DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D13.1: Quantified ESS for 3 mature sites including recommendations for application

Lead Author: Emschergenossenschaft, April 2016

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

D13.1: Quantified ESS for 3 mature sites including recommendations for application

SUMMARY

This Deliverable reports the results of the application of the ESS Evaluation Framework (D11.2) for the three DESSIN mature cases:
PART 1 – Aarhus case (lead author: DHI)
PART 2 – Emscher case (lead author: Emschergenossenschaft)
PART 3 – Llobregat case (lead author: Cetaqua)

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Table of contents

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Introduction

In WP13, the DESSIN ESS Evaluation Framework, developed in WP11, was applied to the three DESSIN mature cases in order to test its applicability. The aim was to quantify ESS, to assess changes in ESS provision, and to conduct a sustainability assessment in order to validate the ESS Evaluation Framework.

The three mature case studies are:
PART 1 – Aarhus case in Denmark
PART 2 – Emscher case in Germany
PART 3 – Llobregat case in Spain

The mature cases represent case studies where innovative solutions were already realized. Therefore, it is possible to compare the status before and after the solution was implemented. The case studies are distributed throughout Europe in order to cover a broad geographical range with diverse environmental conditions and social dimensions. Furthermore, the case studies offer an illustration of a wide variety of ecosystem service types targeted with restoration projects.

Each case was included for specific reasons and has a specific focus:

The innovative solution in the **Aarhus mature case** study is the real-time control of a full urban water cycle with sewers and wastewater treatment plants as well as recipient waters such as lakes, river, and a harbor. All these elements are combined into one model-based real-time decision support system (DSS). The aim of this real-time DSS system was to adapt Aarhus' water system to climate change related challenges and to raise the recreational potential in the city of Aarhus via an improvement of the water quality. Thus, this case has a special emphasis on water quality issues and recreational values.

The **Emscher site** applies the ESS Evaluation Framework to individual sections of the Emscher river network for the status before and after the large-scale Emscher restoration was realized. Subsequently, the results are transferred across the multi-site case study allowing a prognosis for the whole catchment. Service provision is, in the end, related to the costs of the restoration project for the river network as a whole.

The **Llobregat study** has a focus on the economic valuation of changes in ESS provision resulting from the implementation of infiltration ponds. These ponds were created in order to replenish the groundwater reserves and provide drinking and non-drinking water to the Barcelona area. The current and past status and the resulting benefits are assessed for individual beneficiaries.

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The application of the analytical evaluation framework consists of the following steps for each case:

- Selection of key ESS affected by the innovative solutions
- Identification of relevant indicators to measure changes in ecosystem status and service provision
- Quantification of the case-relevant ESS
- Valuation of the final ESS
- Assessment of the innovative solution with regard to sustainability aspects

A reflection of the applicability of the ESS methodology was formulated for each mature site throughout the validation process, going along with the development of the Framework. This provided practical recommendations for the improvement of the methodology during the developmental phase.

The recommendations are reported in the combined **Milestones 21 & 26**.

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D13.1: Quantified ESS for 3 mature sites including recommendations for application

Part 1: Aarhus case

Lead Author: DHI, April 2016

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D13.1: Quantified ESS for 3 mature sites including recommendations for application
PART 1 - Aarhus case

SUMMARY

This Deliverable reports the results of the application of the ESS Evaluation Framework (D11.2) for the Aarhus mature case.

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Table of contents

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List of tables

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List of figures

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List of Acronyms and Abbreviations

BOD	Biochemical Oxygen Demand
CICES	Common International Classification System for Ecosystem Services
ESS	Ecosystem Services
DPSIR	Drivers, Pressures, States, Impacts, Responses
CSO	Combined Sewer Overflow
FEGS	Final Ecosystem Goods and Services
USEPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant

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Executive summary

This report presents the application of the DESSIN ecosystem services (ESS) evaluation framework to the Aarhus mature case study location. The DESSIN sustainability assessment (SA) is also applied. The DESSIN ESS evaluation framework is used to evaluate how proposed technologies may enhance and/or complement ESS, which are defined as services provided by nature to humans. The DESSIN SA adds a holistic perspective to the ESS approach and encourages decision-makers to consider other perspectives when considering whether to implement new technologies.

The ESS evaluation framework is applied in a sequence of nine steps. In the first three steps (steps 0, 1, and 2), the study area is described and important drivers and pressures are identified. In the fourth and fifth steps (step 3 and 4), the proposed technology and its impacts are described, and relevant ESS are selected for detailed evaluation. Methodologies for detailed evaluation of impacts on ESS and human welfare are described in the next three steps (steps 5 through 7). The methodologies are applied in a before-after comparison in the final step (step 8).

In the Aarhus mature case, the technology that is evaluated is a system for control of combined sewer overflows (CSOs). The system includes CSO storage basins, additional treatment capacity at WWTPs, and automated control of a network of pumps, gates, and weirs in order to maximize beneficial use of CSO storage during storm events. The technology was implemented to improve water quality in the Aarhus River, an upstream lake (Lake Brabrand) and the Aarhus Harbour. Because the technology has already been implemented, the technology is evaluated from a retrospective perspective. This, indeed, is the purpose of including mature case studies in DESSIN: to test the framework on technologies where conditions before and after implementation are known.

Two ESS are selected for detailed evaluation. One is the natural degradation of pollutants as they flow through the lake and river. The other is the service provided by the river to individuals who visit the river area for recreational and leisure activities. For the second service, the impact of the CSO control project is evaluated together with a related project to open the Aarhus River channel in central Aarhus. It was found that both services have been enhanced significantly by the CSO control project and, in the case of the second service, the channel opening. The creation of a riverfront leisure area with reasonable water quality in central Aarhus has also resulted in significant positive impacts to human welfare.

The DESSIN SA application provides an opportunity to review the decision-making process that led to the implementation of the Aarhus CSO control project using a holistic perspective. It was found that the approach suggested by the DESSIN SA for the most part encompasses all of the factors that were considered in the Aarhus project and therefore serves as a useful template for decision-making about technology projects.

Introduction

The DESSIN project proceeds from the hypothesis that better understanding of the impact of technologies on ecosystem services (ESS) can contribute to uptake of innovative technologies that complement and/or enhance ESS. In other words, if we are aware of how technologies affect ESS, we may be more likely to develop and implement new technologies that enhance or complement ESS.

To test the DESSIN hypothesis, a framework has been developed for evaluating the impact of technologies on ESS. Because ESS are defined as benefits that humans receive from nature, the framework has been extended to evaluate how changes in ESS contribute to human welfare.

The DESSIN ESS framework is tested at three mature case study locations where innovative technologies that are thought to complement and/or enhance ESS have already been implemented. The three mature locations are used for testing because conditions are known both before and after implementation, so that a before/after comparison can be made. One of the three mature case location is Aarhus, Denmark.

The Aarhus case study technology is a system for control of combined sewer overflows (CSOs) to the Aarhus River, an upstream lake (Lake Brabrand), and the Aarhus Harbour. The system includes additional storage for CSOs; additional sewerage infrastructure to transport storm- and wastewater from CSO storage locations to wastewater treatment plants (WWTPs); additional hydraulic capacity at WWTPs; additional disinfection capacity at WWTPs; and an automated system for real-time control of CSO storage to maximize the beneficial use of storage during storm events. The Aarhus technology is thought to be innovative because of the real-time control element, which reduced the need for constructing additional CSO storage through coordinated operation of the storage that was actually built.

Implementation of the Aarhus case study technology has enhanced ESS by improving water quality in the Aarhus River, Lake Brabrand, and the Aarhus Harbour. These improvements have contributed to making new areas suitable for leisure and recreation activities. The Aarhus technology has also enhanced the capacity of the Aarhus River and Lake Brabrand to degrade bacterial and organic pollution, although this was not a consideration in the design.

The DESSIN ESS framework is tested by evaluating ESS impacted by the Aarhus case study technology in a before-after comparison. Because of resource constraints, the testing is limited to the Aarhus River, even though the project also had impacts on Lake Brabrand and the Aarhus Harbor. When evaluating impacts on human welfare, the technology is considered together with another project to open the Aarhus River in central Aarhus (which had previously been routed underground); because the one of the main goals of the project was to improve aesthetic conditions in the newly opened river, it is difficult to separate the welfare impacts of the two projects.

The Aarhus case study concludes with an application of the DESSIN sustainability assessment, which applies a holistic perspective to evaluating the impacts of proposed technologies.

PART I – Study description

Step 0: Setting the scene

Administrative details

The application and testing of the DESSIN ESS evaluation framework and sustainability assessment at the Aarhus mature site is carried out by DHI. DHI is an independent research and consultancy organization located in Hørsholm, Denmark, and a partner in DESSIN. DHI were a partner in the implementation of significant components of the Aarhus mature case, together with Aarhus Water and Krüger A/S. Aarhus Water are the utility responsible for water, wastewater, and stormwater in the municipality of Aarhus. Krüger are a Danish consulting firm.

Data to support the application and testing of the ESS framework and sustainability assessment are provided by Aarhus Water. Aarhus Water is a private company that is wholly owned by the municipality of Aarhus, and had responsibility for implementing the project components that make up the Aarhus mature case. At the time that the components that make up the Aarhus mature case were conceived, Aarhus Water was a department of the municipality of Aarhus. However, during the course of implementation, the utility was privatized. Aarhus Water are not a partner in DESSIN, and their support of the implementation and testing of the Aarhus mature case is gratefully acknowledged.

Funding for the application and testing of the DESSIN ESS evaluation framework is provided by the European Commission through the 7th framework program for research and innovation, which funds the DESSIN project.

Objectives of the assessment

The Aarhus mature case assessment is carried out with the aim of (i) testing the proposed ESS Evaluation Framework and (ii) testing the DESSIN sustainability assessment.

The hypothesis of the DESSIN project is that better understanding of benefits of ecosystem services can stimulate innovation in technologies that complement these services. As part of this, a framework has been developed for measuring changes in ESS and associated values, with a focus on changes in ESS brought about by the introduction of new technologies. This framework has been tested and refined by applying it at three so-called "mature" sites, where technology projects thought to have had impacts on ESS have recently been implemented. Aarhus is one of the mature sites, along with other sites located in the Emscher River basin in Germany and the Llobregat River basin in Spain. Feedback from Aarhus and the other mature sites is used to refine the DESSIN ESS framework in order to increase the likelihood that it will be useful for estimating the impact of new technologies on ESS.

The DESSIN project also includes a sustainability assessment component that is intended to provide a "holistic" assessment of new technologies, so that other impacts associated with the implementation of these technologies can be assessed together with ESS impacts. The DESSIN sustainability assessment is also tested on the Aarhus mature case.

The intended audience of the mature case assessment consists of researchers and practitioners interested in the ESS approach and how it can be used to support the assessment of proposed technology projects. Increased use of the ESS approach has the potential to increase understanding of the benefits of technologies that enhance or complement ecosystem services. Researchers may be interested in methodological and normative issues related to application of the ESS approach to technologies. Practitioners may be interested in learning more about how the ESS approach can be used to understand the impacts of proposed technology projects.

Overview of the study area

The study area consists of Lake Brabrand and the portion of the Aarhus River running from Lake Brabrand to the Aarhus harbor. The entire study area is located within the municipality of Aarhus, Denmark. The location of Aarhus is shown in Figure 1.

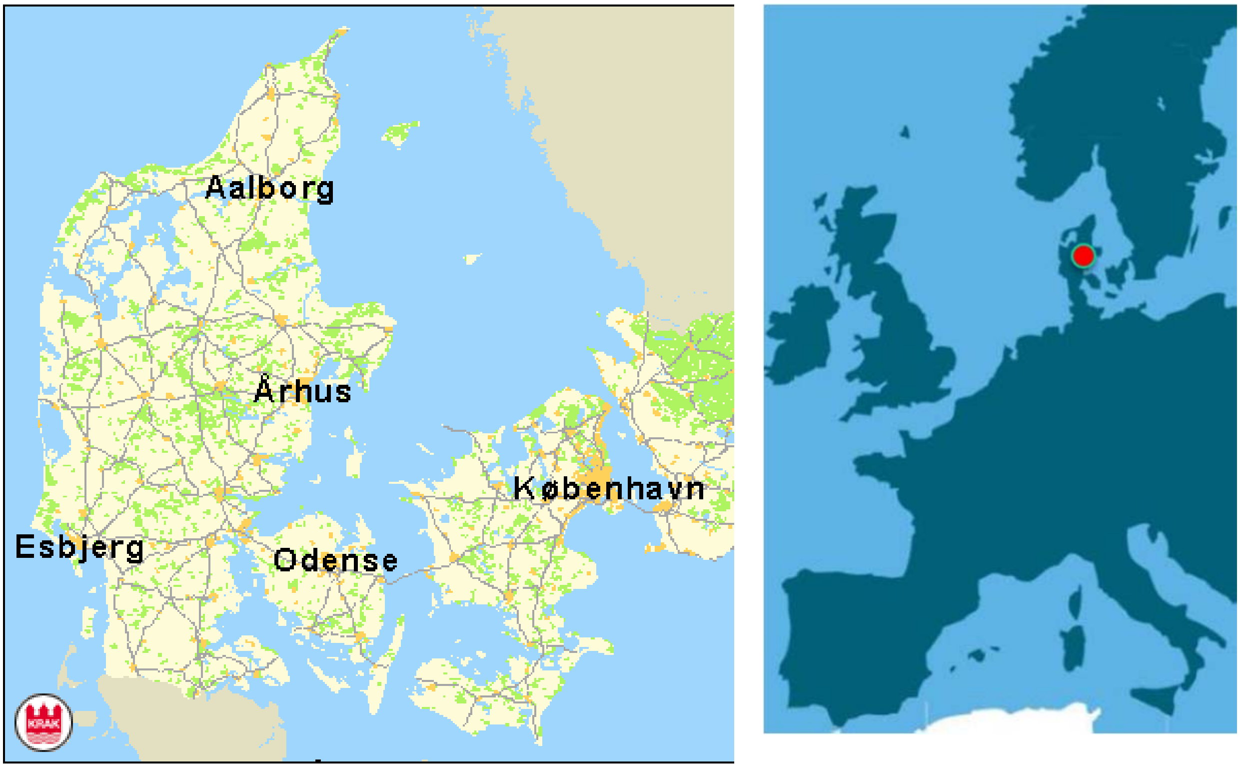

Figure 1 Location of Aarhus in Denmark and in Europe

Aarhus is a harbor city situated on the bay of Aarhus. The city occupies a flat coastal region surrounded by low hills. Aarhus has a humid continental climate characterized by large seasonal temperature differences, with precipitation well-distributed throughout the year. Intense precipitation and flooding are more likely to occur during the summer because of convective activity (i.e., thunderstorms).

The city of Aarhus is the second-largest city in Denmark and the largest in Jutland, or mainland Denmark. The population is approximately 300,000, with about 1.2 million inhabitants residing in the greater Aarhus region. The city is located on the east coast of Jutland and is the largest port in the country, handling 50% of Denmark's container traffic.

The economy of Aarhus has historically been based on food-processing industries serving Denmark's agriculture sector. However, the city is transitioning to become a centre for research and development, as well as a manufacturing centre for clean energy technologies. The University of Aarhus is Denmark's largest by student enrolment and major centre for research. Over the past 30 years, the city has developed a large research park for the incubation of start-up companies in applied science and technology sectors. A number of manufacturers of clean energy technologies are based in Aarhus, including the wind turbine manufacturer Vestas.

Employment in the municipality is distributed among economic sectors as follows:

- Services: 57%
- Trade: 24%
- Manufacturing: 17%
- Other: 2%

The largest age group is 20- to 29-year-olds and the average age is 37.5.

The most important landscape elements in the city are the coastal beaches and surrounding forests, both of which are widely used for recreational and experiential activities. Popular outdoor recreation activities include walking, hiking, cycling and outdoor team sports. Large events such as running are orienteering races are held throughout the year. Watersports like sailing, kayaking, and motor boating are also popular. One of the forest areas includes a large historical landscape of pastures and woodlands, presenting different eras of Denmark's prehistory, from the Stone Age to medieval times.

The Aarhus River is 40 km long and drains a basin of 324 km² on the eastern coast of Jutland, or mainland Denmark. The river originates 54 m above sea level, passes through a number of lakes, including Lake Brabrand, and then travels through the city of Aarhus and exits into Aarhus Harbour. A map showing Lake Brabrand, the Aarhus River, and the Aarhus harbour is presented in Figure 2.

The lake, river, and harbor are all important locations for recreation. Although the projects that are the subject of the Aarhus case were motivated by the desire to improve the aesthetics of the lake, river, and harbour, the analysis here is limited to the lake and river. This is because the complexity of simulating water quality elements in the Aarhus harbour would have required work inputs that would have exceeded resources available for the mature case assessment.

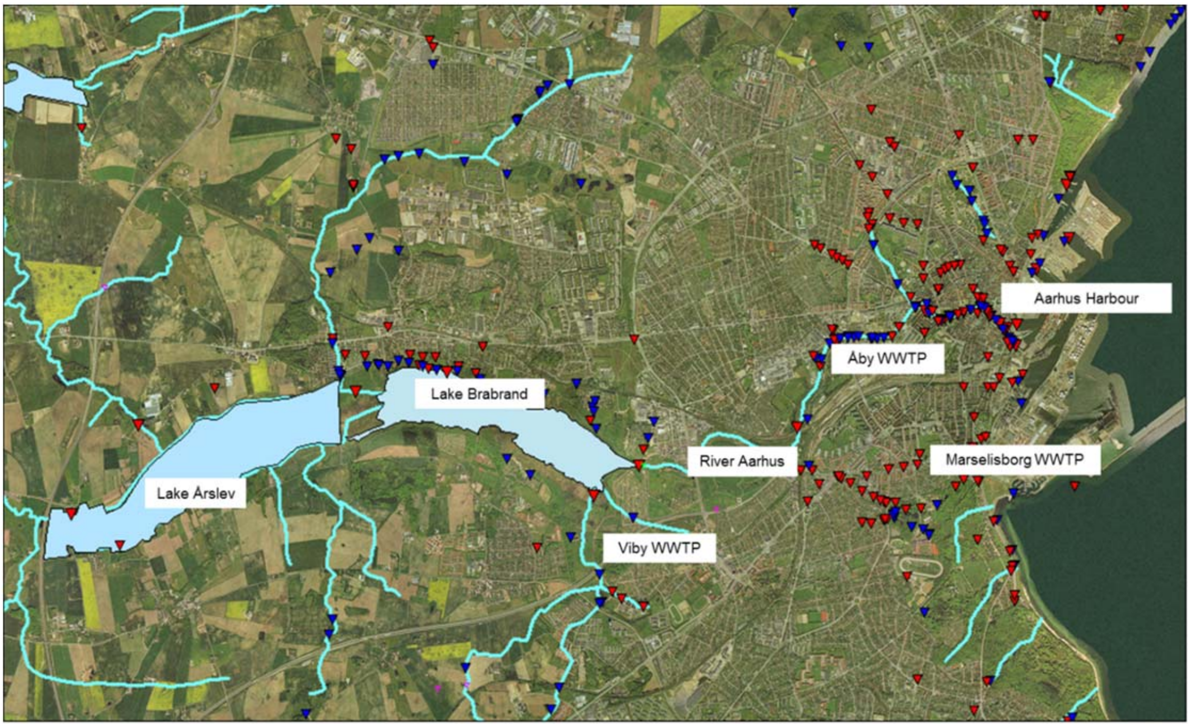

Figure 2 Lake Brabrand, the Aarhus River, and the Aarhus harbor

Stakeholder list

The Aarhus mature case assessment investigates the impact on ESS of projects aimed at improving the aesthetics of Lake Brabrand and the Aarhus River. Stakeholders in these projects include:

- People living in the area.
- The municipal water utility (Aarhus Water).
- businesses serving recreational and experiential users of the lake and river, including:
    - Businesses renting kayaks and other boats.
    - Cafés, restaurants, and bars located along the river.

PART II – Problem characterization

Step 1: Identify drivers

The DESSIN ESS evaluation framework uses a modified version of the DPSIR framework (EEA, 1999) for analysis of environmental impacts and responses. The first step in the application of this framework is to identify the underlying drivers that contribute to the environmental pressures for which technical solutions are being considered. Drivers are defined as human activities that may produce environmental impacts, such as agriculture or industry.

In the Aarhus case, the relevant driver is urban development. The development of the port of Aarhus, along with the increasing use of motor vehicles (i.e., trucks) for transport to and from the port led the covering of the Aarhus River in the 1930s so that the river channel pathway could be used as a road through the city to the port. Expansion of the city to the west along the Aarhus River and later Lake Brabrand led to the use of the lake and river as locations for disposal of stormwater, treated wastewater, and overflows from combined sewers.

Step 2: Identify pressures

The second step in the application of the DESSIN framework is to identify the pressures resulting from the underlying drivers. Pressures are defined as the environmental impacts of drivers. In the Aarhus mature case assessment, three types of pressures are relevant. These include diffuse-source pressures, point-source pressures, and hydromorphological alterations.

Diffuse-source pressures result from pollution that might be caused by various activities and cannot be traced to a single source. Diffuse-source pollution reaches water bodies through hydrologically driven pathways such as surface runoff, soil erosion or leaching. In Aarhus, development in the city has led to the need for a storm sewer network, part of which discharges to the Aarhus River. Pollution resulting from discharges to the river from the storm sewer network is considered a diffuse pressure.

Point-source pressures can be traced to a single, identifiable source, such as a wastewater treatment plant (WWTP). In Aarhus, wastewater is transported through the sewer network to WWTPs, after which the treated effluent is released into natural waterways. Two of the WWTPS, Viby and Aaby, are located on the Aarhus River between Lake Brabrand and the harbour. The locations of the treatment plants can be seen in Figure 2.

In some areas of the city, the same sewer network (a so-called “combined” sewer) carries both sewage and stormwater. Ordinarily, these flows are routed to a WWTP for treatment. However, during intense storm events, the hydraulic capacity of the combined sewer network may be exceeded, requiring overflow points to be built into the network, which discharge a mixture of stormwater and raw sewage. In 2006, more than 70 combined-sewer overflow locations, or CSOs, were present in Aarhus, many of which discharged to the Aarhus River. These CSOs are another type of diffuse pressure.

Hydromorphological alternations exist when the flow characteristics of a water body are substantially changed, including physical alterations of the riverbed, riparian areas, or shorelines. The enclosure of the Aarhus River in the city centre was a significant hydromorphological alteration. A roadway was built over the former river channel and the river was routed through an underground culvert. Figure 3 compares the river channel as it existed before to the current channel.

Figure 3 Aarhus River before (left) and after (right) restoration

PART III – Description of responses & identification of potential beneficiaries

Step 3: Describe the measure and its capabilities

3.1. Description of the measure

The technical measure that is evaluated in the Aarhus mature case study is a real-time control system for the operation of CSO basins and WWTPs located along Lake Brabrand and the Aarhus River. It is a technical measure that operates on pressures.

The real-time control system coordinates storage in CSO basins and WWTP capacity in order to reduce the frequency of CSO events and maximise the beneficial use of CSO storage. The real-time control system was built in combination with increased CSO storage (Figure 4) and increased hydraulic capacity at the two WWTPs that discharge into the Aarhus River. Additional disinfection capacity was also installed at the WWTPs. The real-time control system includes a short-term rainfall forecasting system that is used to help predict the locations of loads to the combined sewer system so that storage can be made available where it is most likely to be needed.

Figure 4 Interior of new CSO storage facility

Approximately 67,000 m^3 of new storage was built along with the real-time control system.

3.2. Claimed/expected capabilities of the proposed measure

The motivation for the real-time control project was to improve water quality in Lake Brabrand, the Aarhus River, and in the Aarhus harbour. The reasons for investing in improved water quality are different for each area.

- **Lake Brabrand:** Lake Brabrand is used for recreational boating and its shoreline is a popular location for recreational activities such as walking and cycling. At the time that the project was proposed, water quality in Lake Brabrand was satisfactory and there were no restrictions on boating in the lake. However, the lake was a receiving water for CSOs, resulting in aesthetic conditions that were frequently unacceptable. In addition, water quality in the lake did not meet requirements for bathing. The motivation of the project with respect to Lake Brabrand was to improve aesthetic conditions in the lake and increase the water quality to a level suitable for bathing.
- **Aarhus River:** Between Lake Brabrand and central Aarhus, the shoreline of the Aarhus River is a popular location for recreational activities such as running and cycling. At the time the project was conceived, the water quality in the river was not suitable for either bathing or for boating. In addition, aesthetic conditions were frequently unacceptable because of CSO discharges. In central Aarhus, most of the river was still covered. A small portion of the Aarhus River in central Aarhus was uncovered in the late 1990s; however, aesthetic conditions in this reach were also frequently unacceptable. The motivation of the project with respect to the Aarhus River was to improve aesthetic conditions and to increase the water quality to a level suitable for boating (but not for bathing).
- **Aarhus Harbour:** The older harbour areas of Aarhus are no longer used for commercial purposes and are being redeveloped for housing and recreation. At the time that the project was conceived, the water quality in the harbour was not suitable for boating or bathing. In addition, aesthetic conditions were frequently unacceptable because of CSO discharges to harbour. As part of its redevelopment plans for the harbour, the city of Aarhus would like to develop areas suitable for bathing and boating. Therefore, the motivation for the project with respect to the Aarhus Harbour was to improve aesthetic conditions and improve water quality to a level suitable for boating and bathing.

In this application of the DESSIN ESS framework, the analysis is limited to effects on Lake Brabrand and the Aarhus River. The quantification of state and impact indicators for the harbour would have required the use of complex hydrodynamic and water quality models, with work inputs exceeding resources available for the Aarhus mature case study. Therefore, the mature case is limited to the lake and river areas.

The impact of the project on human welfare is evaluated together with the project that opened the river in central Aarhus. Although a portion of the Aarhus River was opened almost a decade before the real-time control project was implemented, the majority of the river opening took place in conjunction with the project. In addition, aesthetic conditions in the Aarhus River were such that it was thought that additional work to open the river would be difficult to justify without accompanying water quality improvements. Finally, as will be discussed later, it is difficult to separate the impact of improved water quality on human welfare from the impact of restoring the river. Therefore, the welfare impact of project is evaluated together with re-opening of the river.

3.3. Drivers, Pressures, and/or States Based affected by the capabilities

The real-time control project affects pressures, with resulting impacts on ecosystem states. The opening of the river also affects pressures and resulting ecosystem states. Neither project has direct impacts on drivers.

The following pressures were impacted by the real-time control project and associated infrastructure:

- The real-time control project, together with additional CSO storage and hydraulic capacity at WWTPs, has reduced the frequency and magnitude of CSO events. This has reduced inflows of bacterial contaminants and organic pollution to the river.

- The addition of disinfection capacity installed at WWTPs has reduced inflows of bacterial contaminants to the river.

The re-opening of the river affected the following pressure:

- The re-opening of the river reduced morphological pressures on the river by allowing the river to flow through an open, exposed channel.

The following aspects of the ecosystem state were impacted by the real-time control project and associated infrastructure:

- **Quantity and dynamics of river flow:** The quantity and dynamics of river flow were altered because of the reduction in the frequency of overflow events.
- **Water residence time:** Water residence time increased as result of a decrease in high-flow overflow events that temporarily increase flow rates and reduce travel times.
- **Oxygenation conditions:** Oxygenation conditions changed because of reduced BOD loading to the river.
- **Pollution by other substances (i.e., pollutants that are not EU priority pollutants):** Bacterial pollution decreased as result of reduced loads from CSOs and WWTPs.
- **Probability of water-borne illness from partial body contact and full body contact with river and lake:** The probability of water-borne illness from body contact with the river and lake decreased because of reduced bacterial loads.
- **Presence and description of odor of human origin:** Odors of human origin decreased as result of reduced organic pollution.

The opening of the river in central Aarhus affects the following aspects of the ecosystem state:

- **Depth and width variation:** The opening of the river had a small impact on depth variation due to the conversion from a culvert to an open channel. Width variation was not affected because the restored channel section has a mostly uniform width.
- **Structure of the water body shoreline:** The structure of the water body shoreline was altered when an underground pipe was replaced by an open channel.
- **Oxygenation conditions:** Oxygenation conditions in the river in central Aarhus were altered through increased transport of oxygen across the newly exposed water surface.
- **Pollution by other substances:** Bacterial pollution was reduced slightly through increased degradation as result of exposure to sunlight.
- **Probability of water-borne illness from partial body contact and full body contact with river:** The risk of water-borne illness may have increased because of increased potential for human contact with water after the river was opened.
- **Presence and description of odor of human origin:** Exposure to odor of human origin increased after the river channel surface was exposed.
- **Description of infrastructure to the channel visually impeding otherwise “natural” viewscapes such as bank protection, powerline pole placement, and bridges:** After the river channel in central Aarhus was exposed, the banks were lined with structural bank protection walls (Figure 5).
- **Description of infrastructure on the bank visually impeding otherwise “natural” viewscapes such as railings or buildings:** Riverbanks were lined with railings to minimize the risk of body contact with the water and accidents (Figure 5).

