Economic valuation of Ecosystem Services

Case study Marker Wadden

An economic valuation of the ecosystem services of the Marker Wadden in lake Markermeer to provide insight into the value of the ecosystem benefits to different stakeholders

Eline Marianne Kolb

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Photo: Nils van Rooijen (2020)

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Author	Eline Marianne Kolb
Contact	eline.kolb@student.vu.nl
Student number	2602969
Supervisors	Dr. W.J.W. Botzen, MSc L. Hüsken & MSc M. Tesselaar
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Abstract

The research in this paper is a first attempt to quantify and value the ecosystem services (ES) of the Marker Wadden (MW) project. ES are becoming more important as they are starting to be applied in policy and practice on a more regular basis. In lake Markermeer, the water quality and the ecological quality have deteriorated over the past decades. To enhance the ecological status, the MW were constructed. The MW consist of a total of 1000 hectares artificial marsh islands and underwater landscape and are created from locally dredged material. The project is the result of a public-private collaboration between Natuurmonumenten, the ministry of economic affairs and the ministry of infrastructure and water management, and private parties. As the costs in relation to the benefits are not studied yet, the aim of this study is to research the economic value of the MW project by defining and valuing ES the MW provide for the different stakeholders. The ES are researched in relation to two main functions of the MW: capturing and building with fine sediment and creating habitat. First, the physical effects of the Marker Wadden related to these functions were determined and methods for valuing ES were applied to monetize the physical effects. An assessment of the value of these two functions of the MW is provided. A total benefit between €53,987 and €1,973,412 was calculated in relation to the MW by applying a meta-analysis model and benefit transfer. However, when additional outcomes of monitoring research on the MW are conducted, more precise values of the services can be calculated. Therefore, qualitative insight in the benefits that the different stakeholders receive from the ES of the MW was provided and potential ways of financing the upscaling of the MW and similar nature restoration projects are explored.

Preface

Writing a thesis and doing an internship at Deltares became a little different than expected. The COVID-19 pandemic changed my intern experience at Deltares unfortunately into a working from home experience. In addition, I moved to Delft and started living in a communal group where everyone suddenly had to work from home which was not always easy. However, we all tried to make the most out of it and I present here my final results: a MSc thesis Environment & Resource Management on the economic valuation of ecosystem services of the Marker Wadden. This topic combines the theory I learnt during my master's program at the VU, and practical application in an existing project: The Marker Wadden.

Most of all, I would like to thank Lieke Hüsken, my supervisor, for her enthusiasm, creative thinking and motivating support while writing this thesis. I experienced our meetings as very pleasant, helpful and supportive. Besides helping me with the thesis, she also made it possible for me to experience Deltares as much as achievable at home with sending me webinars or additional information. She also told me about her projects which makes me very enthusiastic to start working myself. In addition, I would also like to thank Stéphanie IJff, as she was very willing to help me with the topic. Besides, she involved me in the KIMA governance team, which I very much appreciated as I have a better idea how the project team works together now. Once the Marker Wadden are open again as they are closed due to COVID-19, I hope we can still go and visit these unique islands.

Furthermore, I would like to thank Max Tesselaar and Wouter Botzen, my supervisors from the VU University, for their time, understanding and support from home. Finally, I would like to thank my boyfriend, roommates, friends and family for their motivating words and interest they showed in my thesis about the Marker Wadden.

I hope you enjoy reading this thesis,

Eline Kolb

Delft, 13th of July 2020

Table of contents

Abstract 2
Preface 3
List of abbreviations 6
List of figures 7
List of tables 7
1. Introduction 8
1.1 Research objective 9
1.2 Research questions and outline 9
1.3 Scope of research project 10
1.4 Outline of the research 10
2. Theoretical background 11
2.1. History, geographical and ecological conditions of lake Markermeer 11
2.2 Building the MW 12
2.3 Governance and financing of the MW 14
2.4 Ecosystem services and economic valuation 15
3. Methods & data 17
3.1 Literature research and data 17
3.2 Identifying and mapping the ES according to TEEB 18
3.3 Quantifying the ES for two scenarios: MW and Business as usual (BAU) 19
3.4 Economic valuation of the physical effects 20
4. Results 21
4.1 Main function 1: Beneficial use of locally dredged material 25
4.2 Main function 2: Creating new habitat 32
5. Discussion 38
5.1 Key outcomes of the study 38
5.2 Limitations of the study 38
5.3 ES of the MW in the context of previous studies 39
5.4 Recommendations for further research 39
6. Conclusion 40
6. References 41
Annexes 47
Annex A 47
Annex B 48
Annex C 51

Annex D 52
Annex E 55
Annex F 60
Annex G 65
Annex H 67
Annex I 68

List of abbreviations

BAU	Business as Usual
BWN	Building with Nature
CEDA	Central Dredging Association
Cl	Chloride
EU	European Union
EC	European Commission
EIA	Environmental Impact Assessment (Milieu Effectrapportage)
ES	Ecosystem Service(s)
EIS	European Invertebrate Survey (Knowledge center for insects)
FFWS	Financing Framework for Water Security
KIMA	Knowledge- and Innovation program MW (Kennis- en innovatieprogramma MW)
KPI	Key Performance Indicator
KRW	Dutch translation of the Water Framework Directive (Kader Richtlijn Water)
MEA	Millennium Ecosystem Assessment
MEP	Monitoring and Evaluation Program
MW	Marker Wadden
N	Nitrogen
NBS	Nature Based Solution
NM	Natuurmonumenten
P	Phosphor
RRAAM	Rijk-Regioprogramma Amsterdam Almere Markermeer, project to improve the water quality to potentially benefit the economic development, recreation and liveability of the area around lake Markermeer.
RWS	Rijkswaterstaat, the department of Public Works and Water Management
TBES	Futureproof Ecological System (Toekomst Bestendig Ecologisch Systeem)
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
W+B	Witteveen + Bos (advisory and engineering company, assisting executing party)
WFD	Water Framework Directive
WTP	Willingness to Pay

List of figures

Figure 1 Lake Markermeer and the MW 8
Figure 2 The MW from above 13
Figure 3 Filling, sedimentation and consolidation 14
Figure 4 Intersection of the MW with the construction steps. 14
Figure 5 Visualization of the methods 17
Figure 6 Conceptual framework of the MW 18
Figure 7 Total economic value of the ecosystem services of the MW 19
Figure 8 ES, benefits and beneficiaries for water quality 25
Figure 9 ES, benefits and beneficiaries for improved soil ecology 28
Figure 10 ES, benefits and beneficiaries for fine sediment as building material 28
Figure 11 ES, benefits and beneficiaries flora development 32
Figure 12 ES, potential benefits and beneficiaries related to improved fish populations 33
Figure 13 ES and potential benefits and beneficiaries related to improved bird populations 34
Figure 14 Biodiversity points shown for MW and BAU 36
Figure 15 Biodiversity points shown for MW and BAU with applying weigh factors 37
Figure 16 The cascade model of ecosystems, ES and human wellbeing 53
Figure 17 The benefit pyramid and TEV versus TSV 53
Figure 18 TEV and valuation methods 54
Figure 19 Water use per sector in the Netherlands 67

List of tables

Table 1 Scale of anticipated change scores 19
Table 2 Expected area of created habitat Boskalis 21
Table 3 Qualification assessment of ES provided by the MW according to TEEB classification 23
Table 4 Beneficiaries of improved water quality 28
Table 5 Beneficiaries building with fine sediment 30
Table 6 Summary of quantitative assessment and economic value main function 1 31
Table 7 Important beneficiaries related to main function 2 35
Table 8 TEEB classification of TEEB for wetlands 47
Table 9 Summary table of services derived from Hüsken (2020) 51
Table 10 Results of quantifying BAU and MW for water quality 56
Table 11 Results of quantifying BAU and MW for soil ecology 57
Table 12 Results for quantifying BAU and MW for fine sediment as building material 58
Table 13 Results of quantifying BAU and MW for knowledge derived from fine sediment 59
Table 14 Results of quantifying the improvement of flora when comparing BAU and MW 60
Table 15 Results of quantifying the improvements in fauna when comparing BAU and MW 61
Table 16 Results of quantifying improvement in fish populations when comparing BAU and MW 62
Table 17 Results of quantifying improvement in bird populations when comparing BAU and MW 63
Table 18 Results of quantifying knowledge on creation of habitat for flora and fauna 64
Table 19 Stakeholder inventory lake Markermeer 65
Table 20 Actors and role initiation phase MW in Dutch 66
Table 21 Actors and role executing phase MW in Dutch 66
Table 22 Biodiversity points calculated for lake Markermeer with MW 68

1. Introduction

In the second half of the last century, anthropogenic activities have drastically changed the ecological state of freshwater bodies in Europe (Grizzetti et al., 2017). Hydrological alterations in freshwater ecosystems, the building of dams and dikes, fish overexploitation, and loss of natural shores by land reclamation have resulted in multiple pressures on freshwater ecosystems, which undermines biodiversity and ecological functioning (Grizzetti et al., 2017). How can freshwater ecosystems be restored and at the same time meet human needs as the water bodies have many economic and recreational services? Ecosystems can only continue to provide these services when restoring measures are implemented to sustain and enhance the ecological quality and biodiversity (Harrison et al., 2010).

Lake Markermeer (Figure 1) is one of this water bodies in Europe where the ecological quality has deteriorated over the last decades (van Riel et al., 2019). The freshwater lake is situated in the Netherlands between the province of Noord-Holland and Flevoland. The main cause of the decrease in ecological- and water quality is the closure of lake Markermeer by the Houtrib dike in 1975 (Noordhuis, 2014). Besides, due to land reclamation the natural shores and the connection with river Ijssel were lost (Zwart, 2008). Consequently, an obstruction in the natural sediment flow in the lake occurred, where the sediments had originally flowed into lake Ijsselmeer and the Waddenzee.

Figure 1 Lake Markermeer and the MW (Copernicus Sentinel 2 ESA, 2018)

Because lake Markermeer is very shallow, with an average depth of 3.6 m, the wind and the waves in the lake cause high rates of resuspension of the sediments (Vijverberg et al., 2011; Kelderman et al., 2012). Over time, the lake became very turbid and consequently the sunlight could no longer reach the deeper water column. As a result, the primary production in lake Markermeer decreased which affected the food chain (Zwart, 2008). A severe decrease in the abundance of aquatic plants, benthos, fish populations, and bird populations was measured (Noordhuis, 2014). The lake is now part of the network of nature protection areas in the European Union (EU): Natura 2000. The goal of Natura 2000 is to stop loss of biodiversity and restore and protect habitat (RWS, 2017).

To improve the ecological quality of lake Markermeer, the project of the Marker Wadden (MW) was initiated by Natuurmonumenten (NM, the Dutch Society for Nature Conservation) and Rijkswaterstaat (RWS, the department of Public Works and Water Management) (van Riel et al., 2019; IJff et al., 2020). During the period from 2016 to 2020, 500 ha of artificial islands and 500 ha underwater landscape with gullies to capture fine sediments, were created (van Riel et al., 2017).

The MW are constructed of Holocene clay, sand, sediments and peat dredged from the bed of the lake and have been built by the executing party Boskalis with support of Witteveen + Bos (W+B), Arcadis and Vista (van Riel et al., 2017; IJff et al., 2020). The goal of the MW is to increase the water quality and to create a 'birds paradise' (IJff et al., 2018). The MW are 'a living lab' and especially learning and innovating building with fine sediment is an important theme. The Knowledge- and innovation program MW (KIMA) has been set up to conduct research and collect knowledge on 3 themes: building with fine sediments, the ecological development on the islands and adaptive governance as the MW are a collaboration between public and private parties (IJff et al., 2020). Multidisciplinary research teams and various types of stakeholders are involved with the MW project.

The construction of the first phase of the MW has almost completed, and researchers are now trying to understand the behavior of the fine sediments and the ecological development on the islands. The initial plan was to create a second phase with more islands and to use the captured fine sediment from the first phase as building material. However, at this point not enough material has been captured in the gullies yet. Besides, there is only financial support for the first phase. The public governmental bodies have financed the MW for the largest part, whereas it was expected that private parties and the EU would finance a larger part of the MW project which was tried but could not be realized (IJff et al., 2020). For upscaling the project or similar nature-based solution (NBS) projects, more financial support should come from private parties. It is therefore important to understand the ecological and economic value of the islands for the different stakeholders of the project, and to establish the benefits for the broad range of stakeholders. These stakeholders could then become private investors for the upscaling phase of the MW.

1.1 Research objective

This study aims that valuing the ecosystem services (ES) that the MW provide, will give important information about the benefits for private and public economic actors. The concept of ES is becoming more important as it is more often applied in policy and practice to support decision making, and to weigh alternative policy options (Schild, 2019). Therefore, this study tries to understand and identify insights about the economic value of the ES the MW provide for the public and private partners that are involved with the MW project. Besides, valuing the ES of the MW will help to identify financing opportunities for upscaling the MW or creating habitat in a similar way elsewhere, on national and international scale (IJff et al., 2020). This research applies valuing techniques for a section of ES related to building with the dredged material that the MW are formed of, and the creation of habitat the islands provide, as the economic value of these services are unknown yet. Besides, the stakeholder landscape is much broader than the economic stakeholders and therefore, societal benefits will be provided by the MW and are analyzed and included in this research.

1.2 Research questions and outline

Resulting from the objective, the main question that will be addressed is the following:

What are the expected economic benefits to the different stakeholders of the MW project, specifically related to building with fine sediment and creating habitats?

Several sub-questions have been created to take a step-wise approach in answering the main research question:

1. Which relevant ES provided by the MW can be identified that benefit the investors?

2. Which key performance indicators (KPI's) are suitable to monitor the levels of ES provided by the MW project?

3. How does the current situation (with MW) differ from the ex-ante situation (without MW) when comparing the KPI's?

4. How can valuation methods be applied on the ecosystem services the MW provide?

5. Which stakeholders benefit from the MW based on the valued ecosystem services and how do they benefit?

1.3 Scope of research project

This research is based on the principles of the FFWS by Altamirano et al. (2019) and *Financing and procurements for improving ecology and water quality* (Hüsken, 2020). In addition, to value ES, this study applies the Economics of Ecosystems and Biodiversity (TEEB) approach by de Groot et al. (2010) on the MW. Hüsken (2020) describes several principles that are important in applying the FFWS on the MW. One of these principles focuses on the services that a measure delivers and the beneficiaries, instead of focusing on delivering projects. This principle takes responsibility for risks and takes lifespan of measures into account. In the case of the MW, this financing principle would mean that stakeholders that benefit from the services the MW provide, could be the ones willing to pay for the upscaling. The value of the services should therefore be established. In future phases of the MW or other BWN projects, this is an important principle as it opens alternative financing options. Hüsken (2020) identifies the main functions and services of the MW (Table 9 in Annex C). However, the services of the MW are identified, the concept of ES and valuation was not yet applied on the functions and services of the MW. Therefore, this research will value the ES of two main functions that the MW provide: Building with fine sediment[1] and creating habitat for flora and fauna to improve the ecosystem of lake Markermeer and increase the biodiversity. The third main function identified by Hüsken (2020) is recreation. This function was not included in this research as the economic value is relatively easy to value compared to the other two functions.

1.4 Outline of the research

The research questions that are mentioned above, are guiding this research towards a valuation of the ES provided by the two main functions of the MW. First, background information is provided in chapter 2 about lake Markermeer, the MW and the concept of ES. Second, in chapter 3 the methodology of this research and valuing ES in this study is elaborated. Third, chapter 4 provides results of the ES analysis. Finally, a discussion, conclusion and recommendations are given in chapter 5 and 6.

[1] And dredged Holocene material.

2. Theoretical background

This chapter will touch upon the theoretical background on three main topics that are important to understand in relation to this case study. First, the historical and geographical-, and ecological conditions of lake Markermeer will be discussed as background information to understand the importance of the MW project. Second, the building of the MW, and its governance and financing aspects will be highlighted. Third, the theory behind the concept of ES and economic valuation of ecosystems will be addressed to understand the theory behind this study in relation to valuing ES of the MW.

2.1. History, geographical and ecological conditions of lake Markermeer

Lake Markermeer is a shallow artificial freshwater lake with a surface of 680 km^2, an average depth of 3.6 m and a volume of around $2.5*10^9$ m^3 (Vijverberg et al., 2011). The Markermeer has a soil composition of clayey sediments, Ijsselmeer deposit, and a Holocene clay layer (Vijverberg et al., 2011). The area is part of the largest freshwater area of Western Europe and the biggest freshwater reservoir in the Netherlands as around 30% of the Netherlands is directly or indirectly dependent on the water from the Ijsselmeer area (RWS, 2018). The area has both environmental and economic importance which is driven by European directives (e.g. Natura 2000 and the Water Framework Directive (WFD), a directive towards a good quality of surface- and groundwater in Europe (Zwart, 2008), and economic ambitions (RRAAM[2], 2013). The lake is an important resting place for migrating bird species. On the other hand, many people live and work in the region around the lake and the area is important for recreational activities.

Lake Markermeer used to be part of the former Zuiderzee estuary and was connected to the Wadden Sea and North Sea. The closure of the Zuiderzee by the Afsluit dike in 1932 resulted in a large freshwater reservoir: lake IJsselmeer. Consequently, the IJsselmeer area became a large and important area for many waterfowl species (van Riel et al., 2019). In 1975, the Houtrib dike was built, and separated lake IJsselmeer in two parts (Vijverberg et al., 2011). The original plan was to drain the smaller lake Markermeer into a polder, however in 2006 the impoldering plan was officially rejected (VROM[3], 2006). The Houtrib dike remained, but it caused a disruption in the natural movements of the sediments which negatively affected the ecological quality of the ecosystem (Noordhuis, 2014). Two third of the soil of the lake is now covered by 30 cm thick sediment layers (NM, 2017). These layers of sediment develop when the clayey soil erodes by the influence of bioturbation[4] (Noordhuis, 2014). However, due to the lake's shallowness, high sediment concentrations in the water column are present which is caused by the wind induced waves and currents that partly erode these sediment layers (Van Riel et al., 2019). Shallow lakes with turbid water limit the development of benthic flora and fauna which affects plant growth and abundance of mussels (Van Riel et al., 2019).

