THE EFFECTS OF WETLAND RESTORATION ON ECOSYSTEM SERVICES IN THE GERMAN MIDDLE MOUNTAINS

An analysis of ecosystem service trade-offs generated by wetland restoration in headwater stream areas

MSc thesis by Olaf de Haan

January 2021

Water Systems and Global Change Group

WAGENINGEN
UNIVERSITY & RESEARCH

Frontpage image provided by Wetlands International.

The effects of wetland restoration on ecosystem services in headwater stream areas

An analysis of ecosystem service trade-offs induced by wetland restoration in the German Middle Mountains

Master thesis Water Systems and Global Change Group in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

Olaf de Haan

January 2021

First supervisor Wageningen University:	dr. ir. Bregje van der Bolt Department of Environmental Sciences Water Systems and Global Change group
Second supervisor Wageningen University:	dr. ir. Raffaele Vignola Department of Environmental Sciences Water Systems and Global Change group
Supervisor Wetlands International:	Eef Silver
Supervisor Stroming B.V.:	Jos de Bijl

Abstract

Over centuries, humans have altered watersheds profoundly to make more use of the river's naturally provided ecosystem services (ESs), *e.g.* drinking water, transportation and irrigation. An example of these alterations is the construction of drainage systems in the headwater stream areas, for agricultural purposes. This led to more peak flows reaching the river system, which increased the chance of flooding.

To reduce these peak flows, restoration of the water retaining wetlands is necessary. This study, therefore, examines the effects of wetland restoration, by using a case study in the German Middle Mountains. This study can be applied to other low mountain regions as well, where peak flows have increased and land-use is extensive. The research qualitatively studies the different ES trade-offs that occur when wetlands are restored. This is done by providing a social-ecological analysis, in which the area's stakeholders are identified and linked to the different ESs, combined with an analysis in which these ESs are studied further in the current situation and in the alternative, hypothetical situation, wherein the restored wetland is added to the system.

In the current situation, wetlands are mainly used for dairy and fibre production, a provisioning ESs. In the alternative situation, the ESs water retention, water purification and biodiversity are more profound, which comes, however, at the cost of provisioning services.

Moreover, a descriptive scenario analysis is performed on the different ways the wetland restoration could be implemented and how this affects stakeholders, depending on which ESs are aimed to be enhanced. The four scenarios include enhancement of water retention, water purification, biodiversity and wet-agriculture. The biodiversity scenario resulted in the largest ESs increase over-all, but also in the largest provisioning services decrease. Within the water retention scenario all ESs are balanced the most.

The study concludes that wetland restoration results in a trade-off in provisioning ESs (dairy and fibre production) and the other identified ESs (water retention, water quality and biodiversity). The magnitude of this trade-off, however, depends on how the wetland project is implemented. This conclusion can be applied to other low mountain regions, where peak flows have increased and land-use is extensive.

Keywords: Ecosystem Services, Wetland Restoration, Building with Nature, Trade-offs, System Analysis

‘Die Natur ist ein einheitliches Ganzes, ein Organismus, in dem die Teile nur in Beziehung von einander funktionieren.’

“Nature is a unified whole, an organism, in which the parts function only in relation to each other.”

(Translation by author)

- Friedrich Schelling, acquired from *Alexander von Humboldt und die Erfindung der Natur,* written by Andrea Wulf (reference quote: Richards 2002m S, 138, 129 ff)

Table of Contents

1. Introduction

In the last century, the system of the river Rhine has been altered profoundly. The river has been straightened, banks have been hardened and floodplains have been disconnected (Wilken, 2006; Grift, 2001; Broseliske *et al.*, 1991). These modifications facilitated optimal use of the services provided by the river and aimed at reducing the river's frequent flooding (Pinter *et al.*, 2006). During these past centuries, the economic value around the river increased enormously. Vast industrial areas arose near the riverbeds, for a large part dependent on the services the river provided (Wilken, 2006). Furthermore, densely populated urban areas formed close to the river, also due to the river's naturally provided ecosystem services (ESs), such as drinking water, transportation and irrigation (Halbe *et al.*, 2018; Wilken, 2006; Shabalova, Deursen & Buishand, 2003). In short, the areas around the Rhine became densely populated and highly productive and thereby gained a high socio-economic value (Te Linde *et al.*, 2011). This high socio-economic value in flood prone areas made flood attenuation of the Rhine all the more important (Pinter *et al.*, 2006).

The alteration of the natural flow of the river Rhine and the use of its ESs did, however, not go without consequences. In addition to the huge increase in demographic and economic value of this area, the natural state of the river changed. Water quality decreased, morphological alterations led to essential habitat disappearance and there has been a trend towards a faster transportation of water from the inlands to the river's delta (Lammersen *et al.*, 2002; Grift, 2001). The latter was caused not only due to alterations in the river itself, like river straightening, but by alterations across the whole watershed. For instance, installing rainwater drainage systems in urban and agricultural areas (Changnon & Demissie, 1996). These drainage systems force precipitation to immediately run-off into the Rhine and its tributaries. Consequently, the water would not remain there to interfere with human practices, such as agriculture (Demissie, Bhowmik & Adams, 1983). However, this results in the precipitated water of the whole area reaching the river all at once. These peak flows used to be reduced by the soil's sponge function; precipitated water flowed slowly through the soil downwards toward the river (Bullock & Acreman, 2003). Artificial drainage upstream erased this natural sponge function, lowering the water's soil retention time, resulting in an increased probability of floods downstream (Otterman *et al.*, 2017; Zemke, 2018).

A possible solution to regain the ecosystem's natural water retention capacity in agricultural areas is by blocking these artificial drainage systems again, thereby restoring the former wetlands around the Rhine's Middle Mountains (*Mittelgebirge)*. This lower mountain range is targeted because it is part of the headwater streams of the Rhine, where a large proportion of the precipitation reaching the Rhine falls. Restoring these wetlands means regaining the ES water retention again. This is illustrated in Figure 1. ESs are benefits to people, provided by nature (Millennium Ecoystem Assessment, 2003). Water retention is not the only ES that would be affected by wetland restoration. Recreating former wetlands also has positive effects on other ESs *e.g.* tourism, water quality, drought risk and biodiversity (Otterman *et al.*, 2017; Mitsch *et al.*, 2005; Zedler, 2003). On the other hand, reconstructing the wetlands will very likely have a negative impact on the direct economic agricultural benefits the area currently provides (Antle & Stoorvogel, 2006). Thus, there are trade-offs in ESs involved in restoring this wetland.

Researching these ES trade-offs of wetland reconstruction is part of a project commissioned by Wetlands International and Stroming. The research project assesses the effectiveness and feasibility of improving the natural sponge effect of wetlands in the German Middle Mountains by restoring wetlands in the upper reaches of the tributaries of the Rhine river (Otterman *et al.,* 2017). This is the wetland restoration whose potential effects on trade-offs among ESs will be studied in this research. This wetland restoration project will from now on be referred to as the Sponge Project.

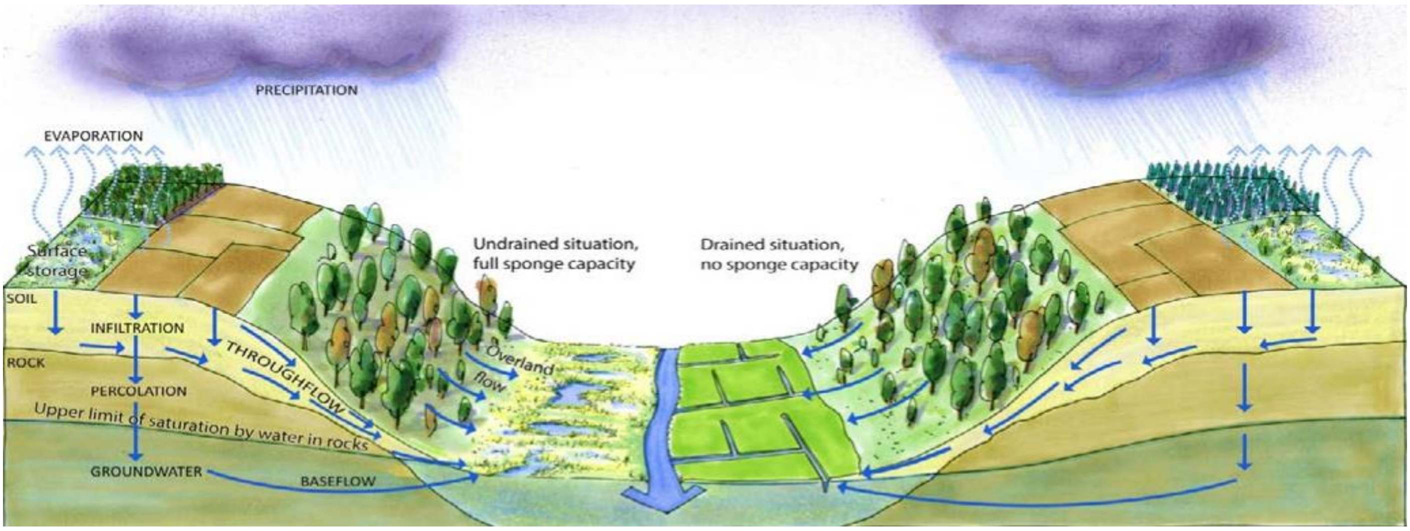

Figure 1 - Illustration visualizing the current anthropogenically modified situation in the German Middle Mountains (on the right) and the proposed situation where wetlands are restored (on the left; Otterman *et al.*, 2017).

Figure 2 - Picture of one of the types of drainage ditches that currently runs through the study area. The drainage pipe transports water rapidly downwards, towards the Kyll, preventing it from infiltrating into the soil (picture provided by Lena Vitzthum, 9 October, 2020).

1.1 Case study area

As mentioned before, this research will be part of a larger research project that assesses restoring wetlands in the upper reaches of the tributaries of the Rhine river to regain their natural sponge effect. This proposed study will use the same areas of research. This section gives a thorough description of the area, essential for understanding its ESs later. Part of this description is the location of the research area and the reasons behind this choice, its socio-ecological status, influence of climate change and its generalizability.

1.1.1 Research area's location

The research area is located in a rural region in the German Middle Mountains, in accordance with the Sponge Project. According to a report by Otterman *et al.* (2017), commissioned by the Sponge Project, this region has a large influence on the Rhine's discharge because here numerous tributaries come together, such as the Mosel, the Main and the Neckar (see Figure 3). Moreover, in this part of the river basin relatively more precipitation falls in the form of rain, compared to the rest of the basin. Also, here more broad U-shaped valleys can be found, which are required for the most efficient wetland restoration. In short, the region of the German Middle Mountains is highly suitable for natural water retention, relative to the rest of the basin (Otterman *et al.*, 2017).

The wetland restoration project zoomed further in on the downstream part of the Mosel catchment. The downstream Mosel catchment contains flat valley floors, a presence of substantial peak flows and a sufficiency of data (Otterman *et al.*, 2017). Therefore this area was chosen to test the possibilities of natural water retention to decrease peak flows that lead to floods. The land use on and around the Mosel's banks include coal mining, urban settlement, pastures, vineyards, timber forestry and other agricultural practices (Zemke, no date; Pies *et al.*, 2007; Hostache *et al.*, 2010; Ashenfleter & Storchmann, 2001; Ott *et al.*, 1991).

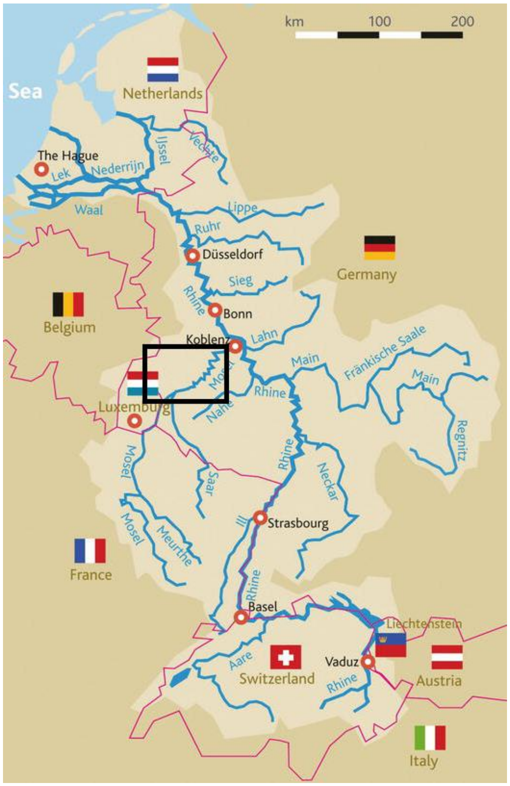

Figure 3 - The Rhine catchment basin, with a box indicating the location of the downstream part of the Mosel tributary (Schulte-Wülwer-Leidig *et al.*, 2018).

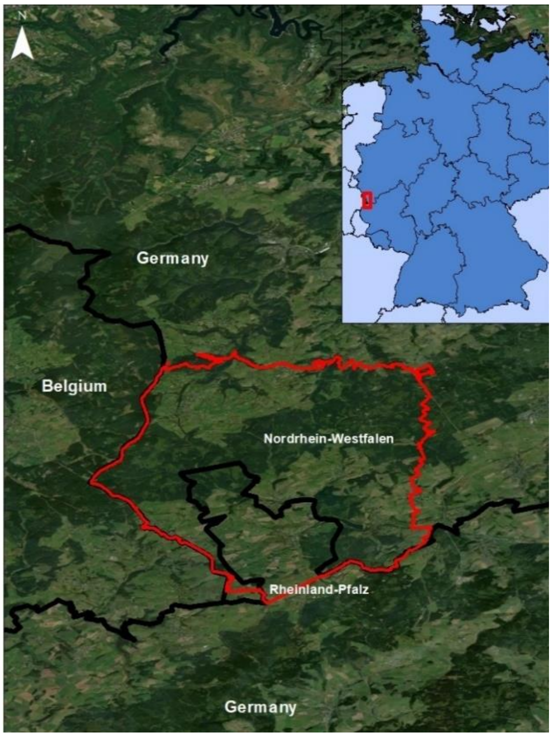

Figure 4 – The research area outlined in red, delineated by the Belgian state border and crossed by a German Federal state border. In the top right figure, the location of the research area within Germany is highlighted in a red square.

This study focusses on extensive land use areas, that can be restored into wetlands. These types of areas are not found directly next to the Mosel, but rather higher up in the Mosel's catchment area. The precise study area is in the upper Kyll catchment area (48.3 km^2), upstream of the Steinebrück discharge station, northwest of Frauenkron (Waterloo *et al.*, 2019). Its location is depicted in Figure 4.

1.2 Socio-ecological status study area

This section aims to get a general idea of the socio-ecological status of the study area and its probable changes in the future. This is important for the later ES identification, as this forms the base of the human aspect of ESs. With socio-ecological status of the research area is meant the status of both the social system (including economic aspects), the biophysical system, and their interactions (Redman, Grove & Kuby, 2004). These interactions are mainly found in the last part describing climate change effects.

1.1.2 – Socio-economic aspects

Figure 4 shows how the border of the two German federal states North Rhine-Westphalia (North) and Rhineland-Palatinate (South) split right through the research area. On the northern side of this border, are the municipalities Hellenthal (7.883 inhabitants) and Dahlem (4.226 inhabitants) located. These are both part of the district Euskirchen. On the southern side of the border lie several small municipalities, all part of the collective municipality Gerolstein (30.860 inhabitants, largest part outside of the research area). Gerolstein is again part of the rural district Vulkaneifel (Statistische Ämter des Bundes und der Länder, 2019). Geographically, the research area lies in the sparsely populated Eifel mountain range. Even though the population in this region is still increasing, mainly due to immigration, age above 65 is over-represented (22.3% in 2013; Ansbacher et al., 2019). This trend of population aging is still present and increasing ((Ansbacher et al., 2019; Föhl & Neisener, 2008).

The economy in the region around the research area is characterized as medium-sized, in national context. Employment is found more in the manual labor sector, such as forestry, construction and agriculture, relative to the rest of Germany (Föhl & Neisener, 2008). Forty percent of the land is used for woodland and another 40 percent for agriculture. The agricultural sector consists mostly of grassland farming and forestry primarily of spruce timber production (Auge, 2020). Still, the service sector is, as it is in the rest of Germany, leading in terms of employment rate (Ansbacher et al., 2019). For example, the share of the service sector is 70% of the total employment in Vulkaneifel. Whereas the manufacturing industry is 27% and only 2.6% of the employment is found in agriculture and forestry (Ansbacher et al., 2019).

The regional land-use numbers are consistent with the research area, where woodland comprises 55% and pastures 42%. The rest is made up by urban fabric. The woodland is divided into coniferous forest (44%), Broad-leaved forest (4%) and mixed forest (6%; Waterloo *et al.,* 2019). See Figure 5 below for a visualization.

Moreover, tourism is one of the most important sources of income, where mainly the natural attractions are popular (Noack & Federwisch, 2019). The visitor's rate in the Eifel is estimated around 5 million per year. To put this into perspective, in Vulkaneifel in 2016, 6.5 touristic visitors per inhabitant were counted. This rate lies far above the average of surrounding regions (Ansbacher et al., 2019). Tourism is still growing and is supported by investments from regional and local authorities. Especially cycling and hiking tourism is seen as potential, wherefore regional cooperation is taking place (Föhl & Neisener, 2008). Also international cooperation to support tourism between Germany, Belgium and Luxemburg is happening in the Eifel. Environmental education is seen as an important goal of this cooperation (Föhl & Neisener, 2008).

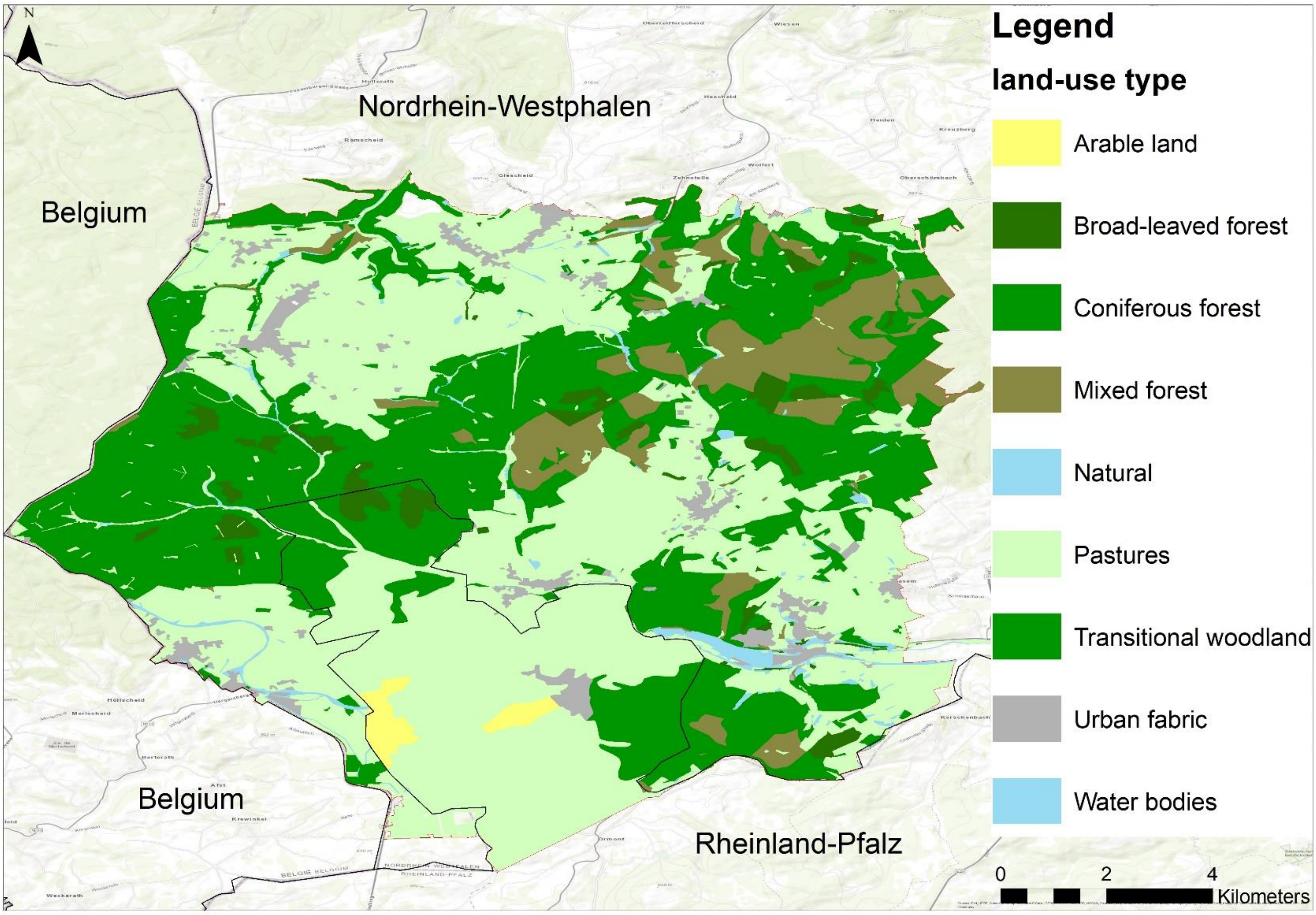

Figure 5 – Land-use distribution in the study area. The national state and federal state borders are shown in black.

1.1.3 – Natural aspects

The research area lies in the *Naturpark Hohes Venn-Eifel (Nordeifel)*. This natural park houses more than 1900 endangered red-list plant and animal species and interference in natural processes is reduced to a minimum (Wiesen & Lammertz, 2016). The mild and humid climate is characterized by oceanic influences and the mean annual precipitation lies around 1200 mm a^{-1} (Havlik, 2002). In the research area, 40% of this precipitation evaporates and 60% is discharged through streams (Waterloo *et al.,* 2019). The natural park is densely forested, dominated by Norway spruces (*Picea abies*), which are also used for forestry (Lehmkuhl, Loibl & Borchardt, 2010; Auge, 2020). These alien species were planted for reforestation, but are planned to be deforested again to speed up renaturalization into a forest dominated by beech (*Fagus sylvatica*) and birch (*Betula pubescens*; Lehmkuhl, Loibl & Borchardt, 2010). The natural park The Eifel encompasses the Natura2000 protection area *Obere Kyll und Kalkmulden der Nordeifel*. This protected area is 1326 hectares large and the Kyll and its tributary rivers are rich in rare fish fauna, specialized in middle mountain streams. These encompass among others the Brook Lamprey (Lampetra planeri) and the Bullhead (Cottus globio; (Kiebel et al., 2018).

The soils in the Eifel region are mainly shallow and sandy. This makes the region's soils poor in retaining water, and nature and agriculture are therefore vulnerable to drought and erosion (Auge, 2020). Moreover, the soil is generally infertile, making it also poor agricultural land (Lehmkuhl, Loibl & Borchardt, 2010). In the research area, gleyic soils can be found on the valley floor, which is a typical wetland soil and also often used for extensive grazing. The upslope areas consist of various types of brown forest soil, which are more fertile than the gleysols (Waterloo *et al.*, 2019).

1.1.4 – Climate change leading to more floods and droughts

Direct effects

North Rhine-Westphalia is expected to see an increase in temperature of 3 degrees Celsius in the period between 2070 and 2100, following a medium emission scenario (RCP 4.5) and 5 degrees Celsius following a worst-case scenario (RCP 8.5; Auge, 2020). This is very likely similar in the neighboring federal state of Rhineland-Palatinate, and thus, also in the research area. In the past 50 years the average yearly temperature has increased with 0.027 degrees Celsius per year. However, in the more mountainous part of the Eifel, where the research area is located, the temperature increase was slightly lower, which is also expected in the future (Auge, 2020). Important for this research is the expected change in precipitation (Asche & Schulz, 2009). In the northern district Euskirchen, the average precipitation is expected to slightly increase, although again less so in the higher Eifel region. Generally speaking, the summers will become dryer and the winters will become wetter. Most alarming, however, is how the weather extremes (rainfall and droughts) are expected to increase over time together with their intensity (Auge, 2020). The indirect effects of these extreme weather changes, and why their increase is so alarming, are explained below.

Indirect effects

There is a direct link between floods and the type of above-mentioned weather extremes (Gavin, Leonard-Milsom & Montgomery, 2011). Floods are already not something uncommon in and around the research area. The district Euskirchen commissioned in 2020 a report on climate change and its effects in their district (Auge, 2020). It mentions that through climate change, rivers will flood more often. The highest increase is in winter, while in spring there might even be a decrease. This is due to more winter precipitation falling as rain, instead of snow (Auge, 2020). This results in precipitation immediately being transported to rivers, instead of later in the year, when the snow thaws. Furthermore, chances of floods increase even in the dryer summers, due to more and heavier heavy rainfall events. The Kyll is mentioned as a river where floods will potentially increase, thereby damaging residential, commercial, transport, infrastructural and agricultural uses around it (Auge, 2020). These damages enormously increased due to settlement in floods plains in the past. Also ground and surface water contamination because of floods is possible, due to local heavy industry (Auge, 2020).

Moreover, due to climate change, extreme weather will become more long-lasting, resulting in more consecutive dry and consecutive wet days. On the one hand is this another flood magnifier, but it also increases the chance of droughts and their severity. Already in the past years, droughts led to sinking water levels and whole water bodies disappearing in the Hellenthal municipality (Auge, 2020). This has led to problems such as crop failure and a danger to the drinking water supply. Especially droughts in the Springs of 2018 and 2019 were destructive for the agricultural sector. Also problems for the water quality due to droughts have been reported. Climate change will exacerbate the above-mentioned problems in Hellenthal, and the rest of the Eifel (Auge, 2020). Droughts reducing the agricultural yield have already been reported in the study area, according to a survey done by Ingenieurbüro Reihsner (L. Vitzthum, personal communication, September 28).

The Eifel's ecosystem is very sensitive to climatic change, as highly specialized species have spread there due to the structural diversity of the landscape (Auge, 2020). The main causes are the earlier mentioned increase in average temperature and in droughts. Forest ecosystems are most prevalent in the region, which have enough buffer capacity to remain unaffected by short droughts. However, the increase in consecutive warm dry days will eventually result in damage to these ecosystems. This also applies to amphibian and fish species. These species need wet ecosystems such as wetlands to remain wet, in order to survive (Brunke, 2008; Auge, 2020). Periods of drought affect ecosystems' regenerative ability and resilience, making them more sensitive to other sorts of threats. Moreover, since habitats are slowly shifting, many species will migrate along with these habitats. The success of their migration will depend on the existence of climate corridors and stepping-stone habitats in the Eifel region (Auge, 2020).

1.1.5 Generalizability of case study area

An important aspect of the wetland restoration studied in this research, is the generalizability of it. According to Wetlands International (2020), this type of NBS can be applied not only in a part of the Rhine basin, but also in other regions in Europe. The type of lower mountain ranges that were found suitable for sponge restoration are abundant in Central Europe. Mountain ranges in the Czech Republic, Poland, France, Great-Britain, Ireland, Austria, Italy and the Balkan countries are mentioned as examples (Wetlands International, 2020). Suitable locations can likely also be found in lower mountain ranges outside of Europe.

This research can be an example study for future research and implementation of wetland restoration for water retention in these above-mentioned lower mountain ranges. For an area to be suitable for wetland and sponge capacity restoration, they have to lie in temperate regions, house the upper tributaries of large rivers and experience high annual rainfall (van Winden, Overmars & Braakhekke, 2004). Moreover, U-shaped valleys, with gradual slopes ending up on flat valley floors are required for wetland restoration similar to this research. This is where the wetlands can reach their maximum water storage potential (Otterman *et al.*, 2017; Wetlands International, 2020).