- **Presence of picnic tables, bathrooms, drinking water, and shade structures:** A number of concrete benches and steps were built to facilitate enjoyment of the river area (Figure 5).
- **Increased utilization for recreation (when this is perceived positively):** An increasing number of people have visited the river for recreational and leisure activities, which may be perceived positively.
- **Overuse (when increased utilization is perceived negatively):** Some could also perceive the increased number of visitors to the river area negatively if the number of users leads to crowding that reduces enjoyment of the river area.

Figure 5 Concrete steps and benches built to facilitate enjoyment of the river area in central Aarhus

Although not provided by ecosystems, these features are perceived to enhance enjoyment of the river. Structural bank protection walls and hand railings are also visible in the background—these features are thought to detract from enjoyment of the river environment. The number of users present in the photo could be perceived positively or negatively, depending on the perspective of the user.

3.4. Case-relevant ESS

In the DESSIN framework, the identification of case-relevant ESS proceeds from the impacts on states identified in the previous step. Briefly, the process is as follows:

1. State impacts are used to identify a list of potential ESS that may be affected by the project. The potential ESS are selected from a list taken from the Common International Classification System for ESS (CICES) (Haines-Young and Potschin, 2013).

2. For each of the ESS identified in step 1, an effort is made to identify a beneficiary. In this step, the US Environmental Protection Agency (USEPA) Final Ecosystem Goods and Services (FEGS) concept (Landers and Nahlik, 2013) is used to help identify links between services and beneficiaries. ESS with beneficiaries are called "final" ESS while ESS without direct beneficiaries are called "intermediate" services. Intermediate services may still be of interest, either because these services contribute to final services, or because they contribute to better understanding of ecosystem processes and functions.

3. For each of the final ESS identified in step 2, the identified beneficiary is compared to the list of stakeholders in the case study area. The final ESS with beneficiaries among the stakeholders are the "case-relevant" ESS. Intermediate ESS may also be included among the case-relevant ESS if these contribute to final ESS or contribute to understanding ecological processes and functions in the case study area.

Following the steps outlined above, we begin by linking states affected by the proposed measure to ecosystem services defined under the CICES classification system. For each service, the CICES "class" is provided in parentheses.

- **Hydrological cycle and water flow maintenance (regulatory and maintenance service):** Ecosystems provide surface water flows through the functions that make up the hydrological cycle. The natural hydrological cycle in Lake Brabrand and Aarhus River has been disrupted by human modifications, including stormwater discharge locations, CSOs, and WWTP discharges. Changes to the state parameters **quantity and dynamics of water flow** and **water residence time** have had impacts on this service, although the impact is not likely to be significant.

- **Dilution by atmosphere, freshwater and marine ecosystems (regulatory and maintenance service):** Ecosystems can dilute polluting loads to either the atmosphere or the water environment if sufficient diluting capacity exists. The Aarhus River and Lake Brabrand, by acting as receiving waters for CSOs and WWTP discharges, provide a dilution service. Changes to the state parameters **quantity and dynamics of water flow** and **oxygenation conditions** have had impacts on this service.

- **Maintaining nursery populations and habitats (regulatory and maintenance service):** Ecosystems provide conditions to support reproduction of species. The Aarhus River and Lake Brabrand both provide this service to a number of plant and animal species. Changes to the state parameters **depth and width variation, structure of the water body shoreline, oxygenation conditions,** and **pollution by other substances** have had impacts on this service.

- **Bio-remediation by microorganisms, algae, plants, and animals (regulatory and maintenance service):** Microorganisms, algae, plants, and animals can degrade pollutants in natural water through the action of physiological processes. Bio-remediation takes place in both Lake Brabrand and the Aarhus River. Changes to the state parameters **water residence time, oxygenation conditions,** and **pollution by other substances** have had impacts on this service.

- **Filtration/ sequestration/ storage/ accumulation by microorganisms, algae, plants, and animals (regulatory and maintenance service):** Microorganisms, algae, plants, and animals can also remove pollutant from natural waters through bioaccumulation and other processes. These pollutant removal processes take place in both Lake Brabrand and the Aarhus River. Changes to the state parameters **water residence time, oxygenation conditions,** and **pollution by other substances** have had impacts on this service.

- **Filtration/ sequestration/ storage/ accumulation by ecosystems (regulatory and maintenance service):** Abiotic components of ecosystems can also remove pollutants from natural waters, for example, sunlight can degrade bacteria. Abiotic processes are active in Lake Brabrand and the Aarhus River. Changes to the state parameters **water residence time, oxygenation conditions, depth and width variation, structure of the water body shoreline,** and **pollution by other substances** have had impacts on this service.

- **Experiential use of plants, animals and land-/seascapes in different environmental settings (cultural service):** Experiential use of ecosystems take place when individuals visit natural areas in order to enjoy sensory experiences provided by ecosystem elements. This ESS is provided when individuals visit the restored river area to enjoy the restored river. Changes to the state parameters **percentage of days of surface water per year**; **presence and description of odour of human origin; description of infrastructure to the channel visually impeding otherwise "natural" viewscapes such as bank protection, powerline pole placement, and bridges; description of infrastructure on the bank visually impeding otherwise "natural" viewscapes such as railings or buildings; presence of picnic tables, bathrooms, drinking water, and shade structures; increased utilization for recreation (when this is perceived positively);** and **overuse (when increased utilization is perceived negatively)** have had impacts on this service.

- **Physical use of land-/seascapes in different environmental settings (cultural service):** Physical use of ecosystems take place when individuals visit natural areas in order to engage in recreational activities. This ESS is provided when individuals engage in running or cycling along the shoreline of Lake Brabrand, or along the Aarhus River. Changes to the state parameters **percentage of days of surface water per year, probability of water-borne illness from partial body contact and full body contact with river, presence and description of odour of human origin, increased utilization for recreation (when this is perceived positively),** and **overuse (when increased utilization is perceived negatively)** have had impacts on this service.

- **Existence values (cultural service):** The existence ESS exists when individuals obtain utility from knowing that aspects of an ecosystem exist, even if they do not experience these aspects directly. Existence values may exist if there are individuals who care about the Lake Brabrand/Aarhus River ecosystem, even if they do not travel to the lake or river to engage in experiential or recreational activities. It is difficult to make conclusions about which state parameters have had impacts on this service. If there were significant numbers of individuals who derive utility from the condition of the Lake Brabrand/Aarhus River ecosystem, it would be necessary to survey these individuals to identify which aspects of the ecosystem are important to them. It is possible that all of the state parameters affected by the projects could be important.

- **Bequest values (cultural service):** The bequest ESS exists when individuals obtain utility from knowing that aspects of an ecosystem will be preserved for use by future generations. Bequest values may exist if there are individuals who care about preserving the Lake Brabrand/Aarhus

River ecosystem for the benefit of future generations. It is difficult to make conclusions about which state parameters have had impacts on this service. If there were significant numbers of individuals who derive utility from maintaining the condition of the Lake Brabrand/Aarhus River ecosystem for future generations, it would be necessary to survey these individuals to identify which aspects of the ecosystem are important to them. It is possible that all of the state parameters affected by the projects could be important.

Step 4: Identification of expected beneficiaries of the changes introduced by the proposed measure

In this step, the "case-relevant" ESS are compared to potential beneficiaries and final subset of "case-relevant" ESS are selected for detailed evaluation.

Most of the services that are considered "regulatory and maintenance" services under the CICES classification system do not have direct beneficiaries. Although these services may contribute to cultural ecosystem that benefit humans, humans do not derive utility directly from them. Therefore, all but one of the regulatory and maintenance services have been classified as "intermediate" ESS.

The following regulatory and maintenance service has a direct beneficiary and is a "final" ESS:

- **Hydrological cycle and water flow maintenance**: This service benefits wastewater treatment plant operators by providing a medium for discharging treated municipal wastewater into the environment.

On the other hand, beneficiaries can be identified for all of the cultural services affected by the Aarhus projects. Relevant beneficiaries have been identified for each of the cultural services. The beneficiary types listed in bold are taken from the USEPA FEGS classification system.

- **Experiential use of plants, animals and land-/seascapes in different environmental settings (cultural service):** The experiential use service benefits **experiencers and viewers** who visit the riverfront environment to enjoy sensory experiences and **resource-dependent businesses** who provide services to experiencers and viewers such as outdoor cafés and restaurants located along the restored river section.

- **Physical use of land-/seascapes in different environmental settings (cultural service):** The experiential use service benefits **experiencers and viewers** who engage in recreation activities that do not involve contact with the water (e.g., running), **boaters** (e.g., kayakers), and **resource-dependent businesses** who provide services to boaters such as kayak rental companies.

- **Existence values (cultural service):** The existence ESS benefits **people who care**.

- **Bequest values (cultural service):** The bequest ESS benefits **people who care**.

The final step in the process of identifying "case-relevant" ESS is to link the beneficiaries identified in step 3 to stakeholders in the case study area.

All of the final services present in the Aarhus mature case have stakeholders in the area. Therefore, all of the services can be considered case-relevant. However, resource considerations did not allow for evaluation of all of these services. Instead, the Aarhus mature case focuses one representative final service. A representative intermediate service is quantified as well so that readers of the DESSIN deliverables can better understand differences between how the two service types are evaluated.

The final service that is selected for evaluation is the **experiential use of plants, animals and land-/seascapes in different environmental settings** service that benefits **experiencers and viewers** who visit the restored river area in central Aarhus (**resource-dependent businesses** also benefit). This service is selected for detailed evaluation because more data are available to perform the evaluation and because the benefits of providing this service are easier to detect relative to the situation before the opening of the river and the accompanying water quality improvements.

Three intermediate services are selected for evaluation: **bio-remediation by microorganisms, algae, plants, and animals; filtration/ sequestration/ storage/ accumulation by microorganisms, algae, plants, and animals;** and **filtration/ sequestration/ storage/ accumulation by ecosystems**. All three of these services are associated with processes that degrade pollutants in natural waters. Because of difficulties with separating the relative contribution of each service, the three services are evaluated together as a single "degradation" service.

The three degradation services contribute to downstream cultural services by making improvements to water quality. However, natural degradation in Lake Brabrand and the Aarhus River was not a consideration in the design of the real-time control system and associated infrastructure. In other words, the water quality improvements that facilitate cultural services have been achieved through technology and infrastructure rather than by regulatory ecosystem services (i.e., it is the real-time control system that has improved water quality in the river, not increased degradation in the river itself). None the less, it is of scientific interest to investigate whether the deployment of water-quality control technology has been accompanied by improvements in the capacity of the lake/river ecosystem to degrade pollution.

Intermediate ESS # 1: Degradation of pollution by microorganisms, algae, plants, animals, and other ecosystem components

This section describes how changes in the degradation ESS are estimated. The degradation ESS is measured with respect to the degradation of three pollutants: E.Coli, Enterococci, and biochemical oxygen demand (BOD).

STATE

Step 5: Identify the parameters that dictate the condition of the system under study and that would be affected by the proposed measure

The following state parameters are related the degradation ESS and affected by the two measures considered in the Aarhus control system (the real-time control system and associated infrastructure; and the opening of the river):

- **Oxygenation conditions:** Oxygenation conditions affect the rate of BOD degradation.
- **Pollution by other substances:** Concentrations of E.Coli, Enterococci, and BOD all affect the rates at which these substances are degraded.
- **Percentage of days of surface water per year:** The presence of surface water affects the degradation of E.Coli and Enterococci, both are which degrade more quickly in the presence of sunlight.

With exception of the last parameter, values of the state parameters are estimated using a simulation model of Lake Brabrand and the Aarhus River. The model simulates water flows along with pollutant fate and transport. Water flows and the advection and dispersion of pollutants are simulated using the software package MIKE 11. Dissolved oxygen, BOD, E.Coli, and Enterococci are simulated using the software package ECOLAB, which is an add-on to MIKE 11 that can be used for water quality modelling. It is necessary to use a simulation model to estimate state parameter values because direct measurements are not available. A schematic of the MIKE 11/ECOLAB model is presented in Figure 6.

Two different ECOLAB models are used to represent water quality. One model represents degradation of E.Coli and Enterococci, while the other represents simulates dissolved oxygen and BOD.

In the E.Coli/Enterococci model, E.Coli degrades according the following equation:

$$(K_m + K_1 * I_{av}) * \frac{EColi^2}{EColi + 10}$$

Where:

K_m = background decay rate

K_1 = decay rate in the presence of light

I_{av} = vertical average light distribution

$EColi$ = E.Coli concentration (cfu/100mL)

Enterococci degrades according the following equation:

$$\left(K_{fEntm} * K_m + K_{fEntd} * K_1 * I_{av}\right) * \frac{Ent^2}{Ent + 1}$$

Where:

K_{fEntm} = background decay rate for Enterococci relative to background decay rate for E.Coli

K_{FEntd} = decay rate for Enterococci in the presence of light relative to E.Coli decay rate

Ent = Enterococci concentration (cfu/100mL)

The decay constants for E.Coli and Enterococci are affected by forcings including temperature, salinity, solar radiation, light penetration, and water depth.

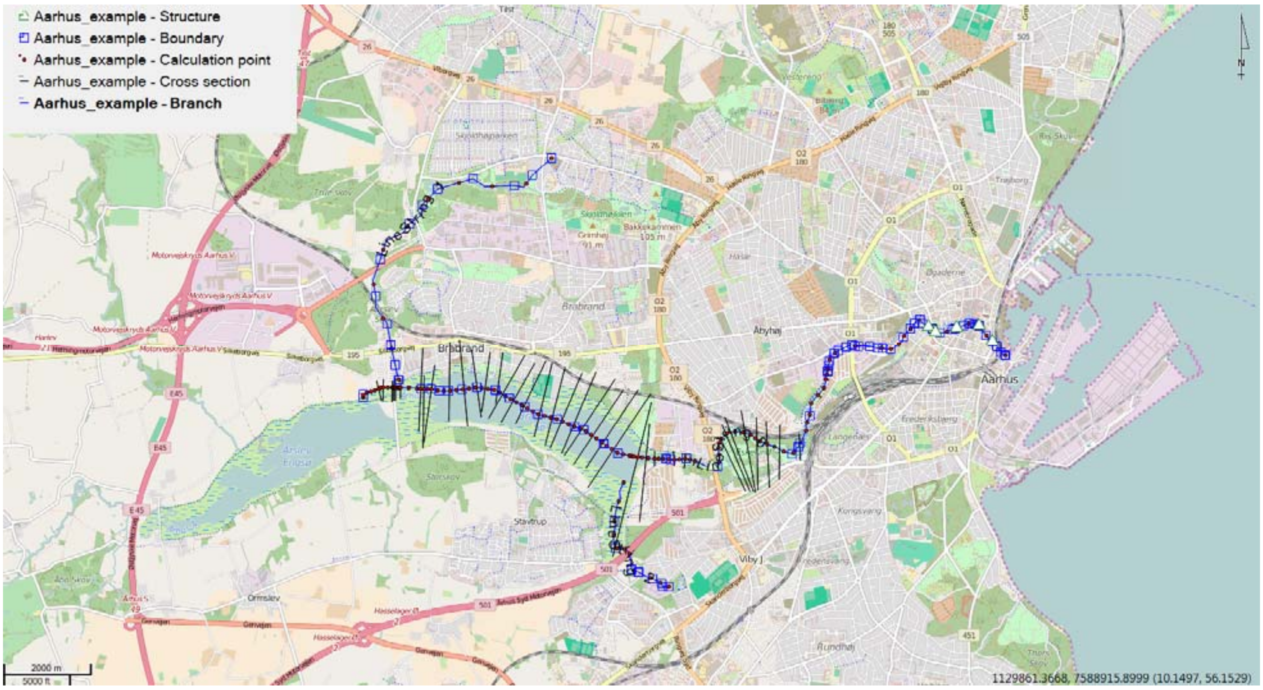

Figure 6 Schematic of MIKE 11/ECOLAB representation of Lake Brabrand and the Aarhus River

In the dissolved oxygen/BOD model, BOD degrades according to the following equation:

$$kd_3 * tetad3^{temp-20} * BOD * \frac{DO}{DO + hdobod}$$

Where:

kd_3 = 1st order decay rate at 20 deg. Celsius

$tetad3$ = Temperature coefficient for decay rate

$temp$ = Temperature in degrees Celsius

BOD = BOD concentration (mg/L)

DO = Dissolved oxygen concentration (mg/L)

$hdobod =$ Half-saturation oxygen concentration

Dissolved oxygen is simulated as a balance of the following:

$DO = reaera + phtsyn - respT - bodd - sod$

Where:

$reaera =$ Reaeration

$phtsyn =$ Photosynthesis in water column

$respT =$ Oxygen consumption from respiration of phytoplankton

$bodd =$ BOD decay rate

$sod =$ Sediment oxygen demand

BOD degradation and the oxygen balance are affected by forcings including temperature, salinity, water depth, horizontal current speed, and light penetration.

Boundary conditions for the MIKE 11/ECOLAB model include timeseries of inflows and pollutant concentrations. Inflows to the catchment area upstream of Lake Brabrand are estimated using a rainfall-runoff model. Inflows from stormwater discharge locations, CSOs, and WWTP outfalls are estimated using a simulation model of the sewer network for the city of Aarhus. A final boundary condition for the model is the water level in the Aarhus harbor.

IMPACT I - PROVISION

Step 6: Select indicators for relating state parameters to ESS.

The indicator that is used to measure the degradation service is the percent removal of each pollutant. This indicator is estimated from outputs from the MIKE 11/ECOLAB model using the following equation:

$$degradation = \frac{inflow - outflow}{inflow} * 100$$

Where:

$degradation =$ degradation indicator (%)

$inflow =$ total mass entering lake/river system (either kg for BOD or cfu for E.Coli/Enterococci)

$outflow =$ total mass reaching Aarhus harbor (either kg for BOD or cfu for E.Coli/Enterococci)

The total mass inflow is estimated as follows:

$$inflow = \sum_{t=1}^{T} \left[\sum_{i=1}^{N} q_{it} * c_{it} + \sum_{j=1}^{M} q_{it} * c_{jt} + \sum_{k=1}^{O} q_{kt} * c_{kt} \right]$$

Where:

$t =$ time index

$i =$ stormwater discharge location index

$j =$ CSO location index

k = WWTP effluent discharge location index

T = Number of time steps

N = Number of stormwater discharge locations

M = Number of CSO locations

O = Number of WWTP effluent discharge locations

q = flow rate (m^3/s)

c = concentration (either cfu/100mL or mg/L)

The total mass outflow is estimated as follows:

$$outflow = \sum_{t=1}^{T} qout_t * cout_t$$

Where:

$qout$ = flow rate at mouth of Aarhus River (m^3/s)

$cout$ = concentration at mouth of Aarhus River (either cfu/100mL or mg/L)

IMPACT II - USE

Step 7.1: Select indicators to measure human use of ESS

This step is not relevant because the degradation service is an intermediate service that is not used directly by humans.

IMPACT II - Monetization

Step 7.2: Select indicators to measure the value of human use of ESS

This step is not relevant because the degradation service is an intermediate service that is not used directly by humans.

Comparison of conditions before and after

Step 8a: Comparison of state indicators before and after

As described in step 6, most of the state parameters relevant for the degradation service are estimated using a simulation model. Two scenarios have been developed in order to represent the lake/river system before and after implementation of the measures under consideration in the Aarhus mature case. The two scenarios use a common simulation period with common hydrological conditions (i.e., rainfall and runoff) so that the only differences between the scenarios are those resulting from implementation of the measures. The simulation period for both scenarios is from 12 June 2015 to 29 August 2015, and the model runs on a one-minute time step. The Aarhus measures are represented in the two scenarios as follows:

- **Real-time control system and associated infrastructure:**

- **Before:** The “before” scenario is represented by setting boundary condition inflow timeseries to values that would have been likely before implementation of the real-time control system and associated infrastructure. The boundary condition timeseries are developed by running a model of the sewer and drainage system for Aarhus municipality. Because it was not possible to obtain a model of the sewer and drainage system as it existed prior to implementation of the project, boundary conditions were developed by simulating the existing system with all of the new CSO storage set to zero storage. This is not a completely accurate representation of the “before” case because additional hydraulic capacity was also added at WWTPs, and it was not possible to remove this feature from the before simulation. In addition, the “Before” scenario does represent bacteria inflows as they existed before the installation of additional disinfections capacity at the WWTPs. Therefore, the “before” scenario most likely underestimates both the extent of CSOs and the concentrations of bacterial pollution from the WWTPs.
- **After:** The “after” scenario is represented using outflows from the simulation model of the existing sewer/drainage system for Aarhus municipality.

- **Opening of Aarhus River:**
  - **Before:** The “before” scenario was originally represented by simulating the portion of the Aarhus River that was covered as a closed reach (i.e., a reach that does not receive sunlight). However, a sensitivity analysis demonstrated that the impact of sunlight on E.Coli/Enterococci degradation was very small because the section that was uncovered was relatively short (~1 km). Therefore, the “before” scenario is simulated assuming that sunlight can penetrate the entire river.
  - **After:** The “after” scenario is identical to the “before” scenario.

A representative boundary condition inflow timeseries is presented in Figure 7, which shows inflow for both the “before” and “after” scenarios.

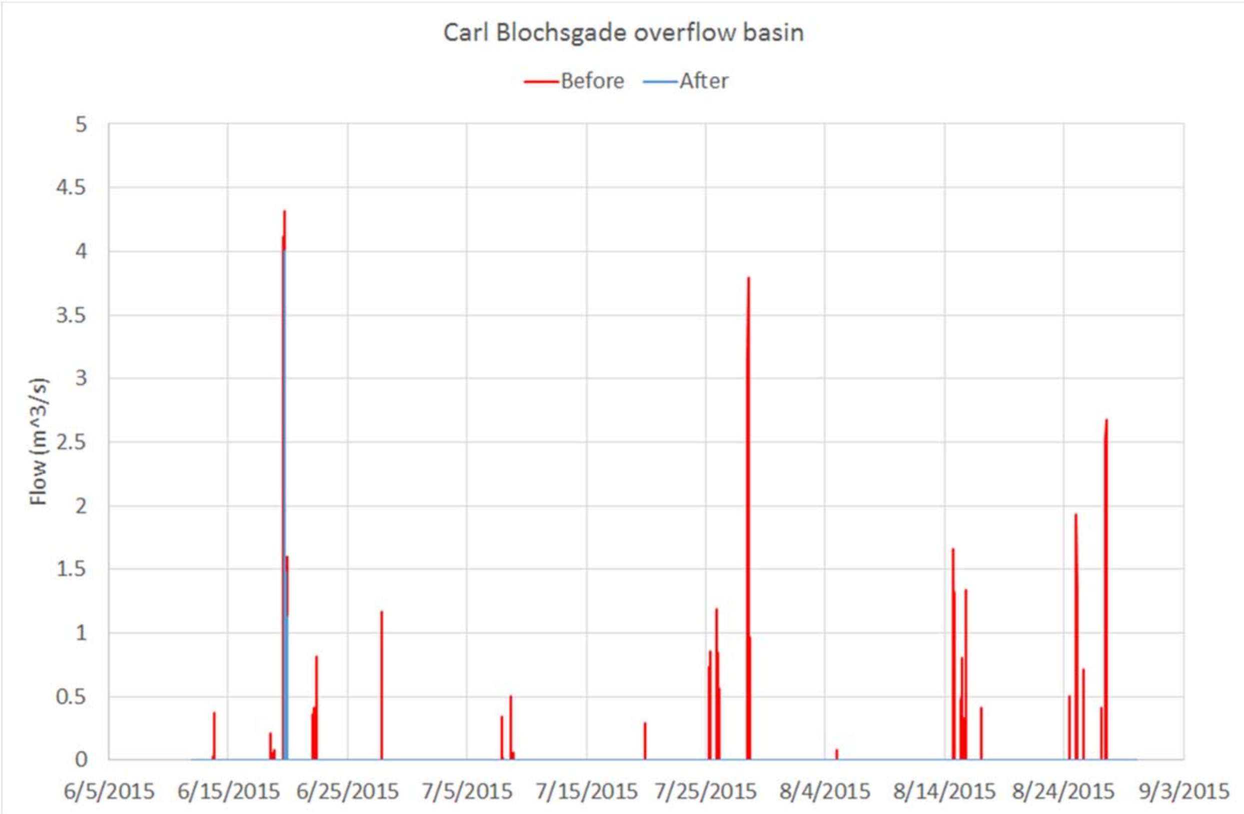

Figure 7 Comparison of inflows to Aarhus River from the Carl Blochsgade CSO basin

The next plots compare timeseries of status parameter values. Figure 8 compares concentrations of dissolved oxygen just upstream of the mouth of the Aarhus River. The comparison shows that dissolved oxygen concentrations are reduced during overflow events, and that this effect is magnified during the larger events that occurred before the project.

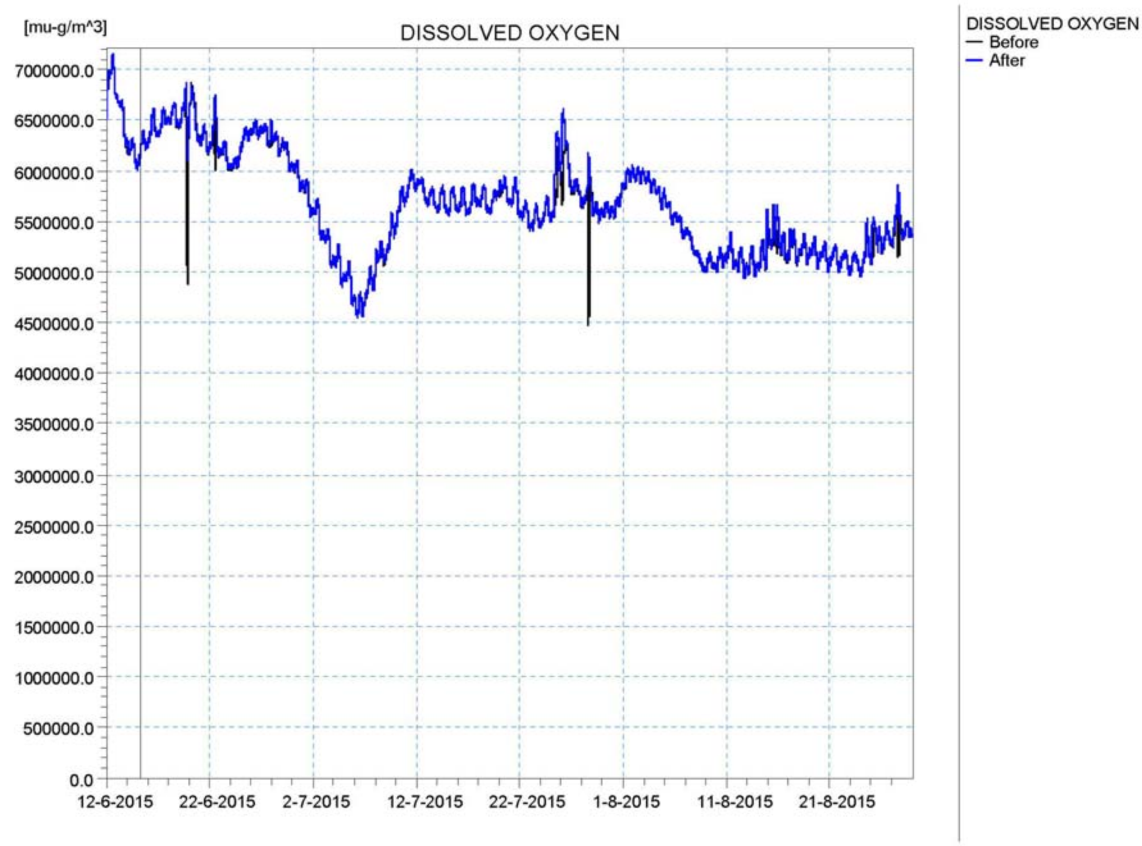

Figure 8 Dissolved oxygen concentrations, just upstream of the mouth of the Aarhus River

Figure 9 compares BOD concentrations at the same location. The figure shows that BOD concentrations increase during overflow events, and this effect is also magnified during the larger events that occurred before the project. Similar patterns are displayed in plots of E.Coli (Figure 10) and Enterococci (Figure 11) concentrations.

