. It is however known that since 2005 some of the zooplankton eating fish also started to rely on the bloody-red mysid (*Hemimysis anomala*). According to De Leeuw *et al.* (2006) this indicates that the amount of zooplankton is declining and the fish thus search for an alternative food-source. More has been written about the zebra mussel (*Dreissena polymorpha*) by, among others, Noordhuis & Houwing (2003) & Noordhuis (2010). They mentioned a decline in mean zebra mussel density of 68% between 1993 and 2006 and suggested the cause could be found in the combination of a decline in food richness combined with abundantly present silt. The decrease in zebra mussel grazing pressure is known to be directly caused by the amount of silt in the Markermeer. Figure 1.6 shows the result of an experiment by Pires *et al.*,(2008), about zebra mussels and their filtration rate, dependent on treatments with 0,25 – 1 g/L silt. They concluded that the higher the amount of silt, the more tough it is for the mussels to filter the water. This creates more difficulties to survive since they have more troubles filtering food out of the water. Noordhuis & Houwing (2003) and Noordhuis (2010) furthermore stated that the situation for the zebra mussel in the Markermeer has always been more difficult than in other lakes because of the innate presence of silt and relatively low algae concentrations in the lake. Those two factors sensitize the zebra mussel for catastrophes like heavy storms during winter (i.e. when the normal circumstances are already hard to endure, it is even more difficult to survive calamities). In the winters of 1992 – 1994 there was an increase in storm activity. As was stated by Noordhuis & Houwing (2003), this contributed to low algae concentrations together with high amounts of suspended matter and a relatively high water temperature. When the water temperature is high, mussels are more active and therefore use more energy, which implicates the need for more food to survive. However, the amount of food supply decreased because of the low algae concentrations and furthermore, the mussels got buried under the sinking sediment. Burying of

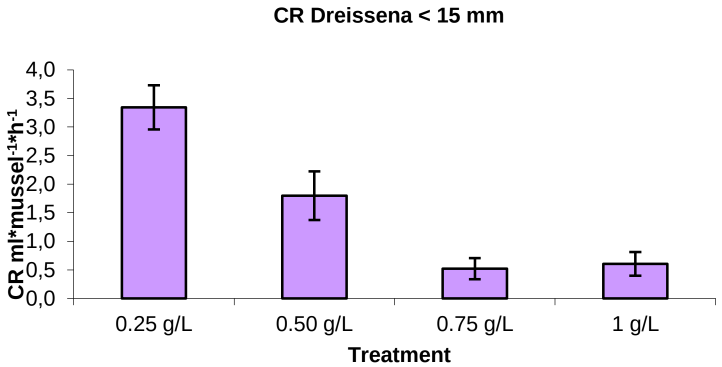


Figure 1.6 The filtration (y-ax, clearance rate, ml mossel^{-1} h^{-1}) of the zebra mussel for treatments with different silt concentrations. (Pires *et al.*, 2008)

mussels happens more often when storms come along, however those years it was reinforced and according to Noordhuis & Houwing (2003) the initial decline of the zebra mussel population thus took place in a very short time span. They also mentioned that, combined with the storms, a higher influx of scaups (*Aythya marila)* took place from the IJsselmeer, causing a higher predatory pressure on the zebra mussels. From that moment onwards, the zebra mussel population remained steady but low, as was the case for the transparency of the water, which can be seen in figure 1.4 from 1992 onwards. Despite some increase in the amount of algae, there was no zebra mussel population recovery. Noordhuis & Houwing (2003) and Noordhuis (2010) stated that the main cause was the decrease in soil cover by the mussels, which resulted in a soil that is more sensitive to re-suspension of silt. It was explained that despite of the high amount of mussel reproduction every year, the abundantly present suspended matter in winter due to storms, causes less survival of the mussels because they get buried under the sinking sediment. This increased winter mortality retains the recovery of the population and because the recovery failed to appear for more than 10 years, they estimated that the chance of spontaneous recovery is slight. When it comes to the filtering capacity and survival of mussels, especially short term silt dynamics thus play an important role. Since the mean suspended matter content does not reach values high enough to cause difficulties in filtering capacity (such as 1g/L, as was shown in figure 1.6), problems arise during windy periods when the mussels got buried under a dense blanket of silt and are unable to filter the water.

- Water plants

Water plants provide suitable habitats for zoo-benthos, they are used by fish as a spawning area, and are an important food source for water plant eating birds. They are also able to increase the transparency of the water, by reducing the water- and sediment circulation (Noordhuis, 2010). Water plants can thus be said to be of major importance to the Markermeer/IJmeer area. They can establish at places where the sunlight can reach the soil during the spring season. Therefore the water cannot be too deep and the transparency has to be good. (Sarink & Balkema, 2008)

Since the 1980s, the area occupied by water plants in the Markermeer/IJmeer area has increased, despite the deterioration of the water transparency (fig. 1.4). In for example the Gouwzee, which is part of the Markermeer, the mean cover of *Characeae* increased from 20% in 1992, to more than 70% in 2007. From the end of the 1990s, the volume of the vegetation fluctuates every year and is highly related to the water transparency and climatic changes. The most important water plants for the lake area are the stonewort (*Chara globularis)* and pondweed (*Potamogeton).* Floating plants and ‘canopy’ forming plants like pondweed have an advantage in turbid water since they grow from the bottom of the lake towards the water surface and spread once they reached the surface. However, when the transparency of the water increases, the pondweeds will be displaced by species that need more transparent water because they do not reach the surface, like stonewort for example. The stonewort positively influences its direct environment by further increasing the water transparency. Despite of the general decrease in water transparency of the Markermeer/IJmeer as a whole, this species has managed to increase. Fish like bream toss the ground and cause uprooting of stonewort. More intensive fisheries on fish species like this are probably also related to the increase of stonewort since less uprooting takes place and the water remains more transparent. The stonewort area in the Gouwzee of the Markermeer is the largest in the Netherlands and is important for the lake itself and the living animals in and around it. (Noordhuis, 2010)

- Fish

Three different types of fish can be distinguished in the food chain: Plankton eating fish, zoo benthos eating fish and predatory fish. The occurring fish species are interconnected with the existence of water plants, which provide spawning habitat and a facility for nursing and shelter. Due to the reconstruction of the Markermeer, gradual declining land-water zones are missing, causing less diversity in habitats and a limited fish fauna. (De Leeuw, 2010)

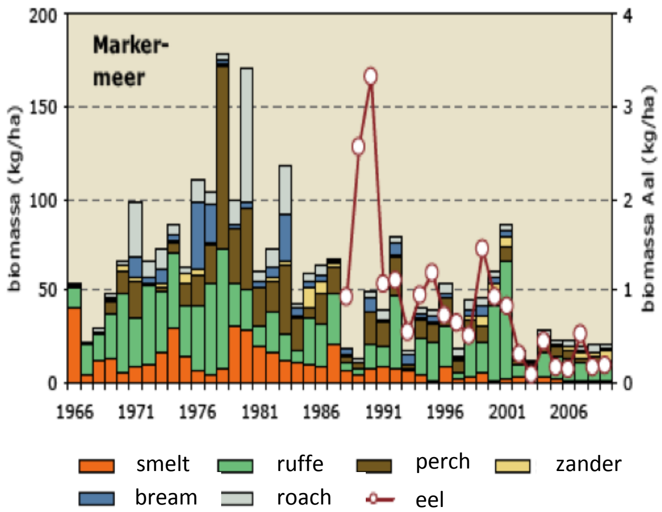


Figure 1.7 The amount of the most important fish species of the Markermeer. (Source: De Leeuw, 2010)

Almost all of the Markermeer fish biomass is determined by approximately 6 species and their biomass is declining, as can be seen in figure 1.7. An overview of the trends in certain important fish species for the Markermeer/IJmeer is shown in table 1.2.

Table 1.2 Trends in important fish species occurrence in the Markermeer/IJmeer area with the reason for the trend. 1=plankton eating fish, 2=benthos eating fish, 3=predatory fish. – indicates a decrease in number, + indicates an increase in number. (Based on: De Leeuw, 2010)

Fish species	- / + Since	Reason
Smelt[1] (*Osmerus eperlanus)*	- late 1980	Fisheries, possibly due to change in food supply and water transparency
Bleak[1] *(Alburnus alburnus)*	+ late 1990	Decrease of smelt amounts
Eel[2] *(Anguilla anguilla)*	- 1960	Difficult to say because of complex biology, probably fisheries and environmental factors
Bream[2] *(Abramis brama)*	- 1990	Fisheries
Roach[2] *(Rutilus rutilus)*	- 1990	Fisheries, possibly due to decline in zebra mussel occurrence
Ruffe[2] *(Gymnocephalus cernua)*	+ 1990	Not fished, possibly due to less food competition with bream
Bullhead[2] *(Cottus perifretum)*	- late 1990	Decline in zebra mussel occurrence, increase of Pos (eggs predator)
Perch[3] *(Perca fluviatilis)*	- 1970	Fisheries, possibly due to decrease of smelt amounts

Since the beginning of the 1980s, the decrease in fish has started, and still continues. According to De Leeuw *et al.* (2006), fishery is the main reason for the decline in amount of fish in the Markermeer/IJmeer. Some fish species however, do have an advantage because of the decline of other species.
Based on figure 1.4 and 1.7, it can be concluded that the silt probably does not have a direct effect on the amount of fish in the Markermeer/IJmeer, but there might be some effects of silt on food sources for the fish which indirectly influences them. However, not much is known about that. The decline with most consequences, especially for certain bird species, is that of the Smelt. In the year 2000 only 15% of the Smelt biomass during the nineteen-eighties was left (Noordhuis, 2010).

- Birds

The total amount of birds in the Markermeer/IJmeer has decreased since the mid nineteen-nineties as can be seen in figure 1.8.

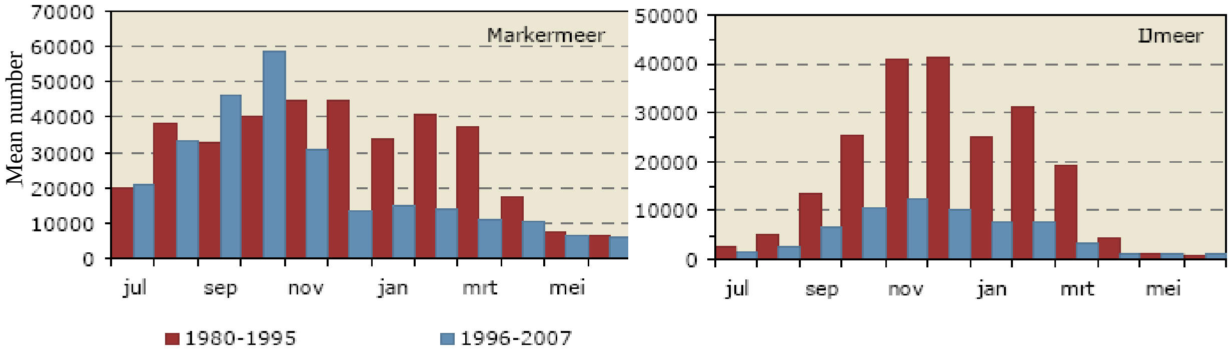


Figure 1.8 The mean amount of birds in the Markermeer & IJmeer during the years 1980-1995 (red) and 1996-2007 (blue). Species that use the area only as a resting place are not taken into account. (Source: Noordhuis, 2010)

Changes in the amount of birds in the Markermeer are less during fall because of the water plant eating birds that occur during that period. Nowadays, the Markermeer/IJmeer area stations around 215.000 birds yearly (Noordhuis, 2010). The birds can be divided into three different classes: the fish eating-, zoo benthos/mussel eating-, and water plant eating birds. Written below is a short summary derived from information of Noordhuis (2010) about the de- or increase of the birds in these groups . The next chapter will provide more detailed information on some specific species out of these groups.