When you look at the socio-economic aspect of sponge restoration suitability, a rural and extensively used area is required, like this research's case study area. This results in enough space for water retention, favorable land prices and stakeholder acceptance (van Winden, Overmars & Braakhekke, 2004). Socio-economically, lower mountain range areas are often similar in the sense of land-use and employment. Generally, these areas are thinly populated and well-covered with forests and agriculture. Mountain soils are often infertile, as they are weakly developed and prone to nutrient removing water erosion. Thus, agricultural yield per hectare is often low in regions similar to the study area, making grassland farming common (Guidi *et al*., 2013). Moreover, tourism is often an important source of income in middle mountain regions, but this depends per area on factors like aesthetics, accessibility and proximity to higher populated areas (Oppermann, 1996). These above-mentioned characteristics are all important aspects of where this research's results could be generalized to.

When looking at climate change effects in other suitable areas for sponge restoration, similar trends and direct effects can be seen as found in this case study area. The indirect effects, however, can differ greatly. These areas will very likely experience similar increases in extreme weather, but these do not necessarily turn into disasters like floods or droughts in the same extend as in the research area. This depends not only on the severity of the extremity, but also on the social vulnerability of the region. This vulnerability differs per region due to differences in class, occupation, ethnicity, gender, *etc.* (Wisner *et al*., 2004). Thus, it cannot be assumed that also indirect climate change effects will be similar in the areas mentioned as suitable for sponge restoration. Therefore, research on implementation of wetland restoration should, next to biophysical research, also include social aspects.

1.3 Knowledge gap

The wetland restoration project that this proposed research is part of, has already researched wetland reconstruction for water retention in the German Middle Mountains. A hydrological study, stakeholder analysis and literature research have already been conducted within the project (Otterman *et al.*, 2017; Waterloo *et al.*, 2019). However, a study about the ESs has not yet been done within this proposed development project. This chapter aims to clarify this gap of knowledge regarding ESs in scientific literature.

In scientific literature, there has been plentiful attention on wetlands and their provided ecosystem services, for instance by Ardon *et al.* (2010) and Maltby and Acreman (2011). There have even been books written about this subject, such as 'Valuing Ecosystem Services: The Case of Multi-functional Wetlands', by Georgiou and Turner (2012) and 'Functional Assessment of Wetlands: Towards Evaluation of Ecosystem Services' by Maltby (2009). These books also mention the trade-offs there are in ESs when a wetland is altered. Moreover, the European Commission has published a series of reports about the guidance of wetlands in the Water Framework Directive (WFD) (European Commission, 2003).

In short, there has been a lot of research on wetlands and the ESs they provide. The link between land use planning and these ESs has gotten much scientific attention in the past decade, but is often hardly involved in (environmental) policy decision making (Bouwma *et al.,* 2018; van Oudenhoven *et al.*, 2018; Zheng *et al*., 2016). This type of policy making or implementation concerns *e.g.* NATURA 2000, European Water Framework Directive or Marine Strategy Framework Directive (Karstens, Inácio & Schernewski, 2019). Especially scarce is ES research involving proposed building with nature (BwN) projects. So, ES research on a wetland that has not been restored yet. This is the gap that this research aims to fill, to create a bridge between more abstract theory on ESs and the more practical field of BwN land use projects, with an anticipatory perspective.

2. Main Research Question and Sub-Questions

This thesis aims to map the likely consequences of wetland restoration in the German Middle Mountains for the already existing, and by the restoration created, Ecosystem Services.

This is done by applying as a main research question: '**What trade-offs between different Ecosystem Services would wetland restoration in headwater stream areas bring about, applied in a case study in the German Middle Mountains?**'

This is subdivided in the following sub questions:

a. Which stakeholders can be identified in connection to wetland restoration in the case study?
b. What Ecosystem Services can be identified in the study area in its current form and how are they generated?
c. What Ecosystem Services can be identified in the study area if restored wetlands would be in place and how are they generated?
d. What are the different wetland implementation scenarios regarding ES enhancement in headwater stream areas?
e. How do these wetland restoration scenarios influence the identified changes in Ecosystem Services and what trade-offs are involved?

3. Concepts and Theories

There are several concepts that are frequently used and mentioned in this study that are of an ambiguous nature. For the sake of clarity, they therefore require some explanation on how these concepts need to be understood. This section first attempts to tackle this ambiguity. Thereafter the analytical research approach of this proposed study is explained.

3.1.1 Ecosystem Services

Around the year 1800 Alexander von Humboldt was the first to recognize a unity within the complexity of the natural world. He was inspired by scientists and philosophers such as Friedrich Scheller (see his quote on page 5). Von Humboldt viewed nature in a holistic way, instead of the individualistic way of thinking that used to be common. He set the foundations of the concept “ecosystem” (Fränzle, 2001). Two centuries later, Ellenberg (1973) defines an ecosystem as ‘*an interacting system between organisms and their inorganic environment which is open but has to a certain degree the ability of selfregulation.*’ (page 1; Boje & Tomczak, 1978). These interactions can be physical, chemical, or biological (de Groot *et al*., 2010). Important to note is that the scale of an ecosystem can vary between just a small plot, to even a regional or national scale (van Oudenhoven *et al.*, 2012).

The benefits to human well-being that such an ecosystem provides are referred to as Ecosystem Services (Maltby & Acreman, 2011; Ojea, Martin-Ortega & Chiabai, 2012; Millennium Ecoystem Assessment, 2003). Human well-being is in this thesis understood as the access of people to basic materials for a good life, freedom of choice and action, health, good social relationships and a sense of cultural identity and security (Díaz et al., 2006). The concept of ESs could be explained as a way to link this human well-being with ecosystems, or to link nature to economy (Muddiman, 2019). ESs include the provision of tangible materials or goods, such as food and building materials, but also more intangible services, such as pollination, maintenance of nutrient cycles and biodegradation. These ESs are produced by ecological processes that are dependent on interactions between plants, animals, microorganisms and abiotic factors (Gordon, Finlayson & Falkenmark, 2010; IUCN, 2020). By all the different ways of ES classifications there are in literature, it becomes clear that ESs is an ambiguous concept (Ojea, Martin-Ortega & Chiabai, 2012). Therefore a clear classification is needed. This research classifies ESs in provisioning services, regulating services, cultural services and supporting services. This classification is similar to the two widely used ES frameworks of The Economics of Ecosystems and Biodiversity (TEEB) and the Millennium Ecosystem Assessment (MEA; Corvalan *et al.*, 2005; Muddiman, 2019). The used ES classification is further explained in Figure 6.

Provisioning Services	Regulating Services	Cultural Services	Supporting Services
Tangible materials that can directly be used:	How processes, resources and properties are regulated:	Non-material benefits:	Also known as habitat services. Fundamental to sustain the other services:
• Food • Water • Fuel • Wood and fiber	• Purification of water • Flood control • Polliniation • Regulation of disease outbreaks	• Recreation • Education • Psychological wellbeing • Spiritual enrichment	• Soil formation • Maintenance of nutrient cycles • Maintenance of the hydrological cycle • Biodiversity

Figure 6 – Classification of ESs in four categories, with an explanation and examples given below (based on de Groot *et al.*, 2010; Corvalan *et al*., 2005; Sadava *et al*, 2014; Muddiman, 2019 & Baptist, 2015).

The MEA connects ESs directly to human health (Corvalan *et al.*, 2005). It also argues that only nature can provide ESs and there is no technical way to replace them. According to Muddiman (2019), ESs can only be fully beneficial to humans when the ecosystem remains unaffected by anthropogenic actions, which is rarely the case. This makes humanity not only the beneficiary, but also the disruptor of ESs. However, this disruption of the system is avoidable, by a sustainable use of ESs. Nonetheless, a thorough understanding of ecosystem composition and function is required for sustainable ESs usage, which is, according to Muddiman (2019), not yet the case.

ES trade-offs

This research explores the trade-offs that occur in ecosystem services due to an intervention in the system. An ES trade-off occurs when the rise of one ES results in the reduction of another (Busch *et al.*, 2012). Such a trade-off can also occur over time, when the reduction happens only slowly. You often see this with supporting ESs, which is a reason why they are often overlooked (Carpenter, Bennet & Peterson, 2006). This ES definition stands on the fact that resources are finite. Thus, land-use and management choices cannot aim to maximize all ESs, but choices have to be made (Turkelboom, 2018).

3.1.2 The ESs in this research

In this section all the ESs that will be used in this research are explained, in order to avoid ambiguity and confusion. These are the more general definitions, but in phase 2 they will be put into the context of the research area. The ESs are categorized by the ES classification system introduced in Figure 6.

- Provisioning Services

Food and Fibre production by grassland farming

Grassland farming provides ESs through the livestock that feeds on the grass that grows on its pastures. The main ESs it provides are food production, in the form of meat and dairy, and fibre production. Food and fibre production are easy to recognize because they both have a direct economic value, expressible in economic terms *i.e.* value in Euro. This makes provisioning services easy to identify, even though they depend strongly on the much harder to recognize underlying supporting and regulating ESs (Rodríguez Ortega *et al.,* 2014).

Raw material provision by forests

The provisioning service of forests is providing wood for raw timber and fuel. The forest is managed by thinning and harvesting trees, which are then used by the wood processing industries. This management is considered highly extensive, as it only happens every five to ten years (Bösch, 2018). Forestry is about the management of forests and sustaining the ESs that forests provide. This requires long scale thinking, since tree regeneration takes 80 to 300 years, depending on the species.

Collecting mushrooms, berries and other edible plant parts is common in Germany and can therefore also be seen as a forest provisioning service. The same goes for hunting, which includes mainly roe deer, red deer and wild boar. However, more value likely lies in the recreational aspect of hunting, which is a cultural ES (Bösch, 2018).

- Regulating Services

Carbon sequestration

Carbon sequestration is about the system's ability to absorb atmospheric carbon. Carbon sequestration happens by plant uptake of CO_2, which is then stored in the plant's biomass and so enters the system and remains sequestered in it. This can (partly) compensate the unnaturally high amount of greenhouse gasses that has been emitted into the atmosphere in the recent ages (Sadava *et al.*, 2014). This is where it connects with the ES climate regulation. When the carbon sequestration is analysed later in this research, also other greenhouse gasses and other emitted environmentally harmful substances are discussed.

Water Retention

Retaining water is part of the hydrological cycle (Bullock & Acreman, 2003). Water precipitates on land, is transported to the sea via rivers and groundwater flows and evaporates into the sky again (Chahine, 1992). Increasing water retention capacity means a time delay between precipitation and river transportation. This hydrological cycle is a supporting ES, and thus a change in this cycle has effects all along the system.

Water retention is a passive form of catchment-scale flood risk management. Water is diverted from the river into an area where it does not do any (economic) damage. This is done to temporarily relieve the river of its water load, in order to keep it from overflowing. Another option to do this is by capturing this water already before it can enter the river. This is the type of water retention this study covers and will be explained in more detail in chapter 7.2.1. Generally, increasing water retention capacity is often done by maintaining or restoring wetlands, such as the river's floodplains. Water retention is often a very effective flood measure, both in ecological as in economic terms. Within passive water retention measures, most focus lies on large-scale ecological projects, instead of small, local projects (Jansky, 2016).

Water Purification

The ES of water purification is closely linked to biodiversity, as almost all organisms that live in or around water bodies require clean water. However, clean water is also vital for humans. Not only as drinking water, but also as irrigation for agriculture. An increase in the use of fertilizers in agriculture has added excessive amounts of nutrients like N and P to agriculture's outflowing water. When this water flows back into nature, this often leads to eutrophication in both freshwaters and coastal waters (Khan & Ansari, 2005). Then the water becomes less useful for nature, since only certain well-adapted species are able to live in these phytoplankton-rich waters. The result is less dissolved oxygen, less light penetration and very low biodiversity (Cederwall & Elmgren, 1990). An excess of agricultural nutrient outflow also results in the water becoming less useful for humans. The groundwater and surface water become less useful as drinking water and unsafe for recreation (Codd, 2000; Khan & Ansari, 2005).

- ## Supporting Services

Biodiversity

Biodiversity is seen as a supporting service and as one of the foundations of ecosystem functions (Balvanera *et al*., 2006; MEA, 2005). Thus, fundamental to sustain the other ESs important for human existence (Sadava *et al*., 2004; Van Der Plas *et al.,* 2016). So, biodiversity is linked to all other ESs, at least in some degree. Biodiversity and these links to other ESs will be further explained in section 3.1.3, as it is an important, but especially ambiguous concept within this research.

- ## Cultural Ecosystem services

Cultural services are the type of ESs that are least compatible with economic labels. Valuation of them is complicated because they are not tangible and hardly commensurable (Chan, Satterfield & Goldstein, 2012). This applies to the ESs recreation and tourism, but to a lesser extent than the inclusion of cultural and moral values, since tourism is more objective in *e.g.* the amount of visitors.

Wetland restoration has an effect on the landscape's aesthetical value, which is an important factor in cultural ESs such as recreation (K. Hendriks, September 30, 2020). On the locations suitable for wetland restoration, recreation is often also a valuable source of income. How high this source is, is highly site specific and hard to determine, as visitors in the area do not necessarily pay directly (Chan, Satterfield & Goldstein, 2012; Ramsar, 2009).

Recreation and tourism in forested and agricultural landscapes

Tourism in agriculture-rich, rural areas comprises of farm-based holidays, ecotourism, walking and riding holidays, adventure, sport and health tourism, hunting, angling and arts and heritage tourism. Forest landscapes mainly provide the possibility for activities such as hiking, horseback riding and biking (Bösch *et al.,* 2018). Rural tourism as an ES benefits employment growth, expansion of the economic base, repopulation, social improvement and revitalization of local crafts, within the rural area (Irshad, 2010). Moreover, it is seen as a good way to diversify the income of farmers (Sharpley & Vass, 2016). The main pull factors of rural tourism are nearby (natural) attractions (*e.g.* lake and forest scenery), activities and facilities (such as good restaurants), and inexpensive accommodation renting prices (Oppermann, 1996; Sharpley & Vass, 2016). However, this differs per region. Moreover, tourists often value the tranquility that a rural area can provide, in contrast to urban areas (Pesonen *et al.,* 2011). This also applies for tourism in forested area. In fact, rural tourism and forest tourism is often connected, as they are often both found in the same region.

Cultural identity

Cultural identity (or cultural heritage) is an example of a hard to commensurate cultural ES. In this research, cultural identity is connected to the landscape and defined as how a culture values and identifies with the landscape around them (Daugstad, Rønningen & Skar, 2006). This translates in this research mainly to land-use practices. Studying cultural identity is mainly done using questionnaires with stakeholders, people living nearby and visitors to the area, studying what personal value the area holds for them (K. Hendriks, September 30, 2020).

3.1.3 Biodiversity

As mentioned, biodiversity, also referred to as biological diversity, is a highly ambiguous concept that needs more explanation. Biodiversity is about the variability in living organisms in a certain area, which apply to different kinds of scales (OTA, 1987). The different types of scale in biodiversity are;

- ecosystem diversity: This embodies diversity on a scale of the whole landscape or ecosystem. For example, a landscape filled with forest, riverine vegetation and grassland is more diverse than a landscape that is comprised of only the latter. Also the complex interactions within and between the ecosystems are included in this term (OTA, 1987; Sadava *et al.*, 2014).
- species diversity: Here the actual number of species per area is meant. For instance, a rain forest generally has a higher species diversity than a pine forest created for timber. This term is also known as species diversity (Sadava *et al.*, 2014).
- genetic diversity: This is the smallest scale of biodiversity and is about the diversity in genes within a population or area. It is the driver of adaptation to environmental change (Sadava *et al.*, 2014). For example, crops are improved by reproducing with only the most economically viable specimens, which results in a crop field where all specimens have highly similar genes. In other words, the genetic diversity is low (OTA, 1987; Swingland, 2001).

In this thesis when biodiversity is mentioned, mainly 'species diversity' will be addressed.

So far ESs have mainly been described from an anthropogenic view; how can nature be useful to humankind. The question if this type of thinking is unethical lies outside the scope of this research, but still should not be overlooked. In this research ESs will be looked at through an anthropogenic view, but this view still often intertwines with the solely natural view on ESs, where you look at the intrinsic value of nature (Baptist, 2015). Biodiversity is a good example of an ES that does not seem to have a clear, tangible and direct anthropogenic function, but more of an intrinsic and indirect one. Yet, the services to humankind that an ecosystem can provide are highly dependent on the biodiversity of that ecosystem, through complex interactions among species (Polasky, Costello & Solow, 2005; Ojea, Martin-Ortega &

Chiabai, 2012). Also for the ecosystem itself biodiversity is important, as it, among others, enhances the processes of the supporting services mentioned in Figure 6. Therefore, biodiversity itself is also part of these supporting services. Thus, preserving the biodiversity of ecosystems is required to maintain the ecosystem's direct and indirect economic potential (Sadava *et al.*, 2014). For this reason, the effects of wetland restoration on biodiversity are important parts of this study.

Van Der Plas *et al.* (2016) explain the importance of a high plant community biodiversity by how the different traits of plants result in different ES provision rates. The plant community's species composition could so even result in ES trade-offs. For example, one tree species grows slow and provides therefore timber of high quality. However, this slow growth also means that its carbon sequestration qualities through biomass-accumulation are low. Other tree species might have exact opposite traits, therefore more different ESs can be provided by the plant community. According to T. Wagner (September 17, 2020), this works similarly in wetlands. A wetland that holds only a few species, might be vulnerable for perturbations like droughts, when the few species that are present require a lot of water. If also species are present that can better cope with droughts, resulting in a higher biodiversity, the wetland in its whole can withstand a drought better. However, since during the drought these drought-vulnerable species are (partly) lost, wetland properties might change. For example, the wetland's filtration capacity could be reduced. In short, higher plant biodiversity results in a lower vulnerability to perturbations.

Wetlands count as ecosystems with one of the highest complexities in the world. Wetland ecosystems contain a high variety in plant and animal groups and are essential as resting places for migratory birds and for drinking water in arid areas (Verones et al., 2013). This is true for large wetland areas, but also applies to small-scale wetlands, such as the one addressed in this research. According to Blackwell and Pilgrim (2011), small-scale wetlands often hold a larger value for biodiversity than their size would suggest, particularly for the regional biodiversity (McCulloch, Aebischer & Irvine, 2003). This claim holds especially for wetlands that are connected to surface waters, like in this research, because then these small wetlands can function as important spawning and nursery grounds for many fish species. Another regional effect on biodiversity that wetlands have is their capacity to filter farmland's excess nutrients and pesticides, which refrains them from ending up in streams and thereby affecting biodiversity in streams and rivers (Hefting, van den Heuvel & Verhoeven, 2013). Blackwell and Pilgrim (2011) also argue that small scale wetlands act as enhancers of biodiversity on the agricultural lands themselves.

3.1.4 Building with Nature

Restoring wetlands to minimize flood risk falls under a relatively new term in water management entitled 'Building with Nature' (BwN), also known as eco-engineering or nature-based solutions. In short, BwN can be defined as pro-active water management projects where natural processes are part of the engineered infrastructure (de Vriend *et al.*, 2014). Important to note is that BwN goes further than just compensating the impact on nature. It even has a positive impact on nature. This is in contrast with hard engineering structures such as dikes, that used to be, and still are in most cases, the standard in water management. In the recent decades it has become clear that these kind of hard engineering structures are not the only solution and might in some cases also increase vulnerability. For instance when they result in settlement in flood prone areas (van Slobbe *et al.*, 2013). The often lower cost of BwN compared to conventional engineering makes BwN also interesting to decision makers (Temmerman *et al.*, 2003). Another factor that makes the need for a paradigm shift towards BwN clearer is climate change and the uncertainties that it gives. Eco-engineering is preferred over hard engineering when it comes to climate change, because of the larger flexibility. Infrastructure built using the BwN concept is better suitable for a gradually changing climate (van Slobbe *et al.*, 2013). However, BwN application does require more knowledge on the local context to be of full value, compared to conventional engineering.

Since BwN involves the use of natural processes to provide services that are of benefit to people's safety, the link with ESs is easily made. According to van Koningsveld and Slinger (2015), the key idea of BwN projects is '*to deliver engineering services while delivering and/or utilizing ecosystem services'.* An example is a large sand nourishment project for deteriorated beaches along the Dutch coast, referred to as the Delfland Sand Engine. Here the regulating ES of sediment transport by the waves is used to slowly, evenly spread out a huge amount of sand to restore the deteriorated beaches that protect the Dutch coast (van Slobbe *et al.*, 2013).

4. Research's scientific framework

4.1 Base of the scientific framework

The research design of this thesis is based on two reports, namely 'Ecosystems and human well-being' and 'Integrating Ecosystem Services into Development Planning', which will be elaborated on subsequently.

The MEA's framework

The first one is 'Ecosystems and human well-being', a report of the conceptual framework working group of the Millennium Ecosystem Assessment (MEA, 2003). It aims at understanding the relationship between ecosystems and human-wellbeing and connecting it to sustainable management and policy options (MEA, 2003). This is in line with the aim of the current research, which is why the framework was chosen as part of the supporting scientific framework for this research.

Important for choosing the MEA's framework is because it forms the base of many important scientific works (*e.g.* the IPCC (Olsson *et al.*, 2019; Mirzabaev *et al.*, 2019; Smith *et al.*, 2019, Ojea, Martin-Ortega & Chiabai, 2012; Fisher, Turner & Morling, 2009, Busch *et al.*, 2012 & de Groot *et al.*, 2010).

The MEA's framework was not only chosen as it has been used in many previous studies within the field of ESs research, it was furthermore chosen because it incorporates dealing with uncertainty. In wetland restoration, uncertainty can be found in the details of the wetland, such as its size, plant composition and how it would be restored, but also stakeholder acceptance and even the exact goals of the restoration itself. Due to the wetland being completely fictional, uncertainties are present and there is only some research being done about its potential effects. The original aim of the wetland restoration is water retention to attenuate floods. So, the wetlands will be restored to temporarily store water, but further details about the project goals are still uncertain. A focus on increasing biodiversity or on decreasing the negative impact on agriculture for instance, might be desirable as well. In short, the outcome of the wetland restoration is still far from certain. This is where the scenario development adapted from the MEA's framework steps in, to analyze which development paths wetland restoration in the research area might take and what this would imply.

Renner, Emerton and Kosmus' framework

The MEA's framework addresses future global climate uncertainty, by including four climate scenarios (Cork *et al.,* 2005). However, it does not address the uncertainty of a development plan that is still only in its first planning stages, as described in the paragraph above. The research approach is therefore supplemented by 'Integrating Ecosystem Services into Development Planning', by Renner, Emerton and Kosmus (2018), commissioned by the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety. This is a six-step guide for development planners to recognize the links between nature and development, to recognize the trade-offs associated with different development plans and to incorporate ESs related opportunities and risks into their decision making. These steps show the development planner the dependence and impact of development on ESs, how the negative impacts and risks can be reduced and how to assess ecosystem conditions (Renner, Emerton & Kosmus, 2018).

The six steps that the guide proposes to integrate ESs into development planning are: (1) Defining the scope and setting the stage, (2) Screening and prioritizing ESs, (3) Identifying conditions, trends and trade-offs, (4) Appraising the institutional and cultural framework, (5) Preparing better decision making and (6) Implementing change. However, only step two and step three are included in the research approach, as the focus is to only on asses the effects of a development plan on the ESs and not include other parts as the institutional background. Of the other remaining steps only parts are imported into this research's scientific design, such as defining stakeholders that can be affected by the development plan, in step 1.

Both used reports overlap in finding and analyzing these links and implications between ecosystems and human society. But where the MEA's report is relatively expansive, abstract and theoretical, Renner, Emerton and Kosmus' framework is concrete and clear on how to implement it. Their work is streamlined towards implementing the MEA's work on a development plan, such as the case study in this research. Their work brings ES theory closer to practice, for instance in wetland restoration projects.

5. Research Methodology

5.1 Scientific background and used framework

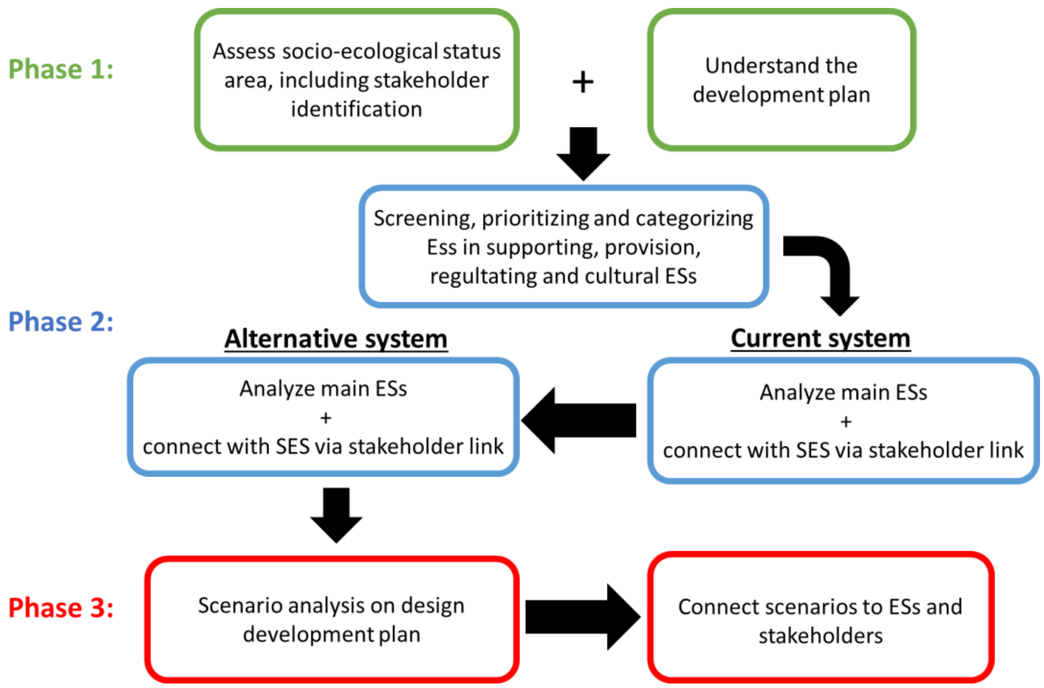

Figure 7 - The ESs-development plan framework that this research applies. The framework can be used to analyze potential impacts of developments plans on ESs and stakeholders. The alternative system is the current system wherein the potential development plan is executed. The manner of executing it is part of the scenario analysis. Important to note is that this framework should only be applied to development projects that are still in the earlier stages of its planning phase, and that preferably use a BwN approach. Provided by author, based on Renner, Emerton and Kosmus (2018) and the Millennium Ecosystem Assessment (2003).

This research's analytical approach is depicted in Figure 7. It is a qualitative and descriptive analysis, designed to aid decision makers in visualizing the potential consequences on the ESs that are currently in place in the potential development plan's area. The approach is divided in three phases. The first phase is the orientation phase, which includes the development plan and information about the area where the plan will be implemented. The second phase forms the base of the approach and focusses on the ESs.

Lastly, in the third phase these ESs are linked to development plan scenarios. Here the different scenarios of how the development plan can be executed and their implications on ESs are examined.

In this research, the framework of Figure 7 is applied to the case study of wetland restoration. Thus, the 'Development Plan' in Figure 7, is the described wetland restoration in the German Middle Mountains. The three phases structure as explained above, is applied to this case study and is discussed in detail below.

Phase 1 – the scope

In phase 1, the socio-ecological aspects of the study area in the German Middle Mountains are studied, including its stakeholders. This is step 2 of the framework of Renner, Emerton and Kosmus (2018), that prioritizes the most relevant ESs related to the study area and the development plan. In this phase, research question a. "**Which stakeholders can be identified in connection to wetland restoration in the case study?**" is answered.

The study area's socio-ecological status is examined by looking at the natural system in the area (*e.g.* biophysical aspects), as well as the social side that interacts with it (*e.g.* land use). In this research, this is mainly covered in chapter 1.2. The social side of the research is further elaborated on by studying the stakeholders which potentially connect to wetland restoration in the study area. The stakeholders' stakes, characteristics and relationships are understood in both the current and the potential wetland system. The required data was acquired through scientific literature, governmental reports and other grey literature. The stakeholder overview shows which ESs are important for the actors in the research area and thus, which ESs should be further studied in phase 2.