In addition, the Houtrib dike caused a disruption in the water supply which resulted in a decrease in nutrient concentrations, an effect that was further strengthened by the successful measures to reduce nutrient loading water systems on a national scale. The concentrations of P and N decreased in the 1990s, and PO_4 became a limiting factor for phytoplankton in the lake. These limitations caused a shift in species composition of phytoplankton and a lower nutrition value of phytoplankton and benthos for fish and benthos-eating birds (Noordhuis, 2014). As a result, the populations of several

[2] Rijk-Regioprogramma Amsterdam-Almere Markermeer (RRAAM) is a project to improve the water quality to potentially benefit the economic development, recreation and liveability of the area around the lake. Goals of RRAAM are to create 60.000 houses and create 100.000 jobs, and besides to create a nature and recreation area of lake Markermeer (RRAAM, 2013)

[3] Vaststelling van de Nota Ruimte, adoption of the strategy for spatial development

[4] 'Bioturbation implies the physical discplacement of particles and water by macrofaunal reworking and ventilation.' (Saaltink et al., 2019, p. 2)

bird species were declining in the 1990s. In addition, land reclamations had resulted in a loss of natural shores and marsh zones that were almost completely replaced by artificial shores and dikes (Zwart, 2008). These zones are important habitat for several bird- and fish species. Noordhuis (2014) presented a scientific advisory report on the downward ecological trends in the IJsselmeer area. According to this report, the cause of the decreased ecological quality is a combination of decreased amounts of nutrients, lack of marsh and natural shores, and accumulation of sediments which all result in lack of habitat and food for waterfowls (RWS, 2014).

Currently, several projects in lake Markermeer aim to improve the ecosystem in the lake (de Rijk et al., 2018). Lake Markermeer is a Natura 2000 protected area, which means that the area is part of the network of nature and biodiversity protection in the EU (van Riel et al., 2019). Noordhuis (2014) studied the water quality and ecological changes in lake Markermeer-IJmeer in relation to the Natura 2000 goals. Because birds are top predators of the food chain of the lake, it is important to tackle the problem at its roots by improving the water quality and decrease turbidity, and by creating more suitable habitats. In addition to Natura 2000, there are several development strategies, laws and regulations[5] involved with improving the ecological status in lake Markermeer as described in IJff et al. (2020). One of the most important ones is the Futureproof ecological system (TBES, Toekomstbestendig Ecologisch Systeem) which attempts to create clear edges along the shores, a gradient in sediments from clear to turbid, land-water zones and improved ecological connections (Noordhuis & Blaas, 2016). Other important development programs are RRAAM, PGAW[6] and Regional Agenda Ijsselmeer 2050[7]. The construction of the MW and several other nature development projects[8] are now contributing to improving the ecological status in lake Markermeer.

2.2 Building the MW

As mentioned in the introduction, the MW are artificial wetlands created from dredged material from the lake with the goal to improve the ecological quality and create a bird's paradise (Hüsken, 2020). The MW are located in the North-Eastern part of lake Markermeer, 4km south of the Houtrib dike Figure 2). The islands have a surface of 1000 ha that increase habitat zones for flora and fauna and include an underwater landscape with zones that provides habitat for aquatic vegetation and fish. In addition, a sand well was created and a gully with a length of 2 km was built (Figure 2), with the goal to capture the fine sediment that can be used as building material for upscaling the MW, and simultaneously improve the water quality (capturing fine sediments reduces turbidity). Besides, the shared goal of NM and the ministry of economic affairs (EA), is to develop new methods and knowledge of building nature with dredged materials (Hüsken, 2020). A final realization goal of the MW is to minimize the management costs in the future by creating a self-sustaining system.

Dredged sediments are often seen as a waste product, however there is an increasing number of projects that use these fine sediments as a circular material in the building environment. According to van der Meulen et al. (2009), around 30 million m^3 sediment from the inland, and 35 million m^3 from the sea is reallocated on a yearly base in the Netherlands, which is an expensive and besides inefficient process. Brils et al. (2014) describe the developments on the reuse of dredged material to

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[5] Water Framework Directive (Kaderrichtlijn Water in Dutch),
[6] 'Programma Aanpak Grote Wateren', the program to create sustainable water bodies in the Netherlands where high quality nature and a strong economy blend (Helpdeskwater, n.d.)
[7] Gebiedsagenda Ijsselmeer 2050 is a collaboration between governmental bodies and provinces which moves towards a futureproof Ijsselmeer area. There are seven objectives: Energy transition, climate adaptation, nature development, recreation, sustainable fisheries, shipping and urban development (Agenda Ijsselmeergebied 2050, n.d.)
[8] Other projects are Oostvaardersoevers (the Oostvaarder shores), Trintelzand and Natuurthermometer (Markermeer-IJmeer, n.d.; van Riel et al., 2019). Coherent projects are 'Gebiedsagenda Ijsselmeer'and 'Nationaal Park Nieuw Land'.

tackle societal challenges and change this inefficient process into a sustainable way of building. The MW are built with dredged material from lake Markermeer. No contaminants were present in the material which made the sediments directly available for use (CEDA[9], n.d.). There are several pilots[10] part of the 'Living Lab for Mud', an integrated approach for sediment management leveraging on the concept of Building with Nature (BWN). The MW is one of these pilots and has the objective to provide knowledge on the use of fine sediments as a natural resource and a more sustainable way of building where nature forms the base of the project (van Eekelen et al., 2017).

Figure 2 The MW from above, with the sand well in the upper left corner, and the gully to capture fine sediment on the mid left (Boskalis, 2015)

The project can be divided in an initiation-, a construction and a management phase as described by IJff et al. (2020). The initiation phase took place between 2012-2015 and the construction between 2015-2020. The project team for the construction was operational in 2015 and in April 2016, the construction of the MW really started by Boskalis with assistance of W+B, Arcadis and Vista. In 2020, the MW will be finished and handed over to the managers of NM. In 2020, the MW will be finished and handed over to the managers.

Using fine sediments for construction is a complex process, since it starts as a fluid material which needs time to consolidate and become more robust. The step-wise approach Boskalis practiced to create the wetland habitats with this material, consisted of building the compartment dikes (sand and

[9] Central Dredging Association
[10] Other projects are the 'Kleirijperij', slib motor Harlingen, and Marconi kwelderontwikkeling on a national level, and Habitat restoration of the Green Bay in Lake Michigan (CEDA, n.d.), and Cliffe pools habitat enhancement (RSPB,n.d.) on an international level. Living lab for Mud projects can be found at Ecoshape (https://www.ecoshape.org/en/projects/living-lab-mud/)

stones), filling the compartment with fine sediment (Holocene clay mixed with water), sedimentation, consolidation, drying and crust forming processes, and is shown in Figure 3 and Figure 4.

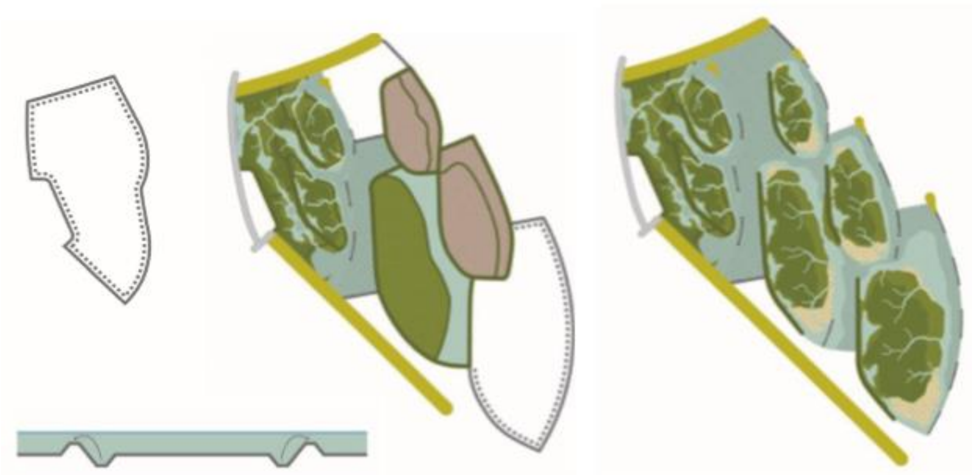

Figure 3 From left to right: filling, sedimentation and consolidation (Boskalis, 2015)

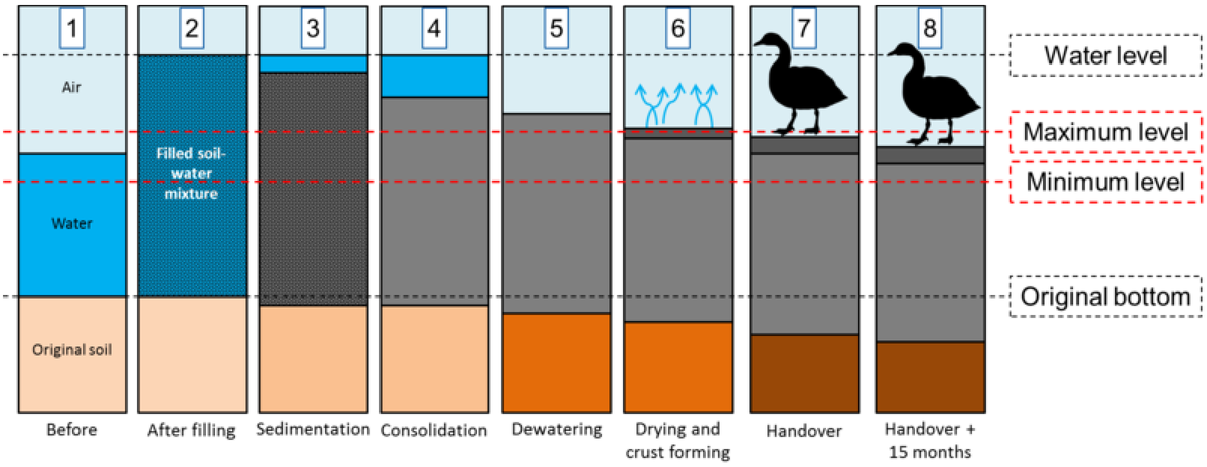

Figure 4 From left to right: Intersection of the MW with the construction steps; before, filling, sedimentation, consolidation dewatering, drying and crust forming, and when finished (CEDA, n.d.).

Many lessons can be learned from the ecological development of the MW and building islands with dredged material and from the interaction between the different stakeholders. KIMA is the research program that conducts applied and scientific research on the MW and provides the monitoring and evaluation program (MEP). Research for KIMA is done by RSW, NM, Deltares and Ecoshape partners (KIMA, n.d.-a). The goal of KIMA is to provide knowledge about the MW, divided into three main themes: building with fine sediments, the ecological development of the MW and adaptive governance. KIMA started in 2018, ends in 2021 and will be evaluated in 2022 (de Rijk et al., 2018).

2.3 Governance and financing of the MW

The MW project is an alliance of private and public actors, whereby the NGO NM and the governmental organization RWS form the 'project team' in which they work together, combine their knowledge and share risks (Hüsken, 2020). The World Bank (2014), defines public-private cooperation as:

'A long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance' (World Bank, 2014, p. 14)

The public-private cooperation of the MW project is described by Altamirano & Grotenbreg (2019), IJff et al. (2020) and Hüsken (2020). In the Netherlands, a building project where an NGO and the government cooperate, is unique (IJff et al., 2020). The KIMA governance research theme therefore investigates collaboration, adaptivity and continuity between the stakeholders of the MW. These stakeholders include the public-private cooperation between NM and RWS, but also the executing parties (Boskalis and W+B), de financing actors (Ministries and Provinces), and the knowledge institutes involved in KIMA. The roles and contribution of each of the stakeholders is described by IJff et al. (2020) and can be found in Table 19-Table 21 Annex G.

Constructing a new archipelago, as is the case with MW, is costly and cannot be financed by nature organizations alone. The project of the MW is therefore jointly financed by NM with contribution of the dream fund of the national lottery (€30.5 million[11]), the provinces of Flevoland (€6.5 million) and North-Holland (€4 million), the ministry of infrastructure and water management (I&W), and the ministry of EA (€ 37 million) and the municipality of Lelystad (€500.000) (IJff et al., 2020). However, acquiring budget was not easy as the subsidies of EU funds were rejected and private parties were financing less than expected (IJff et al., 2020). Therefore, the government had to pay more than they planned, and are hesitant to finance upscaling phases of the project as long as its effectiveness in improving the ecological status of lake Markermeer is not proven.

2.4 Ecosystem services and economic valuation

Ecosystems are essential to sustain life on earth as they provide resources and services that contribute to human wellbeing (Koetse, Brouwer & van der Beukering, 2015). The ES approach is a concept that explains the relation between ecosystems and human society by apprehending benefits that humans derive from nature. The concept emphasizes the dependence of humans on ecosystems (MEA, 2005; Schild, 2019). Since the publication of Daily (1997), Costanza et al. (1997) and the Millennium Ecosystem Assessment (MEA, 2005), research and policy interest in the ES approach has grown thoroughly. By now, there are several conceptual frameworks, definitions and classification systems regarding ES. However, there is still much debate about definitions and classifications (de Groot et al., 2010; Fisher and Turner, 2008).

The Economics of Ecosystems and Biodiversity (TEEB) study by van der Groot et al. (2010) is one of the main studies in the field of ES and has been widely applied. The United Nations (UN) has embraced the TEEB initiative as a strategic plan to sustain and enhance biodiversity (Hendriks et al., 2014). TEEB underpins the importance of ecosystems and biodiversity for global economic and issues related to climate, poverty and natural resources. In the cascade model by de Groot et al. (2010), the link between the ecosystem and benefits for humans is step-wise explained (Figure 16 in Annex D). Four types of ES can be distinguished in the framework of TEEB: provisioning, regulating, habitat and cultural services. The TEEB framework is used in this case study on the MW. Besides TEEB there are several frameworks that are often used in ES assessments. They offer the possibility to incorporate environmental effects of human actions into decision-making and policy objectives. In the Netherlands, 'Atlas Natuurlijk Kapitaal' is an important example of initiatives that use the concept of ES (Schild, 2019).

[11]From the contribution of NM, €1 million is financed by business and NGO's (IJff et al., 2020)

To be able to work with ES in policy and decision-making, the magnitude of ecosystems and their services need to be quantified. Two types of valuation techniques have been developed that try to approximate the value of ES: ecological and economic valuation approaches. For ecological measuring, ES can be estimated by using a set of KPI's, and mapping and modelling techniques (de Groot et al., 2010). The contribution of ES to the provision of services is then measured. Economic valuation techniques are focusing on estimating the monetary value of the benefits provided by ES. There are four categories in economic valuation: Market-based methods, revealed preference methods, cost-based methods and stated preference methods (Horlings et al., 2020). This study focuses on the economic valuation of the ES the MW provide. A more detailed description of the methods is available in Annex D. The method that should be applied on a certain ES, depends on the output. Some services provide benefits that can directly be traded on the market (direct use value), whereas other services provide indirect benefits to end products (indirect use value) (Schild, 2019). In addition, when values cannot directly or indirectly be derived from market prices, the monetary value can be based on hypothetical markets (non-use value). The total economic value (TEV) framework (Figure 18) is used for describing the total value of an ecosystem and is helpful to decide which economic valuation method should be applied on a certain ES. This framework (Figure 18) gives a more detailed overview which valuation method can best be applied on the different ES, and whether a service is easy or difficult to monetize. The framework will be explained in the following chapter.

3. Methods & data

This chapter explains the methodological approach applied in this study on the ES of the MW, with the main question '*What are the expected economic benefits to the different beneficiaries of the MW, specifically related to building with dredged material and creating habitat?'*

As a backbone for this research, the stepwise TEEB approach is followed (Figure 5) to value the economic benefits of the two main functions. The first step is mapping the different ES, the second step is to quantify the ES, and the third step is to value and monetize the ES (de Groot et al., 2010). TEEB exists of specific approaches for different ecosystems and TEEB for wetlands (Table 8 in Annex A) was applied on this case study.

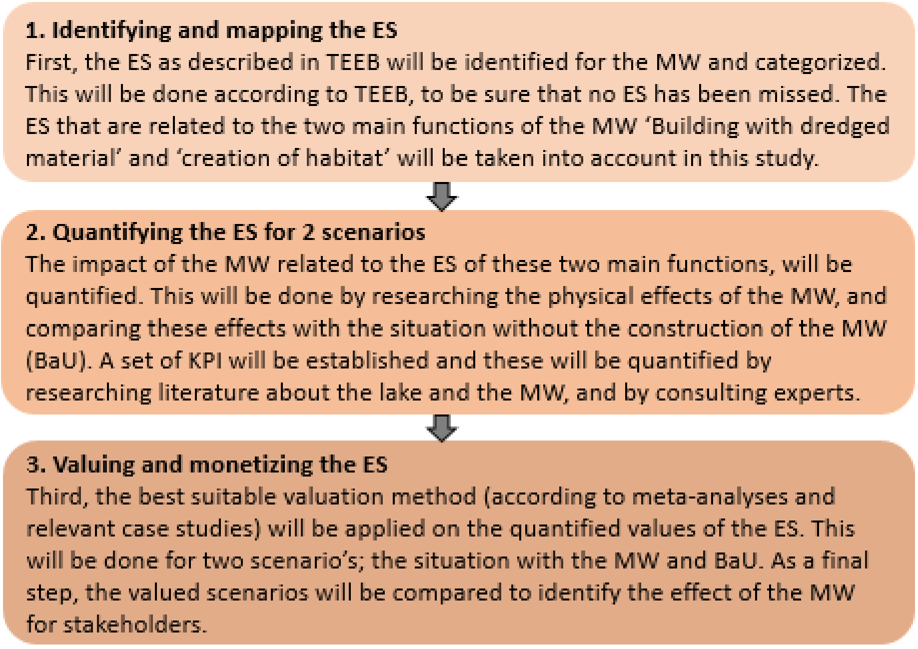

Figure 5 Visualization of the methods

3.1 Literature research and data

This study involves the application of several ES valuation methodologies, where data was mainly derived from existing scientific literature, experts, reports and websites. Several Dutch and international ES valuation studies were first analyzed to understand the valuation of ES in practice (e.g. da Silva, 2012; Smit, Blom & Warringa, 2012). Second, a selection was made in relevant literature on the MW and lake Markermeer. Scientific literature (e.g. Van der Winden et al., 2019; Van Riel et al., 2019), reports, the RWS (2014) and midterm evaluations that were available on the topic were used to gather data for this research (de Rijk & Dulfer, 2020; de Rijk et al., 2018). Databases that are used to find relevant scientific papers about the ES valuation theory and the MW are Google Scholar and VU library. Besides, reports were gathered at the website of KIMA, the publications database of the Ministry of I&W, the publications database of Deltares and RWS. Keywords that were used to gather literature on the MW were 'Marker Wadden', 'Markermeer', 'water quality', 'ecology', 'habitat creation' and 'building with fine sediments'.