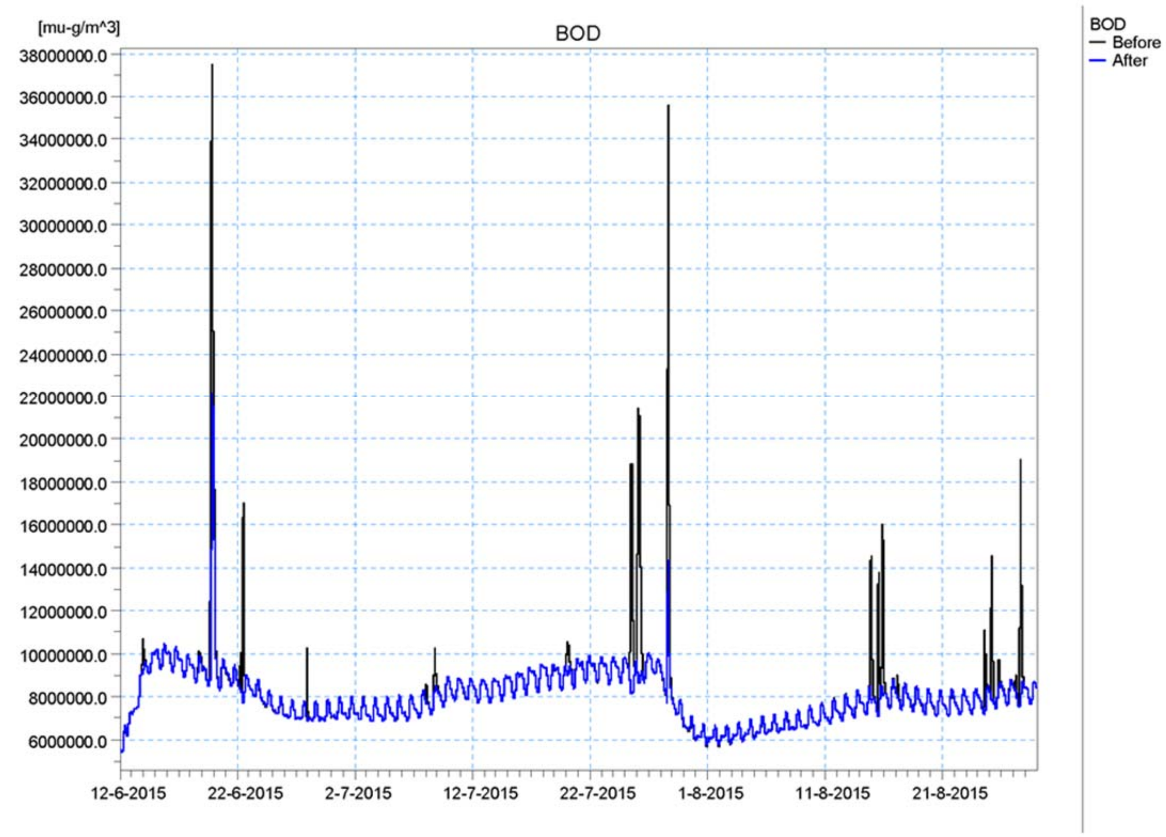

Figure 9 BOD concentrations, just upstream of mouth of Aarhus River

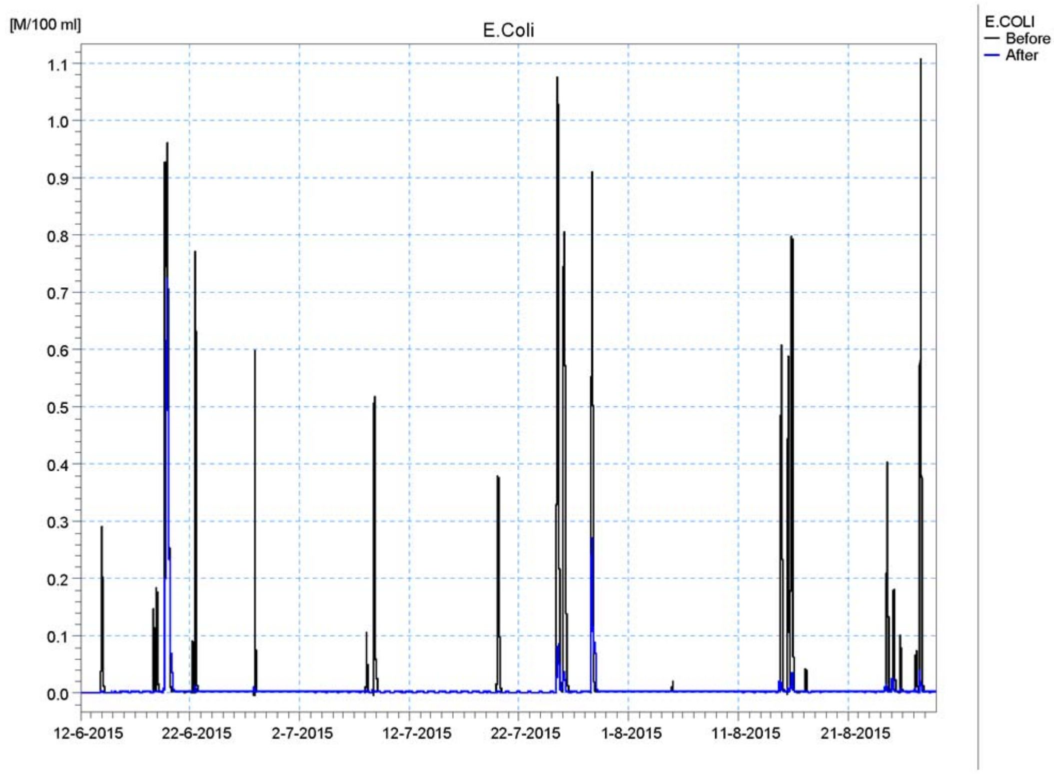

Figure 10 E.Coli concentrations, just upstream of mouth of Aarhus River

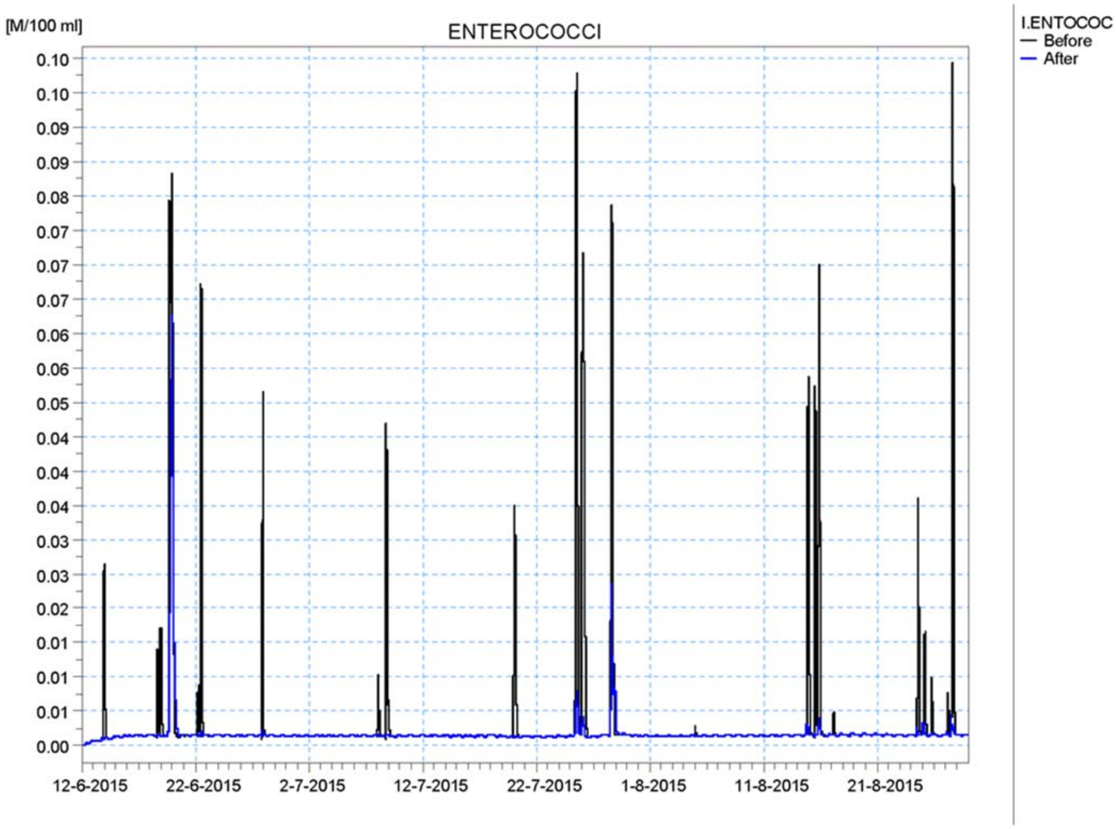

Figure 11 Enterococci concentrations, just upstream of mouth of Aarhus River

Step 8b: Comparison of impact I indicators before and after

Values for the impact I degradation indicator described in step 6 are presented in Table 1. The table shows that degradation of E.Coli and Enterococci increased significantly after implementation of the measures, most likely because of increased residence times. The same phenomenon is observed for BOD, although the effect is less pronounced due to the higher background concentration of BOD. The indicator values presented for BOD in Table 1 are measured over a shorter period within the model simulation period. The shorter period (25 July to 29 July) was chosen in order to use a period with a higher frequency of overflow events, so that the ratio of BOD from overflows to background BOD would be greater (making the degradation service easier to detect).

Table 1 Comparison of degradation values for E.Coli, Enterococci, and BOD

Pollutant	Indicator value (Before)	Indicator value (After)
E.Coli	0.37	0.75
Enterococci	0.30	0.54
BOD	0.20	0.25

Final ESS # 1: Experiential use of plants, animals and land-/seascapes in different environmental settings

This section describes how changes in the experiential use ESS are estimated. The experiential use ESS focuses on use of the restored river reach in central Aarhus.

STATE

Step 5: Identify the parameters that dictate the condition of the system under study and that would be affected by the proposed measure

The following state parameters are related the experiential use ESS and affected by the two measures considered in the Aarhus control system (the real-time control system and associated infrastructure; and the opening of the river):

- **Oxygenation conditions:** Oxygenation conditions affect the rate of BOD degradation, which is related to the presence of odors of human origin.
- **Pollution by other substances:** BOD pollution is related to the presence of odors of human origin, while E.Coli and Enterococci are related to the probability of water-borne illness from full or partial body contact with the river.
- **Structure of the water body shoreline:** The structure of the water body shoreline was changed when the river channel was opened.
- **Percentage of days of surface water per year:** The percentage of days of surface water per year was also changed when the river channel was opened.
- **Probability of water-borne illness from partial body contact and full body contact with river:** Although the river reach running through central Aarhus is not used for swimming or boating, the perception of risk of illness from partial body contact with the river could affect experiential users' perceptions of the river's aesthetics.
- **Presence and description of odor of human origin:** The presence of odor of human origin is perceived as having a negative impact on river aesthetics.

Oxygenation conditions and pollution by other substances are estimated using modeling as described above in the description of the degradation ESS.

The two morphological state parameters, structure of the water body shoreline and percentage of days of surface water per year, are estimated using simple indicators. The length of the river channel in the central city that is open represents the structure of the water body shoreline. The percentage of days of surface water per year is either 100% or 0% depending on whether the river channel is open or not.

The probability of water-borne illness from partial body contact from the water is represented by the percentage of the simulation period in which the concentrations of E.Coli and Enterococci exceed the typical values of WWTP effluent after disinfection. The Aarhus River in the central city is not suitable for bathing, and the Aarhus measures were not intended to improve river water quality to this level. It is not realistic to use thresholds such as the EU Bathing Water Directive standards for E.Coli and Enterococci to estimate this indicator because river concentrations of both bacteria usually exceed these levels. In any case, this indicator is used to assess river aesthetics rather than actual suitability for bathing. Therefore, WWTP effluent concentrations are used as proxies for a maximum concentration that is acceptable from an aesthetic standpoint. Threshold values used to estimate this indicator are provided in Table 2.

Table 2 Threshold conditions defining maximum acceptable concentrations

Bacterial pollutant	Threshold concentration (cfu/100 mL)
E.Coli	15,000
Enterococci	5,000

The two indicators are combined by taking a simple average.

The presence of odor of human origin is linked to the concentration of organic matter in natural waters, which measured by BOD. It is assumed that odors of human origin may be present when the concentration of BOD in the river is greater than 10 mg/L. Therefore, the percentage of the simulation period in which the concentration of BOD exceeds 10 mg/L is used as an indicator for the presence of odor of human origin.

In PART IV – Response evaluation, a number of other state parameters were described as related to the experiential use service. These include:

- **Description of infrastructure to the channel visually impeding otherwise "natural" viewscapes such as bank protection, powerline pole placement, and bridges**
- **Description of infrastructure on the bank visually impeding otherwise "natural" viewscapes such as railings or buildings**
- **Presence of picnic tables, bathrooms, drinking water, and shade structures**
- **Increased utilization for recreation (when this is perceived positively)**
- **Overuse (when increased utilization is perceived negatively)**

All of these parameters refer to anthropogenic elements (infrastructure built by humans or humans themselves) that contribute to or detract from the experiential use service. These parameters are not included in the before/after impact assessment because none of them are relevant for the "before" case and therefore would be difficult to use in a before/after comparison. However, it would be useful to consider these status parameters when comparing two or more potential measures.

IMPACT I - PROVISION

Step 6: Select indicators for relating state parameters to ESS.

To estimate the extent to which the experiential service is provided, we aggregate status indicators that have been identified as being linked to human enjoyment of rivers in urban settings. The analysis relies on findings presented in Weber and Ringold (2015), which identified features of rivers and streams important to the public in a city in the southwestern United States. The study authors identified approximately 50 potential indicators. Three of these have selected as indicators of ESS provision, as these indicators are 1) possible to estimate and 2) were altered substantially by the Aarhus measures. The state indicators are:

- **Percentage of days of surface water per year**
- **Probability of water-borne illness from partial body contact and full body contact with river**
- **Presence and description of odor of human origin**

These indicators are estimated as described in the previous section on state parameters.

To estimate an overall level of ESS provision, an aggregation method is used to combine values for the three status indicators. The aggregation method proceeds according the following steps:

1. **Normalization step:** First, each indicator is normalized according to the following formula: $z = \frac{x - min}{max - min}$

   Where:

   Where:

   $z =$ normalized indicator

   $x =$ indicator value

   $min = 0$

   $max =$ higher of the two indicator values

   If the indicator is for a value that should be minimized, such as the odour indicator, then the min and max values in the above equation are reversed, and the maximum is assumed to equal the sum of the two indicator values.

2. **Weighting step:** Next, each indicator is ranked in order of priority. The priority rankings are used to weight the normalized indicators, with weights inversely proportional to the priority rankings. Rankings and weights assumed for the experiential use indicator are provided in Table 3.

   Table 3 Priority ranks and weights given to status parameter used to estimate experiential use service indicator

Status parameter	Rank	Weight
Percentage of days of surface water per year	1	0.5
Probability of water-borne illness from partial body contact and full body contact with river	3	0.33
Presence and description of odour of human origin	2	0.17

The presence of surface water, as measured by the first indicator, is judged the most important status indicator because without a visible river, it would be impossible to provide the ESS. Odour is judged to be more important the probability of water-borne illness because users of the ESS are more likely to be exposed to odours than with the water itself.

3. **Aggregation step:** Finally, the impact I (provision) indicator is estimated by taking the weighted sum of the three normalized indicators using the weights shown in Table 3.

It is important to note that the normalized indicator described above cannot be used to compare ESS provision across sites; it is an ordinal indicator for comparing different alternatives at the same site.

IMPACT II - USE

Step 7.1: Select indicators to measure human use of ESS

To estimate the extent to which the experiential service is actually used, we estimate the number of individuals living within 8 km of the restored river reach. Because data are not available on the actual number of visitors, we make an assumption about the maximum number of visitors likely to make day trips to the area. In a study mapping cultural ecosystem services in Europe, Paracchini et al. (2014) assumed that 8 km is the maximum distance that individuals are willing to travel for short day trips, while 80 km is the maximum distance that individuals will travel for longer (i.e., full-day) trips. We assume that most visits to the restored river are short day trips (e.g., an afternoon visit to a café or an evening walk).

It is important to note that the use indicator used here is not related to the provision indicator. In other words, we do not estimate use of the experiential use service as a function of the extent to which this service is provided. This is because we were not able to find information relating use of the restored river section to the state indicators used to estimate ESS provision (i.e., percentage of days of surface water per year, probability of water-borne illness from partial body contact and full body contact with river, and presence and description of odor of human origin). It would be interesting to know about how various state parameters linked to cultural ESS are related to actual use; however, this appears to be an underdeveloped segment of the research literature (for a recent review, see La Rosa et al., 2015).

IMPACT II - Monetization

Step 7.2: Select indicators to measure the value of human use of ESS

The economic value of the experiential use service is measured by estimating the marginal contribution of the restored river reach to house and apartment values in Aarhus. The estimate uses marginal value data contributed by IFRO (2013).

The beneficiaries of the experiential use service provided by the restored river reach are resource-dependent businesses and experiencers and viewers. As described in the previous section, we assume that most experiencers and viewers visiting the river are local residents making short day trips; in other words, residents of the area. We further assume that the economic rents paid to operators of cafés, restaurants, and bars located along the river (in other words, additional income that is due to location along the river rather than other competitive advantages) are captured by landlords through increase in the price of leasing retail properties. Given these assumptions, it is reasonable to assume that an assessment of the marginal contribution of the river to property values in the area captures most of the benefit provided by the experiential use service.

IFRO (2013) surveyed residential properties in Aarhus and used regression analysis to estimate the marginal contributions of different amenities to property values. From the list of amenities contributing to house price values, the following are thought to be relevant for the Aarhus mature case:

Table 4 Contributions of different amenities to house prices in Aarhus

Amenity	**Impact on house price (% of sales price)**
Park within 1000m walking distance	0.67 per hectare of park
Access to different types of businesses within 1200m walking distance	0.38 per type of business

Table 4 is based on average house price value of 384,000 € in Aarhus

Table 4 shows that two different amenities are thought to be relevant. IFRO (2013) also measured the marginal contribution of a nature area to house values. However, the restored river is considered a park, not a nature area, because it is not a natural landscape but rather an urban landscape with natural elements. The restored river features a number of new businesses including cafés, restaurants, and bars. Although, none of these business types are new in central Aarhus, it is possible to argue that a riverfront establishment for eating or drinking constitutes a new type of business that did not exist before. When estimating the impact of the Aarhus measures on house prices, we assume that park with a size of 5 hectares has been created, and that one new business type has been introduced.

IFRO (2013) also surveyed apartment values in Aarhus. From the list of amenities contributing to apartment values, the following are thought to be relevant for the Aarhus mature case:

Table 5 Contributions of different amenities to apartment prices in Aarhus

Amenity	**Impact on house price (% of sales price)**
Park within 600m walking distance	0.45 per hectare of park
Access to different types of businesses within 1000m walking distance	0.45 per type of business
Number of bars, cafés, and restaurants with 100m walking distance	-0.45 per type of business

Table 5 is based on average apartment price value of 224,000 € in Aarhus.

Table 5 shows that one additional amenity is considered relevant for apartments. Apparently, establishments for eating and drinking can have a negative impact on apartment prices when located too closely. When estimating the impact of the Aarhus measures on house prices, we assume that park with a size of 5 hectares has been created, one new business type has been introduced, and twenty new bars, cafés, and or restaurants exist.

Figure 12 Riverfront restaurant, Aarhus

Just as the indicator for ESS use was not a function of the indicator for ESS provision, the indicator for ESS value is not a function of ESS use. If exact numbers of visitors to the river reach were available, and a functional relationship between the utility experienced by each visitor and the willingness to pay for that utility were known, it would be possible to estimate the value of the service to experiencers and users. Similarly, if information were available about the amount spent by each customer were available, it would be possible to estimate the benefit to resource-dependent businesses. However, in the absence of detailed information about visitors, utility, and spending, it was thought to be more reasonable to estimate values based on the property market.

Comparison of conditions before and after

Step 8a: Comparison of state indicators before and after

The following state parameters are considered relevant for the experiential use service:

- Oxygenation conditions
- Pollution by other substances
- Structure of the water body shoreline
- Percentage of days of surface water per year
- Probability of water-borne illness from partial body contact and full body contact with river
- Presence and description of odor of human origin

Values for the first two indicators were presented in the results for the degradation service. The other values are reported in Table 6.

Table 6 Status indicators for experiential use service

Indicator	Unit	Value (Before)	Value (After)
Length of restored river section	m	0	1000
Percentage of days of surface water per year in lower Aarhus River	%	0	100
Probability that E.Coli concentration exceeds concentration of WWTP effluent	%	8.1	3.1
Probability that Enterococci concentration exceeds concentration of WWTP effluent	%	6.2	1.8
Probability that BOD concentration exceeds 10 mg/L	%	5.3	2.2

Step 8b: Comparison of impact I indicators before and after

Values for the dimensionless indicator that aggregates the values presented above (with the exception of "Length of restored river" are presented in Table 7.

Table 7 Comparison of ESS provision indicators for experiential service

Scenario	Value
Before	0.195
After	1

Step 8c: Comparison of impact II indicators before and after

Numbers of visitors to the restored river area are compared in Table 8.

Table 8 Comparison of ESS use indicators for experiential service

Scenario	Value
Before	0
After	186,760

Step 8d: Comparison of impact II value indicators before and after

Estimated changes in house prices resulting from the creation of a new park area (the restored river reach) and a new type of business (riverfront eating and/or drinking establishment) are presented in Table 9 and

Table 10.

Table 9 Total contribution of new park area to house values in Aarhus

Parameter	Value
Number of houses within 1000 m	2750
Average house value	384,000 €
Marginal house value change per hectare park	0.67%
Size of restored area	5 ha
Total change in value	35.3 million €

Table 10 Total contribution of new type of business to house values in Aarhus

Parameter	Value
Number of houses within 1200 m	3644
Average house value	384,000 €
Marginal house value change per new type of business	0.38%
Number of new types of businesses	1
Total change in value	5.3 million €

Estimated changes in apartment prices resulting from the creation of a new park area; a new type of business; and new bars, cafés, and restaurants are presented in Table 11, Table 12, and Table 13.

Table 11 Total contribution of new park area to apartment values in Aarhus

Parameter	Value
Number of apartments within 600 m	12,676
Average apartment value	224,000 €
Marginal apartment value change per hectare park	0.45%
Size of restored area	5 ha
Total change in value	63.8 million €

Table 12 Total contribution of new type of business to apartment values in Aarhus

Parameter	Value
Number of apartments within 1000 m	23,448
Average apartment value	224,000 €
Marginal apartment value change per new type of business	0.45%
Number of new types of businesses	1
Total change in value	23.6 million €

Table 13 Total contribution of bars, cafés, and restaurants in Aarhus

Parameter	Value
Number of apartments within 100 m	488
Average apartment value	224,000 €
Marginal apartment value change per bar, café, or restaurant	-0.45%
Number of new bars, cafés, and restaurants	20
Total change in value	-9.8 million €

The numbers of apartments presented in Table 11, Table 12, and Table 13 are the total number of independent addresses on all subdivided property parcels. Therefore, it is possible that some of these are offices, retail spaces, or other non-residential addresses. Because the marginal values estimated by IFRO (2013) were estimated for residential properties, it may not be appropriate to apply these values to commercial properties. However, it is likely that commercial property values increased by similar amounts because of additional business opportunities created by the river restoration.

Step A: Definition of the assessment and decision case

The DESSIN Sustainability Assessment (SA) adds a holistic perspective to the ESS approach. The purpose of the SA is to encourage decision-makers to consider other perspectives when considering whether to implement new technologies.

The objective of the SA for the Aarhus case is to test the DESSIN SA framework. In the DESSIN SA framework, indicators are used to assess impacts in five different "dimensions" that are typically considered in decision making about infrastructure projects. These dimensions include the following:

- Social
- Environmental
- Financial
- Governance
- Assets

More information about the dimensions of the SA is provided in the cookbook and companion document.

In the Aarhus mature case study, the DESSIN SA is carried out by estimating indicator values so that the impact of the Aarhus measures on each of the above dimensions can be estimated. Some comments on how the different indicators could be used in decision-making are also provided.

The SA is carried out as a retrospective assessment, as the Aarhus measures have already been implemented. In many cases, it was not possible to estimate indicator values because the required data were not collected during the implementation of the measures and cannot be obtained now. In other cases, it was not possible to estimate indicator values because of resource constraints. In these cases, an effort is made to explain how the indicators could have been estimated.

As with the DESSIN ESS assessment, the SA can be applied to more than one proposed measure, so that different proposed measures can be compared. In the Aarhus case study, it is possible to apply the SA to other measures besides the ones that were implemented, as many different combinations of measures were considered in the project-planning phase. However, none of the other proposed measures have been included in the SA because of the difficulty of obtaining data to compute indicators. In other words, the SA is only applied to the measures that were actually implemented.

Step B: Selection of indicators

In the DESSIN SA, the first step is to select indicators for each dimension that are appropriate for the case location and technology. Indicators are selected from a standardized list provided in the DESSIN cookbook. A detailed list of all indicators selected for assessment can be found in the annex to this chapter (see ANNEX-PART V). As noted in the annex, it was not possible to obtain data to estimate values for each of the indicators that were judged appropriate for the Aarhus case.

Step C: Definition of additional indicators

No further data was found to be available and thus no additional indicators relevant for the decision case were derived.

Step D: Data collection and assessment

Data were collected for the assessment from Aarhus Water, which was the implementing agency for the Aarhus measures. Some indicators from the DESSIN ESS evaluation are also used in the SA. These indicators and their values are presented in Table 14.

Table 14 Indicators used in the Sustainability Assessment obtained from the DESSIN ESS evaluation

SA indicator ID	SA dimension	SA parameter	DESSIN status or ESS provision parameter	unit	before	after
S111	Social	Presence of microbial pathogens in water bodies used for recreational activities	Probability of water-borne illness from partial body contact and full body contact with river (E.Coli)	%	8.06	3.07
S111	Social	Presence of microbial pathogens in water bodies used for recreational activities	Probability of water-borne illness from partial body contact and full body contact with river (Enterococci)	%	6.24	1.75
S151 S152	Social	Economic impact via new or growing business from recreation/visiting activities or other types of economic growth linkted to the solutions effects on the ecoystem Non-market value of recreational/visiting activities	Economic value of experiential use service	[€]	0	120E+6
F113	Financial	Avoided costs and / or additional monetary benefits from enhanced ecosystems use	Economic value of experiential use service	[€]	0	120E+6
A151	Assets	Percentage of load removed	Degradation of E.Coli	%	0.37	0.75
A151	Assets	Percentage of load removed	Degradation of Entercocci	%	0.30	0.54

A151	Assets	Percentage of load removed	Degradation of BOD	%	0.20	0.25

Step E: Results and discussion

Social dimension

The social dimension of the SA attempts to measure the effects of a solution on human welfare. In the application of the SA to the Aarhus case, indicators related to public health, employment, and economic welfare have been considered.

The public health indicators considered in the SA suggest an improvement because concentrations of E.Coli and Enterococci have decreased. However, it is unlikely that many residents of Aarhus contracted water-borne illness from the river before the Aarhus measures were implemented. The river in the central city was not accessible to the public before it was opened. Even after some smaller sections were opened in the late 1990s (prior to implementation of the water quality measures), it would have been difficult to make contact with the river because of steep embankments and railings that were put in place. It may be that some residents contracted illness though contact with the more accessible upstream portions of the river. However, this area was officially off-limits to swimming and other recreational uses prior to implementation of the measures, and remains off-limits to swimming

It was not possible to obtain data related to employment impacts of the Aarhus measures. Consulting firms and contractors were involved in the design and construction of the measures. However, these enterprises may have been able to find other opportunities for work had the measures not been implemented. The real-time control system was designed to function through a system of computer forecasting tools, sensors, and automatically controlled gates and pumps, and therefore does not require significant numbers of additional workers. The new cafés, bars, and restaurants that opened alongside the restored river reach may have created new employment if they did not reduce demand for these services in other parts of the city.

The most significant impact on human welfare brought about by the Aarhus measures was the creation of a natural space in the middle of the city for the enjoyment of city residents. While this can be measured in a number of ways, the Aarhus case study uses an assessment of the marginal contribution of parks and new types of businesses to house and apartment prices in the city. There is considerable evidence that the presence of the river and associated amenities have made the city centre a more attractive place to live, and that this is reflected by increases in willingness to pay for housing in the area. According to assessment applied here, this amount could be as much as 120 million €.

Regardless of how social impacts are measured, it was clear from interviews conducted with officials from the municipality of Aarhus and the water utility that social considerations were the major drivers of the project. The perceived social benefits that led to implantation of the measure included:

- Better water quality for swimming and water sports
- Better aesthetic conditions

- Better living conditions in the city center in order to attract a well-educated population

Environmental dimension

The environmental dimension of the DESSIN sustainability assessment aims to measure the environmental consequences of implementing new technology. The implementation of new technologies has environmental consequences, including energy use and consumption of raw materials.