Moreover, an understanding of the network of stakeholders in the area gives a more context-specific view on the ESs, land-use and the changes that wetland restoration could bring about in the study area. This is important for the scenario analysis in phase 3, where the scenarios about wetland design need to be in line with the context of the case study area. Furthermore, at the end of this research, recommendations will be made, which are also connected to the stakeholders, their land-use and the land-use planning this research studies.

Also the development project itself has influence on the analyzed ESs, as this implies which ESs will be affected due to the wetland restoration and thus also require more insight to finally understand to what trade-offs wetland restoration leads.

In this initial phase 1, questions will be asked as 'How is the ecosystem(s) in the area built up?', 'What does the area socially look like?', 'what are the main economic activities?', 'Are there historical or future trends that might be of importance for the development plan?', 'What are the relevant stakeholders for this development plan?' and 'What ESs do these stakeholders use?' (Renner, Emerton & Kosmus, 2018).

Phase 2 – ecosystem services

Phase 2 covers the ESs. These ESs are categorized the same way as in Figure 6, to decrease their complexity (Renner, Emerton & Kosmus, 2018). Then they are linked together and understood thoroughly. This is done firstly by defining the ESs conceptually, which is covered in the 'Concepts and theories' section in this research. Then, the ESs that are relevant in how the research area currently is, are put into this current context. Lastly, the ESs that are relevant in the context of the potential system, wherein the wetland is restored, are put into this context. To clarify, water retention is hardly happening in the current situation, as water is quickly transported downstream through ditches and is thus currently of low relevance. However, in the potential wetland situation, it is of high relevance, as water retention is highly increased.

Phase 2 forms the core of this research's analytical approach. Here questions are asked such as 'What ESs are there currently in the area?", 'How does human society currently benefit from these ESs?', 'How does the development plan influence any of the identified ESs?' and 'How does this influence on ESs affect stakeholders?'.

The ES description of the alternative wetland system forms a bridge to phase 3, where this alternative system is divided into four scenarios, which are analysed. In phase 2, the alternative wetland system is described in a general sense and talks about which ESs are potentially altered, their underlying mechanisms and the links between the ESs. Phase 3 dives further into this, by studying four approaches to implement this wetland restoration. These four approaches all focus on different sets of ESs and are referred to as scenarios.

Phase 3 – scenario analysis

Phase 3 consists of a scenario analysis that develops scenarios on the different ways the development plan could be implemented, according to which set of ESs they aim to enhance (see Figure 8). Moreover, it is described how these implementations would each differently affect the ESs that are in place and how each scenario would therefore affect the identified stakeholders. The more is still uncertain about the practical implementation of the development plan, the stronger and more important this scenario analysis is.

The scenario technique that is used is called normative-narrative and falls under the creative-narrative scenario techniques, according to Kosow and Gaßner (2008). This scenario technique is used to create scenarios regarding maximizing different ESs and explore these. Normative-narrative scenarios combine potentialities that are rooted in the reality of the present, with regard to the preferred developments (Kosow & Gaßner, 2008). Thus, realistic scenarios are developed from the current situation into several potential situations wherein different ESs are maximized. These different maximized ESs are chosen to be realistic and important to maximize, combined with outcomes from expert interviews. This is also why this scenario technique was chosen, as it emphasizes on bringing in knowledge from experts and persons involved in the development project (Kosow & Gaßner, 2008). Furthermore, this scenario technique is simple in use and adequate for qualitative scenario development (Kosow & Gaßner, 2008). Compared to other scenario techniques, normative-narrative scenarios spur for creative thinking, while still remaining in reasonably realistic margins. It should be kept in mind however, that scenarios created this way, should mainly be used as an illustration or a basis for the end-stage of project results (Kosow & Gaßner, 2008).

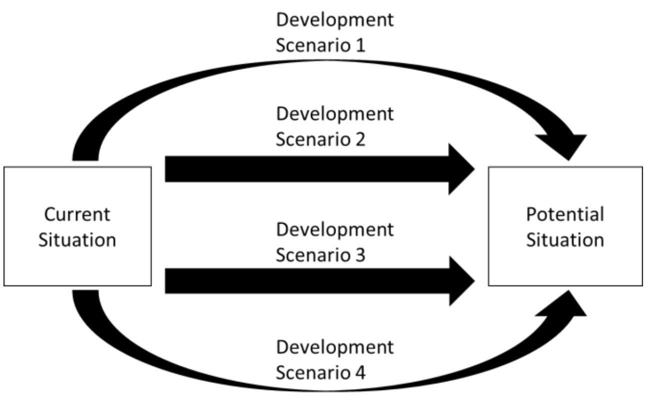

Figure 8 – There are different paths a development project could take to get to the desired potential situation. These all have different implications on the earlier identified ESs. These paths are referred to as scenarios.

The questions asked in phase 3 include 'What possible scenarios are there for the implementation of the development plan?', 'What does the development plan in these scenarios look like?', 'How are ESs affected in each scenario?' and 'What would each scenario mean for the stakeholders?'

The scenarios' effects on ESs, or in other words, the trade-offs, are visualized using a radar diagram. Each ES is represented by a bar of a certain length. These lengths are not quantified, as this research does not provide any quantification on ES effect. However, this conceptual trade-off estimation structure is able to highlight possible responses to wetland design and reveal otherwise hidden assumptions (Defries, Foley & Asner, 2004). Moreover, these radar diagrams show in a clear way how ESs respond to each scenario, making them comparable to each other, to the other scenarios and to the current situation. Even though it is not an ES, socio-economic feasibility is also added to the radar diagram. Whereas the ES effects described above are based on literature and interview results, socio-economic feasibility is mainly based on own interpretation. Socio-economic feasibility represents how feasible the scenario is, regarding social and economic aspects. In the radar diagrams, it is clearly shown for each bar what the information source for the length of that bar is, to be open about what is own view and what comes from scientific literature or interviews.

5.2 Data collection methods

Below, the methods of data collection used in this research are explained in detail.

5.2.1 Literature Review

The main method of this research is literature review. This implies browsing through scientific literature using academic finders, such as Google Scholar, to answer the research questions. In addition, German policy reports and plans, reports from NGOs, articles, environmental impact reports, *et cetera*, were analysed. Furthermore, some already written reports from within the Sponge Project have been used as sources of information.

5.2.2 Expert interviews

In addition, semi-structured interviews with experts were held. The interviews were used to fill in the information gap in the literature research's outcome. For example, when literature was too broad and could not provide specific enough information, this became subject of the interviews. The use of expert knowledge in environmental assessments is seen as important, if not essential (Lohani *et al.*, 1997). Most experts were researchers found within the Wageningen University and Research (WUR). Using WUR websites and Google, experts on the topics that required more information were found and contacted via email or phone.

The interviews were semi-structured. Thus, beforehand a list of questions was prepared, but the interview was still in a conversational matter. This way, issues that come out as more important, to the interviewer or the interviewee, can be explored further (Longhurst, 2003). The interviews were mostly online. All interviews had dissimilar topics and questions, since they were based on the interviewees' expertise and on the information that was still required for the research and not found in literature. Thus, a purposive sampling method was used; a method wherein only the most useful interviewees are approached, instead of having a large sample size (Cresswell & Cresswell, 2017). There is not a single interview guide, because of the high variation in interviewees, Therefore, different questions were prepared for each interview. Table 1 gives the names of the interviewees (all consented to name publication) and a concise topic of the questions per interview. The information derived in interviews is used throughout the whole thesis, thus the interviews covered all topics touched upon in this thesis. In total, seven experts have been interviewed.

Table 1 – information overview of the interviewed experts

Interviewed experts (and their background)	Expert in what (relevant) field, thus main topic of the interview	Date of interview
T. Wagner (WUR)	Wetland water purification	September 17, 2020
R. Verdonschot (WUR)	(Wetland) Ecology	September 29, 2020
R. van Beek (WUR)	Cultural Geography, cultural ESs	October 5, 2020
J. Hoffmann (Stiftung Natur und Umwelt RLP)	Wetland restoration projects and their effects on ESs	October 6, 2020
K. Hendriks (WUR)	Ecosystem services (all categories)	September 30, 2020
R. Vroom (Radboud University)	Paludiculture (wet-agriculture)	October 12, 2020
M. de Jong (Independent)	Paludiculture (wet-agriculture)	October 22, 2020

6. Phase 1 – the scope

Phase 1 aims at gaining an understanding of the study area's social system, to find out which ESs are relevant to analyze. The stakeholders in the area are analysed to see which stakes they hold within the system and to understand the relationships between them. These are then connected to ESs. This connection between stakeholders and ESs, together with studying the socio-ecological aspects of the study area, is what sets the base for phase 2.

6.1 – Stakeholder overview

This section aims at getting an understanding of the stakeholders that are present in the research area and the ESs they use. These are the ESs the research will use for further study. Firstly, the German government system requires explanation, afterwards a table including all relevant stakeholders is given.

Germany's government system

Due to Germany's long history of being divided states into the partly sovereign federated states they are now, their complex administrative system requires some understanding. As is visible in Figure 9, the municipalities (*Gemeinde*), form the base of the administrative system. Several municipalities together can form a district (*Kreis*), or rural district (*Landkreis*). The research area lies in the district Euskirchen and rural district Vulkaneifel. The (rural) districts are part of a federal state (*Bundesland*). The federal states have their own constitution and political institutions (van der Stroom, 2017). This is important to realize, because the research area lies partly in North Rhine-Westphalia (NRW) and partly in Rhineland-Palatinate (RLP). Between the districts and the ministry of the state lies the government district (*Regierungsbezirk*), that act as an intermediary (van der Stroom, 2017). In RLP, the research area lies in the government district Trier and in NRW it lies in the government district Köln. Then, at the top, there is the central German state itself, which is divided in different federal ministries. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, is the most significant ministry for this research (Deutschland, 2018).

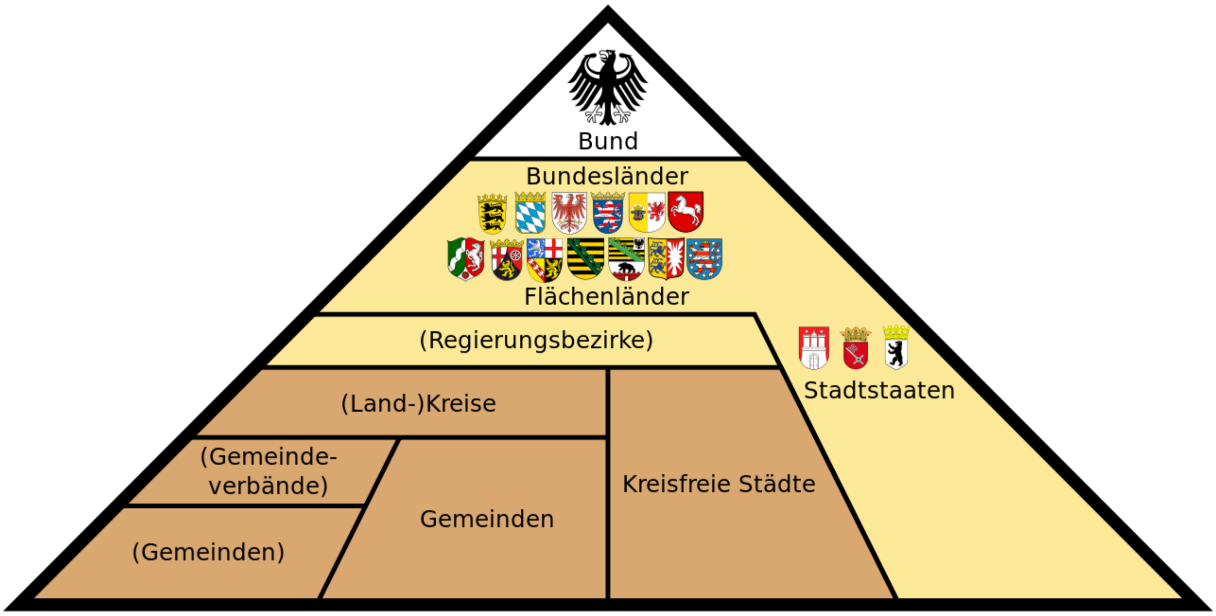

Figure 9 - Pyramid of how the administrative system of Germany in divided (Liuzzo, 2006).

Stakeholders

Table 2 shows which relevant stakeholders are identified in the area through literature search, who they are and how wetland restoration could potentially affect them. The connection between stakeholders and the ESs they use, is also shown.

Table 2 – An overview of the main stakeholders in the study area that can be connected to wetland restoration. The table's structure and its components are based on Raum (2018) and its content is based on literature research. The used ESs per stakeholder are summed up and underlined in the fourth row, at the end of each text. In brackets it is also indicated what the stakeholder's main ES is. If this is not indicated, all ESs are of similar importance.

Key Stakeholders	Operation level	Description	Connection to wetland restoration and ESs
River commissions (International commission for protection of the Rhine, International commission for protection of the Mosel and Saar)	Trans-national	Organizations that work internationally for river water quality, sustainable development, flood prevention and WFD implementation.	Wetland restoration is an opportunity for better water quality, flood prevention and WFD implementation in the Rhine and the Mosel. (Hydrological cycle (main), Water quality, flood prevention)
Waterway and Shipping Administration (WSA) and the German Federal Institute of Hydrology (BfG)	Regional	Are both responsible for the federal waterways. The BfG advises the federal ministries and the WSA on how to manage the waterways in their jurisdictions (van der Stroom, 2018).	Wetland restoration influences water quality and discharge in the rivers downstream through water retention. These rivers are partly the responsibility of these federal institutions (van der Stroom, 2018). (Hydrological cycle (main), Water quality, water retention,)

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	(Trans-) National	Responsible for policies shaping the legal framework involving the topics in its name. This includes transposing European Union (EU) directives into national law. It also represents Germany in international context regarding these topics and funds research and development on these topics (BMU, 2019).	Wetland restoration helps reach national and international directives and goals, that this ministry has to realize. These are *i.a*. in biodiversity, species protection, greenhouse gas emission (*e.g.* with carbon sequestration), water management, soil conservation, resource efficiency and tourism (BMU, 2019). (Biodiversity, species conservation, climate regulation, carbon sequestration, hydrological cycle, nutrient cycle, tourism)
Waterboards NRW	Regional	Unlike most other federal states, NRW relies on waterboards for the state's water management. The research area is divided over several of these waterboards. The responsibilities of the waterboards are established in a particular law for each single waterboard, set up by the federal state. The waterboards execute these laws. (Vidaurre et al, 2016).	They are responsible for controlling water discharge in catchment area, supplying water for drinking water production, hydrology and for providing a certain established level of flood protection. Also informally manage reservoir water level, for flood control and flow maintenance during dry periods (Vidaurre et al., 2016). These are all influenced by wetland restoration. (hydrological cycle (main), water retention, water quality)
Agricultural ministries NRW and RLP	Regional	Both ministries do not cover exactly the same topics, but both are responsible for creating legislation directed upon them by the federal ministries involving agriculture, often combined with food safety, animal welfare and environmental protection (MWVLW, no date).	Wetland restoration is important for the agricultural ministries, as the project will take place on land that is currently used for agriculture, which is their main legislative topic. (Food and fibre production (main), water quality, biodiversity/habitat conservation)

Environmental ministries NRW and RLP	Regional	Both ministries do not cover exactly the same topics, but both are responsible for creating legislation involving clean air, clean water, good climate, fertile soils, the diversity of animal and plant species and habitats (MUEEF, no date). In NRW the environmental and agricultural topics are covered by the same ministry, so this ministry is in this research split-up between the environmental and agricultural federal stakeholders.	Wetland restoration is interesting for these parties, since it potentially improves the water quality, water flow and species diversity and habitats, which they are responsible for in the study area. It also impacts agriculture, of which the NRW ministry is also responsible. (Water quality, hydrological cycle, biodiversity/habitat conservation)
Districts and Municipalities **(District Euskirchen, rural district Vulkaneifel and their municipalities Dahlem, Hellenthal and the collective municipality Gerolstein)**	Local	Responsible for organizing and administrating the affairs of the local community and implementing state law. The districts administer supralocal services, that exceed municipalities (Haschke, 1998; Vidaurre et al., 2016).	Related to wetland restoration is the municipal responsibility of administering land-use planning. Furthermore, wetland restoration is of interest to the municipalities, since they are responsible for *e.g.* attenuating natural disasters like floods, clean drinking water, water abstraction, water legislation, land cultivation and in general for implementing (environmental) laws (Auge, 2020; Haschke, 1998; Vidaurre et al, 2016) (hazard regulation (flood/drought), water quality, hydrological cycle, food and fibre provision)
Nature organizations and environmental NGOs	All levels	Sponge Project partners (Wetlands International, Stroming, WWF), but also the Natura2000 natural park *Hohes Venn-Eifel (Nordeifel))*. They advocate a higher biodiversity and better rare species protection in the region.	The Sponge Project partners set up studies about wetland restoration. The natural park in the research area would benefit from a lift in biodiversity, water quality and a more regular water flow. (Biodiversity (main), water quality, hydrological cycle)
Farmers/landowners	local	The private landowners, such as farmers and foresters in and around the research area.	Wetland restoration requires land that is still mostly in the hands of private owners. This is where a competing interest is identified. However, wetland restoration also brings advantages for this stakeholder, through ESs such as tourism, flood prevention. Also financial land compensation can benefit them. (Food and fibre

			production (main), tourism, flood prevention)
Tourism branch	Local	Hotel owners, the catering sector and the tourists themselves	The study area is located in the Eifel, an area where economic gain for tourism is high. Thus, the tourism branch is also a stakeholder, as wetland restoration might increase or decrease the touristic pull factors. (Tourism)
Communities	local	Local inhabitants that live in and around the research area.	The inhabitants that live in and around the research area are directly or indirectly affected by wetland restoration in their region. They are economically affected by diminishing provisioning services, but they also benefit when water quality, tourism, flood and drought prevention are improved. (Food and fibre production, water quality, tourism, hydrological cycle)

Generalizability of the stakeholders

The exact stakeholders per study case will always differ. However, similarities in other regions suitable for sponge restoration can be found. Even though the governance system is likely not the same as the German system, the governing powers are often represented by municipalities and provinces, that have similar interests as in the description above. These provinces are often divided in a similar way into ministries that focus on environment, water management, agriculture *et cetera*. The water management tasks can lie in an individual governmental branch, as is the case in NRW, or within ministries, as in RP. Also the identified farmers and landowners are a very generalizable stakeholder, that are always, at least partly, negatively affected by wetland restoration in the form of land requirement. This makes them often the main opposing stakeholder. Their exact stakes and power still differ per region. In summary, the precise actors, their stakes and their connection to a sponge restoration project might often be different, but the common thread is usually similar.

7. Phase 2 – Ecosystem Services

In phase 2 there is a focus on the ESs. The ESs in the research area in its current form are identified, further explained and connected. Hereafter the ESs of the alternative system, wherein the wetland is restored, will be subject to a similar analysis. Phase 2 ends with a final analysis section, where the ES outcomes are put into the context of the whole system and linked to the previously identified stakeholders.

The ESs that are analysed are chosen based on the stakeholder analysis in phase 1. The ESs that were found to be important for stakeholders in the research area, are analysed in this phase. The ESs that are studied might be different in other wetland restoration cases, as this thus depends on the area's stakeholders. Also the socio-ecological status analysis is important for choosing which ESs to study. In this analysis the research area was understood better, which also justified which ESs are important in the case study area.

7.1 ESs in the current system

This section identifies and explains the main ESs that are found in the research area. It overlaps partly with the following section about ESs in the potential system, where ESs such as biodiversity and carbon sequestration are also leading terms. Important to keep in mind is that wetland restoration, as studied in this research, will only take place on areas where currently extensively used pastures are located (which covers 42% of its land), not in intensively farmed, forested or developed areas. Nevertheless, also ESs only produced by forests will be taken into this current-ESs analysis *e.g.* raw material provision. This is because forests comprise the largest part of the region's land-use (55%) and wetland restoration could still affect them and the processes they are part of *e.g.* the water cycle and nutrient cycles. The land-cover in the area is, roughly, half pasture and half forest. The ESs explained in this section are mostly divided in a similar sense, where one part covers the discussed ES in a pasture land-cover and one part covers the ES in a forest land-cover. The research question that will be answered in this section is '***What Ecosystem Services can be identified in the study area in its current form and how are they generated?***'.

7.1.1 Provisioning Services

Food and fibre production by pastures

Grassland farming provides meat, dairy and fibre. The amount of these that is produced depends on the type of farming. For instance, organic farming can affect the yield, but also the pressure on other ESs, such as biodiversity (Haas, Wetterich & Köpke, 2001). The proportion of organic farming in the districts the research area lies in is higher than the average of the federal states they lie in. For example, in 2016 in Euskirchen the land-use for organic farming lay between 8 – 16 % of total land-use for farming, while most districts in North Rhine-Westphalia remained under 8 % (IT NRW, 2018). Organic farming can decrease the pressure that a farming system has on the biodiversity. The next identified ES class will look more into the pressure grassland farming has on biodiversity.

Raw material provision by forestry

The timber industry is, especially in scarcely populated rural areas like the study area, economically highly valuable. Collecting mushrooms, berries and other edible plant parts is also considered as a raw material that the forests in the study area provide. The same applies for hunting (Bösch, 2018).

7.1.2 Supporting Services

Biodiversity

This section will look into the quality of the current biodiversity in the area, to uncover its relationship with the other ESs. The area currently mainly consists of pastures and forests, which both take up around 50% of the land-use. Biodiversity in both of these land-use types is studied, while keeping the research area in mind.

Biodiversity in Pastures

Nitrogen as a biodiversity threat

Around 1810 and 1937 there were two large waves of conversion of natural area into agricultural land happening in and around the research area. Slowly, this agricultural land, that consisted of both grassland farming and crop cultivation, has been changed into solely grassland farming. A result of this land-use change from natural to agriculture, is a stark increase in the soil, groundwater and surface water nitrogen (N) content. The reason for this high N content is the excessive amount of fertilizer addition in agriculture, even in the extensively used pastures (Schumacher, 2013). For the extensive pastures this fertilizer is mostly in the form of ruminant manure. Moreover, since about 20 years, there has been a N deposition from the atmosphere onto the land of about 20 – 25 kg of N per hectare. All this excess N leads to an on average lowering of biodiversity in and around pastures, according to a publication of the German Information and Coordination Center for Biodiversity (Schumacher, 2013). They do however mention that compared to the average N input from fertilizer, the atmospheric N deposition is still low.

In high contrast to the negative image sketched above, in the NRW part of the Eifel, research shows that in some places a high species-richness was found (alpha-diversity of 30-39 species/1m² and 40-55 species/10m²; Schumacher, 2013). This is labelled as high to very high biodiversity. Those areas were mainly dairy cattle farms that fell under agri-environmental measures since the last 20 to 25 years. These measures involve using less N, but also having humid or periodically wet grasslands. This humid or periodically wet grassland is the type of grassland that has seen the greatest loss in area in the past centuries, while they house the highest biodiversity (Schumacher, 2013). Land-use change into (the most profitable) agriculture has been the main instigator for this.

Some of the pastures lie in nature protection areas. This means that in these pastures, N use is restricted. This restriction ranges from a complete halt on fertilizer addition, to a lower legal application limit. How severe this restriction is, differs per federal state (Project meeting, personal communication October 2, 2020). Moreover, fertilizer application in the proximity of 4 meters of a water body, such as a stream, is not allowed. This also applies to not protected areas. There is a N application limit of 80 kg per hectare and a phosphorous (P) application limit of 30 kg per hectare. Both can be exceeded if they are removed through harvested material (L. Vitzthum, personal communication, September 28, 2020). According to a survey amongst farmers in the research area, there is no pesticide application. Furthermore, the main fertilizer application is the manure that the grazing animals produce, the remainder is mineral fertilizer (L. Vitzthum, personal communication, September 28, 2020).

Grassland communities

The biodiversity in pastures depends not only on the amount of fertilizer that is applied, but also on the grassland-plant communities that inhabit it. Ryegrass (*Lolium)* is the most common species to comprise pastures in NRW and they support an average of 23 species per 25 m^2. This is one of the lowest averages of all grassland species used for pastures (Schumacher, 2013). In NRW, species poor intensive pastures comprise around 80%, whereas meagre pastures, humid/wet pastures and hay pastures account for the remainder. However, since around 1995, populations of many rare and endangered species in the norther Eifel have slowly been recovering or re-appearing (Schumacher, Weis & Opitz, 1998; Weis 2001). Likely due to stricter laws regarding fertilizer. Still, biodiversity in and around pasture areas remains low and far away from former, natural levels (Schumacher, 2013).

Biodiversity in Forests

Threatening invasive species

As mentioned in the section above, in the past there was more uncultivated and natural area in the Eifel. This consisted mainly out of forests made up of beech (*Fagus sylvatica*) and birch (*Betula pubescens)*. However, nowadays, Norway spruces (*Picea abies*) dominate the forests, which is already a decrease in diversity in itself. Moreover, this species is not native to the German Middle Mountains, which often results in negative effects on biodiversity. (Lehmkuhl, Loibl & Borchardt, 2010). How severe this threat to biodiversity is, differs on the density of the planted spruce trees, their management and the soil (Aarrestad *et al.*, 2014). Generally, introducing spruce into deciduous forests affects structure, growth form and biomass production of the forest (Halldorsson *et al*., 2007). Especially so if the deciduous forest naturally houses a large biodiversity, such as in the research area (Auge, 2020). Moreover, spruce introduction reduces solar radiation underneath the canopy, especially in winter. This changes micro-climate, water balance, nutrient circulation and the litter layer's chemical composition and degradation rate. These effects were seen in the Eifel by Heine *et al.* (2019). The changes in water balance are important in respect to wetland restoration. Forests in general have a highly positive influence on the soil's water storage capacity (R. Verdonschot, September 29, 2020; K. Hendriks, September 30, 2020). Moreover, Heine *et al*. (2019) have found that spruce dominance lowers fungal species richness, compared to beech. In short, even though it is difficult to say how severely, forest biodiversity in the research area is certainly lowered by Norway spruce domination.

Nutrient inflow
Also the N and P inflow from pastures situated above forests, has its negative effects on forest biodiversity (Bösch *et al.*, 2018). Species that are adapted to high nutrient availabilities can take advantage of this inflow and can outcompete species adapted to a lower, more natural nutrient availability (R. Verdonschot, September 29, 2020). This way the nutrient outflow of agriculture above forests reduces its biodiversity. Also the earlier mentioned atmospheric N deposition has negative effects on forests' biodiversity (Schumacher, 2013).

Biodiversity in the current system
To sum up, biodiversity in the current system is low in the pastures, due to a nutrient excess and a low diversity in grassland-plant communities in the pastures themselves. Thus, provision of the ES biodiversity is small. Also the forests' biodiversity is lower than it once was, mainly due to historic afforestation with Norway spruce. Yet, the forests' biodiversity is still high, so in this half of the area's land cover the ES biodiversity is provided abundantly.

7.1.3 Regulating Services

Carbon sequestration

Grassland farming
The level of carbon sequestration of grassland farming lies in general very low in Germany. In fact, grassland farming almost always balances out as a CO_2 emitter. This applies to organic, extensive and intensive systems, although intensive systems emit most (Haas, Wetterich & Köpke, 2001). Especially so, compared to the former, more vegetated, natural areas in the region, which had a high carbon sequestrating value. The same applies to emissions of other substances damaging global and local climate, such as CH_4, SO_2, PO_2 and N holding compounds (Haas, Wetterich & Köpke, 2001). In short, the ES carbon sequestration is not provided in grasslands. In fact, there is carbon emission, along with emission of other climate detrimental substances.