3.2 Identifying and mapping the ES according to TEEB

First, the TEEB conceptual framework has been applied to the MW (Figure 6). The framework links ecosystems and human wellbeing for the case of the MW. From upper left to upper right, Figure 6 shows the structure, processes and functions of the ecosystem, and how these relate to ES and human wellbeing. The functions are defined by de Groot et al. (2010, p.19) as ‘interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services.’ The ES the ecosystem provides for human wellbeing, are divided in economic, societal and ecological benefits. Indicators are used to measure the value of their impact. In the lower right, governance and decision-making processes are described which should keep balance between the ecological, socio-cultural and economic values. Finally, drivers of trends which are linked to the structure and processes are shown in the lower left.

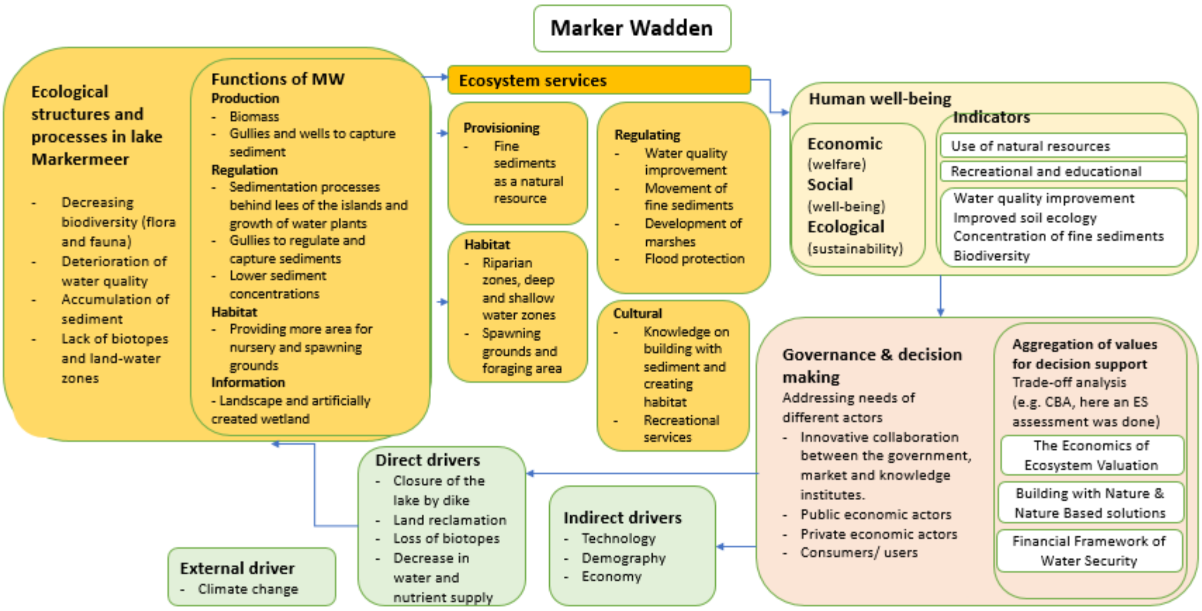

Figure 6 Conceptual framework of the MW for linking the ecosystem and human wellbeing, derived from de Groot et al. (2010)

As described in chapter 2.5, the TEV framework has been applied which takes both the use and nonuse values into account that stakeholders and society win or lose from changes in ES. TEV is shown in Figure 7 with examples of the MW, adapted from Koetse, Brouwer & van der Beukering (2015). Use values are in general easier to value than non-use values, as use values are market-based and non-use values are based on hypothetical markets. In addition, the term Total System Value (TSV) was mentioned in TEEB (2009). Besides the monetary value, TSV also takes the quantitative and qualitative values and insecurities into account and gives therefore a more complete overview of the value of an ecosystem (Figure 17 in Annex D)

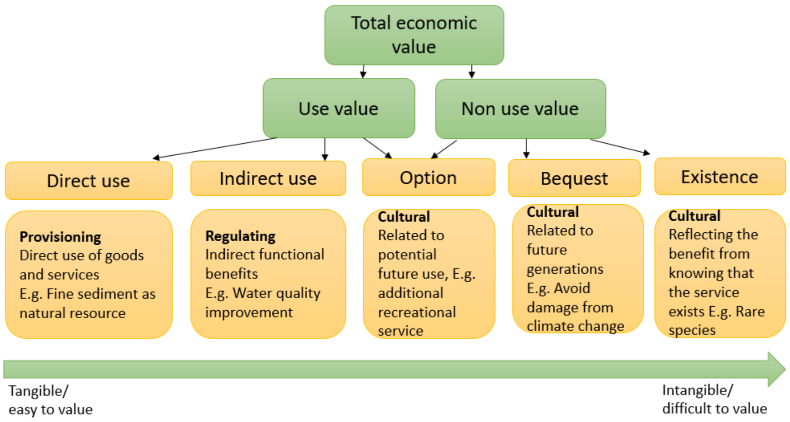

Figure 7 Total economic value of the ecosystem services of the MW, adapted from van der Beukering et al. (2015)

Second, a qualitative assessment (chapter 4.1) was undertaken to ensure that all possible ES are considered as described in Defra (2007). The purpose is to describe which ES are likely to be provided by the MW and its possible influence. The scores are mainly based on the environmental impact assessment (RWS, 2014) of the MW, the researched literature (e.g. van der Winden et al., 2019) documents and planning reports and expert knowledge. The qualitative assessment shows the expected anticipated change of the MW (Table 3) with scores as used in Defra (2007) (Table 1). To ensure that the ES fit within the scope of this research, the relation of the service to main function 1 or 2 is included. ES related to one of the main functions with expected significant impacts were considered for further evaluation.

Assessment of effect	Score
Potential significant positive effect	++
Potential positive effect	+
Negligible effect	0
Potential negative effect	-
Potential significant negative effect	--
Gaps in evicence	?

Table 1 Scale of anticipated change scores (Defra, 2007)

3.3 Quantifying the ES for two scenarios: MW and Business as usual (BAU)

Two scenarios were compared in this study. The first scenario is the current situation where the construction of the MW has been executed. There will be studied how the ES related to two main functions of the MW changed in the lake. The second scenario, BAU, consists of lake Markermeer without the MW. In the future, possibly more islands will be built to enhance the water quality and ecological system of lake Markermeer. However, it is unclear yet if (and when) this will be realized and because of that, a future scenario will not be described. To get insight in who can participate in financing the upscaling of this project, recommendations will be given with a focus on the benefits that potential investors can have from the MW project.

To be able to quantify the level of service provision for both scenarios, a set of KPI's was identified and carefully selected. Literature research was done to establish the most suitable KPI's and valuation methods (e.g. Russi et al., 2013; Maes et al., 2014). Besides, the Midterm review of KIMA provided useful indicators on physical effects of the MW.

The level of valuation differs per ES. For some ES, KPI’s are related to change in habitat area and species abundance. Other ES, such as knowledge provision, are quantified based on the number of educational programs. Besides, there is a distinction between intermediate and final ES (DEFRA, 2007). For example, supporting services often impact other services, but cannot directly be used. For some services (especially regulating services), it was very difficult to quantify the physical effects due to lack of data, and therefore sometimes not possible to provide a complete valuation of the ES. It is therefore important, that research on the valuation of ES continues.

3.4 Economic valuation of the physical effects

When the physical effects of both scenarios were quantified as far as possible with the available data, a monetary valuation technique has been applied on the service. Economic valuation of ES has been applied with guidance of literature on ES valuation methodologies (de Groot et al., 2010; Haines-Young & Potschin, 2009; Klooster et al., 2018; Defra, 2007). As beforementioned, these techniques are described in Annex D. Besides data from literature, experts and reports, index numbers have been applied from Ruijgrok et al. (2006) to be able to monetize certain ES.

It is important to note that it was not always possible to gather enough data for monetary valuation of an ES. Where this was the case, the ES were only valued in quantified or qualified terms, depending on the available data. This is confirmed by da Silva (2012), who states that services cannot always be valued monetarily, and sometimes a quantitative assessment is not even possible. However, it is still important to address the effects of a projects to communicate the risks and insecurities to stakeholders or policy makers (Klooster et al., 2018).

4. Results

The MW exist of different habitat types as described in van Riel et al. (2017). The expected total of created habitat, area and the expected value for nature is described below in Table 2.

(Expected) type of habitat MW	Area (ha)	Expected nature value
Deep water (turbid) (4-5m)	-	Habitat shellfish, crustacean and mosquito larvae.
Deep water (clear) (4-5m)	322	Gradient from clear to turbid water, foraging area for grebes and diving ducks.
Well en gullies	126	Fish habitat
Sandy shore	24	Musselbed and Chara spp. habitat.
Sand plates	25	Breeding and spawning grounds for birdspecies
Stone banks	9	Hard substrate macrofauna, food for gulls and terns.
Pile row	24	Musselbed
Shallow sheltered water	231	Fish and foraging area
Dry reed land	27	Habitat for birds
Varied reed land	147	Less important for N2000
Shallow pools, land vegetation (verlandingsvegetatie)	51	Foraging area
Reed marsh and rush fields	114	Gradients and exchange with the (shallow) waterzone.
Mud flats	48	Marsh with wave dynamics and pioneer vegetation.
Total	1148	-

Table 2 Expected area of created habitat Boskalis (2015), van Riel et al. (2017)

First, a qualitative assessment of the effects of the MW was undertaken according to the TEEB classification system (Table 2). The expected benefits and a qualitative assessment of the anticipated change of the MW are presented. In addition, it has been determined whether the services are relevant for main function 1 or 2 to ensure the ES fits within the scope of this research.

Provisioning services	Marginal benefit assessment	Anticipated change	Related to main function
Food provision	The MW do not provide food on the islands as it is created to provide habitat and to improve the water quality. However, the MW do provide new habitat and spawning grounds for fish which can positively influence the fisheries in the lake. In the EIA (RWS, 2014), it is stated that the amounts of fish in lake Markermeer are very low. However, with the construction of the MW, 20km^2 (3%) of fishing area will be lost. The EIA (RWS, 2014) expects no significant positive change in fisheries.	0	No
Fresh water supply	The MW contribute to water quality improvement; however, they do not supply freshwater and therefore there is no change.	0	No
Raw materials:	One of the main ideas of the MW is to capture fine sediment in the gully, which in the future can be used as a	+	Yes, function 1

Building material	building material for upscaling (Boskalis, 2015). However, according to experts (van Kessel, personal communication, 06-05-2020), at the moment this process is going slower than expected.		
Raw materials: Natural materials	Optionally, bio-based materials for commercial purpose have been researched by Beumer et al. (2017). Expected is that in total 174 ha of reed habitat will be created, which could potentially be used for rooftops. However, this activity will be a negative factor for several bird species on the MW. The MW are created to provide habitat in the first place, and therefore it is questionable whether this will be done in practice.	0/+	No
Genetic resources	For crop improvement and medicinal purposes. The MW do not provide this service.	0	No
Medicinal resources	As this service is not found in literature, the MW do most likely not provide this service.	0	No
Ornamental resources	Decorative plants, pet animals or artisan work. This service was not found in literature about the MW and is therefore not included.	0	No
Regulating services			
Air quality regulation	Capturing fine dust and chemicals (de Groot et al., 2010). This service was found in the literature on wetland ES as micro-climate stabilization. During the creation of the islands NO2 and PM10 was emitted, however less than the limit. Reduction in any other emissions due to vegetation is not expected. No significant effects. The estimation of the EIA (RWS, 2014) is 0. Besides, no valuation of this service was done in meta-analyses on wetlands (Brander et al., 2006).	0	No
Climate regulation	Regulation of the chemical composition of the atmosphere and temperature. In meta-analyses on wetlands, no valuation of this service was found (Ghermandi et al., 2008). No contribution of the MW found in literature.	?	No
Moderation of extreme events	The MW provide flood protection of the Houtrib dike as a natural barrier that decreases wave heights (Beumer et al., 2017). Moreover, the service of flood control and storm buffering was found in literature on wetland valuation (Brander et al., 2006; Ghermandi et al., 2010).	+	Related to other functions
Water purification	The MW should enhance the water quality by capturing fine sediment in the gully (Beumer et al., 2017; van Riel et al., 2019). Moreover, water quality improvement is an ES that was found in literature on (constructed) wetland valuation studies (Brander et al., 2006; Ghermandi et al., 2008). The EIA (RWS, 2014) show some local positive impacts on the water quality, especially in relation to sediment concentrations.	+	Yes, function 1
Erosion prevention	Soil maintenance and formation, sediment retention and erosion prevention (de Groot et al., 2010). The lee zones behind the MW show higher levels of consolidation of the soil and besides higher levels of vegetation cover (Van der Winden et al., 2019; Vonk et al., 2019). It may be concluded that there is a positive effect on soil consolidation local level.	+	Yes, function 1

Nutrient cycling	According to Saaltink et al. (2017), wetlands provide the service of nutrient cycling. However, economic valuation of this service is not found in literature.	+	Yes, function 1
Biological control	Ecosystems are important for regulating pests and diseases. Birds, bats, flies, wasps, frogs and fungi act as natural controls (TEEB, 2010). As these animals are present on the MW, there may be a net positive effect. However, this has not been valued in the literature and is therefore unknown.	?	Yes, function 1
Habitat services			
Lifecycle maintenance	Nursery service to several flora and fauna species. Spawning area for fish and breeding area for birds are provided (RWS, 2014; Boskalis, 2015; van Riel et al., 2019)	++	Yes, function 2
Gene pool protection	The MW provide habitat to several terrestrial and aquatic species, the islands are beneficial to the conservation of biodiversity (RWS, 2014; Boskalis, 2015; van Riel et al., 2019).	++	Yes, function 2
Cultural services			
Aesthetic information	Appreciated scenery, nature and tranquility. The MW provide nature that can be enjoyed through walks, a watchtower and 3 bird watching sites (NM, 2017). Besides, the MW can be enjoyed from boats that pass by and enjoy the view (Hüsken, 2020).	++	Related to other functions
Recreation and tourism	Recreational networks, visitor center, expeditions with tour guide, watchtower and bird watching sites are present on the islands (NM, 2017).	++	Related to other functions
Inspiration for culture, art and design	The Netherlands is known as 'Nederland Waterland' and the MW provides status as an international showcase. (Beumer et al., 2017) International attention for the project was for example provided by the NY Times, as they wrote a newspaper article about the MW (van der Winden et al., 2019). Besides, potentially beneficial as it may be interesting to photographers as the MW provide habitat to bird species and flora and fauna is present on the islands.	++	Related to other functions
Spiritual experience	Nature and wilderness do have a positive effect on spiritual value, however no specific literature about provision of this service by the MW was found. In meta-analyses of wetlands (Ghermandi et al., 2010), this service was not valued.	0/+	No
Information for cognitive development	Scientific and practical knowledge on ecological processes and construction processes on manmade wetlands. Learning experiences for visitors, learning through publications and articles, learning by television programs and radio broadcasts (IJff et al., 2018).	++	Yes, related to function 1 and 2

Table 3 Qualification assessment of ES provided by the MW according to TEEB classification (adapted from da Silva, 2012).

According to the literature and summarized in Table 3; no negative effects of the MW were found. However, for some services the impact is unknown due to information gaps. In the following sections, the ES that are related to the main functions 'beneficial use of sediment' and 'creation of habitat' have been further evaluated. The ES are appointed as described by Hüsken (2020). For the first main function, the quantification and economic valuation for the following ES was done:

1. Water quality improvement in lake Markermeer
2. Soil ecology improvement in lake Markermeer
3. Building with fine sediment and knowledge derived from building with fine sediment by constructing the MW

For the second main function Creation of habitat, the following ES are quantified and valuated:

1. Improvement in flora and fauna species and abundance
2. Improvement of fish species and abundance
3. Creating a bird’s paradise
4. Educational and scientific knowledge provided by the creation of habitat.

4.1 Main function 1: Beneficial use of locally dredged material

1. Water quality improvement by capturing fine sediments

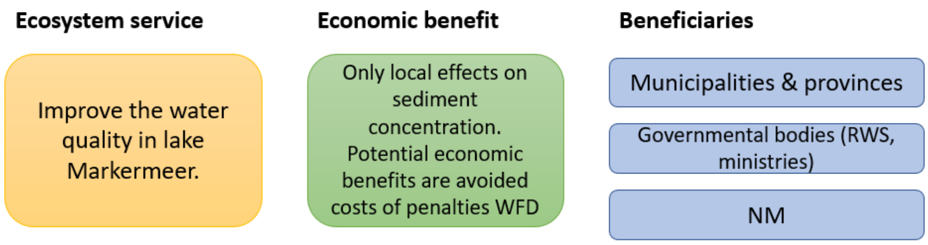

Figure 8 ES, benefits and beneficiaries for water quality, derived from (Horlings et al., 2020)

Water quality improvement in lake Markermeer is one of the main goals of the MW. This paragraph attempts to estimate the value of water quality changes in lake Markermeer as result of the MW. The MW provide this service mainly as result from decrease in sediment concentrations in the water column by capturing fine sediment in a gully. In addition, the islands might influence the stream of sediment in the lake (RWS, 2014).

KPI's to measure water quality were defined according to the WFD indicators and can be divided in ecological and chemical-physical indicators. These indicators are described in Klooster et al. (2018) as suitable indicators to quantify the physical impacts of nature projects. Data was found in literature and reports on lake Markermeer and the MW (e.g. Van Riel et al., 2019; Noordhuis, 2014). In Table 10 in Annex E, the effects of the MW in relation to water quality were compared to BAU. It appeared that quantified effects were only available for transparency and sediment concentrations in the water column. On other KPI's, only qualitative information was found or recent data about the indicator was not available.

There are various valuation methods described in literature to value water quality improvement. In the TEV framework, the value of water quality enhancement in a freshwater body (and therefore the method) depends on its function (e.g. direct use value for drinking water purposes but non-use value when water quality improvement supports recreation). Market price methods or avoided cost methods can be applied when the water quality for drinking water improves. According to Ghermandi et al. (2010) who compared 375 studies on ES valuation of wetlands, the most commonly used valuation methods for water quality improvement are replacement cost and contingent valuation (CV). However, in practice (e.g. da Silva, 2012), water quality enhancement is not often valued as it is mostly a regulating service that is often already captured by services related to recreation, fish productivity and habitat. This is confirmed by Keeler et al. (2012) and Vrebos et al. (2014). They state that the value of the service is mostly linked to supporting other ES, such as increasing commercial fisheries, improved soil quality, higher aesthetic value or enhancing water related recreation. Valuing changes in water quality can thus be challenging compared to other ES as it affects many aspects of human wellbeing and the benefits reach different groups of beneficiaries on different spatial and temporal scales.