The environmental dimension (as defined in the DESSIN SA) does not appear to have been a major consideration in the design of the Aarhus measures, apart from the obvious goal of improving water quality. However, the project did have other environmental impacts, such as the use of concrete and other building materials in the construction of storage basins and new pipes to deliver wastewater from storage basins to WWTPs. Operation of the real-time control system requires energy inputs to run pumps and gates. There is no doubt that the project has led to an increase in energy usage, some of which is supplied by the burning of fuels that contribute to greenhouse gas emissions.

A methodology that can be used to develop a comprehensive overview of the environmental impacts of a technology is Life Cycle Assessment (LCA). More information about LCA is provided in Box 1.

Financial dimension

The financial dimension of the DESSIN SA is concerned with whether measures are affordable to agencies with responsibility for implementation and financing. Where agencies serve a social purpose (such as municipal water utilities) costs can also be compared to the social benefits of projects.

In the Aarhus case, financial costs were a major consideration in the choice of measures implemented. A number of different alternatives were considered in the planning of the real-time control system and associated infrastructure, including one that would have made the Aarhus River suitable for swimming. This alternative was rejected because the costs of achieving this level of water quality were not thought to justify the benefits.

Although not part of the Aarhus mature case, it is worth noting that the Aarhus water quality improvements project also included development of warning system for bathing water quality in the Aarhus harbour. The warning system has resulted in considerable savings in spending on infrastructure (~25 million €) because the EU Bathing Water Directive permits more frequent violations of water quality standards if a warning system is in place.

The innovative nature of the Aarhus real-time control project also attracted outside funding from the EU. The project was a demonstration site in the EU research project PREPARED (Jensen et al., 2014), which contributed funds to the development of the technologies implemented in the project.

The Aarhus measures were funded by an increase in rates paid by customers of the Aarhus water utility. These rate increases have been sufficient to fund the project. However, as an agency that serves the public interest, it is interesting to compare the social benefits of the measures to the costs. The cost implementing the real-time control system and associated infrastructure was approximately 47 million €, and the cost of operating the project is about 600,000 € per year. The river was opened in three stages, one coinciding with the implementation of the real-time control project; however, estimates of the cost

Box 1 Life cycle assessment (LCA)

LIFE CYCLE ASSESSMENT (LCA)

The construction of measures requires the use of natural resources, and the operation of new infrastructure and control systems may lead to additional energy use and related emissions. Life cycle assessment is an established framework to quantify and compare the impact of alternative solutions. The results of an LCA can be used to communicate the environmental impact of alternative infrastructure solutions to decision makers and other stakeholders.

Life Cycle Assessment is described in the ISO 14040 series of standards. An LCA consists of four steps (ISO, 2006): 1. Goal and scope definition, 2. Life Cycle Inventory (LCI), 3. Life Cycle Impact Assessment (LCIA), and 4. Interpretation of results.

For the LCI and LCIA, data are commonly available from existing databases. A number of LCA tools exist to carry out the calculations. The results are commonly stated for a number of impact categories, such as Global warming potential, ozone depletion, acidification, eutrophication, ecotoxicity and human toxicity, etc. In addition, parameters such as depletion of limited resources may be included in the assessment. For comparison and easier communication, the results in each impact category may be normalisation into person-equivalents (PE).

LCA tools have been used to analyse alternative scenarios for urban water systems.

- In Sweden for example, a tool for substance flow analysis and LCA (ORWARE/URWARE) was applied to compare eight scenarios for wastewater and organic waste handling in the city of Göteborg. The results from the LCA were then combined in a multi-criteria analysis, with other parameters such as cost, acceptance by the users and by the utilities, microbial risk, and technical function/robustness (Göteborgs Stad, 2007). The work was based on a framework for strategic planning of urban water systems (Malmqvist *et al*., 2006)
- In Denmark, LCA methodology was used to compare scenarios for central softening of drinking water (Godskesen *et al*., 2012), and for the supply of non-potable water to a new part of a city (Rygaard et al., 2014).

LCA methodology can be applied to quantify the environmental impacts of the measures carried out in Århus to improve the urban wastewater system. Compared to the situation in 2006, the measures could have positive (*e.g.* reduced freshwater and marine eutrophication) and negative effects (*e.g.* increased energy use, leading to increased greenhouse gas emissions). The assessment should include the entire life cycle of the new infrastructure, *i.e.* construction, operation and decommissioning phases.

If LCA were applied to the Aarhus case,the system boundaries should at least include the part of the sewer system affected by the investments (including retention basins), overflows to the water bodies, the wastewater treatment plants, and the recipients. If thesystem produces more or less biogas or heat than before, these aspects should be included as well.

For an LCA of the scenarios in Aarhus, the LCA tool *EASETECH* (Clavreul *et al.*, 2014) could be used, which has been developed primarily for Danish conditions. Like several other LCA tools, EASETECH was originally developed to compare systems for waste management. However, EASETECH is also a mass and substance flow model and has been applied for water and wastewater systems, including wastewater treatment plants (Yoshida *et al*., 2014).

of opening the river are not available. The benefits of opening the river and the associated water quality improvements are estimated to be 120 million €. However, this benefit estimate is limited to the benefit of opening the river in the central city, and does not include the social benefits of water quality improvements to the lake, the upper river section (between the lake and the central city), and the harbour.

Governance dimension

The governance dimension of the DESSIN SA investigates the political acceptability of measures, along with the extent to which measures contribute to regulatory compliance.

The water quality improvements resulting from the real-time control system and associated infrastructure were driven by the EU Bathing Water Directive, which has been adopted in Danish national standards for bathing waters. These improvements have resulted in water that is suitable for bathing in Lake Brabrand and parts of the Aarhus harbour. However, water quality in the Aarhus River, while much improved, is not of bathing water quality, as the costs of achieving this objective were thought to outweigh the benefits.

The governance dimension of the DESSIN SA also includes indicators that measure the complexity of gaining acceptance for projects that require approval by actors in the political system. It was not possible to quantify any of the indicators of political complexity suggested by the DESSIN SA. However, political support was a major consideration in the decision to move forward with the Aarhus measures. The Aarhus River has an important cultural role in the community, as the river was the site of Viking harbour that was the original reason for settlement of the area. In addition, there is broad support for restoring the old harbour area, which was also a motivation for the project. Finally, it was thought that construction of an innovative environmental restoration project could contribute to Aarhus's image as a so-called "green-blue city", thereby attracting a well-educated population as well as marketing opportunities for firms involved in the project. Further information about the governance factors that contributed to the Aarhus measures is available in the accompanying DESSIN deliverable, "Report on governance regime factors conducive to innovation uptake".

Assets dimension

The assets dimension of the DESSIN SA provides information on the reliability and resilience of technical measures. This dimension also provides an opportunity to assess whether proposed solutions have the potential to create risky or unsafe working conditions.

In the water sector, climate change is important resilience consideration. In the Aarhus case study, climate change is of concern because it is expected to lead to more intense rainfall events, which may increase the likelihood of CSOs. In the planning for the Aarhus real-time control system, the system was simulated using a climate change scenario in which precipitation intensity (not the total amount) was increased by 20% compared to a historical baseline. One of the reasons that the implemented system was selected was that it was found to offer sufficient capacity to absorb more intense rainfalls resulting

from the climate change scenario.

Although not a consideration in design, the real-time control system and associated infrastructure have contributed to resilience by increasing the capacity of the Aarhus River to remove pollution. This impact results from the increased travel times that have occurred when overflow events are captured by storage and routed through WWTPs instead of being released to the river in a short time period. Because of the resulting longer travel times, more degradation takes place as water makes its way down the river. This impact has been quantified for E.Coli, Enterococci, and BOD, and results are presented in the Annex.

A final consideration in the design of the Aarhus measures that is relevant for the Assets dimension is workplace safety. During the design phase, one option that was considered (but not implemented) was to install local treatment for CSO discharges at storage basins. This option would have eliminated the need to route overflows captured by local storage to WWTPs, reducing costs for pumping and sewer network expansion. However, local treatment facilities require maintenance activities that have the potential to lead to workplace accidents. For this reason, local treatment was not considered in the final design of the system.

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ECOLAB

ANNEX: REPORTING TABLES

Element of Part I	Instructions	User entries
Administrative details	1. Provide general information about: • the entity/ies involved in carrying out the assessment • the provider/s of information for the assessment • - the provider/s of funding for the assessment	• *DHI* • *DHI, Aarhus Water* • *EU FP7 project*
Objectives of the assessment	2. • Define the intended audience of the results (*Who will be the main recipient of the outcome report?*) • Define and explain the specific purpose and the expected outcomes of carrying out the assessment (*What do you want to achieve by assessing changes in ESS in your area?*).	*Intended audience: Researchers* *Objectives: The assessment is carried out with the aim of (i) testing the ESS Evaluation Framework proposed and (ii) testing the DES-SIN sustainability assessment.*
Overview of the study area	3. Provide a detailed description of the study area considering: • geographical location (e.g. Mediterranean region, Western Europe, Nordic region) • spatial extent • environmental attributes (e.g. climate type, topography, water quality levels, water availability) • economic activities taking place in the area (e.g.	• *Nordic region* • *Aarhus River and Lake Brabrand (the entire area is located within the municipality of Aarhus, and most of the surrounding catchment area is urban).* • *Environmental attributes:* o *Humid continental climate (large seasonal temperature differences, precipitation well-*

	land use, land use transitions, comparison of activities by share of GDP) • socioeconomic profile (e.g. population density, average household income, age profile) • sociocultural aspects (e.g. value systems, role of landscape and land use in identity formation).	*distributed throughout the year)* o *Harbor city situated on the bay of Aarhus. City occupies flat coastal region with surrounding area characterized by low hills.* • *Traditionally a port city and industrial center for the refinement of agricultural products. Transitioning to become a center for green technologies, as well as research and development. Employment by sector:* o *Services: 57%* o *Trade: 24%* o *Manufacturing: 17%* o *Other: 2%* • *Aarhus has a population of 259,754 on 91 km2 with a density of 2,854/km2. The largest age group is 20- to 29-year-olds and the average age is 37.5.* *The most important landscape elements in the city are the coastal beaches and surrounding forests, both of which are widely used for recreational and experiential activities. Popular outdoor recreation activities include walking, hiking, cycling and outdoor team sports. Large events such as running are orienteering races are held throughout the year. Watersports like sailing, kayaking, and motor boating are also popular. One of the forest areas includes a large historical landscape of pastures and woodlands, presenting different eras of Denmark's prehistory, from the Stone Age to medieval times.*

Stakeholder list	4. Elaborate an exhaustive list of the stakeholders present in the area.	*people living in the area;* *water utility;* *municipal environment department;* *kayak rental companies located on the Aarhus River;* *cafes and restaurants located on the restored riverfront*
Terminology	5. If necessary after going carefully through the DESSIN Glossary, include the definitions of any additional case-specific terminology here.	

1. Characterisation Table for Drivers

The list of drivers is based on MARS, 2014.

DRIVER	SPECIFICATION (to be input by the user)	RANKING (OPTIONAL) (to be input by the user)
Urban development	Development of the city of Aarhus and associated urban infrastructure	1

2. Characterisation Table for Pressures

The relation between the pressure categories and the drivers is based on IMPRESS Guidance No. 3 and MARS, 2014

DRIVER IDENTIFIED IN THE STUDY AREA	PRESSURE CATEGORY	SPECIFICATION
Urban development	Diffuse source pollution	Development in the city has led to the development of a storm sewer network that discharges to the Aarhus River. In some areas of the city, there is also a combined sewer network that sometimes overflows to the river.
Urban development	Point source pollution	Development in the city has also led to the construction of wastewater treatment plants, two of which discharge to the river.
Urban development	Morphological	Development in the city led to enclosure of the Aarhus River in the city center, with a street being built over the former river channel and the river routed through an underground culvert.

PART III – Description of responses and identification of potential beneficiaries

3.1 Description of the proposed measure:

The proposed measure is a real-time control system for the operation of CSO basins and WWTPs located along Lake Brabrand and the Aarhus River. The real-time control system coordinates storage in CSO basins with WWTP capacity in order to reduce the frequency of CSO events and maxmimize the beneficial use of CSO storage. The real-control system was built in combination with increased CSO storage and increased hydraulic capacity at the two WWTPs that discharge into the Aarhus River. The motivation for the project was to improve water quality in Lake Brabrand, the Aarhus River, and in the Aarhus harbour. In this application of the DESSIN ESS framework, the analysis is limited to effects on Lake Brabrand and the Aarhus River. The impact of the project on human welfare is evaluated together with a second project, in which the Aarhus River in central Aarhus was opened (it had previously been routed underground below a street). Because a main motivation for the project was to improve the aesthetics of the newly re-opened river, it is thought that the benefits of the project should be considered together in tandem with the project to re-open the river.

3.2 Claimed/expected capabilities of the Proposed Measures:

Proposed Measure	Claimed/expected capability	Qualitative description	Quantitative description
- Expansion of CSO storage basins and WWTP capacity *- Real-time control of CSO basins and WWTPs*	*- improvement of water quality* *- reduction in the frequency of cobined sewer overflow events*	*- Reduction in the amounts of bacteria and BOD discharged Lake Brabrand and the Aarhus River* *- Reduction in the frequency of CSO overflows*	*- Change in total mass discharge of bacteria and BOD during a three-month analysis period.* *- Change in the number of overflow events during a three-month analysis period.*

Proposed Measure	Claimed/expected capability	Qualitative description	Quantitative description
- Opening of Aarhus river in central Aarhus	*- improvement of the physical structure of watercourses*	*- Opening of the Aarhus River in central Aarhus*	*- Change in the length of river channel routed through an underground tunnel.*

3.3 Driver, Pressure, and/or State affected by the capabilities:

Proposed Measure	Capability		
	Effect on DRIVER (from D catalogue)	Effect on PRESSURE (from P catalogue)	Effect on STATE (from S catalogue)
Aarhus restoration and real-time control system: *- Expansion of CSO storage basins and WWTP capacity* *- Real-time control of CSO basins and WWTPs* *- Opening of Aarhus river in central Aarhus*	*n/a*	*- improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)* *- improvement of the physical structure of watercourses by improving river morphology*	*See tables below*

Effect on State: Biological status parameters

		Effect on STATE (from S catalogue)			
Proposed measure	**Claimed / expected capability**	Composition, abundance and biomass of phytoplankton	Composition and abundance of macrophytes and phytobenthos	Composition and abundance of benthic invertebrate fauna	Composition, abundance and age structure of fish fauna
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)	Minimal impact due to presence of eutrophic upstream lake (Lake Brabrand)	Limited impact	Limited impact	Limited impact
	Improvement of the physical structure of watercourses by improving river morphology	Limited impact	Limited impact	Limited impact	Limited impact

Effect on State: Hydromorphological status parameters

		Effect on STATE (from S catalogue)						
Proposed measure	**Claimed / expected capability**	Presence of transversal migration barriers	Quantity and dynamics of water flow	Connection to groundwater bodies	Water residence time	Depth and width variation	Structure and substrate of the water body bed	Structure of the water body shoreline
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)	No impact	Some impact, through reduction in overflow events	Limited impact	Significant impact, through reduction in overflow events	No impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	No impact	Limited impact	Limited impact	Limited impact	Some impact on depth variation through opening of open channel. Little impact on depth variation because the restored river channel has a uniform width.	Limited impact	Significant impact, through opening of the river channel

Effect on State: Physiochemical status parameters

		Effect on STATE (from S catalogue)							
Proposed measure	**Claimed / expected capability**	Transparency	Thermal conditions	Oxygenation conditions	Salinity	Nutrient conditions	Acidification status	Pollution by priority substances	Pollution by other substances
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)	Minimal impact due to presence of eutrophic upstream lake (Lake Brabrand)	Limited impact	Significant impact, through reduction of BOD discharge to river	Limited impact	Limited impact	Limited impact	Limited impact	Significant impact on discharges of bacteria to river, through reduction of overflow events
	Improvement of the physical structure of watercourses by improving river morphology	No impact	Limited impact	Some impact, through increased reaeration in the restored river section.	Limited impact	No impact	Limited impact	No impact	Small impact on degradation of bacteria, through increased exposure to sunlight

Effect on State: Human appreciation/dislike/concern/interest (water elements)

		Effect on STATE (from S catalogue)						
Proposed measure	**Claimed / expected capability**	Percentage of days of surface water per year	Minimum surface water flow, minimum surface water volume, and minimum aquifer volume, per year	Probability of water-borne illness from drinking tap water associated with river water	Probability of water-borne illness from partial body contact and full body contact with river	Annual probability of flooding inundating sensitive property	Whether minimum thalweg depth allows for swimming	Minimum main channel depth and width, class of rapids, and presence of navigation hazards such as downed trees
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)	No impact	No impact	No impact	Significant impact through reduction of CSO discharges	No impact	No impact, as the river water quality is not suitable for swimming	No impact
	Improvement of the physical structure of watercourses by improving river morphology	Significant impact in the restored river reach	No impact	No impact	Some impact because of easier access to water body	No impact	No impact	No impact because the restored river section is not used for navigation

Effect on State: Human appreciation/dislike/concern/interest (water elements, continued)

		Effect on STATE (from S catalogue)						
Proposed measure	**Claimed / expected capability**	Annual probability of flooding at or above bankfull	Annual probability of sudden increase in flow volume and velocity making wading or driving through established crossings dangerous	Probability of illness due to nearby surface water via vectors such as mosquitoes	Total volume of flow per year and minimum surface water flow per year	Clarity of water, depth of visibility	Presence of the sound of flowing water	Presence and abundance of algae
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure (through reduction of the frequency of overflow events)	No impact	No impact	No impact	Small impact through reduction of CSO discharges	Limited impact due to presence of eutrophic lake upstream	No impact	Limited impact due to presence of eutrophic lake upstream
	Improvement of the physical structure of watercourses by improving river morphology	No impact	No impact	No impact	No impact	No impact	Limited impact because the river gradient and flow are not sufficient to create flows that can be heard	Limited impact

Effect on State: Human appreciation/dislike/concern/interest (vegetation elements)

		Effect on STATE (from S catalogue)							
Proposed measure	**Claimed / expected capability**	Presence and abundance of trees large enough to provide shade for people	Presence and abundance of lush green vegetation including shrubs, grass and reeds (other than large trees)	Presence and abundance of invasive plants	Total number of different types of appreciated plant species (see other Vegetation themes)	Presence and abundance of wildflowers	Presence and abundance of non-native plants high in allergens or high in water use	List of plant species present that are in danger of extinction	List of plant species present that are edible or medicinal
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact

Effect on State: Human appreciation/dislike/concern/interest (fish and wildlife elements)

		Effect on STATE (from S catalogue)					
Proposed measure	**Claimed / expected capability**	Presence and abundance of bird species	Presence and abundance of mammal species, especially larger mammals, including predators	Presence and abundance of game fish species	Presence and abundance of all fish species	Presence and abundance of wildlife known to harm humans, damage property, or that are commonly feared	Presence and abundance of reptile species
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	Limited impact	No impact	Limited impact	Limited impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	No impact	No impact	Limited impact	Limited impact	No impact	No impact

Effect on State: Human appreciation/dislike/concern/interest (fish and wildlife elements, continued)

		Effect on STATE (from S catalogue)					
Proposed measure	**Claimed / expected capability**	List of fish and wildlife species present that are in danger of extinction	Presence and abundance of invasive wildlife	Total number of different types of appreciated fish and wildlife species (see other Fish and Wildlife themes)	Presence and abundance of abnormalities in wildlife susceptible to pollution-induced mutations, such as amphibians	Presence and abundance of frog species	Presence and abundance of butterfly species
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	No impact	No impact	No impact	No impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	No impact	No impact	No impact	No impact	No impact	No impact

Effect on State: Human appreciation/dislike/concern/interest (other elements)

		Effect on STATE (from S catalogue)					
Proposed measure	**Claimed / expected capability**	Presence and abundance of garbage and/or graffiti along waterways	Presence and description of odor of human origin	Presence and extent of paved trails	Description of infrastructure to the channel visually impeding otherwise "natural" viewscapes such as bank protection, powerline pole placement, and bridges	Description of infrastructure on the bank visually impeding otherwise "natural" viewscapes such as railings or buildings	Presence and extent of unpaved trails
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	No impact	Significant impact due to reduction of CSO overflow events	No impact	No impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	No impact	Significant impact in restored river reach during CSO overflow events	No impact	Restored river section in central Aarhus includes protected (non-natural) banks	Bank railings were built for public safety purposes as part of the restoration project	No impact

Effect on State: Human appreciation/dislike/concern/interest (other elements, continued)

		Effect on STATE (from S catalogue)				
Proposed measure	Claimed / expected capability	Presence of picnic tables, bathrooms, drinking water, and shade structures	Increased utilization for recreation (when this is perceived positively)	Presence of homeless persons or camps, and presence of crime	Overuse (when increased utilization is perceived negatively)	Presence and description of sound of human origin
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	No impact	No impact	No impact	No impact	No impact
	Improvement of the physical structure of watercourses by improving river morphology	Benches were built along the riverfront as part of the restoration project	Significant impact	No impact	Possible significant impact if excessive use of the restored reach is perceived negatively	No impact

3.4 Case-relevant ESS:

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
Hydromorphological Quantity and dynamics of water flow Water residence time	*Hydrological cycle and water flow maintenance*	*Liquid flows*	*Mediation of flows*	*Regulation & Maintenance*
	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
Hydromorphological	*Maintaining nursery*	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological*	*Regulation & Maintenance*

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
Depth and width variation Structure of the water body shoreline	*populations and habitats*		*conditions*	
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
Physiochemical Oxygenation conditions Pollution by other substances	*Bio-remediation by micro-organisms, algae, plants, and animals*	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
	accumulation by ecosystems			
	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Maintaining nursery populations and habitats	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
Human appreciation/dislike/concern/interest (water elements) Percentage of days of surface water per year Probability of water-borne illness from partial body contact and full body contact with river	*Experiential use of plants, animals and land-/seascapes in different environmental settings*	*Physical and experiential interactions*	*Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*
	Physical use of land-/seascapes in different environmental settings	*Physical and experiential interactions*	*Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*
	Existence values	*Other cultural outputs*	*Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
	Bequest values	*Other cultural outputs*	*Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*
Human appreciation/dislike/concern/interest (other elements) Presence and description of odor of human origin Description of infrastructure to the channel visually impeding otherwise "natural" viewscapes such as bank protection, powerline pole placement, and bridges Description of infrastructure on the	*Experiential use of plants, animals and land-/seascapes in different environmental settings*	*Physical and experiential interactions*	*Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*
	Physical use of land-/seascapes in different environmental settings	*Physical and experiential interactions*	*Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*
	Existence values	*Other cultural outputs*	*Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
bank visually impeding otherwise "natural" viewscapes such as railings or buildings Presence of picnic tables, bathrooms, drinking water, and shade structures Increased utilization for recreation (when this is perceived positively) Overuse (when increased utilization is perceived negatively)	*Bequest values*	*Other cultural outputs*	*Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]*	*Cultural*

4.1 Comparison of case-relevant ESS with potential beneficiaries and FEGS:

CICES Class *(restricted to ecosystem type)* *(from Step 3)*	**Beneficiary** *(Categories and Sub-Categories)*	**FEGS** *(Importance of FEGS to the Beneficiary)*
Hydrological cycle and water flow maintenance	*Wastewater treatment plant operators*	*medium for discharging [treated municipal wastewater] into the environment*
Dilution by atmosphere, freshwater and marine ecosystems	*Wastewater treatment plant operators*	*medium for discharging [treated municipal wastewater] into the environment*
Maintaining nursery populations and habitats	*No direct beneficiary*	
Filtration/ sequestration/ storage/ accumulation by ecosystems	*No direct beneficary*	
Bio-remediation by micro-organisms, algae, plants, and animals	*No direct beneficary*	
Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*No direct beneficary*	
Experiential use of plants, animals and land-/seascapes in different environmental settings	*Resources-dependent businesses (operators of cafés and restaurants along the restored riverfront)*	*Opportunity for placement of infrastructure in environment*
	Experiencers and viewers	*Opportunity to view the environment; landscape that provides a sensory experience; sounds and scents that provide a sensory*

		experience
Physical use of land-/seascapes in different environmental settings	*Resource-dependent businesses (kayak rental companies)*	*Opportunity for placement of infrastructure in environment*
	Experiencers and viewers	*Opportunity to view the environment; landscape that provides a sensory experience; sounds and scents that provide a sensory experience*
	Boaters	*Medium and conditions for recreational boating*
Existence values	*People who care*	*Knowing that the environment exists*
Bequest values	*People who care*	*Knowing that the environment exists*

4.2 List of stakeholders (Part I) compared to list of beneficiaries (FEGS):

List of stakeholders	List of beneficiaries	FEGS appropriate?
People living in the area	*Experiencers and viewers* *Boaters* *People who care*	*Yes*
Municipal wastewater agency	*Wastewater treatment plant operators*	*Yes*
Kayak rental companies located on the Aarhus River	*Resource-dependent businesses*	*Yes*
Cafes and restaurants located on the restored riverfront	*Resource-dependent businesses*	*Yes*

4.3 Intermediate and final ESS table:

Measure	Capability	ESS affected (use CICES and US EPA catalogue)					Beneficiaries (use US EPA categorization)[1]
		CICES section	CICES division	CICES group	CICES class	DESSIN ESS (use US EPA nomenclature where applicable)[2]	(no beneficiary = only intermediate service)
Aarhus restoration and real-time control system	Improvement of water quality via reduction of point and diffuse pressure	Regulation & Maintenance	Mediation of flows	Liquid flows	Hydrological cycle and water flow maintenance	**medium for discharging [treated municipal wastewater] into the environment**	**Wastewater treatment plant operators**
		Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Dilution by atmosphere, freshwater and marine ecosystems	**medium for discharging [treated municipal wastewater] into the environment**	**Wastewater treatment plant operators**
		Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals		
		Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals		
		Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Dilution by atmosphere, freshwater and marine ecosystems		
		Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Filtration/ sequestration/ storage/ accumulation by ecosystems		
		Regulation & Maintenance	Maintenance of physical, chemical, biological conditions	Water conditions	Chemical condition of freshwaters		

		Regulation & Maintenance	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats		
		Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	**Opportunity for placement of infrastructure in environment** **Opportunity to view the environment; landscape that provides a sensory experience; sounds and scents that provide a sensory experience**	**Resource-dependent businesses** **Experiencers and viewers**
		Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Physical use of land-/seascapes in different environmental settings	**Opportunity for placement of infrastructure in environment** **Medium and conditions for recreational boating**	**Resource-dependent businesses** **Experiencers and viewers** **Boaters**
		Cultural	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Other cultural outputs	Existence values	**Knowing that the environment exists**	**People who care**
		Cultural	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Other cultural outputs	Bequest values	**Knowing that the environment exists**	**People who care**
	Improvement of the physical structure of	Regulation & Maintenance	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats		

	watercourses by improving river morphology	Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Filtration/ sequestration/ storage/ accumulation by ecosystems		
		Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	**Opportunity for placement of infrastructure in environment**	**Resource-dependent businesses** **Experiencers and viewers**
		Cultural	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Other cultural outputs	Existence values	**Knowing that the environment exists**	**People who care**
		Cultural	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Other cultural outputs	Bequest values	**Knowing that the environment exists**	**People who care**

[1] The US EPA categorization of beneficiaries can be found in the appendix (pages 46-70) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

[2] The US EPA nomenclature of ecosystem services can be found in the appendix (pages 46-70) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Link between Intermediate ESS and FEGS:

Some of the intermediate ESS Listed in table 4.3 have the potential to contribute to the end-use cultural services. For example, Filtration/ sequestration/ storage/ accumulation by ecosystems contribute to improved water quality, which may improve the cultural ESS utilized by experiencers and viewers enjoying the restored riverfront. However, these ESS were not a consideration in the design of the project (i.e., the water quality targets have been achieved using grey infrastructure solutions).