The fish eating birds show the largest decline in numbers in the Markermeer/ IJmeer area. This decline is related to the decrease in both the amount of smelt and transparency of the water. The cormorant is the only exception on this decline since it is not fully dependent on smelt as a food source. Catching of the fish is difficult for the birds, due to the limited transparency of the water. However, when the water would be too bright, the fish could detect the attack of the birds in an early stage and hide before they are captured, which will also create difficulties for the birds. The zoo benthos eating birds are especially dependent on the zebra mussel, mostly during the winter period. However, other preys such as mosquito larvae and lobsters, are also important as a food source (some of these birds will even eat plant material). Due to the decline of the zebra mussel population, the amount of zoo benthos eating birds also decreased in the first years of the nineteen-nineties. The decrease was mainly concentrated in the area where the birds could not forage on plants. In contrast with the former groups, the only group of birds showing a stable or even increasing amount is the group of plant eating birds. Grazers of terrestrial plants as well as birds that forage on water plants both showed an increasing trend. The grazers, such as goose and wigeons, forage on grasslands and fields, and the increase might also have something to do with the changes in agricultural activities such as use of fertilizers. The increase in plant eating birds like the red-crested pochard, is caused by the expansion of water plants. (Noordhuis, 2010)

This chapter described the development of the Markermeer/IJmeer area from the moment of birth until the current situation. Specific attention has been draw to the silt amount in the lake and the consequences for the transparency of the water and the impact on the food-chain.

Chapter 2: The quality challenges of the Markermeer/IJmeer area

In this chapter, Natura-2000 and the Water Framework Directive (WFD) are introduced and the requirements for the Markermeer/IJmeer that have been set for habitat types and birds will be discussed. The last paragraph will hand a short overview of the different consortia and their plans concerning the improvement of the Markermeer/IJmeer area in terms of water quality and biodiversity.

2.1 Natura-2000 & the Water Framework Directive

The Markermeer/IJmeer is listed as a Natura-2000 area. Since the area is also covered by the WFD, it should reach requirements set by Natura-2000, which are incorporated in the Nature Conservation act and the Flora & Fauna act, as well as the WFD which is incorporated in the Dutch Water act. Before taking a closer look into those requirements an explanation of what Natura-2000 and the WFD include is needed.

2.1.1 Natura-2000

Natura-2000 is the most important piece of EU nature and biodiversity policy. As mentioned by Natura-2000 (2012a), it is an EU wide network of protected nature areas of European importance composed of sites designated under the Birds- and Habitat Directives which are incorporated in the Nature Conservation- and Flora & Fauna act. The aim of Natura-2000 is to guarantee long-term survival of the most valuable and threatened species as well as habitats of Europe. It consist of Special Areas of Conservation (SAC) established under the Habitats Directive (Habitat richtlijn, 1992), and Special Protection Areas (SPAs) designated under the Birds Directive (Vogelrichtlijn, 1979). The Natura-2000 network is not a structure where all human activities are excluded. The accent is on assuring that management of the area is sustainable in an ecological and economic way and if an area is not meeting the requirements it should be recovered (Natura-2000, 2012b). 80% of the habitat types and species in the Netherlands have an unfavorable conservation status (Regieburea Natura-2000, 2011). According to the PDN (2009), the Netherlands have the duty to improve this current unfavorable conservation status since they can get sanctioned if they do not take action. Article 6 of the habitat directive states that conservation measures should be taken for the protected areas to create a favorable conservation status. By assessment of new projects that are made concerning a protected area, a consideration has to be made whether the plans can continue. When the measures to reach the requirements have insufficient effect, there is a risk that the Natura-2000 areas are not resilient enough, which can cause troubles since activities in and around the area will sooner have a negative impact on protected species and habitats. In this situation, license applications for new activities in the area will be more critically judged and less soon granted. So when the requirements are not reached it is not only negative for nature, but also the activities by humans in the area can be negatively influenced. (Habitat richtlijn, Art. 6, 1992) The Netherlands contributes to Natura-2000 with 162 terrestrial areas, with a total surface of about one million hectares (Ministerie van LNV, 2006). As described in PDN (2009) the Markermeer/IJmeer belongs to the Natura-2000 landscape '*Lakes and Swamps'* and the total Natura-2000 area of the lake covers 68.463 ha. Figure 2.1 shows the Natura-2000 area of the Markermeer/IJmeer as well as the parts belonging to the Habitat- and Bird Directive areas. Paragraph 2.2 will discuss the habitat type and important bird species of the Markermeer into detail.

Figure 2.1 The Natura-2000 area of the Markermeer with Habitat- and Bird Directive areas. The picture on the left shows the full Natura-2000 area of the Markermeer/IJmeer. In the middle picture, the Habitat Directive areas are shown, and the picture on the left shows the Bird Directive areas of the Markermeer/IJmeer. (Source: Ministerie EL&I, 2012a)

2.1.2 Water Framework Directive (WFD)

Since December 2000, the Water Framwork Directive (WFD), incorporated in the Dutch Water act (waterwet, 2009), is applied on the Dutch waters. Goal of this directive is the protection and quality retention of all the ground – and surface waters through Europe by the year 2015 (Rijkswaterstaat, 2012). In a summary of the WFD as provided by Rijkswaterstaat (2012) it is stated that the WFD protects rivers, lakes, coastal waters and groundwater and sets ambitious goals to make sure all the European waters will meet a good condition in 2015. It requires a management-system per basin, in which the fact that water does not have political borders is taken into account and because of that, it requires transgressing collaborations between countries and all involved parties. It will make sure that all interested parties, including social organizations and local communities, actively participate in water-management. Furthermore, it will provide a decrease and restriction of pollution, regardless of the source (agriculture, industrial activities, urban areas, etc.) and it requires a water – price policy, which will make sure that the contaminator pays for the damage. At the same time, it keeps the environmental interest and the interest of those who are dependent on the environment balanced.

2.1.3 General requirements of Natura-2000 and WFD for the Markermeer/IJmeer

The requirements of the habitat- and bird directives as well as the WFD for the Markermeer/IJmeer are listed in a management- and development program for the 'Rijkswateren' for the years 2010 - 2015 as is provided by 'Rijkswaterstaat' (Rijkswaterstaat, 2009a). The requirements of Natura-2000 and the WFD for the Markermeer/IJmeer that are listed in this management- and development program, can be divided into four themes according to Rijkswaterstaat (2009a), with specific requirements to improve the bottlenecks within those themes. These themes with the most important requirements, as well as the proposed measures are listed in table 2.1.

Table 2.1 The four themes with requirements and the proposed measures of the WFD and Natura-2000 of the management- and development program for the Rijkswateren, and thus also for the Markermeer/IJmeer for the years 2010 – 2015. (Source: Rijkswaterstaat, 2009a)

Theme	Requirements	Proposed measures	WFD/Natura-2000
Sufficient water	Warrant freshwater availability	Adaptation of drainage- and water level management	WFD
Clean water	Decrease of eutrophication Improve transparency of the water	Reconstruction of lake bottom & reducing emissions of sewage purification plants	WFD & N2000
Habitat	Development of gradual land-water transitions (on behalf of water- & shore plants, soil animals and fish) Improve habitat quality (in terms of undisturbed nature and space)	Extension of shallow shore zones & recovery of swamps	WFD & N2000
Connections	Decrease of barriers for fish migration	Creation of fish passage, introduction of fish friendly sluice management and introduction of sustainable fisheries	WFD & N2000

2.2 Habitats and birds

The two European directives on birds and habitats are transposed in the Dutch Flora & Fauna act as well as in the Nature Conservation act. These acts protect wild living animals and plants and provide rules on the protection of the plants and animals, as well as their habitats (Flora & Fauna act, Art. 1&2, 1998). The occurrence of birds and habitats listed in the Flora & Fauna- and Nature Conservation act are thus of a major importance for a Natura-2000 area such as the Markermeer/IJmeer. For the Markermeer/IJmeer, the Characeae water is the most important habitat type included in the habitat directive (Profiel habitat type H3140, 2008). This habitat type is assessed by using assessment parameters. Furthermore, national objectives are set up to conserve and improve some of those assessment parameters. For a specific area like the Markermeer/IJmeer, bottlenecks concerning the assessment parameters are listed and measures are created to tackle the existing bottlenecks (Kiwa Water Research & EGG-consult, 2007). Paragraph 2.2.1 will give an overview of all of those aspects for the Characeae water in the Markermeer/IJmeer.

Paragraph 2.2.2 will hand more detailed information about some specific water plant eating-, mussel eating- and fish eating bird species in the Markermeer. Despite the decline in amount of water birds in the Markermeer/IJmeer area, they are still of great international importance, since they are protected because of the Flora & Fauna act (Ministry of EL&I, 2012). Box 2 provides general information about the birds, as well as assessment parameters, their rates, explanations and the goals for this specific bird species.

2.2.1 Habitat type of the Markermeer/IJmeer – Characeae waters

For all of the Natura-2000 sites, conservation objectives for different habitat types are formulated, which are included in the designation orders and further outlined in Natura-2000 management plans of the sites. The realization of the objectives requires insight in the maintenance, threads and perspectives concerning these goals. It is therefore necessary to solve bottlenecks by the implementation of measures in order to reach the conservation objectives. (Kiwa Water Research & EGG-consult, 2007). Table 2.2 shows an overview of the general profile and assessment aspect of the Characea waters in general and the bottlenecks and measures (in terms of silt) specifically for the Markermeer.

Table 2.2 Overview of the Habitat type – Characeae waters – of the Markermeer/IJmeer with general information as well as specific aspects concerning the Markermeer/IJmeer. (Based on: Profiel habitat type H3140, 2008; Kiwa Water Research & EGG-consult, 2007)

General profile habitat type		
Official name	Calcareous oligo-mesotrophic waters with benthic *Chara* spp. Vegetations (H3140)	
Short name	Characeae waters	
Recent development	Positive distribution trend (1994-2004), in recent years slightly negative.	
Relative European importance	Large: Widely spread in Europe, but limited in western Europe. Dutch waters are major site of H3140, have a high species richness and contain 50% of all European H3140 waters	
Assessment parameter	**Rate (National level)**	**Explanation of rating**
Natural distribution	Favorable	Since 2004, due to increased distribution
Surface area	Moderate unfavorable	More surface area is needed to create a favorable rating
Quality	Moderate unfavorable	Due to turbid waters. Sustainable conservation is difficult because of that
Future perspective	Moderate unfavorable	The chances of sustainable conservation are unclear, introduction of the WFD however shows perspective for improvement
Overall judgment	Moderate unfavorable	Concluded from assessment parameters above
National objectives	Conservation of distribution area and surface area, improvement of quality	
Bottlenecks Characeae waters of the Markermeer/IJmeer		**Explanation of bottlenecks**
Decline of transparency caused by re-suspension of silt by wind (waves)		Caused by limited water depth, large surface area and silt soil. Aggravated by creation of the 'Houtribdijk'
Decline of transparency by decrease in amount of zebra mussels		The amount of suspended matter & -algae probably increased with the declining zebra mussel occurrence (mussel decline: caused by increase of the amount of storms and predation pressure by ducks)
Decline of transparency by re-suspension of silt due to recreation shipping		The recreation shipping has increased, and motorized boats cause more re-suspension on a local scale. (It is not clear to what extent this bottleneck plays a role)
Measures to tackle bottlenecks		
Creation of dams, shallowing the area, and/or dredging pits		Dams should cause a decrease of the effect of wind. Shallowing the area causes more light availability for plants, dredging of pits can create silt deposition locations.
Regulation of recreation shipping		By zonation and restriction on speed of motorized boats, turbidity can possibly be reduced. Inspection on this measure is essential.