Forests
On the opposite side of the carbon emitting dairy industry, are the forests that cover the research area. When managed sustainably, they do provide the regulating service of carbon sequestration. Carbon is stored in the underground and aboveground biomass, deadwood, soil and litter layer. Moreover, carbon is stored in the wooden products that are derived from timber that comes from the forest. The sequestration of this carbon is an ES that regulates the climate, so the benefits are shared globally (Bösch *et al.*, 2018).

7.1.4 Cultural Ecosystem Services
The areas suitable for sponge effect restoration are often rich in recreating visitors because these area's lie in less populated lower mountainous areas, that are, at least in West and Middle-Europe, often close

to populated regions. In combination with their often high aesthetical value due to their forested landscape diversity and hilly terrain, they are appealing for tourism and recreation (K. Hendriks, September 30, 2020; Kienast *et al*., 2012). This section looks into the cultural ESs of the current system, to later understand how wetlands might impact or enhance these.

Recreation in agricultural and forest landscapes

Since the study area lies in the Eifel, a region rich in recreating visitors, cultural ESs should not be overlooked. The importance of tourism for the economy in this region has already been covered in phase 1. The research area covers both recreation in agricultural areas and in forests. Recreation in the research area is considered an important ES.

Cultural identity

Cultural identity in the research area is an ES that is hard to study. Questionnaires with stakeholders could form an idea of the cultural identity of aspects in the landscape, such as the agricultural fields that have to make place for the potential wetland (K. Hendriks, September 30, 2020). However, this was not a part of this research due to time restrictions, as such an inquiry on cultural identity is highly time consuming. However, it is expected that the farmers in the area hold a cultural identity to some degree to this agricultural land, as agriculture has been the main source of income for about two centuries. Their type of farming likely became part of their lifestyle and traditional rural culture, as they identified themselves with it (Daugstad, Rønningen & Skar, 2006). Thus, (extensive, pasture) agriculture then also gets a cultural importance, rather than just a provisioning service.

However, agriculture can also be seen as a disruptor of cultural identity, as the natural land use had to make way for agriculture, 200 years ago. This is stressed by one of the interviewees, as in the research area the natural wetland and forests that are now gone, also likely formed people's cultural identity (R. van Beek, October 5, 2020). In the alternative system section this will be elaborated upon further.

7.2 ESs in the alternative system

This section aims to identify the main ESs in the alternative system. This is the same system as the current one described above, but one wherein wetland restoration is introduced. This means that there is a change in land-use, as pastures makes place for wetland. So, the provisioning services food and fibre production disappear. However, in the areas around the wetland would still be pastures that provide this ES. These pastures are still affected by the restoration of wetland, due to the raised water table, which intervenes with their farming practices (L. Vitzthum, personal communication, September 28, 2020).

In this section the main ESs in the alternative system, where a wetland is introduced, are described. This section aims to answer the research question "***What Ecosystem Services can be identified in the study area if restored wetlands would be in place and how are they generated?***".

7.2.1 Supporting Services

Water retention

This section focusses on the wetland restoration's main goal, increasing the research area's water retention capacity. This section aims to get an idea of the effects of the water retention that the increased sponge capacity of a wetland provides, which include both decreasing flood risk and drought risk.

Flood reduction

Water retention is most commonly practiced downstream in the river basin. The area of research in this study is however upstream, where water retention looks different. Here focus lies on slowing down the rate of the hydrological cycle by improving soil filtration, slowing down overland flow, reducing channel velocity and increasing evaporation (Collentine & Futter, 2018). Here the link between the ESs water retention and maintenance of the water cycle is made. The sponge capacity principle of wetland restoration builds on this link. It helps slow down the hydrological cycle, by restoring the sponge capacity of the soil. This increases the time between rainwater precipitation and rain water eventually reaching the river, thereby decreasing flood risk (J. Hoffmann, October 6, 2020). This principle will be explained further in this section.

How this sponge capacity works, has been introduced in the introduction section. Also the reason why the German Middle Mountains were chosen for the research area is explained there. Within this low mountain chain, up to 8% of the area covered by local catchments of Rhine tributaries are suitable for sponge function restoration. The technical requirement for an area to be suitable is presence of u-shaped valleys with a flat bottom where rainfall is high (Otterman *et al.,* 2017). Otterman *et al.* (2017) assess that the biggest impact on flood build-up is in the local catchments, where drainage peaks are reduced by 5-8%.

Using a SWAT+ and a WFLOW model, Waterloo *et al.* (2019) also found that this kind of local wetland restoration could potentially reduce flood risk in the downstream area. On a small scale (the upper Kyll catchment area), their results show that the effect of wetland restoration would have no significant effect on average daily discharge per month, as expected. However, the median daily discharge does increase. This indicates a lower peak discharge, where the peaks are more spread out over time. Peak flows were mostly reduced in winter and spring, when historically also most floods happen (Auge, 2020; Waterloo *et al*., 2019). Thus, discharge peaks become lower and broader due to wetland restoration and thereby flood risk is decreased. An example of an outcome that shows such lower and broader discharge peaks is provided in Figure 10 below.

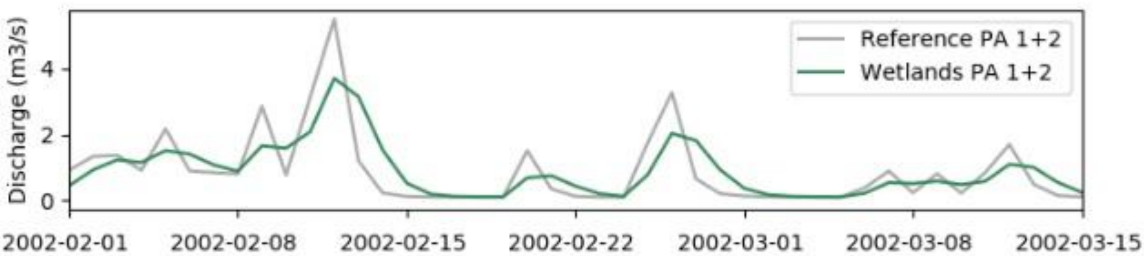

Figure 10 - One of the small scale results of Waterloo et al. (2019). Visible is that discharge peaks become lower and broader in the wetlands scenario, compared to the present reference situation. Other small scale results show a similar trend.

Scale is in this study is defined in the context of the whole Rhine's watershed. Thus, effects in the research area or upper Kyll catchment area are considered as small scale. The above-described peak flow reductions were also found on a large scale, in the Mosel basin or the whole Rhine basin. This was done by expanding the surface of wetland restoration to a larger scale and implement this in the WFLOW model. However, the effects for both of these much larger scales were substantially lower. The difference is explained by relatively less suitable land for wetland restoration, compared to the small upper Kyll catchment (Waterloo et al., 2019). This trend is also seen in how the peak flow reduction is higher in the Mosel basin, than in the river Rhine basin. However, even though the relative effect is smaller, still the reduction of peak flows in terms of total volume is large (Waterloo et al., 2019). Especially in the most extreme situations, a small decrease in peak flow could be the difference between a flood or just high water. Still, the largest gains in flood reduction are achieved on the local level and smaller on regional or basin-wide scale (Otterman et al., 2017).

Drought reduction
Also important to note is that this increase in median daily discharge also has a positive effect on low flows. This is due to water retaining longer in the soil, resulting in an increase in the continuous water flow during the whole year. This is called the base flow. Waterloo *et al*. (2019) found that the low flows increase in volume by 10% – 30% in summer and fall, which are the driest periods (Auge, 2020). This means that the base flow was increased. This shows that wetland restoration also has a potential reducing effect on local drought risk (Waterloo *et al*., 2019). Reducing this local drought risk could also have (small) positive effects on basin wide drought problems, such as low river water, which affects shipping, energy production and irrigation for agriculture (Van Kreveld *et al.,* 2013).

The effectivity of drought attenuation of wetland restoration is questionable, however. The intensity of a drought is mostly determined by how long it lasts, while a flood is mostly determined by how much water falls in several days. So, the probability of a drought increases with time, while the probability of a flood increases with rainfall severity (Otterman *et al*., 2017). Therefore it remains uncertain if an increased sponge capacity results in enough buffer capacity to also adequately attenuate droughts, according to Otterman *et al.* (2017). To effectively buffer droughts using water infiltration, they recommend infiltration on the plateaus, instead of at hill bottoms. Moreover, the longer the travel time is between the moment of precipitation and the water reaching the Kyll, the larger the amount of evaporated water is. Especially during warm and sunny days, this evaporated (and transpired) water can be substantial. This evaporation could sometimes go up to 30 to 40 percent (T. Wagner, September 17, 2020). Thus, even though wetlands do temporarily store water to buffer dry periods, water is also lost from the system through evapotranspiration in wetlands. In some cases this can lead to wetlands actually intensifying the effects of droughts, instead of reducing them, according to a study by Bullock and Acreman (2013). They analysed 71 studies regarding the link between wetlands and droughts and found that around two-third concluded that the studied wetland reduced the water flow during dry periods. Increased evaporation was pointed out as the main instigator, which is highly differential per location.

Some sources disagree with the doubt regarding the drought attenuation potential of water retention. R. Verdonschot (September 29, 2020) mentioned in a personal interview how even when the drought buffer capacity might be lacking to keep up the water availability for direct anthropogenic uses such as irrigation and shipping, it is still sufficient to keep up the natural processes. These natural processes, such as the nutrient cycle, only require a small amount of water, compared to anthropogenic water needs. The most important requirement for these natural processes is a constant water inflow, instead of a variable inflow. This constant water inflow can be achieved by reconstructing the sponge capacity (R. Verdonschot, September 29, 2020). Having a more stable water flow is also beneficial for nature during heavy rainfall events, as due to peak flows stream banks' natural, gradual transition disappears (Buijse *et al*., 2019).

Wetland restoration's positive effect on drought reduction is shared by J. Hoffmann (October 6, 2020). He is positive that restoring the sponge capacity is the best way to increase the system's drought buffer capacity. In similar projects where the water drainage systems were blocked, this was clearly visible and these effects were scientificly proven (Zemke, 2018). The drought buffer effect reached its highest potential after about three years. In the dry spring and summer periods, water outflow at the bottom of the system was about 140% higher than the inflow, due to the enhanced water retention of the soil. When the drought was too severe however, the soil's buffer capacity did not suffice anymore. A dry period of this magnitude has to last for several months, as it did in the spring/summer of 2020 (J. Hoffmann, October 6, 2020).

To summarize
The proposed wetland restoration greatly enhances the provision of the ES water retention, which is part of the supporting service 'maintenance of the hydrological cycle'. This water retention results in a decrease of flood risk on a small scale (within the upper Kyll catchment area), due to peak discharge

reduction. On a larger scale (Mosel basin or the whole Rhine basin), this effect also occurs, but in a lesser sense. Moreover, water retention decreases drought risk. However, this link is less strong and also less clear. Still, it is expected that droughts will be reduced due to sponge restoration, at least to some extent. This will benefit nature, but if it also has direct societal benefits in and around the research area, remains unclear.

Biodiversity

Restoring wetlands will very likely increase the biodiversity in the study area and thereby also these positive effects it brings about. How much biodiversity is potentially increased, in what way and what the link with the other researched ESs are, will be covered in this section.

Vegetation build-up over time in a potential wetland

Expert interviews and literature study shows that due to the large amount of nutrients deposited in the current system, the potential wetland would in the first years, or even a decade, comprise of only vegetation adapted to nutrient-rich conditions (K. Hendriks, September 30, 2020; R. Verdonschot, September 29, 2020; Yu *et al.*, 2018). After this period, the system becomes less nutrient rich, as clean, recently precipitated water enters and nutrients get filtered out. However, nutrients will remain abundantly available to organisms, since agriculture upstream keeps producing nutrient affluent. Due to the large instream of nutrients, a large biomass of wetland vegetation would grow, as it did in comparable situations in the Netherlands (K. Hendriks, September 30, 2020). Biodiversity in such a restored wetland system is not as high as in natural situations, albeit still undoubtedly higher than in the current situation (Hansson *et al.*, 2005). This large biomass would show several succession stages, but it would likely stop changing significantly once a (wet) forest is reached (K. Hendriks, September 30, 2020; R. Verdonschot, September 29, 2020). A wet forest would likely mainly consist of tree species adapted to wet soils, such as willow (*Salix spp*), ash (*Fraxinus spp*) and Alder (*Alnus glutinosa;* K. Hendriks, September 30, 2020).

Vegetation management for biodiversity

With extensive management of the wetland, these succession stages can be manipulated. For instance, the vegetation could be kept low enough to prevent trees from growing (K. Hendriks, September 30, 2020; R. Verdonschot, September 29, 2020). The species that prefer more of an open environment, of both flora and fauna, can be preserved this way. The biodiversity would then be much higher than in the final forest state. If this is combined with some areas that do grow into the tree state, ecosystem and species diversity would be highest (K. Hendriks, September 30, 2020). For the ES water quality, vegetation management is also an important factor. This will be elaborated further in the water quality section.

Connectivity

Connectivity is highly important for species to get a foothold in the area, especially shortly after reconstruction. Through connections with other more biodiverse areas, a wetland's biodiversity can grow (Leibowitz, 2003). The fact that the wetlands will be small, makes the need for connections only larger, because smaller areas tend to have a smaller biodiversity (R. Verdonschot, September 29, 2020). Connections can go over land, but also over water, since the wetland will be connected to the Kyll river. Over water, active upstream migration is hard for invertebrates, as they then have to swim upstream (Buijse *et al*., 2019). Since the case study area is in the upper parts of the Kyll, this means that invertebrate colonization over water will be low. Fish species are better able to migrate upstream, but are often blocked from reaching upstream wetlands by dams (R. Verdonschot, September 29, 2020). The Kronenburger dam in the Kyll is an example of this. It was finished in 1979 to lessen flood risk and to increase local recreation potential (Landtag Nordrhein-Westfalen, 2016). Also more downstream, in the Mosel, hydropower dams block migrating fish (Behrmann-Godel & Eckmann, 2003). For fish species that migrate, such as eels, these obstructions can greatly hamper dispersal into the potential wetland (Behrmann-Godel & Eckmann, 2003).

More common than aquatic dispersal to upstream areas like the study area, are terrestrial and aerial dispersal. The quality of a terrestrial connection depends on the landscape (*e.g.* type or amount of vegetation) between the potential wetland and the source area. This could then function as a steppingstone, or migration corridor. Further influential factors are distance to the source population and size of this source population. In practice, most upstream areas are however physically very isolated (Buijse *et al*., 2019).

To summarize
Biodiversity in the alternative wetland system is higher than in the current system. How much higher depends mostly on the inflow of agricultural nutrients, the connectivity to other biodiverse areas and the management of the wetland's vegetation. A return to the former natural, more biodiverse wetland situation, is likely no longer possible, due to the excessive nutrient inflow.

7.2.2 Regulating Services

Water purification

This section studies the water quality effects in the alternative wetland system. As mentioned in the water quality definition, excessive use of fertilizer in agriculture leads to a lower water quality. This also happens to a certain extend in the study area and could be treated by restored wetlands (Kiebel et al., 2018; Dunne *et al.*, 2005). How this purification ES works, is explained in this section. Important to note is that water quality also has a link to the provisioning service of providing clean drinking water.

Nitrogen
In the study area the main fertilizer application is in an organic form. Cows roam the pastures and excrete this manure over the land. This manure contains organic N, which is mineralized by microbes in the soil into ammonium (through ammonification), which is then converted into nitrate and nitrite (through nitrification). The latter two volatilize out of the system when they are converted into nitrogen gas, which is called denitrification (Azeez & Van Averbeke, 2010; Hansson *et al.,* 2005). The denitrification process' speed mostly depends on nitrate loading, carbon availability, pH and redox conditions (Hansson *et al.,* 2005). This denitrification is the fundamental principle of N purification by wetlands; water stagnates in a wetland, which leads to denitrification. Most N leaves the system by this gaseous escape route, which is best accelerated by a shallow wetland. In short, a wetland removes N from the water that flows through it, which makes the water cleaner (T. Wagner, September 17, 2020).

Phosphorous
Wetlands also purify the water from P. Like N, P also first enters the study area's system in an organic form, via cow manure. These organic compounds are mineralized into phosphates (Oehl *et al.*, 2004). This purification process contrasts with that of N in that the P removal process does not have a gaseous stage where it can escape the system. P is partly taken up by plants and algae, but the larger part remains in the soil when it precipitates with metals or is adsorbed by substrates (Drizo *et al.*, 1997; T. Wagner, September 17, 2020). Thus, P does not leave the system as easily as N does. A deeper wetland increases P filtration capacity the most, but this is in contrast with the N removal process (Hansson *et al.*, 2005; T. Wagner, September 17, 2020). The removal of P in water depends mainly on pH, redox conditions, Fe, Ca and Al sediment concentrations (to which it binds), sediment composition (*i.e.* particle size) and P loading in the overlying water column (Kröger *et al.,* 2012).

To summarize
Due to the wetland's ES water purification, water that flows from the alternative wetland system into its headwater stream (the Kyll), will be of higher quality than it is in the current situation. This is because of the wetland's ability to take up the N and P that are found in harmful quantities in the agricultural wastewater.

Carbon sequestration

This section explores the prospective wetland system's carbon sequestration potential.

Soil carbon

The potential of soil carbon sequestration due to wetland restoration in the case study area is low. This is due to the absence of soil capacity to build up a high organic content. A peat layer would be an example of such a high organic layer. In the study area these type of soils cannot form, be conserved and accumulate because the soil's organic compounds are mineralized too fast by its microorganisms. These microorganisms are able to decompose these organic compounds so fast due to the large amount of nutrients that are available in the system, partly due to the extra nutrient emission of agriculture in the present situation. (R. Verdonschot, September 29, 2020). However, before agriculture arrived in the area, these types of high organic soils were likely already not present, as the main soil types are all mineral soils with only a low to medium organic matter content (R. Verdonschot, September 29, 2020; Otterman *et al*., 2017). In short, the soil's carbon sequestration capacity in the case study area's alternative system is low, which is mainly caused by a nutrient inflow from agriculture and the absence of nutrient poor soils that are unable to decompose organic compounds fast.

However, other areas suitable for wetland restoration might have a dominance of other soil types. As soil type is the most important factor for soil carbon storage, carbon sequestration might be a more valuable ES in these areas (Hagedorn *et al.*, 2001). Further research in these areas on carbon sequestration is required to provide more insight. Still, if there is a similar inflow of excess agricultural nutrients, then also here carbon rich layers like peat probably cannot form anymore.

Vegetation carbon

Another way carbon is stored, is in the wetland's (living) vegetation itself, in its biomass. How much this exactly is, depends on the plant species' characteristics. Even though this carbon storage is higher than in pastures, it is still modest. To compare, a forest would store a lot more carbon than a wetland. According to Otterman *et al*. (2017), in a similar area, the captured CO_2 (equivalents) of forest would in 20 years be ten times higher than in wetland vegetation.

However, the amount of carbon stored in the vegetation does decrease and stop after a while. This is because plants grow and take up CO_2, but this CO_2 is released again as they decay. Thus, when a biomass equilibrium is reached, there is no extra carbon sequestration anymore. But, when biomass is extracted and used in a sustainable manner where it does not decay in time, the carbon sequestration capacity is increased again (K. Hendriks, September 30, 2020). An example of this type of extraction can be cutting off reed and using it for housing insulation material (J. Hoffmann, October 6, 2020). Then the reed can take up CO_2 again to form more biomass, while the cut-off biomass is stored as insulation material without decaying for a considerable amount of time.

7.2.3 Cultural Ecosystems

Recreation and ecotourism

The recreational value of wetlands is high. It is one of the most important direct economic activities in wetlands and is also often comparable to indirect ES values (Ghermandi & Fichtman, 2015; Yu *et al.*, 2020). The recreation potential of an area is mostly linked to its aesthetical value, but accessibility is also very important (K. Hendriks, September 30, 2020). Common wetland recreation examples are hunting, recreational fishing, wildlife observation and photography (Yu *et al.*, 2018). These activities also all apply to the potential wetland in this study, although they are dependent on size, which is still uncertain for the potential wetland. According to Yu *et al.* (2019), the combination of agriculture and wetlands, as is the case in the alternative wetland system, leads to an increase in the recreational value. This was also mentioned in several interviews (K. Hendriks, September 30, 2020; R. Verdonschot, September 29, 2020).

Mainly the increase in landscape diversity is stimulating recreation, which is enhanced by adding wetlands to a landscape that primarily consists of forest and agricultural fields (K. Hendriks, September 30, 2020).

Forests are seen as the landscape with the highest recreation potential in the Netherlands. This is very likely relatable to the German case study area. People prefer forest landscapes aesthetically the most and can house more people than most other landscape types (K. Hendriks, September 30, 2020). Water bodies, such as wetlands, are also popular landscape characteristics, although they are more of an open type of landscape (Kienast *et al.*, 2012). A combination of open and closed landscape is the most preferred by people (K. Hendriks, September 30, 2020). To summarize, it is expected that wetland restoration increases the recreational value.

Cultural identity

Wetland restoration infringes the cultural identity that people have with farmland in the research area. In the section on cultural identity in the current system it was already explained how on the one hand agriculture likely holds a cultural value in the research area to some extent, but on the other hand also came in the place of natural area that likely also had its cultural identity. Moreover, the cultural identification of agriculture might also be less present for stakeholders less related to these farmlands, such as the tourism branch (R. van Beek, October 5, 2020). These stakeholders might welcome wetland restoration, as they value the natural aspects in the area more (*e.g.* forest and wetland). Moreover, the area of restored wetlands will be small, compared to the large area of agriculture that still remains afterwards. Yet, fact remains that wetland restoration will mean a disappearance of agricultural land, which likely conflicts with the local rural cultural identity.

7.3 Final analysis ESs

Figure 11 summarizes the results of phase 2. It shows how all ESs are positively affected by wetland restoration, except for dairy production and timber production. These were found by comparing the current situation to the alternative wetland situation. Wetland restoration has a negligible effect on timber production, because the restoration only costs pastureland. An effect can likely be seen when forests are situated downstream the wetland, as the forest's incoming water quality then becomes higher. Still, as most forests are upstream, the effects on it are shown as negligible in Figure 11 (L. Vitzthum, personal communication, September 28, 2020).

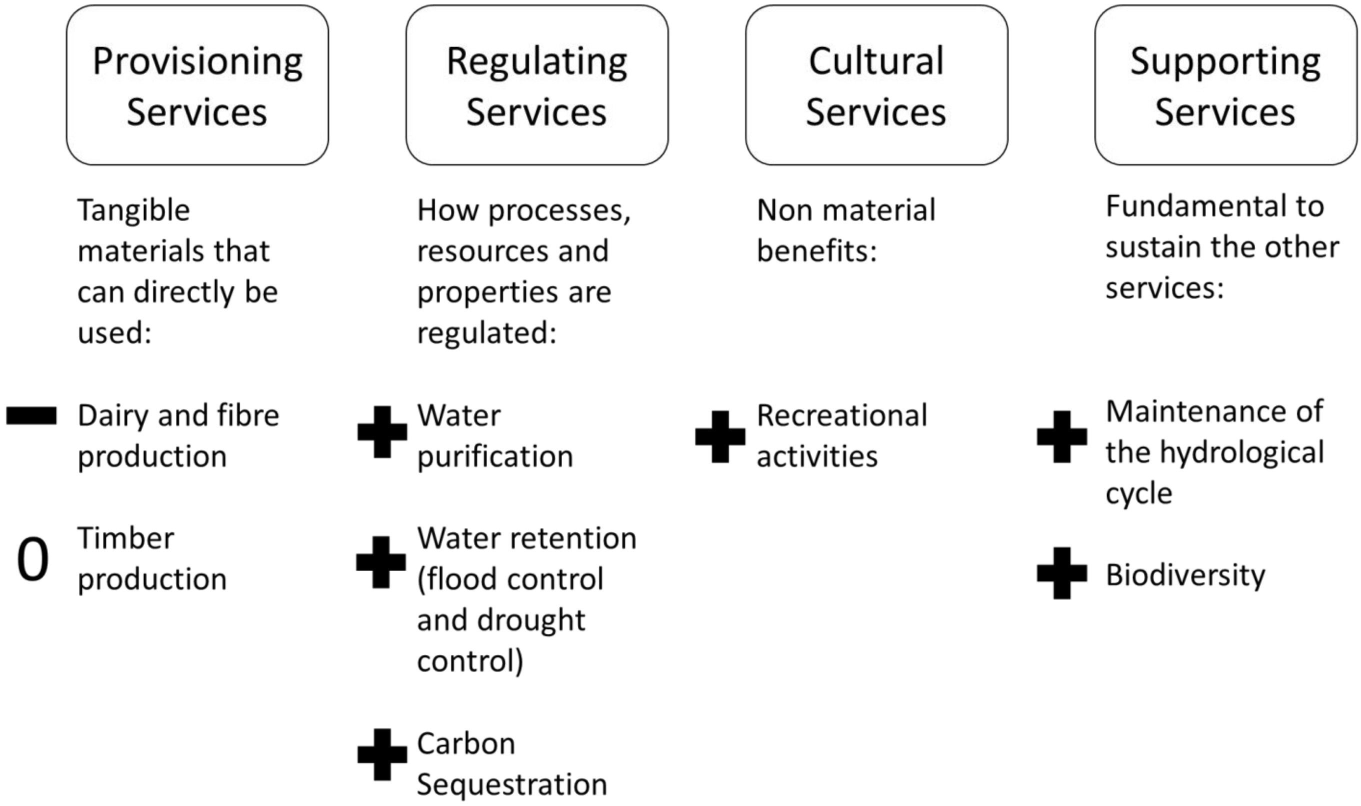

Figure 11 – The end result of the Ecosystem Service trade-offs that wetland restoration brings about. A plus sign shows a positive effect on this ES due to wetland restoration. A minus sign shows a negative effect and a zero shows that wetland restoration has a negligible effect on this ES.

Table 3 - The results of phase 2 linked to the stakeholders found in phase 1.

Key Stakeholders	Operation level	Used ESs, linked to wetland restoration	Level of impact on these ES	Conclusion
River commissions **(International commission for protection of the Rhine, International commission for protection of the Mosel and Saar)**	Trans-national	Water purification, flood prevention, hydrological cycle	All impacted positively	The river commission's goals are positively affected by wetland restoration (+)
WSA & BfG	Regional	Water purification, water retention, hydrological cycle	All impacted positively	WSA and BfG's goals are positively affected by the wetland restoration (+)
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	(Trans-) National	Biodiversity, species conservation, climate regulation, carbon sequestration, hydrological cycle, nutrient cycle, tourism	All impacted positively	The ministry's goals are positively affected by the wetland restoration (+)
Waterboards NRW	Regional	Water retention, hydrological cycle, water purification	All impacted positively	The waterboards' goals are positively affected by the wetland restoration (+)
Federal state's environmental ministries	Regional	Water purification, hydrological cycle, biodiversity/habitat conservation, Food and fibre production	All impacted positively, but food and fibre provision impacted negatively	The environmental ministries' goals are mostly positively affected by wetland restoration, but also partly negatively (+/-)
Federal state's agricultural ministries	Regional	Food and fibre production (main), water purification, biodiversity/habitat conservation	Main ES is impacted	The agricultural ministries' goals are impacted mostly negatively, as their main ES is negatively affected (-).
Districts and Municipalities	Local	Hazard regulation (flood/drought), water purification, hydrological cycle, food and fibre provision	All impacted positively, but food and fibre provision impacted negatively	The local districts and municipalities' goals are positively affected by the wetland restoration (+)

Nature organizations and environmental NGOs	Varying levels	Biodiversity, water purification, hydrological cycle	All impacted positively	Environmental NGOs' goals are positively affected by the wetland restoration (+)
Farmers	local	Food and fibre production (main), tourism, flood prevention	Main ES is impacted negatively	Farmers are negatively affected by wetland restoration (-)
Tourism branch	Local	Tourism	All impacted positively	The tourism branch's goals are positively affected by the wetland restoration (+)
Communities	local	Food and fibre production, water purification, tourism, hydrological cycle	All impacted positively, but food and fibre provision impacted negatively	The communities are both negatively and positively affected by wetland restoration (+/-)

Table 3 above shows the results of Figure 11 combined with the found stakeholders of phase 1 (Table 2). It can be seen that the stakeholders that work on a scale larger than local, almost all benefit from wetland restoration. The local stakeholders, that are more dependent on the ES 'food and fibre production', are more negatively impacted. Of all stakeholders, the farmers are the only ones that are only negatively impacted by wetland restoration. The next section also looks into these kinds of impacts.