As mentioned in Ghermandi et al. (2010), the value of water quality improvement is often estimated by CV studies and replacement costs. Dutch studies that calculated replacement costs or the WTP of enhanced water quality have not been found. Due to the little data and effects that are currently available on water quality improvement by the MW, it is not yet possible to apply valuation methods on this service. However, Ghermandi et al. (2008) provide a regression model to apply a meta-analysis function on this ES in wetlands. Therefore, the value of water quality is captured in the meta-analysis calculation of the total value of the MW. However, expectations and potential beneficiaries of water quality improvement have been described in the following paragraphs. Freshwater users according to CBS (2020) are agriculture, forestry and fisheries, resource extraction, food- and stimulant industry and chemical industry, energy, water companies and garbage companies. However, the quality demand differs per sector (Figure 19 in Annex H

Water quality and quantity demand in the Netherlands). In lake Markermeer, the NUON power station, agriculture, recreation and fisheries are important users of freshwater and potential beneficiaries of enhanced water quality (RWS, 2018). Potential beneficiaries of ecological developments due to improved water quality, are captured in chapter main function 2.

First, options for drinking water in lake Markermeer were explored as around 40% (500 million m^3/year) of the Dutch tap water consumption is originated from surface water and a large part is originated from lake IJsselmeer (KWR[12], 2019). The quality of the surface water needs to meet the WFD criteria for drinking water purposes. In lake Markermeer, the drinking water function has been researched by Bonte & Zwolsman (2009). The concentration of substances needs to be below the human toxicological concentration (RIVM[13], 2020). It appeared that from the most relevant water quality indicators in lake Markermeer (sodium, chloride (Cl), sediment, temperature, chlorofyl-a and sulfate concentrations) were problematic. This makes the water less suitable as a drinking water source (Bonte & Zwolsman, 2009). In addition, the high concentrations of sediment are a negative factor for the potential of drinking water. Although sediment concentrations locally improved as a result of the MW, it seems to be too early to draw a conclusion on drinking water companies as potential beneficiaries as the criteria are not met and changes in water quality are local. Therefore, the market price method to estimate the value of improved water quality, cannot be applied. Water is in the MW context an intermediate service that supports other services.

RWS is responsible for reaching WFD goals (KWR, 2019), whereas the Ministry of EA needs to the achieve Birds- and habitat directive and Natura 2000 directives. Avoided costs of enhanced water quality can be linked to the WFD goals and are indirectly connected to the Birds- and habitat, and Natura 2000 directives. Infringements can be severe when the WFD is not met or not enough measures are taken to meet the goals and can lead to fines and the EU Court of Justice, which for example happened to Germany because of water pollution caused by nitrates (EC, 2016). However, costs of these infringements are very case specific, and an indication of avoided costs cannot exactly be given. Therefore, it can only be concluded that the local decrease of sediment concentrations and increased transparency positively contribute to reach the directives.

Another important potential beneficiary of water quality improvement is the agricultural sector, which is a high water-consuming sector as visible in Figure 19 in Annex H

Water quality and quantity demand in the Netherlands. The agricultural yield in the area contains €1.7-2.9 billion. Water quality requirements for agriculture will probably increase due a shift to more capital-intensive agriculture (ten Brinke et al., 2008). Water quality is therefore important in relation to this stakeholder to maintain the function as a buffer for drought periods. The IJsselmeer area (which contains lake IJsselmeer, lake Markermeer and lake Veluwemeer) has a freshwater buffer of around 400 million m^3 water (RWS, 2018) which will be sufficient until 2050. When this water has insufficient quality and is therefore not available, damage costs of drought for agricultural yields by index numbers (Ruijgrok et al., 2006) are estimated €1200 per ha. However, according to ten Brinke et al. (2008) these quality requirements are mainly related to Cl levels, whereas the MW are improving the water quality mainly by decreased sediment concentrations. Therefore, this stakeholder has not been further analyzed in this research.

Near Diemen, the NUON energy station uses water from lake Markermeer for cooling processes (RWS, 2018). However, data on cooling water quality of this engine was not found. The MW are on the other

[12]KWR Water reserachcycle research institute

[13] National institute for Public Health and the Environment (In Dutch Rijksinstituut voor Volksgezondheid en Milieuhygiëne)

side of the lake which makes the effect on water quality for cooling water probably very low to insignificant. In addition, water quality improvement potentially benefits the economic development, recreation and liveability of the area around the lake (RRAAM, 2013). The increase in value of houses near a waterbody is estimated 0.12% extra by Ruijgrok et al. (2006). However, according to Reinhard et al. (2007) there are no Dutch studies that investigate the relation between water quality improvement and the value of houses.

The analyzed beneficiaries related to improved water quality in lake Markermeer are described in Table 4. Figure 8 provides an overview of this paragraph.

Beneficiary	(Potential) benefit	Contribution MW?
Drinking water companies	When the water quality improves sufficient so that the water of lake Markermeer can be used as source for drinking water.	0 There are still problematic substances in the water which makes the water less suitable for drinking water. However, sediment concentrations are locally decreased.
NUON cooling factory	A certain level of water quality is required for cooling water.	0 No data was found.
Fisheries	Possibly indirectly affected when the water quality improves significantly and influences the biomass of fish.	0 No results yet, according to the EIA (RWS, 2014), no change is expected yet as fisheries have 3% less area to available compared to BAU, and simultaneously the improved habitats for fish may contribute to increase in biomass of fish.
Agriculture	Quality standards are sufficient to use the lake as buffer in dry periods and therefore avoided damage costs.	0 As the MW contribute to lower concentrations of sediment and not to lower concentrations of Cl in the water column, the MW do not contribute to meet the standards of this stakeholder.
Provinces and municipalities	Improved economic development of the region and more recreation.	+ The province of Flevoland and surrounding provinces and municipalities benefit as the MW are contributing to increased economic and ecological development.
Government	Avoided infringements WFD, Habitat- and Birds directive and Natura 2000 directives.	+ As the water quality locally improves in relation to sediment concentrations and transparency, the MW contribute to the WFD goals.

NM	Status and increase in members.	+ As initiator and manager of the MW.

Table 4 Beneficiaries of improved water quality

2. Soil ecology of lake Markermeer and the MW

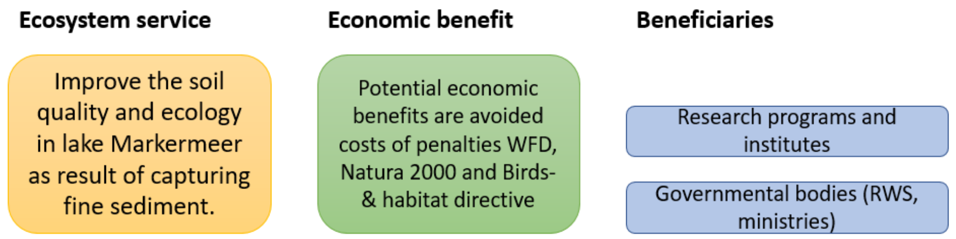

Figure 9 ES, benefits and beneficiaries for improved soil ecology, derived from (Horlings et al., 2020)

In this paragraph, the role of the MW in the functioning of the bed of lake Markermeer, the interaction between sediment, biota and the benthic system is explored (Figure 9). Currently, the bed of the lake is covered with a thick sediment layer (Kelderman et al., 2012).

Economic valuation soil ecology is difficult as the service is a supporting and regulation service that affects other services (Adhikari & Hartemink, 2016). Valuing this service could lead to double-counting and is therefore often not valued in ES assessments (da Silva, 2012). In the context of the MW, this ES is mainly related to improving habitat for water plants, benthos and macrofauna, and could therefore positively influence the food web in the lake. A table with physical effects is created Table 11 Results of quantifying BAU and MW for soil ecology in Annex E. However, effects of the MW on soil ecology should be further researched before drawing conclusions.

Water quality and services related to main function 2 are mostly affected when the soil ecology of the lake would improve. Therefore, beneficiaries of the service of improved soil ecology can be linked to water quality changes and to beneficiaries of main function 2. In addition, beneficiaries would mostly relate to research programs and institutes, and when directives are being reached, it would be beneficial to governmental bodies due to avoided infringements.

3. Fine sediments as a building material

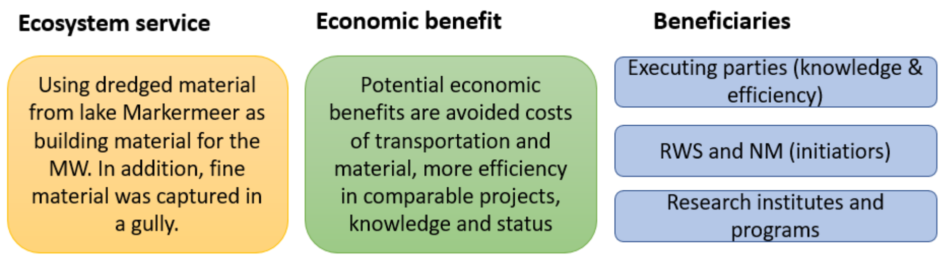

Figure 10 ES, benefits and beneficiaries for fine sediment as building material, derived from (Horlings et al., 2020)

Sand is being extracted from the lake and used as building material. The Holocene clay is a by-product that normally would not be used and would have placed back in the lake. However, for the MW the material was used as a building material to create habitat. Habitat creation, restoration and enhancement projects are technically the most achievable objectives with this dredged material (Yozzo et al., 2004). There are two types of material involved in the construction process of the MW; The first is Holocene material which contains clay, sediment, peat and sand, and the second is fine, mobile sediment that covers the soil of the lake (KIMA, n.d.-b). The MW are all built of Holocene material, and the fine material has not been used yet. However, research on the characteristics of this material is done in 3 research compartments on the MW. According to experts (Van Kessel, personal communication, 06-05-2020), the process of capturing fine sediment in the gullies goes more slowly than expected and has therefore not yet been used as building material.

The total amount of sediment on the bed of the lake is estimated between 63 and 100 million m^3, and erosion is estimated 0.75 million m^3 per year (RWS, 2014; Vijverberg, 2008). With the construction of the MW, both the underwater landscape and the islands were expected to influence the sediment streams and concentrations in the water column. The gullies and lee zones have been designed to capture the sediment that possibly can be used for upscaling and to improve water quality. An amount of 20 million m^3 sediment was estimated to be captured in a period of 10 years (RWS, 2014). This gully is therefore potentially beneficial to the soil ecology and the water quality. Besides, knowledge on building with this material is gained. This service includes thus all the services of main function 1. The physical effects are described in Table 12 in Annex E.

Valuation methods that were applied on this service are market prices and avoided costs as done by Kwakernaak et al. (2015). They measured the value of the ecosystem benefits by making use of dredged sediments for dike strengthening in the Eems-Dollard estuary. They used avoided costs as a method for estimating the value of dredged sediments as building material. For the transportation costs of clay, they estimated an avoidance of €7 for transportation costs per m^3. In addition, when the clay does not have to be imported from other provinces or countries, the external effects of transportation are reduced and have a positive effect on decreasing CO_2 emissions. In total: 30 million m^3 sand, clay and sediments were used (all from lake Markermeer). Direct Market prices of sand and clay per m^3 were found in Ruijgrok et al. (2006). Prices per m3 clay are estimated €11.13, Prices per m^3 sand are estimated €7. However, according to Vijverberg (personal communication, 26-05-2020), prices for the dredged material are very location specific which makes that these values from Ruijgrok et al. (2006) cannot easily be applied. Prices of clay and sediment are very dependent on ripening of the clay, location and transport of the clay, and therefore hard to predict. However, when estimating with these values: €7 (avoided costs per m3 clay for transportation) * 14 million m^3 of Holocene clay (used for the islands according to NM up to 2018) = €28 million avoided when clay without transportation costs from lake Markermeer can be used instead of shipping material from elsewhere. In addition, when the gully indeed provides 20 million m^3 fine sediment and can be used as material, €140 (20*7) million can be avoided for upscaling costs. Besides, knowledge of using this material is already known from the construction of the MW and therefore the process will be executed with more efficiency.

Other potential use of the captured fine sediment are agricultural purposes or in the building environment, however then ripening processes are involved depending on the purpose (Kwakernaak et al., 2015). Therefore, these options should be further researched.

Beneficiaries (Table 5 and Figure 10) are mostly companies related to dredging activities; CEDA, Boskalis, possibly other dredging companies in the Netherlands because of knowledge that is provided about using sediments as a building material. However, there are requirements for the consolidation and strength of the material. Therefore, more research needs to be done on building with dredged material and fine sediments. Moreover, the ecological quality improves which makes that stakeholders related to improved ecological quality (main function 2) benefit.

4. Knowledge collected from 'fine sediments as a building material'

Research on the beneficial use of dredged material is relatively new and knowledge about using this material is therefore valuable (CEDA, n.d.). Purposes of dredged material are flood risk management, navigability, nature development, water quality improvement, building material and supporting local economies. Knowledge is developed to be able to use of sediment as building material for the MW, and this paragraph tries to explore the value of this service that arose from the MW project.

Keywords used to find publications in scientific literature are 'beneficial use of dredged sediment' 'building with nature' and 'habitat creation'. Information was gathered from reports, literature, websites and interviews with experts (Annex B). Described in Table 13 in Annex E. The knowledge provided by using sediment as building material is beneficial to Boskalis, but also some knowledge is transferred and shared with RWS and NM. Research institutes and programs can potentially benefit from the knowledge (Vijverberg, personal communication, 26-05-2020). One track of the KIMA research, is to provide knowledge and research on building with fine sediments. This knowledge is important to set up guidelines for designing islands build from sediment. Chemical and ecological development processes are important in the consolidation processes. Research compartments with sediment are set up and monitoring activities take place.

Kwakernaak et al. (2015) qualitatively values the knowledge derived from using fine sediment as building material. They define this as 'an international potential showcase which improves the knowledge position of the Netherlands in the world'. Stakeholders that are potential beneficiaries related to building with dredged material in the Netherlands could be the dredging partners from CEDA: Boskalis, Royal Netherlands Institute for Sea Research (NIOZ), Royal Haskoning DHV, IHC Merwede, Deltares, TU Delft, Lijn in water, Wageningen University & Research (WUR), 'Vereniging van waterbouwers', van Oord, Unie van waterschappen, W+B, UTwente, Arcadis, Natuurlijke klimaatbuffers, Wetlands international, EU and the ministry of I&W (CEDA, n.d.).

Beneficiary	(Potential) benefit	Contribution MW?
Dredging companies (Boskalis)	Improves knowledge and expertise on building with dredged material or fine sediment.	+
NM and RWS	As initiators of the project their status increased by building habitat in a unique way.	+
Research Institutes	Research and knowledge on building with dredged material	+

Table 5 Beneficiaries building with fine sediment

Summary of the assessment main function 1

A summary of the value of main function 1 is given in Table 6.

ES	Quantitative value MW	Monetary value
1. Water quality improvement	Van der Winden et al. (2019) concludes that especially on the lee zones where primary production and plankton develops, the clarity of the water increases. Transparency will increase between 0-10% compared to BAU, and sediment concentrations will decrease with 15-30 mg/L (RWS, 2014) Nutrients in soil and water are increased. More primary and secondary production is expected. Biological indicators WFD have not been taken into account for lake Markermeer with effects MW yet. Final qualification BAU: sufficient Chemical indicators WFD have not been taken into account for lake Markermeer with effects MW yet: P and N levels are good, however	Qualitative: + Research gap: Not possible due to lack of data on water quality improvement MW, and lack of suitable methods. Has therefore been included in regression model analysis.

	there are specific pollutants in the water which makes the final qualification a ‘not sufficient’ (Agenda IJsselmeergebied 2050, n.d.).	
2. Soil ecology	Fine material was captured in the gully and sediment concentrations in the water column around the MW are decreased.	Qualitative: + Research gap: Insufficient data and suitable methods
3. Sediment	The MW have been constructed with 13 million m^3 sand and 14 million m^3 dredged Holocene material.	Qualitative: + Research gap: Depends on transportation costs and characteristics of material. An estimation was made of €28 million avoided when clay without transportation costs from lake Markermeer can be used instead of shipping material from elsewhere. In addition, when the gully indeed provides 20 million m^3 fine sediment and can be used as material, €140 million can be avoided for upscaling costs. However, ripening costs need to be defined and more research on the material is needed to decrease the width of this assumption.
4. Knowledge sediment	‘an international potential showcase which improves the knowledge position of the Netherlands in the world’ (Kwakernaak et al., 2015).	Qualitative: + Research gap: methods need to be developed. It was not possible to link KPI’s to suitable method for this ES.

Table 6 Summary of quantitative assessment and economic value main function 1

4.2 Main function 2: Creating new habitat

This chapter explores the value of the ES that were derived from this main function. In addition, an overview of the value of this function is provided at the end of the chapter.

1. Flora development on the MW

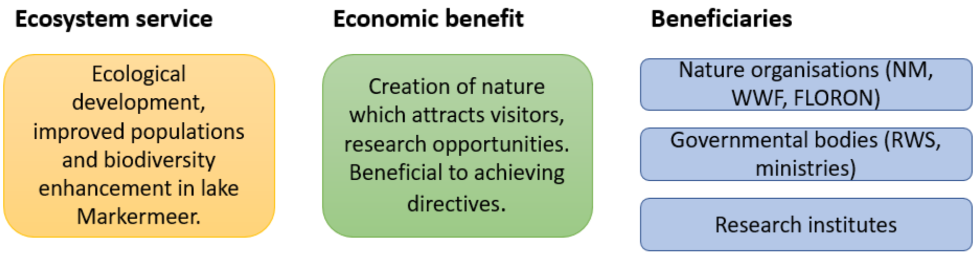

Figure 11 ES, benefits and beneficiaries flora development, derived from (Horlings et al., 2020)

Vegetation along the shores of lake Markermeer has been influenced negatively by the waves and wind-induced erosion (van Riel et al., 2017). The MW provide habitat for many plant species, on both the islands and the underwater landscape. According to the EIA (RWS, 2014), the MW can improve the availability of nutrients which is positive for the development of flora. This is confirmed by Saaltink et al. (2017), who studied the interplay between the hydrological regime and sediment type on ecosystem functioning by determining nutrient availability on the MW. In addition, the development of gradients in the lake will lead to a higher diversity of suitable habitats for water plants. As determined by Van der Winden et al. (2019), water plants are now more abundant in the lee zones behind the islands. In the open lake, there is still wave-induced sediment movements that limits the development of water plants. In this paragraph, the economic value of plant species in the lake and the effect of the MW will be determined.The quantification of this service is presented in Table 14 in Annex F. The Red list for flora (Sparrius et al., 2012) was compared with the list with species found on MW (NM, 2018a). Vulnerable species were present (2, corn chamomille, salsola tragus). No nature protection law species have been found in literature for both the BAU and MW scenario. In addition, 2 N2000 habitat types classified. Habitat type H3140 (Lakes with stonewort with a cover of 25-30%) and H3150 (Lakes with water-soldier and pond weeds with a cover of less than 2%) (N2000, n.d.). However, no changes in percentages of N2000 habitat as a result of the MW were found. In addition, the total area of created habitat where plants have settled was derived from van Riel et al. (2017).

