Evaluating actual and potential ecosystem service mapping and quantification at a Dutch water board in a river restoration project: a case study

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This Master Thesis has been prepared and written according to the Examination Regulation of the Master Programme TWM at the University Duisburg-Essen and the Examination Regulation of the Master Programme Environmental Sciences at the Radboud University Nijmegen. This includes all experiments and studies carried out for the Master Thesis.

The Thesis has been written at the water board Aa en Maas in the Netherlands.

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I declare that I have prepared this Master Thesis self-dependent according to § 16 of the Examination Regulation of the Master Programme Transnational ecosystem-based Water Management (TWM) published at 9 August 2005 at the Faculty of Biology at the University of Duisburg-Essen.

I declare that I did not use any other means and resources than indicated in this thesis. All external sources of information have been indicated appropriately in the text body and listed in the references.

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Signature of the Student

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1. Summary

International efforts have been made to promote ecosystem service (ES) assessment and ES integration in policy making, following the Millennium Ecosystem Assessment and the EU 2020 Biodiversity Strategy. Due to the decentralised approach of the Dutch government on ES integration into national accounting, knowledge on ES in the Netherlands is fragmented. This fragmentation of knowledge can hinder the integration of ES in spatial planning and policy making for organisations such as the water board Aa en Maas. This thesis evaluated the actual and potential use of ES mapping and valuation for decision-making by the water board Aa en Maas, using the river restoration project 'Gebiedsplan Raam' as a case study. Based on economic, ecological and social relevance in this project, five ES were selected, and assessment methods for these ES were identified and evaluated. Where possible, the effects of the river restoration plan on ES delivery were calculated. These ES quantifications revealed that weir construction and heightened target water tables will lead to increased ground water tables, with the largest increases in the direct proximity of the river. Consequently, crop and livestock production in the direct proximity of the river will be negatively impacted due to increased waterlogging. However, nature targets set for the area will not be achieved, even with the highest ground water table increase. Furthermore, blue and green elements can contribute up to € 5,053,380.00 to the total property value in the area. These results illustrate the how ES mapping and quantification can aid decision-making at the water board Aa en Maas through identification of mismatches in ES supply and demand, and how it can aid in the identification of possible mitigating measures. Although some ES could be quantified and valuated, and some quantification instruments that are already in use may be modified to enable ES valuation, more ES mapping and quantification tools are needed to successfully integrate ES into spatial planning.

2. Introduction

In the late 1960s, the first concepts describing the functions and values of nature, and the dependence of mankind on society, were conceived. These relations were coined as 'ecosystem services' (ES) in the 1980s and have since the 2000s become more mainstream (De Groot, Braat, and Constanza, 2017). Currently, ES are defined as "the contributions of ecosystem structure and function (in combination with other inputs) to human well-being" (Burkhard and Maes, 2017; Remme *et al.*, 2017). These contributions include provisioning services, including material resources as food, wood and water, but also regulation and maintenance and cultural services. Regulating services include flood mitigation, water and air filtration, and cultural services include benefits such as cultural and historical identity (Haines-Young, R. and M.B. Potschin, 2018). These ES are a result of processes within the ecosystems themselves (Schneiders & Müller, 2017), such as sequestration of fine particulate matter in the air by plants. This leads to cleaner air, and less health issues related to air pollution amongst individuals living in the vicinity. Many measures taken by, for instance, water boards, may influence certain ecosystem processes, and can thus lead to changes in delivered ES. Without ES assessment and mapping, these losses or gains in the value of natural capital would not be taken into account. Furthermore, by valuating and monetising these benefits, natural capital can be included in economic decision-making, such as cost-benefit analysis. This way, mapping, analysis, and valuation of ES can help natural resource managers in their decision-making processes to gain a more complete view of benefits and drawbacks of projects and measures, and the economic importance of natural capital. Furthermore, ES mapping can be used to identify areas of high ecological sensitivity, and to enhance engagement between stakeholders and decision-makers (Maes *et al.*, 2017).

Propelled by the Millennium Ecosystem Assessment (MEA, 2005), international efforts to promote ES protection and assessment have been made (Paulin *et al.*, 2020). For instance, the EU 2020 Biodiversity Strategy promotes ES integration into national accounting, as well as the bolstering of natural capital by restoring green infrastructure (EC, 2011; 2013; 2019; Maes *et al.*, 2017). Similar policies have been enacted around the world (Maes *et al.*, 2017). Although most national governments of EU members have largely outsourced the actual implementation of ES to local government policymakers, there are still clear differences between countries (Verburg *et al.*, 2014). While the national governments of the United Kingdom and Belgium have developed clear viewpoints on ES integration into policies, and have started to use ES in regional development, the Netherlands utilise a less transparent and decentralised ES approach (Verburg *et al.*, 2013; 2014). Verburg *et al.* (2014) note that this decentralised approach in the Netherlands leads to unambitious government agencies and fragmentation of knowledge, forcing intermediate organisations and consultancy agencies to develop themselves as central knowledge hubs. However, it is also noted that this offers a chance for local experiments with a holistic approach to economics and nature.

Despite the national and international efforts of integrating ES into spatial planning, ES mapping and analysis is currently not yet explicitly used at the water board Aa en Maas. However, people at water board have become aware of ES, and have expressed interest in exploring how ES can be used by the water board and what the benefits of ES integration into spatial planning are. Since there is little to no central approach of the Dutch national and provincial governments on ES use in (water management) policy, experience with and knowledge of the integration of natural capital in policy and practice must be obtained elsewhere. Therefore, the aim of this master thesis is to evaluate the actual or potential use of ES mapping and valuation for decision-making by the water board Aa en Maas. To that end, the 'Gebiedsplan Raam´, a river restoration project by this water board, was used as a case study to address the following research questions:

- Which ES are relevant for river restoration in the Lower Raam?

- How can these ES be assessed?
- Is the required data available? If not, how can the necessary data be obtained?
- How do the proposed measures in the Gebiedsplan Raam impact ES functioning in the Lower Raam area?

3. Materials and methods

3.1. Study area and 'Gebiedsplan Raam'

Under the name 'Gebiedsplan Raam', the water board Aa en Maas, together with other parties, such as Natuurnetwerk Brabant and the municipalities in the Raam valley, have developed a project plan for the Raam river basin. The main goals are improvement the area's core values and functioning, both from an ecological (biodiversity) standpoint as well as from a hydrological (flood safety) standpoint. These core values include small-scale scenery, this cultural-historical landscape, as well as the natural beauty of the area (Besselink, 2018). Considering the scale of the project, the project has been divided into four subprojects, based on different branches of the Raam river, all addressing specific local issues. These subprojects are not all carried out at the same time; for instance, the Peel canal subproject has already successfully been completed, whereas plans for the Lower Raam and the Graafsche Raam have yet to be finalised. Since the latter has not yet been finalised, as of this moment, and multiple scenarios for several measures affecting ES have not been decided on, this subproject was chosen as a case study. In particular, this thesis focuses on the upstream part of the Raam river from the planned weir 'Egweg', which includes the Lower Raam, the Biestgraaf and a part of the Graafsche Raam (figure 1). The Defence Canal, which is also connected to the Raam, was not part of the study area.

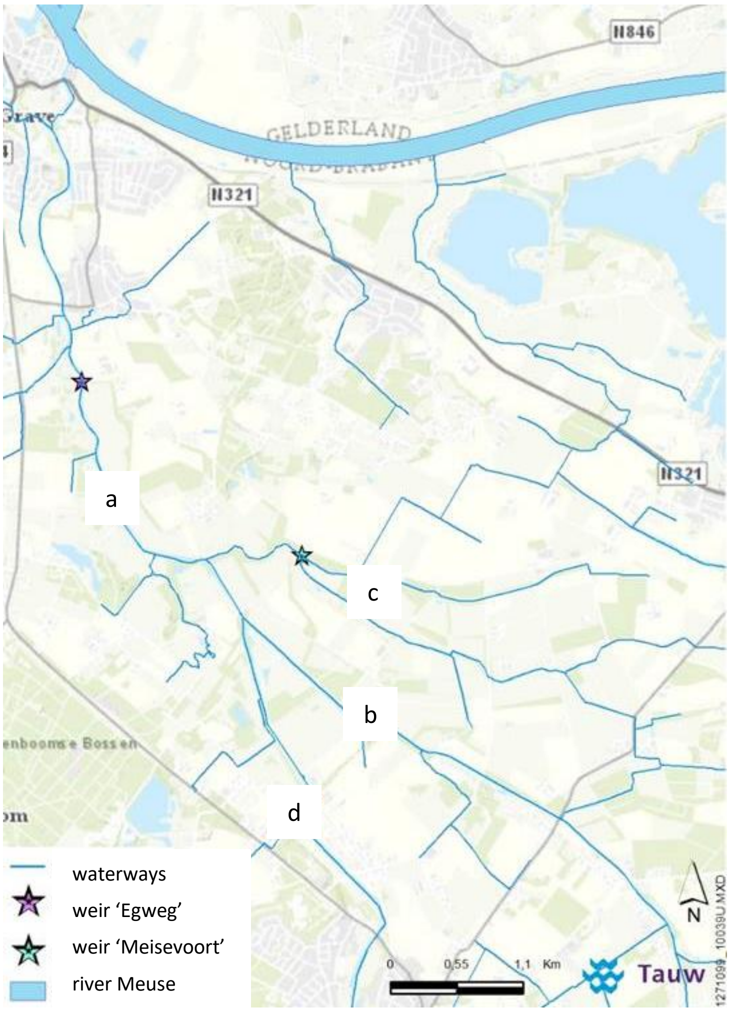


Figure 1 The study area and the locations of the weir 'Meisevoort' and the planned weir 'Egweg'. Waterway a is the Graafsche Raam, b is the Lower Raam, c is the Biestgraaf and d the Defence Canal (modified after G. Atsma, personal communication, 12-11-2020).