Causal loop diagram

Figure 12 below shows a causal loop diagram that incorporates and locates the identified ESs into the system and adds wetland restoration effects to it. Important to note is that not all system links are made, but only the main links are shown. The system is made up of factors and links between the factors. These factors are colorized by which scale they affect. The links can be negative or positive. If a link has two arrows on each side, it shows a feedback loop. These loops can also be negative or positive. The 'local to higher scale' means that the factor influences on local scale, but also on higher scales. A factor of a higher scale is seen as having its effects outside of the upper Kyll watershed. Local is when the effects are still within this watershed. An example is the factor 'flood'. Floods can be local, then they affect agriculture still within the Kyll watershed. However, a flood somewhere downstream in the Rhine watershed can be connected to water build-up in the research area, making the flood trans-national and both happening on local and higher scale.

The economy as a factor in Figure 12 is split up in direct and indirect economy. This should be interpreted as how some factors have a direct effect on the economy, in the sense that if something changes in that factor, there are immediate effects for the economy. For example, is the local job market collapses, this has immediate negative effects on the (local) economy. Indirect effects are effects that end up in the economy as well, but with more delay and a longer route (*i.e.* it moves through several factors first). Floods are an example of this. When a flood occurs and there is economic damage, this has effects on the economy. However, this (partly) goes through several factors first, before it arrives at the factor of economy. For example, a flood can cause property damage, which leads to new building regulations.

These regulations have implications on the housing market, which is again connected to the economy. Note that these intermediate factors are not shown in Figure 12. They deviate too far from the research and unnecessarily complicate it and are therefore left out.

Figure 12 shows how wetland restoration only has direct effects on ‘local agricultural productivity’ and ‘water retention’. However, by tracing the effect arrows, it can be seen how more indirectly connected factors, such as the climate or economy, are affected as well. These effects thus cross scale boundaries. Furthermore, a dotted line is added to Figure 12. This represents a division between the system; sub-system 1 and sub-system 2.

Sub-system 1 – the local socio-economic system

Wetland restoration affects ‘local agricultural activity’ negatively, as Figure 12 depicts. Due to the positive link it has on its linked factors, wetland restoration’s negative influence spirals down into food and fibre provision, the local job market and eventually in the (direct) economy. This forms the base of sub-system 1.

The first sub-system, on the left of the dotted line, has a more local scale and is mainly negatively influenced by wetland restoration. Moreover, it contains most socio-economic factors (and ESs), including the direct economy.

Sub-system 2 – the larger scale biophysical system

Wetland restoration also affects the indirect economy, but in a positive way. The factor ‘(indirect) economy’ is part of the second subsystem, located on the right side of the dotted line in Figure 12. Due to the positive feedback loops between ‘water quality’, ‘biodiversity’ and ‘water retention’, wetland restoration creates a self-boosting positive influence that traces up into the whole of sub-system 2. Sub-system 2 mainly consists of factors that are more on the higher scale.

Part of sub-system 2 is ‘reached WFD goals’. The WFD is important to mention because its goals are highly represented in the second sub-system, as it focusses more on the natural side of the system (*e.g.* on ESs such as water quality, biodiversity, water retention).

In short, sub-system 2 is less on the local scale than sub-system 1, contains more of the biophysical part of the system and is positively affected by wetland restoration.

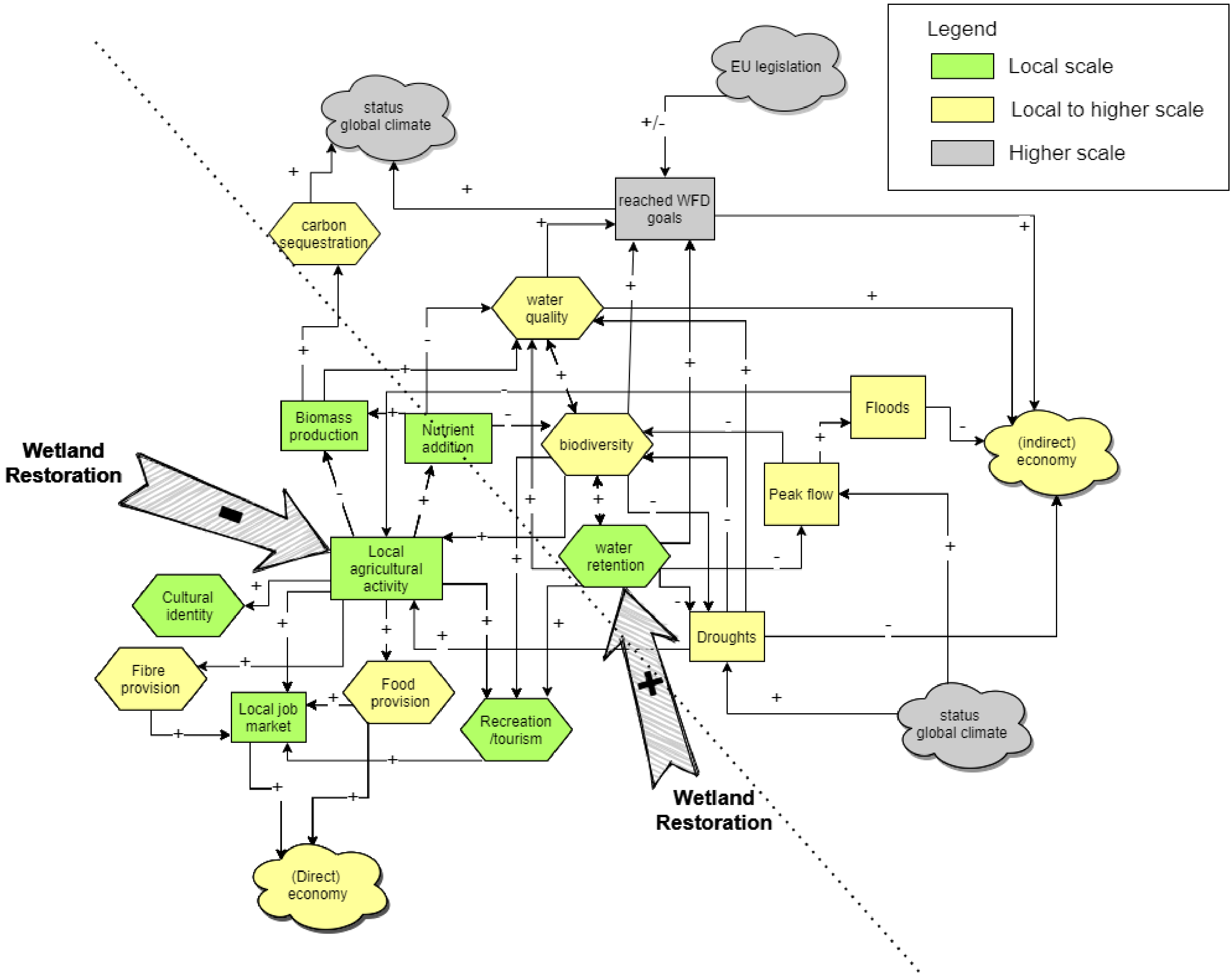

Figure 12 – Causal loop diagram showing where wetland restoration affects the system. The boxes that the system consists of are referred to as factors. The local-larger scale factors (in yellow) have both effects on local scale and on the larger scales. These larger scales include regional, national and trans-national. The arrows indicate the links between each factor and the plusses and minuses show if this is a reinforcing or a deteriorating link. The factors framed in a hexagon represent the analysed ESs. The factors on the edges, visualized as clouds, are factors that lie outside the system and outside this research, but are still of high importance for the system. They influence the system, but are also influenced by it. The large arrows show which factors in the system are directly influenced by wetland restoration and if this is positively or negatively. The dotted line is an imaginary dividing line between the two sub-systems. On the left the local socio-economic sub-system can be seen and, on the right, there is the larger scale biophysical sub-system.

8. Phase 3 – Scenario development

8.1 The scenarios

Phase 3 consists of a descriptive scenario analysis regarding the implementation design of the prospective wetland. In the first part, the research question **"What are the different implementation scenarios for wetland restoration?"** is answered. In the end, four wetland implementation scenarios were chosen. Scenarios are used to counter the uncertainty concerning how the wetland will look like and how this affects ESs. These scenarios include differences in wetland design *e.g.* wetland size, shape and depth (Hansson *et al.,* 2005), vegetation management and how realistic they are. The scenarios are each based on enhancing a different set of ESs and describe how maximizing these ESs is done and how other ESs are affected in the process. Understanding the relationship between the scenarios and ESs is part of the last sub question "**How do these wetland restoration scenarios influence the identified changes in Ecosystem Services?**".

Four scenarios are sketched: 1) only water retention, 2) water quality, 3) biodiversity and 4) wet-agriculture. In the last three scenarios water retention is also enhanced, on top of the aimed for ESs. Figure 13 gives an overview of the four scenarios.

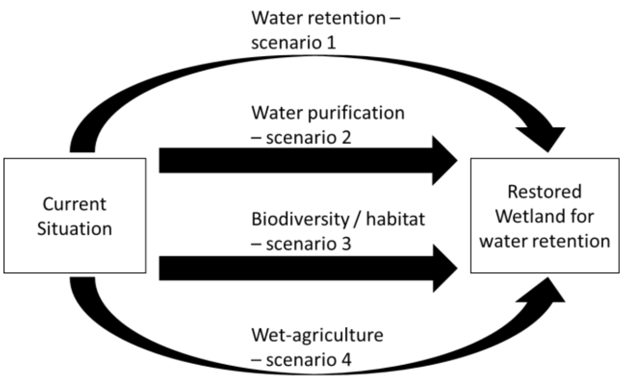

Figure 13 – Visualization of the different design scenarios that lead to a restored wetland that retains water.

These scenarios are chosen with the ESs of phase 2 in mind. So, the ESs that are most prone to enhancement with high results. For example, there is no scenario that focusses on maximizing climate mitigation. Climate mitigation *e.g.* through carbon sequestration is not a realistic scenario, as phase 2 showed that soil carbon storage would not be high in the research area. However, climate mitigation is still mentioned in the scenarios through the ES carbon sequestration. The results of phase 2 are combined with the information found on the actual project and the research area, to get realistic scenarios. For example, restoring wetlands in the whole study area is not realistic, as around half of the land is currently used for grassland farming and the other half is forest. Farmers will not give up their land willingly and forests already bring about many important ESs, including water retention. Thus, smaller wetlands on more devised locations are more realistic. Gaining more qualitative knowledge on how these smaller wetlands roughly might look like, is the aim of this section.

Scenarios' preconditions

This research sees wetland restoration as a part of BwN. This precondition means that the wetland restoration has to stay within BwN standards, which has its effects on the boundaries of the scenarios. This is different from most conventionally restored wetlands. Their water flow is often unnatural and they lack natural aquatic functions (Ellis, Shutes & Revitt, 2003). This wetland restoration strives for a minimal use of anthropogenic influences, such as filtration stations or large water managing constructions to adhere to BwN principles. The wetland will form naturally, after blocking the ditches that currently run through the area. Herein a certain amount of direction towards a desired wetland design is possible, but there is a limit to this. These limits are determined by preconditions, such as staying within BwN principles. These preconditions explain why only these four scenarios were chosen. Within each scenario it will be explained to what extend it stays within the preconditions, as this is important to understand how realistic the scenarios are.

Another precondition is wetland size. Space in the research area is not abundant or free of price, as it has to compete with land-uses like grassland farming. Therefore, in each scenario, a balance between wetland size and the scenario's focus is sought for. Moreover, as the wetlands are placed in the valley of the Rhine's headwater streams, the room available for these wetlands depends on the hillslopes around it. If these hillslopes are very steep, up until right before the stream, they are referred to as a V-shaped valleys. Then water cannot be retained over a large surface, as water is forced downwards and cannot stagnate. This may lead to water retention being only possible up until a few meters away from the stream. U-shaped valleys, however, have more space for water retention. These valleys become less steep closer to the stream and thus water can be spread out over a larger surface, resulting in a larger wetland. Still, these wetlands can only reach a maximum size of 20 meters away from the stream. This is because these small streams in the upper reaches of the Rhine's tributaries are small, often only 1 meter deep. This amount of water can simply not be spread out over more than 20 meters, even if the slope is very small to nonexistent (M. Waterloo, personal communication, October 27, 2020). Both types of valleys occur in the research area, but it is unknown in what ratio (Otterman *et al*., 2020).

8.2 Scenario 1: Water Retention

This scenario covers a focus on a wetland designed solely to renaturalize the hydrological cycle by restoring the sponge capacity of the soil. This is the restored wetland's effect that is the main aim of wetland restoration. As explained in Phase 2, still other ESs are affected as well. Positively affected ESs are water quality, biodiversity, recreation, education and in a lesser sense, carbon sequestration. A higher decrease in greenhouse gas emissions than carbons sequestration, is achieved with the partial removal of grassland farming that restoring wetland results in. This removed grassland farming, however, also provided the provisioning service food and fibre production. These therefore disappear in the precise wetland restoration area in this scenario. The water retention of this scenario leads to both flood and drought attenuation. The difference in wetland design to decrease droughts or floods, is also covered.

Wetland Design

Increasing the water retention, means increasing the time it takes precipitated water to reach the river. When water moves through the soil, instead of over land, this time rises tremendously. A large factor in this, is the much higher resistance the soil offers. Thus, for the most efficient water retention, the soil's water uptake capacity needs to be very high, so as much water as possible flows via soil instead of over land. Also the presence of vegetation increases resistance (Waterloo *et al.*, 2019). This is because vegetation positively affects surface and subsurface characteristics that increase resistance *e.g.* hydraulic conductivity and surface roughness (Wilcox, Breshears & Turin, 2003). Because of these factors the soil's water retention capacity was much higher in the likely original, natural state of the wetland, compared to the grassland state it is in now. Moreover, the wetland likely used to be vegetated for a large part by mosses (R. Verdonschot, September 29, 2020). These mosses take up water very well and can store it for a long time within, using capillary action. The exact water holding capacity differs per moss species, but is generally higher than vascular plants (Anderson, Lambrinos & Schroll (2010). Moreover, mosses are also very resilient to changing weather circumstances, such as dry periods that can occur in the Eiffel area (J. Hoffmann, October 6. 2020). However, a wetland like this cannot form with the high inflow of nutrients from the extensive farming in the area. The final vegetation state is therefore a wet forest, which has a lower water retention than the original mossy wetland. This refrains this scenario from reaching its maximum water retention potential. Yet, the water retention capacity of such a wet forest is still fairly high (R. Verdonschot, September 29, 2020).

To reach maximum water retention, a patchwork of spongy wetlands works better than one large wetland with the same total area (van Kreveld *et al.*, 2013; van Winden, Overmars & Braakhekke, 2004). This combines well with the often little space that is available for wetland in lower mountain valleys. Especially when these smaller wetlands are well-placed, on the locations where they can intercept most waterflow. This is at the foot of the hills, where both ground and surface water that precipitated on the plateau and on the slope itself collects. Then the water is retained right before it flows into a stream to enter the river system (Otterman *et al*., 2017). Thereby, the peak flow is dampened just before it can do real flooding damage.

Wetland Design for Droughts

The wetlands proposed in this research are too small to properly attenuate droughts. This applies to all scenarios. It was already mentioned how and why a wetland's sponge capacity is better capable of slowing down a large amount of rain by water retention, than it is in storing water for months without any inflow (Otterman *et al.*, 2017). This is why wetlands that are constructed to mitigate droughts, should be larger than wetlands for flood mitigation (K. Hendriks, September 30, 2020). He mentioned that for a wetland to properly mitigate droughts, (natural) water basins are required. Only the sponge capacity of the soil is insufficient. In the context of this research this could be translated to pools and lakes, where water is stored to be used by nature and agriculture during dry periods. However, in this research there is not enough space for these type of water bodies. Drought mitigation through wetlands should be sought for outside of this research's scope, more uphill, on the plateaus, or further downhill (Otterman *et al.*, 2017)

Time until maximum Water Retention

Once the drainage gullies are blocked from water through-flow, water retention immediately starts. Water is stored on the surface and as it slowly percolates into the soil (K. Hendriks, September 30, 2020). The earlier described increased soil's sponge capacity, however, takes longer to form. This depends on the formation of structure in the soil, catalyzed by vegetation growth. How long it takes until the maximum potential of this sponge capacity is reached is impossible to say, as it is highly context specific and there is a lack of research on this. Still, when plants start to root in the soil, the sponge capacity will begin to develop. However, reaching the maximum sponge capacity will only happen on a long time scale, likely over one hundred years (R. Verdonschot, September 29, 2020).

Other ESs

According to T. Wagner (September 17, 2020), water purification already starts when water is retained in a wetland for one or two days. Therefore, in this scenario, the ES water purification is already provided. It is not as high as in the upcoming scenario, but high, nevertheless.

Also the ES tourism is enhanced in this scenario. Not much, because this scenario's wetlands are small. Still, there is an increase in landscape diversity (K. Hendriks, September 30, 2020), so the tourism potential is enhanced.

The current ES food and fibre production is affected the most, because pastures have to make way for the proposed wetland. However, the wetlands in this scenario can remain small, so they do not take up a lot of pastureland. This is one of the main reasons why the socio-economic feasibility in Figure 14 is high in this scenario. Still, the water table is raised by the wetlands, which has negative implications for grassland farming around them (L. Vitzthum, personal communication, September 28, 2020).

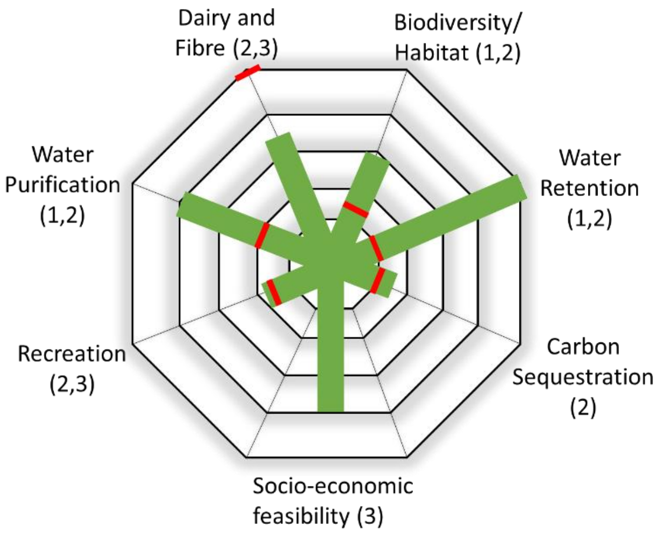

Figure 14 - Radar chart of how this scenario affects the identified ESs in green. The ESs' current situation is represented by the red lines. Also the socio-economic feasibility is added. The numbers in parentheses behind each factor show the source; 1=literature, 2=interviews, 3= own interpretation.

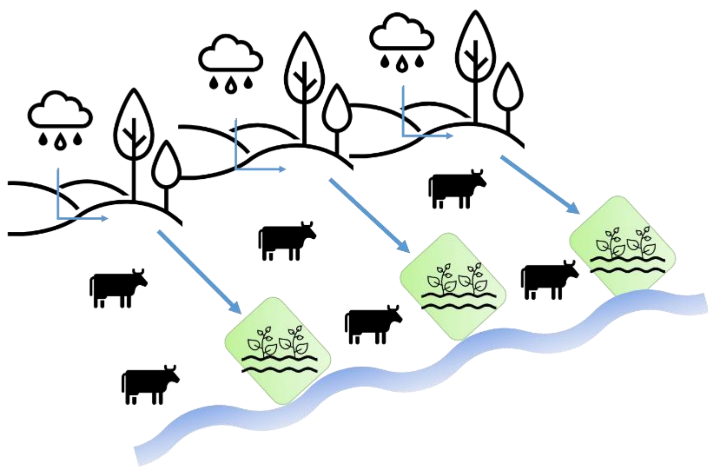

Figure 15 - A schematic visualization of the research area in this scenario. The figure is not on scale; the wetlands can only reach a maximum of 20 meters from the stream.

In short

This scenario focusses on fully enhancing water retention. Most important is the proper placement of the wetlands. They have to be placed where most water passes, which are the lowest points between hills, next to the stream (Figure 15). Also size is important for how much water can be retained by the wetland, but as space is lacking, the most important factor remains accurate wetland placement. This way they can be most efficient and small, thereby taking up less agricultural area. Water retention will immediately start after blocking the ditches, but the maximum sponge capacity will take much longer to form.

8.3 Scenario 2: Water Purification

The second scenario combines water retention with acquiring the maximum water purification capacity that a restored wetland can bring. This is a very natural combination, as water retention is the main mechanism of water purification in a wetland (T. Wagner, September 17, 2020). This scenario studies how this mechanism can be enhanced, so the risk of eutrophication of aquatic ecosystems further downstream is diminished.

In phase 2 the mechanisms of natural N and P removal was already explained, which is the base of a wetland's water purification ES in agricultural areas. This scenario builds further upon this explanation, but looks more at wetland designing to improve these mechanisms.

Wetland Design Conflict

Purifying water in a wetland from P or N is of a conflicting nature. The P removal mechanism benefits from a wetland with deep water bodies with a small surface, while the N removal mechanism benefits from shallow water bodies with a large surface (Hansson *et al.*, 2005; T. Wagner, September 17, 2020). Therefore is wetland design for this scenario subjected to trade-offs in design goal.

Phosphorous

For a wetland's P filtration capacity, the sedimentation and adsorption process is most important. Therefore, this process in increased with a higher water table and smaller wetland, where there is not too much wave activity (Hansson *et al.*, 2005; T. Wagner, September 17, 2020). What should be taken in consideration is that P will accumulate in the wetland, as explained in phase 2. This eventually results in a saturation of phosphorous in the soil and subsequently in losing the wetland's capacity of P filtration. Then the only solution to fully regaining this capacity is excavation of the wetland, to remove and replace the saturated soil (T. Wagner, September 17, 2020). According to Ellis, Shutes and Revitt (2003), replacement generally needs be done after 10 to 15 years for wetlands that were restored solely for purification purposes. The wetland in this scenario is not solely build for purification, so it would likely take longer than 15 years until P saturation is reached. How long exactly depends on the P inflow. Such soil excavation does have a very large impact on flora and fauna in the wetland and thus does not fall within BwN principles.

Nitrogen

The denitrification process is maximized with a large surface area and a low water table, as explained in Phase 2 (Hansson *et al.*, 2005; T. Wagner, September 17, 2020). Thus, with a high surface/volume ratio, N filtration is increased (Hansson *et al.*, 2005). Creating a truly large surface are is not possible in this case study, as the wetland's edge can only go as far as 20 meters from the headwater stream. So, to create some more area, the wetlands of this scenario are broader than in the previous scenario.

General Filtration

What applies to both N and P filtration processes, is that residence time is key (T. Wagner, September 17, 2020). So, to increase both processes, retention time should be increased. Moreover, the water flowing through the wetland should be as continuous as possible. The peak flows that are apparent in the study area interfere with this required continuous water flow, but this can be countered using a water basin just upstream of the wetland. A (natural) pond would suffice to maintain a steady inflow (T. Wagner, September 17, 2020). Also important for the wetland's filtration efficiency is that the wetland is formed so it catches all the water that flows down equally, so there are no differences in retention time (T. Wagner, September 17, 2020). In the water retention scenario this is already partly covered by 'proper placement of the wetlands'. This scenario builds further upon that.

Vegetation Management

The filtration capacity differs per plant species. Therefore, planting the right species can optimize the wetland's water quality ES (T. Wagner, September 17, 2020). A wetland that consists of only several good filtrating species in the wetland does however results in a low resilience against droughts and floods/peak flow, because biodiversity is then very low. The above proposed pond that maintains a steady water inflow could also partly counter these weather extremes. Still, it will likely not protect against heavy droughts or rainfall.

The vegetation that filters and adsorbs the nutrients in the wetland can become saturated. Then nutrient uptake, and thereby filtration capacity, is lowered. Therefore, the wetland vegetation needs to be occasionally cut down and taken away, to take the nutrients that they adsorbed out of the system again. This would keep the wetland most efficient in taking up nutrients and thereby have the highest filtration capacity (T. Wagner, September 17, 2020). This type of management would not be harmful to the wetland's vegetation like the soil excavation. On the contrary, in order to keep the biodiversity highest in the potential wetland system, occasional vegetation management like this is required. This keeps the area suitable for a larger arrange of species, instead of when it ends into a wet forest (R. Verdonschot, September 29, 2020; K. Hendriks, September 30, 2020). If this is not done on all places, a more diverse landscape is also created, with open areas and forested area. Thereby the aesthetical value is increased, which is linked to recreation (K. Hendriks, September 30, 2020).

Timing of Water Purification

The purification capacity of the wetland already starts when the water can remain in the wetland for one or two days (T. Wagner, September 17, 2020). This will likely happen immediately after blocking the drainage gullies. Because in this scenario water purifying plants are planted when the gullies are blocked, the maximum capacity is reached early. Still, also in this scenario it takes a long time until the sponge capacity is created. However, it likely goes faster than in the previous scenario, as the planted plants can already start rooting faster.

Other ESs

Already some effects on biodiversity, water retention and recreation have been mentioned. The strong relationship between water quality and biodiversity is however, not covered yet. Good water quality requires a low amount of nutrients in the water, resulting in a higher biodiversity. This applies both locally and downstream, such as in the Rhine (R. Verdonschot, September 29, 2020). When the water contains too many nutrients, micro-organism growth is accelerated. These micro-organisms take up oxygen, thereby lowering the oxygen levels in the water. This is detrimental for most other organisms, so it decreases biodiversity (R. Verdonschot, September 29, 2020). This is another way how the good water quality of this scenario increases biodiversity. On the other hand, the planting of only good filtrating plants results in a low plant biodiversity in the wetland itself. Thus, the biodiversity in this scenario is still not much higher than in the previous scenario.

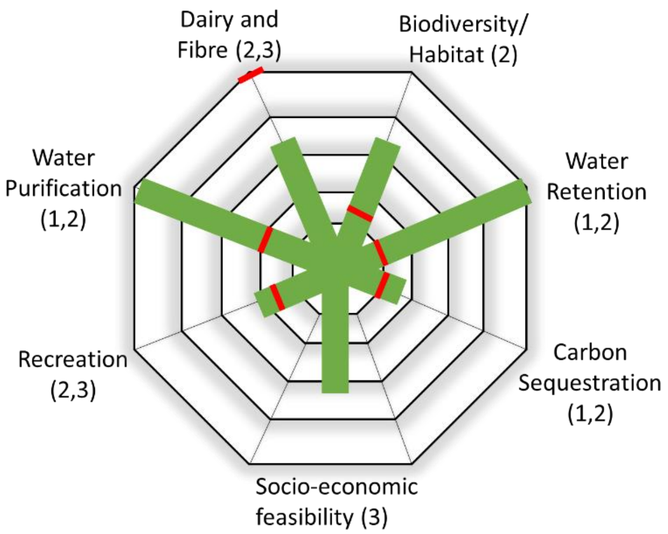

Figure 16 - Radar chart of how this scenario affects the identified ESs in green. The ESs' current situation is represented by the red lines. Also the socio-economic feasibility is added. The numbers in parentheses behind each factor show the source; 1=literature, 2=interviews, 3= own interpretation.