Estimating the value of this service was done by applying a meta-analysis model and by calculating biodiversity points. The study of ten Brink et al. (2011), who estimate the overall economic value of the benefits provided by the Natura 2000 Network, provides an overview of studies that estimate the economic value of Natura 2000 habitat. In total, 387 ha of the MW provide habitat for flora. In ten Brink et al. (2011), the total site value per ha per year for lake and marsh N2000 sites in the Netherlands is estimated by Kuik et al. (2006) on €5,944. This value was derived from 6 studies that include benefits related to recreation, habitat, protection of biodiversity and non-use values (Kuik et al., 2006). Kuik et al. (2006) made a rough distinction in functions of the ecosystems and for supporting and habitat services, the annual value is estimated €590 per ha. Therefore, the value of habitat provision for flora could be estimated on €590*387= €228,330. However, this includes supporting services and therefore the real economic value of flora is probably lower. A third method that could be applied are CV studies. WTP for biodiversity maintenance, which is the price that households are willing to pay per year for biodiversity maintenance was estimated on €25 for marsh areas (Ruijgrok et al., 2006). However, the number of households in the area that prioritize biodiversity need to be determined and this method is therefore not applied to the MW. In addition, avoided costs of several directives are present (Natura 2000, Birds- and habitat directives) as the chances that these will be reached were improved because vulnerable species were found on the MW. As most of these methods include habitat for other species (e.g. birds and fish species), the value of flora is captured in the total estimated value provided in the overview later in this chapter.

The development of flora on and around the MW (Figure 11), is beneficial to nature organisations (NM, World Wild Fund (WWF), Floron), to researchers and universities and to visitors with an interest to flora. In addition, enhancing financing options for habitat provision can be reached with biodiversity offsets and mitigation banking[14] (Smit, Blom & Warringa, 2012; Broughton & Pirard, 2011). Moreover, public co-financing can be used which involves financing goals of which a percentage of the GDP is used for biodiversity enhancement or preservation. However, according to Smit, Blom & Warringa (2012), a lot of research on this option was done in the Netherlands, but no practical implementations were found of this finance construction.

2. Improve the fauna of lake Markermeer with the construction of MW

In addition to flora, the MW are bringing fauna species to the Markermeer area. Birds and fish species are described in the next paragraph. In addition, the value of the remaining fauna species was evaluated. The quantification is described in Table 15 in Annex F. However, little information is found on fauna species (other than fish and bird species in lake Markermeer). Therefore, fauna will not be valuated further. In total, the EIA (RWS, 2014) evaluates the effect of the MW on fauna as positive (+). Methods that could be applied when more data is available are similar as the ones described in the previous chapter on flora. Beneficiaries are similar as in the previous paragraph (excluding Floron).

3. Fish populations in lake Markermeer

Figure 12 ES, potential benefits and beneficiaries related to improved fish populations (adaped from Horlings et al., 2020)

The MW function as an important nursery and spawning habitat for several fish species. This paragraph values the changes in fish populations. De Leeuw & Van Emmerik (2019) researched the presence of fish species around the MW and in total, 21 species were found. According to de Leeuw & van Emmerik (2019), The Dutch association for Sport fishing is researching the fish species and biomass in the created spawning area and habitat provided by the MW. In addition, Van der Winden et al. (2019) concludes that spawning fish were directly found around the MW after the construction. Species that were found are described in Table 16 in Annex F. 1 Red list specie and 1 specie that is important in relation to the Natura 2000 directives were found. In total, 533 ha habitat for fish species is created. The value of biodiversity maintenance and habitat provision is included in the total calculated value in the overview later in this chapter.

The fish stock of lake Markermeer and lake IJsselmeer is measured yearly by Imares (van Herpen et al., 2015). The biomass of fish in the lake was estimated 65 kg/ha in 1998 and 20 kg/ha in 2013. A negative trend was shown for eel, bream and ruffe, whereas roach, pike-perch, and smelt show an uncertain trend (van Herpen et al., 2015). According to EIA (RWS, 2014), the fisheries need to follow several laws and policies and licenses are divided by the ministries. In total, 20 fishing companies have

[14] Transferable rights for biodiversity conservation. This can be biodiversity offsets which are transferable rights for the economic value of services provided by biodiversity. In addition, mitigation banking includes restoring or conservation of habitat which compensates for negative effects (Smit, Blom & Warringa, 2012).

licenses. The market price method is an often used and suitable instrument to predict the monetary benefits for the commercial fisheries. The objective is then to measure the total economic surplus (sum of consumer surplus + producer surplus) for the potentially increased fish harvest with the construction of the MW compared to the BAU situation. However, this method cannot be used as it is very uncertain to predict the future fish stocks and the contribution of the MW. According to the EIA (RWS, 2014) the total area for fisheries decreases with 20km^2 (3%), whereas the fish stock is expected to improve with the construction of the MW. Final evaluation of the EIA is therefore 0/+. Although fish species are present, additional information on biomass of fish species in lake Markermeer and therefore longer monitoring is needed to calculate potential changes in fish stock in the lake.

Beneficiaries are nature organizations, and potentially commercial fisheries however more research needs to be done to verify this hypothesis. However, trade-offs between commercial fisheries and ecological development can occur when fish populations improve and therefore, more research is necessary. An summarized overview is given in Figure 12).

4. Bird populations in and around lake Markermeer

Figure 13 ES and potential benefits and beneficiaries related to improved bird populations (adaped from Horlings et al., 2020)

Due to the decrease in number and abundance of birds in lake Markermeer since 1990's, the goal of the MW is to create a 'birds paradise'. In Table 17 in Annex F, the BAU situation is compared to the MW for bird species and populations in lake Markermeer. Van der Winden et al. (2019) concludes that the MW are colonialized by many different birds compared to the BAU situation. 120 bird species were found in total (NM, 2018b). 2 Red list species were found, including the gull-billed tern with a chick (NM, 2020). According to Van der Winden et al. (2018), birds can be seen as an indicator for primary production and fish abundance around the MW. The common tern is an indicator for the fish abundance in the surrounding areas of the MW. Breeding success of the common tern provides information about the carrying capacity that the MW provide and the amount of food (fish) in the water. According to Mouissie (2019), the common tern in 2017 now meet the standard compared to 2014 because of the construction of the MW.

This service of the MW (Figure 13) is contributing to the goals of the Birds and habitat directive and N2000 as certain species were found and populations were increased. However, methods for this service separately were not found and therefore the value of this ES is included in the biodiversity points calculation and applying a meta-analysis model (Ghermandi et al., 2008).

Beneficiaries are NM, Ministry of EA (Birds- and Habitatdirective & Natura 2000). 'Vogelbescherming' and Sovon.

5. Research and education: flora and fauna

The MW project created opportunities for public engagement and learning of the ecological developments on the constructed islands (schools, colleges, research institutes, and other interested groups and individuals). In this paragraph, the benefits of research and education opportunities are explored, quantified and valued as far as possible. The effects are shown in Table 18 in Annex F. Beumer et al. (2017) did an exploring study on natural capital of the MW. As opportunities for education and research, they appoint KIMA, MEP, PhD research, Flora and fauna counting days, guided tours, apps for visitors, documentaries about the MW and information on websites was found. Target groups are students, Dutch inhabitants, policymakers and the business community.

Valuation methods that have been used are the direct market prices related to education, entrance fees and fees for guided tours where visitors learn about ecological development on the MW. Blom, Smit & Warringa (2012) use entrance fees and guide costs for the monetary valuation of education in case study ‘het Zwin’. However, they appoint the difficulty of monetizing this ES. Da Silva (2012) used the same method, derived from Mourato et al. (2010). Ajwang’Ondiek et al. (2016) used the number of educational excursions and a questionnaire with the Likert scale (1-5) to grade the level of utilization of the ES. Index numbers related to this ES were not found. Entrance fees of €4.2 for members of NM, and €6 for non-members (NM, n.d.) were found. Besides, prices for bird excursions are €52.5 (NM, n.d.). It needs to be addressed that these prices are mostly related to the service of recreation and are therefore not valued for the service in this paragraph.

Beneficiaries of education and research about flora and fauna and ecological development on the MW are nature organisations (Vogelbescherming), NM, the government, research institutes and the wider public.

Summary of economic value main function 2: Creation of habitat

To summarize the economic value of main function2, the biodiversity points are calculated for lake Markermeer (BAU compared with MW), and the meta-analysis model of Ghermandi et al. (2008) was applied to the MW. Besides, an overview of the important beneficiaries related to this function was given in Table 7 Important beneficiaries related to main function 2.

Beneficiary	**(Potential) benefit**	**Contribution MW?**
NM	Improves knowledge and expertise on building with dredged material or fine sediment.	+
Ministry of EA	Helps to reach Natura 2000 goals and contributes to goals of Habitat- and birds directive.	+
Floron	Vulnerable flora species are present on the MW.	+
Sovon & Vogelbescherming	Bird populations and rare species have settled on the MW.	+
Research institutes	Unique and interesting area for research insitutes.	++
Commercial fisheries	Fish species are present around the MW, however no improvement in biodiversity has measured yet and besides area for commercial fishing is lost as it became land.	0
Society	Learning about the ecological processes and importance of the MW from visiting the islands.	++

Table 7 Important beneficiaries related to main function 2

A practical and transparent method described by Klooster et al. (2018), is to value an ecosystem in biodiversity points (in Dutch known as 'Natuurpuntenmethodiek'). The biodiversity points are calculated by multiplying three components: the area of natural ecosystems affected (in hectares or square kilometers), the ecological quality of the area, and a weight factor per type ecosystem. This method was applied on lake Markermeer by van Puijenbroek & Sjitsma (2009). A separation in the following ecosystems was made: shore zones (9 km^2), shallow zones without water plants (8.5 km^2), shallow zones with water plants (76.5 km^2), deeper water (600 km^2) and marsh (0 km^2). The quality was derived from the biological WFD indicators.

*Biodiversity value (points) = surface of ecosystem (km^2) * quality * weigh factor*

Van Puijenbroek & Sjitsma (2009) make an estimation of the value of lake Markermeer of 286 points. They estimated that to meet the WFD goals in lake Markermeer, between 375 and 416 nature points are needed. Their estimation to meet the Natura 2000 is to improve the waterfowl populations, an estimation of 358 points was made to meet N2000.

The MW project (1148 ha as described in van Riel et al., 2017) might have changed the biodiversity points. Therefore, the value of lake Markermeer with the MW was calculated. This value (Table 22 Biodiversity points calculated for lake Markermeer with MWis derived from the data in van Puijenbroek & Sjitsma (2009), van Riel et al. (2017) to calculate the changes in area. In addition, the ecological quality indicators as described in Mouissie (2019) were used as they were also used by van Puijenbroek & Sjitsma (2009).

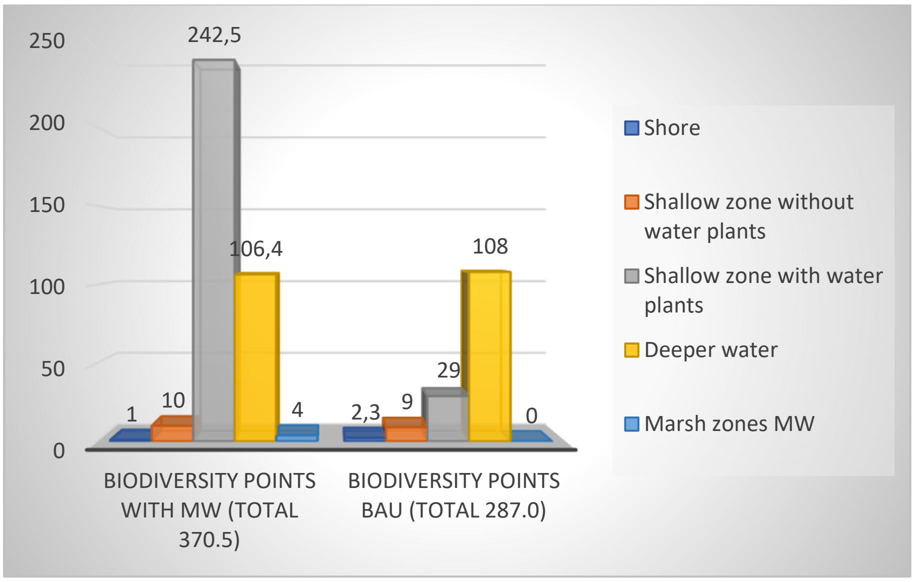

Figure 14 Biodiversity points shown for MW (based on own calculations) and BAU (Based on Puijenbroek & Sjitsma (2009)

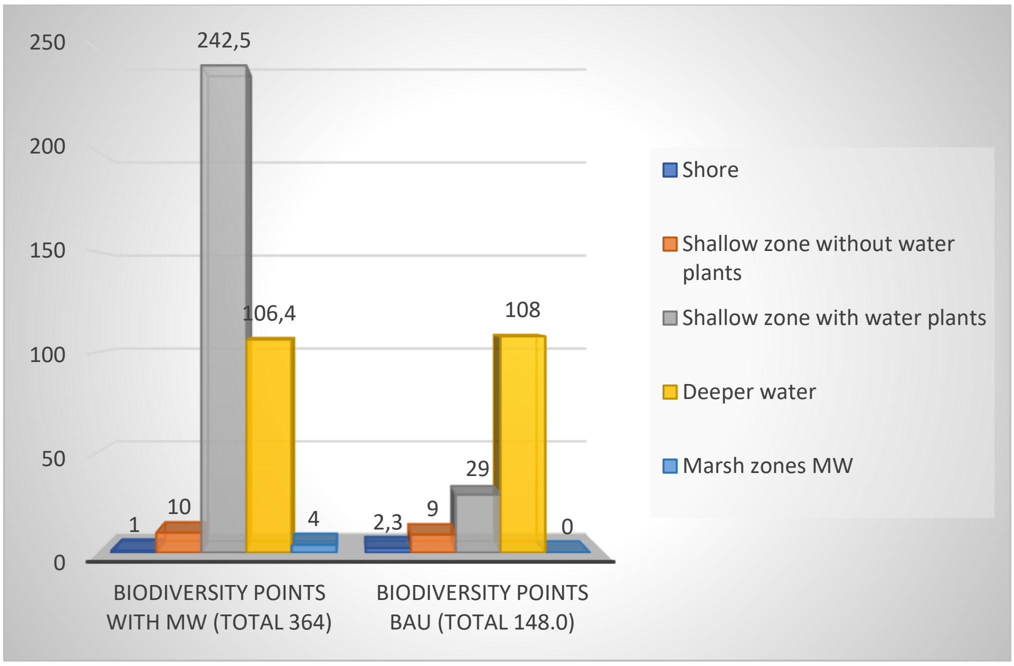

Figure 15 Biodiversity points shown for MW and BAU with applying weigh factors (Based on Puijenbroek et al., 2014)

According to this calculation and the assessment of van Puijenbroek & Sjitsma (2009), the goal of N2000 in biodiversity points is reached. However, it is important to also look at the goals separately as not all goals are reached yet when looking at other figures. In addition, this is mentioned in Puijenbroek & Sjitsma (2009): This method is an indicative calculation of the total biodiversity value and does not provide information about the separate goals and objectives of Natura 2000. The biodiversity points for BAU and MW are shown in Figure 14. As weigh factors were not applied in the calculation of van Puijenbroek & Sjitsma (2009), but were applied in later research on biodiversity points (van Puijenbroek et al., 2015), two calculations were made (Figure 14 and Figure 15).

The monetary value of the provision of habitat is estimated with the regression model of Ghermandi et al. (2008). This method has been applied in ES assessments to calculate the value of habitat provision (e.g. in da Silva, 2012).

The method and calculation are further explained in Annex I. The total annual value that was calculated for services that can be applied on the MW (biodiversity enhancement, water quality, non-consumptive recreation and aesthetic value) the MW lays in between €53,987 and 140,295. When applying the value of Natura 2000 area by Kuik et al. (2006) on the MW, an annual benefit for the provision of habitat including the supporting services, is much higher €667,320 (€590*1,148 ha). In addition, in Ghermandi et al. (2008), the service of biodiversity enhancement in humanmade wetlands is estimated €1,719 per ha per year based on Meyerhoff and Denhardt (2007). This would lead to a value of €1,973,412. Therefore, a first attempt to estimate the total value of main function 2 is between €53,987 and €1,973,412. However, this value contains many uncertainties and is a wide assumption that needs to be further researched and verified.

5. Discussion

5.1 Key outcomes of the study

This study is a first attempt to estimate the economic value of the different ES provided by the MW and thereby underpins the importance of including the economic value of ES in practice. The economic value of the MW project is particularly interesting to stakeholders that benefit from the project and this opens possibilities in financing options for upscaling and similar NBS projects. However, this study does not provide a complete economic value of the MW as not all functions of the MW and therefore not all possible services are included.

The ES related to the main functions building with dredged material and creating habitats were explored and valued as far as possible. This was done according to TEEB and the study of Hüsken (2020). The benefit provided by the two main functions were mostly valued qualitative. Even though many research gaps were discovered during this research and therefore broad assumptions were derived when estimating the economic value of the ES, the results are valuable as they provide information about the relative benefits of ES of the MW. In addition, they touch upon important categories of stakeholders that could be approached for the upscaling or similar NBS projects, on national or international scale. As a reference, global estimated values derived from the regression model of Ghermandi et al. (2008) and the study of ten Brinke et al. (2011) were applied to the provided habitat. A net benefit between €53,987 and €1,973,412 was derived from these studies. These values give a rough estimation of the total value of the ES provided by the two main functions of the MW. However, these values are derived from other areas and should therefore only be interpreted as an estimation.

A value of 370.5 biodiversity points was measured for lake Markermeer with inclusion of the MW and compared with the situation BAU, which has a value of 287 points as calculated by Ten Brinke et al. (2011). This value indicates that the provision of several habitats for flora and fauna contributes to the Natura 2000 goals, the Birds- and Habitat directive, and the ecological component of the WFD. However, it cannot be concluded that the goals are reached yet as this method gives a relative indication of the total biodiversity value and does not provide information about the monetary value or separate goals and objectives of Natura 2000.

According to Hein et al. (2006), including stakeholders of different scales enhances the applicability of ES valuation to support decision making. In addition, it provides a basis for determining the size of potential compensation payments to users. In this study, the main beneficiaries are the wider public, the government, NM and Boskalis.