2.2.2 Water birds in the Markermeer/IJmeer

Table 2.3 shows the different kind of birds and their specific species which occur in the Markermeer/IJmeer area. Chapter 1 already showed some information about the general trends in the different kinds of birds and below, more specific information about one species per fish eating-, plant eating-, and mussel eating water birds will be given.

Table 2.3 The different kinds of birds occurring in the Markermeer/IJmeer area (Source: Ministerie van LNV, 2006)

Kind of bird	Species
Fish eating water birds	Cormorant (*Phalacrocorax carbo*), Goosander (*Mergus merganser*), Red-breasted Merganser (*Mergus serrator*), Smew (*Mergellus albellus*), Great Crested Grebe (*Podiceps cristatus*), Common Tern (*Sterna hirundo*), Black Tern (*Chlidonias niger*), Little Gull (*Hydrocoloeus minutus*), Black-headed Gull (*Chroicocephalus ridibundus*), Herring Gull (*Larus argentatus*), Common Gull (*Larus canus*), Great Black-backed Gull (*Larus marinus*)
Plant eating water birds	Red-creasted Pochard (*Netta rufina*), Eurasian Coot (*Fulica atra*), Eurasion Wigeon (*Anas Penelope*), Mute Swan (*Cygnus dor*)
Mussel eating water birds	Common Pochard (*Aythya ferina*), Tufted Duck (*Aythya fuligula*), Greater Scaup (*Aythya marila*), Common Goldeneye (*Bucephala clangula*)

Box 2 on the next page, will hand some information about three specific species of water birds to hand a more concrete view on what is happening with certain water plant eating-, mussel eating and fish eating birds. The general trend shows a favorable national conservation status with a favorable future perspective for the plant eating water birds. Mussel and fish eating birds however, show respectively a highly- and moderate unfavorable national conservation status due to declines in the amount of food, and both of the future perspectives are moderate unfavorable.

As can be seen in box 2, for all of the three species no national recovery objective is stated. Before the national recovery objectives are created, the possibilities concerning the improvement of the quality of the Markermeer/IJmeer living area should be investigated. When this is done, national recovery objectives for the birds as well as recovery objectives for the birds in the specific area can be formulated. (Ministerie van LNV, 2006)

It is thus of great importance that the water quality in terms of silt shall increase as soon as possible to create a better living area for animals like the smelt and zebra mussel. To do so, it is initially important to do research about the possibilities to improve the quality. Only when this is done, the national recovery objectives for the birds can be stated and the conservation status can probably be recovered.

Box 2 Assessment of the smew, eurasian wigeon and common pochard

The tables below show specific information on three types of bird species. Since not much information on those bird species specifically in the Markermeer/IJmeer area was found, the tables give a general overview of the situation of those birds in the Netherlands. An analysis of opportunities and bottlenecks as provided for the habitat type of the Markermeer does not exist. The species were chosen because, except for the plant eating birds, a national core task is stated for their preservation. (Source: Ministerie van LNV, 2006, profielendocument Smient, Nonnetje & Tafeleend, 2008)

Plant eating water bird	Eurasian wigeon (*Anas penelope*)	
Main food source	Water plants (Characeae) and grasses	
National conservation status	Favorable	Due to sufficient amounts of food
National recovery objective	Not yet present	
National core tasks N-2000	n/a	
N-2000 goal	Preservation of the size and quality of the living area with capacity for a population of 258.200 birds (seasonal average). Some decline by intensified land use (i.e. by nature development) is accepted	
Housing of global international population in the Netherlands	50-75%	
Future perspective	Favorable	

Fish eating water bird	Smew (*Mergellus albellus)*	
Main food source	Smelt	
National conservation status	Moderate unfavorable	Due to decline in amount of smelt
National recovery objective	Not yet present	
National core task N-2000	4.01W*	
N-2000 goal	Preservation of the size and quality of the living area with capacity for a population of 690 birds (seasonal average) (As well as creating sufficient availability of fish)	
Housing of global international population in the Netherlands	15-25%	
Future perspective	Moderate unfavorable	

Mussel eating water bird	Common pochard (*Aythya ferina)*	
Main food source	Zebra mussel	
National conservation status	Highly unfavorable	Due to decline in amount of zebra mussels
National recovery objective	Not yet present	
National core task N-2000	4.01W*	
N-2000 goal	Preservation of the size and quality of the living area with capacity for a population of 20.900 birds	
Housing of global international population in the Netherlands	15-25%	
Future perspective	Moderate unfavorable	

*Core task 4.01W states that a more balanced system should be pursued, together with a good water quality for water plants, fish and shellfish for the preservation of birds like the smew and common pochard.

So far it is shown that the amount of silt in the Markermeer/IJmeer creates problems concerning the quality of the habitats in the lake and has a negative impact on the species living in the area. Species are highly dependent on the quality of their habitat and the national conservation statuses, of for example birds depending on the Markermeer/IJmeer area, reach from favorable to highly unfavorable. The Netherlands have the duty to make sure requirements by Natura-2000 and the WFD are reached. The main problem is now identified and a closer look can be taken on the approaches made to recover the Markermeer/IJmeer area.

2.3 Plans

From 2007 until today, under the lead of the province of ‘Flevoland’ and ‘Noord-Holland’, governments and social organizations are debating about the future of the Markermeer/IJmeer area (TMIJ, 2009). Figure 2.2 gives an overview of the consortia that were formed (TMIJ, NMIJ & WMIJ) and their plans. Both the groups and the plans are discussed in the subsequent text.

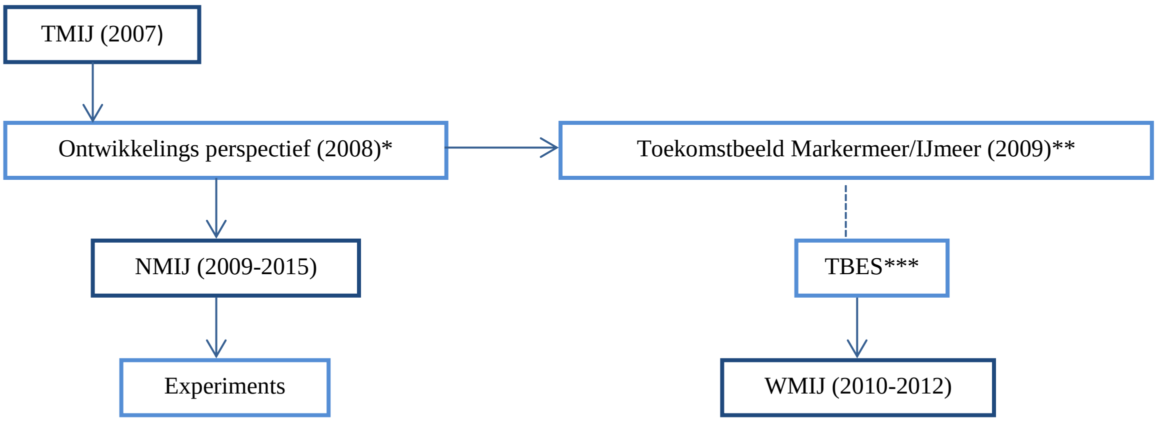


Figure 2.2 Overview of the consortia (dark blue boxes) and plans (light blue boxes) concerning the Markermeer/ IJmeer area. * Development perspective, ** Future vision Markermeer/IJmeer, *** Toekomst Bestendig Ecologisch System (future resistant ecological system).(Based on: MIJ, 2012; TMIJ, 2009 & Rijkswaterstaat, 2009b)

The first group of governments and social organizations, founded in 2007, was the consortium ‘Toekomstagenda Markermeer IJmeer’ (TMIJ). They created a development perspective, ‘Investing in the Markermeer and IJmeer’, in 2007-2008 (Rijkswaterstaat, 2009b). With this perspective the TMIJ wanted to reach improvement of the system, which goes beyond the legal requirements of Natura-2000 (MIJ, 2012a). In 2009, the consortium ‘Natuurlijker Markermeer IJmeer’ (NMIJ) was founded, under the management of ‘Rijkswaterstaat’, to perform continuing experiments during 2009-2015 on the assumptions made in the perspective. Using small scale pilot studies, the most effective and sustainable measures had to be found. (TMIJ, 2009) Rijkswaterstaat (2009a) stated that the experiments should at least indicate:

1. How the amount of silt should be reduced in the Markermeer/IJmeer area
2. How the biodiversity and dynamics of the habitats for plants and animals could increase
3. How the different areas could be connected

The costs for those pilot studies sum up to 25 million euros (MIJ, 2012a).

The original perspective has been amplified and extended resulting in the ‘Toekomstbeeld Markermeer IJmeer’, which is an elaboration on the development perspective that represents the situation in the summer of 2009 (MIJ, 2012a). An integrated part of the ‘Toekomstbeeld’ is the ‘Toekomstbestendig ecologisch systeem’ (TBES). MarkermeerIJmeer (2009) states that if the plans of the development perspective and ‘Toekomstbeeld’ become reality, the Markermeer/IJmeer will be resistant against climate change, storms and variations in the water level, but also against human use of the area by leisure activities or fisheries. When the government decided that the TBES project plan should become reality, the ‘Werkmaatschappij Markermeer IJmeer’ (WMIJ) was founded, existing of the ministries of Infrastructure and Environment, Economic affairs, Agriculture and Innovation and the provinces of ‘Noord-Holland’ & ‘Flevoland’. The WMIJ should specify the ‘Toekomstbeeld’, but especially investigate the TBES in terms of the three most important cornerstones: ecology, economy and sustainable use and financing. (MIJ, 2012b)

The consortia and plans concerning the Markermeer/IJmeer are listed and the WMIJ and TBES are introduced. Now, the next chapter can provide more insight in the further development of the TBES, because the TBES is of high importance for the development of the plans concerning the improvement of the quality of the Markermeer/IJmeer, which are also discussed in chapter 3.

Chapter 3 Towards a future resistant ecological system

This chapter will discuss the plan provided by the WMIJ regarding the TBES, which had to be adapted since it was too expensive according to the government. To reduce the costs even more it was requested that new alternative plans had to be developed through an open-market application. These plans resulted into three approaches. Highly shortened representations of those approaches will be given, in which their main contents will be discussed. The impacts will be explained shortly and are discussed into detail in chapter 4.

3.1 The assignment for the plans and origination of the final approaches

The WMIJ (2012) presented an optimization report concerning the TBES in November 2011. The basis of the TBES is formed by four ecological requirements; transparent edges along the coast, a gradient in silt from transparent to turbid water, wide gradual land water transition zones and improvement of ecological connections(MIJ, 2012c). The optimization report presents measures which are needed to recover the quality of the Markermeer/IJmeer regarding those requirements. These measures are:

- The creation of a large scale swamp, of 4.500 ha South of the 'Houtribdijk'
- The creation of 12 kilometers of lee-structures along the coast of 'Noord-Holland'
- The creation of a foreshore (the 'Lepelaarplassen') of 300 ha near 'Flevoland'
- The use of lake-soil to create the 'Marker Wadden'/ lee structures

Besides these measures the optimization report proposes:

- A phased approach of the projects
- A synergy between ecology, leisure activities and dike reinforcement

WMIJ & RRAAM (2012) stated that the initial costs of the TBES were estimated at 1.1 billion euro. Since this plan and its interventions so far were too expensive, the WMIJ formulated less expensive solutions to create improvement of the ecology and water quality of the Markermeer/IJmeer. This optimization study, with the measures as listed above, showed a reduce in costs of 20-40% and in this way, the costs will decrease to 630-880 million euro. It argues for an approach with separate phases, so in the next 10 to 15 years, 200-280 million euro has to be invested. Within this time, the Markermeer/IJmeer will change from a deteriorating system to a system where the quality is increasing. As a result of the optimization report and to reduce the costs even more, an open-market-application was issued concerning the nature development plans. This was performed by the WMIJ in 2012.