In this section of the Raam river, a variety of challenges are to be tackled. The most important goals for the water board are nature conservation and restoration, whilst also ensuring flood safety and acknowledging the needs of the agricultural industry in the area. Whereas the Water Framework Directive (WFD) calls for brook development and improved fish migration, Natuurnetwerk Brabant (NNB) mandates the development of wet meadows downstream (Besselink, 2018). At the same time, upstream water drainage needs to be ensured for agricultural fields, when needed. Additionally, extra room for water retention, during peak discharge as well as during droughts, will be developed. To achieve these goals, swampy banks are to be constructed, 50 to 100 metres wide, with side-channels and pools, so that nature can develop. This will also create extra space for water retention during peak discharge. Furthermore, a weir is to be constructed (weir 'Egweg'), to raise the water table. The water table at weir 'Meisevoort' will also be raised (figure 1). This will lead to a rise in the ground water levels, and this way, the goals set by the NNB are to be achieved. Lastly, historical and cultural elements are to be restored or made visible, bike paths are to be constructed and information signs are to be placed (Besselink, 2018).

3.2. Ecosystem service selection

In order to aid the selection of the most important ecosystem services for this project, the stakeholders and stakeholder groups (i.e. those affected and involved, such as terrain managers, decision-makers and other interest groups) relevant to this river renaturation plan were identified, using the listed stakeholder groups in Besselink (2018) and a C Factor analysis carried out by the water board. Where it is unclear how Besselink (2018) has identified the stakeholder groups, the water board used the C Factor analysis, a communication approach used by Dutch governments to identify involved parties in large projects. Within a C Factor analysis, the goal, strategies and approaches are outlined in order to determine stakeholders and their involvement, so communication strategies can be determined (CommunicatieRijk, 2020). This resulted in a detailed list with all the parties that have an interest in the 'Gebiedsplan Raam´. Based on this stakeholder list and the stakeholders presented by Besselink (2018), a compact list with the most important stakeholders and their interests was constructed (Appendix B, table 1), to aid in the selection of ecosystem services. In turn, this served to in the compilation of ES applicable to the 'Gebiedsplan Raam' project plan, based on the ecosystem service list from the Common International Classification of Ecosystem Services (CICES) framework (version 5.1; appendix A).

The CICES framework was chosen over other ES frameworks such as the TEEB (The Economics of Ecosystems and Biodiversity) and the UK National Ecosystem Assessment frameworks, due to the easy-of-use of its cascade ES operationalisation system and its current application in the Dutch national Natural Capital Atlas (ANK) (ANK, 2020; Potschin & Haines-Young, 2016; STOWA, 2018). The CICES framework groups ES into three main sections: provisioning services, regulation & maintenance services and cultural services. These sections are then further divided into divisions, groups and classes, which are the final ES. Each service is assigned a code which enables easy referencing to the ES framework (Appendix A).

Then, further prioritisation was based on ES importance within the 'Gebiedsplan Raam', as well as their general importance for the water board and other stakeholders, and likelihood of ES being relevant for future projects by the water board. Importance was based on ecological importance and (potential) economic importance specifically for the Raam valley. Furthermore, provisioning, regulation and maintanance and cultural services, as well as biotic and abiotic services were to be represented in the final ES selection, in order to ensure a representative selection of all services. This led to a list of five ecosystem services that were highly relevant for the 'Gebiedsplan Raam', which were to be quantified (table 1). Indicators were determined as well, to identify how the ecosystem service could be quantified, aiding in ES quantification model selection.

Table 1 Final selection of the 5 priority ES that were to be quantified and evaluated, with ES indicators that could be used to measure ecosystem service delivery.

Ecosystem service	**CICES code**	**ES indicators**
Ground water provisioning	4.2.2.2	Ground water availability / sub-surface retention
Hydraulic cycle and flow control	2.2.1.3	Surface retention / avoided flood damages
Crop and livestock provisioning	1.1.1.1 & 1.1.1.2	Crop yield / livestock produce
Nature policy goals	Not recognised by CICES	Completion policy goals / success chance of the development of target vegetation/nature as outlined by policy
Cultural and aesthetic values	3.1.0.0	Property value

3.3. Model selection

Using literature databases Web of Science and Google Scholar, assessment methods and computer models for quantification of ES delivery and ES mapping were obtained. Keywords were "ground water provisioning", "crop provisioning", "livestock provisioning", "macrophyte shading/shadowing", "valuation aesthetical ecosystem services", "valuation cultural ecosystem services", and were combined with "model", "mapping" and "assessment". Additionally, through communication with researchers in the field of ES, as well as communication with data-analysts and advisors at the water board, additional models and tools were obtained. This included computer models already in use by the water board, which were also included in the following evaluation of the models. Since many of these models and tools consist of multiple modules or sub-models, only the modules or sub-models for the relevant ES (table 2) were evaluated.

To evaluate these models and tools, model output needs for all five ecosystem services were determined, based on ES description by CICES version 5.1 and with practical application by the water board in mind. Output of the selected tools and models was compared to the output needs for their respective ES, to identify useful ES mapping instruments. After this selection, data needs and data availability for these instruments were determined for a final assessment.

Table 2 ES quantification models, model instruments and tools for ES mapping or quantification that were evaluated for practical application at the water board Aa en Maas. Greyed out are the models or tools that were not used in ES quantification.

Model name	Description	Relevant ES	Reference
iMOD	Ground water modelling instrument, based on the MODFLOW ground water model.	Ground water provisioning	Vermeulen *et al.* (2020)
STOWA Ecologische Sleutelfactoren (ESF)	Modular toolset developed by the Dutch Stichting Toegepast Onderzoek Waterbeheer (STOWA) for assessment of the ecological Water Framework Directive (WFD) goals, which includes a module on discharge dynamics and ground water, as well as a module on aquatic ES.	Ground water provisioning; hydraulic cycle and flow control	Mellor *et al.* (2017); Reeze & Laseroms (2018)
SOBEK Suite	Modelling instrument for, among others, flood risk modelling, currently in use at water board the Aa en Maas.	Hydraulic cycle and flow control	Deltares (2020)
Riparian shade model Tauw	Computer model for calculation of stream shading by stream bank vegetation, developed by the Tauw consultancy agency for the water board Aa en Maas.	Hydraulic cycle and flow protection	Tauw (2019)
InVEST	As a model suite, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) can be used to map and value a range of ES.	Hydraulic cycle and flow control; crop provisioning; cultural and aesthetical values	Natural Capital Project (2020)
WaterWijzer Landbouw	Mapping and modelling instrument to map and calculate the effects of changes in water management and climate on crop production, currently in use at the water board Aa en Maas.	Crop and livestock provisioning	Werkgroep Waterwijzer Landbouw (2018)
AVANAR	Tool for mapping supply and demand of recreational activities, such as walking and cycling.	Cultural and aesthetical values	De Vries, Hoogerwerf, De Regt (2003)
NC-model	Model set for mapping and quantification of ES in the Netherlands.	Cultural and aesthetical values	Paulin *et al.* (2020); Remme *et al.* (2017)
TEEB-stad	Tool for quick assessment of the economic value of ecosystem services in urban environments in the Netherlands.	Cultural and aesthetical values	Platform31 (2013); RIVM (2015)

3.4. Practical application

For each ES, a preliminary impact analysis was performed if possible, on the impacts of the proposed measures taken in the river restoration project on ES delivery. Lastly, these experiences were combined in an evaluation, in order to devise recommendations for the water board Aa en Maas on the implementation of ES in water management policy, as well as recommendations for the scientific community working on the development of ES quantification models.