5.2 Limitations of the study

It has been challenging to quantify and value ES with the current availability of data and monitoring results. This limitation is mentioned in many ES assessment studies (e.g. da Silva, 2012; Barbier, 2013). According to Barbier (2013), the biggest challenge in quantifying and valuing ES is inadequate knowledge to link individual physical changes in ecosystem structure and function to the production of valuable goods and services. In addition to the MW project, for instance, there are other projects that try to enhance the water quality and ecological quality in the lake. The effects of the individual projects have not been studied separately.

Moreover, it was challenging to value the ES separately and besides to avoid double-counting of ES. Therefore, it was decided to estimate the monetary value only on the main functions and not on the separate ES derived from the functions. However, as it is important to include the relative signifiance of services, a hierarchic order of the relative value of ES could be included. Besides, some services conflict with each other; trade-offs. Additional research focusing on the trade-offs between services would give additional information of the importance of a certain ES in relation to other services of the MW.

5.3 ES of the MW in the context of previous studies

According to Barbier (2013), there is a growing number of studies in the field of ES and valuation methods. Research is still trying to improve on valuing ES and strengthening the various methods. Many studies provide ES assessments, but these studies often come with research gaps and complexities.

As the MW is a unique project, valuing ES of a similar nature restoration project in the Netherlands has not been done before. The study of Blom, Smit & Warringa (2012) provides three case studies on valuing the economic benefits derived from ES in N2000 protected areas in the Netherlands and Belgium. Mostly qualitative values were given, and benefits they calculated were often derived from other studies. A very interesting aspect of their study is that besides calculating ES benefits, they research for (alternative) co-financing options. In addition, the most comparable assessment study in this field was provided by da Silva (2012). It values the ES provided by Steart Peninsula, a coastal nature conservation management project where farming ground was changed into wetland habitats. Da Silva followed the steps as used in Defra (2007). This framework was also mentioned and used in Klooster et al. (2018), which has been used as a guideline in this research paper.

5.4 Recommendations for further research

There certainly is a need for a longer period of monitoring activities on the MW to get more data to apply on valuation methods for ES. Moreover, there is a need for further studies on ecosystem valuation as there are uncertainties in the economic valuation steps, as mentioned in the above paragraphs.

Various KPI’s are available to quantify the physical effects of a measure (in this case the MW). However, the KPI’s could not always easily be linked to the available monetary valuation methods. In addition, connection of the KPI’s to the different stakeholders was not always possible. An example is the value of knowledge that is provided by the construction of the MW. KPI’s are provided on this service in the literature to quantify the ES (e.g. Maes et al., 2014). However, in practice this ES is only valued qualitative and valuation techniques have not been found in literature and other ES valuation studies. One important result is that for upscaling, less research would be needed as a lot of knowledge is already there from the first phase which enhances efficiency and therefore probably decreases costs. To be able to value this service, additional KPI’s and valuation methods should be developed.

The costs of the project and the contribution of the stakeholders is known. However, the extent to which a certain investment indeed contributed to a certain ES was not researched. The costs in relation to the benefits are therefore important to include in further research. According to Warringa, Blom & Smit (2012), it is also important to engage stakeholders in the process. The findings of this study could therefore be presented to stakeholders, for example by organizing a workshop. The results could then be verified which strengthens the results.

In addition, this research could be complemented by including additional main functions of the MW and ES described in the qualitative assessment. One important service that is expected, is that the MW are supporting flood protection of the Houtrib dike, which probably enhances the lifespan of the dike and therefore decreases strengthening costs. In addition, recreation on the islands and increased recreation in lake Markermeer delivers additional economic value to the MW. Finally, future uncertainties such as climate change are not included in this research but are important to take into consideration.

6. Conclusion

This study assesses the ES that the MW provide with regard to building with dredged material and creating habitats, to highlight the significance of ES in policy and practice. The economic and societal benefits have been assessed which affect a broad range of stakeholders involved in the MW project. In addition, this research highlights stakeholders that can potentially invest in the upscaling of the MW project. First, relevant ES in relation to two main functions were established and KPI's were defined. Second, the physical effects were gathered from literature, reports and experts, and the MW was compared with the BAU scenario. Third, valuation methods were applied and where possible, the physical effects were monetized. A total benefit between €53,987 and €1,973,412 was calculated in relation to the MW by applying a meta-analysis model and benefit transfer. This study is therefore provisional, and not a complete analysis of the economic value that the MW provide. In addition, this research has important limitations as research and monitoring on the MW are still in process, and therefore data was not always sufficient to apply valuation techniques. Moreover, continued progress in the concept of ES and valuation methods will be essential to improve ES assessments so that the economic value of services provided by nature can be applied on a more regular basis in policy and practice.

6. References

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Annexes

Annex A

TEEB classification system for wetlands

Provisioning services	**Examples of indicators (Maes et al., 2014)**
1. Food	Crop yield, climatological parameters
2. (Fresh) water supply	Evapotranspiration, population density
3. Raw materials	Reeds cutting
4. Genetic resources	Land cover
5. Medicinal resources	Land cover
6. Ornamental resources	-
Regulating services	
7. Air quality regulation	Deposition velocity, pollutant concentration
8. Climate regulation	Above and below ground biomass
9. Moderation of extreme events	Annual flood, hazard
10. Regulation of water flows	Ground water, nutrient retention
11. Waste treatment/ water purification	Human excretory, nutrient deposition
12. Erosion prevention	Erodibility, land use, slope, soil char.
13. Nutrient cycling/ maintenance of soil fertility	Soil char., land cover, nutrient retention
14. Pollination	Cost of bees, crop yield
15. Biological control	Pest density
Habitat services	
16. Lifecycle maintenance (e.g. nursery service)	Above ground biomass
17. Gene pool protection (conservation)	Land cover
Cultural services	
18. Aesthetic information	Distance to scenic site, protected areas
19. Opportunities for recreation and tourism	Accessibility, cultural heritage, footpaths
20. Inspiration for culture, art and design	Land use, land cover, landscape values
21. Spiritual experience	Not found in Maes et al. (2014)
22. Cognitive information (education and science)	Not found in Maes et al. (2014)

Table 8 TEEB classification of TEEB for wetlands (Russi et al., 2013)

Annex B

Interviews

T. Vijverberg (Dutch) 26-05-2020

In essentie is de MW een commercieel aanlegproject, een project dat op standaard Rijkswaterstaat (RWS) wijze op de markt is gezet. Het speciale aan de MW is, dat het project een andere driver heeft dan normaal gezien het geval is; namelijk het ecologisch ontwikkelen van het Markermeer. Het is daarnaast een landaanwinning wat lokaal bijdraagt aan vastgoedkontwikkeling, uitbreiding van de steden en kustbescherming. Als bouwmateriaal is Holocene klei uit het Markermeer gebruikt.

Het unieke aan dit project is het vergroten van de ecologische waarde. Vanuit maatschappelijk oogpunt en ecologisch oogpunt. Hoe kunnen we dat maken? De manier van benaderen werd dus omgedraaid, wat nieuwe kennis oplevert. Daarnaast was de vraag; Hoe bouw je met dit materiaal? Hoe doe je dit uitvoeringstechnisch?

De kennis voor de bouw van de MW was deels al in huis. Kennis omtrent berekeningen en de aanleg was er bijvoorbeeld wel, al zijn sommige dingen aangepast tijdens het proces. Bepaalde opgedane kennis is ook weer meegenomen. Het lastige blijft dat kennis vooral onder de mensen zelf blijft. Wel is er opgedane kennis in rapporten opgeschreven. Dit is kennis met commerciële waarde en deze blijft intern. Specifieke technisch inhoudelijke onderwerpen zijn met studenten uitgediept, die kennis wordt wel openbaar.

Kennis die wordt opgedaan draagt deels ook bij aan KIMA, het gedrag van stranden bijvoorbeeld. Dit is de technische/ecologische kennis. Uitvoer-technische kennis met commerciële waarde wordt over het algemeen niet gedeeld. Wat er wel gedaan wordt binnen het projectteam (ook met opdrachtgever) zijn inhoudelijke sessies, over de hoofdthema's en de grootste risico's. Hier vind kennisoverdracht plaats naar de opdrachtgever.

Het doel was het creëren van habitat met gebaggerd materiaal. Hergebruik van materiaal gebeurt normaal voor zover dat mogelijk is. Er lopen wel dergelijke projecten bij Boskalis, al zijn dat meestal geen projecten die specifiek als doel hebben om natuur te creëren. Een voorbeeld zou de herstelwerkzaamheden ter bescherming van het vogeleiland Griend zijn in 2016. Het eiland dreigde weg te spoelen en heeft een brede vooroever gekregen ter bescherming van verdere afslag. Daarnaast is de suppletie met zand op Oosterschelde, wat puur voor ecologisch herstel is gedaan, een ander voorbeeld. Een dergelijk project komt niet vaak voor, zeker niet internationaal gezien. Wel is er in Engeland voor de National Society Birds een project gedaan: Cliffe Pools Habitat Enhancement. Een project wat wil laten zien dat habitatontwikkeling kan bijdragen aan het verhogen van biodiversiteit. Er zijn putten uitgegraven, en gebaggerd materiaal vanuit de omgeving is gebruikt. Dit project is echt een voorbeeld van de Beneficial use of sediments.

Internationaal was en is er veel aandacht voor de MW, wat het een heel leuk project maakt. Of de MW nu echt verandering heeft gebracht en meer soortgelijke projecten heeft opgeleverd valt moeilijk te zeggen. Het is een voorbeeldproject wat je met gebaggerd materiaal zou kunnen doen. MW is ook een voorbeeld van een NGO als klant. Je werkt niet vaak voor NGO's, maar maakt het wel heel interessant.

Hoofdcompartimenten zijn gemaakt met de Holocene klei, en een deel met zand. Het is een mix van materiaal. Het fijne slib wat in de geulen nu zinkt, is op dit moment nog niet gebruikt. Er is nog geen concreet idee of en wanneer dit kan worden gebruikt omdat het gedrag van het materiaal anders is dan het materiaal waar we nu mee bouwen en daardoor lastig te voorspellen. Nu zijn het slechts heel dunne laagjes. Daarnaast, hoe hoger je productie en hoe groter je machine, hoe groter je de eilanden kan maken. Met het dunne slib zou dit langzamer gaan en zover zijn we nog niet. Het materiaal voor

MW hoefde overigens niet schoon gemaakt te worden. In havens is dat vaak wel het geval, wat het complex en duur maakt.

In theorie is dit materiaal ook wel bruikbaar voor een andere doeleinden, dat ligt aan eisen voor sterkte van landaanwinning. Ligt er echt aan wat voor doeleinden je het gaat gebruiken. Voor habitat is de sterkte-eis heel laag, dus makkelijk om het materiaal geschikt te houden. Hoe sterker het materiaal moet zijn, hoe meer kosten dit met zich meebrengt. Economisch gezien moet het wel rendabel zijn. In theorie kan het, maar brengt risico's en kosten mee.

Marktprijzen zijn heel specifiek voor slib en zand. Transportafstanden en kosten verschillen heel snel, zelfs al voor de andere kant van het meer zou het erg kunnen verschillen. De MW zijn kostenefficiënt gebouwd doordat er winputten vlakbij waren met een redelijk hoge productie van materiaal. Als je dit 10 of 20 km verplaatst brengt dit al veel hogere kosten mee. Het hangt echt af van de lokale situatie, in hoeverre grondverbetering moet worden toegepast en van hoever het zand vandaan moet komen. In Japan wordt er wel veel gebouwd met fijn materiaal omdat het zand daar van ver weg moet komen, maar dit zijn complexe en dure technieken. Los van financiële vragen en vragen rondom wetgeving en politiek (of je zand mag halen uit ander land), kan het technisch wel gerealiseerd worden. Zand wordt daarnaast schaarser dus met bepaalde thema's zijn we wel bezig.

Lokaal hebben de MW zeker effect. Het creëren van verschillende habitats in een meer met harde randen levert ecologische ontwikkeling op. Een ander voorbeeld in het meer waar natuurontwikkeling heeft plaatsgevonden is Trintelzand. Als je het nu zo ziet is het ecologisch gezien lokaal behoorlijk vooruit gegaan. Op de eerste monitoringsresultaten zie je wel echt effect. Wat moet je met het meer als geheel doen om ecologisch te verbeteren? Gradiënten tussen land en water zijn van belang. In bepaalde delen wordt al gedaan wat nodig is, maar de westkant is ecologisch gezien nog niet aantrekkelijk.

T. van Kessel 06-05-2020

T. van Kessel heeft kennis van slib en sediment dynamica. Vanuit die expertise is hij bij de MW betrokken geraakt. De ANT projecten waren de aanleiding voor de MW, er wordt niet voldaan aan KRW. Er zijn verschillende workshops gehouden en een van de varianten was het OER moeras. Kennis nodig van slib dus van daaruit werd T. van Kessel uitgenodigd.

Boskalis zat in het winnende consortium. Bouwen met slib. Efficiency: hoeveel hectare natuur voor hoeveel geld. RWS trok dat en NM zat hier ook. De kennis was er deels al door een proefeiland en wat monitoring. Algemene kennis over consolidatie was er al wel, deels ook via afstudeerders en proeven. Adaptief beleid.

In de eerste fase zijn de eilanden ontwikkeld van Holocene klei. Het ingevangen sediment kan gebruikt worden voor de natuurlijke uitbouwing. Tot op heden is dit nog niet gedaan. Dat heeft ook met kosten te maken. Klei is veel goedkoper dan het vers ingevangen materiaal. Tot nu toe 100% holoceen klei gebruikt. Slib is duur vanwege het grote areaal. Operationeel veel lastiger. Slibvangput.

Natuurlijke aanslibbing moet het slib brengen, zou pas over een paar jaar zou zijn. Op dit moment holocene klei. Zand van onder Markermeer wordt in bouw gebruikt/ commercieel. Via pijpleidingen naar MW gebracht.

Holocene klei gebruik: ook rijpen voor dijkversterking of op andere plekken wetlands creëren (maar hier zitten transportkosten aan verbonden).

Slibmodel: ook met de MW in het rooster, al wel wat scenarios. Resolutiekwestie (rooster met hogere resolutie/ trager). Nog bezig met een optimum vinden. Wat heeft het betekent voor de troebelheid van het Markermeer? Er spelen veel factoren mee, zoals meer wind=meer troebelheid, waterplantontwikkelingen, bodem substraat en schelpdieren. Als je een afname in slibconcentratie ziet kan het ook door allerlei andere factoren zijn. Met een model kun je verschillende scenarios doen (vb zelfde wind met en zonder MW). Nog geen eindruns gedaan en meetgegevens rapporten nog niet af. Wat er wel zien: er wordt slib ingevangen door de slibgeul, wel minder dan verwacht. Luwte: meer slib. Ideeen die er waren klopt wel aardig. Verwachting nog steeds dat het nog wel werkt, alleen op welke schaal?

KIMA moet eind volgend jaar alle metingen af hebben, en dan staat er nog tot half 2022 voor eindrapportage. Medio 2022 moet het klaar zijn. Ook Ecoshape: eind dit jaar (tussenrapportage).

Onderzoekscompartimenten: openbaar. Andere compartimenten zijn eerder aangelegd, daar valt ook van te leren. Die data delen is lastig. Perceptie Thijs: Empirisch en praktisch onderzoek, wat ze merken is dat hun voorspelling/ grote compartimenten met inhomogeen materiaal (met zand en kleiballen). Ze zien wat minder in het van te voren doorrekenen en meer in ruwe schatting en adaptief bezig zijn. Data die ze hebben is lastig te interpreteren. Data niet delen door waardevol. Enorm conclurrentievoordeel. Optie 2: niet heel veel data/ lastig te interpreteren. Praktische kennis zit bij Boskalis. Bouwproces is een andere expertise.

De Bak met water zit niet meer op slot, er is wat reuring. De milieukwaliteit verbetert.

Annex C

Function	*Service*		*Description of expected effect*		*Benificiaries*							*Revenue Mechanism*	*Procurement strategy consideration*		
Naam/Functie	**Geleverde diensten**	**Type**	**B.A.U**	**Na implementatie**	**Rijks-overheid**	**NM**	**Aannemer**	**Bedrijfs-leven**	**BV-Ned**	**Maat-schappij**	**Overig**	**Potential Revenue flow**	**Inkopen van product, process of R&D**	**TRL**	**Aanbestedingsprocedures**
1. Invangen en vastleggen van slib (hoofdfunctie)	Verbetering van waterkwaliteit	Publiek	verslechtering	Verbetering	√					√		Voorkomen van economische (groei) restricties	Process / R&D	3-4	Innovation Partnership
	Verbetering van bodem ecologie	Publiek	verslechtering	Verbetering						√			Process / R&D	3-4	Innovation Partnership
	Natuurlijk grondstof beschikbaar als bouwstof	Common res.	niet aanwezig	Verbetering			√	√				Slib is nu afval product - betalen voor afvoer	Product / R&D	3-4	Innovation Partnership
	Kennisontwikkeling over inwinning van slib	Publiek / Club	niet aanwezig	Verbetering			√	√	√			Minder kosten voor baggeraars (slib zich in centraal depot)	R&D	3-4	Pre-commercial procurement
2. Bieden van nieuwe habitat (hoofdfunctie)	Verbetering flora	Publiek	verslechtering	Verbetering	√	√				√			Process / R&D	3-4	Innovation Partnership
	Verbetering vis populaties	Common res./Publiek	verslechtering	Verbetering	√	√				√	Vissport-vereniging	Lidmaatschap toename / Visopbrengst	Process / Product/ R&D	3-4	Innovation Partnership
	Verbetering vogel populaties	Common res./Publiek	verslechtering	Verbetering		√				√	Vogelaars-verenigingen	Lidmaatschap toename	Process / R&D	3-4	Innovation Partnership
	Kennisontwikkeling over verandering flora en fauna	Publiek / Club	niet aanwezig	Verbetering	√		√	√	√				R&D	3-4	Pre-commercial procurement
	Kennisontwikkeling over bouwen met slib	Publiek / Club	niet aanwezig	Verbetering	√		√	√	√			Slib is nu afval product - betalen voor afvoer/kopen bouwmateriaal	R&D	3-4	Pre-commercial procurement
3. Bieden mogelijkheden recreatie (hoofdfunctie)	Recreatie vanaf het water	Publiek	Aanwezig	Verbetering		√				√	Vaar-verenigingen	Lidmaatschap toename / toegangsprijs/ Liggeld	Process / Product	7-9	"Off the shelf" - beschikbaar
	Recreatie vanaf het land	Club / Privaat	niet aanwezig	Verbetering		√				√	Vogelaars-verenigingen	Lidmaatschap toename / toegangs(overtocht)prijs	Process / Product	7-9	"Off the shelf" - beschikbaar
	Recreatie overnachtingen	Club / Privaat	niet aanwezig	Verbetering		√				√	Landal	Lidmaatschap toename / toegangsprijs	Process / Product	7-9	"Off the shelf" - beschikbaar
4. Beschermen (nevenfunctie)	Betrouwbare en continue levering van diensten	n.a.	niet aanwezig	Verbetering	√	√				√			Process / R&D	3-4	Innovation Partnership
	Self-sustainable	Publiek	niet aanwezig	Verbetering		√	√						Process / R&D	3-4	Innovation Partnership
	Kennisontwikkeling gedrag harde/zachte randen	Publiek / Club	niet aanwezig	Verbetering			√	√	√				R&D	3-4	Pre-commercial procurement
	Kennisontwikkeling natuurlijke dynamiek	Publiek / Club	niet aanwezig	Verbetering			√	√	√				R&D	3-4	Pre-commercial procurement
5. Vervolgfases MW mogelijk maken (nevenfunctie)	Natuurlijk grondstof beschikbaar als bouwstof	Common res.	niet aanwezig	Verbetering			√	√		√		Kosten besparing vervolg fasen / (Minder milieu belasting)	Product	3-4	Competitive Dialogue / Competitive procedure with negotiation
	Logistieke verbetering tijdens bouw vervolg	Publiek / Club	niet aanwezig	Verbetering	√	√		√				Kosten besparing vervolg fasen	Process	4-6	Competitive Dialogue / Competitive procedure with negotiation
6. Leren voor het vervolg (nevenfunctie)	Kennisontwikkeling (totaal)	Publiek / Club	niet aanwezig	Verbetering	√	√	√	√	√				R&D	3-4	Pre-commercial procurement
7. Beheerbaar (nevenfunctie)	Besparing middelen (kosten/materiaal)tijdens beheerfase	Publiek / Club	niet aanwezig	Verbetering	√	√		√				Kosten besparing beheer	Process / R&D	3-4	Innovation Partnership

Table 9 Summary table of services, derived from Hüsken (2020)

Annex D

List of valuation methods for ES

According to Klooster et al. (2018), there are four types of valuation methods for ES:

- Market-based methods
- Revealed preference methods
- Stated preference methods
- Cost-based methods

Market-based methods

Market-based methods are market prices, resource rent and rent prices. The market prices can directly calculate the WTP for goods and services.