The open-market-application resulted in 10 entries of various consortia. Three of the consortia and Natuurmonumenten were chosen to elaborate their plans concerning the TBES (WMIJ & RRAAM, 2012). A short overview of the different consortia with the similarities and differences within their plans is listed below.

The three consortia are:

- Consortium Witteveen & Bos, research center B-ware, the Radboud University of Nijmegen, Altenburg & Wymenga and HOSPER & Boskalis – *Luwtestructuren, de essentie van het TBES, naar een stapsgewijze realisatie van doelen.*
- Consortium Grontmij, De Vries & Van de Wiel – *Twee halen een betalen, ecologie en veiligheid van het Markermeer*
- Consortium Kransmeer, existing of Tauw, Posad, Robusta, Tebezo and LAgroup – *Kunstmatige structuren als katalysator voor ecologie in het Markermeer-IJmeer*

And in addition to the three consortia:

- Natuurmonumenten – *Marker Wadden, sleutel voor een natuurrijk en toekomstbestendig Markermeer*

By comparing the different plans, the WMIJ & RRAAM (2012) analyzed the similarities:

- All of the partnerships emphasize their doubts about the outcomes of the ecological processes on the long term. A phased approach is recommended by all of the groups.
- Several partnerships recommend to experiment with new construction techniques for development of the lee-structures and, when necessary, also for the construction of large land-water transition zones.
- An important statement concerns the reduction of costs by realization of measures in the more shallow part of the Markermeer (along the coast of Noord-Holland), which is less expensive compared to measures in the deeper part of the lake.
- Two of the consortia hand the advice to focus on the endangered Natura-2000 species since for those species the legal review is most urgent.
- Two of the consortia state that the most extensive measure with the highest costs, the creation of a large swamp, should be abandoned, or postponed as long as possible.

The major differences of the plans concern their focus (WMIJ & RRAAM, 2012):

- A gradual start where all of the TBES measures (as listed above) are combined – the original plan & Consortium Kransmeer.
- A specific focus on lee-measures before the coast of Noord-Holland and (for now) no swamp realization – Consortia Grontmij and Witteveen & Bos.
- The emphasis on reduction of free floating silt and creation of wetland (swamp) in the deeper part of the lake and less focus on the part before the coast of Noord-Holland – Natuurmonumenten.

The outcomes of the open-market-application resulted in three approaches for the possible measures, which can be linked to the plans of the open-market-application (WMIJ & RRAAM, 2012). The names and summaries of the approaches, derived from the report of WMIJ & RRAAM (2012), are as follows:

'Cautious Marker Wadden'

This approach will use the plan proposed by Natuurmonumenten. It will control the silt in the deeper part of the Markermeer. A 'silt motor' will be made, that guides the silt to the Houtribdijk where it is used as building material for a large swamp area. The constructing of lee-structures will be limited. The development of the Marker Wadden will create shallow land water transition zones and it causes a gradual increase of the quality of the Markermeer/IJmeer area. It is expected to meet the Natura-2000 purposes.

'Lee measures Noord Holland'

This approach will not integrate the whole system and TBES, but instead focuses on the lee-structures and with that on the most urgent Natura-2000 purposes of this moment. Because it only uses lee-structures it relies on a measure that already has been applied in other locations and uses a proven construction technique. Gradual land-water transitions will only be created when necessary to reach the Natura-2000 requirements. This approach can be linked to the plan of the consortia Grontmij and Witteveen & Bos.

'Innovative TBES'

This approach will use the same methods as the original plan and integrates some of the technical innovations of all of the open market applications. The foreshores of the Lepelaarplassen will be realized as well as the fish-passage. Furthermore lee structures and the Marker Wadden will be created. The approach stresses the ecosystem of the Markermeer/IJmeer as a whole and it can be seen as a combination of the plans made by the different consortia & Natuurmonumenten.

In 2009, it was decided to start with the first phase TBES, which exists of research concerning the improvement of the Markermeer/IJmeer ecosystem, as well as the start of the creation of (at least) 5 kilometers of lee-measures near the coast of Noord-Holland. The state and provinces of Noord-Holland & Flevoland, raised €9 million to realize this first phase. The open-market-approaches are related to the second and third TBES phases. The second phase TBES exists of the realization of the ecological measures which are needed within a certain approach to reach an effect. In this way, the ecological downward trend can possibly be turned within 10-15 years. The third phase TBES, concerns the period in which the final goal of a TBES will be reached (25-30 years). (WMIJ & RRAAM, 2012) Table 3.1 on the next page, shows an overview of the different approaches with their costs, benefits and disadvantages.

Table 3.1 The different approaches regarding the TBES, with their costs per phase, benefits and disadvantages. (Modified from: WMIJ & RRAAM, 2012)

Approach for TBES	Costs (million €)	Benefits	Disadvantages
TBES plan optimized by WMIJ	Phase 1: 9 Phase 2: 200-280 Phase 3: 430-600 Total: 630-880*	- Ecologically complete - Restricted legal risk - Acceptable regional basis - Proven techniques: safe	- Relatively expensive
Cautious Marker Wadden	Phase 1: 9 Phase 2: 110-170 Phase 3: 240-348 Total: 350-518*	- Ecological system leap - Restricted legal risk - Large regional support - Cheaper than basic plan (40%) - Utilize private money NPL** - Possibility for synergy with dike reinforcement 'Houtribdijk'	- Uncertain technique - Approach for silt problem has still to be proven - More research concerning effectiveness N-2000 is needed
Lee measures Noord-Holland	Phase 1: 9 Phase 2: 266-364 Phase 3: 89-343 Total: 335-706*	- Priority for current N-2000 bottlenecks - Proven techniques - Possibility for synergy with dike reinforcement NH - Cheaper than basic plan (40%)	- Unilateral NH-coast - Lack of chances for recreation in wetland - Nuisance for recreation shipping - No regional support - Ecologically less complete - Legal risk
Innovative TBES	Phase 1: 9 Phase 2: 180-280 Phase 3: 242-600 Total: 422-880*	- Ecologically complete - Restricted legal risk - Acceptable regional support - Chance to reduce costs (30%) by innovation - Utilize private money NPL**	- Could turn out to be expensive

The costs of the 1st phase are excluded from the total costs, since the first phase previously started and the money is already raised. The NPL is the Nederlandse Postcode Loterij, which sponsors the Marker Wadden with €15 million.*

3.2 Contents of the three approaches

Cautious Marker Wadden

The Marker Wadden is a project designed by Natuurmonumenten, an association which manages nature areas in the Netherlands since 1905 (Natuurmonumenten, 2012a). According to Natuurmonumenten (2012b) the main goal of this project is to tackle the problems in and around the Markermeer at the source: the silt. They want to create a wetland with a total surface area of 10.000 hectares between Enkhuizen and Lelystad. At the deeper side of Lelystad, a swamp with high food availability will be formed, while at the more shallow side of the Enkhuizerzand, sand- and shell banks with shallow waters rich in water plant vegetation will be created. People are welcome in the area for leisure activities as aquatic sports and walking, and the area is arranged to combine walking trails with parts of the swamp people cannot reach to create forage- and nursery habitats for birds. The project will follow a phased approach and in the first phase, an island area of 1000 ha is created, of which 500 ha will be situated above the water and the other half will be below the water surface, including the land water transition zones.

There are two main cornerstones in the Marker Wadden project: the improvement of the productivity of the open water and in this way increasing the food availability, and the creation of a swamp area constructed of islands to create a natural shore area. Natuurmonumenten (2012) states that in any case, the first priority is the controlling of the silt, since otherwise the system will remain unstable and vulnerable. The silt layer, which now covers the lake soil and creates problems for fish and suffocates mussels, will be removed and is used as building material for the wetland. The wetland will exist of nature beneath the water surface (silt trapping rifts and wells) and above the water surface (islands). The rifts and wells will contribute to the Natura-2000 requirements of the Markermeer itself, while the islands above the water will contribute to the Natura-2000 requirements for the Netherlands as a whole.

The submerged landscape is equipped in such a manner that the silt can be collected and removed from the system with as little effort as possible (figure 3.1). 4 grooves of 3-4 km will be made perpendicular to the dominant flow direction to capture silt. The closer to the swamp, the deeper the grooves will be to transport the silt to the swamp, where the grooves will come together in a rift near the swamp. A well will be created close to the swamp to collect the silt, and from the well, a pump with pipelines will transport the silt to the silt depots where the swamp will be created. Between the silt capture system and the swamp itself, a reef will be created, which will reduce the impact of waves against the swamp and in this way acting as breakwater to protect the swamp against erosion.

Figure 3.1 The silt collecting system of the Markermeer with trenches, the rift and well along the swamp. (Natuurmonumenten, 2012b)

The islands above the water surface will be created from clay out of the soil of the Markermeer, and water which is rich in silt. From one cubic meter of clay, two cubic meters of swamp will be created, while for the silt this is vice versa. Sand will not be used to create the islands because spurting of sand to create the islands is costly. Furthermore, because chances of cultivation of the sand by willow forest are high, the use of sand is undesirable. A cost efficient construction method will be used to create the islands. Atolls with firm edges will be made, which, apart from the edges, exist of the silt rich water, with water plants and shore vegetation. Water exchange with the Markermeer will create creek patterns because of erosion and sedimentation. The water from the upper layer of the swamp will be extracted by the water plants, causing soil formation. A crust from one to a couple of centimeters will be formed on the thick water, which will develop until the ground level reaches the water level. The inner part of the island will thus float on the thick, silt rich water. (Natuurmonumenten, 2012b) According to Natuurmonumenten (2012) the Marker Wadden project will result in a reduction of free floating silt in the whole Markermeer/IJmeer area, since it is used to create the swamp. This positively influences growth of water plants, which is also facilitated by more land-water transition zones and the swamp itself. The loss of silt will furthermore cause better living conditions for mussels and fish, providing a larger food-source for water birds. The swamp also provides a forage and breeding area for those birds, which will probably increase in amount.

Lee measures 'Noord-Holland'

The concept of creating lee structures in front of the coast of Noord-Holland is described in more detail in the proposals of the consortia Grontmij *et al*. (2012) and Witteveen & Bos *et al*. (2012). Both state that lee structures are essential to reach the requirements set by Natura-2000, which is underlined most, and the WFD. When it comes to the placement of the structures, both of the consortia also hand in the same option of long dams situated parallel to the coast of Noord-Holland in relatively shallow waters (2-4 meters). Since the elaboration of Grontmij *et al.* was done in most detail and has, in my opinion, the best options to reduce costs and create new wetland, most of the details discussed next, are based on their plan.

According to Grontmij *et al.* (2012), a bay structure, in which only one side of the lee can exchange water with the Markermeer, gives the best solution to reach the requirements. The lees will be connected to the coast by a sand dam, placed perpendicular to the coast (fig. 3.2). Together with shallowing of the water behind the lee, less flow of the water creates more clear water by reducing the dynamics. Because of that, there will be habitats for Natura-2000 and WFD goal species behind the lees. Before the coast of Noord-Holland, 13.5 km of those lee structures will be created.