3.4.1. Ground water provisioning

Currently, the water board has modelled the new ground water levels based on the construction of the two new weirs and the increased surface water levels. This was using iMOD, which makes use of a modified version of MODFLOW (a ground water flow modelled developed by the U.S. Geological Survey). Since this model is already in use, all the data that is needed, is already available.

In order to calculate the effects on the ground water table in the Lower Raam valley, the water board used four scenarios that were used as input for the iMOD ground water model instrument. These scenarios differed in the water tables at the existing weir 'Meisevoort' and the weir 'Egweg', which is to be constructed under the Gebiedsplan Raam (table 3).

Table 3 Target water tables at weir 'Egweg' and 'Meisevoort' for the current situation, as well as scenarios 1, 2, 3 and 4 in the project plan 'Gebiedsplan Raam´. As a target water table, under normal hydrological conditions, the water table is to be kept at this level. However, the actual water table can be temporarily raised or lowered when required (e.g. during high precipitation periods).

Scenario	Target water table at weir 'Egweg' [m above NAP (Amsterdam Ordnance Datum)]	Target water table at weir 'Meisevoort' [m above NAP]
current	(currently not constructed yet)	7.85
1	7.40	8.00
2	7.60	8.15
3	7.80	8.30
4	8.00	8.40

For the years 2010 through 2017, the effects on the ground water table were calculated as if the weir 'Egweg' had been constructed. This was done for all water table scenarios, including the historical water table. This way, model accuracy could be tested to historical ground water table data, and sample size was increased, in order to obtain a climate representative map. Furthermore, for each scenario, three maps were generated: one for the mean highest ground water table (MHW, Dutch: GHG), one for the mean spring ground water table (MSW, Dutch: GVG), and one for the mean lowest ground water table (MLW, Dutch: GLG). Vermeulen *et al.* (2020) state that the definition of the MHW is "the mean value of the three shallowest groundwater depths measured in one year (in meter beneath soil surface), averaged over a period of 8 years with bi-weekly measurements or simulation-results". The MLW is defined similarly, but with the the deepest ground water depths instead of the shallowest. The MSW, on the other hand, is calculated using three dates near April 1st (Vermeulen *et al.*, 2020).

A model that is not currently used, but seemed to be useful, is a model from the STOWA Ecologische Sleutelfactoren toolset. This model, currently in development by STOWA, is called 'discharge dynamics and ground water' (Dutch: sleutelfactor afvoerdynamiek en grondwater) for ground water ES functioning. Although this model covers important aspects in stream functioning, it solely focuses on ecologically important aspects of stream functioning instead of ground water hydrology (Reeze & Laseroms, 2018). Therefore, this model by STOWA is not suited to assess the ground water provisioning ES. Since the currently used iMOD instruments already provide the needed calculations on ground water provisioning, the iMOD model instruments were deemed adequate to assess ground water provisioning. Therefore, the calculations the water board had carried out were used in the ES assessment for the case study.

3.4.2. Hydraulic cycle and flow regulation

In the stream restoration plans, the current, steeply sloped stream banks will be transformed to more natural, gradually sloped, swamp-like banks, with inundation zones and bank vegetation. To assess the impacts of these measures on hydrological cycle and flow regulation, the effects of macrophyte shading by riparian vegetation was to be investigated, as well as the effects of the extra inundation zones. Although there is evidence that intense shading can be used to control the growth of macrophytes (Bunn *et al.*, 1998; Collins *et al.*, 2019; Kałuża *et al.*, 2020; Köhler *et al.*, 2010; Verdonschot, 2016a, 2016b), and the water board has made use of a model to calculate current stream shading by riparian vegetation (Tauw (2019), no models on the effects shading of macrophyte by bank vegetation were found. Thus, these effects could not be quantified.

Currently, the water board Aa en Maas uses the SOBEK model suite to model flood risk. However, at the moment of this study, channel and stream bank designs were not yet known. Therefore, the effects of the natural stream banks on flood safety could not be calculated. Furthermore, use of the TEEB-stad model to quantify avoided damages, due to possible a reduction in flood risk, as an ES indicator, was to be assessed. As input to calculate an indication of avoided damages due to flood risk reduction, this model needs the reduction in chance of flooding. Currently, the SOBEK flood risk model that is used by the water board, cannot provide this. Therefore, hydrological cycle and flow regulation was not assessed in the case study.

3.4.3. Crop and livestock provisioning

Recently, the water board Aa en Maas started to use the WaterWijzer Landbouw (Werkgroep Waterwijzer Landbouw, 2018) to calculate the effects of changes in water management and climate on agricultural production. Not only does the WWL account for direct effects such as drought stress, oxygen stress and salt stress on crop yield, but indirect effects (such as delayed sowing and harvesting due to prevailing hydrological conditions) are included as well (Werkgroep Waterwijzer Landbouw, 2018). All necessary data, such as ground use, soil type and ground water levels are already available to the water board, since it has the tool already in use. Scenario modelling is possible using ground water table maps modelled using the iMOD instruments. Since this model can be used to comprehensively calculate impacts of climate and changes in water management on crop production, which was chosen to be an indicator of this ES, the WaterWijzer Landbouw was deemed to be suited for the quantification of crop and livestock provisioning.

The increased ground water levels in the ‘Gebiedsplan Raam’, due to the increased water tables at the weirs ‘Egweg’ and ‘Meisevoort’, will likely also have consequences for agriculture in the area. To quantify the damages and avoided damages (of decreased drought stress for crops), the water board has recently started to use the WaterWijzer Landbouw (Werkgroep Waterwijzer Landbouw, 2018).

As a reference, first the potential crop production was calculated. Then, crop production for the years 2010 to 2018 were calculated, using the historical ground water table data for these years. Following this, crop production for the years 2010 to 2018 were calculated again, but this time using the in iMOD modelled ground water table data for weir water table scenarios 3 and 4 (table 3). Using this method, the direct and indirect effects of the increased ground water tables on crop production were calculated. These results were in the form of area maps displaying the potential crop losses due to the individual effects for all scenarios.

3.4.4. Nature policy goals

Since the contribution of nature to the achievement of nature policy is not a recognised ES, no models or methods to assess this service, exist. Therefore, no quantification for the project plan could be carried out.

3.4.5. Cultural and aesthetical values

Besides recreational activities, cultural natural capital is generally rather difficult to quantify, as they mostly describe feelings and experiences that nature can provide. However, a quantitative assessment is desired to enable comparison between different options, strategies and areas, aiding in the decision-making process. Moreover, monetary quantification is more tangible for direct stakeholders, such as locals and decision-makers. Therefore, the contribution of cultural and aesthetic values on property prices were quantified. However, due to time constraints, assessments were limited in extent and can therefore only serve as an indication as to the effects on ES delivery.

Two models were chosen to evaluate this ES in the case study: the NC-model and the TEEB-stad model. Both tools rely on the correlation of blue and green elements (such as ponds, open water, hedgerows and parks) and property prices, determined by studies carried out throughout the Netherlands (Luttik and Zeilstra, 1997; Paulin *et al.*, 2020; Platform31, 2013; Remme *et al.*, 2017; RIVM, 2015; Ruijgrok *et al.*, 2006). Whereas the for the TEEB-stad tool the contribution of nature on property has to be calculated manually, for the NC-model, property value maps for the entire Netherlands have already been calculated (personal communication M. Paulin). For quantification with TEEB-stad, first, in ArcGIS, the houses in a 400-meter radius from the Lower Raam were identified, using property data from the publicly available land register (Dutch: Basisregistratie Adressen en Gebouwen, BAG (Kadaster, 2020)). Subsequently, property prices of the individual houses (Dutch: WOZ-waarde) were determined using the WOZ-waardeloket (Rijksoverheid, 2020a), a publicly available database on property values. Using the TEEB-stad model, the contribution of nature to property prices were calculated by multiplying property prices with a contribution fraction (RIVM, 2015). The property value map from the NC-model had been calculated in a similar way: just as the TEEB-stad model, the contribution of blue and green elements within a certain distance of a given property to that property had been calculated. For all properties within 400 meters radius of a park or water, or within 30 meters (viewing distance), the property price had multiplied with fraction between 0.05 and 0.12, depending on the blue and green elements (Paulin *et al*., 2020; Remme *et al.*, 2018).