Stated preference methods

Stated preference methods are methods as CV and choice experiments (CE) that identify the WTP and preferences of a population and thereby calculate welfare values (Horlings et al., 2020).

Revealed preference methods

Revealed preference methods are travel costs and hedonic pricing (Horlings et al., 2020). The travel cost method is related to recreational ES and calculates the actual travel costs of visitors. The hedonic pricing method determines the value of a (marketed) product in relation to the proximity and quality of the natural environment.

Cost-based methods

Cost-based methods are replacement costs and avoided damage. The replacement cost method is a relevant method for regulating services (flood protection or water filtration) and estimates the value of the service based on the cost that would be associated with replacing the service with a man-made alternative (Horlings et al., 2020). The avoided damage method estimates the damage that would occur when the service would be lost. This method is also mainly used for regulating services, and presumes that individuals are willing to pay to avoid damage (Horlings et al., 2020)

Methods and literature used to define the ES of the MW

As a guideline, *The economics of ecosystems and biodiversity* (de Groot et al., 2010) and *Werkwijzer Natuur* (Klooster et al. 2018), have been used. *Methodologies for defining and assessing ecosystem services* (Haines-Young & Potschin, 2009) and *Economic Valuation Methods for ecosystem services* (Koetse, Brouwer & van der Beukering, 2015) provided insights in how to value the ES. For defining KPI's Maes et al. (2014) and de Rijk & Dulfer (2020) were mainly applied.

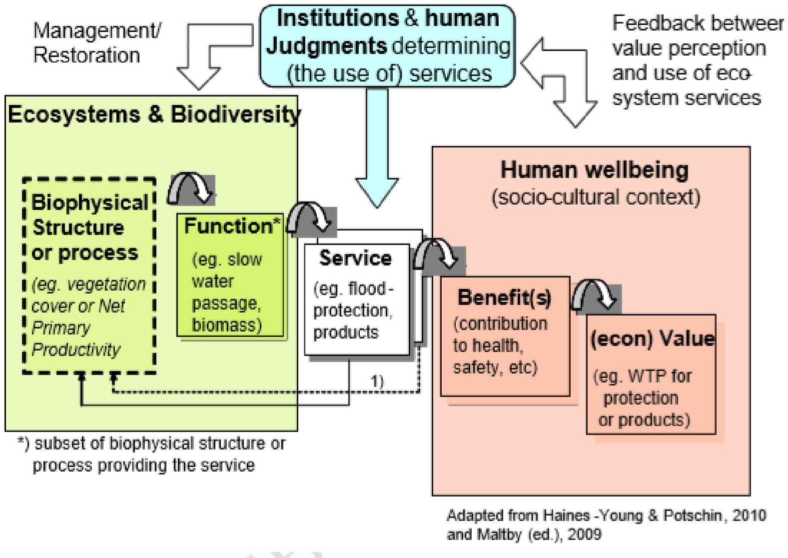

Figure 16 The cascade model of ecosystems, ES and human wellbeing (de Groot et al., 2010, adapted from Haines-Young & Potschin, 2009)

The cascade model shows the steps from biophysical structure and processes towards benefits and economic value. The model is explained by de Groot et al. (2010) through an example: Primary production (a process) is necessary to maintain a fish population (the function). This fish population can be harvested to provide food (service). The fish is a benefit as it contributes to human health and does have economic value as humans are willing to pay a certain amount of money for this fish.

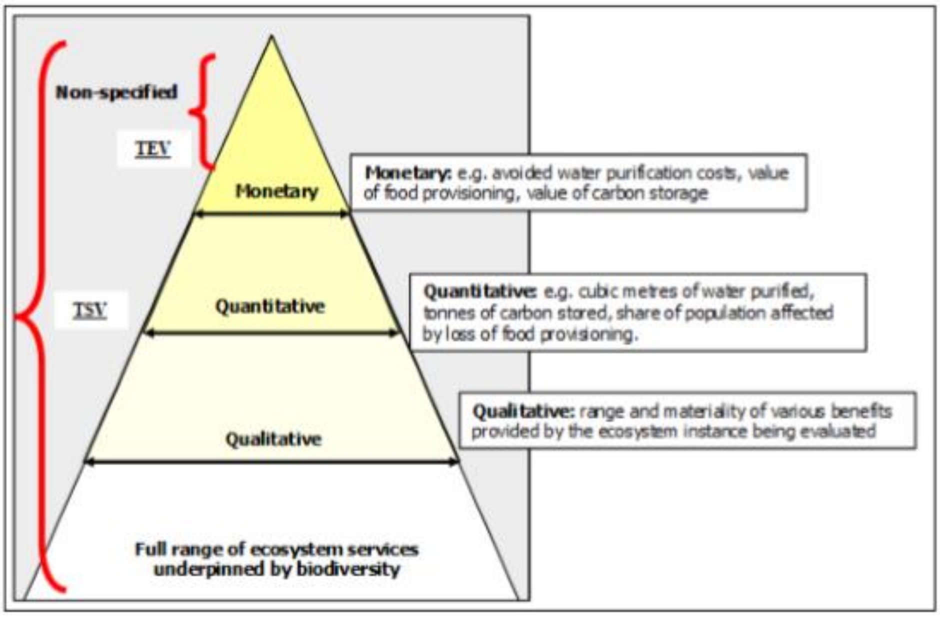

Figure 17 The benefit pyramid and TEV versus TSV (TEEB, 2009)

The benefit pyramid where TEV and TSV are compared, is shown in Figure 17. TEV exists of the monetary value whereas TSV also includes the quantitative and qualitative value, and the full range of ES underpinned by biodiversity (TEEB, 2009).

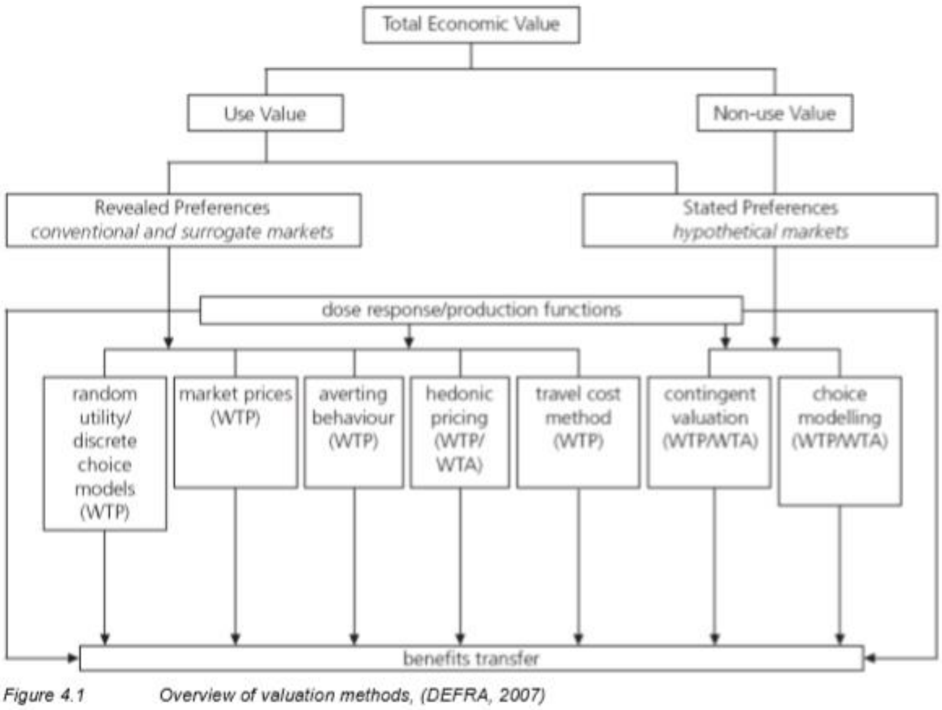

Figure 18 TEV and valuation methods (Defra, 2007)

The TEV framework can be used to define the methods that can be used for valuing ES (Figure 18). ES with use values can best be valued by RP whereas non-use values can best be valued by using SP methods (Defra, 2007).

Annex E

Quantitative assessment tables main function 1

1. Water quality

KPI	Unit	BAU (2016)	MW (2020)
pH	-	7.7-9.1 (Van Riel et al. 2019), 8,7 (Mouissie, 2019).	Expected is that the pH will not change because of the buffer capacity of the soil of lake Markermeer (RWS, 2014).
Cl	Mg/l	Average concentration measured at 4 locations in lake Markermeer: 120 mg/l (RWS 2014, van Riel et al. 2019)	No results and effects known yet, however also not expected according to the EIA (RWS, 2014).
Temperature	C	Depends on location, time of the year and depth (van Riel et al. 2019). Central and location MW: average around 15 C, became a little higher over time.	Water temperature is important in relation to several species in the lake (van Riel et al., 2019). Temperature is being measured near the MW, however results or expected effects of the MW were not found.
Oxygen	Mg/l	Low concentrations: < 3 mg/l (van Herpen et al., 2015).	No data was found.
Transparency **Sediment concentration**	m Mg/L	0.5-1 (Maarse, 2014) Average concentration of the lake lays between 0-80 mg/L. (0 on the shores, in the middle around 80). Around MW sediment concentration between 30-50 mg/l (Maarse, 2014). De Lucas Pardo et al. (2013): average concentration of 50 mg/l	In the lee zone, behind the MW higher transparency was measured (van der Winden et al., 2019). RWS, 2014: Will increase between 0-10% Van der Winden et al. (2019) concludes that the clarity of water in lake Markermeer increased local around the MW. This was measured by satellite photos. However, construction works of the MW still disturbs the natural flow of water and may cause more turbidity as expected (RWS, 2014). Drawing updated conclusions may be valuable once the construction work is finished. Noordhuis & Blaas (2016) conclude that simulations and calculations of the construction of the MW predict that the MW will influence water sediment concentrations at the eastern side of the islands and the middle of the lake. However, they conclude that it is important to place more monitoring pillars around the MW to measure effects.

			EIA (RWS, 2014): Modelling and calculations expect that a large area (Houtrib dike towards the middle of the lake) will decrease the concentration with 15-30 mg/l.
Phosphor (P)	Mg P/l	Yearly mean P in 2015: PO_4 0, Ptotal 0.04. Decreasing trend, which is according to van Riel et al. (2019) partial due to different monitoring methods (Van Riel et al., 2019). Mouissie (2019): The P levels meet the standard.	EIA (RWS, 2014): groundwater may be disturbed by sand extraction and increase concentration P. Mouissie (2019): The P levels meet the standard, decrease of concentrations will not lead to improvement of quality.
Nitrogen (N)	Mg N/l	Yearly mean N (Van Riel et al., 2019) in 2015: NO_3 0.12, NO_2: 0.01, NH_4: 0.015 Mouissie (2019): The N levels meet the standard.	Compared with 2014, in 2017 the N concentrations in the lake (that already were sufficient) were slightly improved (Mouissie, 2019). However, MW have not been taken into account but will be taken into account in the next report of 2020.
Chlorofyl	µg/l	Around the MW 32.5-40 (Maarse, 2014). Ranges from <=25-50 in the whole lake.	Van der Winden et al. (2019) concludes that on the lee zones where primary production and plankton develops, the clarity of the water increases. Nutrients in soil and water are increased. More primary and secondary production.
Classes WFD (qualitative)	1-5	Biological: phytoplankton and macrofauna are moderate/ sufficient, the other water flora and fish are qualified as ‘good’. Final qualification: moderate/ sufficient Chemical: P and N levels are good, however there are specific pollutants in the water which makes the final qualification a ‘not sufficient’ (Agenda IJsselmeergebied 2050, n.d.).	No results yet, however, in 2017 there were still specific pollutants found in the water (Mouissie, 2019), which makes the chemical status likely unchanged. The MW have increased spawning area for fish so that may be qualified as ‘good’ and increased the amount of water plants between the MW and the Houtrib dike (Vonk et al., 2019), which may be qualified as ‘good’. There are however, many factors that influence water quality in lake Markermeer. According to EIA (RWS, 2014): 0/+

Table 10 Results of quantifying BAU and MW for water quality

2. Soil ecology

KPI	Unit	BAU (2016)	MW (2020)
Soil characteristics		The lake is covered with a sediment layer between 10-20 cm (Kelderman et al., 2012).	Chemical and physical indicators are measured by KIMA around the MW (de Rijk & Dulfer, 2020). However, no results are available

			yet. Increase of shallow zones can improve the soil ecology (Vonk et al., 2019)
Nutrient cycling		Due to resuspension processes and high levels of turbidity, primary production is limited.	According to Van der Winden et al. (2019), on a local scale, an improved availability of nutrients in the soil was measured. This is beneficial to the growth of plants and algae, and on local scale, the primary production increased.
Soil biota		The ecological quality of the lake is negatively influenced by the sediment layer which suffocates the benthic zone. Bioturbation processes can increase nutrient concentrations and aerate the upper layer of sediment (Saaltink et al., 2019).	Shallow zones are created which in theory improves soil biota (van Riel et al., 2017). Sulfur bacteria are present and are influencing the food web and reduce the wind induced movement of sediment (de Rijk & Dulfer, 2020).
Geomorphology	-	The bed exists of clay and loam that was formed in the Holocene. This is covered with a fine silt layer which is eroded material from the IJssel river (Kelderman et al., 2012).	The Holocene material has been used to construct the MW and 1000 ha of islands and underwater landscape were created between 2016-2020.
Accumulation of sediment around MW and in gully	cm	Kelderman et al. (2012) determined sediment characteristics, the average thickness of the layer is estimated between <10 and >20 cm.	There is a layer of 20 cm sediment captured in the gullies, and 5-10 cm around the MW. However, according to experts (van Kessel, personal communication, 06-05-2020) this process is going slower than expected.

Table 11 Results of quantifying BAU and MW for soil ecology. KPI's were defined according to de Rijk & Dulfer (2020), Adhikari & Hartemink (2016) and Maes et al. (2014).

3. Sediment

Indicator	Unit	BAU (2016)	MW (2020)
Dredged material: Sand	m^3	3-4 million m^3 Sand is yearly extracted from the Ijsselmeer area (Agenda IJsselmeergebied, n.d.)	NM (2017): For the construction of the first island in 2016, 4,500,000m^3 sand (beach, walking paths, soft edges and harbor). 75,000 tons of stone for the hard edges and harbor dams. In 2017: 7,500,000 m^3 sand for the island In 2018: construction of the fifth island, 1,000.,00 m^3 sand. Total: 13 million m^3 sand
Dredged material: Holocene clay (including peat and sediment)	m^3	0	NM (2017): In 2016: 3,500,000 m^3 material for the construction of marshes. In 2017: 8,500,000 m^3. In 2018: 2,000,000 m^3.

			Total: 14 million m^3 of Holocene clay.
Habitat created from dredged material in lake Markermeer	ha	0	MW create 1000 ha of habitat. Besides, project 'Trintelzand' creates 155 ha of habitat

Table 12 Results for quantifying BAU and MW for fine sediment as building material. KPI's to measure the physical effects of the construction of the MW with dredged material were defined according to de Rijk & Dulfer (2020) and Klooster et al. (2018).

4. Knowledge derived from building with fine sediments

Indicator	Unit	BAU (2016)	MW (2020)
Publications in scientific literature	Number of publications	US: Minello et al. 1987, Yozzo et al. (2004), UK: Bolam et al. (2005).	Several publications on the MW and use or characteristics of dredged material (amongst others Barciela Rial et al., 2017).
Number of similar projects		Boskalis (n.d.): RSPB cliffe pools habitat enhancement (started 2015). Griend, creating a birds island in le Havre (created from dredged material) CEDA (n.d.): In total 39 case studies were found which apply beneficial sediment use. Examples are Habitat and wetland restoration Brightlingsea (started 2016), Between 2012 and 2016, several projects to restore the eroding marshes at the mouth of Lymington Estuary (UK) Habitat restoration and creation of islands: 8 case studies found that started before or in 2016 (CEDA, n.d.)	According to Vijverberg (personal communication, 26-05-2020), not easy to answer. In lake Markermeer, project 'Trintelzand' creates habitat and simultaneously strengthens the Houtrib dike. 'Nationaal park Nieuw Land' is the overarching project to improve nature in and around lake Markermeer and create more habitat. Boskalis (n.d.): 'Boskalis and Wetlands international will intensify collaboration to enhance and restore coastal wetland habitats (both to support coastal protection and fisheries, and to store some of the worlds largest quantities of carbon.) Moreover, we are committed to strengthening the knowledge base and sharing the learnings from the collaboration with the sector as a whole.'
Knowledge transfer		?	KIMA, CEDA, Ecoshape, and educational institutes. According to Dulfer & de Rijk (2020), the KIMA congress, excursions, workshops, presentations and publications are all contributing to dissemination of the knowledge provided by KIMA.