STEP 5, 6, 7 & 8:

ESS FACTSHEET # 1

ESS HEAD	
Measure influencing the ESS	Aarhus restoration and real-time control system
Capability influencing the ESS	Improvement of water quality via reduction of point and diffuse pressure
CICES Section	Regulation & Maintenance
CICES Division	Mediation of waste, toxics and other nuisances
CICES Group	Mediation by biota Mediation by ecosystems
CICES Class	Bio-remediation by micro-organisms, algae, plants, and animals Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals Dilution by atmosphere, freshwater and marine ecosystems
ESS *(use US EPA nomenclature!)*[2]	None (Intermediate Service)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Rivers and streamsB) Lakes and ponds
Temporal scope	A) June-August B) June-August
Spatial scope	A) Aarhus River from Lake Brabrand to sea B) Lake Brabrand

FEGS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	Intermediate Service
For FEGS: Intermediary ESS required *(use CICES catalogue!)*	
For Intermediate services: FEGS affected & other Intermediate ESS required	Potential impact on downstream cultural services; however this ESS is not required to provide these services.
Regulatory Threshold	
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE

	Case-relevant Element	Indicator	Output unit	Data sources & data availability	Indicator quality *(see explanation in Box XX!)*	Data quality *(see catalogue in Box XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	Diffuse source pollution	1. Concentrations of bacteria in CSO discharges 2. Concentrations of BOD in CSO discharges 3. Flows rates from CSO discharge locations	1. cfu/L 2. mg/L 3. m^3/s	1. Model output 2. Expert judgement 3. Model output		
	Point source pollution	1. Concentrations of bacteria in WWTP discharges 2. Concentrations of BOD in WWTP discharges 3. Flows rates from WWTP discharge locations	1. cfu/L 2. mg/L 3. m^3/s	1. Expert judgment 2. Expert judgment 3. Model output		

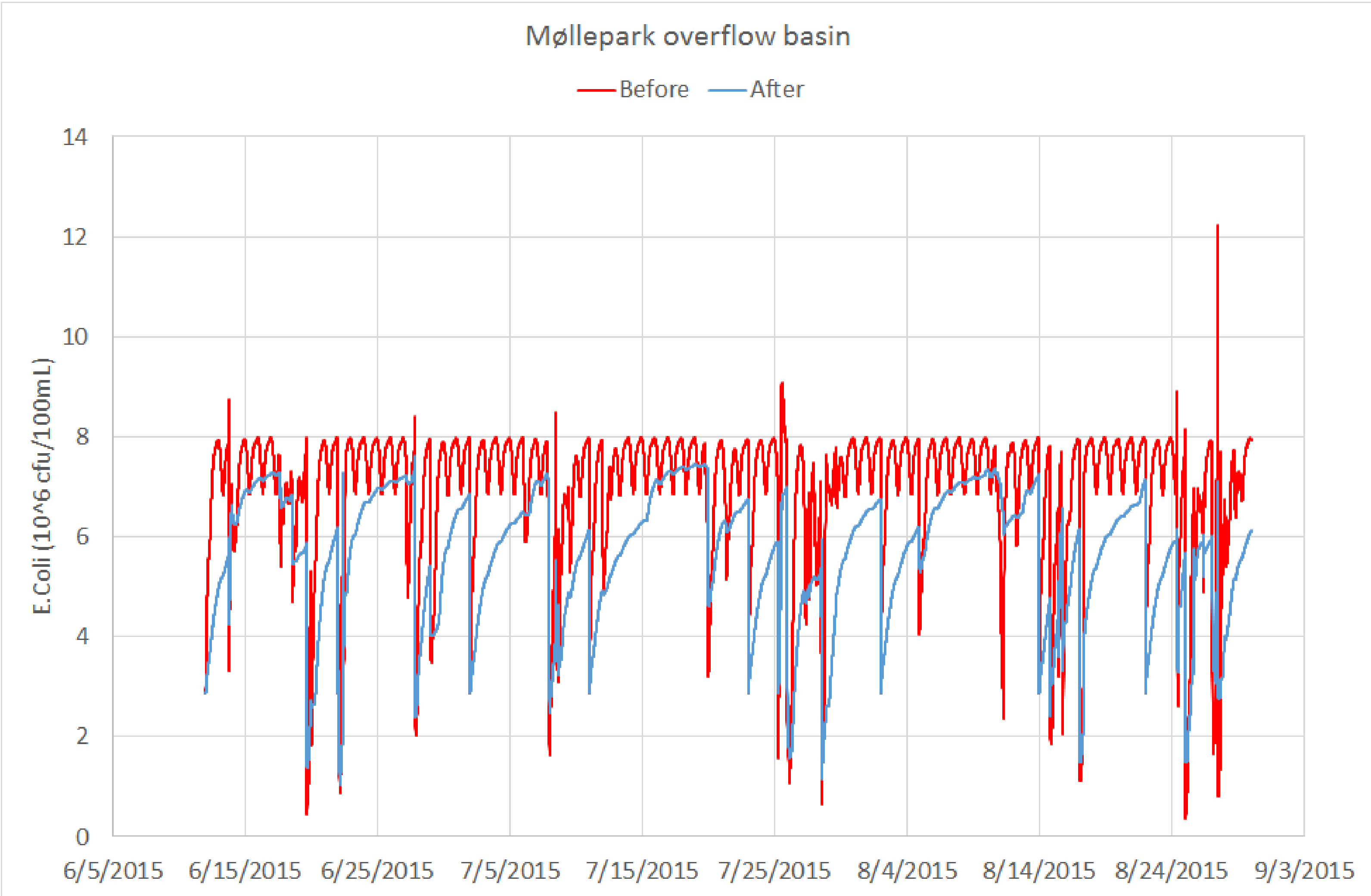
	Morphological disturbance	Length of covered river section	m	GIS analysis		
RESPONSE *(describe in detail)*	Real-time control system and associated infrastructure	1. Concentrations of bacteria in CSO discharges 2. Concentrations of BOD in CSO discharges 3. Flows rates from CSO discharge locations 4. Concentrations of bacteria in WWTP discharges 5. Concentrations of BOD in WWTP discharges 6. Flows rates from WWTP discharge locations	1. cfu/100mL 2. mg/L 3. m^3/s 4. cfu/100mL 5. mg/L 6. m^3/s	1. Model output 2. Expert judgement 3. Model output 4. Expert judgment 5. Expert judgment 6. Model output		
	Opening of river	Length of covered river section	m	GIS analysis		
STATE *(only those relevant for the assessment of Impact I)*	Oxygenation conditions	Concentration of dissolved oxygen in Aarhus River	mg/L	Model output		
	Pollution by other substances	1. Concentration of E.Coli in Aarhus River and Lake Brabrand 2. Concentration of Enterococci in Aarhus River and	1. Cfu/100mL 2. Cfu/100mL 3. mg/L	1. Model output 2. Model output 3. Model output		

		Lake Brabrand 3. Concentration of BOD in Aarhurs River				
	Percentage of days of surface water per year	% of analysis period with visible surface water flows	Dimensionless	Flow record		
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Degradation of E.Coli	Ratio of E.Coli exiting mouth of Aarhus River compared to amount entering Aarhus River and Lake Brabrand	Dimensionless	Model output		
	Degradation of Enterococci	Ratio of Enterococci exiting mouth of Aarhus River compared to amount entering Aarhus River and Lake Brabrand	Dimensionless	Model output		
	Degradation of BOD	Ratio of BOD exiting mouth of Aarhus River compared to amount entering Aarhus River and Lake Brabrand	Dimensionless	Model output		
IMPACT II - USE		*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - Monetization		*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
INDICATOR TABLE - Further explanation						

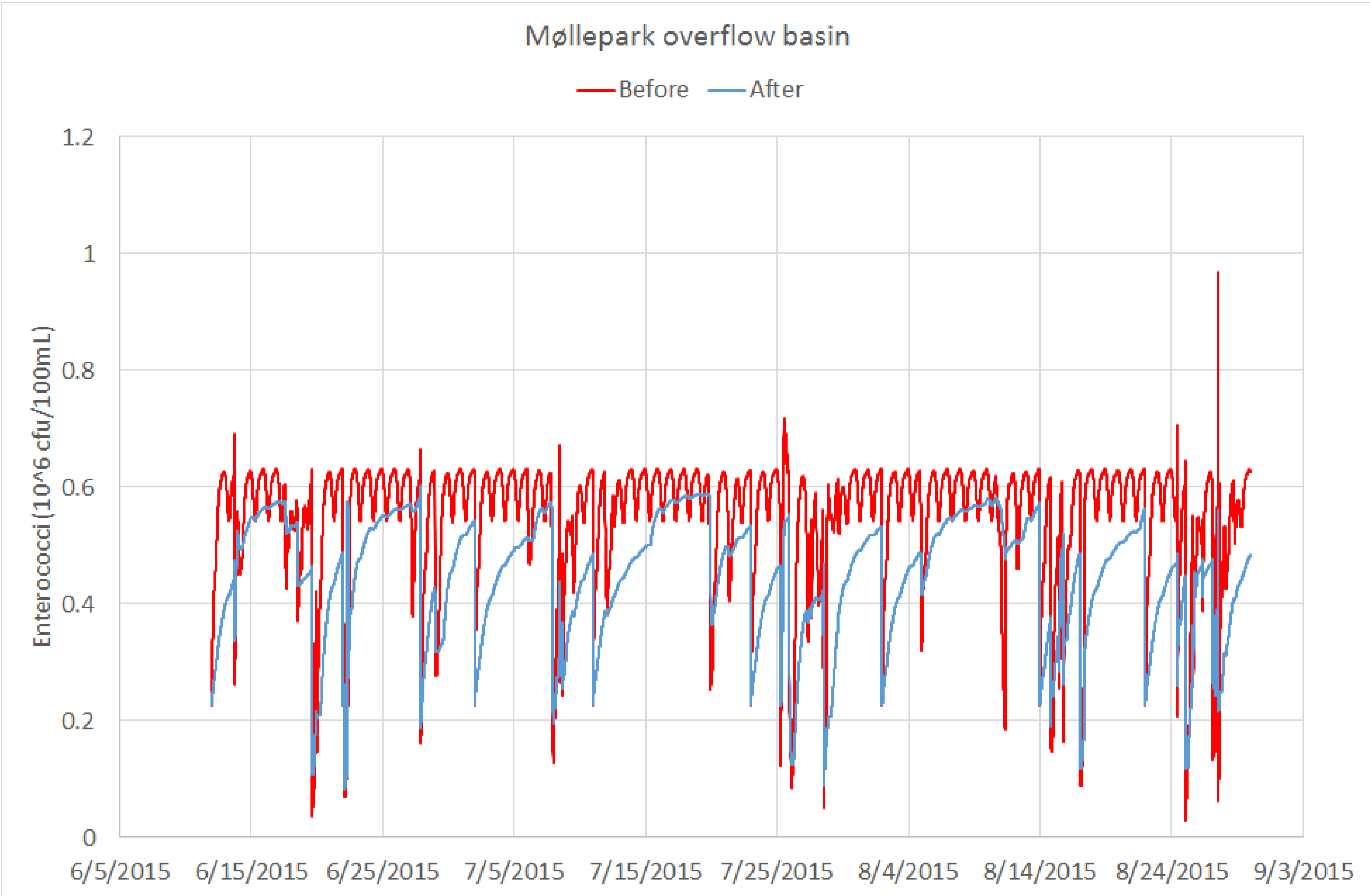
RESULTS TABLE				
	Case-relevant Element	Output	Output unit	Comments
PRESSURE	Diffuse source pollution: E.Coli concentration in CSO discharges	Timeseries ouput, see representative plots below	cfu/100mL	
	Diffuse source pollution: Enterococci concentration in CSO discharges	Timeseries ouput, see representative plots below	cfu/100mL	
	Diffuse source pollution: BOD concentration in CSO discharges	No change from “before” to “after”. Both assume constant 50 mg/L.	mg/L	
	Diffuse source pollution: CSO flow rates	Timeseries ouput, see representative plots below	mg/L	
	Point source pollution: E.Coli concentration in CSO discharges	No change from “before” to “after”. Both assume constant 15E+3 cfu/100mL.	cfu/100mL	
	Point source pollution: Enterococci concentration in CSO discharges	No change from “before” to “after”. Both assume constant 5E+3cfu/100mL.	cfu/100mL	
	Point source pollution: BOD concentration in CSO	No change from “before” to “after”. Both assume constant 20 mg/L.	mg/L	

	discharges			
	Point source pollution: CSO flow rates	Timeseries output, minimal difference between "before" and "after" scenario	mg/L	
	Length of covered river section	Before: 1000m After: 0m	m	
STATE	Oxygenation conditions	Timeseries ouput, see representative plots below	mg/L	
	Pollution by other substances: E.Coli	Timeseries ouput, see representative plots below	cfu/100mL	
	Pollution by other substances: Enterococci	Timeseries ouput, see representative plots below	cfu/100mL	
	Pollution by other substances: BOD	Timeseries ouput, see representative plots below	mg/L	
	Percentage of days of surface water per year	In central Aarhus, before: 0% In central Aarhus, after, 100%	Dimensionless	
IMPACT I - PROVISION	Degradation of E.Coli	Before: 37%	Dimensionless	More natural degradation of E.Coli takes place in the "after" scenario
		After: 75%	Dimensionless	
	Degradation of Enterococci	Before: 30%	Dimensionless	More natural degradation of E.Coli takes place in the "after" scenario
		After: 54%	Dimensionless	
	Degradation of BOD	Before: 20%	Dimensionless	Natural degradation of BOD about equal in the "before" and "after" scenarios
		After 25%	Dimensionless	
IMPACT II - USE		*not to be quantified*	*not to be quantified*	*not to be quantified*

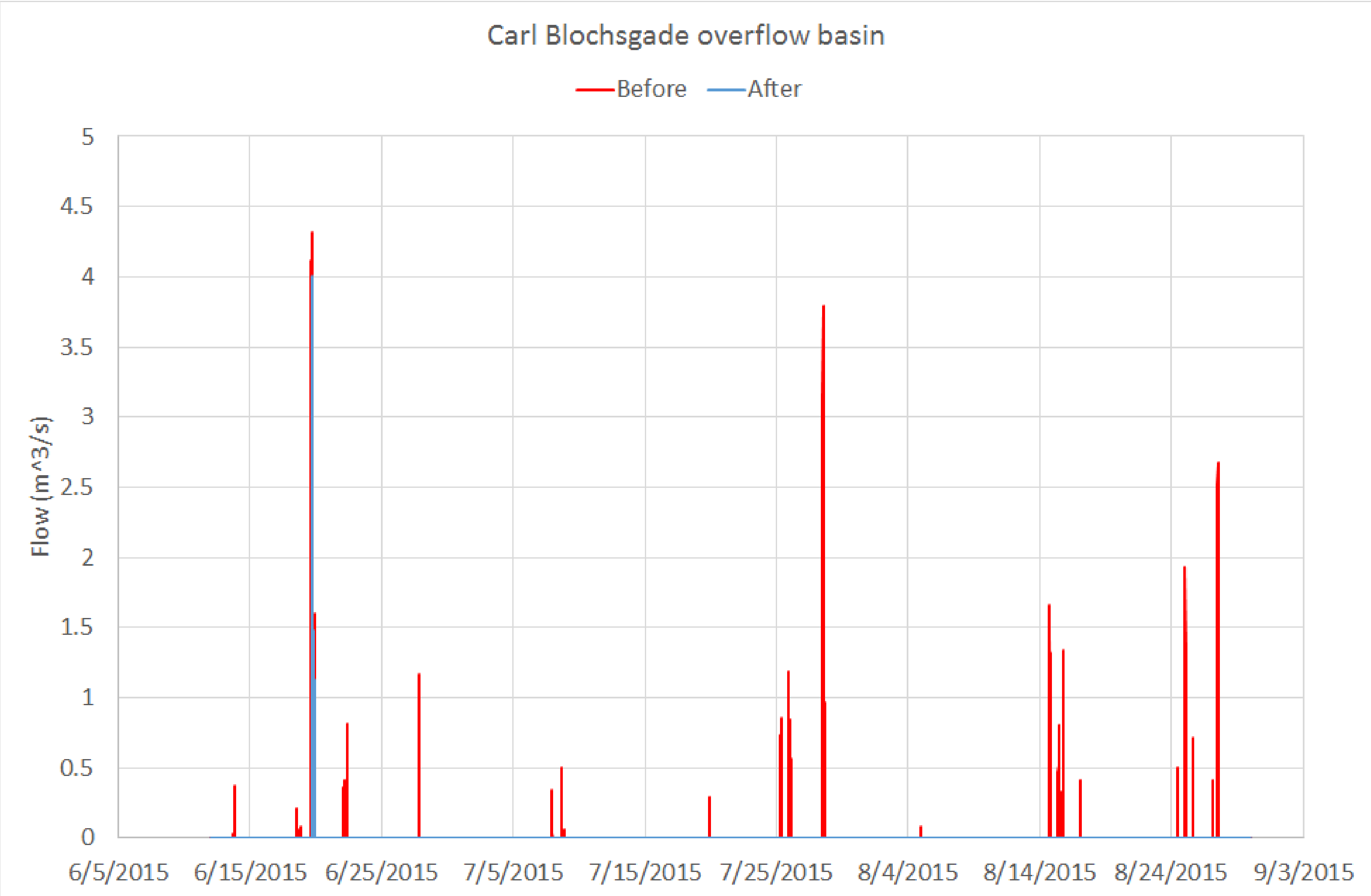
IMPACT II - Monetization		*not to be quantified*	*not to be quantified*	*not to be quantified*
RESULTS TABLE - Description				
Pressure indicator: Comparison of TS of E.Coli concentrations at Møllepark overflow basin				



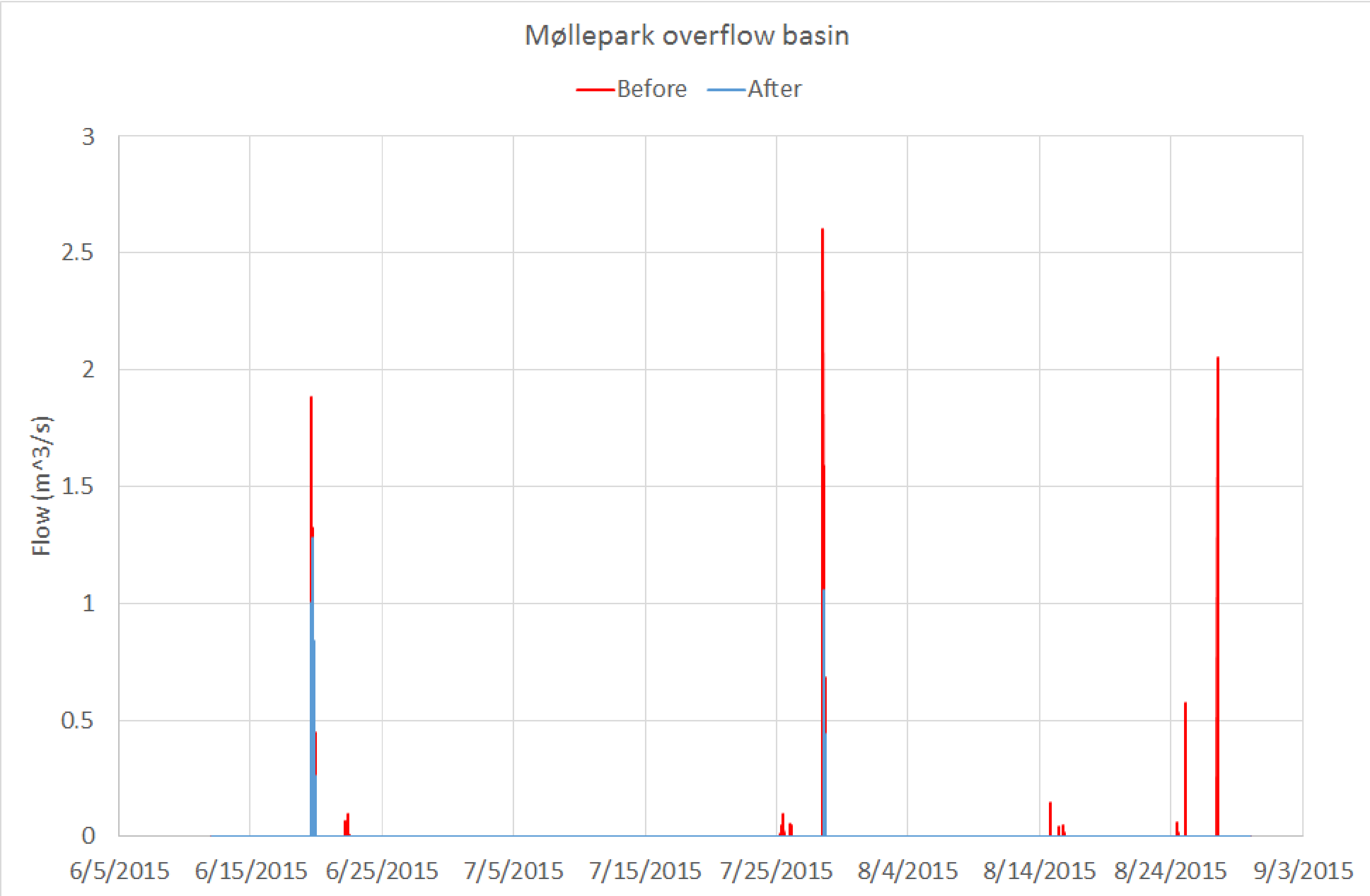
Pressure indicator: Comparison of TS of Enterococci concentrations at Møllepark overflow basin



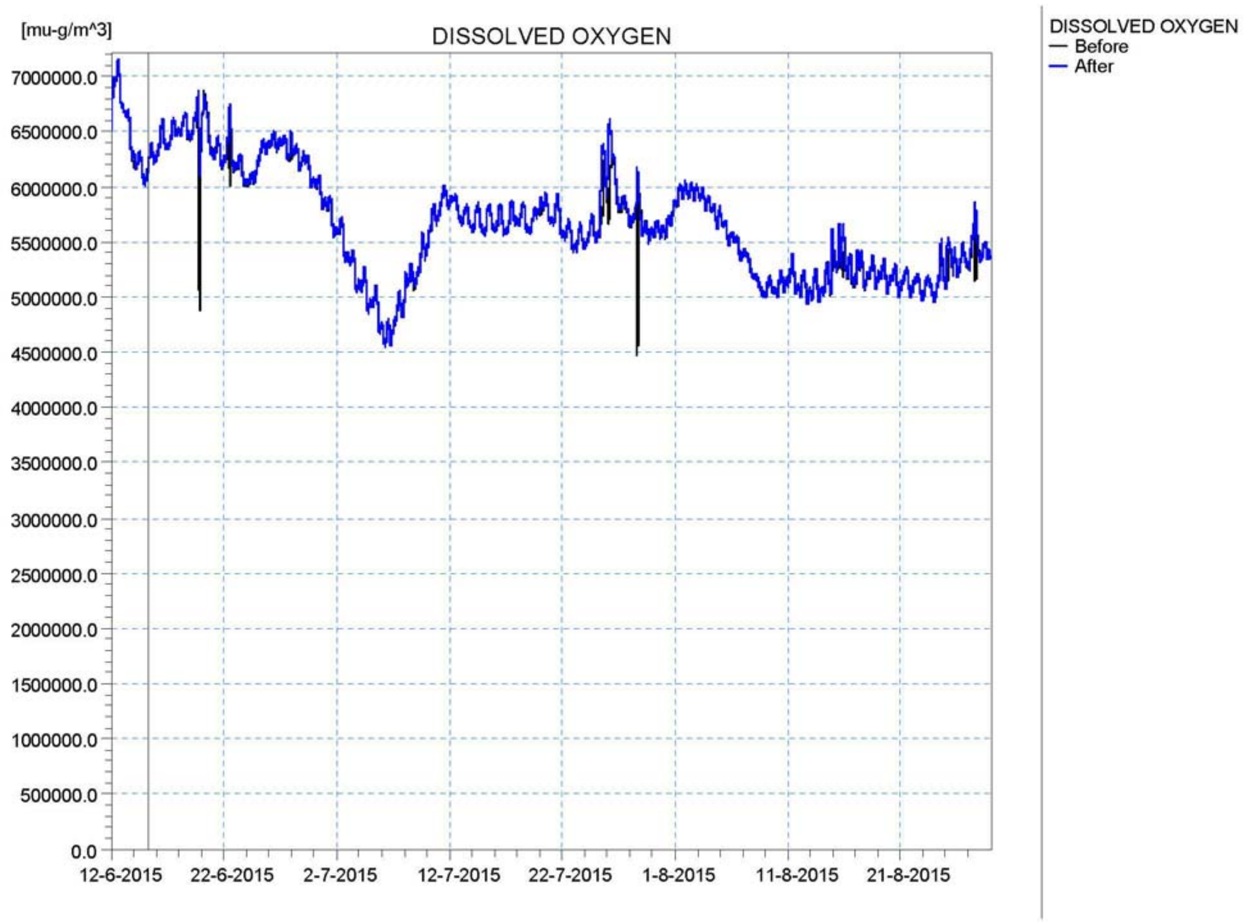
Pressure indicator: Comparison of TS of CSO discharges at Carl Blochsgade overflow basin



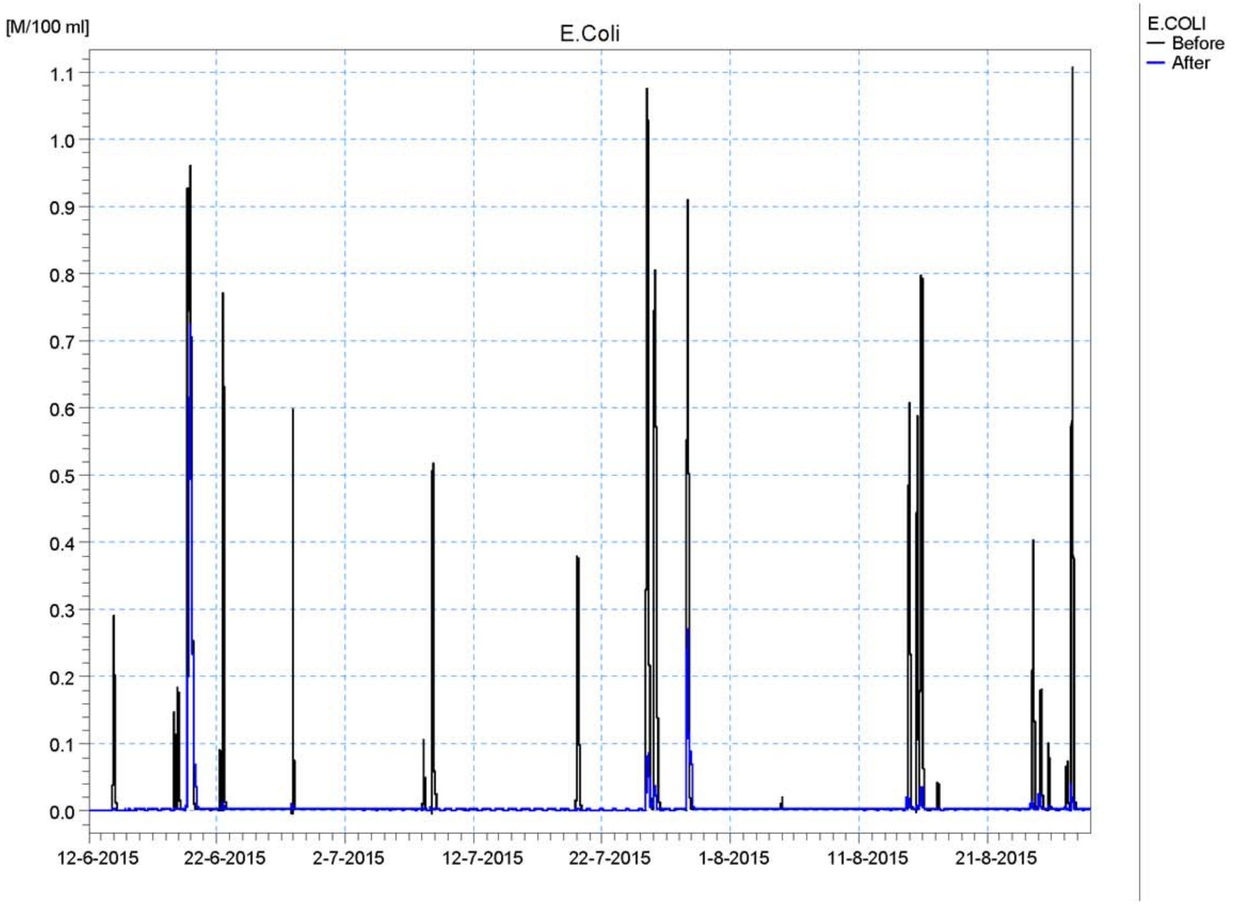
Pressure indicator: Comparison of TS of CSO discharges at Møllepark overflow basin