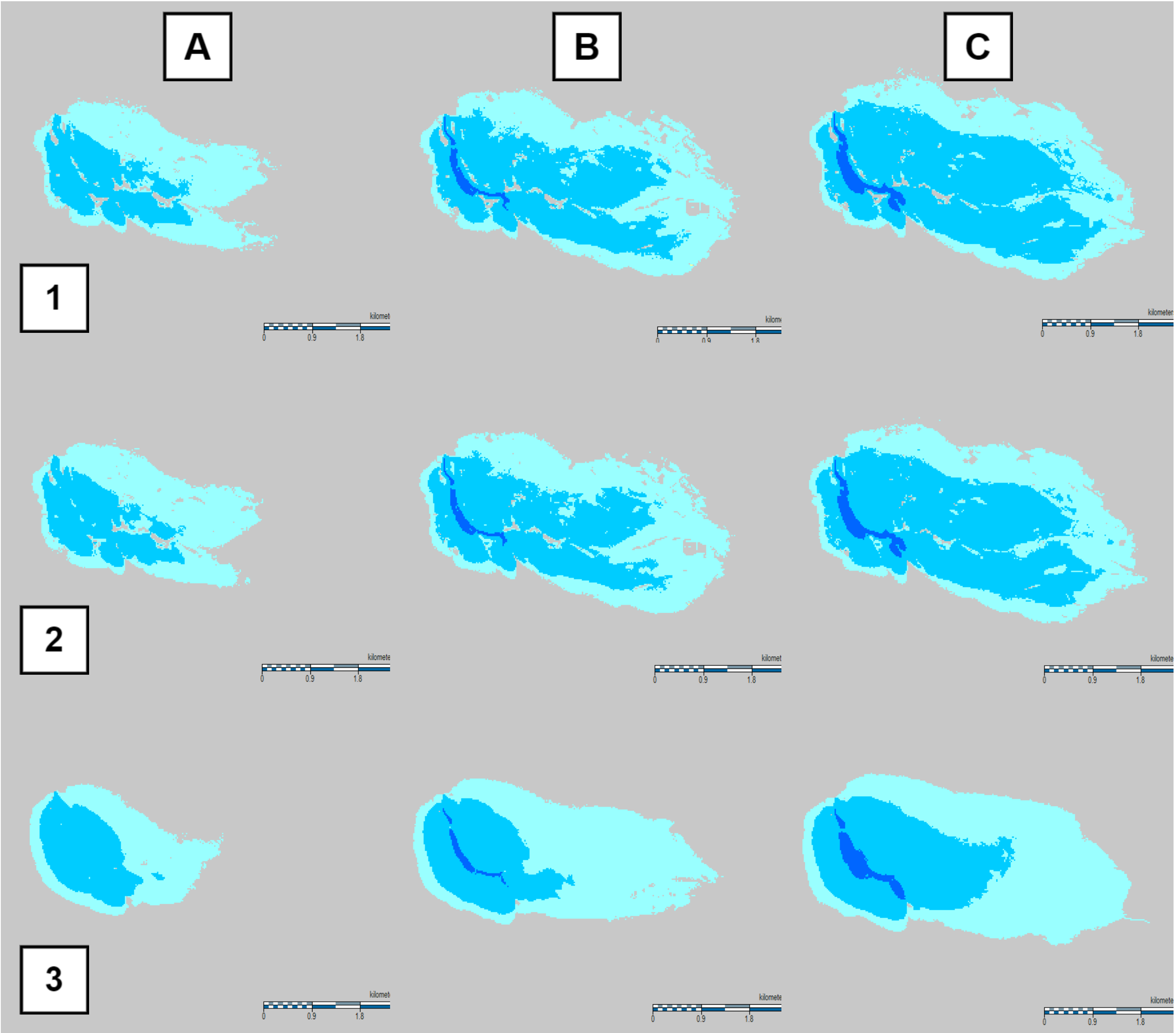
4. Results

4.2. Ground water provisioning

Construction of the weir ‘Egweg’ and raising of the water table at both this weir and the weir ‘Meiservoort’ will result in changes in the ground water tables. Quantification using the iMOD ground water modelling tools has yielded area maps displaying changes in ground water table (figure 2). Here, large differences in ground water tables between the different scenarios (table 3) can be seen, as well as between the MHW, MSW and MLW calculations.

For all scenarios, the largest increases in ground water table are found concentrated along the Raam river. Whereas in scenario 4 the maximum rise of the ground water table is 81 cm here, in scenario 3 this is 61 cm and in scenario 2, the ground water table does not rise more than 45 cm compared to the actual ground water table (figure 2). Not only is the maximum rise of the ground water table in scenario 4 higher than the maximum rise in scenario 2, but a larger area also experiences a rise in ground water levels as well.

These maximum rises in ground water tables are the same for each scenario across the MHW, MSW and MLW calculations. However, as can be seen in figure 2, the areas impacted by a rise in the ground water tables are limited in the MLW calculations, compared to their MHW and MSW counterparts.



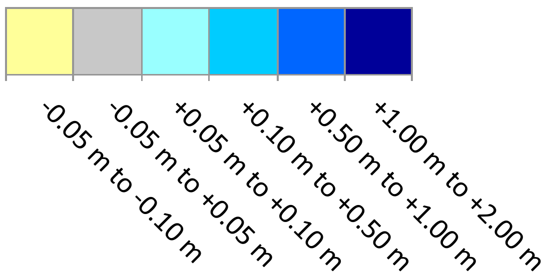


Figure 2 The calculated rise in the ground water table (in meters) for the increased target water tables in the Lower Raam at the 'Meisevoort' and 'Egweg' weirs, compared to the target water table and average ground water table between 2010 and 2018.

The rise in the ground water table was calculated for the target water table scenarios 2 (column A; a 20 cm increase in target water table at 'Egweg', and 30 cm at 'Meisevoort'), scenario 3 (column B; respectively + 40 cm and +45 cm) and scenario 4 (column C; respectively + 60 cm and + 55 cm). Furthermore, for all scenarios, the new ground water tables were calculated for the mean high ground water table situation (row 1), mean spring ground water table (row 2) and mean low ground water table (row 3).

Data provided by C. van Rens (personal communication, 25-06-2020)

4.2. Crop and livestock provisioning

Using the WaterWijzer Landbouw, the effects of the previously calculated changes in ground water table on potential crop yield were calculated by the water board. These effects were divided in direct effects (waterlogging and drought stress (figure 3)), as well as indirect effects and the combined effects (figure 4). Included in the indirect effects are, among other factors, delayed sowing and delayed harvesting due to unfavourable hydrological conditions, leading to reduced crop yields.

Throughout the Lower Raam, drought stress is observed, accounting for potential crop yield losses between 5% and 30% (figure 3). In target water table scenarios 3 and 4 (table 3), some positive effects, up to a 10% decrease in crop loss, on drought stress can be observed (figure 3). These effects are mainly confined to the direct vicinity of the Lower Raam, where the ground water table will rise the most. For most of the area, increases in the ground water table are not high enough to affect crops, and crop losses due to drought stress remain the same as in the 2010 – 2017 period.

Between 2010 and 2018, waterlogging of crops did not impact crop production, apart from a few selected areas (figure 3, row 2). However, along the Lower Raam, with the increased ground water tables in scenario 3 and 4, more crop losses due to waterlogging will occur. In some areas, reductions in crop yield of to up to 100% of the potential crop yield are expected. However, just as the positive effects of the increased ground water tables on drought stress, these negative effects are limited to meadows and fields in the direct vicinity of the Lower Raam (figure 3).

The indirect effects of the heightened target water tables and the subsequent ground table increases on crop production are similar to the effects of waterlogging on crop production: where little potential crop yield loss (>10%) was attributed to these indirect effects between 2010 and 2018, in scenario 3 and 4, potential crop yield losses of 15% to 25% are expected in some places directly along the Lower Raam (figure 4).

Overall, whereas in the direct vicinity of the Lower Raam, the crop yield between 2010 and 2018 was around 30% lower than the potential crop yield, in scenario 3 and 4, crop losses can be close to 100% of the potential crop yield at selected locations (figure 4, row 2). This is, however, in stark contrast to the majority of the Raam valley, which is largely unaffected by the measures to increase ground water tables.

4.2. Aesthetic & cultural values

For the river restoration efforts in the Lower Raam, 234 properties were found to be within a 400-meter radius of the stream, and for 192 of these properties, property values (WOZ) were available (table 4). The missing property values for the other 42 properties can be explained by the fact that they are not residential properties, but rather industrial or commercial buildings, or by the fact that their municipality has not determined the property values yet. In the study area, the mean property value per property was € 328,989.58 (± € 111,374.13). Using an 8% contribution of blue and green elements to property price, as used in the TEEB-stad tool (RIVM, 2015; Ruijgrok & De Groot, 2006), this would result in a mean added contribution of € 26,319.17 per property. For the entire area, this results in a combined value of € 5,053,280.00 (table 4).