			Collaboration between Boskalis and Wetlands international (Boskalis, n.d.) Educational element for visitors about the behavior of sediment at the sediment compartments (Boskalis 2015).

Table 13 Results of quantifying BAU and MW for knowledge derived from fine sediment as building material. KPI's to define the knowledge in terms of ES, are derived from Maes et al. (2014).

Annex F

Quantitative assessment tables main function 2

1. Improvement flora

Indicator	Unit	BAU (2016)	MW (2020)
Plant species	Nr of species	Above-ground: 0 EIA (RWS, 2014): Water plants have not been measured on the location of the MW because of depth and type of the soil (Noordhuis & Blaas, 2016). In total: 12 water plant species are present in lake Markermeer (Vonk et al., 2019)	Above-ground: 127 (NM, 2018a) According to Vonk et al. (2019) it is expected that new plant species will settle, but this is not confirmed yet.
Nature protection law species	Nr of species	0	0
Red list species	Nr of species	0	2
Natura 2000 habitattypes	Nr of habitat types	1 (Meet requirements of the Nature thermometer 2014) Thermometer level H3140: 1.05 De H3150 was not incorporated in Natura 2000 in 2014, and because of that not measured.	2 (Meets requirements of Nature thermometer 2017 by Mouissie, 2019) H3140: 0.95 H3150: 1
Habitat creation	Area in ha	0 Habitat suitability Chara spp. and stonewort aound the MW (Maarse, 2014): 0 (in a range from 0-1) Waterplants: 0 In Vonk et al. 2019, an overview of the water plant cover (%) was given for the period 2005-2016. In 2016 this was 38% covered with mainly starry stonewort (23%), stonewort (10%) and pondweed (3%).	The sandy shore (24 ha) is suitable habitat for stonewort. The shallow water (231 ha) is suitable habitat for stonewort. The shallow pools and marshland vegetation (51 ha) are suitable habitat to stonewort and marshland vegetation. Total: 387 (derived from Boskalis, 2015; van Riel et al., 2017). Vonk et al. (2019, the contribution of the MW is that gradients in depth will lead to more diversity of habitats for water plants

Table 14 Results of quantifying the improvement of flora when comparing BAU and MW

2. Fauna

Indicator	Unit	BAU (2016)	MW (2020)
Species	Nr of species	?	According to van der Winden et al. (2019): mosquitos, several beetle species, rare insects (bath white, papilio machaon, colias croceus, cricket mole, long horned

			grasshopper, red veined darter, hemianax ephippiger, crimson speckled and aglossa caprealis. During an excursion with the knowledge centre for insects (EIS), 28 species were not found in the province of Flevoland before. No results yet, however EIS excursion (knowledge centre for insects) measured 1 snail specie, 20 spider species, and 198 insects. Bats: common pipistrelle, tiny pipistrelle, nathusius's pipistrelle and serotine bat (NM)
N2000 species		Thermometer lake Markermeer in 2014: 1.02 Pond bat lake Markermeer: 920 (hunting area) and 500 (migratory)	?
Red list species		?	?
Habitat creation	Ha	?	According to van Riel et al. (2017): 9 ha beneficial to macrofauna, 231 ha suitable for insects.

Table 15 Results of quantifying the improvements in fauna when comparing BAU and MW

3. Fish

Indicator	Unit	BAU (2016)	MW (2020)
Fish species	Nr of species	21	21 (de Leeuw & van Emmerik, 2019). All the fish species that live in lake Markermeer were present around the MW (Sportvisserij NL).
Red list species	Nr of species	1 (Ide) Biomass: 0.03kg/ha (Kroes et al., 2013)	1 (Ide)
Natura 2000 species	Nr of species	EIA (RWS, 2014): Houting, bitterling, freshwater lamprey, Bibbaud loach, catfish, Miller's thumb.	1, Bibbaud loach is present around the MW (van der Winden et al., 2019). Miller's thumb not found in researched reports.
Habitat creation	Area in ha	1000 ha deep water	357 ha fish habitat + 174 spawning area (Van Riel et al. 2017)
Fish production	Catch in tonnes	195 (pike-perch), 82 (bream), 56	Not found in literature, netto change of zero expected due to a loss of fishing area (20km^2 or 3%), whereas

		(roach) and 55 (perch)	the spawning grounds can improve the abundance of fish in the lake (RWS, 2014).
Number of fishing licenses/ Number of fishermen	Numbers	20	?
Status of fish population	Species composition, age structure, biomass kg/ha	In lake Markermeer, the biomass for fish was estimated 65 kg/ha in 1998 and 20 kg/ha in 2013 (van Herpen et al., 2015)	According to de Rijk & Dulfer (2020), it is expected that the MW positively affect the fish populations in the lake, the young fishes that are now present around the MW will spread over the lake.

Table 16 Results of quantifying improvement in fish populations when comparing BAU and MW

4. Birds

Indicator	Unit	BAU (2016)	MW (2020)
Red list species IUCN	Nr of species	Widgeon, common goldeneye, common tern, godwit (NT), Shoveler (VU), Little gull (CR), Black tern (EN). In total: 7 (Noordhuis, 2014; SOVON, n.d.)	Common tern, widgeon, black-winged stilt, European swallow, common goldeneye, yellow wagtail, meadow pipit, great black-backed gull, godwit, house martin, fieldfare, red-breasted merganser, common sandpiper, redshank, skylark and sea eagle (NT) (17) Ringed plover, little tern, sandwich tern, shoveler, teal and curlew (VU) (6) Arctic tern, whinchat, pintail duck, Kentish plover, wheaterar, snipe, garganey, black tern (EN) (8) Little gull, Montagu's harrier, ruff (CR) (3) Golden plover, gull-billed tern (EW in the Netherlands) (2) In total: 36 (NM, 2018b)
Natura 2000 species	Nr of species and abundance	Conservation objectives for the following bird species were set (Van Riel et al., 2017): great crested grebe, cormorant, spoonbill graylag goose, barnacle goose, widgeon, gadwall, shoveler, red-crested pochard, common pochard, tufted duck, scaup, common	NM (2018b): Cormorant, great crested grebe, spoonbill, greylag goose, barnacle goose, widgeon, gadwall, shoveler, red-crested pochard, common pochard, tufted duck, common goldeneye, smew, goosander, little gull and common tern were present.

		goldeneye, smew, goosander, coot, little gull, common tern and black tern.	Coot was not in this list, however has been seen on the islands (waarneming.nl).
Habitat creation	Ha	Due to land reclamation and artificial shores, habitat and habitat quality for birds was decreased over the past decades. In addition, the degraded quality resulted in lack of food which decreased presence and numbers of birds (species).	In total 965 ha created for different bird species

Table 17 Results of quantifying improvement in bird populations when comparing BAU and MW

5. Knowledge flora and fauna

Indicator	Unit	BAU (2016)	MW (2020)
Education on MW Number of visitors, Excursions, Visitor centers	Numbers	0	Visitors do not pay for education; however, visitors do learn during their visit. In 2019, 20.000 visitors visited the MW (personal communication NM, A. Boosten). NM made an indication of the estimated number of visitors per year (Gemeente Lelystad, 2018) is 73,000 per year. In total this will provide between €306.600-438,000, dependent on NM memberships. However, part of the visitors will be children (€3), and partly be part of the bird excursions (€52.5). The profit goes to the management and conservation of the MW. 'Duizend soortendag' a counting species day with volunteers (NM). *Entrance fee of €4.2 for members of NM, and €6 for non-members (NM, n.d.). **Price for bird excursions are €52.5 (NM, n.d.)
Education about MW School learning/ lesson packages Documentaries Newspaper articles	Numbers	0	TV programmes with the focus to educate children; Willem Wever, Klokhuis (3), SchoolTV (2) TV report Eenvandaag, Nieuwsuur, Vroege Vogels, Radioprogrammes (Vroege Vogels, Radio 1 news), Newspapers (New York Times, several Dutch Newspapers). Minecraft in support of teaching sustainable spatial planning in secondary education lessons learned from the MW project (Opmeer et al., 2018). This project was presented on the CSEDU[15] 2018.
Research: monitoring sites by scientists, number of scientific projects, articles, studies	Nr of projects KIMA (Beumer et al., 2017)	0	Yearly meeting of researchers that work on flora and fauna and the food web on the MW, they share their yearly results and plans for the next year (NM, 20-02-2020). Yearly KIMA congress to share new research results about different tracks.

[15] International Conference on Computer Supported Education

			Publications are widespread and a complete overview was not found, Google scholar (21), KIMA publications (6), Universities involved (10), websites: KIMA, NM, Boskalis, markermeerijmeer. Van der Winden et al. (2019) provides a (incomplete) overview of excursions, participation projects, newspapers, and radio and television programs.
Visitors, guided tours	Number	0	2 Walking routes (total 8.5 km) (NM) In 2019: 20.000 visitors (NM, personal communication)
Bird watching sites waterfowl	Amount	0	3 (NM, 2017)

Table 18 Results of quantifying improvement in knowledge on creation of habitat for flora and fauna when comparing BAU and MW

Annex G

Stakeholder Analysis

First, all possible stakeholders have been inventoried by researching the current activities around lake Markermeer. The inventorisation of the IJsselmeer area (Verbeek et al., 2011) was first analyzed. In addition, de Rijk et al. (2018) provides some information about the use and users of the MW.

Stakeholders around lake Markermeer (Verbeek et al., 2011)	NM, Staatsbosbeheer RWS (Ijsselmeer area, North-Holland) Water boards (Zuiderzeeland) Water boards (Amstel, Gooi en Vecht; Hollands Noorderkwartier) Recreatieschap (West-Friesland) Provinces (Noord-Holland, Flevoland) Association for professional charter (In Dutch, Vereniging voor beroepschartervaart) HISWA-RECRON (organization for watersports and recreation in the Netherlands) ANWB (Royal Dutch Tourist Association) Watersport verbond Sportvisserij Nederland (Dutch Association for recreational fishing) Ministry of Agriculture Werkgroep IJmeer Ferry services (Connexxion, Marken Express) Recreation (other)
Activities around lake Markermeer (Verbeek et al., 2011)	Sand extraction Commercial fisheries Commercial shipping (Beroepsvaart) Nature management and conservation Monitoring activities Management and conservation measures (dikes) Barrages Windmoles Sewage plants Power plant Dredging activities Camping & recreation (waterskiing, surfing, sailing, swimming, walking, sports on the beach, recreational fishing, ice skating, recreational flights)
Economic goals (de Rijk et al., 2018)	RRAAM Commerical fisheries Sustainable energy Recreation Mobility
Societal goals (de Rijk et al., 2018)	Open for public Education
Environmental goals (de Rijk et al., 2018)	Landscape of value Area with archeological importance

Table 19 Stakeholder inventory lake Markermeer

Actor	Rol initiatiefase

Projectteam MW	NM	Initiatiefnemer, financier, werven extra financiering, werken aan maatschappelijk en bestuurlijk draagvlak, concept ontwikkeld met RHDHV, lid Stuurgroep Marker Wadden
	RWS Midden-Nederland	Verantwoordelijk uitvoeren aanbestedingsproces, verantwoordelijk beheer grote wateren, TBES doelstellingen, KRW en N2000 Markermeer, bevoegd gezag projectplan Waterwet, beheerder en secretaris Stuurgroep MIJ, lid Stuurgroep Marker Wadden
	RHDHV	Adviesrol aan Natuurmonumenten over procedure/vergunningen
Executing party	Boskalis	Lid winnend consortium aanbesteding, maker ontwerp
	Witteveen+Bos	Lid winnend consortium aanbesteding, maker ontwerp
Investors	Ministerie EZ (inclusief latere LNV)	RRAAM partner, financier, partner WMIJ consortium, gezag passende beoordeling (vogel- en habitatrichtlijn, Natura2000) gemandateerd aan provincie, voorzitter Stuurgroep MIJ, lid Stuurgroep Marker Wadden.
	Ministerie IenM (later IenW)	Financier, partner WMIJ consortium, bevoegd gezag ontgronding rijkswateren (gemandateerd aan ILT), verantwoordelijk uitvoering KRW, in Stuurgroep MIJ namens Rijkspartijen, lid Stuurgroep Marker Wadden.
	Provincie Flevoland	Financier, partner WMIJ consortium, bevoegd gezag natuurbeschermingswet, lid Stuurgroep MIJ, lid Stuurgroep Marker Wadden

Table 20 Actors and role initiation phase MW in Dutch (IJff et al., 2020)

Actor		Rol aanlegfase
Projectteam MW	NM	Verantwoordelijk voor de aanleg, trekker Projectteam Marker Wadden, VZ Stuurgroep Marker Wadden , kernteam KIMA
	RWS Midden-Nederland RWS PPO RWS GPO	Verantwoordelijk voor aanleg en projectmanagement, lid Projectteam Marker Wadden, kernteam KIMA VZ Dagelijks Bestuur marker wadden
Executing parties	Boskalis	Uitvoerder project
	Witteveen+Bos	Ondersteuning/advies uitvoering project
Investors	Natuurmonumenten	Financier en Opdrachtgever samen met RWS
	Ministerie EZ (inclusief latere LNV)	Gezag passende beoordeling (vogel- en habitatrichtlijn, Natura2000) inpassen aanleg Marker Wadden binnen N2000 wetgeving, voorzitter Stuurgroep MIJ, lid Stuurgroep Marker Wadden.
	Ministerie IeM (later IenW)	In Stuurgroep MIJ namens Rijkspartijen, lid Stuurgroep Marker Wadden.
	Provincie Flevoland	Rol vooral gericht op verantwoordelijk voor TBES , lid Stuurgroep Marker Wadden.

Table 21 Actors and role executing phase MW in Dutch (IJff et al., 2020)

Annex H

Water quality and quantity demand in the Netherlands

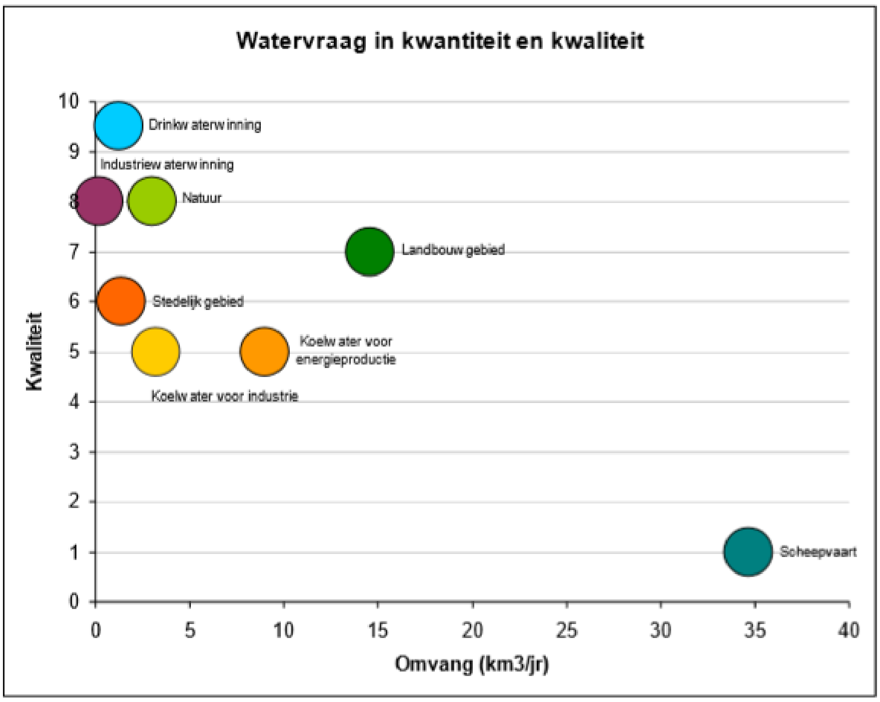

Figure 19 Water use per sector in the Netherlands, indication of the demanded quantity and quality per sector on average per year (Klijn et al., 2012, p. 77)

Annex I

Calculations

Biodiversity points

Zone	Area (km^2)	Quality	Biodiversity points BAU	Biodiversity points MW	Weight factor	MW with weigh factor	BAU with weigh factor
Shore	9.24	0.045*	0.1	0.5	2.3	1	2,3
Shallow zone without water plants	9.01	0.53*	4.5	5	2.0	10	9
Shallow zone with water plants	78.81	1.23*	11.5	97	2.5	242,5	29
Deeper water	591.72	0.45	270	266	0.4	106,4	108
Marsh zones MW (+ Trintelzand)	3.70 (+1.55)	0.54**	0	2	2.0	4	0
Total	685.5	0.56		370.5 (+1)		364	148

Table 22 Biodiversity points calculated for lake Markermeer with MW

The current quality indicators were used when possible, and where not (*) the values from van Puijenbroek & Sjitsma (2009) were used. The quality indicator for marsh zones (**) was derived from Wortelboer et al. (2011) who calculated biodiversity points for the Afsluit dike. This indicator is used as it is the value for marsh zones in the Netherlands that is closest to the Markermeer. A weight factor was not used in Puijenbroek & Sjitsma (2009), in later research, weightfactors as used by Puijenbroek et al. (2015). Weight factors are derived from Puijenbroek et al. (2014, table 3).

Calculation (Ghermandi et al., 2008)

The meta-analysis function of Ghermandi et al. (2008) is:

$$\ln(y_{ij}) = \alpha + \beta_S X_{Sij} + \beta_W X_{Wij} + \beta_C X_{Cij} + u_j + e_{ij}$$

where α is a constant value, and β is the coefficient for a certain variable (s= study variables, w= wetland variables and c= context variables).

Variables included in the meta-analysis function are the following:

1. Constant term (3.522)
2. Wetland area (hectares) (1,148, derived from van Riel et al., 2017)
3. GDP per capita (€44,920, derived from the World Bank, n.d.)
4. Population in a 50km radius (3,227,994, derived from the World Bank, n.d.)
5. Substitute wetland area in 50 km radius (hectares, 155 ha from Trintelzand was used here)
6. Habitat type: manmade wetlands
7. Ecosystem services: water quality improvement, non-consumptive recreation, amenity and aesthetics, biodiversity enhancement.
8. Marginal value

The calculation has been executed exactly as in da Silva (2012).