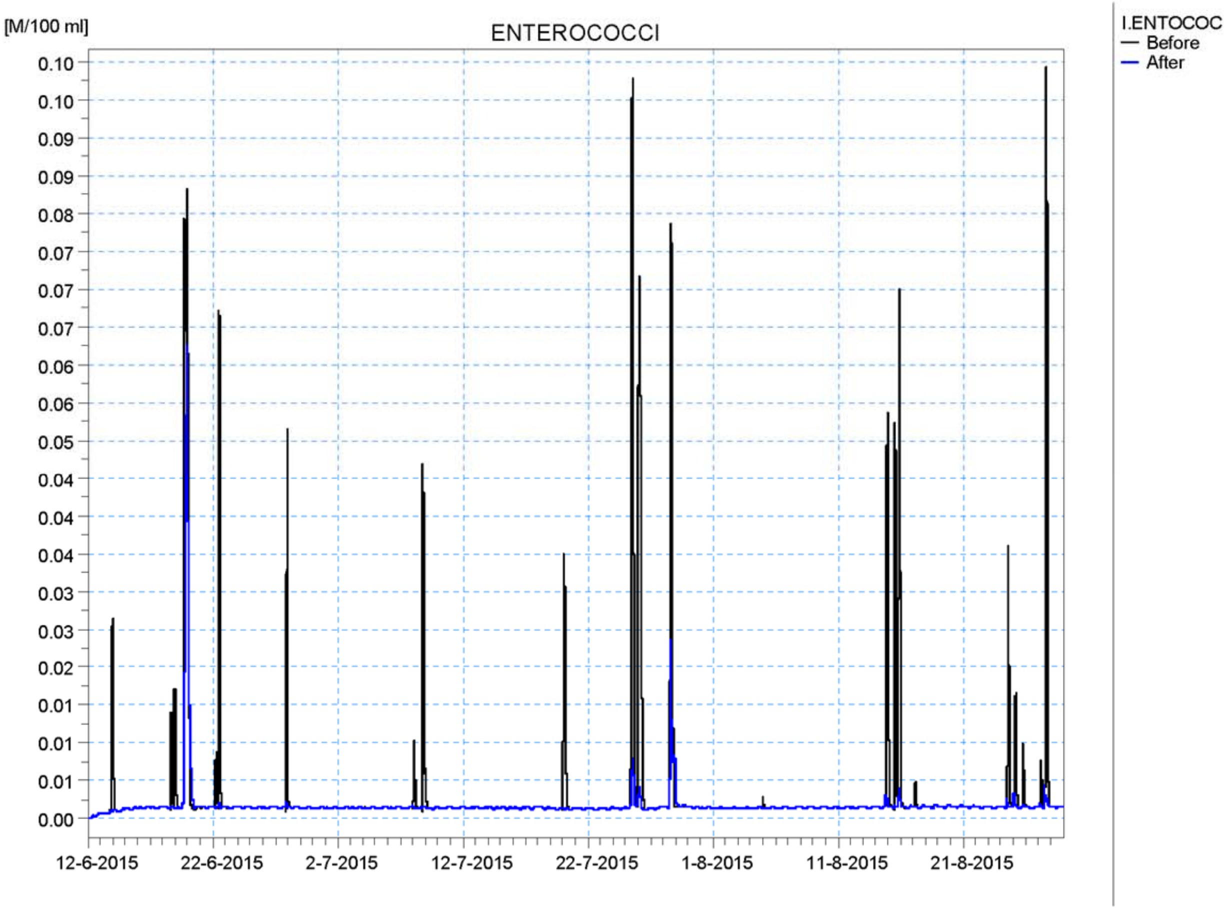
State indicator: Dissolved oxygen conditions near mouth of Aarhus River



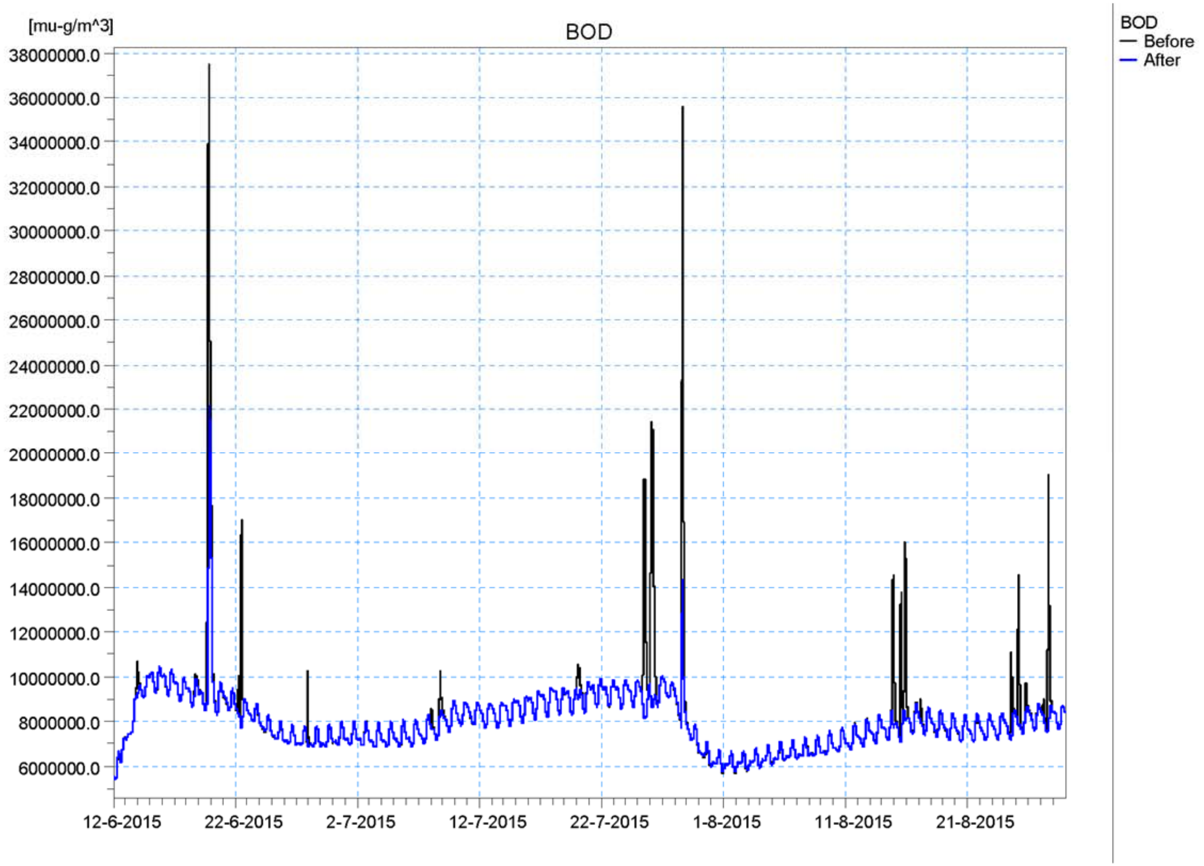
State indicator: E.Coli concentration near mouth of Aarhus River



State indicator: Enterococci concentration near mouth of Aarhus River



State indicator: BOD concentration near mouth of Aarhus River



[mu-g/m^3]
BOD
38000000.0
36000000.0
34000000.0
32000000.0
30000000.0
28000000.0
26000000.0
24000000.0
22000000.0
20000000.0
18000000.0
16000000.0
14000000.0
12000000.0
10000000.0
8000000.0
6000000.0
12-6-2015
22-6-2015
2-7-2015
12-7-2015
22-7-2015
1-8-2015
11-8-2015
21-8-2015
BOD
Before
After

ESS FACTSHEET # 2:

ESS HEAD	
Measure influencing the ESS	Aarhus restoration and real-time control system
Capability influencing the ESS	Improvement of water quality via reduction of point and diffuse pressure Opening of Aarhus River in central Aarhus
CICES Section	Cultural
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Physical and experiential interactions
CICES Class	Experiential use of plants, animals and land-/seascapes in different environmental settings
ESS *(use US EPA nomenclature!)*[2]	**Opportunity to view the environment; landscape that provides a sensory experience; sounds and scents that provide a sensory experience**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Rivers and streamsB) Lakes and ponds
Temporal scope	A) June-August B) June-August
Spatial scope	A) Aarhus River from Lake Brabrand to sea B) Lake Brabrand
FEGS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FEGS
For FEGS: Intermediary ESS required *(use CICES catalogue!)*	Hydrological cycle and water flow maintenance
For Intermediate services: FEGS affected & other	

Intermediate ESS required	
Regulatory Threshold	
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Experiencers and viewers

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Box XX!)*	**Data quality** *(see catalogue in Box XX!)*
DRIVER *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From*	Diffuse source pollution	1. Concentrations of bacteria in CSO	1. cfu/L 2. mg/L	1. Model output		

IMPRESS/WISE) (only those addressed by the capability??)		discharges 2. Concentrations of BOD in CSO discharges 3. Flows rates from CSO discharge locations	3. m^3/s	2. Expert judgement 3. Model output		
	Point source pollution	1. Concentrations of bacteria in WWTP discharges 2. Concentrations of BOD in WWTP discharges 3. Flows rates from WWTP discharge locations	1. cfu/L 2. mg/L 3. m^3/s	1. Expert judgment 2. Expert judgment 3. Model output		
	Morphological disturbance	Length of covered river section	m	GIS analysis		
RESPONSE *(describe in detail)*	Real-time control system and associated infrastructure	1. Concentrations of bacteria in CSO discharges 2. Concentrations of BOD in CSO discharges 3. Flows rates from CSO discharge locations 4. Concentrations of bacteria in WWTP discharges 5. Concentrations of BOD in WWTP	1. cfu/100mL 2. mg/L 3. m^3/s 4. cfu/100mL 5. mg/L 6. m^3/s	1. Model output 2. Expert judgement 3. Model output 4. Expert judgment 5. Expert judgment 6. Model output		

		discharges 6. Flows rates from WWTP discharge locations				
	Opening of river	Length of covered river section	m	GIS analysis		
STATE *(only those relevant for the assessment of Impact I)*	Oxygenation conditions	Concentration of dissolved oxygen in Aarhus River	mg/L	Model output		
	Pollution by other substances	1. Concentration of E.Coli in Aarhus River and Lake Brabrand 2. Concentration of Enterococci in Aarhus River and Lake Brabrand 3. Concentration of BOD in Aarhurs River	1. Cfu/100mL 2. Cfu/100mL 3. mg/L	1. Model output 2. Model output 3. Model output		
	Structure of the water body shoreline	Length of restored river section	m	GIS analysis		
	Percentage of days of surface water per year	% of analysis period with visible surface water flows	Dimensionless	Flow record		
	Probability of water-borne illness from partial body contact and full body contact with river	1. % of analysis period that concentration of E.Coli in Aarhus River exceeds that of tertiary WWTP effluent	1. Dimensionless 2. Dimensionless	1. Model output 2. Model output		

		2. % of analysis period that concentration of Enterococci in Aarhus Riverexceeds that of tertiary WWTP effluent				
	Presence and description of odor of human origin	% of analysis period that concentration of BOD exceeds 10 mg/L	Dimensionless	Model output		
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Provision of opportunity to experience riverfront environment	Dimensionless indicator aggregating state indicators 4-6 above, with all “after” case values set to one, and all “before” case vales set to a weighted fraction of the corresponding “after” case values.	Dimensionless	Aggregate of state indicators		
IMPACT II - USE	Use of opportunity to experience riverfront environment	Number of individuals residing within a distance of 8 km.	Numver of individuals	GIS analysis		
IMPACT II - Monetization	Change in property values resulting from creation of the restored river area	Marginal contribution of one hectare of new park area to house prices withing a 1000m radius	€	GIS analysis		
		Marginal contribution of one hectare of new park area to apartment prices withing a	€	GIS analysis		

		600m radius				
		Marginal contribution of one new type of business to house prices withing a 1200m radius	€	GIS analysis		
		Marginal contribution of one new type of business to apartment prices withing a 1000m radius	€	GIS analysis		
		Marginal negative contribution of one new bar, café, or restaurant to apartment prices withing a 100m radius	€	GIS analysis		
INDICATOR TABLE - Further explanation						

RESULTS TABLE				
	Case-relevant Element	Output	Output unit	Comments
PRESSURE	Diffuse source pollution: E.Coli concentration in CSO discharges	Timeseries ouput, see representative plots in ESS 1 presentation	cfu/100mL	
	Diffuse source pollution: Enterococci concentration in CSO discharges	Timeseries ouput, see representative plots in ESS 1 presentation	cfu/100mL	
	Diffuse source pollution: BOD concentration in CSO discharges	No change from “before” to “after”. Both assume constant 50 mg/L.	mg/L	
	Diffuse source pollution: CSO flow rates	Timeseries ouput, see representative plots in ESS 1 presentation	mg/L	
	Point source pollution: E.Coli concentration in CSO discharges	No change from “before” to “after”. Both assume constant 15E+3 cfu/100mL.	cfu/100mL	
	Point source pollution: Enterococci concentration in CSO discharges	No change from “before” to “after”. Both assume constant 5E+3cfu/100mL.	cfu/100mL	
	Point source pollution: BOD concentration in CSO discharges	No change from “before” to “after”. Both assume constant 20 mg/L.	mg/L	
	Point source pollution: CSO flow rates	Timeseries output, minimal difference between “before” and “after” scenario	mg/L	
	Length of covered river section	Before: 1000m After: 0m	m	

STATE	Oxygenation conditions	Timeseries ouput, see representative plots below	mg/L	
	Pollution by other substances: E.Coli	Timeseries ouput, see representative plots in ESS 1 presentation	cfu/100mL	
	Pollution by other substances: Enterococci	Timeseries ouput, see representative plots in ESS 1 presentation	cfu/100mL	
	Pollution by other substances: BOD	Timeseries ouput, see representative plots in ESS 1 presentation	mg/L	
	Length of restored river section	Before: 0 After: 1000	m	
	Percentage of days of surface water per year in lower Aarhus River	Before: 0% After: 100%	Dimensionless	
	Probability that E.Coli concentration exceeds concentration of WWTP effluent	Before: 8.1% After: 3.1%	Dimensionless	Assessed near downstream end of Aarhus River
	Probability that Enterococci concentration exceeds concentration of WWTP effluent	Before: 6.2% After: 1.8%	Dimensionless	Assessed near downstream end of Aarhus River
	Probability that BOD concentration exceeds 10 mg/L	Before: 5.3% After: 2.2%	Dimensionless	Assessed near downstream end of Aarhus River
IMPACT I - PROVISION	Dimensionless indicator aggregating state indicators 4-6 above, with all "after" case values set to one, and all "before" case vales set to a	Before: 0.195 After: 1	Dimensionless	Presence of surface water weighted highest, followed by odor, and then probability of illness through partial body

	weighted fraction of the corresponding “after” case values.			contact
IMPACT II - USE	Use of opportunity to experience riverfront environment	186,760	Number of persons living within 8km of restored river section	
IMPACT II - Monetization	Change in house values resulting from creation of the restored river area	35.3E+6	€	
	Change in house values resulting from new types of businesses located at restored river area	5.3E+6	€	
	Change in apartment values resulting from creation of the restored river area	64E+6	€	
	Change in apartment values resulting from new types of businesses located at restored river area	23.6E+6	€	
	Change in apartment values resulting from more cafes, bars, and restaurants located at restored river area	-9.8E+6	€	
RESULTS TABLE - Description				

This section presents results for indicators suggested by the DESSIN Sustainability Assessment that are considered relevant for the Aarhus case. It was not possible to estimate values for all indicators. In cases where it was not possible to estimate indicator values, comments are given where appropriate.

Social dimension

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
S111	Presence of microbial pathogens in water bodies used for recreational activities	Percent of time during simulation period that E.Coli concentration exceeds 15E+3/100mL	ESS evaluation	8.06%	3.07%	Thresold concentration is based on typical concentration for wastewater effluent. Simulation period is 12 June 2015 to 29 August 2015.
S111	Presence of microbial pathogens in water bodies used for recreational activities	Percent of time during simulation period that Enterococci concentration exceeds 5E+3/100mL	ESS evaluation	6.24%	1.75%	Thresold concentration is based on typical concentration for wastewater effluent. Simulation period is 12 June 2015 to 29 August 2015.

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
S121	Economic impact (incl. Indirect and induced impacts) derived from initial spending for the solution itself	Amount spent on implementing project (€)	Aarhus Municipality	Not applicable	47,000,000 €	Amount reflects direct spending on the project itself, information about indirect and induced impacts not available (identical to indicator F111)
S131	Number of jobs, amount of employment created by implementation of technology/solution			Not applicable	Not available	Unlikely that new jobs were created, as no new positions were created in the water utility to run the real-time control system
S132	Number of jobs, amount of employment derived from improved cultural services			Not applicable	Not available	Likely that many new jobs were created due to the construction of bars, restaurants, and other amenities located along the restored river section
S141	Number of beneficiaries affected	Number of beneficiaries	GIS analysis	Not applicable	186,760	Number of residents living within 8 km
S142	Categories of beneficiaries affected			Not applicable	Not available	

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
S151	Economic impact via new or growing business from recreation/visiting activities or other types of economic growth linkted to the solutions effects on the ecoystem	Economic value (€)	ESS evaluation	Not applicable	120,000,000 €	Not possible to distinguish between two values (based on estimates of changes in property values that include both commercial and residential properties)
S152	Non-market value of recreational/visiting activities	Economic value (€)				

Environmental dimension

DESSIN SA parameter ID	Parameter	Value (before)	Value (after)	Comments
En121	Efficient use of energy	Not applicable	Not available	
En124	Green energy usage	Not applicable	Not available	
En125	Energy consumed	0	Not available	Although no indicators are available, the project has resulted in an increased use of energy because of additional pumping stations, control gates, and other elements of the real-time CSO control system

DESSIN SA parameter ID	Parameter	Value (before)	Value (after)	Comments
En131	Materials, chemicals and other consumables	Not applicable	Not available	
En132	Recovery of wastes	Not applicable	Not available	

Financial dimension

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
F111	Investment expenditure in €	Expenditure (€)	Aarhus Municipality	0 €	47,000,000 €	
F112	Annual operational expenditure in €	Expenditure (€)	Aarhus Municipality	0 €	600,000 €	
F113	Avoided costs and / or additional monetary benefits from enhanced ecosystems use	Economic value (€)	ESS evaluation	Not applicable	120,000,000 €	Identical to S151/152
F114	Other sources of financing aligned to the solution			Not applicable	Not available	A small portion of the project was funded through participation in the EU PREPARED project.

Governance dimension

DESSIN SA parameter ID	Parameter	Source	Value (before)	Value (after)	Comments
G111	Compliance improvement w/ relevant EU standards (WFD, BWD)	Aarhus Municipality	Not compliant	Compliant	One of the drivers of the Aarhus project was a plan to create a public bathing area in the Aarhus Harbor. The EU BWD was used to define the bathing water quality targets that should be met at the harbor bathing area. Because the DESSIN analysis area (the restored reach of the Aarhus River) does not include the harbor or harbor bathing area, we do not have quantitative indicator values avaiable for this metric. However, bathing water quality in the harbor bathing area has been improved as a result of the project so that BWD compliance has been achieved.
G112	Compliance with relevant national, local standards	Aarhus Municipality	Not compliant	Compliant	National standards for bathing water quality are identical to EU (BWD) standards.
G121	Number of actors/stakeholders involved in operations and monitoring		Not applicable	Not available	
G122	Communicative events		Not applicable	Not available	
G131	Monitoring		Not applicable	Not available	
G132	Information dissemination		Not applicable	Not available	

Assets dimension

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
A112	Mean time between failure		Aarhus Municipality	Not applicable	25 years	Estimated system lifetime used in project cost-benefit analysis
A131	Adaptive capacity as: The probability that the item is able to function at time t (availability at time t) for any given loads	Annual overflow volume to Aarhus River given 20% increase in precipitation (m^3)	Aarhus Municipality	700,000	318,900	20% increase is intended to represent climate change scenario
A141	[Hours of exposed or "dirty work" on the site/total hours of work per year]*100			Not applicable	Not available	Although no quantitative indicator is available, this was a major consideration in the design of the project. The project that was eventually built did not include local treatment of CSO discharges because it was thought that servicing of local treatment facilities would require working in high-risk settings that could result in workplace injuries.

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
A142	Risk episodes, injuries on the site/total hours of work in test period			Not applicable	Not available	Same as above
A151	percentage of load removed (E.Coli)	Percent of load to river that is degraded during simulation period	ESS Evaluation	36.9%	75.1%	Simulation period is 12 June 2015 to 29 August 2015.
A151	percentage of load removed (Enterococci)	Percent of load to river that is degraded during simulation period	ESS Evaluation	30.5%	54.1%	Simulation period is 12 June 2015 to 29 August 2015.
A151	percentage of load removed (BOD)	Percent of load to river that is degraded during simulation period	ESS Evaluation	25%	20%	Simulation period is 12 June 2015 to 29 August 2015.

DESSIN SA parameter ID	Parameter	Indicator	Source	Value (before)	Value (after)	Comments
A211	Number of complaints about the technology (due to for instance Noise, Dust, Estetics, landscape)/reference time			Not applicable	Not available	
A222	Start-up time			Not applicable	Not available	

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DESSIN
DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

DESSIN

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D13.1: Quantified ESS for 3 mature sites including recommendations for application

Part 2: Emscher case

Lead Author: Emschergenossenschaft, April 2016

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D13.1: Quantified ESS for 3 mature sites including recommendations for application
PART 2 - Emscher case

SUMMARY

This Deliverable reports the results of the application of the ESS Evaluation Framework (D11.2) for the Emscher mature case.

DELIVERABLE NUMBER	WORK PACKAGE
13.1	WP13
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
Emschergenossenschaft	Gerner, N. (EG); Nafo, I. (EG); Birk, S. (UDE); Winking, C. (UDE); Wortberg, T. (UDE); Wencki, K. (IWW); Strehl, C. (IWW); Niemann, A. (UDE)
QUALITY ASSURANCE	
Internal	By Nafo, Birk, Wencki, Strehl, and the internal DESSIN expert group of Emschergenossenschaft.
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DISSEMINATION LEVEL	x PU = Public □ PP = Restricted to other programme participants □ RE = Restricted to a group specified by the consortium. Please specify: ________________________________ □ CO = Confidential, only for members of the consortium

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Table of contents

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List of Acronyms and Abbreviations

C	Carbon
COD	Chemical oxygen demand
CSO	Combined sewer overflow
EG	Water management association Emscher (“Emschergenossenschaft”)
ESS	Ecosystem Service
FEGS	Final Ecosystem Goods and Services
FESS	Final Ecosystem Service
GEP	Good ecological potential
GIS	Geographical Information System
IESS	Intermediate Ecosystem Service
N	Nitrogen
NRW	North-Rhine-Westphalia
P	Phosphorous
SI	Saprobic index
TOC	Total organic carbon
UDE	University of Duisburg-Essen
WFD	Water Framework Directive
WTP	Willingness to pay
WWTP	Wastewater treatment plant

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List of Figures

List of tables

Executive summary

In the **Emscher mature case study** we evaluated the changes in ecosystem services (ESS) resulting from a large-scale restoration project. This restoration project, the Emscher re-conversion, started with the construction of an underground sewer network in the Emscher catchment. Subsequently, it aims at restoring all water bodies which have been open sewage channels for the last 100 years. As part of the restoration is already completed, data are available for comparing ecosystem characteristics before and after the conversion took place. Based on this data, the DESSIN ESS Evaluation was applied to assess resulting changes in several ESS. Where required, data gaps were filled using predictions or estimations.

Following the Steps 0 to 8 of the **DESSIN Cookbook**, we started the assessment with the description of the study area and its characteristics. In this step, we also identified the most important stakeholders in the area. Later on, this step is helpful for the detection of beneficiaries of ESS. Subsequently, the most important Drivers and Pressures were identified. By providing a detailed description of the Response, which is in this case the Emscher re-conversion, it was found that the Response aims at alleviating from the Pressures rather than to affect the Drivers. The reduction in Pressures results in an improved State of the ecosystem under study. Several relevant parameters of State were identified and indicators selected and assessed. Based on these parameters of State affected by the Response, hypothetically existing ESS were listed along with their respective hypothetical beneficiaries. The latter were compared with the list of stakeholders which was developed in the beginning. Those ESS having a beneficiary, were classified into final ESS (FESS) while the remaining ESS were classified as Intermediate ESS (IESS) in case they act as prerequisites for the provision of FESS.

The IESS and FESS identified and assessed in this case study are:

- IESS # 1: *Self-purification: N retention*
- IESS # 2: *Self-purification: P retention*
- IESS # 3: *Self-purification: C retention*
- IESS # 4: *Biodiversity*
- FESS # 1: *Opportunity for placement of infrastructure and reduced risk of flooding*
- FESS # 2: *Opportunity for placement of infrastructure in environment*
- FESS # 3: *Opportunity for biking & recreational boating*
- FESS # 4: *Opportunities to understand, communicate, and educate*
- FESS # 5: *Knowledge that a restored river area exists, with suitable water quality (i.e. Good ecological potential (GEP))*

These IESS and FESS were assessed using indicators. The FESS were further monetized using economic methods. Finally, the resulting benefit was compared to the initial spending for implementation of the solution.

Further ESS were identified as being case-relevant but were not assessed quantitatively in this study:

- ESS: *CO_2 sequestration*
- ESS: *Local climate regulation*
- ESS: *In-stream cooling effect*
- ESS: *Research opportunities*
- ESS: *Drinking water provision in the downstream Rhine catchment*

These ESS were described qualitatively.

Furthermore, **climate change related challenges** were discussed and possible impacts on ESS provision and use were described qualitatively.

As part of the DESSIN Cookbook, we also conducted a **sustainability assessment** of the Emscher re-conversion. This assessment provides information on a number of environmental, social, financial as well as governance and assets related aspects which were not yet covered in the ESS assessment.

Introduction

This document reports on the application of the DESSIN ESS Evaluation Framework in the Emscher mature case study. The DESSIN Cookbook was followed step-by-step in order to identify case-relevant key ESS, quantify them via appropriate indicators, and value the changes in ESS provision resulting from the measure conducted.

In the Emscher case, the Emscher re-conversion project, a large scale restoration project, represents the innovative solution or measure, whose effects on ESS provision are to be evaluated. As the Emscher catchment has sections (streams or sub-catchments) in different restoration stages – some of which are already fully restored – a comparison of before and after the implementation of the solution is possible.

According to DESSIN's Description of Work, the application of the Framework was conducted for individual streams or stream sections of the Emscher River network and the results were transferred or scaled up across the multi-site case study. This allows a prognosis for the whole catchment. Final ecosystem service provision is related and compared to the total costs of the restoration project for the river network as a whole. This comparison takes into consideration the lifetime of the effects of the measure as well as the time for implementation of the measure. A comparison of costs and benefits for individual sections was not appropriate, as for some ESS (e.g. *Opportunity for biking*) a partitioning of the resulting benefit into individual sub-catchments is not possible.

An assessment of service provision for restoration scenarios (like e.g. for an intermediary restoration stage) was not useful, as for instance the evaluation of some biological indicators for different restoration stages was not meaningful.

Predicted climatic changes in the area were considered and effects on ESS were assessed qualitatively in order to demonstrate future trends and shifts in importance of single ESS.

A sustainability assessment was conducted for the Emscher restoration in accordance with Part V of the DESSIN ESS Evaluation Framework as well.

SETTING THE SCENE

Step 0. SETTING THE SCENE

0.1 Administrative details

The present Ecosystem Services Evaluation study is conducted by Emschergenossenschaft (EG) in collaboration with University Duisburg-Essen (UDE) and IWW as part of the EU FP7 project DESSIN. EG's main tasks are wastewater treatment, care and maintenance of water bodies, flood protection, regulation of water flows, groundwater and rainwater management, and two major and outstanding keynote tasks that were agreed upon by the associates: the construction of underground wastewater channels and the re-naturalization of the open wastewater conduits.

0.2 Objectives of the assessment

The assessment is conducted with the aim of (i) testing the ESS Evaluation Framework proposed and (ii) identifying the benefits resulting from the Emscher re-conversion project for subsequently conducting a cost-benefit analysis. The intended audiences are researchers working on the topic of ESS as well as potential practitioners for the application of the ESS Evaluation Framework.

0.3 Overview of the study area

The Emscher catchment is located on the eastern side of the Rhine River in the federal state of North-Rhine Westphalia (NRW; Figure 1). About 2.2 M people live and work in the Emscher catchment, the so called “Ruhrgebiet”, which is one of the most densely populated areas in Europe (Table 1).

The Emscher catchment basin covers 865 m^2 and belongs to two geographical regions in the Northern Lowlands: Westphalian Lowlands and Lower Rhine Plain. The highest and lowest elevation in the catchment is 150 m above sea level at the Emscher source in Holzwickede, south east of Dortmund and 25 m at the Emscher mouth in Dinslaken, where it meets the River Rhine (Figure 2). The Emscher River is 85 km long and the total length of the stream network within the basin is 341 km. Mean discharge at Emscher mouth is approximately 16 m^3/s. The basin is exposed to temperate seasonal climate with maritime influence. Average annual temperatures range from 8.5 and 10.5 °C with mean annual precipitation of 800 mm.