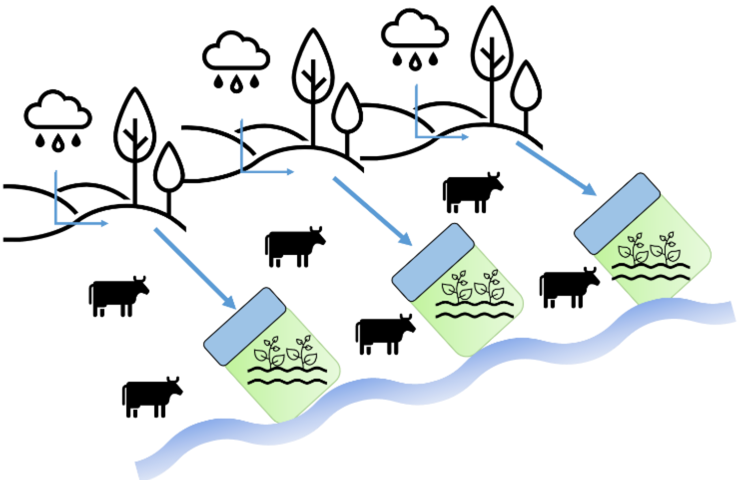

Figure 17 - A schematic visualization of the research area in this scenario. The figure is not on scale; the wetlands can only reach a maximum of 20 meters from the stream.

In short

This scenario focusses on filtering the agricultural nutrient inflow using a shallow wetland that contains selected good filtration plants. The wetland is broader than in the previous water retention scenario and a natural pond is added at the front (most uphill part) of the wetland (Figure 17). Vegetation mass is occasionally removed to keep the nutrient uptake efficient. The filtration of P is not optimal, as the wetland cannot be deepened and its soil cannot be removed. Also in this scenario water is retained to a high degree, relative to the current situation.

8.4 Scenario 3: Biodiversity and Habitat Restoration

It has been mentioned before that a land-use change from grassland farming to wetland restoration for water retention has a positive effect on biodiversity (R. Verdonschot, September 29, 2020). Partly because biodiversity poor pasture is removed, partly because the wetland is a habitat that can house a higher diversity than pasture. This scenario explores how the latter can be enhanced. Besides biodiversity, the term habitat restoration is coined in the title. According to J. Hoffmann (October 6, 2020), for these types of wetland restoration projects in Germany, the focus lies often on habitat restoration, rather than biodiversity. This is more conform Natura2000 and WFD guidelines and habitat restoration should be what results in native species resettlement, which does often lead to a higher biodiversity. Hoffmann mentioned that gaining a large biodiversity is not the goal per se, but the goal rather is regaining the right, native biodiversity. This is achieved by habitat restoration. So, the ES biodiversity, that this scenario strives to maximize, is closely correlated with habitat restoration. For clarity, this scenario is referred to as the biodiversity scenario, but it should be kept in mind that it also covers habitat restoration.

Wetland Design

When designing a wetland to enhance biodiversity, there are several paths to take. If there is only a focus on rare plant species, then a small wetland would already suffice. These could then grow from the seedbanks that likely still remain in the soil (R. Verdonschot, September 29, 2020). This would combine well with water retention, that also only needs tactically placed small wetlands. However, for housing also a big variety of larger fauna, a larger wetland surface is necessary. This is the desired situation in this scenario. As discussed earlier, headwater streams are small and do not contain much water, making it hard to restore wetlands with a large area (M. Waterloo, personal communication, October 27, 2020). However, they could become large due to their length. They could trail alongside the stream for hundreds of meters, even kilometers. Then a large surface area could still be met. This would then form a riparian zone around the stream, which would make the stream's land-to-water transition more gradual. This greatly strengthens the headwater system hydro-morphologically, physical-chemically and biologically. It would result in a different and richer species composition, compared to the current abrupt dry to wet transition (Buijse *et al*., 2019). This applies to both the wetlands surrounding the stream, but also the stream itself, because the shoreline complexity of the stream is improved (Hansson *et al*., 2005). An example of the potential transition zone is an alder (*Alnus)* forest. (Buijse *et al*., 2019). Moreover, this would restore the sponge function all along the stream as well. Thus, restoring a riparian wetland zone along the headwater streams would also be beneficial for regaining water retention (Buijse *et al*., 2019).

The largest ecological improvement this scenario's wetland adds to the region, is a large increase in diversity of the whole region's landscape. This landscape diversity results in a mosaic of different habitats close to each other. This heterogeneity in the landscape means more heterogeneity in the regionally occurring species (R. Verdonschot, September 29, 2020).

An additional ecological advantage of the created green strip in this scenario is the increased connectivity between suitable habitat areas. This is especially of high importance in areas such as the study area, since it lies in a natural park. Moreover, as this strip of wetland would show high connectivity, natural reintroduction of species would faster. However, as in this scenario only natural area along the streams is restored, the mountaintops still form an obstacle for species migration and DNA exchange (R. Verdonschot, September 29, 2020). Creating green, over-land corridors between different streams, would help overcome this (Buijse *et al*., 2019). Yet, this is not part of this scenario, as this lies outside the scope of this research.

Another problem that still affects biodiversity in this scenario is the edge effect. Edge effect is the influence of a neighboring ecosystem. This edge effect is highest at the ecosystem transition zone (the edge) and reduces further away from the edge (Hofmeister *et al.*, 2013). In this research, the pastures above the wetland are the source of an edge effect on biodiversity (R. Verdonschot, September 29, 2020).

A narrow wetland, with only a maximum width of 20 meters, does only to some degree stop the edge effect created by the pastures above. It is not enough to eliminate these effects entirely. Already in a forest, this edge effect is still in effect after 20 meters (Hofmeister *et al*., 2013). A wetland, due its higher penetrability, lower tree density and much lower vegetation canopy, is expected to buffer edge effects less than forests. Thus, habitat degradation due to edge effect would occur over the entire restored wetland zone.

To what extent habitat restoration is possible, depends in regions like the study area often on the available nutrients in the soil and water. Generally speaking, when a natural area is rich in nutrients, biodiversity is low. Nutrient low natural areas often show a higher biodiversity (R. Verdonschot, September 29, 2020). Translated to the case study, this means that the wetland's original habitat state cannot be restored and biodiversity cannot be restored to as high as it once was, even in this ecological scenario. Nevertheless, the proposed wetland restoration strip would be a large boost to the region's landscape diversity. Especially compared to the current situation, biodiversity of the whole area would be raised substantially (R. Verdonschot, Personal communication, 29 October, 2020).

Timing and Management

In the first years after the blocking of the ditches, biodiversity would rapidly go up, as new pioneer species settle in the recently wettened soil. This would be followed by several vegetational succession stages. The speed of the succession of these stages depends partly on the appearance of them already in the current system. Reed is an example of a species group that can rapidly expand, if already present in the area (K. Hendriks, September 30, 2020). The final succession stage is a wet forest, which has a high carbon storage due to its large biomass. Compared to the earlier stages, biodiversity in this forest would then be lower. The forest stage's water retention capacity would be at its maximum, but this maximum was also already reached in its preceding stages. Thus, the biodiversity could be kept higher by extensively managing the vegetation, without it affecting the water retention capacity (K. Hendriks, September 30, 2020; R. Verdonschot, September 29, 2020).

If the intensity of the management is done in different degrees in the area and in some places not at all, the earlier mentioned heterogeneity of the landscape can be increased. This would be the most beneficial situation for biodiversity, but also for the recreational value, as a more diverse landscape is also stimulating for this ES (K. Hendriks, September 30, 2020).

The question remains however, if this extensive management would bring back the original habitat, or if it merely creates a new, anthropogenically influenced one. Then again, as described in phase 2, the original habitat already lies beyond reach, even in the potential system, due to the extra influx of nutrients. This extra nutrient inflow is what would likely push the whole wetland area into the forest stage. How exactly the original habitat looked like, is unknown, but it was likely not only forest. Rather of a more mosaic type of landscape. It likely housed moss species, but also contained patches of trees. Heterogeneous extensive management could bring the area closer to this original situation, therefore this is part of this scenario.

Other ESs

The ES water purification would also be enhanced in this scenario (T. Wagner, September 17, 2020). This is for the same reasons as mentioned in the water retention scenario. However, in this scenario the water purification would be higher, because the wetland forms a uninterrupted riparian buffer zone around the stream, thereby intercepting and retaining all water that flows downhill. This means that more water is purified than in the water retention scenario. Similar riparian buffer zones in agricultural areas are mentioned in literature as a good mechanism to purify water from N and P (Mander *et al*., 1997; Walton *et al*., 2020; Anbumozhi, Radhakrishnan & Yamaji, 2005; Zheng *et al*., 2016 and many more).

This scenario would result in the biggest loss in agricultural land, because it requires the largest area. This means the biggest ES trade-off between food production and biodiversity. Still, only the farmland closest to the stream would be transformed, with a maximum of 20 meters away from the stream. As fertilizer application was already restricted within four meters from the stream (L. Vitzthum, personal communication, September 28, 2020), the farmland that would be converted to wetland is likely not the farmer's most valuable land. Still, this would happen for hundreds of meters or several kilometers far along the stream. Thus, this scenario would still require a lot of pasture and would increase the height of the groundwater level on the remaining pastures. This has implications on the socio-economic feasibility in Figure 18.

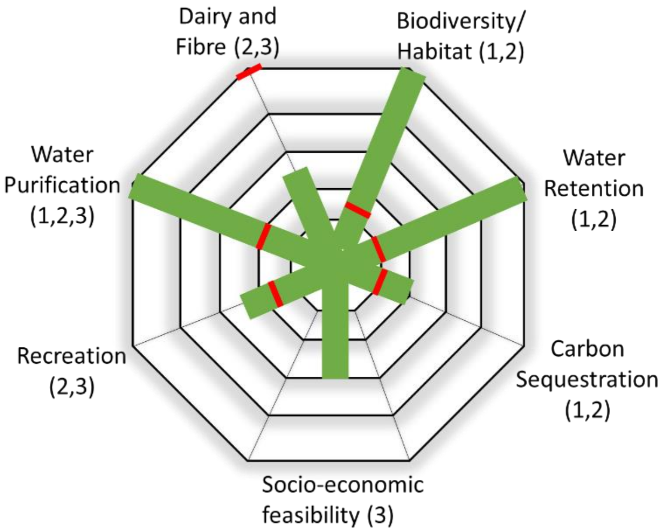

Figure 18 - Radar chart of how this scenario affects the identified ESs in green. The ESs' current situation is represented by the red lines. Also the socio-economic feasibility is added. The numbers in parentheses behind each factor show the source; 1=literature, 2=interviews, 3= own interpretation.

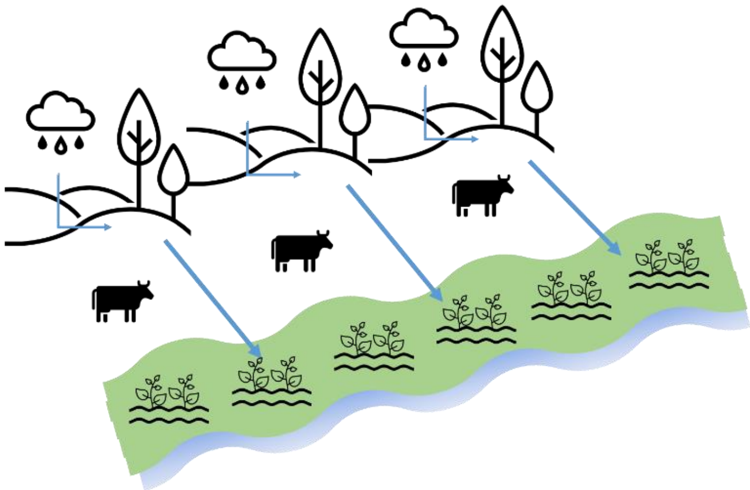

Figure 19 - A schematic visualization of the research area in this scenario. The figure is not on scale; the wetlands can only reach a maximum of 20 meters from the stream.

In short

This scenario focusses on habitat restoration, next to water retention. It proposes a narrow wetland that runs directly next to the headwater stream (Figure 19). This wetland's width ranges between several meters and 20 meters, depending on the slopes around it. To still cover a large area, the wetland is several hundred meters to some kilometers long, to considerably enhance the regional landscape diversity. Biodiversity is also enhanced by the sharp increase in the headwater stream's shoreline complexity and varying extensive biomass management. Moreover, this large strip of wetland has a sponge capacity that buffers peak flows, but also forms a good filtration zone for the inflow of agricultural nutrients.

8.5 Scenario 4: Wet-agriculture

This scenario is furthest apart from the rest. It is the only scenario that focusses on provisioning services, in combination with water retention. This scenario is chosen to explore a way to lessen the negative impact that wetland restoration has on the local agricultural productivity and the stakeholders that are connected to it. Figure 20 shows this part of the causal loop diagram of the researched system. The large negative 'wetland restoration' arrow is what this scenario aims to minimize. Negative effects initiated by this arrow result in negative effects on sub-system 2, the social-economic part of the system, as discussed in chapter 7.3. Thus, with decreased negative wetland effects, the stakeholders connected to sub-system 2 are impacted less.

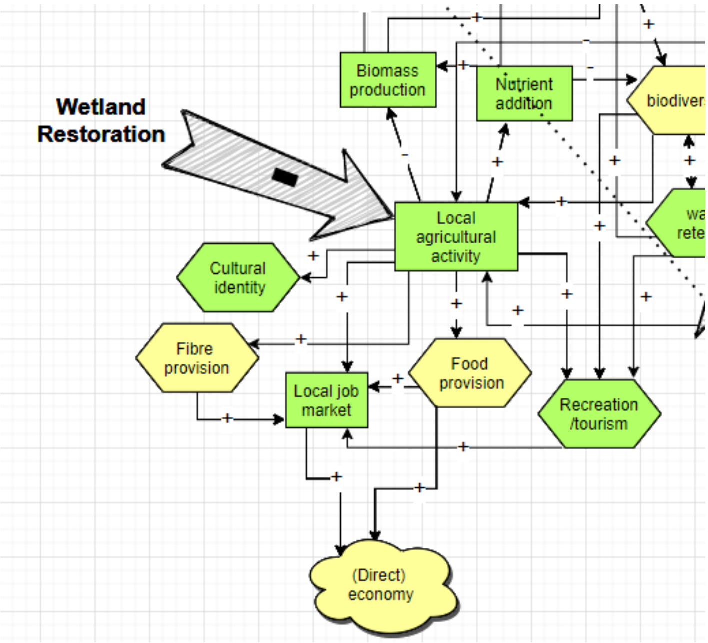

Figure 20 – A detail from Figure 12. This is the part of the diagram that this scenario focusses on.

Minimizing the impact on local agricultural activity, but still increasing the water retention, can be done using wet-agriculture (Bestman *et al*., 2019a). Wet-agriculture is cultivation of crops that can grow in circumstances with a higher water table than conventional crops. So, the farmers that have to make room for wetland restoration in the other scenarios, still have land to cultivate in this scenario. They simultaneously retain water as well. However, the farmers do have to completely switch the type of agriculture they practice, at least in the dedicated wetland area. Here they change from dairy farming to crop cultivation.

The combination of wet-agriculture on the lower parts of the hillslope, with grassland farming above, goes well. Grassland farming likely provides enough nutrient inflow into the cropland, so fertilization is not necessary (R. Vroom, October 12, 2020). In this section, first, the type of crops that are suitable for wet-agriculture in the research area are discussed. Second, the effects on the other identified ESs are discussed, followed by a discussion of how realistic this scenario is.

Wetland Design

Three helophyte crops have been identified as most credible for wet-agriculture in the research area. These are reed (*Phragmites australis*), willow (*Salix spp*) and cattail (*Typha spp*; R. Vroom, October 12, 2020, M. de Jong, October 22, 2020; Bestman *et al*., 2019a and Bestman *et al*., 2019b). All of the crops are able to handle a wet soil or thrive in it, are clonal and are endemic to Germany (Bestman *et al*., 2019a; R. Vroom, October 12, 2020).

Reed (Phragmites australis)

Reed can be cultivated for renewable energy or as a raw material (Wichmann, 2017). This raw material can be used for thatching, (cow) fodder, litter in the stable or ground cover in agricultural practices such as bulb growing. These practices have been done so already for centuries (Bestman *et al*., 2019a; T. Wagner, September 17, 2020). Reed also sequestrates a lot of carbon and has a high revenue per kilo. It was also chosen as a credible crop for wet-agriculture in the research area because its highly suitable for water retention areas, that experience both dry and wet periods (Bestman *et al*., 2019a). Furthermore, reed is very efficient in filtering passing water from nutrients as N and P. Harvesting reeds requires special machinery, that is equipped for large scale harvesting. The harvesting is labor intensive, especially harvesting reed for raw material (Wichmann, 2017).

Cattail (Typha spp.)

Cattail looks similar to reed, but it produces a very distinctive cigar-like seed head at the top of its stem. Cattail spreads very easily and produces a thick vegetation. It is already being cultivated in, among others, Germany (Bestman *et al*., 2019a). Several parts of the plant can be used. The seeds that it produces function well as construction and isolation material, due to their fungicidal good insulation properties. The rest of the plant can be used as renewable energy or cow fodder (R. Vroom, October 12, 2020). The latter could lead to a more closed nutrient cycle, when it is used as fodder for the cows uphill. Cattail can withstand floods well, without the final yield being impacted. Droughts are more dangerous for the yield, but too severe droughts can damage the crop (R. Vroom, October 12, 2020; Bestman *et al.*, 2019b). In Germany there is already a market for cattail produce for construction purposes (Bestman *et al.*, 2019a). For the harvesting similar special machinery is required and it is labor intensive (M. de Jong, October 22, 2020).

Willow (Salix spp.)

Willow was historically already often cultivated in wet areas. Due to this long history of cultivation, many willow hybrids have been formed (Bestman *et al.*, 2019a). Willow is used for renewable energy, wood production, fibre production and (cow) fodder (Kuzovkina & Quigley, 2005). A low water level is most beneficial for willow growth, but willows can survive higher levels as well. This makes willow an excellent species to grow in water retention areas. It has also been mentioned in an interview as one of the tree species that will likely naturally start to develop in the proposed wetland’s final succession stages (K. Hendriks, September 30, 2020). This is why willow is a credible wet-agriculture crop in the research area. Also willow harvesting requires specially designed machinery and is highly labor intense (Bestman *et al.*, 2019a; Walsh *et al*., 2003).

Low economic Feasibility

All three most credible crops are labor intense and require special machinery for harvest. This results in high costs for a farmer, if (s)he makes the switch to wet-agriculture. Especially the investment in special, costly machinery means that a large area for wet-agriculture is required, in order to make it economically feasible (M. de Jong, October 22, 2020; R. Vroom, October 12, 2020). However, this large area is not available in the research area. Due to the slopes around the head water stream, wet-agriculture is only possible between several meters to 20 meters from the stream. This is for the same reasons as why wetland is not possible further away from the stream; water cannot stagnate due to the slope. Harvest by hand is also possible, but this would result in very high labor costs (M. de Jong, October 22, 2020).

Research using a fictive plot of 1 hectare has shown that cattail production is not yet economically feasible, but with scaling up it might become so (de Jong, 2020). To compare, if the most optimistic (but hardly realistic) wet-agricultural plot width of 20 m is taken, then the wetland would have to be 500 m long to reach 1 hectare. An agricultural field this long, or longer, is impractical and would likely drive up the costs of labor even more. The economic feasibility of cattail production in the research area was also deemed questionable by other interviewed experts (J. Hoffmann, October 6, 2020; R. Vroom, October 12, 2020). These results are expected to be similar with reed and willow farming in the research area, as they too require large investments by the farmer and thus require such a long and impractical strip of land. Yet, such a long strip of wet-agriculture does have some similar advantages as in the biodiversity scenario. These are explored in the next section.

In short, in the current situation, wet-agriculture will very likely not produce as much income as the same area of pastures do now. Wet-agriculture income will probably not even be enough for farmers to get by. In the future the demand for product from wet-agriculture might increase, but currently it is too low (J. Hoffmann, October 6, 2020). Therefore famers will likely not make the switch to wet-agriculture, resulting in a low socio-economic feasibility in this scenario.

Otterman *et al*. (2017) mention that compensating farmers for their loss in income could be a solution. This would fit well with the EU's Common Agricultural Policy, as it leads to a more sustainable agricultural sector (European Commission, 2019). Also carbon credits could be a viable solution (de Jong, 2020). Such compensations could make this scenario more realistic, but studying these are not within the scope of this study. Famer compensation could also be applied to make the other scenarios more realistic, as they all involve negative consequences for farmers and their income.

Other ESs

Carbon sequestration has already been mentioned above as an ES of wet-agriculture. Again, in the case of the research area, this is mainly achieved in the plant's biomass. The most carbon is sequestered in the root part of the crops. How long the sequestered carbon remains locked, depends on what is eventually done with the crop. Producing isolation material with cattail is a good example of how carbon remains locked for a large period of time (Bestman *et al.*, 2019a).

All three wet crops work also very well for water retention, because they are adapted against both floods and droughts. They are also good at water purification, for which they area already often used in practice. They purify best in summer, when growth rate is highest (Bestman *et al.*, 2019a; Bestman *et al*., 2019b).

Also biodiversity is expected to rise when wet-agriculture is practiced. In the area itself they provide a new habitat, which will increase the species richness. In the landscape they can provide a connection zone between different areas (Bestman *et al.*, 2019a; Bestman *et al*., 2019b). In the research area these different areas would be the grasslands uphill and the head stream area more downhill. This is where this scenario shows some overlap with the biodiversity scenario. Also here the regional landscape diversity is enhanced, the headwater stream's shoreline complexity is increased and a good filtration zone for the inflow of agricultural nutrients in created (Hansson *et al.*, 2005).

The in phase 2 identified ES cultural identity is also of importance in this scenario. In this scenario the local, rural, agricultural identity of the population is infringed the least. The farmers remain farmers, instead of having to sell a part of their land so it can be restored into wetland. However, the type of farming does rigorously change. The change from cultivating food for human consumption into cultivating a crop only used for energy or fibre production might not be welcomed by all farmers (K. Hendriks, September 30, 2020).

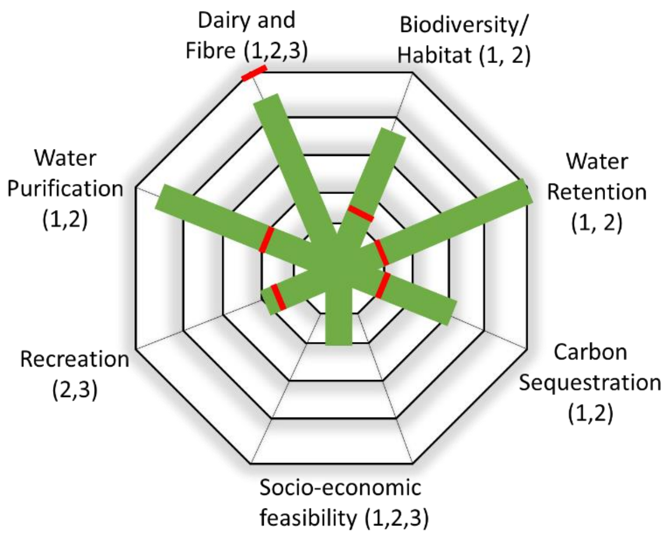

Figure 20 - Radar chart of how this scenario affects the identified ESs in green. The ESs' current situation is represented by the red lines. Also the socio-economic feasibility is added. The numbers in parentheses behind each factor show the source; 1=literature, 2=interviews, 3= own interpretation.

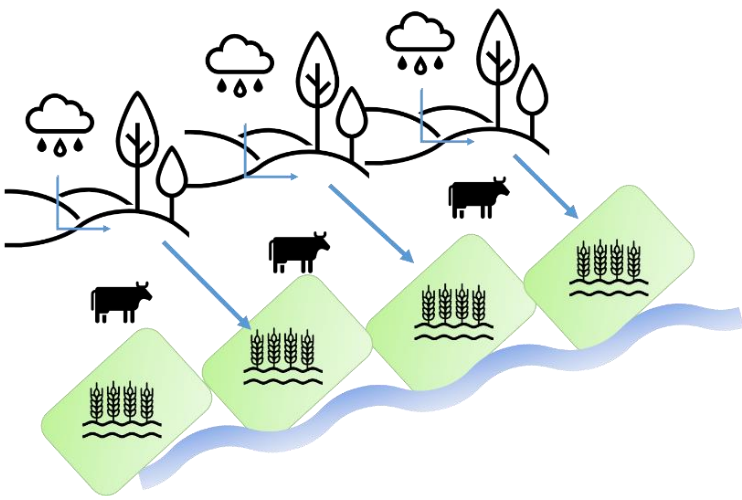

Figure 21 - A schematic visualization of the research area in this scenario. The figure is not on scale; the wetlands can only reach a maximum of 20 meters from the stream.

In short

This scenario focusses on preserving agriculture, combined with increasing the water retention. This is done by creating wet-agricultural fields from up to the edge of the stream until as far uphill as possible (Figure 21). Reed, willow and cattail production have been identified as most realistic wet-agriculture crops. As the wet-agricultural fields can only reach up to a maximum of 20 meters far from the stream, the wet-agricultural fields will be too small to become economically viable, even if the fields are elongated for hundreds of meters along the stream. This makes this scenario not realistic. It could become more realistic with farmer compensation. The scenario has good implications for identified ESs as water purification, water retention, biodiversity/habitat restoration and carbon sequestration.

8.5 Scenario outcome comparison and linkage to stakeholders

Comparison scenarios

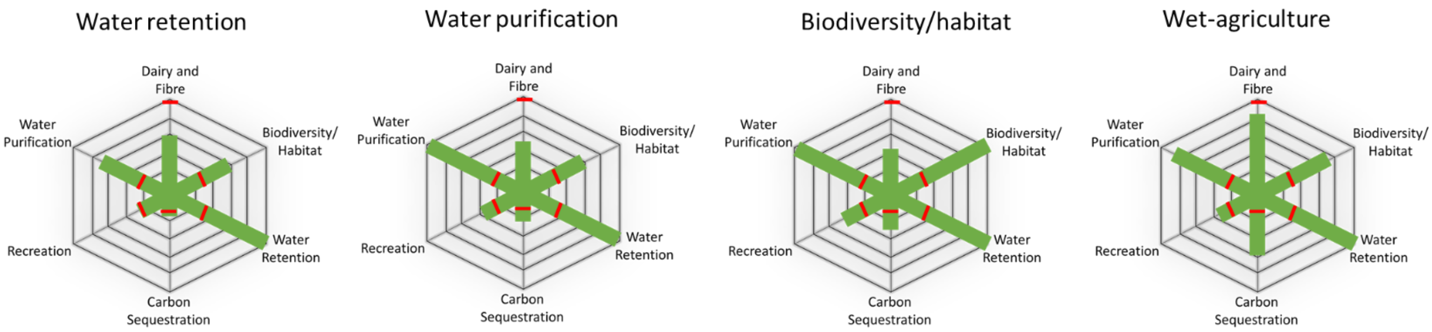

Figure 22 - Effects on ESs per scenario. The red bars represent the ESs in the current situation.

In Figure 22, the effects per scenario are repeated, but with only a focus on the ESs. This shows the ES trade-offs per scenario are clearer and makes comparable easier. All scenarios show a high decrease in dairy and fibre provision, except for the wet-agriculture scenario. Moreover, the main aim of wetland restoration, water retention, is greatly enhanced in all scenarios, compared to the current situation. Also water purification is high in all scenarios. Therefore, the water purification scenario itself loses relevance, as the wetlands in the other scenarios already purify water well. Recreation and carbon sequestration differ slightly per scenario, but there are no striking differences. Also biodiversity shows a high increase in all scenarios, compared to the current situation. However, in the biodiversity scenario the most.