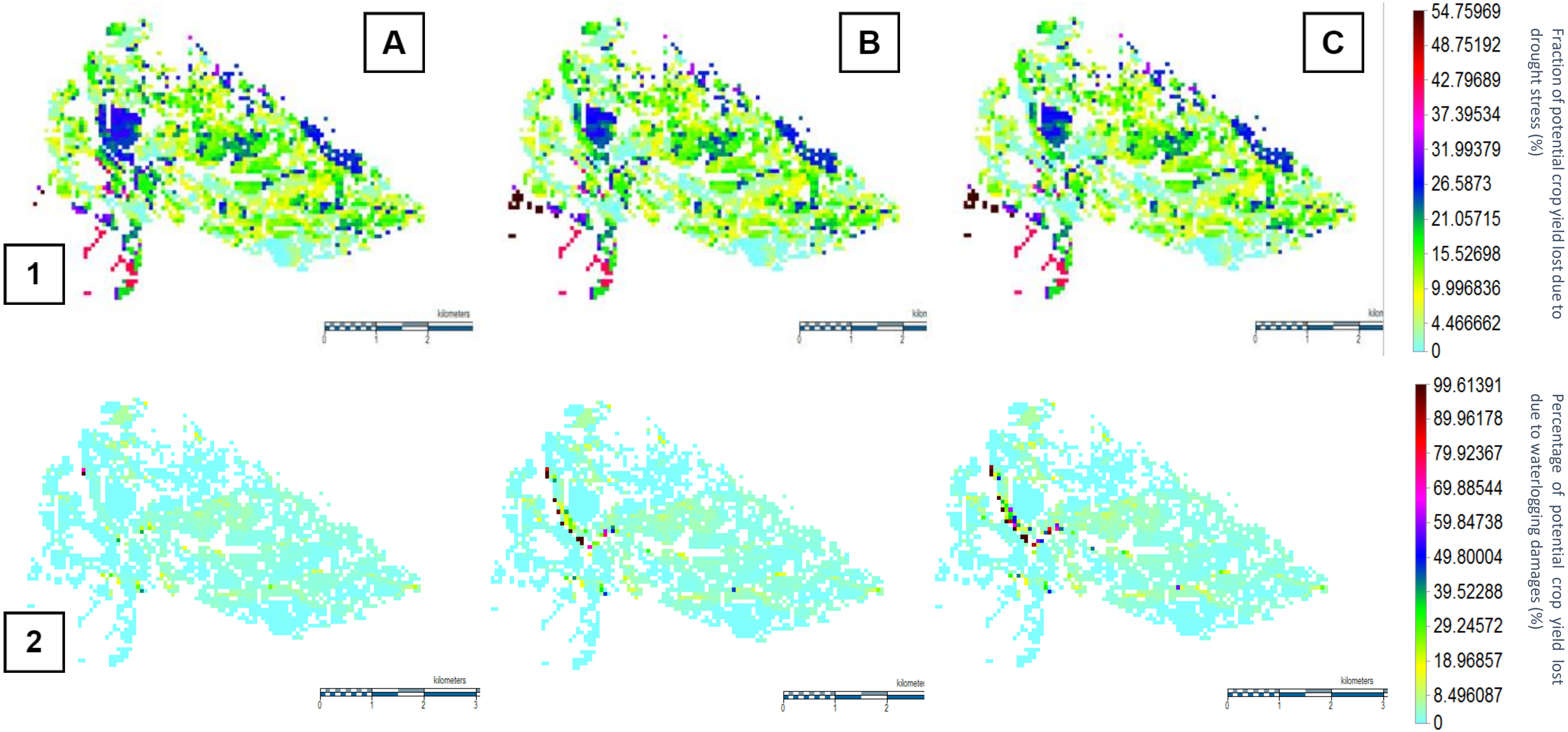


Figure 3 Drought (1) and waterlogging damages (2) in percentages of potential crop yield reduction due to changes in ground water level. To calculate both drought and waterlogging damages, first, the potential crop yield (i.e. crop yield under optimal hydrological conditions) was calculated. Secondly, the average crop yield between 2010 and 2018 was calculated (A), as well as the average crop yield between 2010 and 2018 if target water table 3 (B) and 4 (C) were used in this period. Here, the individual effects of drought stress and waterlogging stress on the potential crop yield, can be seen. Both the damages due to drought stress and waterlogging are expressed as a percentage of the potential crop production.

Data provided by C, van Rens (personal communication, 06-10-2020).

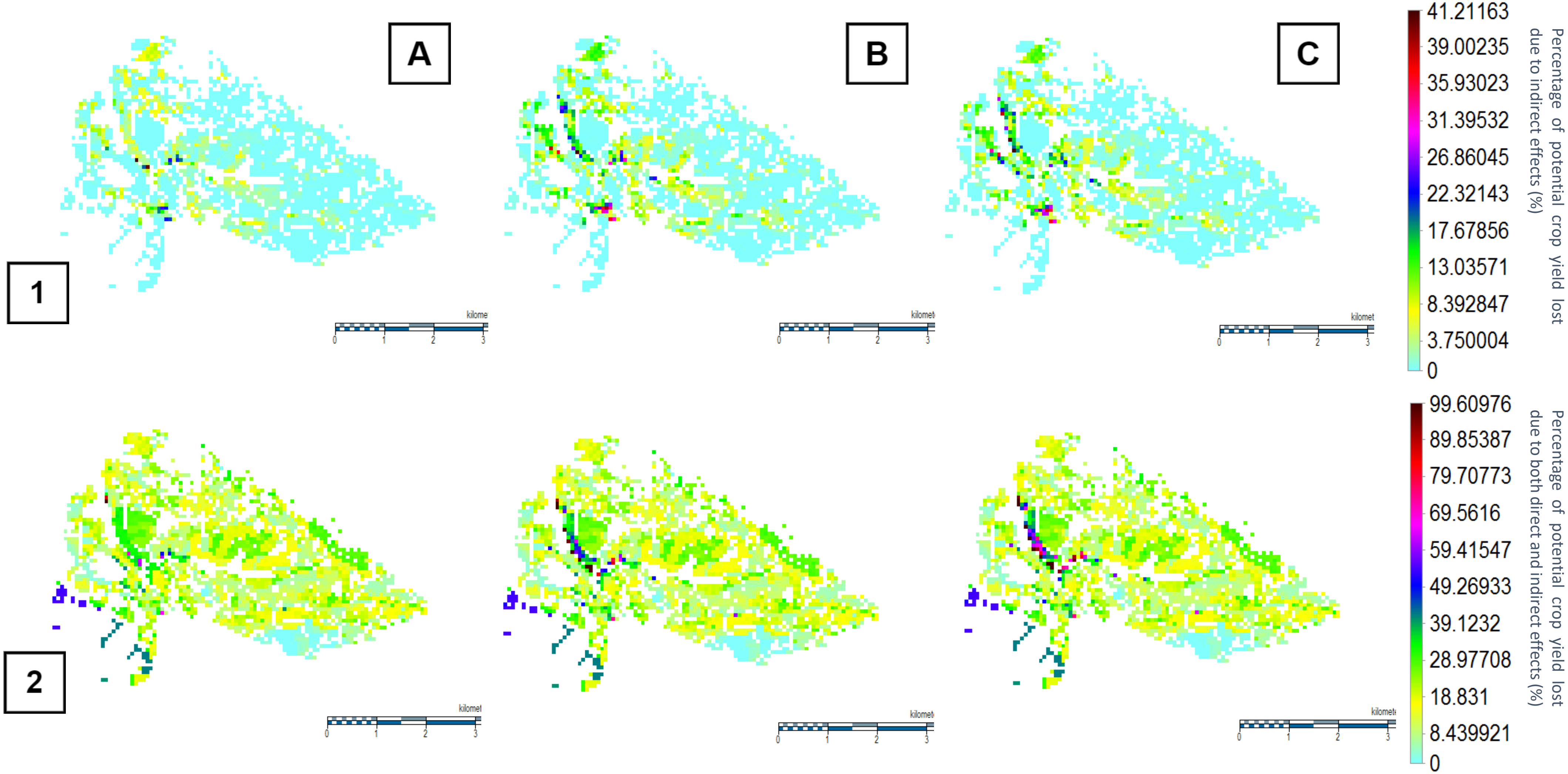


Figure 4 Indirect (1) and total (drought, indirect and waterlogging combined) damages (2) in percentages of potential crop yield reduction due to changes in ground water level. To calculate both the indirect and total damages, first, the potential crop yield (i.e. crop yield under optimal hydrological conditions) was calculated. Secondly, the average crop yield between 2010 and 2018 was calculated (A), as well as the average crop yield between 2010 and 2018 if target water table 3 (B) and 4 (C) were used in this period. Here, the crop losses due to indirect effects and the combined effects on the potential crop yield, can be seen. Both the damages due to the indirect effects and the combined effects are expressed as a percentage of the potential crop production.

Data provided by C. van Rens (personal communication, 06-10-2020).