Figure 1: Location of the Emscher catchment within North-Rhine Westphalia, Germany, and Europe.

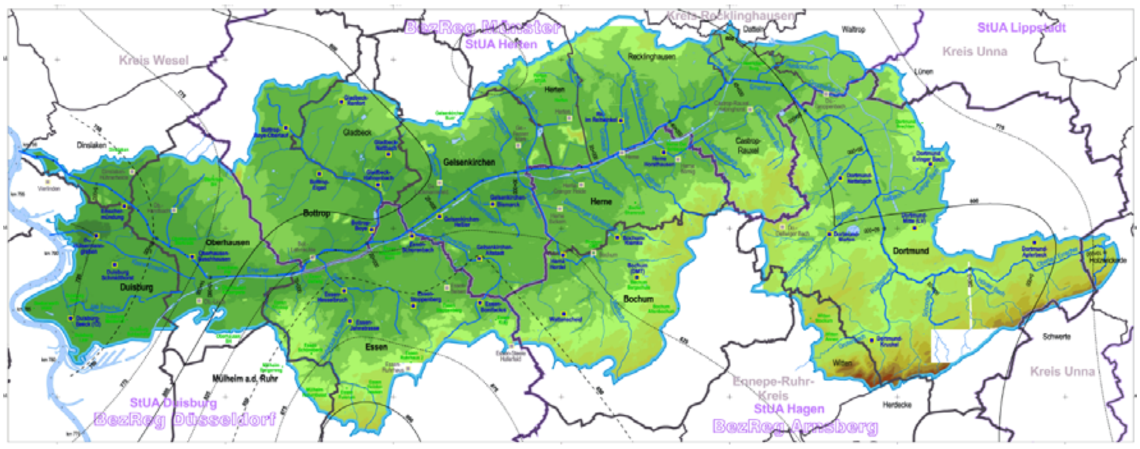

Figure 2: Physical map of the Emscher catchment, colour code for elevation (green: 3-20 m above sea level, brown: 220-257 m above sea level) (source: Hydrotec, Hochwasser-Aktionsplan Emscher, 2004)

Until 1860, the Emscher River was a slow flowing, meandering river (Figure 3) with a length of 109 km from its source in Holzwickede to its discharge into the river Rhine, draining a catchment of approximately 784 km².

The former land use in the Emscher basin was mainly urban settling, coal mining, steel production and steel processing. A shipping channel and a network of roads were built for that purpose.

With the start of industrialization and a rapid urban growth by 1860, the regular inundation of the extensive Emscher floodplains resulted in frequent flooding of the urban and industrial areas close to the river. In addition, the Emscher River received increasing amounts of waste water originating from industry and settlements. Flooding of the contaminated river lead to the spreading of water-borne diseases and epidemics.

Flood defense required coordinated efforts of the municipalities along the Emscher River that founded the Emschergenossenschaft (EG) in 1899, associating individual cities of the Ruhrgebiet, and mining and industrial companies active in the area. The main task of this association was to assure water and waste water discharge and to avoid further flooding, resulting in a straightened and channelized Emscher River. As a result of this first Emscher conversion, the original river length was reduced to 85 km; floodplains were cut off and at the water bodies were lowered by up to 5 m; further actions were channel bed fixation with concrete beds as well as shore embankment.

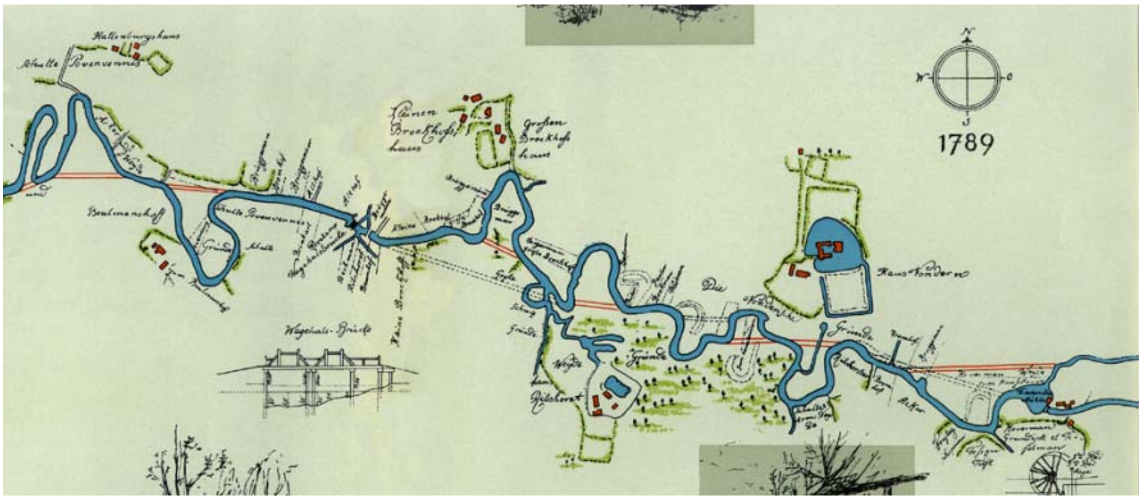

Figure 3: Emscher catchment in 1789

Mining subsidence in the area resulted in depressions of up to 30 m, causing disturbed river discharge and rising groundwater levels. To restore the water flow, pumping stations were built in the entire catchment and the river mouth was relocated northwards to Dinslaken, increasing the catchment size to 865 km². Continuing mining subsidence precluded the use of culverts for wastewater discharge to avoid leakage due to braking pipes. Wastewater was thus discharged in open aboveground channels. Underground discharge, separated from the natural river bed, was not considered possible because subsidence would have caused underground pipes to break.

With ending of the industrial area in the 1960s mining subsidence slowly diminished. By 1990, culverting became feasible again, advancing the planning of the second Emscher conversion or Emscher re-conversion. The aim was to separate the wastewater from the river water, using culverts routing the sewage to wastewater treatment plants (WWTP). Eventually, the original Emscher River and its tributaries should be revitalized.

To date, 40% of the Emscher area is depressed due to mining subsidence. This generates a constant need for controlling the water discharge and groundwater level in the catchment, performed by pumping stations (Figure 4).

Figure 4: Emscher catchment with subsidence areas (yellow) approximately 40% of the catchment area).

Today's land use is a very densely populated area with 17 cities that form one metropole conglomerate. Agriculture is less prominent in this area then in NRW in average; business has shifted towards service companies. A shipping channel in parallel of the Emscher and a network of highways and roads is present. Artificial land cover (incl. urban settlements, industrial areas and transport infrastructure) amounts to ~ %, agricultural land use ~ 18% (incl. pastures and cropland), natural area (incl. 12.5% of forested area) ~ 22% (Emschergenossenschaft 2009). 2.2 M inhabitants live in the Emscher basin with a mean population density of 2,775 inhabitants/km². During industrialization the number of inhabitants in the Ruhr area as increased steeply, however, with high fluctuations. In 2006, 400,000 people less lived in the area compared to 1961. Further decrease in inhabitant number is expected by the Landesamt für Datenverarbeitung und Statistik Nordrhein-Westfalen (LDS NRW) and the Bertelmann-Stiftung (Junkernheinrich et al. 2008). Making up only 2.5% of the area of NRW, the Emscher region achieves 10.5% of NRW's total annual gross value added (MUNLV NRW 2006).

Table 1: Emscher socio-economic data (Source: Emschergenossenschaft 2009)

Area	Data
Catchment area	865 km² (= 2.5% of state NRW)
Population	2.2 M inhabitants
Population per km²	2,775 inhabitants /km²
Artificial land cover	~ 50%
Agricultural land cover	~ 18%
Natural land cover (incl. forested area)	~ 22%

The people in the area are used to avoid the streams in the area since 1900, when the streams turned into a system of open wastewater channels. In a densely populated area, places for local recreation are highly demanded. Therefore, one of the main benefits from the Emscher re-conversion is to re-allow the experiencing of the Emscher River and its tributaries and to bring recreation along waterways back to the people.

Spatial scale of ESS assessment:

The Emscher basin comprises the main Emscher River and its tributaries divided into nine subcatchments. In this study, we selected eleven “focus streams” (Figure 5), i.e. river sections at the Emscher and its tributaries differing in their ecological development potential and in the date of restoration („age“). The case-relevant key ESS for the Emscher case are evaluated for these focus streams and, in a second step, the results are transferred and scaled up to the entire Emscher catchment.

Upscaling to basin level is conducted via similarity of stream profiles (width, depth, form), based on 5 different profile types.

ESS provision beyond the Emscher catchment area is not assessed (e.g. drinking water provision in the downstream Rhine River).

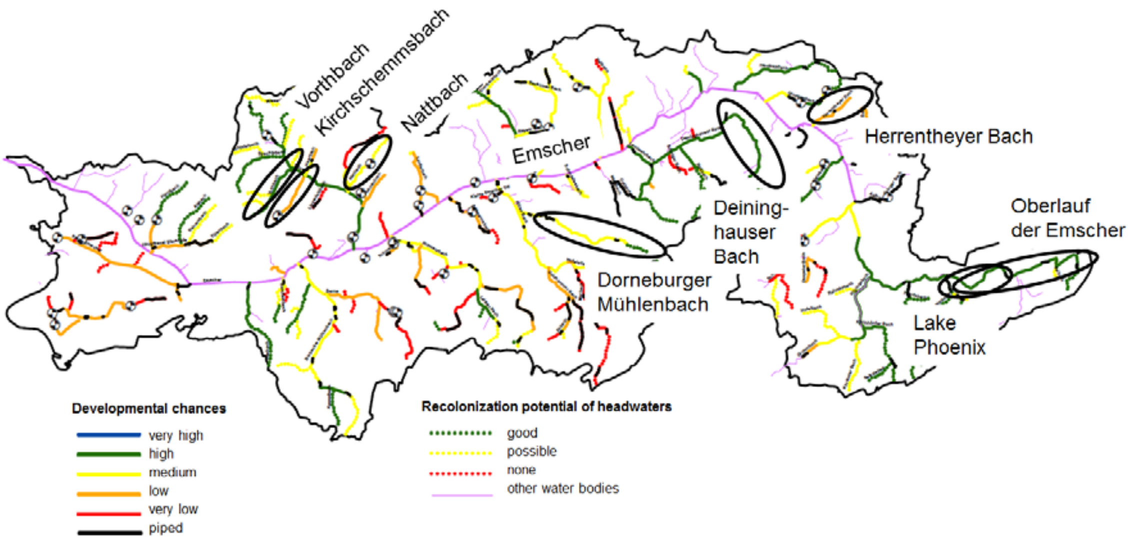

Figure 5: Focus streams within the Emscher basin. Color codes indicate ecological development potential of the streams (Source: Semrau et al. 2007).

Temporal scale of ESS assessment:

The 30-year project Emscher re-conversion started in 1990 and is intended to be completed in 2020. Thus, the Baseline scenario we consider is the scenario “BEFORE” and the scenario after implementation is “AFTER” the Emscher re-conversion.

0.4 Stakeholder list

The following local stakeholders could be identified based on the Description of work of DESSIN. They consist of representatives from governmental and non-governmental organizations, water utilities and water boards, environmental interest groups, business facilitators, water users and others.

- People living in the area
- Recreators (boaters, bikers, walkers)
- Researchers, environmental educators
- Industry
- Mining companies
- Industrial forestry
- NGOs
- Water board (= WWTP operator, CSO operator)
- Chambers of commerce
- Industrial memorial tourism

0.5 Terminology

No further additions needed. For abbreviations, see the list of acronyms.

DRIVERS

Step 1. DRIVERS

The challenges in the region are diverse; however, all of them are related to the former mining activities (coal mining, steel production), industrialization, and urbanization. During more than a century, wastewater was transported together with the Emscher surface water in open waste water channels. Both the Emscher and its tributaries were channelized and surrounded by dikes, which turned them into heavily modified water bodies. This is also recognized in the WFD's requirements concerning the Emscher catchment.

1.1 DRIVER: Flood protection

Flood protection – along with the need to discharge wastewater – was the most important driver for the first Emscher conversion, resulting in a manmade open wastewater system. Though the second Emscher conversion aims at renaturalizing the streams, an adequate level of flood protection has to be guaranteed at any time.

1.2 DRIVER: Industry

Industry is an important factor since the 1860s, when coal mining, steel production and steel processing started. Now it has shifted towards service providers.

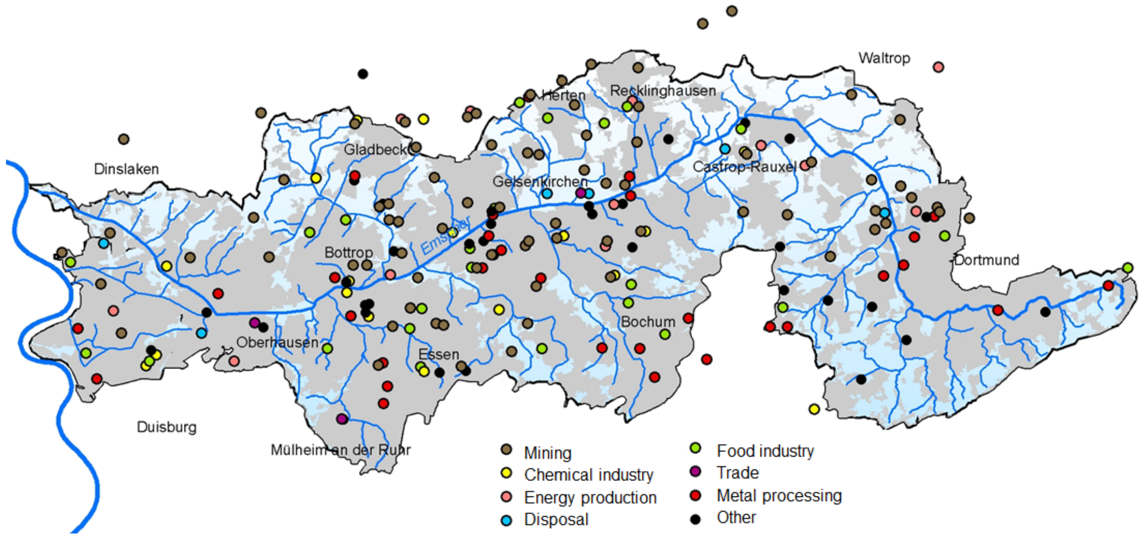

Figure 6: Industry and commerce in the Emscher basin (Source: Emschergenossenschaft 2009)

1.3 DRIVER: Tourism & recreation

Tourism in the Ruhr area is not relevant except for some industrial/cultural heritage sites. Local recreation, however, is very important for the inhabitants of the Emscher cities.

1.4 DRIVER: Transport

A dense network of transport routes through the area shapes the landscape and often run alongside of the Emscher or its tributaries. These include roads, highways, and the most travelled railway route in Germany. Shipping does not take place in the Emscher, however, an artificial shipping channel (the Rhein-Herne-Kanal) was built just alongside the Emscher.

1.5 DRIVER: Urban development

The urban development in the Emscher basin started in the 1860s and the basin is now one of the world's most densely populated areas. About half of the area in the basin is artificial land cover. The respective land use is commonly progressing directly up to the water body environment.

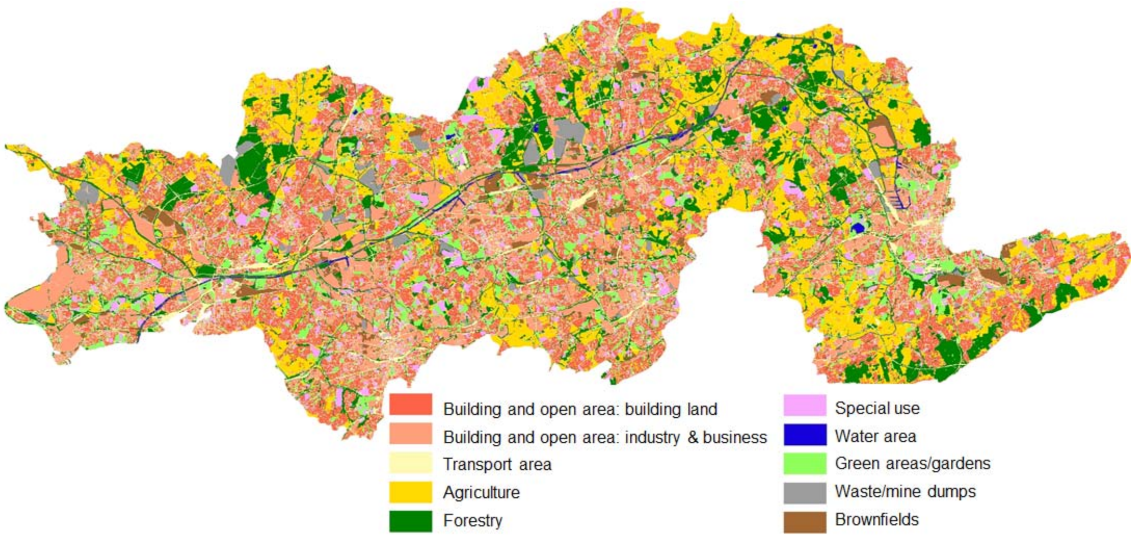

Figure 7: Land use in the Emscher basin. (Source: Landesvermessungsamt NRW 2006)

PRESSURES

Step 2. PRESSURES

The drivers in the Emscher basin as described above, are all strongly linked to and resulting from each other. Subsequently, also the pressures resulting from them are interwoven.

2.1 PRESSURES: Industry, urbanization and transport related pressures

Diffuse sources of industrial pollution can result from run-off following deposition of air emission. Also run-off from roads and sealed surface is to be considered.

However, mainly point sources of pollution are of concern. After completion of the Emscher re-conversion, these point sources will be: 290 CSO facilities and 4 large-scale WWTPs. The volume of waste water disposed in the basin is 0.6 billion m^3/a. Due to the dense population and the high variety of industrial branches, the pollution consists of diverse substances. Municipal wastewater consists of mainly an organic carbon load as well as nutrients (nitrogen and phosphorus) but also of pharmaceutical residuals, and pesticides/biocides. Industrial wastewater can contain high loads of hydrocarbons and metals. Mining effluents contain hydrocarbons and metals as well as high chloride loads.

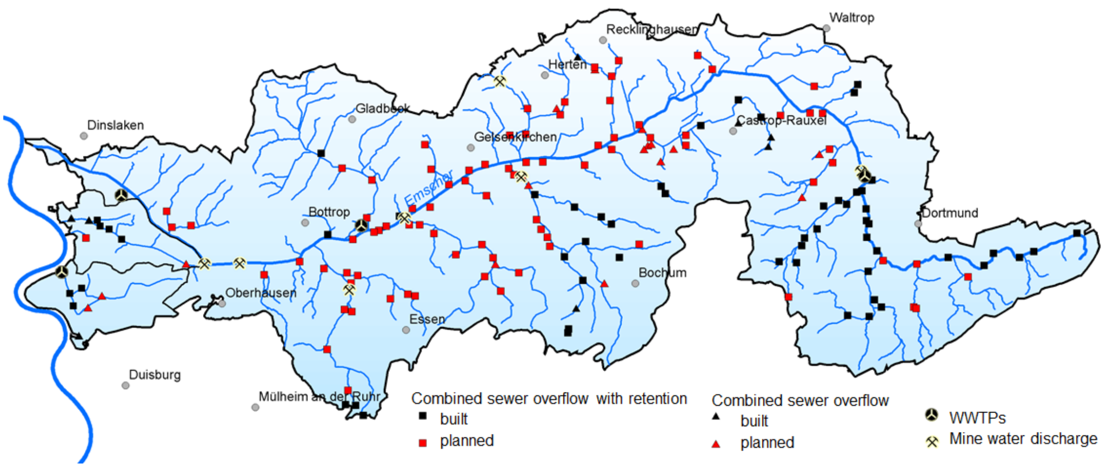

Figure 8: Point sources to the Emscher streams (CSOs and communal WWTPs), status 2008 (Source: Emschergenossenschaft 2009)

Apart from diffuse and point source pollution, the morphology of the landscape was changed in order to create dry area for industry, housing, and transport ways. These drained subsidence areas are assured by a flood protection concept for the entire basin, described in the next paragraph.

2.2 PRESSURES: Flood protection related pressures

The requirement for flood protection in the area led to the decision to channelize the streams and encase them by dikes in the end of the 19^{th} century. This caused an alteration of stream morphology and hydrology. At that time, also pumping stations and other manmade structures were installed to maintain the discharge function of the Emscher and its tributaries, which was disrupted due to subsidence. All these activities resulted in hydromorphological pressures.

PART III – Description of Responses and identification of potential beneficiaries

RESPONSES

Step 3. RESPONSES

3.1 Description of the proposed measure

The re-conversion of the Emscher River and its tributaries is the measure/innovative solution which is being evaluated in this study. It is a restoration project, lasting for 30 years (from 1990 until 2020) and affecting all water bodies in the catchment. The total budget for this multi-site project is 4.5 billion €.

The restoration process consists of two steps:

1st step:

The separation of surface water and wastewater by constructing an underground combined sewer network (with a total of 423 km of sewers) both along the Emscher tributaries and the Emscher River itself. Via this step the water quality is considerably improved.

2nd step:

Subsequently, the Emscher and its tributaries are renaturalized aboveground in their morphology and connectivity. A total of 341 stream km will be restored in the catchment.

As part of this multi-site project, several technologies have been taken up as part of the Emscher re-conversion. These are, e.g.:

- four large-scale energy efficient WWTPs,
- 290 combined sewer storage channels storing large volumes of water during rain events,
- 7 large-scale pumping plants necessary to allow waste water in the future Emscher waste water channel to reach the river Rhine and 121 pumping plants to drain subsidence areas and connect tributaries to the Emscher main stream,
- innovative ideas for flood water retention areas, such as a public lake (Lake Phoenix, Dortmund), a zoo (Zoom, Gelsenkirchen), vegetated basins, secondary floodplains.

A scheme of the Emscher re-conversion process is depicted in Figure 9.

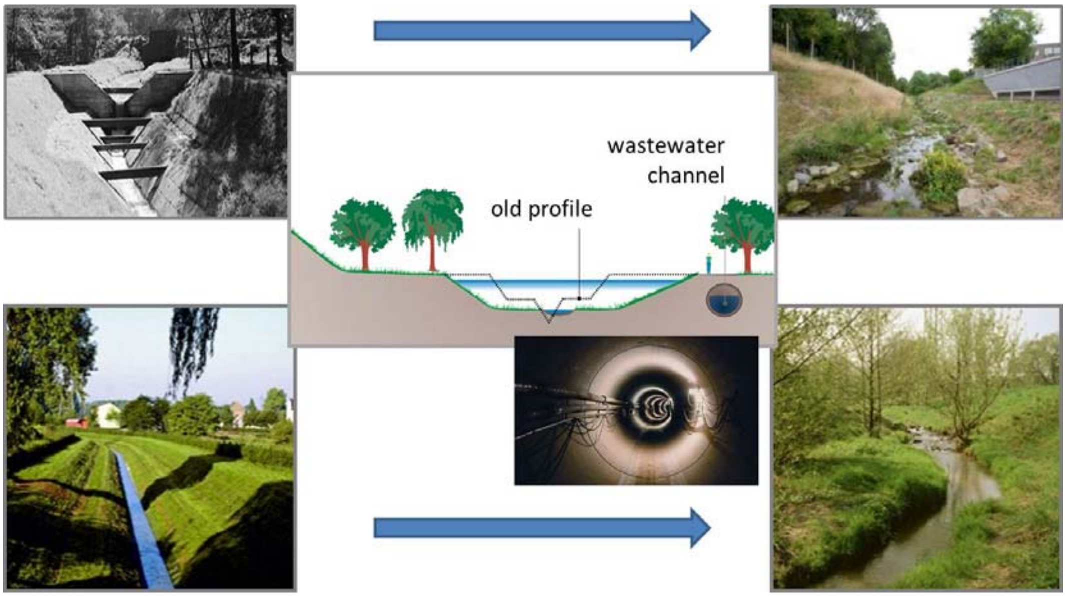

Figure 9: Emscher re-conversion. Left: open wastewater channels in the former river beds before restoration, center: conversion process by building underground wastewater channels and widening the river profile, right: near natural river bed after restoration.

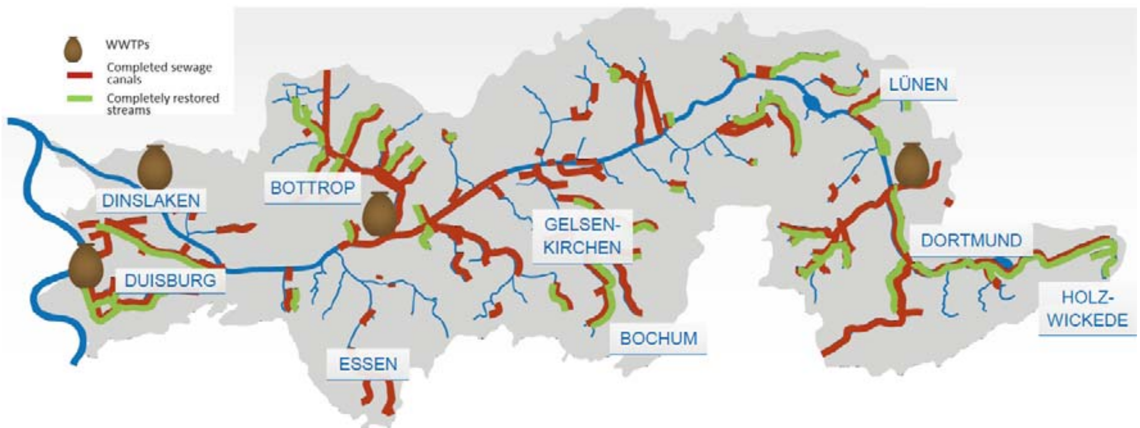

Figure 10: Emscher re-conversion progress, status 2015, showing the two steps: 1st building of sewage system (red) and WWTPs and 2nd restoring streams (green), status 2015.

3.2 Claimed/expected capabilities of the proposed measure

The Emscher re-conversion has the following capabilities:

- Improvement of water quality (tested)
- Reduction in the frequency of overflow events (tested)
  - After the Emscher re-conversion, 290 CSO facilities will exist, able to hold a total volume of combined sewage of 571,826 m³. An area of 200.5 km² (¼ of the catchment) will be drained by the system. Additionally, a volume of 165,000 m³ can be retained inside the sewage channels. This results in a storage capacity of 32 m³/ha.

- Improvement of the physical structure of watercourses (tested)

3.3 Driver, Pressure, and/or State affected by the capabilities

No DRIVERS are affected by the Emscher re-conversion.

However, the following PRESSURES are affected by the capabilities:

- Reduction of point and diffuse pressure

  These pressures can be, for instance, organic or chemical pollution reaching the streams via run-off (diffuse) or from CSO facilities during rain events (point). Also oxygen-depleted effluent from WWTPs to streams is a relevant point pressure.

- Reduction in the frequency of overflow events

  Combined sewer overflow events represent point sources at which combined sewage is discharged into recipient waters during rain events.

- Mitigation of morphological alteration

  Drivers such as flood protection and urbanization caused straightening and channelizing of streams, representing morphological alterations.

Each of these reduced pressures results in an improvement of various parameters of STATE.

- A reduction of point and diffuse pressures allows for physicochemical conditions within the recipient water bodies coming closer to natural conditions. These physicochemical parameters are, for instance, transparency, thermal conditions, oxygenation conditions, salinity, and nutrient conditions. Also the concentrations of hazardous substances discharged into the water body are reduced via a reduction of this pressure.

- A reduction in the frequency of overflow events also represents a reduction of a point pressures, in this case, from CSOs. As a result, the same physiochemical parameters as mentioned above are affected.

- A mitigation of morphological alteration affects the hydromorphology of streams, bringing hydrology and morphology closer to the natural state. Hydrology reflects the parameters water quantity, the dynamics of water flow as well as water residence time. Morphology is concerning depth and width variation in a water body, the structure and the substrate of a stream bed as well as the structure of the shoreline.

All capabilities also positively affect biological parameters of STATE, e.g. the occurrence and abundance of macrophytes and phytobenthos, and similarly, aquatic communities of benthic invertebrates and fish.

Furthermore, all capabilities result in improved cultural parameters of STATE. These parameters are, for instance, human appreciation and interest or dislike and concern in relation to water, vegetation, fish and wildlife, odor, noise and infrastructure as well as the presence of other people.

3.4 Case-relevant ESS

Case relevant ESS are expected to be changed as an effect of the Emscher re-conversion's capabilities on Pressures and State. The case-relevant ESS identified for the Emscher case are listed in the Annex (Table Step 3.4). These represent all ESS from the CICES classification (Haines-Young, Potschin 2013) that are hypothetically changed due to the proposed measure.