Stakeholder linkage

Table 4 below shows how the results of the scenario analysis of phase 3 is connected to the identified stakeholders of phase 1. They have been grouped together if they are connected similarly. It shows how most scenarios are beneficial for almost all stakeholders.

Table 4 - How key stakeholders are affected by the scenarios

Key Stakeholders	How they are affected by the scenarios
- WSA & BfG - Waterboards NRW - River commissions	As their focus lies mainly on managing the water cycle within their jurisdictions (van der Stroom, 2018; Vidaurre et al, 2016), which complies mostly to the ES water retention, the water retention scenario is most beneficial. All other scenarios are also beneficial, compared to the current situation, as water retention is also enhanced in these. However, their socio-economic feasibility is not as high as in the water retention scenario.
- Federal state's environmental ministries - Environmental NGOs	The biodiversity/habitat restoration scenario is most beneficial for this stakeholder, because their interest lies in the ESs water quality, water flow and species diversity and habitats (MUEEF, no date). All other scenarios are also beneficial, because all enhance these ESs in some way. The biodiversity/habitat scenario the most.
- Federal state's agricultural ministries - Farmers/landowners	All scenarios impede the current agricultural businesses in the research area (dairy and fibre), so all scenarios are detrimental for these stakeholders and thus undesired. However, agricultural federal ministries also need to explore ways to make agriculture more sustainable (MWVLW, no date). Herein all scenarios could be interesting for them. The wet-agriculture scenario likely the most, as it impedes agriculture the least. For the farmers, the most negatively affected stakeholder (see Table 3), this wet-agriculture scenario is also the best of the undesired scenarios.
- Districts and Municipalities	The municipalities have a very broad interest (Haschke, 1998; Vidaurre et al., 2016), so the scenario with the highest gains in ESs, but also with the least trade-offs, is in their interest. This is the biodiversity scenario. However, as this impedes the many farmers in their municipalities, this will likely result in friction. The earlier suggested compensation for farmers could offer a solution.
- Tourism branch	The ES tourism turns out to be only slightly increased in all scenarios. The biodiversity scenario increases it the most.
- Communities	This stakeholder represents the local population and thus has a very broad interest. Therefore, the scenario with the least ES trade-offs is chosen. This is the biodiversity scenario. However, as this impedes the many farmers among the communities, this will likely result in friction. The suggested compensation for farmers could offer a solution and raise this scenario's socio-economic feasibility.

9. Discussion

This chapter discusses how the results of this research fit into other scientific research. This includes discussing the applicability of the ES approach combined with a scenario analysis in the context of wetland restoration in its earliest planning stages. Furthermore, the methods of this research are critically discussed, to find improvements for similar future research.

9.1 Results into a broader perspective

This section compares the results to the results of similar research, to find similarities and dissimilarities. This shows how this research adds to the currently available literature on wetland ESs. It should be noted however, that ES research on prospective wetlands is rare, especially in the combination with a scenario analysis regarding wetland design. Most ES research is also quantitative. Yet, with a broader view, comparisons to validate the results of this research can still be made.

The identified ESs and trade-offs

In phase 2, and later also in phase 3, this research recurringly identified a trade-off between provisioning services (food and fibre production) and the other types of ESs (*e.g.* water retention, water purification and biodiversity). The study of Zheng, Wang and Wu (2019) shows that these results match the average ES trade-off study results. They show in a systematic review of 47 ES trade-off studies that the conflict between provisioning services and other ESs, as found in the current research, is the most common type of ES trade-off. They conclude that especially a trade-off pair between food production and regulating services or biodiversity is recurrent (80% of total pairs). In the radar diagrams of phase 3 it can clearly be seen that this is also the case in the current research. Furthermore, about half of all ES trade-off studies were driven by land-use changes, as is the case in the current study. Zheng, Wang and Wu (2019) also stress the importance of analyzing multiple stakeholders when studying and comparing ESs, which also characterizes this research.

This research identified water quantity regulation, water quality, biodiversity, carbon sequestration and recreation as the main ESs enhanced by wetland restoration. Moore and Hunt (2012) studied the ESs that stormwater retention wetlands can provide and found highly similar ES provision results. Their research approach is comparable to the current research, in how they also use a holistic evaluation, involving all types of ESs, including cultural ESs. They found that carbon was mostly sequestered in vegetation's biomass and biodiversity was mostly determined by the shoreline complexity, in line with the results of this study. It should be noted though, that Moore and Hunt (2012) did a comparing and mostly quantifying study, making the methods different from the current study.

Jessop *et al.* (2015), studied ES trade-offs in existent restored wetlands in Illinois, USA. They also conclude that wetland restoration is always inherent to trade-offs, not all can be enhanced maximally. The current research found that water retention and water quality combine well. Jessop *et al.* (2015)'s results conform with this research's result, as they found a positive correlation between water purification from N and water retention. They also found a negative correlation between nutrient filtering and biodiversity. Such a negative correlation was not found in the current research. In fact, this research anticipates a slight increase in biodiversity when a wetland is restored with a focus on water purification. The explanation is likely that this research compares a low-biodiverse pasture with a restored wetland, while Jessop *et al.* (2015), compare between wetlands. Also large differences between our studies in wetland size, geographical location and surrounding landscape are apparent. These differences can have large implications on the way the ecosystem is build up and provides ESs. Ziter (2016) mentions *e.g.* abiotic factors, habitat type and community as important ES providers. Location and surrounding landscape are highly influential on these factors. This is an important footnote when comparing results between the current study and Jessop *et al.* (2015)'s study, but also for comparing ES results in general (de Groot *et al*., 2012; Kuik & de Vos, 2010).

Scenario analysis

As mentioned above, similar scientific research involving scenarios on wetland restoration design is scarce. However, the research of Zheng *et al.*, (2016) shows important similarities. They modelled the trade-offs in four different prospective land-use types in an important water extraction area, also used for agriculture, in China. They also found that management practices maximizing just one ES, such as agriculture, most often result in a decrease in other ESs. Their scenario analysis showed that ES trade-offs are minimized when land-use is more balanced. In their case this was in the scenario with a combination of forest, grassland and agriculture, as opposed to less versatile land-use (Zheng *et al*., 2016). This relates to the current research's results in the sense that this also showed that a more versatile land-use leads to a better distribution of ESs. This was shown in phase 2 by how introducing wetlands to a purely agricultural area, raised ESs. The scenario analysis (phase 3) showed that adding even more wetland area to this agricultural region, resulted in an even higher increase in total ESs. The biodiversity scenario is the best example of how more wetland area results in more ESs. Important to note, is that the provisioning ESs did not increase, but declined. All other ESs did increase.

In Zheng *et al.* (2016)'s study biodiversity was not incorporated. This is in line with the bulk of the literature, where biodiversity is seen as a factor closely connected to ESs, but not an ES itself. This might be a reason why no properly comparable literature was found regarding wetland ES trade-offs where biodiversity was one of the main research objects.

9.2 Reflection on the scientific framework

Application of the ecosystem service approach

The ecosystem service approach used in this research aims at understanding the socio-economic system, the ecological system and, especially, their connections. This inevitably results in having a very broad base that takes many variables into account. Hansson *et al*. (2005) refer to this as a 'helicopter perspective'. They do admit that this broad approach leads to a simplification of the system, which does have its downfalls. However, it has the strength of revealing that enhancing some desired ESs of wetland restoration in headwater stream areas conflict (*e.g.* food provision and biodiversity), whereas other ESs are both enhanced in the process (*e.g.* water retention and water purification). Less broad research, more focused on only one or several processes and ESs, might have not been able to identify all ESs trade-offs and synergies found in this research. A point also raised by Ziter (2016). Moreover, the broad approach of this study, in combination with previous studies, might form a base for potential wetland ES estimations (Hansson *et al*., 2005). The type of predictions that this study encourages could be studies regarding different areas, quantitative studies, or studies more focused on just one ES.

Incommensurability

Yet this broad base of the ES approach can also be seen as not broad and all-inclusive enough, a point raised by Chan, Satterfield and Goldstein (2012). They show critique on the ES approach by pointing out how the approach tries to embody everything, to treat all matters equally, so ESs can be compared and a fair value to them can be assigned. However, the nature of some ES is incommensurable, meaning that a fair value comparison to identify trade-offs cannot be made. Cultural ESs are often hard to compare to the other, more clearly objective ESs. Comparing spiritual value to the value of water quality in a fair way, for instance, seems hardly possible. Moreover, ES measurements and comparisons are often done in economic terms. Yet, putting an economic term on spiritual values, would imply that these values can be bought, which is not realistically the case and might be culturally offending. Therefore these types of intangible, incommensurable and cultural values are often not included in the ES approach, or they end up only in the after-thought of the research, but are left out of the actual ES trade-off scheme (Chan, Satterfield & Goldstein, 2012).

This research tried to incorporate these 'incommensurable' ESs as well, in the identification and trade-off schemes. This was done by keeping the research qualitative, in order to not put any invalid and precise (economic) value on the cultural ESs. In this research, cultural identity is an example of an ES mostly based on incommensurable values. Also recreation is rather incommensurable, as it is partly based on aesthetics. These ESs were hard to add to comparing figures such as the radar Figures in phase 3 (Figures 14, 16, 18 & 21). One way to still take these 'incommensurable' ESs into account was by adding socio-economic feasibility to the comparison. The likely opinion of farmers and locals have a large stake in how social and economically feasible a scenario is. This socio-economic feasibility is also connected to cultural identity and heritage, because a scenario that conflicts with these values, becomes less feasible of actually realistically occurring. Incommensurable values were taken into account when the scenarios' socio-economic feasibilities were rated. A downside of incorporating these 'incommensurable' values is that it has its implications on the generalizability of the results of this research. These cultural ESs are very site specific and thus cannot be generalized as easily as other classes of ESs (Chan, Satterfield & Goldstein, 2012).

Stakeholder analysis

These cultural ESs that are more socially based, could also have gotten a clear value in a thorough stakeholder analysis. This research only identified and explained the stakeholders by using literature. A more thorough stakeholder analysis could contain interviews with the stakeholders as well, to incorporate them better into the research. Additionally, the stakeholder analysis could be connected more to the scenario analysis, by mapping stakeholder willingness per scenario. This would give a better and more objective understanding of the scenarios' socio-economic feasibility in the area. This would also strengthen recommendations that follow from the research, as stakeholder willingness is often the biggest obstacle in development project realization (T. Hartmann, personal communication, March 3, 2020). The strength a thorough stakeholder analysis, as described above, would add to the research was already clear during the initial stages of this research. However, due to Covid-19 restriction this was not possible and the analysis had to be reduced to only literature-based.

Qualitative versus quantitative ES research

This research was purely qualitative and descriptive and the drawbacks this implicates should be discussed. Quantitative ES research results can directly apply economic systems and so be used to clearly show the full costs and benefits of a change in an ecosystem. The results also include non-marketed ESs and are easy to compare and use for decision makers (Busch *et al*., 2012). However, quantitative ES studies require comprehensive data, in order to include all relevant ESs in the system and not under- or overestimate their values (Busch *et al*., 2012). In this research about a fully prospective, restored wetland, such comprehensive data was lacking, thus a qualitative research was required. According to Busch *et al.* (2012), a qualitative approach is most comprehensive in identifying the consequences when changes in an ecosystem are made. This results in well-argued and informed argumentation of unquantifiable data, adequate for identifying causal linkages, trade-offs, trends and providing an overview (Busch *et al*., 2012). For these reasons qualitative research was most well-suited for this conducted research. However, qualitative research remains only a proxy-indicator and thus works well as an initial analysis step, transitioning in more quantitative research (Busch *et al*., 2012). Therefore, to make the results of this research most worth-while, it should be succeeded by quantitative research.

Extrapolation of the results

Results from ES approach studies cannot be extrapolated lightly, even though extrapolating the results of this study for future wetland restoration is aimed for. ESs are context specific and thus is the transfer of ES value from a local or regional study to a larger area inherent to limitations (de Groot *et al*., 2012). The compared ES values can differ depending on the economic assets and actors involved (Busch *et al*., 2012). Therefore should similar research in headwater stream areas in middle mountain regions identify these actors in the region using a new stakeholder analysis, as they likely differ from this research. Moreover, demographics, socio-economic and cultural aspects differ per region, as do the environmental values. Thus, for similar research, the SES should be reconsidered. There is a spatial variance in the characteristics of ESs, as they are not constant in terms of quantity and quality (Kuik & de Vos, 2010). In short, the results of this research cannot lightly be applied to other seemingly similar areas, but proper research regarding the ES specificities of that area is required, as local context is what eventually is decisive for the results of ES research (Bullock & Acreman, 2003; Kohler *et al*., 2017).

ESs' spatial scales

ES research is also obstructed by another type of spatial complication inherent to ESs; the scale ESs operate on. There is a wide range of ES users on different spatial levels, requiring research to look at the local level, but also to incorporate different governance and geographical scales (Muradian and Rival, 2012; Raum, 2018). This research focused more on the local scale, while several applied ESs do not solely operate on this level. Water purification is a good example. In this research mainly the local effects of water purification were examined, while purification in headwater streams also has positive effects on water quality throughout a whole watershed (Alexander *et al.*, 2007; Elsin, Kramer & Jenkins, 2010). Tracing down all ESs throughout the Rhine's watershed was not included in this research due to time restrictions, so the main focus was kept on the local scale. Further research regarding wetland ESs should be aware of the different spatial scales ESs can operate on and consider including them, to add more strength to the results.

Choice of conceptual framework

This research used a conceptual framework made by the author, based on the Millennium Ecosystem Assessment (2003) and Renner, Emerton and Kosmus (2018) (See Figure 1A and 3A in the Appendix). The research involved wetland restoration, meaning that an already disturbed system was (partly) restored back to its original state. This notion made it harder to find an appropriate conceptual framework, as they often focus on system deterioration, instead of improvement. Choosing the ES approach, meant that the research both involved social and ecological aspects (MEA, 2003). This was deemed necessary, as a restoring a wetland mainly has ecological implications, but as in the case study this would take place on currently agricultural land, also large socio-economic implications. Therefore, the ES approach is recommended for future research on wetland restoration. Still, also other conceptual frameworks could have been chosen, which are discussed below.

The resilience concept, with its foundations tracing back to Holling (1973), is mostly applied to describe the deteriorating effects on a system. Still, it could have been used for this research as well, as its main focus is on a systemic change and its effects within the (ecological) system. Wetland restoration is a driver of such change. By using this concept, the focus would have been more on the resilience of the ecological state and how wetland restoration would have improved it. The resilience concept would have been well appliable in this research, as it is well usable for linking social systems to the ecological system (Fisher *et al*., 2013). However, including this social side is often criticized within science, as resilience and system thinking can overlook contextual complexity, which social science understands better (Fisher *et al*., 2013). Thus, the ES approach of the MEA (2003) is deemed more appropriate for answering the research questions of this research, since it incorporates the social side of the research better.

The TEEB framework comes very close to the actual framework used in this research (Fisher *et al*., 2013), making it also very applicable for answering the research questions. It also uses ESs, but has more focus on valuation of them. This is why the MEA (2003)'s framework was chosen over the TEEB framework, because, as mentioned above, there was not enough specific data available for ES quantification.

Adding to the MEA's framework the more practical framework of Renner, Emerton and Kosmus (2018), or a similar more practical framework, is also recommended when wetland restoration is studied using a case study. This framework looks better at the specific circumstances of the study area, whereas the MEA's framework is more generalized. Furthermore, it incorporates stakeholders well and leads to more applicable results on wetland restoration for policy makers.

Scenario analysis in ES context

Combining a scenario analysis with the ES approach is uncommon in scientific research. The research that does exist with this combination often does not use literature research or interviews, but produces scenarios through modelling or spatial analysis (*e.g.* Butler *et al*., 2013; Huang *et al*., 2019; Troy & Wilson, 2006 & Zhang *et al*., 2019). This seems to be the standard when ES scenarios are analysed, and thus likely the preferred method. Some scarce literature does incorporate both literature research and expert interviews to produce a scenario analysis (Kohler *et al*., 2017). In a review on expert knowledge for ES research by Jacobs *et al*. (2015), expert knowledge is seen as a good way of tackling uncertainty regarding *e.g.* scenario analyses. Still, it does have its pitfalls, as it could be too simplistic and lack scientific underpinning (Jacobs *et al.,* 2015). Yet, they do state that the potentials outweigh these disadvantages, as long as the ES research based on expert knowledge is seen more as a starting point, that could lead to more focused research using more precise methods. This is also how this research's scenario analysis should be seen. It is a useful starting point, but as it is merely based on literature and expert knowledge, careful use for decision making is required. Ideally, further research using *e.g.* quantifying scenario analyses including models or spatial analysis, is done before practical decisions are taken based on this scenario analysis.

9.3 Methodological limitation

Among the methods of this descriptive ESs research are literature research and interviews. In this section it is discussed how these methods could be improved or could be strengthened with additional methods, in future research.

Subjectivity

Whatever type of ES research is chosen, subjectivity remains an issue in assigning values to ESs (Busch *et al*., 2012). In the scenario analysis this was countered by providing the information sources of how the values of ES affectedness were found. This included stating when it was based on the author's own interpretation. Choosing these four scenarios in the scenario analysis, was part of the interviews, but still remain partly subjective. Other pathways could have been researched as well. Also the selection of interviewees was subjective, as almost all were from within the WUR. A broader base in interviewees would have strengthened the interview results. However, this was not possible due to time and personal network restrictions. In future research, more objectivity can be achieved with a broader base in interviewees. Decreasing subjectivity in choosing the scenarios could be achieved by incorporating stakeholders and their views more.

Assumptions made

This research is based on the assumption that wetland restoration has a positive influence on water retention and on restoring the natural water cycle. However, this assumption is not yet fully validated, as field experiments in this area lack (Zemke, 2018), research on other types of wetlands than floodplain wetlands lacks (Bullock & Acreman, 2003) and blocking ditches does not necessarily always lead to higher water tables (Green *et al.*, 2017). Therefore, further (field experimental) research on blocking ditches to create wetlands and its effects on water retention is recommended. These type of field experiments should encompass experimental wetlands where the uptake of agricultural nutrients (*e.g.* N and P) is measured, along with the (long term) effects on the water cycle. These effects include both water retention during peak flows, but also during periods of droughts. Especially on the latter more research is required, since this current research encountered ambiguous opinions regarding how effective wetland restoration is in minimizing drought effects on water flow. Measuring the water in- and outflow of an area before and after wetland restoration for at least several years would give good indications on wetland restoration's water retention capabilities. This type of future research involving experimental wetlands already lies within the scope of the Sponge Project.

Methodological recommendations

The summarizing figure of phase 2 (Figure 11) only shows whether wetland restoration has positive, negative or negligible effects on the identified ESs. The figure would have had more strength if a degree in enhancement was shown. For example, it seems clear that water retention is more enhanced by wetland restoration than recreation. Yet, this difference is not visible now. This research was not able to provide enough evidence to claim a gradation in effect on ESs. However, this research did provide such a gradation in the scenario analysis. Here a gradation in ES enhancement could be made due to the scenario analysis' descriptive and anticipatory nature. Also because the subjectivity per scenario is clearly mentioned.

What also would have strengthened the results, is adding field work to the methods. This would have made the research less purely theoretical, by adding a more practical method. For instance, by interviewing farmers and other stakeholders in the area. This would have been an improvement, because then the knowledge about the case study area would not have only come from literature. According to Brown (2008), has using case studies in qualitative research proven to be a good addition. They can provide insight in the real-life environments (Yin, 2005). In addition to literature on the case study area, fieldwork could have provided more insight into the real-life environment. It would have strengthened the bridge between the theoretical and the practical side of this research better. Moreover, it could have provided a verification of the read literature, regarding the current situation of the case study. At the initial stages, fieldwork was planned, but due to Covid-19 restrictions it was cancelled.

10. Conclusions

This research aimed to understand the trade-offs in ESs generated by wetland restoration in head water stream areas. The German Middle Mountains were used as a case study area, in compliance with the Sponge Project, that this research is connected with. Wetland restoration focusses on increasing water retention upstream to decrease floods in the whole water basin. This is done by restoring wetlands, to increase the water holding capacity of the soil. In the case study area, the proposed wetland will be restored on area where currently pastures are situated. This wetland can only be restored close to the headwater stream, as otherwise the slope is too steep to retain water. So, the proposed wetlands are small. To find the ES trade-offs when converting a part of the pastures to wetland, this research combined literature study with expert interviews. Moreover, a research design was made, for analyzing ES trade-offs in BwN projects in their first planning stages.

In phase 1, the stakeholders in the case study area were identified and connected to ESs (Table 2). This yielded ESs from all four different ES categories. These ESs were further analysed in phase 2. In the current system, provisioning services are high, through dairy and fibre production. This dairy farming is connected to the region's cultural identity. The other identified ESs are low in provision. Biodiversity in the pastures is much lower than its former natural levels, because of nutrient application (mainly N and P) through cow manure and low diversity in grassland-plant communities. Also carbon sequestration is low. In the forested areas, these ESs are still much higher.

In the alternative system, wherein the wetland is restored, most ESs are enhanced. The proposed wetland restoration greatly enhances water retention, which is the main reason this wetland restoration study was set-up. Water retention leads to a decrease in floods by flattening peak discharge into the headwater stream. The largest effects are seen small scale, as opposed to regional or basin-wide scale. Water retention likely also reduces droughts, but this is less certain than flood reduction. Also water quality is enhanced, due to filtration of N and P by plant uptake. Carbon sequestration is only slightly enhanced due to the naturally low organic matter content of the soil. Biodiversity is substantially increased by less manure input, more connectivity to other biodiverse areas and by biomass management. There is a decrease in dairy production, as pastures have to make way for wetland. This also has its implications on local rural cultural identity. With respect to the stakeholders, wetland restoration is mainly positive. For the stakeholders connected to farming, such as the farmers and the agricultural ministries, it is not.

In phase 3, four scenarios regarding restored wetland's design to enhance different ESs were made and analysed: 1) water retention scenario, 2) water quality scenario, 3) biodiversity/habitat scenario and 4) wet-agriculture scenario. The last three scenarios also all include water retention, but they are combined with enhancing another ES as well. The water quality scenario is judged as not appropriate, as in all scenarios the water quality is already enhanced to a high extend. Also the wet-agriculture scenario emerged unrealistic, as the proposed wetlands are too small to be economically viable for wet-agriculture.

In the water retention scenario, small wetlands are placed on the lowest points between the hills next to the stream, to most effectively catch and slowdown most water. Due to the small area of the wetlands, there is low impact on dairy production. This makes this scenario most realistic and likely less unpopular by the stakeholders depending on farming. For the other stakeholders this scenario is favorable, as it increases the ESs water quality and biodiversity. In the biodiversity/habitat scenario, a long and narrow wetland directly next to the headwater stream is proposed. Biodiversity is enhanced by the increased regional landscape diversity, connectivity, shoreline complexity and by an extensive, varying biomass management. This scenario costs a lot of pastureland, which makes it likely disfavored by the stakeholders connected to dairy farming, which has its implications on the feasibility of this scenario. However, for all other ESs, this scenario is highly positive, as it forms a long water retaining green buffer strip between the pastures and the headwater stream.

To answer the main research question, this research found in wetland restoration a clear trade-off in provisioning ESs (dairy and fibre production) and the other identified ESs (water retention, water quality and biodiversity). How exactly the wetland will be designed in the end, has its implications on the extend of these trade-offs. A wetland forming a long green buffer zone balances the wetland restoration trade-offs more towards regulating and supporting services, while a focus on just restoring water retention balances the trade-off towards provisioning services. Nevertheless, also with the focus on only water retention, the other ESs (mainly water quality & biodiversity) would be considerably increased.

Recommendations for wetland restoration

Based on this research, I suggest several recommendations for future policy-making on wetland restoration in lower mountain ranges:

- Policy makers can use the results of the scenario analysis as a prediction of what ES trade-offs will occur when wetlands are restored with a certain aim on ES enhancement. These goals can differ per area and policy case. If this goal is solely enhancing **water retention**, not much pasture area needs to disappear as the wetlands remain small and are placed where they collect most water. Because the provisioning ESs are impacted least in this scenario, it has least negative consequences for land-use owners, such as dairy farmers. However, this stakeholder remains affected by wetland restoration the most. Moreover, all other ESs studied in this research are also enhanced (*e.g.* water quality and biodiversity).

- If the wetland restoration aims at nature development, the **biodiversity** scenario is recommended. It proposes a narrow wetland directly next to the headwater stream that improves connectivity to other biodiverse areas, regional landscape diversity and stream shoreline complexity. Next to biodiversity and habitat quality, also water retention and water quality are enhanced. More so than in the scenario explained above. However, trade-offs arise in the large amount of land required. Therefore, this scenario has a high impact on agricultural businesses.

- Aiming for enhancing **water quality** is only recommended when it is an absolute goal, as water quality is already enhanced to a large extent in the other scenarios. Restoring a wetland by encouraging **wet-agriculture** is not recommended, as it requires much larger areas to become economically viable.

11. Literature list

Aarrestad, P. A., Myking, T., Stabbetorp, O. E., & Tollefsrud, M. M. (2014). Foreign Norway spruce (Picea abies) provenances in Norway and effects on biodiversity.

Alexander, R. B., Boyer, E. W., Smith, R. A., Schwarz, G. E., & Moore, R. B. (2007). The role of headwater streams in downstream water quality 1. JAWRA Journal of the American Water Resources Association, 43(1), 41-59.

Anbumozhi, V., Radhakrishnan, J., & Yamaji, E. (2005). Impact of riparian buffer zones on water quality and associated management considerations. Ecological Engineering, 24(5), 517-523.

Anderson, M., Lambrinos, J., & Schroll, E. (2010). The potential value of mosses for stormwater management in urban environments. Urban ecosystems, 13(3), 319-332.

Ansbacher, P., Giglmaier, S., Zapf, K., Petersen, S., Dietz, J., Harkort, L., & Bähring, K. (2019). Klimaschutzteilkonzept „Nachhaltige Mobilität “für den Landkreis Vulkaneifel.

Antle, J. M., & Stoorvogel, J. J. (2006). Predicting the supply of ecosystem services from agriculture. American Journal of Agricultural Economics, 88(5), 1174-1180.

Ardon, M., Morse, J. L., Doyle, M. W., & Bernhardt, E. S. (2010). The water quality consequences of restoring wetland hydrology to a large agricultural watershed in the southeastern coastal plain. Ecosystems, 13(7), 1060-1078.

Ashenfleter, O., & Storchmann, K. (2001). The quality of vineyard sites in the Mosel valley of Germany. In Napa Valley Conference of the VDQS Society.

Azeez, J. O., & Van Averbeke, W. (2010). Nitrogen mineralization potential of three animal manures applied on a sandy clay loam soil. Bioresource technology, 101(14), 5645-5651.

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J. S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology letters, 9(10), 1146-1156.

Baptist, M.J. (2015). Building with nature video #09 - The Building with Nature Philosophy @ TU Delft 2015. TU Delft. Dataset.

Behrmann-Godel, J., & Eckmann, R. (2003). A preliminary telemetry study of the migration of silver European eel (Anguilla anguilla L.) in the River Mosel, Germany. Ecology of Freshwater Fish, 12(3), 196-202.

Benayas, J. M. R., & Bullock, J. M. (2012). Restoration of biodiversity and ecosystem services on agricultural land. Ecosystems, 15(6), 883-899.

Bestman, M., Eekeren, N. Van, Egas, Y., Houwelingen, K. Van, Koornneef, A., & Pijlman, J. (2019b). Eindrapportage Veen Voer en Verder.

Bestman, M., Geurts, J., Van, Egas, Y., Houwelingen, K. Van, Lenssinck, F., Koornneef, A., & Pijlman, J., Vroom, R., Eekeren, N. (2019a). Natte teelten voor het veenweidengebied.