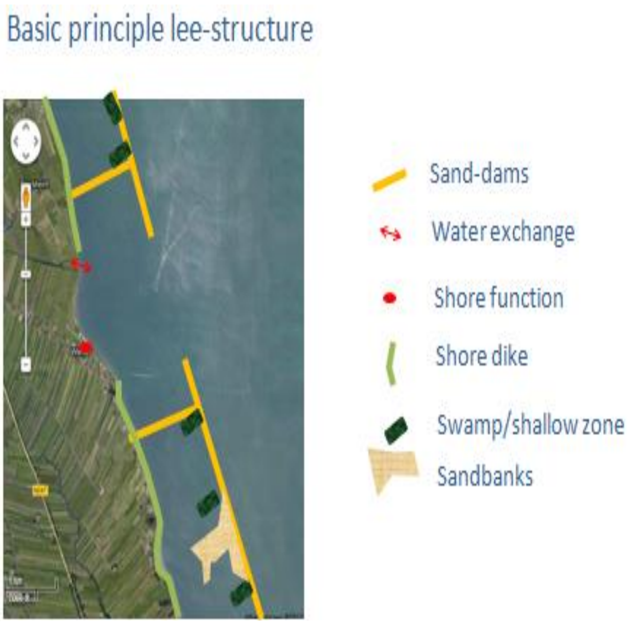


Figure 3.2 The basic principle of the lee structures. (Modified from Grontmij *et al.*, 2012)

Grontmij *et al.* clearly states that it would be best to develop the lee structures out of sand-dams, creating island-like lee structures, because it reduces the costs and the building material can be found in the Markermeer itself. By creating three dams, which are separately connected to the coast, the current shore functions are connected with the Markermeer, sailboats can get through the bay openings and water exchange will still be possible. The sand dams do need to be maintained, so once every 3-5 years, erosion will be compensated and mowing of the developed vegetation should be done twice a year for which grazing by cattle is also a considerable option.

There are a lot of different ways to deal with the space between the lee structures and the coast of Noord-Holland. The most profitable would be no further development at all, but some shallowing is probably desirable. On the other hand, more new nature can be created by placement of sandbanks, swamp zones, islands and beaches. Since it can be done using material from the Markermeer itself, costs can be reduces as much as possible. A proper zoning of the different parts is essential to combine leisure with nature. (Grontmij *et al.,* 2012)

Both of the consortia hand in the option of creating extra lee measures at the Enhuizerzand, near the Houtribdijk, since this area is also very suitable. However, the lees along the coast of Noord-Holland are the main priority. An important aspect, listed by Witteveen & Bos, is monitoring of the lee structures on silt deposition at the lees. This silt deposition should be limited to create a habitat suitable for plants and mussels. By collecting soil for the creation of the lees at strategically chosen places near the lees, silt can deposit there, not influencing the lee structure.

Behind the lee structures, transparent water will develop since silt cannot reach that part anymore. So this is also the place where new vegetation can develop, providing shelter for fish, and food as well as forage areas for birds. Mussels can also establish around the lee structure, providing even more food for birds. (Grontmij *et al*, 2012) However, the lee structures as planned by Grontmij *et al.* (2012), cover a relatively small part of the Markermeer area, with 162 ha of land water transition zones and 135 ha of island-like lee structures, so the effect of this measure will be minor compared to the Marker Wadden.

Innovative TBES

The two approaches listed above are both part of the Innovative TBES plan, where the Marker Wadden and lee-measures are combined with other innovations of the open-market application. Since the Innovative TBES will take the fish passages and the stepping stones near the lepelaarplassen as were listed in the Kransmeer approach (2012) mostly into account, those two will be described below.

- *Stepping stones near the Lepelaarplassen*

One of the measures planned by the Kransmeer consortium (2012), is the so called ‘stepping stones’ in front of the Lepelaarplassen near the coast of Flevoland. Those ‘stepping stones’ will exist of floating islands, and the Kransmeer consortium (2012) states that they will create a better relation between water and land, and improve the exchange possibilities for animals. The islands will function as rest-, nest-, and forage habitats for birds and more variation in water depth and clearness of the water around them will be created. The islands will be equipped on the basis of the requirements of Natura-2000 goal species. By creating more habitat diversity and connections with areas outside of the Markermeer with as less disturbance as possible, the Markermeer will be more attractive to animals. Figure 3.3 shows the placement of the different aspects of the plan as provided by the Kransmeer consortium. A dam will function as lee structure, protecting the islands against wind and waves. Geotubes are places underneath the islands to trap silt. The amount of silt will rise in time, and when the silt amount increased sufficiently, it can take over the function of the floating island. The floating islands will be 0.5-2.5 ha and placed 300-500 meters out of the coast. They will be created out of natural and recyclable material, with soil and reed on top. Anchors will be used to keep the islands in place. Furthermore, near the dike, a soft foreshore will be created with a gradually declining land-water transition.

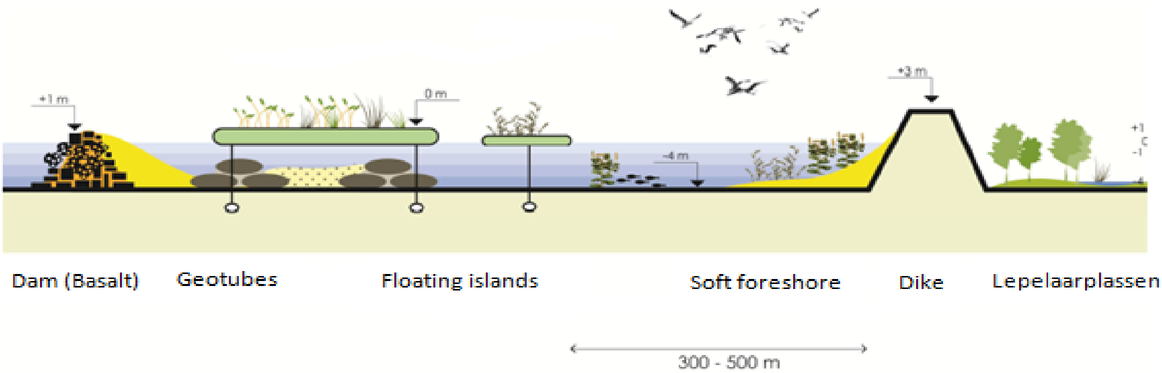


Figure 3.3 An overview of the stepping stones near the Lepelaarplassen (Source: consortium Kransmeer, 2012)

- *Fish passages*

The subsequent text describes the idea of the Kransmeer consortium (2012) to implement fish passages around the Markermeer. Fish need gradually declining land water transition zones with vegetation as a nursery and spawning grounds. According to Noordhuis & van Schie (2007), there is an unnatural species- and age composition of fish populations in the lake, because the Markermeer/ IJmeer area only has a few of those land water transition zone habitats. Since the desired habitat of fish differs in each life stage, they need to migrate if those habitats are far apart. Preferably, the habitats are closely connected so there is a gradual transition from shore vegetation areas to open water. By creating fish passages, vegetation rich areas such as the 'Volgermeerpolder', can be connected to the Markermeer/IJmeer. This could be done on 20 locations along the area. However, in order to disclose sufficient nursery and spawning areas, it is enough to adapt 10 structures, such as sluices and pumping stations, so they are passable for fish. By connecting those proper habitats, the production of the Markermeer in terms of fish will increase. (Kransmeer, 2012)

The stepping stones will provide a forage and spawning area for birds, while at the same time collecting silt beneath them creating local silt reduction. In the first instance, the stepping stones contain steep land-water transitions and do not provide much habitat for mussels and fish. When the accumulated silt takes over the function of the islands however, there will be gradual land-water transitions. So on the long term, there will be living space for mussels and fish, providing food for the birds. The fish passages only benefits the fish, and as a consequence of the passage, vegetation rich habitat outside the Markermeer/IJmeer can be reached and used for spawning and shelter, which will cause a rise in fish production of the Markermeer/IJmeer. (Kransmeer, 2012)

This chapter provided information on the assignment for the measures concerning the TBES. It described how the open-market-application resulted in three approaches, the Marker Wadden, lee structures along the coast of Noord-Holland and Innovative TBES, and summarized their contents. The differences in focus were outlined and initial information about the possible results was given. Now that this is clear, the final chapter will dive deeper into the impacts of the plans on the Markermeer/IJmeer.

Chapter 4 The effectivity and efficiency of the approaches

This chapter will discuss the impacts of the Marker Wadden, lee structures and Innovative TBES approaches. It will zoom in on the effects on the amount of silt in the lake, the Natura-2000 and WFD requirements and objectives as well as the requirements of the TBES. When the terms effectivity and efficiency are explained, the expected impacts will be listed. To decide which of the approaches is most effective and efficient, a Multi Criteria Analysis (MCA) will be used.

4.1 Effectivity and efficiency

The term effectivity can be seen from different perspectives and levels, and is used on two scales for this thesis. The first is in terms of silt reduction on its own, and the second is on a broader scale, in which effectivity is related to the requirements set by the WFD, Natura-2000 (Table 2.1) and the TBES (paragraph 3.1).

- Effectivity is de amount of silt reduction: the more silt reduction, the more effective the approach is
- Effectivity is also the amount of achieved requirements set by the WFD, Natura-2000 and TBES: the more achieved requirements, the more effective the approach is on a broader scale

Efficiency relates to the costs of the solutions.

- The cheaper the solution is, the more efficient it is compared to an expensive one, in which the efficiency has to be seen in relation with the effectivity. (For example, when two approaches have the same effectivity, and one of them is cheapest, this one is most efficient at the same effectivity and thus the best solution. While, when two approaches differ in effecitivity, and the least effective approach is cheapest, the most efficient approach is not the best solution).

The MCA, which is done later on in this chapter, will provide an answer to the question which approach is most effective and/or efficient.

4.2 The expected impacts of the three approaches

The Marker Wadden, lee structures along the coast of Noord-Holland and the Innovative TBES all will have different impacts on the ecosystem. The expected impacts of each of the approaches on silt will be listed and the impact on Natura 2000, WFD (table 2.1) and TBES requirements (paragraph 3.1) will be discussed into more detail, with exception of the freshwater availability requirement, since this thesis focuses on the ecological aspects. Furthermore, the improvement of habitat- size and quality for water plants, mussels, birds and fish is discussed. The information in the following paragraph is derived from the plans of the three consortia and Natuurmonumenten, combined with information listed in the 'toetsingskaders', which contain a detailed review of the contents of the plans. When relations concerning species and their environment, or inter-species relations are discussed, they are mostly direct relations and simplified as was mentioned in the introduction since the exact relations are difficult to predict and no use of threshold values was made. In reality, those relationship will be more nuanced.

4.2.1 The Marker Wadden

Impacts on silt

Since the construction of the Marker Wadden relies on the use of silt, the total amount of silt in the Markermeer/IJmeer will decline over time. Within the first phase of the construction the amount of silt in de Markermeer/IJmeer will decrease with 20%. (Natuurmonumenten, 2012b)

Impacts on the Natura-2000-, WFD- and TBES requirements

With the reduction of silt as discussed above, the total transparency of the lake will logically improve. Within the archipelago of islands, lee-water will develop and since water plants will establish there, it will contribute to the increase of transparent edges (Toetsingskader Markerwadden, 2012). Because of the transparent edges and the silt catching structures such as the grooves and the well, it is expected that a silt gradient will develop. It is however still unclear how the islands will influence the silt flows directly around them, so this has to be investigated using a silt model (Toetsingskader Markerwadden, 2012).