Table 4 Properties and property values in a 400-metre radius of the Lower Raam, and the contribution of blue and green elements on the property values of these properties.

Properties in a 400-metre radius of the Lower Raam		
Number of houses identified in a 400 m radius around the Lower Raam		234
Without a publicly available property value		42
With a publicly available property value		192
Property values		
Median value per property	€	304,500.00
Mean property value per property	€	328,989.58
Standard deviation	€	111,374.13
Contribution of blue and green elements to the property values		
Contribution of blue and green elements to the property values (RIVM, 2015)		8.00%
Total contribution in the Lower Raam area	€	5,053,280.00
Mean contribution per property	€	26,319.17

5. Discussion

5.1. Ecosystem services

5.1.1. Ground water provisioning

Due to the presence of agriculture on sandy soils, damming and the fact that a significant part of the Raam is situated lower than the Meuse river it merges with, regulation of ground water provisioning is all but natural in the Raam area. Despite being a highly regulated ES, ground water provisioning remains an important ES in the Raam valley. This ES may not always provide a direct benefit, but does contribute to other natural capital, such as crop and livestock provisioning, as well. For this reason, the water board Aa en Maas already maps ground water tables using the iMOD model instruments. Whereas the STOWA's 'discharge dynamics and ground water' model only focuses on the ecologically important aspects of stream flow and is thus not suitable for the assessment of this ES, iMOD does assess this adequately.

From the calculations on the consequences of the proposed increases of the water table in the Lower Raam as well as the construction of a new weir, several scenarios with different surface water tables were calculated. Although close to the Lower Raam, the ground water table will considerably rise (up to 81 cm in scenario 4), in the extended area, the rise in the ground water table is substantially less. Especially in the MLW situations, the rise in ground water table outside the direct proximity of the Lower Raam is considerably lower, and the overall area experiencing a rise in ground water table smaller. Since subsurface water retention is especially important for agricultural and ecological needs during the MLW situations, this is unfortunate. Furthermore, even in scenario 4 with local increases of 81 cm in the water table, ideal ground water tables for all nature goals will not be achieved.

5.1.2. Hydrological cycle and flow regulation

Within the river restoration plans, hydrological cycle and flow control in the Lower Raam is mainly affected by the creation of more natural swamp banks that will replace the current banks, as well as the development of vegetation on these banks. Although these stream restoration plans have been proposed with WFD-goal compliance in mind, the proposed shading and construction of swampy stream banks can also have a positive effect on flood safety. However, since the design of the banks and the stream profile was still in an early phase, calculations on the impacts on flood safety were not possible. On the other hand, no models regarding shading, macrophyte growth and the impacts on flood risk were found.

Currently, although the water board does test all their surface waters for flood risk compliance, the actual flood risk is unknown. This is due to the SOBEK modelling instruments that are used, having a traffic light style of output: it only tests whether a water system complies with the applicable safety norms, and does not give the actual flood risk (Deltares, 2020). Thus, currently, the model instruments can only be used in scenario modelling to check whether a given scenario would result in compliance or noncompliance with the flood safety norms. However, with some extra steps, the current water safety modelling instruments could be used to visualise the value of the 'additional' value that the stream restoration measures have. If it were possible to calculate the actual flood risk in relation to the previous flood risk or the mandated norm, it would be possible to calculate the reduced damages from prevented floods. The TEEB-stad model offers a quick calculation module for this situation. Using an improvement of flood risk reduction in a percentage based on the national NBW (Nationaal Bestuursakkoord Water) water safety norms (Rijksoverheid, 2009) and the amount of affected properties, the total sum of reduced damages is calculated (RIVM, 2015). Although these calculations are rather crude and general, as it uses several assumptions, does not include damages to agricultural fields and is not useful for an in-depth damage analysis, it still is a good starting point for such calculations. The benefit of such an analysis would lie in visualising risk assessment to locals and in visualising the benefits of flood protection. For instance, while the costs of the construction of inundation zones or swampy stream banks are rather clear, the benefits (the avoided flooding damages) can often be vague to locals (e.g. a 1 in 20 chance of flooding) and might not be counted in an economical cost- benefit analysis. When monetised, the (economic) effects of flood risk reduction might be more relatable to the local property owners and decision-makers.

As for the impacts of macrophyte shading on hydraulic cycle and flow regulation, no models on the effects of shading on macrophyte growth were found. This is unfortunate, since outputs of the shading models could be useful in modelling macrophyte growth, which in turn can be used in flood risk calculations or in maintenance planning. Until reliable models are developed, in-situ on an ad-hoc basis monitoring and assessment can be used to evaluate the effectiveness of stream shading for future reference.

Although intensive shading (covering >50% of the stream) is especially effective on counteracting the growth of fast-growing macrophytes (Köhler *et al.*, 2020; Verdonschot, 2016a, 2016b), successful shading is dependent on several factors. These factors include stream direction (north-south or east-west), vegetation height and vegetation width. Tree height should be 2 to 3 times the width of the stream, and vegetation with should be 6 to 7 meters for an east-west oriented stream, whereas a north-south oriented stream needs a vegetation with of 18 to 20 meters for optimal shadowing. Furthermore, branches should extend above the water, and a closed canopy or a lot of undergrowth are preferable as well (Verdonschot, 2016b). Köhler *et al.* (2009) also note that a "rather high tree density" is required to achieve the required shading levels, when shading from bank vegetation is used to manage extensive macrophyte growth. Lastly, Verdonschot (2014) indicates the shaded parts of a streams should be between 0.8 and 1.3 kilometres for optimal effects. Currently, only few, relatively short stretches of the Lower Raam are sufficiently shaded, resulting in a net shading of 17% of the stream. The water board aims for 50%, to comply with WFD goals. Since the development of shading and the effects of shading on macrophytes are hard to estimate, the exact effects on flood risk are unclear as well. Although the exact effects are unclear, if the tree cover goal of 50% of the stream is achieved, it can be assumed that this increase in shadow will have a negative effect on macrophyte growth. A decrease in macrophyte growth means that resistance within the stream channel will be lower as in the current situation as well. However, this would not necessarily lower the flood risk, as the macrophytes in the main channel are mowed up to two times a year, to ensure sufficient discharge capacity to prevent flooding. Thus, the actual impact of shadowing on flood risk reduction will be negligible. However, this does not mean that this ES does not have any value. In contrary: currently, by mowing, the water board is doing what the ES could provide with shading. Thus, the value of shadowing would be saved costs on the mowing of macrophytes, as less mowing is likely needed. Furthermore, reduced mowing puts also less stress on the ecosystem. However, the increase in bank vegetation could also have a negative impact on sludge accumulation due to increased leaf and debris influx, especially in streams with a low flow velocity (Tibosch, 2020). Too much sludge and sediment accumulation will require the water board to dredge, will cost money, possibly offsetting the reduced mowing costs.

5.1.3. Crop and livestock provisioning

Use of the WaterWijzer Landbouw by the water board Aa en Maas has revealed that the increase of ground water tables as calculated by the ground water models will overall negatively impact crop and livestock production due to a mismatch in supply and demand of ground water. Although drought stress, which accounted for a 10% to 30% loss of the potential crop yield between 2010 and 2018, will decrease in the vicinity of the Lower Raam, this benefit is offset by waterlogging and indirect damages. These impacts are concentrated in the near vicinity of the Lower Raam, where the increases of the ground water tables are the highest. Due to uncertainties, the economic impacts have not been calculated, but at some locations, potential crop yield losses can near 100% (figure 4). However, despite these losses, the economical drawbacks are expected to be relatively low, both due to the limited area that is negatively affected and due to the prevalence of relatively low-value crops such as grassland, corn, sugar beets, potatoes and cereals in this area (Ministry of Economic Affairs and Climate Policy, 2020; Aa en Maas, 2020). Furthermore, mitigation measures against waterlogging are not included in the WWL model. Mitigation measures could include extra drainage of strongly affected agricultural fields, temporary lowering of the ground water table during sowing and harvesting periods, and financial compensation. Therefore, the calculated damages are expected to be higher than the actual damages.

5.1.4. Nature policy goals

Although “improvement of chance of success of the development of target vegetation/nature as outlined by policy” is not a recognised ES, it could be considered as one, since through ecosystem functioning, chances of the development of target vegetation or target nature improve. Since this is not a recognised ES, no literature on this service exists. However, for some cases, the water board already partly models this service. Large parts of the Raam valley are classified as part of the Natuurnetwerk Brabant (NNB), part of the former Ecologische Hoofdstructuur (EHS). The idea of the EHS was to connect large and ecologically valuable areas together by creating natural corridors (ecologische verbindingszones, EVZs) and areas with specific nature types (natuurdoeltypen), which can both act as stepping-stones for migrating wildlife. For example, as part of the NNB, of the once prevalent wet meadows of the *Cirsio dissecti-Molinietum* type (Dutch: blauwgraslanden) should return to the Raam valley (Besselink, 2018). Using the SOBEK ground water modelling data, it was found that even the highest ground water scenarios were not sufficient to achieve all nature type goals. However, the province of Brabant is responsible for NNB goal completion (Rijksoverheid, 2020b). While the province of Brabant partly maps the NNB nature goals (Provincie Brabant, 2020) and shares NNB goals with the water board when working together on projects such as the ‘Gebiedsplan Raam’, not all NNB goals are readily accessible to the water board.