Blackwell, M. S. A., & Pilgrim, E. S. (2011). Ecosystem services delivered by small-scale wetlands. Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, 56(8), 1467–1484. https://doi.org/10.1080/02626667.2011.630317

Boje, R., & Tomczak, M. (1978). Ecosystem analysis and the definition of boundaries in upwelling regions. In Upwelling ecosystems (pp. 3-11). Springer, Berlin, Heidelberg.

Bösch, M., Elsasser, P., Franz, K., Lorenz, M., Moning, C., Olschewski, R., ... & Weller, P. (2018). Forest ecosystem services in rural areas of Germany: Insights from the national TEEB study. Ecosystem Services, 31, 77-83.

Bouwma, I., Schleyer, C., Primmer, E., Winkler, K. J., Berry, P., Young, J., ... & Vadineanu, A. (2018). Adoption of the ecosystem services concept in EU policies. Ecosystem Services, 29, 213-222.

Broseliske, G. H., De Jong, J., & Smit, H. (1991). Historical and present day management of the River Rhine. Water Science and Technology, 23(1-3), 111.

Brown, P. A. (2008). A review of the literature on case study research. Canadian Journal for New Scholars in Education/Revue canadienne des jeunes chercheures et chercheurs en education, 1(1).

Browne, K. (2005). Snowball sampling: using social networks to research non-heterosexual women. International journal of social research methodology, 8(1), 47-60.

Buijse, A. D., Verdonschot, R. C. M., Van Puijenbroek, P., & Verdonschot, P. F. M. (2019). De haarvaten van het ecologisch riviernetwerk: Consequenties van fragmentatie en het belang van landbruggen en oeverzones. Landschap: tijdschrift voor landschapsecologie en milieukunde, 36(2), 68-77.

Bullock, A., & Acreman, M. (2003). The role of wetlands in the hydrological cycle. Hydrology and Earth System Sciences, 7(3), 358-389.

Busch, M., La Notte, A., Laporte, V., & Erhard, M. (2012). Potentials of quantitative and qualitative approaches to assessing ecosystem services. Ecological indicators, 21, 89-103.

Butler, J. R., Wong, G. Y., Metcalfe, D. J., Honzák, M., Pert, P. L., Rao, N., ... & Brodie, J. E. (2013). An analysis of trade-offs between multiple ecosystem services and stakeholders linked to land use and water quality management in the Great Barrier Reef, Australia. *Agriculture, ecosystems & environment*, *180*, 176-191.

Carpenter, S. R., Bennett, E. M., & Peterson, G. D. (2006). Scenarios for ecosystem services: an overview. Ecology and Society, 11(1).

Cederwall, H., & Elmgren, R. (1990). Biological effects of eutrophication in the Baltic Sea, particularly the coastal zone. Ambio. Stockholm, 19(3), 109-112.

Chahine, M. T. (1992). The hydrological cycle and its influence on climate. Nature, 359(6394), 373-380.

Chan, K. M., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. Ecological economics, 74, 8-18.

Changnon, S. A., & Demissie, M. (1996). Detection of changes in streamflow and floods resulting from climate fluctuations and land use-drainage changes. Climatic change, 32(4), 411-421.

Codd, G. A. (2000). Cyanobacterial toxins, the perception of water quality, and the prioritisation of eutrophication control. Ecological engineering, 16(1), 51-60.

Collentine, D., & Futter, M. N. (2018). Realising the potential of natural water retention measures in catchment flood management: Trade-offs and matching interests. Journal of Flood Risk Management, 11(1), 76-84.

Cork, S., Peterson, G., Petschel-Held, G., Alcamo, J., Alder, J., Bennett, E., ... & Zurek, M. (2005). Four scenarios. Ecosystems and human well-being: Scenarios, 2.

Corvalan, C., Hales, S., McMichael, A. J., Butler, C., & McMichael, A. (2005). Ecosystems and human well-being: health synthesis. World health organization.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

Cui, B., Yang, Q., Yang, Z., & Zhang, K. (2009). Evaluating the ecological performance of wetland restoration in the Yellow River Delta, China. Ecological Engineering, 35(7), 1090-1103.

Daugstad, K., Rønningen, K., & Skar, B. (2006). Agriculture as an upholder of cultural heritage? Conceptualizations and value judgements—A Norwegian perspective in international context. Journal of Rural Studies, 22(1), 67-81.

De Groot, R. S., Fisher, B., Christie, M., Aronson, J., Braat, L., Haines-Young, R., ... & Portela, R. (2010). Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations (pp. 9-40). Earthscan, Routledge.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... & Hussain, S. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem services*, *1*(1), 50-61.

de Jong, M. (2020). Paludiculture or paludifuture?-Environmental and economic analysis of cattail-based insulation material from paludiculture in The Netherlands (Master's thesis).

de Jonge, V. N., Pinto, R., & Turner, R. K. (2012). Integrating ecological, economic and social aspects to generate useful management information under the EU Directives'‘ecosystem approach’. Ocean & Coastal Management, 68, 169-188.

De Vriend, H., van Koningsveld, M., & Aarninkhof, S. (2014). ‘Building with nature’: the new Dutch approach to coastal and river works. In Proceedings of the Institution of Civil Engineers-Civil Engineering (Vol. 167, No. 1, pp. 18-24). Thomas Telford Ltd.

Defries, S., Foley, A., & Asner, P. (2004). Balancing human needs and ecosystem function Figure 1. Schematic representation of transitions in land use in a country or a region within a. Frontiers in Ecology and the Environment, 2(5), 249–257.

Demissie, M., Bhowmik, N. G., & Adams, J. R. (1983). Hydrology, hydraulics, and sediment transport, Kankakee and Iroquois Rivers. Illinois State Water Survey.

Drizo, A. F. C. A., Frost, C. A., Smith, K. A., & Grace, J. (1997). Phosphate and ammonium removal by constructed wetlands with horizontal subsurface flow, using shale as a substrate. Water Science and Technology, 35(5), 95.

Dunne, E., Culleton, N., O'Donovan, G., & Harrington, R. (2005). A Farm Scale integrated constructed wetland to treat farmyard dirty water. Teagasc.

Ellenberg, H. (1973). Ziele und Stand der Ökosystemforschung. In Ökosystemforschung (pp. 1-31). Springer, Berlin, Heidelberg.

Ellis, J. B., Shutes, R. B. E., & Revitt, D. M. (2003). Guidance manual for constructed wetlands. Environment Agency.

Elsin, Y. K., Kramer, R. A., & Jenkins, W. A. (2010). Valuing drinking water provision as an ecosystem service in the Neuse River Basin. Journal of Water Resources Planning and Management, 136(4), 474-482.

European Commission (2019). The common agricultural policy: separating fact from fiction. Derived on November 25, 2020 from https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-separating-facts-from-fiction_en.pdf

European Commission (2003). Common implementation strategy for the water framework directive (2000/60/EC) (Guidance document No 7). ISBN 92-894-6967-6.

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological economics, 68(3), 643-653.

Fisher, J. A., Patenaude, G., Meir, P., Nightingale, A. J., Rounsevell, M. D., Williams, M., & Woodhouse, I. H. (2013). Strengthening conceptual foundations: analysing frameworks for ecosystem services and poverty alleviation research. *Global Environmental Change*, *23*(5), 1098-1111.

Fränzle, O. (2001). Alexander von Humboldt's holistic world view and modern inter-and transdisciplinary ecological research. Northeastern Naturalist, 8(sp1), 57-90.

Georgiou, S., & Turner, R. K. (2012). Valuing ecosystem services: the case of multi-functional wetlands. Routledge.

Ghermandi, A., & Fichtman, E. (2015). Cultural ecosystem services of multifunctional constructed treatment wetlands and waste stabilization ponds: Time to enter the mainstream? Ecological Engineering, 84, 615–623. https://doi.org/10.1016/j.ecoleng.2015.09.067

Giordano, R., Mysiak, J., Raziyeh, F., Vurro, M., & Mattei, F. E. E. (2007, November). An integration between cognitive map and causal loop diagram for knowledge structuring in river basin management. In Proc. 1st Intern. Conference on Adaptive & Integrated Water Management.

Government of Canada (2017). Forest ecosystem products and services. Derived on June 6, 2020 from https://www.nrcan.gc.ca/our-natural-resources/forests-and-forestry/sustainable-forest-management/forest-ecosystem-products-services/13177

Green, S. M., Baird, A. J., Holden, J., Reed, D., Birch, K., & Jones, P. (2017). An experimental study on the response of blanket bog vegetation and water tables to ditch blocking. Wetlands Ecology and Management, 25(6), 703-716.

Grift, R. E. (2001). How fish benefit from floodplain restoration along the lower River Rhine. Wageningen, The Netherlands: Wageningen University.

Guidi, P., Falsone, G., Mare, B. T., Simoni, A., Gioacchini, P., & Vianello, G. (2013). Relating loss of soil fertility to water aggregate stability and nutrient availability in mountain agricultural calcaric soils. EQA-International Journal of Environmental Quality, 11(11), 1-16.

Haas, G., Wetterich, F., & Köpke, U. (2001). Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agriculture, ecosystems & environment, 83(1-2), 43-53.

Hagedorn, F., Maurer, S., Egli, P., Blaser, P., Bucher, J. B., & Siegwolf, R. (2001). Carbon sequestration in forest soils: effects of soil type, atmospheric CO2 enrichment, and N deposition. European Journal of Soil Science, 52(4), 619-628.

Halbe, J., Knüppe, K., Knieper, C., & Pahl-Wostl, C. (2018). Towards an integrated flood management approach to address trade-offs between ecosystem services: Insights from the Dutch and German Rhine, Hungarian Tisza, and Chinese Yangtze basins. Journal of Hydrology, 559, 984-994.

Halldorsson, G., Oddsdottir, E.S. & Eggertsson, O. (eds.) 2007. Effects of afforestation on ecosystems, landscape and rural development. -Proceedings of the AFFORNORD conference, Reykholt, Iceland, June 18-22, 2005. TemaNord 2007/508.

Hansson, l. A., Brönmark, C., Anders Nilsson, P., & Åbjörnsson, K. (2005). Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both?. Freshwater Biology, 50(4), 705-714.

Hefting, M. M., van den Heuvel, R. N., & Verhoeven, J. T. (2013). Wetlands in agricultural landscapes for nitrogen attenuation and biodiversity enhancement: Opportunities and limitations. Ecological Engineering, 56, 5-13.

Heine, P., Hausen, J., Ottermanns, R., Schäffer, A., & Roß-Nickoll, M. (2019). Forest conversion from Norway spruce to European beech increases species richness and functional structure of aboveground macrofungal communities. Forest Ecology and Management, 432, 522-533.

Hentschel, A. (2001): Zur Integration von Landwirtschaft und Naturschutz in Grünlandregionen der Westeifel (NRW). – Dissertation Bonn, 293 S.

Hofmeister, J., Hošek, J., Brabec, M., Hédl, R., & Modrý, M. (2013). Strong influence of long-distance edge effect on herb-layer vegetation in forest fragments in an agricultural landscape. Perspectives in Plant Ecology, Evolution and Systematics, 15(6), 293-303.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, *4*(1), 1-23.

Hostache, R., Lai, X., Monnier, J., & Puech, C. (2010). Assimilation of spatially distributed water levels into a shallow-water flood model. Part II: Use of a remote sensing image of Mosel River. Journal of hydrology, 390(3-4), 257-268.

Huang, Q., Zhao, X., He, C., Yin, D., & Meng, S. (2019). Impacts of urban expansion on wetland ecosystem services in the context of hosting the Winter Olympics: a scenario simulation in the Guanting Reservoir Basin, China. *Regional Environmental Change*, *19*(8), 2365-2379.

Irshad, H. (2010). Rural tourism-an overview. Edmonton, Canada: Government of Alberta.

IT NRW (2018). Statistische Berichte. Agrarstrukturerhebung in Nordrhein-Westfalen 2016. Information und Technik NRW: Düsseldorf.

IUCN (2020). Ecosystem Services. Retrieved on 8 May 2020 from https://www.iucn.org/commissions/commission-ecosystem-management/our-work/cems-thematic-groups/ecosystem-services

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., & Schneiders, A. (2015). 'The Matrix Reloaded': A review of expert knowledge use for mapping ecosystem services. *Ecological Modelling*, *295*, 21-30.

Jansky, B. (2006). Water retention in river basins. Acta Universitatis Carolinae-Geographica, 38(2), 173-184.

Jessop, J., Spyreas, G., Pociask, G. E., Benson, T. J., Ward, M. P., Kent, A. D., & Matthews, J. W. (2015). Tradeoffs among ecosystem services in restored wetlands. Biological Conservation, 191, 341-348.

JRC (2020). Nature-based solutions for climate change adaptation and water pollution in agricultural regions – Landscape elements for water retention (LWR) in a continental plains environment. JRC/IPR/2020/LVP/0448. 1157049.

Karstens, S., Inácio, M., & Schernewski, G. (2019). Expert-based evaluation of ecosystem service provision in coastal reed wetlands under different management regimes. Frontiers in Environmental Science, 7, 63.

Khan, F. A., & Ansari, A. A. (2005). Eutrophication: an ecological vision. The botanical review, 71(4), 449-482.

Kienast, F., Degenhardt, B., Weilenmann, B., Wäger, Y., & Buchecker, M. (2012). GIS-assisted mapping of landscape suitability for nearby recreation. Landscape and Urban Planning, 105(4), 385-399.

Kohler, M., Stotten, R., Steinbacher, M., Leitinger, G., Tasser, E., Schirpke, U., ... & Schermer, M. (2017). Participative spatial scenario analysis for alpine ecosystems. *Environmental management*, *60*(4), 679-692.

Kosow, H., & Gaßner, R. (2008). Methods of future and scenario analysis: overview, assessment, and selection criteria (Vol. 39, p. 133). DEU.

Kröger, R., Lizotte Jr, R. E., Douglas Shields Jr, F., & Usborne, E. (2012). Inundation influences on bioavailability of phosphorus in managed wetland sediments in agricultural landscapes. Journal of environmental quality, 41(2), 604-614.

Kuik, O. J., & de Vos, H. (2010). Scaling up ecosystem benefits - a contribution to The Economics of Ecosystems and Biodiversity (TEEB) study. (EEA Report; No. No 4/2010). Office for Official Publications of the European Union.

Kuzovkina, Y. A., & Quigley, M. F. (2005). Willows beyond wetlands: uses of Salix L. species for environmental projects. Water, Air, and Soil Pollution, 162(1-4), 183-204.

Lammersen, R., Engel, H., Van de Langemheen, W., & Buiteveld, H. (2002). Impact of river training and retention n flood peaks along the Rhine. Journal of Hydrology, 267(1-2), 115-124.

Landtag Nordrhein-Westfalen (2016). Sanierung des Staudamms Kronenburger See. Drucksache 16/10837.

Leibowitz, S. G. (2003). Isolated wetlands and their functions: an ecological perspective. Wetlands, 23(3), 517-531.

Liuzzo, D. (2006). Administrative Gliederung Deutschlands. Derived on February 4, 2021 from https://commons.wikimedia.org/wiki/File:Administrative_Gliederung_Deutschlands.png

Loeb, R., Boxman, A. W., Lamers, L. P. M., Lucassen, E. H. E. T., Smolders, A. J. P., Roelofs, J. G. M., ... & Miletto, M. (2006). Biogeochemical constraints on the ecological rehabilitation of wetland vegetation in river floodplains. In Living Rivers: Trends and Challenges in Science and Management (pp. 165-186). Springer, Dordrecht.

Lohani, B. N., Evans, J. W., Everitt, R. R., Ludwig, H., Carpenter, R. A., & Tu, S. L. (1997). Environmental impact assessment for developing countries in Asia: Volume 1-overview. Asian Development Bank.

Longhurst, R. (2003). Semi-structured interviews and focus groups. *Key methods in geography*, *3*(2), 143-156.

Maltby, E. (2009). Functional assessment of wetlands: towards evaluation of ecosystem services. Elsevier.

Maltby, E., & Acreman, M. C. (2011). Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrological Sciences Journal, 56(8), 1341-1359.

Mander, Ü., Kuusemets, V., Lõhmus, K., & Mauring, T. (1997). Efficiency and dimensioning of riparian buffer zones in agricultural catchments. Ecological engineering, 8(4), 299-324.

McCulloch, G., Aebischer, A., & Irvine, K. (2003). Satellite tracking of flamingos in southern Africa: the importance of small wetlands for management and conservation. Oryx, 37(4), 480-483.

Millennium Ecosystem Assessment (2003). Ecosystems and human well-being: a framework for assessment. Washington DC: Island press.

Millennium Ecosystem Assessment (2005). Ecosystems and human well-being (Vol. 5, p. 563). Washington, DC: Island press.

Mirzabaev, A., Wu, J., Evans, J., Garcia-Oliva, F., Hussein, I. A. G., Iqbal, M. H., ... & Tena, F. (2019). Desertification: IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse gas fluxes in Terrestrial Ecosystems.

Mitsch, W. J., Zhang, L., Anderson, C. J., Altor, A. E., & Hernández, M. E. (2005). Creating riverine wetlands: ecological succession, nutrient retention, and pulsing effects. Ecological Engineering, 25(5), 510-527.

Moore, T. L., & Hunt, W. F. (2012). Ecosystem service provision by stormwater wetlands and ponds–a means for evaluation?. Water research, 46(20), 6811-6823.

Muddiman, S. (2019). Ecosystem Services: Economics and Policy. Springer.

Oehl, F., Frossard, E., Fliessbach, A., Dubois, D., & Oberson, A. (2004). Basal organic phosphorus mineralization in soils under different farming systems. Soil Biology and Biochemistry, 36(4), 667-675.

Ojea, E., Martin-Ortega, J., & Chiabai, A. (2012). Defining and classifying ecosystem services for economic valuation: the case of forest water services. Environmental Science & Policy, 19, 1-15.

Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., ... & Sonwa, D. J. (2019). Land Degradation: IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse gas fluxes in Terrestrial Ecosystems.

Oppermann, M. (1996). Rural tourism in southern Germany. Annals of tourism research, 23(1), 86-102.

OTA (1987). Technologies to maintain biological diversity. Congress of the US, Office of Technology Assessment.

Ott, M., Su, Z., Schumann, A. H., & Schultz, G. A. (1991). Development of a distributed hydrological model for flood forecasting and impact assessment of land-use change in the International Mosel river basin. In Proc. of the Vienna Symposium. IAHS Pub (No. 201).

Otterman, E., Braakhekke, W., Winden, A. Van, Deursen, W. Van, Zeitler, F., Silver, E., Roels, B., Schoch, D. (2017). Restoration of the marshes in the valleys of the middle mountains of the Rhine basin for flood and drought risk reduction.

Pesonen, J., Komppula, R., Kronenberg, C., & Peters, M. (2011). Understanding the relationship between push and pull motivations in rural tourism. Tourism Review.

Pies, C., Yang, Y., & Hofmann, T. (2007). Distribution of polycyclic aromatic hydrocarbons (PAHs) in floodplain soils of the Mosel and Saar River. Journal of Soils and Sediments, 7(4), 216-222.

Pinter, N., van der Ploeg, R. R., Schweigert, P., & Hoefer, G. (2006). Flood magnification on the River Rhine. Hydrological Processes: An International Journal, 20(1), 147-164.

Polasky, S., Costello, C., & Solow, A. (2005). The economics of biodiversity. Handbook of environmental economics, 3, 1517-1560.

Ramsar (2009). Factsheet 9: Recreation & Tourism. Gland, Switzerland, Ramsar Convention Secretariat

Raum, S. (2018). A framework for integrating systematic stakeholder analysis in ecosystem services research: Stakeholder mapping for forest ecosystem services in the UK. Ecosystem services, 29, 170-184.

Renner, I., Emerton, L. & S. Kosmus, M. (2018). Integrating Ecosystem Services into Development Planning. A stepwise approach for practitioners. Bonn and Eschborn: Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH.

Rodríguez Ortega, T., Oteros Rozas, E., Ripoll Bosch, R., Tichit, M., Martín López, B., & Bernués Jal, A. (2014). Applying the ecosystem services framework to pasture-based livestock farming systems in Europe.

Sadava, D., Hillis, D. M., Heller, H. C., & Berenbaum, M. (2014). Life: The Science of Biology. Sunderland, MA.

Satz, D., Gould, R. K., Chan, K. M., Guerry, A., Norton, B., Satterfield, T., ... & Basurto, X. (2013). The challenges of incorporating cultural ecosystem services into environmental assessment. Ambio, 42(6), 675-684.

Schulte-Wülwer-Leidig, A., Gangi, L., Stötter, T., Braun, M., & Schmid-Breton, A. (2018). Transboundary Cooperation and Sustainable Development in the Rhine Basin. Achievements and Challenges of Integrated River Basin Management, 123.

Schultz, G. A. (1995). Changes on flood characteristics due to land use changes in a river basin. In US-Italy Research Workshop on the" Hydrometeorology, Impacts, and Management of Extreme Floods". Perugia (Italy).

Schumacher, W. (2013). Biodiversität extensiv genutzter Grasländer und ihre Erhaltung durch Integration in landwirtschaftliche Betriebe–Erfahrungen und Ergebnisse 1985-2012*. Agrobiodiversität im Grünland–nutzen und schützen, 70-99.

Schumacher, W., J. Weis & F. Opitz (1998): Zur Populationsentwicklung seltener und gefährdeter Orchideen in Offenlandökosystemen der Eifel während der letzten Jahrzehnte.- Jahresberichte Naturwissenschaftlicher Verein Wuppertal 51: 230-255

Shabalova, M. V., Van Deursen, W. P. A., & Buishand, T. A. (2003). Assessing future discharge of the river Rhine using regional climate model integrations and a hydrological model. Climate research, 23(3), 233-246.

Sharpley, R., & Vass, A. (2006). Tourism, farming and diversification: An attitudinal study. Tourism management, 27(5), 1040-1052.

Smith, P., Nkem, J., Calvin, K., Campbell, D., Cherubini, F., Grassi, G., ... & Nkonya, E. (2019). Interlinkages between desertification, land degradation, food security and greenhouse gas fluxes: Synergies, trade-offs and integrated response options. Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems.

Swingland, I. R. (2001). Biodiversity, definition of. Encyclopedia of biodiversity, 1, 377-391.

Te Linde, A. H., Bubeck, P., Dekkers, J. E. C., De Moel, H., & Aerts, J. C. J. H. (2011). Future flood risk estimates along the river Rhine. Natural Hazards and Earth System Sciences, 11(2), 459.

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. Nature, 504(7478), 79-83.

Troy, A., & Wilson, M. A. (2006). Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. *Ecological economics*, *60*(2), 435-449.

Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., ... & Rusch, V. (2018). When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. Ecosystem services, 29, 566-578.

Van Der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., ... & Barbaro, L. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. Nature communications, 7(1), 1-11.

van Koningsveld, M. & Slinger, J.H., (2015). Building with nature video #03 - The Building with Nature Philosophy @ TU Delft 2015. TU Delft. Dataset.

van Kreveld, A., Blom, E., Bösiger, R., Damm, C., Goll, B., Schlphohl, H., Leimgruber, B., Sluiter, H., Vertegaal, P., van Zadelhoff, E., Braakhekke, W., Litjens, G., Willems, D. & van Winden, A. (2013). A green Rhine corridor. Future proofing Western Europe's largest river for people, nature and the economy. Stroming BV: Nijmegen.

Van Oudenhoven, A. P., Aukes, E., Bontje, L. E., Vikolainen, V., Van Bodegom, P. M., & Slinger, J. H. (2018). 'Mind the Gap'between ecosystem services classification and strategic decision making. Ecosystem services, 33, 77-88.

van Oudenhoven, A. P., Petz, K., Alkemade, R., Hein, L., & de Groot, R. S. (2012). Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological Indicators, 21, 110-122.

van Slobbe, E., de Vriend, H. J., Aarninkhof, S., Lulofs, K., de Vries, M., & Dircke, P. (2013). Building with Nature: in search of resilient storm surge protection strategies. Natural hazards, 66(3), 1461-1480.

van Winden, A., Overmars, W., & Braakhekke, W. (2004). Storing Water Near the Source. Natural Water Storage in the Low Mountain Ranges in the Catchments of the Rhine and the Meuse. Abridged version. Stroming BV.

Verones, F., Saner, D., Pfister, S., Baisero, D., Rondinini, C., & Hellweg, S. (2013). Effects of consumptive water use on biodiversity in wetlands of international importance. Environmental science & technology, 47(21), 12248-12257.

Walsh, M. E., Daniel, G., Shapouri, H., & Slinsky, S. P. (2003). Bioenergy crop production in the United States: potential quantities, land use changes, and economic impacts on the agricultural sector. Environmental and Resource Economics, 24(4), 313-333.

Walton, C. R., Zak, D., Audet, J., Petersen, R. J., Lange, J., Oehmke, C., ... & Kotowski, W. (2020). Wetland buffer zones for nitrogen and phosphorus retention: Impacts of soil type, hydrology and vegetation. Science of The Total Environment, 138709.

Waterloo, M.J., Gevaert, A., Kersbergen, A., Hegnauer, M., Becker, B., de Roover, S.A.W. (2019). Wetland restoration impact on streamflow in the Rhine River Basin (Project No: 190957).

Weis, J. (2001): Naturschutzfachliche Erfolgskontrolle des Vertragsnaturschutzes am Beispiel der nördlichen Eifel.- Aachen, Shaker Verlag, 270 S.

Wetlands International (2020). Technical offer. Restoration of the sponge function in wetland soils of the Rhine Basin.

Wichmann, S. (2017). Commercial viability of paludiculture: a comparison of harvesting reeds for biogas production, direct combustion, and thatching. Ecological Engineering, 103, 497-505.

Wilcox, B. P., Breshears, D. D., & Turin, H. J. (2003). Hydraulic conductivity in a piñon-juniper woodland: Influence of vegetation. Soil Science Society of America Journal, 67(4), 1243-1249.

Wilken, R. D. (2006). The recovered Rhine and its history. In The Rhine (pp. 47-87). Springer, Berlin, Heidelberg.

Yang, S., Zhao, W., Liu, Y., Wang, S., Wang, J., & Zhai, R. (2018). Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China. Science of the total environment, 644, 556-566.

Yin, R. K. (Ed.). (2005). Introducing the world of education: A case study reader. Sage.

Yu, X., Mingju, E., Sun, M., Xue, Z., Lu, X., Jiang, M., & Zou, Y. (2018). Wetland recreational agriculture: Balancing wetland conservation and agro-development. Environmental Science & Policy, 87, 11-17.

Zedler, J. B. (2003). Wetlands at your service: reducing impacts of agriculture at the watershed scale. Frontiers in Ecology and the Environment, 1(2), 65-72.

Zemke, J. J. (2018). Anthropogenically altered runoff processes in a waterlogged headwater catchment within the National Park Hunsrück-Hochwald, Germany. Erde, 149(2–3), 102–116. https://doi.org/10.12854/erde-2018-373

Zemke, J.J. (no date). Effects of rewetting actions on stormflow runoff in drained headwater wetlands (poster). Koblenz: Institute for Integrated Natural Sciences, Department of Geography.

Zhang, D., Huang, Q., He, C., Yin, D., & Liu, Z. (2019). Planning urban landscape to maintain key ecosystem services in a rapidly urbanizing area: A scenario analysis in the Beijing-Tianjin-Hebei urban agglomeration, China. *Ecological Indicators*, *96*, 559-571.

Zheng, H., Li, Y., Robinson, B. E., Liu, G., Ma, D., Wang, F., ... & Daily, G. C. (2016). Using ecosystem service trade-offs to inform water conservation policies and management practices. Frontiers in Ecology and the Environment, 14(10), 527-532.

Zheng, H., Wang, L., & Wu, T. (2019). Coordinating ecosystem service trade-offs to achieve win–win outcomes: A review of the approaches. Journal of Environmental Sciences, 82, 103-112.

Ziter, C. (2016). The biodiversity–ecosystem service relationship in urban areas: a quantitative review. *Oikos*, *125*(6), 761-768.