Already after the first phase of the Marker Wadden project, 500 ha of shallow water is created around the islands, as was mentioned in paragraph 3.2, which will contribute to the large scale land-water transition zones. These land water transition zones will expand further when the project continues. Those land water transition zones will contribute to the increase of the habitat size for water plants, mussels, fish and birds. Because of the rich in silt, shallow waters in the archipelagic shaped island area, more habitat is created for swamp vegetation to grow. Since extra lee-waters with less water flow arise around the swamp area, as well as several lee structures made out of shells in other parts of the Markermeer, as was explained in paragraph 3.2, water plants are provided even more suitable habitat to establish. Mussels can also establish in the land water transition zones and can live on the lee structures derived from exposed Zuiderzee shells, which will expand their suitable habitat. The size of the fish habitat will enlarge in terms of shelter and spawning areas provided in parts of the shallow waters where vegetation has established. This vegetation will also offer a foraging place for water birds and the habitat of the birds will expand even more because at least 500 ha of suitable islands is created within the first phase of the Marker Wadden project.

Not only the size of the habitat changes, the quality is also influenced by the Marker Wadden project. The source of the improvement of the quality is the silt reduction, which is expected to positively influence the quality for all of the animal groups this thesis focuses on. Furthermore the transparent edges and land water transition zones also might have a positive impact on the animals, which is reinforced by the reduction of silt. Water plants can establish more easily because of the transparent water combined with land water areas which the Markermeer lacks nowadays. Since mussels prefer habitats with shells and sand instead of silt, the reduction of silt is expected to improve the quality of the mussel habitat and will cause growth of the mussel population. Furthermore, filtering the water for food is more easy when less silt occurs, and when mussels cover the soil, less silt enters the water column since it is more difficult to get re suspended, so the occurrence of mussels is self-reinforcing. Since the silt layer on the bottom of the Markermeer suffocates fish grounds and disturbs the food chain, disappearance of it would expose a soil existing out of clay, which will be rich in zoo benthos and probably provides sufficient food for fish to live. Together with the shelter and spawning areas provided by the water plants, the quality of fish habitat increases even more. The quality of bird habitat will also rise because the Marker Wadden is a self-sustaining system, with a lot of surface for birds to forage and rest. People cannot reach the inner part of the islands, so they do not disturb the bird habitat, and because of the increase in amount of plants, mussels and fish, the birds have sufficient food. The Marker Wadden does not focus on a fish passage. According to the Toetsingskader Markerwadden (2012), it is expected that ecological connections between different nature areas in the Netherlands are improved by the islands since they provide a stepping stone for swamp species. However, the functioning of stepping stones is debated since they should be made species-specific. A consequence of the Marker Wadden will be a decline in open sailing water, however, the area will be accessible by foot, can be seen from the land, and provides opportunities for small recreation such as canoeing. It will probably have a positive impact on the tourism in and around the area. Since the goal of the project is to provide a self-sustaining system, maintenance is not needed. The costs of the project are lowest compared to the other projects (see table 3.1) and the Postcode loterij already said to provide 15 million euro.

4.2.2 Lee structures along the coast of Noord-Holland

Impacts on silt

The lee structures approach does not influence the total amount of silt in the way the Marker Wadden project does. Since the structures only are placed along the coast of Noord-Holland, they will not noticeably influence the silt content in the open water of the Markermeer/IJmeer area. Even though water exchange is possible and silt can be deposited in the lee-waters, it will probably not reach the amount of silt reduction as provided by the Marker Wadden project, since there it is used and cannot return to the open water, which theoretically is possible for the lee structure approach.

Impacts on the Natura-2000-, WFD- and TBES requirements

Since the lee structures are placed along the coast of Noord-Holland, they will create transparent edges along the coast because of lee waters between the structures and the coast. This will not influence the total transparency of the rest of the water because the open water of the Markermeer will remain a silt container. Due to that, there will not be a silt gradient in the lake. It has to be remarked, that when

further shallowing of the area between the lee and the coast is necessary, there is a high chance of disappearance of the transparent edges (Toetsingskader marktuitvraag, 2012).
Land water transition zones will be created, however on a small scale, with a total of 162 ha, as as mentioned in paragraph 3.2. When the lee structures are created, care has to be taken about the already existing habitats along the coast. When the lees will be situated on a spot with low vegetation or benthos, they will improve the habitat size of plants, mussels, fish and birds. Since the area is 162 ha, the impact will not be on the large scale as is considered for the Marker Wadden project, but it will have the same consequences on this smaller scale. Plants, mussels and fish can establish in the more transparent lee water, so their habitat does increase. Birds can thereafter forage on the extra water plant areas as well as on the 135 ha of lee structures.
Because the shallow parts of the lee structures have two sides: a lee side behind the lee and a side with more disturbance at the part facing the open water, different kind of habitats will be created, with an expected improved quality compared to the current situation (Toetsingskader marktuitvraag, 2012). The quality of the habitats will however only rise in the places where the lees are situated. The habitat quality of the open water will, in contrast to the Marker Wadden project, not increase. Apart from that, the transparent edges will provide an improved quality of habitat for plants and mussels, which will cause even more transparency of the water. The fish can again, use the water plant habitat as spawning an shelter area and this provides more food for the birds. Furthermore, the birds can rest on the lee structures, increasing their habitat quality. However, two marginal comments have to be made. Large vegetation will develop on the sandy lees quite easily and because of that, the advice was given to mow the lees twice a year, which will cause disturbance for the birds. The other note is that there is a chance of silt deposition on the rough side of the lee structure. In that case, especially mussels will not establish there. Because it is preferred to prevent silt deposition at that side, it has to be monitored and when large amounts of silt are deposited, measures have to be taken. Fish passages are not included in this approach. (Grontmij *et al.*, 2012)
Because the lee structures cover only a relatively small part of the area and since they are a quite closed systems, the ecological connections to the rest of the lake will not be sufficient. Small scale leisure is possible in the lee waters and the structures can be seen from the mainland. The open sailing water however is declining and the lee structures itself are not accessible for humans. So the structures can positively influence tourism. However, as is the case for the previously listed aspects, only on a small scale. The lees have to be maintained by mowing twice a year and additional sand has to be placed at the rough side of the lees to compensate for erosion. Concerning the costs, the project is in the second place, since it is neither most cheap nor most expensive.

4.2.3 Innovative TBES

Since the innovative TBES is a combination of the Marker Wadden and the lee structures along the coast of Noord-Holland, most of the impacts will be a combination of those two approaches. For that reason those impacts will not be discussed another time. For the subsequent impacts, only the impacts of the extra components of the innovative TBES – the fish passages and stepping stones – will be discussed.

Impacts on silt

The extra impact on silt will be caused by the stepping stones in front of the Lepelaarplassen. Given that silt is captured beneath the stepping stones, and that it will replace the floating stepping stone islands, there will be a reduction of silt in the Markermeer. However, compared to the amount of silt captured by the Marker Wadden project, it will have a minor contribution to the silt decline in comparison with the Marker Wadden project, and it is a long term process since the silt is not actively captured.

Impacts on the Natura-2000-, WFD- and TBES requirements

The Toetsingskader marktuitvraag (2012) states some question marks about the functionality of the stepping stones within the Markermeer area, since the impacts will only be small, and there is no prove of succeeding. Nevertheless, if the impacts do occur they will have some influence, although on an even smaller scale than the lee structures since the surface area is 36 ha.

Since the silt will be captured beneath the stepping stones because of a reduce in the height of waves, on the long term (around 2040), it is expected that transparent edges will develop, because the silt will take over the function of the floating islands (Kransmeer, 2012). The total transparency will be influenced and a silt gradient will develop because of the capture of silt, both however on the long term. The land-water transition zones will, when the silt replaced the floating islands, be expanded by the stepping stones with +/- 36 ha. On first instance, the water around the islands will be too deep for water plants to develop, it however does provide living habitat for mussels and fish from the beginning on. This living area will be further expanded in terms of spawning and shelter area, when the silt islands are formed and water plants can grow. The bird habitat does, immediately after placing the stepping stones, increase by 36 ha of islands. The islands can be a resting area, however there is some disturbance when the floating islands are replaced for the silt ones, which on the first hand might be unsuitable as habitat for birds. On the long term, the habitat quality rises as it does within the other approaches because of transparent edges and gradual land water transition zones.

The fish passages, which are included only in the innovative TBES approach, will create extra habitat size for the fish, and possible also an improved quality of the habitats since they are able to migrate to other waters with extra (already vegetation rich) spawning areas. It is not sure whether or not these fish passages will have an effect on fish migration and the size of the fish populations yet, but when this is the case, fish eating birds will benefit from it since there is more food available. According to the Toetsingskader marktuitvraag (2012) it is expected that the islands will also increase the connection with other nature areas in the Netherlands since they can be used as stepping stones.

However, the same remark has to be made as was done for the Marker Wadden in terms of being suitable as a stepping stone; it might not function as is expected because of the specific requirements by different species. The stepping stones are not accessible for humans, but they can be seen from the shore and the area around it is suited for small scale leisure and it thus might be interesting for tourists. Whether the fish passage needs extra maintenance was not stated. The stepping stones do need some maintenance because the floating islands do have to be replaced when enough silt is accumulated underneath them. Since the innovative TBES approach combines the Marker Wadden with the lee structures and amplifies it with the fish passage and stepping stones it is the most costly approach of all.

4.3 The most effective and/or efficient approach – The MCA

In order to find out which approach is the most effective and or efficient, is analyzed by the use of a Multi Criteria Analysis. A multi criteria analysis (MCA) is a method used for comparing various alternatives that account for a wide range of criteria, which are not all expressed in monetary terms (Wicke, 2012). This analysis is used to compare the three different approaches regarding the TBES that were discussed in paragraph 4.2: the Marker Wadden, lee structures and Innovative TBES concerning the main objective to recover the ecology and quality of the Markermeer/IJmeer area. Criteria are listed on the basis of the three cornerstones of the TBES: Ecology, economy & sustainable use and financing. The ecological criterion takes three out of the four requirements into account: the creation of transparent edges along the coast, a gradient in silt from transparent to turbid water and land water transition zones (Optimalisatierapport WMIJ, 2011). The criterion of improved ecological connections was left out because there are some uncertainties about possible improvements, which makes it difficult to score. The Natura-2000 and WFD requirements as were listed in table 2.1 are also taken into account, as well as the conservation objectives of the Natura-2000 (Box 2). The requirement to warrant freshwater availability is not included in the MCA since this is about the availability of drinking water for the people and cities surrounding the area, and not about the Markermeer itself. The criterion of economy and sustainable use only focuses at tourism/leisure and maintenance of the area since a major focus of the approaches lies also there. The last, financial criterion, targets at the costs of the construction of the approaches. Furthermore, indicators are formulated as measurable concretizations of the criteria to use in the MCA. The transparent edges and silt gradient are combined in the silt reduction indicator, since the MCA otherwise will become too complicated and extensive. The gradual land water transition zone indicator speaks for itself, and it is also one of the Natura-2000/WFD requirements. Transparency of the water and the fish migration indicators both also belong to those requirements. The size and quality of habitats of water plants, mussels, fish and birds relate to the conservation objectives criterion. The size of fish habitat focuses especially on extra spawning and shelter areas. In table 4.1 on the next page, an overview of the main objective, approaches, criteria and their indicators are shown.