Besides the NNB, Water Framework Directive (WFD) goals are to be achieved in the Lower Raam. These require the Lower Raam to have a good ecological potential. WFD compliance is measured using water system analyses, such as the STOWA ESF (Mellor *et al.*, 2017). The STOWA ESF model also allows scenario mapping and can thus be used to map the effects of measures such as river restoration on compliance with WFD policy goals (Mellor *et al.*, 2017).

In conclusion, as far as this can be considered an ES, the water board Aa en Maas already partly maps this ES using models and instruments that are already in place. However, due to different entities being responsible for different nationally mandated nature policy goals (such as the NNB and WFD), no holistic mapping of nature policy goals is undertaken. While there is communication between the water board and the province of Brabant when working on projects such as 'Gebiedsplan Raam' to integrate both NNB and WFD goals in the project, integral ES mapping between the province and the water board could aid in nature conservation (Vihervaara *et al.*, 2017) and increased success of accomplishing nature policy goals.

5.1.5. Cultural and aesthetic values

Using the TEEB-stad model, it was calculated that the Lower Raam can contribute approximately € 5,053,280.00 in total property value for all properties in a 400-metre radius around the Lower Raam, with an average of € 26.319,17 per property. However, there are some side notes to these results. First of all, it was assumed that the river restoration efforts will result in nature that is enjoyable to the locals, akin a park. Secondly, although the TEEB-stad model is based on different studies carried out in the Netherlands (Luttik and Zeilstra, 1997; Platform31, 2013; RIVM, 2015; Ruijgrok *et al.*, 2006) and should be representative for the entire country, the 8% contribution of nature to the property price might be relatively high in this very rural area. For example, White and Leefers (2007) found that natural resource amenities in rural areas were valued lower in rural areas than in suburban areas. Thirdly, although the TEEB-stad model is not an inherently spatial model, it was used in combination with a spatial component in this assessment. By using ArcGIS and property data to identify properties, additional uncertainty has been introduced. Furthermore, TEEB-stad is not useful for case-specific, in-depth analyses, and should only be used as a quick indicator for the aesthetical effects of blue and green elements on existing properties. Lastly, it should be kept in mind that the output of this ES is a single output. This is in contrast to the outputs of other ES, which are recurring, yearly, benefits, since these services generate their benefits continuously, year-round. This also partly explains why the contribution of nature to property value is so high. On the other hand, property values are in general quite high. The Dutch national mean property value was € 270,000 on the 1st of January 2020 (CBS, 2020), whereas the mean property value in the research was € 328.989,58 per property.

Although the economic value of this impact might seem to trump contributions by other ES, economic value is not the sole indicator of importance. For instance, the importance of an ES can depend on the area and individual stakeholder interests (Verburg, Selnes & Bogaardt, 2014). Some cultural values, such as spiritual values, can be priceless to individuals, whereas they are of little economical value.

Another available model is the NC-model, which, just as the TEEB-stad model, calculates the contribution of blue and green elements to property value. As the NC-model makes use of the most recent spatial data to map and quantify ES at a high resolution and is more frequently updated than TEEB Stad (M. Paulin, personal communication), the NC-model is more up to date. Furthermore, unlike the TEEB Stad tool, the NC-Model is an inherent spatial model. Therefore, no extra calculations have to be used as is the case with TEEB Stad, leaving less room for errors and making it more accurate (M. Paulin, personal communication). A map for the current situation in the Netherlands is readily available.

However, the NC-model is designed for ES mapping. Implementing ES scenario modelling will require altering spatial input data to reflect the effects of each measure that will be affecting ES delivery. For scenario modelling the contribution of new blue and green elements in the NC-model, the LCEU water map used to identify water would need to be altered, as well as the input data for the identification of vegetation (Remme *et al.*, 2020). For mapping the current contribution of green elements to property values, a vegetation map was constructed using a height map, data from the public land register (BAG), infrared aerial photography and a map showing high-voltage power lines (Remme *et al.*, 2020). Altering this vegetation map and the water map to model the contribution of blue and green elements to property value in multiple different scenarios might thus be a lot of work.

5.1.6. Other ES

Many more ES exists besides the ones that were covered in this thesis (Appendix A), including other services that might be (economically) important to the water board or other actors in projects that the water board is involved in. For the 'Gebiedsplan Raam', the recreational value of nature is also important, as expressed by Besselink (2018), and pollination could also prove to be important in the heavily agricultural Raam valley. Additionally, the restoration of the natural stream banks with bank vegetation could also have positive effects on bank erosion and the influx of nutrient-rich runoff from adjacent agricultural fields. Benefits of these services could be expressed as reduced maintenance costs for erosion prevention and increased chances of compliance with WFD goals. Benefits of nutrient sequestration could also be expressed as the costs it the water board would have to make to achieve similar nutrient concentrations using other methods such as treatment of runoff water or treatment of the Lower Raam itself. If nutrient sequestration by bank vegetation was included in the study, then this would likely have resulted in a large contribution, since the Lower Raam does have problems with nitrogen loads exceeding the WFD norms (Besselink, 2018).

Other ES that would likely have had little economic impact in the river restoration plan, but could prove to have a (significant) economic benefit in other areas. These benefits include, but are not limited to: health benefits by sequestration of fine particulate matter and harmful airborne substances; mitigation of the heat island effects in large build-up area and reduced costs for storm water treatment due to filtration by macrophytes in halophyte filters (Appendix A).

However, for successful mapping and quantification of ES, sufficient knowledge needs to be available, just as the correct mapping and quantification tools need to be available. Since the Dutch government has assumed a decentralised approach to ES promotion and integration into national accounting (Verburg *et al.*, 2014), knowledge and tools should be obtained from knowledge hubs and research centra such as STOWA, Deltares and the RIVM (Dutch National Institute for Public Health and the Environment). Other water board might also have experience with mapping and quantifying ES and could also be approached.

5.2. Recommendations

5.2.1. Future management

ES mapping can be useful in a variety of stages in a project. In early stages, ES mapping can be useful in determining priorities and stakeholders. In later stages, ES quantification and mapping could be used by, for example, the water board Aa en Maas to determine ES supply and use, as well as the balance of burdens and benefits (Albert *et al.*, 2017; Geneletti and Mandle, 2017; Paulin *et al.*, 2020; RIVM, 2015). ES valuation enables ES to be compared across other services and goods consumed by society, and could provide the water board with new arguments for nature conservation or creation (Albert *et al.*, 2017; Brander and Crossman, 2017). For example, mapping of cultural and regulating ES demands and supply (such as PM sequestration and recreation) can be used to highlight the importance of green elements on physical and social well-being.

Using scenario modelling in ES mapping and quantification, bottlenecks and trade-offs in ES delivery can be identified (Albert *er al.*, 2017). For example, the modelling of crop and livestock provisioning using the WaterWijzer Landbouw has shown that a few selected areas close to the Lower Raam can lose up to 100% of their potential crop yield. Based on this information, mitigating measures or compensation schemes may be devised.

Furthermore, on order to map certain ES, new mapping and quantification models may have to be adapted and existing tools may have to be modified. An example is the SOBEK modelling instruments, of which the output cannot be used as input for the TEEB Stad flood risk calculations. Additionally, input data that is currently not available to the water board might be needed for the mapping of ES. For ES mapping, input data may be obtained from public databases such as the Dutch Natural Capital Atlas (ANK, 2020).

Lastly, in absence of models quantifying the effects of shading on macrophyte growth and flood safety, in-situ monitoring can help the water boards to gain first-hand experience with this form of macrophyte control. However, for reliable evaluation of the effects of shading of macrophytes by bank vegetation, it is important that actual shading and macrophyte cover are measured before as well after the bank restoration efforts. To effectively assess macrophyte cover, drones with multispectral cameras could be used (Penning *et al.* 2018).