Table 4.1 Overview of the objective, approaches, criteria and indicators

Objective	Recovery of the quality of the Markermeer/IJmeer area generating a robust ecosystem
Approach	Marker Wadden, lee structures, Innovative TBES
Criteria	Ecological: Transparent edges along the coast, a gradient in silt from transparent to turbid water, gradual land water transition zones, Natura- 2000 & WFD requirements (table 2.1) and conservation objectives (in terms of size and quality of the living areas, box 2). Economic & sustainable use: tourism/leisure and maintenance Financial: Costs
Indicators	Silt reduction, transparency of water, gradual land water transitions, fish migration, size and quality of habitats of: water plants, mussels, fish and birds, tourism/leisure, maintenance, costs

An effect/performance table, shown in table 4.2, is created to perform an MCA on the three approaches. Each of the approaches is scored from 0 to 1, for all of the 11 indicators. The best outcome for a certain criterion scores 1, and the others score lower values. Those lower values always are relative to the highest score. As an example: the silt reduction in the Innovative TBES will be highest and thus scores 1. Since the lee structures only cause silt reduction along the edges, not influencing the other parts of the Markermeer, it scores 0,1. The silt reduction by the Marker Wadden project is relatively high, so it scores 0,7 and the 0,2 left in the Innovative TBES to get 1 as a total, is the score of the silt reduction by the stepping stones. When real numbers were available, for example on the size of habitats, the maximum size available as a possible habitat was taken, and the numbers between 0 and 1 were calculated by taking the highest total size as 100% (=1). In the case of tourism/leisure and the fish migration, 1 is not scored since respectively the open sailing water declines in size and it is not sure whether the fish passage really causes more fish migration to occur. To score the approaches for the cost criterion, an interval standardization is used (-((score-lowest score)/(highest score-lowest score))+1) to standardize the costs of the approaches, in which the approach with the lowest costs scores 1 and with the highest costs 0.
To take the relative importance of each of the indicators into account, they were given a certain weight, which is multiplied with the score of each indicator and summed up to a final score for the approach as a whole (weighted summation). When the weight for all of the indicators is equal (which would be 0,066 since the total has to be 1), the outcome shows that the lee structure approach scores lowest (0,2), followed by the Marker Wadden (0,7) and the Innovative TBES (0,9). Since it would be interesting to see how the different approaches score when the weight varies, three weighing scenarios are made, which will be discussed in the next section.

Table 4.2 The effect/performance table for the three designs (Marker Wadden, lee structures and Innovative TBES) with their scores for the individual indicators and variations in weight (W1, 2 and 3).

Objective	Criteria	Indicators/Design	Marker Wadden	Lee structures	Innovative TBES	W1	W2	W3
Recovery of the quality of the Markermeer/IJmeer area generating a robust ecosystem	Ecological: Transparent edges, silt gradient, land water zones, Natura-2000, WFD & conservation objectives	*Silt reduction*	0,7	0,1	1	0,084	0,25	0,084
		Transparency of water	0,8	0,1	1	0,084	0,25	0,084
		Gradual land-water transitions	0,7	0,2	1	0,017	0,017	0,05
		Quality of water plant habitat	0,6	0,3	1	0,017	0,017	0,05
		Size of water plant habitat	0,7	0,2	1	0,017	0,017	0,05
		Quality of mussel habitat	0,8	0,1	1	0,017	0,017	0,05
		Size of mussel habitat	0,8	0,1	1	0,017	0,017	0,05
		Quality of fish habitat	0,6	0,3	1	0,017	0,017	0,05
		Size of fish habitat	0,7	0,2	1	0,017	0,017	0,05
		Fish migration	0	0	0,6	0,017	0,017	0,05
		Quality of bird habitat	1	0,5	0,6	0,017	0,017	0,05
		Size of bird habitat	0,7	0,2	1	0,017	0,017	0,05
	Economic & sustainable use	*Tourism/Leisure*	0,5	0,2	0,8	0,084	0,084	0,084
		Maintenance	1	0,5	0,3	0,084	0,084	0,084
	Financing	*Costs*	1	0,48	0	0,5	0,167	0,167

4.3.1 Weighing scenarios of the MCA

The weighing scenarios that are made can be linked to the explanation of efficiency and effectivity in the beginning of this chapter. The first one (W1) focuses on the financial aspect, representing the efficiency of the approaches, the second (W2) which is about the silt aspect, represents the effectivity in terms of silt reduction, while the third (W3) focuses on the Natura-2000/WFD/TBES aspect and represents the effectivity on the broader scale. The outcomes of the MCA are calculated using a weighted summation, as is explained above. Weighing all of the indicators individually is difficult, since there are 15 indicators, and the differences would be small. For that reason, the indicators are distributed over 4 groups, as can be seen by the coloring in table 4.2. The first group contains the silt indicators (green), the Natura-2000, WFD and TBES requirements are divided among the second group (purple), the third group contains the economic and sustainable use indicators (blue) and the cost indicator is assigned to the fourth group (red). The silt indicators would also fit in the second group, but since this is seen as a separate aspect within the MCA (W2 focuses on silt by itself), they

are listed independently. As a result, the groups (with the exception of the economic and sustainable use indicators) can be linked to the three different weighing scenarios that are made.
When the focus lies on a certain group, this group as a whole is given the weight of 0,5. When the group exists of more than 1 indicator, as is the case for the silt and Natura-2000/WFD/TBES groups, this 0,5 is equally divided among the indicators of that specific group. The residual 0,5 is equally divided among the 3 three other groups. In this way each group gets 0,167, which again is equally divided among the indicators of the group when they exist of more than 1 indicator. The results of this weighing system can be seen in the weights listed in table 4.2.

4.3.2 Outcomes of the MCA

When each indicator is multiplied by its individual weight for each of the approaches and summed up to a total, the outcomes of the MCA are as shown in figure 4.1.

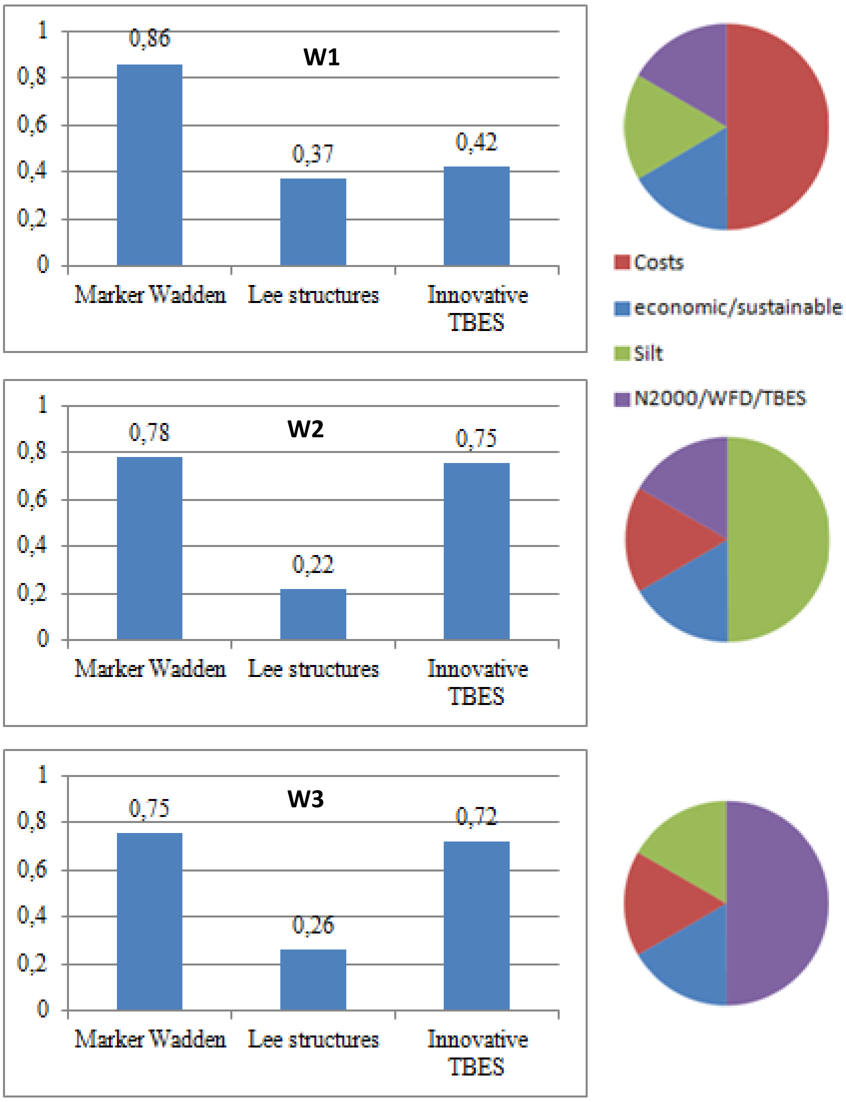


Figure 4.1 Outcomes of the MCA calculated by a weighted summation. The graphs show the final scores of the three approaches for each of the weighing scenarios, which are shown in the pie charts beside the graphs. From the top downwards, the outcomes of W1, W2 and W3 are shown.

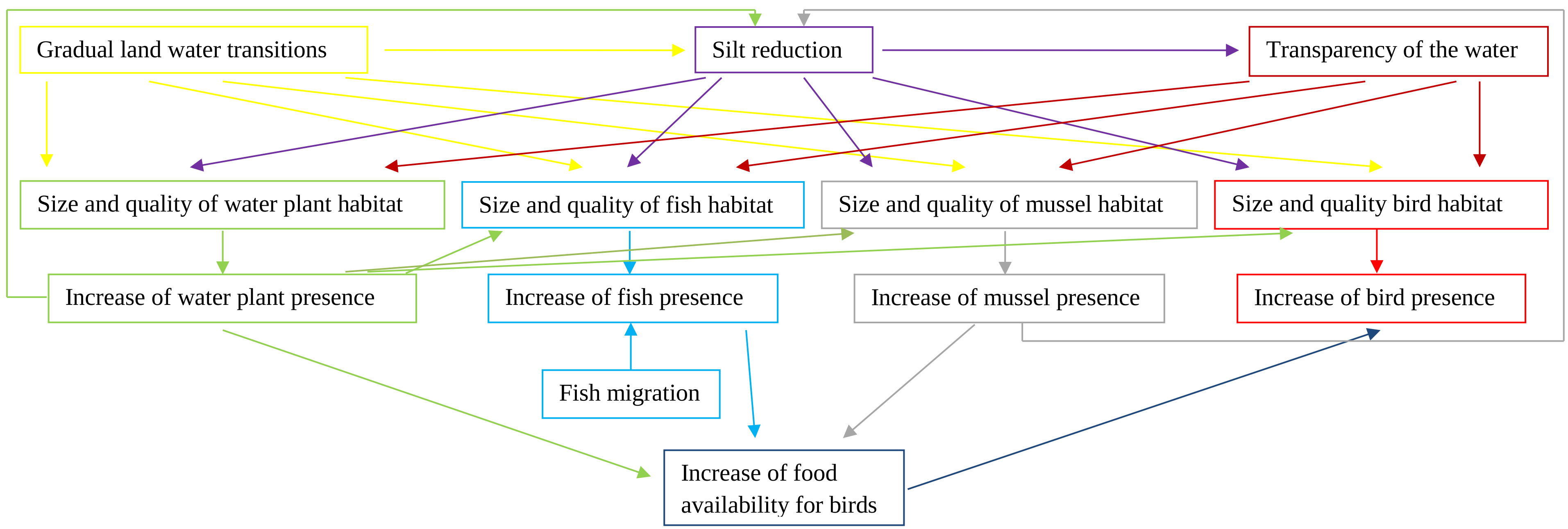
As can be seen, the lee structure approach scores lowest in all of the three cases, as was also the case for the non-weighted outcome of the approach discussed earlier and is thus most inefficient and ineffective. However, when comparing the Marker Wadden Project and the Innovative TBES with the non-weighted outcomes, the outcomes are vice versa. The Marker Wadden project scores highest for all of the three weighing scenarios. Although the differences between the Marker Wadden and Innovative TBES for the silt and Natura-2000/WFD/TBES scenarios are quite small, it can be concluded that the Marker Wadden project is most efficient and most effective, both on the silt focused scale and the broader scale. The fact that the outcome of the Marker Wadden is in any case highest, is probably because of the influence of the cost indicator. Even though the share in the silt and Natura-2000/WFD/TBES case is only 0,167, the difference between 0 and 1 causes the Marker Wadden to be ranked best. Since the Marker Wadden are part of the Innovative TBES approach, after finishing the Marker Wadden project, it can always be further developed towards the Innovative TBES approach.

4.4 The Marker Wadden and the further development Markermeer/IJmeer ecosystem

As was discussed earlier, the Marker Wadden has a lot of influences on the Markermeer/IJmee area. From the entrapping of silt, to the expansion of habitat of water plants, mussels, fish and birds as well as improvement of the quality and providing extra opportunities for tourism and leisure in the area. In the scheme shown on the next page (fig. 4.2), the different ways in which those ecological aspects influence each other are shown. What will happen concerning the further development of the Markermeer/IJmeer can be seen in this scheme, since the development does not end with just extra, good quality habitats. When the size and quality of different habitats increase, this will cause a rise in presence of water-plants, mussels, fish and birds, all influencing and consolidating each other. As an example, the establishment of water plants and mussels further enhances the reduction of silt. Birds, such as the eurasion wigeon, smew and common pochard will increase in appearance because of more food availability and an improvement in their habitat. The conservation status of especially the smew and common pochard will than move from unfavorable to favorable in a couple of years, and will contribute to the ceasing of the decline in amount of birds in the Markermeer and IJmeer area as could be seen in figure 1.7.

With the project, a self-maintaining system is created, which complies with the requirements of the Natura-2000/WFD and TBES. Current conditions will be improved and continuation of alarming declines will be prevented. The Marker Wadden will provide habitats for important wetland species and results in a diverse landscape, where nature will be combined with leisure.

Figure 4.2 Scheme of the influences of ecological aspects on each other.



Discussion

During the previous chapters some assumptions and demarcations have been made and some information was not there to be found. The first part of this discussion will go into further detail about those aspects since this is important to know considering the outcome of the MCA for example. After that, a short review on the outcome of the Marker Wadden is made concerning the silt reduction of the water and plant growth and the innovative character of the project. Finally, before listing the conclusions and recommendations some roles for scientists are highlighted.

Demarcations

Within this thesis not every single aspect of the impacts in and around the Markermeer/IJmeer area could be taken into account, so demarcations and assumptions, which will be discussed on the next page, had to be made to specify the subject and the research area.

Two important demarcations have been made that were encountered during the writing of this thesis. The first is the influence of fisheries. Even though fishery is one of the main reasons for the decline in fish, as was stated in chapter 1, it has not been discussed in any of the following chapters. The main reason is the focus on the approaches concerning the quality of the Markermeer/IJmeer. The plans focus on the ecological aspects and on leisure, but do not hand solutions for (illegal) fishery practices on the Markermeer/IJmeer. Nevertheless, the question how to control fisheries, so excessing fishing of certain species does not occur, is a very important one. Solving the problems concerning suitable habitats and food availability for fish, causing an increase in the fish populations, is not where it ends. People have to understand the value of the growth of fish populations since certain bird species rely on them as a source of food. When fishery practices keep continuing the way it does now, population growth will cause more capture and food for humans, instead of more food for the birds.

The second demarcation is about not mentioning the upcoming quagga mussel in the Markermeer. This mussel is not discussed since it is a recently upcoming exotic species, colonizing the Markermeer/IJmeer area. It would be easy to state that if this mussel is upcoming and more resistant to the deteriorating circumstances in the Markermeer/IJmeer (Noordhuis, 2010), this is a positive case and no action has to be taken to improve the situation for the zebra mussel, since it probably can be replaced by the quagga mussel, which would provide an alternative food source (Noordhuis, 2010) for mussel eating birds. However, it would be better to improve the current situation concerning the zebra mussel, so this population has the ability to increase, especially since there is no proof yet of the significance of the quagga mussel (Noordhuis, 2010). There is of course the possibility that when the current quality of the water in terms of silt improves, the quagga mussel still has an advantage over the zebra mussel, but it is worthwhile to try to improve the current circumstances to provide a more suitable habitat for the zebra mussel in the first instance.

What could not be found

The most important information that was not found is an opportunities and threats analysis for certain bird species in the Markermeer/IJmeer area and other specific information on bird species in that area. Most of the information found was about the Netherlands as a whole. The opportunities and threats analysis does exist for the habitat type in the Markermeer, but is not yet created for the Markermeer/IJmeer birds.

General assumptions

One of the first assumptions that was made in the introduction was about the Markermeer being an invariable system in terms of the water residence time and as a consequence also in the amount of silt. However, it could also be read that this in reality is not the case, since the residence time is 15-18 months. It is possible that there is a slight natural de- or increase of the silt amount, due to the supply or discharge of water. Since a report of Witteveen & Bos (2005) about the silt problems in the Markermeer stated that there does not seem to be an external supply of silt and that the silt content of the Markermeer could be seen as that of a closed system, this assumption seems to be in accordance to the actual situation, not influencing the outcomes of this thesis.

The other assumption was about the simplified relationships between certain species and their environment, as well as inter-species relations, which were assumed to be linear. This was done because it is difficult to predict what the exact impact of certain changes in another species or the environment will be. Within an ecosystem the actual relationships are more difficult than the linear assumption which has been made for this thesis, so the outcome of the different approaches might be influenced by this. However, they probably will not be the opposite from the relations described earlier since for example, a rise in amount of food for a certain species will have a positive effect on their occurrence. The real relationships will just be more nuanced.

MCA Assumptions

A lot of assumptions have been made concerning the Multi Criteria Analysis in chapter 4, which might influence the outcome of the MCA. On the first hand, there are some demarcations within the criteria for the MCA. The 'improvement of ecological connections', one of the requirements, was left out. This was mainly done because there are some uncertainties in accordance to this requirement concerning the approaches, and it is not sure how the approaches will contribute to this improvement. For that reason it is difficult to score the approaches. However, when ecological connections are seen as extra, newly created habitats in the Markermeer, improving the connection to areas around the lake for mainly birds, the influence of adding this criterion would probably be in favor of the Innovative TBES, since that is the plan where most new areas are created. The Marker Wadden would score high also, since this contributes mostly to the Innovative TBES approach. Furthermore, fresh water availability was also left out since this does not correspond to the focus of this thesis, which is about the silt itself and the ecological aspects. When this criterion would have been included, it would probably be placed within the economic criteria, which now only covers tourism. Tourism was taken into account because of the approaches provide information about the impact on tourism and leisure activities, and this can be seen as the most important economic aspect for this moment. Since the availability of fresh water is probably not influenced by the plans, in such a manner that there won't be sufficient fresh water available for the people living around the area, it would not have made a noticeable difference for the outcome.

The scores of the approaches within the MCA could have been divided differently for most of the indicators. When exact numbers for areas in terms of islands or land water transition zones were given, these were used to calculate the relative differences compared to the approach which provided the largest newly created areas. This was for instance, done for the sizes of the habitats for plants, mussels, fish and birds. For those areas, it was assumed that all of the available area will be suitable for, and used by all of these species to establish or live. However in reality, the plants and animals will not use all of the available area since not all of it will be suitable as a habitat, or because they simply do not need the space. Since it is difficult to predict which quantity of the area the species will or will not cover/use, the total amount of hectares was used. However, since the scores are all relative to each other, they would probably not be considerably different when the area, which really is used by the species, was predicted and used. The scores of the indicators with a lack of quantitative information, for example the quality indicators, were set up by the comparison with the best approach. The other quantities are all relative to this approach and to each other and could differ when it is done another time by someone else. But with the use of the available information about the approaches and some logical thinking and comparing, it is not expected that these scores would be substantially different. The lee structures for example will always be ranked lowest for most of the indicators. The distinction between the Marker Wadden and Innovative TBES could differ more or less than it does now, possibly influencing the outcome, but even when the Innovative TBES would recall the best approach, it would be recommendable to start with the Marker Wadden project since this contributes most to the Innovative TBES.

The weight distribution of the MCA is now divided among 4 groups, while it might be better to weigh all of the indicators individually. Because there are 15 indicators of which it is hard to say whether the mussel habitat or the fish habitat for example should be more important, this is quite difficult to do. For that reason the distribution over 4 groups was chosen. The allocation of the weights, where the group that is focused on gets 0,5 and the three other groups each get 0,167 to divide among the indicators of that group, was chosen because the group that is stressed most gets two times the emphasize it would have had when the division was equally made. This also can be done in a different way, but for the goal of this thesis, investigating which one of the approaches is most effective and or efficient, it was best to give one of the groups most attention, and the rest an equal, lower weight.

The Marker Wadden and improvement of the water quality – a short review

Improvement of the water quality in terms of silt is one of the main goals of the Marker Wadden. It can however, also create changes which in the first instance seem positive, but can turn out to be negative after a while. Development of open, non-dense, vegetation of pondweed can provide potential habitat for mussels and (young) fish. This in contrast with dense characea vegetation, which has a negative impact on the possibility to establish for mussels, and this might also be the case for fish. Since the pondweed needs a water depth of about 2 meters, and the characea prefer a water depth of 1 meter, it is of major importance to vary the depth of the land-water transition zones in such a way that the characea waters will not extensively grow, taking away suitable habitat for fish. (Grontmij *et al.*, 2012) There are also some uncertainties about the optimal morphological conditions for fish, and it is important to find out what the best living area, morphological as well as in sediment, looks like and how those areas can provide in all life stages of the fish. (Grontmij *et al.*, 2012)

The Marker Wadden itself has an innovative character and since a project like this has never been done before, there might be some resistance against it. Of course there are some uncertainties about the development of the silt-islands, and the operation of the whole project. It thus requires creativity from the hydraulic engineering sector in combination with natural occurring processes. This of course will create some risks, because it is not know for sure to what extend the project actually might work. On the other hand, it provides opportunities and challenges for all of the people working on it. And when it does work, which seems to be likely, there will be many positive outcomes for the Markermeer/IJmeer area.

Conclusion and recommendations

The amount of silt in the Markermeer/IJmeer area negatively influences the ecosystem. Although the amount of water plants has been stable over the last couple of decades, the populations of zebra mussels, fish and birds declined rapidly and are nowadays stable but very low, or still decreasing. The goal of this thesis was to provide an answer to the question what the most effective and efficient approach is to solve the silt problem in the Markermeer/IJmeer area, in perspective of the EU water Framework Directive and the Natura 2000. The outcome of the Multi Criteria Analysis (MCA) showed that compared to the lee structure- and the Innovative TBES approach, the Marker Wadden approach of Natuurmonumenten, concerning the creation of a large scale swamp area using silt as building material, provides the most effective and efficient solution to the deterioration of the Markermeer/IJmeer in terms of costs, the silt content of the lake and the requirements set by Natura-2000, the Water Framework Directive (WFD) and the Toekomst Bestendig Ecologisch Systeem (TBES).

It would be recommendable to start the development of the Marker Wadden despite of its innovative character and the uncertainties which still are present, since it seems that it will induce positive impacts at different levels. Involving scientists with different backgrounds in this project will be helpful to provide answers to remaining questions about the construction and the definite effects of the Marker Wadden project.

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