5.2.2. Future research

Despite the existing knowledge on the suppression of macrophyte growth through shading by bank vegetation and the effects on flood risk (Köhler *et al.*, 2020; Verdonschot, 2016a, 2016b), no models or instruments are currently available to map or quantify these effects. Quantification models like these, in combination with ES valuation, can facilitate spatial planning and provide added value for decision-making (Albert *et al.*, 2017; Brander and Crossman, 2017), for example in river restoration projects like 'Gebiedsplan Raam'. Despite decentralised approach of the Dutch government (Verburg *et al.*, 2013; 2014), ES mapping and quantification tools and maps are developed by governmental organisations such as the RIVM (ANK, 2020; RIVM, 2015). However, for successful application and integration of ES in spatial planning, more ES mapping and quantification models are needed. Lastly, compatibility of models, shared input data between models and the use of easy-to-obtain or public available data or indicators are preferred, since those who need to use the instruments, such as water board and local governments, might not have the means or expertise to operate complex models (Verburg, 2014). This is illustrated by the fact that the water board Aa en Maas already needs to contract consultation agencies for calculations and designs for projects such as the 'Gebiedsplan Raam'.

6. Conclusion

Despite the goals of the Millennium Ecosystem Assessment and subsequent agreements (EC, 2011; 2013; 2019; Maes *et al.*, 2017; MEA, 2005), the concept and application of ES are not yet fully integrated in spatial planning, as illustrated by the river restoration project 'Gebiedsplan Raam', carried out by water board Aa en Maas. Although the concept of ES was not explicitly used by the water board, two ES, ground water provisioning and crop and livestock provisioning, were already mapped and quantified in the planning and design of the river restoration project. However, other ES, such as hydrological cycle and flow control, could not be mapped and assessed due to a lack of mapping and quantification instruments, and due to the incompatibility of existing tools: although knowledge on macrophyte growth suppression by bank shading is available (Köhler *et al.*, 2020; Verdonschot, 2016a, 2016b), no quantification tools exist. Furthermore, the output of the currently used instruments to model flood risk is not compatible with the TEEB Stad ES valuation tool, illustrating the need for compatible instruments.

Concluding, despite being limited in the number of ES and ES mapping and quantification models that were evaluated, this thesis has shown that ES mapping and quantification could aid the water board Aa en Maas by giving insight in the achievement of policy goals, the identification of mismatches in ES supply and demand and aid in the search for mitigating measures. For example, an increase in the ground water table will lead to increased crop losses in select areas close to the Raam river. Based on this information, decision-makers at the water board can devise compensation plans or ways to minimalize crop losses. Furthermore, this thesis has highlighted the need for more ES mapping and quantification models, as well as the possibility of adapting models currently in use to enable ES valuation.

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Appendix A

Ecosystem services as classified in the CICES (Common International Classification of Ecosystem Services) version 5.1

Section	Division	Group	Class	Code	Class type
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	1.1.1.1	*Crops by amount, type (e.g. cereals, root crops, soft fruit, etc.)*
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	1.1.1.2	*Material by amount, type, use, media (land, soil, freshwater, marine)*
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated plants (including fungi, algae) grown as a source of energy	1.1.1.3	*By amount, type, source*
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes	1.1.2.1	*Plants, algae by amount, type*
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Plants, algae by amount, type*
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown as an energy source	1.1.2.3	*Plants, algae by amount, type*
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Animals reared for nutritional purposes	1.1.3.1	*Animals, products by amount, type (e.g. beef, dairy)*
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	1.1.3.2	*Material by amount, type, use, media (land, soil, freshwater, marine)*
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Animals reared to provide energy (including mechanical)	1.1.3.3	*By amount, type, source*

Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Animals by amount, type*
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	*Animals by amount, type*
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Animals by amount, type*
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Plants, algae by amount, type*
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Plants, algae by amount, type*
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Material by type/source*
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	*Animals by amount, type*
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	*Material by type/source*
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	*By amount, type, source*
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*By species or varieties*
Provisioning (Biotic)	Genetic material from	Genetic material	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*By species or varieties*

	all biota (including seed, spore or gamete production)	from plants, algae or fungi			
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Material by type*
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*By species or varieties*
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	*By species or varieties*
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Material by type*
Provisioning (Biotic)	Other types of provisioning service from biotic sources	Other	Other	1.3.X.X	*Use nested codes to allocate other provisioning services from living systems to appropriate Groups and Classes*
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	*By amount, type, source*
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	*By amount & source*
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	*By amount, type, source*
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	4.2.1.4	*By amount, type, source*

Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking	4.2.2.1	*By amount, type, source*
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	4.2.2.2	*By amount & source*
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source	4.2.2.3	*By amount & source*
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs	Other	4.2.X.X	*Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes*
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	*By type of living system or by waste or subsistence type*
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*By type of living system, or by water or substance type*
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	By type of living system
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Noise attenuation	2.1.2.2	By type of living system
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	By type of living system

Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*By reduction in risk, area protected*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	*By reduction in risk, area protected*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*By depth/volumes*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Wind protection	2.2.1.4	*By reduction in risk, area protected*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Fire protection	2.2.1.5	*By reduction in risk, area protected*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*By amount and pollinator*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*By amount and dispersal agent*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	*By amount and source*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	2.2.3.1	*By reduction in incidence, risk, area protected by type of living system*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	2.2.3.2	*By reduction in incidence, risk, area protected by type of living system*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality	2.2.4.1	*By amount/concentration and source*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	*By amount/concentration and source*

Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	*By type of living system*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	*By type of living system*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*By contribution of type of living system to amount, concentration or climatic parameter*
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*By contribution of type of living system to amount, concentration or climatic parameter*
Regulation & Maintenance (Biotic)	Other types of regulation and maintenance service by living processes	Other	Other	2.3.X.X	*Use nested codes to allocate other regulating and maintenance services from living systems to appropriate Groups and Classes*
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	3.1.1.1	*By type of living system or environmental setting*
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3.1.1.2	*By type of living system or environmental setting*

Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*By type of living system or environmental setting*
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	*By type of living system or environmental setting*
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*By type of living system or environmental setting*
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*By type of living system or environmental setting*
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*By type of living system or environmental setting*

Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	*By type of living system or environmental setting*
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	*By type of living system or environmental setting*
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	*By type of living system or environmental setting*
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*By type of living system or environmental setting*
Cultural (Biotic)	Other characteristics of living systems that have cultural significance	Other	Other	3.3.X.X	*Use nested codes to allocate other cultural services from living systems to appropriate Groups and Classes*

Abiotic Extension (includes water)

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Section	**Division**	**Group**	**Class**	**Code**	**Class type**

Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	By amount, type, source
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	By amount & source
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	By amount, type, source
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	4.2.1.4	By amount, type, source
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking	4.2.2.1	By amount, type, source
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	4.2.2.2	By amount & source
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source	4.2.2.3	By amount & source
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs	Other	4.2.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for nutritional purposes	4.3.1.1	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for material purposes	4.3.1.2	Amount by type

Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for as an energy source	4.3.1.3	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances or ecosystem properties used for nutritional purposes	4.3.2.1	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances used for materials	4.3.2.2	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind energy	4.3.2.3	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Solar energy	4.3.2.4	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Geothermal	4.3.2.5	Amount by type
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy	Other	4.3.2.6	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by freshwater and marine ecosystems	5.1.1.1	Amount by type

Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by atmosphere	5.1.1.2	Amount by type
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	5.1.1.3	Amount by type
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes	5.1.2.1	Amount by type
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	5.2.1.1	Amount by type
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Liquid flows	5.2.1.2	Amount by type
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Gaseous flows	5.2.1.3	Amount by type
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes	5.2.2.1	Amount by type
Regulation & Maintenance (Abiotic)	Other type of regulation and maintenance service by abiotic processes	Other	Other	5.3.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes

Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Physical and experiential interactions with natural abiotic components of the environment	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	6.1.1.1	Amount by type
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Intellectual and representative interactions with abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable intellectual interactions	6.1.2.1	Amount by type
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	6.2.1.1	Amount by type
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Other abiotic characteristics that have a non-use value	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value	6.2.2.1	Amount by type
Cultural (Abiotic)	Other abiotic characteristics of nature that have cultural significance	Other	Other	6.3.X.X	Use nested codes to allocate other provisioning services from non-living systems to appropriate Groups and Classes

Appendix B

Stakeholders and stakeholder groups involved in the planned project in the Lower Raam valley and their interests.

Stakeholders and stakeholder groups	Stakeholder main interests
Water board Aa en Maas	Flood safety; water quality; nature development
Farmers (local/farming collective ZLTO)	Retention; crop production
Municipalities Grave, Mill en Sint Hubert, Cuijk	Flood safety; recreation
Locals, owners, and lease owners	Flood safety; nature development
Brabants Landschap	Nature development; historical/cultural services; recreation
RBT (tourism board) Land van Cuijk	Recreation; historical/cultural services; nature development
Province of North Brabant	Flood safety; water quality; recreation; nature development
Culture historical and environmental groups	Historical/cultural services; nature development; water quality