Step 4: Identification of expected beneficiaries of the changes introduced by the proposed measure

4.1 Comparison of case-relevant ESS with potential beneficiaries and FESS

Following the DESSIN Cookbook, all final ESS (FESS) that correspond to the case-relevant ESS selected in Step 3.4 are selected from Landers, Nahlik (2013) (Annex, Table Step 4.1). Each of the identified FESS is listed together with the respective beneficiaries (Landers, Nahlik 2013).

4.2 List of stakeholders (Part I) compared to list of beneficiaries (US EPA)

Finally, based on list of stakeholders (Part I), we identified those beneficiaries actually present in our study area. These are:

- Residential Property Owners
- People who care
- Boaters
- Experiencers and Viewers
- Researchers
- Educators and Students

There is no Drinking Water Treatment Plant in the Emscher basin which could benefit from water provision for drinking. There are also no industries which use the Emscher water for non-drinking purposes. Thus, there are no direct beneficiaries for provisioning services (water provision) in the Emscher region. As the Emscher River is a tributary of the Rhine River it contributes to drinking water provision in the downstream Rhine catchment area. This ESS provision, however, is beyond the spatial scope of the present assessment.

4.3 Categorization of case-relevant ESS into Intermediate ESS and final ESS

Combining the output of 3.4 and 4.3 results in the list of ESS below. Which *Intermediate ESS* might be preconditions for *final ESS* is shown by arrows.

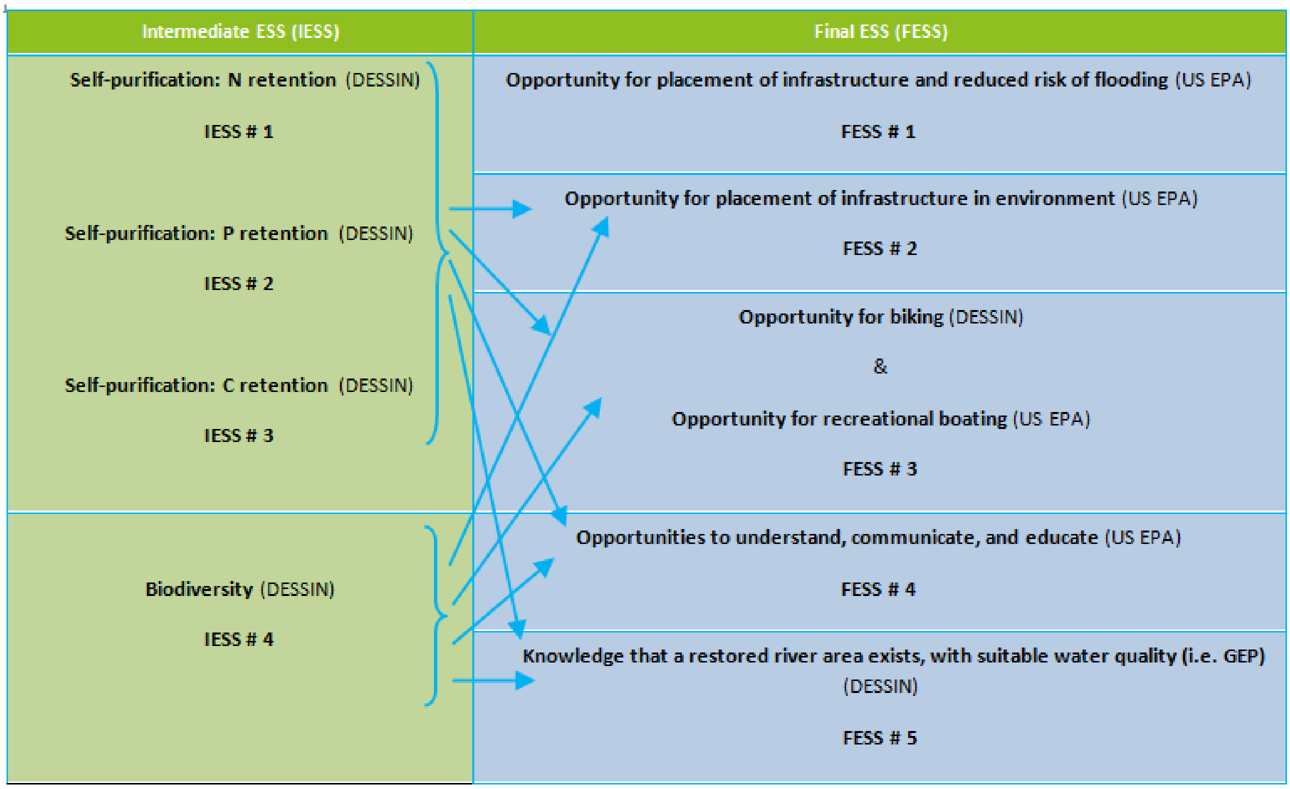

Figure 11: Key Intermediate ESS (Regulating & Maintenance ESS, green) and final ESS (Cultural ESS, blue) relevant for the Emscher mature case that are to be evaluated. Arrows show the links between IESS and FESS.

These *Intermediate ESS* and *final ESS* will be assessed. IESS that are case relevant but are not assessed are CO_2 sequestration (Global climate regulation by reduction of greenhouse gas concentrations) and Local climate (Micro and regional climate regulation). Similarly, a FESS not assessed is: Research opportunities (Educational). These ESS are only discussed qualitatively.

5. STEPs 5, 6, 7 and 8

For each of the case-relevant ESS mentioned above, the STEPS 5, 6, 7 and 8 are conducted one after the other. In STEP 5 parameters hypothetically affected by the proposed measure were identified. In STEP 6 indicators for quantifying Impact I Provision were selected. In STEP 7 appropriate economic methods for assessing Impact II - Use and resulting benefits were chosen. Finally, in STEP 8 a quantification of the expected changes in State, Impact I and Impact II before and after implementation of the measure was conducted. The identified parameters, selected indicators and economic methods, and the respective results are presented and discussed below for each ESS.

Note that for all IESS, the evaluation process stops after the Impact I Provision assessment, because no direct beneficiary within the study area could be identified. Thus, there is no use of this ESS by humans and, therefore, also no change in human well-being (i.e. no resulting benefit).

For FESS, on the other hand, beneficiaries are present in the area and are using the services which are provided by the ecosystem. Therefore, a use and a benefit could be assessed. Note, however, that for FESS we could not assess the Impact I Provision by the ecosystem. Furthermore, FESS are dependent on the provision of IESS but this dependency could not be quantified.

Regarding the results of the quantitative IMPACT II assessments it shall be noted, that no complete aggregation of the different calculated economic figures was pursued. This is due to the fact that the results partly express figures with different "economic meanings". So by simple means their direct unadjusted aggregation is theoretically incorrect, since different economic evaluation methods have been used for each calculation. The aggregation would need a careful interpretation and adjustment process which was out of scope of this mature case study. For additional information on this topic it shall be referred to the explanations in Step 7 of the DESSIN cookbook and in chapter 5 of the companion document.

5.1 IESS # 1: Self-purification: N retention

The Regulating & Maintenance service "*Nitrogen retention*" is provided by a denitrification capacity of streams (A) and floodplains (B). This denitrification service is conducted by bacterial communities on the surface of and within the sediment/soil. Nitrifying bacteria transform ammonium (NH_4+) to nitrites (NO_2-), and subsequently, the nitrites to nitrates (NO_3-). Denitrifying bacteria then transform nitrates to atmospheric nitrogen (N_2). This process leads to a removal of the nutrient nitrogen from the river water. It takes place at the water-sediment interface in the river itself (A) and at the land-water interface of the floodplain during flooding (B). Thus, the process mainly depends on the wetted or potentially wetted surface. In the floodplain, the soil type is also important, as the second part of the process is occurring under anaerobic conditions only. The initial N concentration in the water is of importance when a final N concentration is to be obtained or a load removal is to be calculated.

As part of the Emscher re-conversion, stream profiles are widened and secondary floodplains are connected (Figure 12). This increases the stream bed area (A) and also provides a larger water-sediment surface where N turnover can place. Furthermore, on the enlarged water-sediment and land-water surface vegetation can grow, holding back P and C from the river water (see 5.2 and 5.3).

Figure 12: Emscher re-conversion at the Borbecker Mühlenbach. left side: technical state, middle: directly after restoration, right side: two years after restoration (Source: Johann, Frings 2016).

In the Emscher basin, this self-purification process does not have a direct beneficiary, as there are no stakeholders in the Emscher catchment directly using the water for drinking or non-drinking purposes. Drinking water provision in the downstream Rhine catchment is beyond the scope of the study.

This Intermediate service, however, is important for providing a number of Cultural services in the catchment, specifically, FESS # 2-5. The reason is that a better water quality promotes the recreational use of the water bodies (FESS # 3) and also the attractiveness of the water environments for housing (FESS # 2), for education and research (FESS # 4), etc. Self-purification is an important ecosystem function which gives a stream the capability to quickly recover from occasional and short term pollution events, e.g. from CSO emissions. Furthermore, it enhances the capability to further improve water quality after discharge points from WWTP. This ecological function needs to be in place in order to achieve the good ecological potential (GEP) in a water body. FESS # 5 covers this aim of achieving the GEP.

5.1.1 STATE (IESS # 1)

Methods

The parameters

- water-sediment surface area (in-stream, i.e. in the river bed) and
- area of land-water interface (in the floodplain without the river bed)

have been derived for A) stream beds, B) floodplains, and C) vegetated basins (see Annex), respectively.

For A, the water-sediment surface has been obtained from stream profiles (Source: EG, planning data) extracted from hydrological models (Jabron, Hydrotec). The profiles' wetted surface area, projected water surface area and volume are calculated based on stream geometry of single sections, the length of these sections as well as their inclination and water level. The profiles of the open wastewater channels (BEFORE) and the restored streams (AFTER restoration) could be compared (Figure 13).

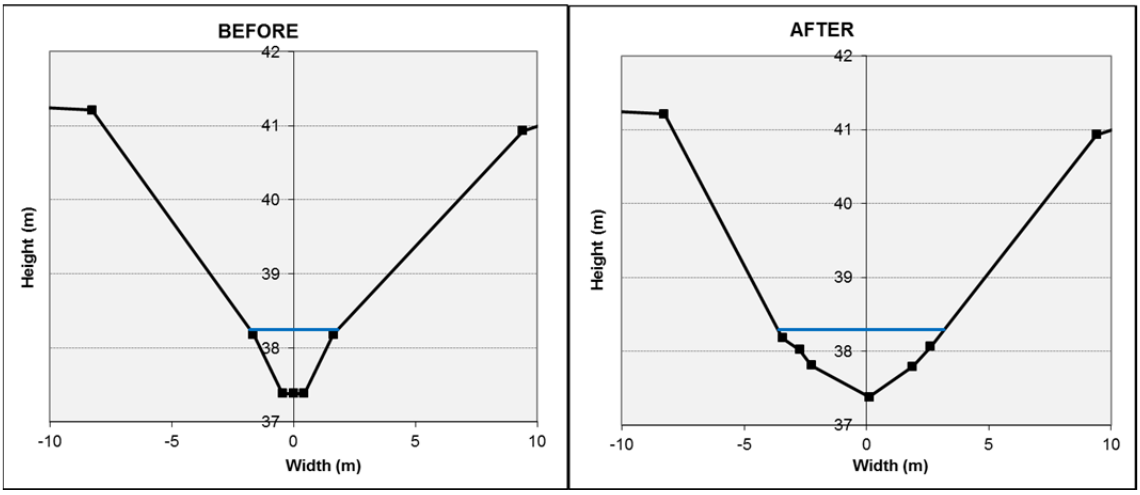

Figure 13: Excerpt from Excel-Tool showing stream profiles and calculating in-stream wetted surface (water-sediment surface), projected surface (water surface area) and volume based on stream bed profiles BEFORE and AFTER the Emscher re-conversion (Source Excel tool: UDE, data source: EG)

For B, the land-water interface is derived from the actual floodplain in the Emscher area, which we defined as the area that is statistically flooded every 50 (or 100) years, mapped in GIS (Geographical Information System) as HQ50 lines (or HQ100, in case no HQ50 line is mapped) (Data source: UDE, EG; Figure 14). Furthermore, land use was identified for these areas, acting as a proxy for soil type.

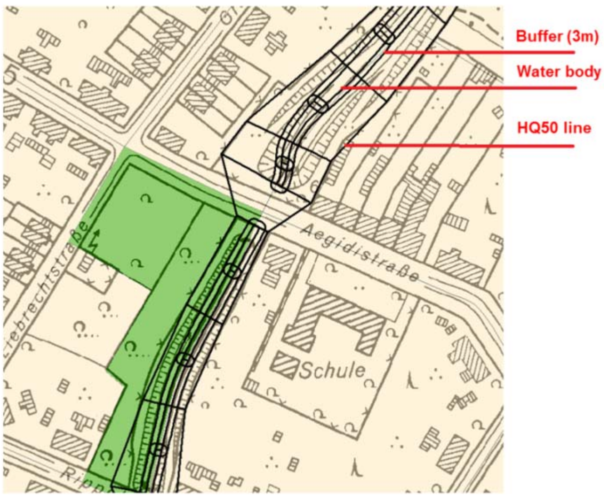

Figure 14: Excerpt from GIS map on stream location, floodplain (HQ50) area, and land use within the floodplain (Data source: EG, UDE).

Furthermore, initial N concentration, specifically NH_4N which represents the ecologically most relevant and predominant part of nitrogen in the water, was obtained from monitoring campaigns (Data source: EG, UDE).

All parameters of State were assessed for the DESSIN focus streams and then scaled up to basin level according to similarity of stream profiles.

Results & discussion

BEFORE the conversion, the total in-stream wetted surface (A) in the Emscher catchment was considerably smaller than AFTER (Figure 15).

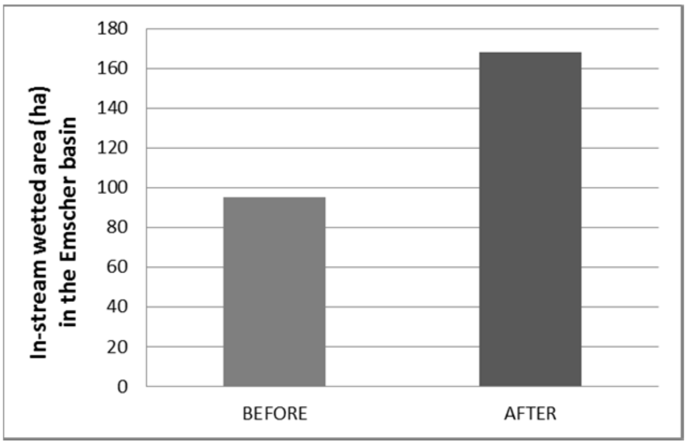

Figure 15: In-stream wetted area in the Emscher basin BEFORE and AFTER the restoration (Data source: EG)

For part of the streams in the Emscher basin, the land-water interface in the floodplain (B) does not change due to the restoration while for another part of the streams it increases. This results in an overall increase of the potentially wetted surface in the floodplains of the Emscher basin (Figure 16). This information was derived from the ecological development potential evaluated for each water body in the Emscher basin (Semrau et al. 2007; Semrau et al., internal documents 2013). Land use within the HQ50 areas changed from 75% grassland, 20% woodland, and 5% concrete bed (EG, expert opinion) to 45% grassland and 55% forested area (derived from land use data for the DESSIN focus streams, UDE). Thus, the overall area increases as does the proportion of forested area due to a decrease of grassland area. Further information can be obtained from the Annex.

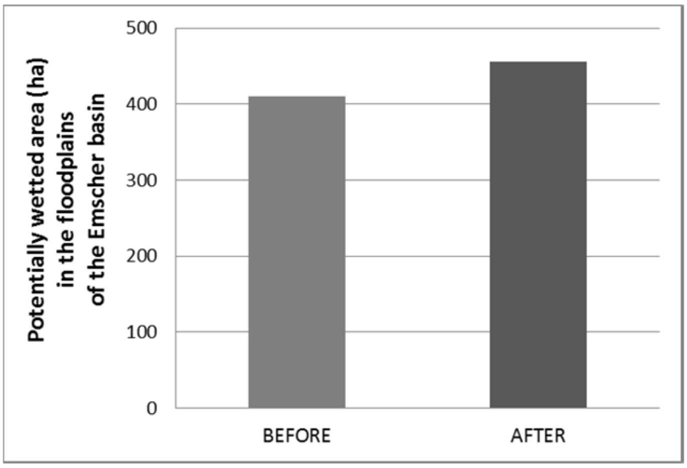

Figure 16: Potentially wetted area in the floodplains of the Emscher basin BEFORE and AFTER the restoration (Data source: EG)

The results show that the potentially wetted area in the floodplain is approx. 4 times larger than the wetted in-stream area and approx. 8 times larger than the projected surface area in-stream (Figure 21). Note, however, that the area in the floodplain is not constantly wetted but only occasionally.

5.1.2 IMPACT I - Provision (IESS # 1)

Based on the State parameters and standard denitrification rates obtained from literature, two indicators for Impact I Provision have been developed:

A) Potential denitrification in-stream

B) Potential denitrification in the floodplains (i.e. without the river bed)

A) Potential denitrification in-stream

Methods

The instream N retention was calculated based on stream bed profiles (Figure 13) and literature values (according to Niemann 2001) on denitrification rates. Calculations were conducted in an Excel-tool (Figure 17) developed by UDE. The Excel-tool is a simplified water quality model. It allows estimating the turnover of carbon and nutrients (N, P) in a given river reach. The results provide a rough estimation of the self-purification capacity for aerobic river systems.

To assess the potential N turnover BEFORE the restoration, we applied a standard concrete bed profile (Figure 13, left side). Upscaling from four DESSIN focus streams to the entire Emscher basin was done according to similarity of stream profiles. Further details can be obtained from the Annex.

In-stream retention of N, P, and C

Time	Geometry	
	wetted surface	volume
[d]	[m²]	[m³]
1	6,321	3,384

Legend
editable
calculated
final result
headdings

Initial concentration		
COD [mg/l]	N [mg/l]	P [mg/l]
14.02	0.02	0.02
meanCOD	meanNH4	meanPtotal

Initial load		
COD [g]	N [g]	P [g]
47450.50	67.69	81.23

Mass Transfer		
COD [g/(m²*d)]	N [g/(m²*d)]	P [g/(m²*d)]
1.20	0.003	0.01

Retention per day and section		
COD [g/(d)]	N [g/(d)]	P [g/(d)]
7585.59	18.96	4.55

Retention per hour and section		
COD [g/(h)]	N [g/(h)]	P [g/(h)]
316.07	0.79	0.19

Loads after transfer (1h)		
COD [g]	N [g]	P [g]
47134.43	66.90	81.04

Concentration		
COD [mg/l]	N [mg/l]	P [mg/l]
13.93	0.02	0.02

Retention per meter		
COD [g/h*m]	N [g/h*m]	P [g/h*m]
0.1	0.0	0.0
[g/h*km]	[g/h*km]	[g/h*km]
135.77	0.34	0.08

Figure 17: Excerpt from Excel-Tool modeling in-stream retention of N, P, and C based on stream bed profiles, initial concentrations and retention rates obtained from literature (Source Excel tool: UDE, data source: EG).

Results & discussion

Figure 18 shows the in-stream N turnover in one year scaled up to the entire Emscher basin based on the DESSIN focus streams. We detected an increase from 1.04 t to more 1.84 t of NH_4N eliminated from the water body per year.

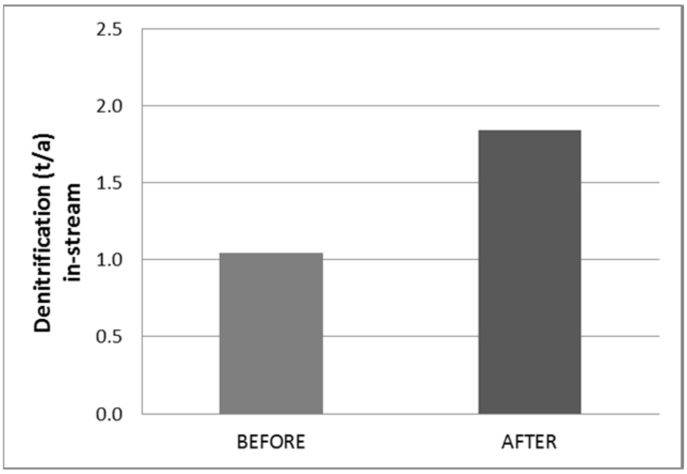

Figure 18: Total in-stream N turnover in the basin BEFORE and AFTER the Emscher re-conversion. The calculation is based on stream bed profiles and literature values on denitrification rates (Source Excel tool: UDE, data source: EG).

B) Potential denitrification in the floodplains

Methods

The calculations of indicator B are based on the land-water interface represented by the HQ50 areas along the streams (Figure 14). Subsequently, we applied a rule of thumb based calculation using literature values on denitrification rates for different soil types according to Scholz et al. (2012). Soil types were derived based on land use types. N turnover was estimated for each of the DESSIN focus streams, based on the area of a certain soil type and the specific denitrification rate for this soil type. Upscaling to the entire Emscher catchment was conducted according to the similarity of stream profiles. For the potential N turnover BEFORE the restoration, we applied an average standard land use within the HQ50 area (EG, personal communication), being: 75% grassland, 20% forest, and 5% concrete surface. Grassland and forest area was conservatively assigned the soil type with the lowest denitrification rate. Further details can be obtained from the Annex.

Results & discussion

The total N turnover in the floodplain increased from BEFORE to AFTER (Figure 19), which is due to the increased land-water-interface area (Figure 16).

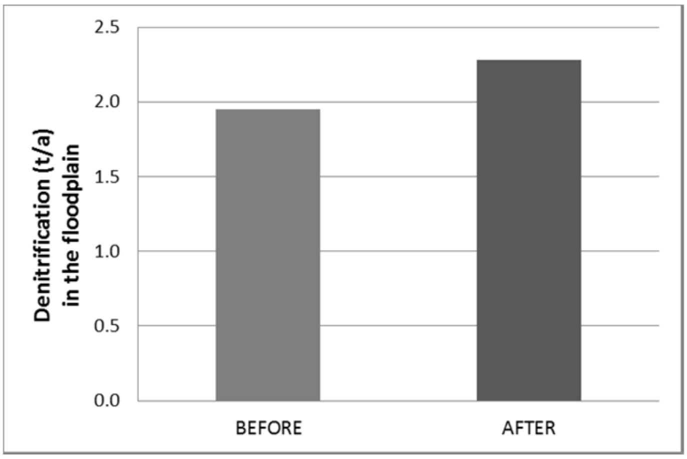

Figure 19: N turnover in the total floodplain of the Emscher basin BEFORE and AFTER the Emscher re-conversion. The calculation is based on the HQ50 areas and literature data on denitrification rates (Source Excel tool: UDE, data source: EG).

We showed that the level of the total in-stream N turnover in the Emscher basin is comparable to the total turnover in the floodplains. The total in-stream wetted surface area (Figure 15) is only about a quarter of the total floodplain area (Figure 16). However, the denitrification rates we applied for in-stream turnover (Niemann 2001) are twice as high as those applied for the floodplains (Scholz et al. 2012). This is reasonable, as denitrification within the stream takes place constantly, while denitrification in the floodplain occurs only under anaerobic soil conditions during flooding. In total, similar N turnover for the in-stream process and the process in the floodplain are obtained. In both cases, turnover AFTER the reconversion is higher than BEFORE.

The combined N turnover in streams and in the floodplains sums up to 2.99 t/a BEFORE and 4.12 t/a AFTER the reconversion.

5.1.3 IMPACT II – Use & resulting benefit (IESS # 1)

There is no direct beneficiary, and thus, no direct use and resulting benefit for this Intermediate Regulating & Maintenance service. It is a prerequisite for final Cultural services. FESS # 2-5 are reflecting the use and the resulting benefits from this service as outlined in the introduction of the present chapter 5.1.

If appropriate beneficiaries were in place, economic methods that could be applied are e.g. opportunity costs (i.e. avoided treatment costs) by drinking water treatment plant operators or comparative treatment costs in WWTPs.

Uncertainty

It has to be pointed out that both methods described above rely on values on retention rate obtained from scientific literature. No field measurements of specific retention rates in the streams investigated were available.

The wetted surface calculation based on stream bed profiles seems to be quite an accurate method. The floodplain area, on the other hand, is derived from the HQ50 lines, which is the area statistically flooded once in 50 years. Parts of this area are flooded more regularly. Information on e.g. the HQ1 area was, however, not available.

Thus, the methods represent only a rough estimate of the complex progresses happening in the ecosystem. A number of simplifications had to be accepted (e.g. the wetted surface area derived from profiles does not consider the additional surface increase due to sediment instead of concrete bed) and estimations to be made (e.g. concerning land use before the re-conversion). Also seasonal differences (i.e. temperature dependency) and the dependency of the turnover rate on the initial concentration were disregarded.

Note also that we did not assess the nutrient retention in the vegetated basins. These act as artificial floodplains in the Emscher catchment and will, thus, have a considerable share in nutrient retention.

Also the methodology for upscaling the results from the focus streams to the entire Emscher basin is related to some uncertainty, as we upscale according to similarity of stream types (5 types, all streams categorized via expert knowledge) weighted by stream length.

To validate our results, we compared them to those obtained by Scholz et al. (2012) who assessed N, P, and C retention for the 25 rivers with the largest floodplains in Germany. Their results reveal e.g. for the floodplains of the Ruhr an N retention of approx. 250 t/a and for the Lahn of approx. 100 t/a. As they have considered the denitrification taking place both in the floodplain and the river, we also need to combine our results on denitrification in stream and in the floodplain. This sums up to 4.12 t/a (AFTER). It has to be considered that the Ruhr basin with 4485 km^2 is considerably larger than the Emscher catchment and that it has extensive floodplains for drinking water provision by bank filtration. Considering this, the results obtained here are in a similar range as those assessed by Scholz et al. (2012).

5.2 IESS # 2: Self-purification: P retention

The Regulating & Maintenance service "*phosphorous retention*" is a result of the retention of particle-bound phosphorous by macrophytes in streams (A) and of the retention of particle-bound phosphorous by vegetation in floodplains (B). The in-stream process takes place at the area covered by macrophytes (Figure 20), while the process in the floodplain takes place at the land-water interface during flooding. In-stream (A), the projected surface (i.e. the water surface as seen from above) as well as the initial total P concentration in the water are of importance when a final P concentration is to be obtained or a load removal is to be calculated. In the floodplain (B), the land use is applied as a proxy for vegetation types within the potentially wetted area.

Figure 20: In-stream growth of macrophytes in the Oberlauf der Emscher and vegetation in the secondary floodplain.

During the Emscher re-conversion, where stream profiles are widened and secondary floodplains are created, both the water surface area and the land-water interface are enlarged, increasing the P retention capacity.

Similarly as N retention, P retention does not have a direct beneficiary in the Emscher catchment. Therefore, the evaluation does not go beyond the Impact I Provision assessment. P retention, however, is also an important IESS for providing FESS # 2-5.

5.2.2 STATE (IESS # 2)

Methods

Similar as for N retention, the parameters

- projected in-stream surface area and
- area of land-water interface (in the floodplains, without the river bed)

were evaluated for A) stream beds, B) floodplains, and C) vegetated basins (see Annex), respectively, using the same methods as reported in 5.1.2.

Furthermore, initial P concentrations, specifically total P, were obtained from monitoring campaigns.

Results & discussion

BEFORE the conversion, the in-stream projected surface area was considerably smaller than AFTER (Figure 21).

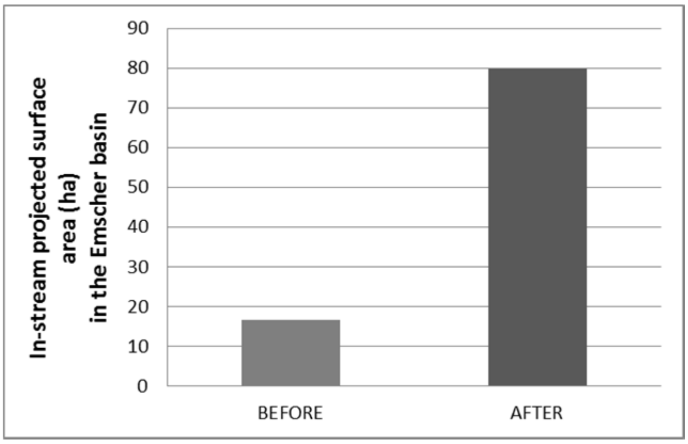

Figure 21: In-stream projected surface area in the Emscher basin BEFORE and AFTER the restoration (Data source: EG)

5.2.2 IMPACT I - Provision (IESS # 2)

Similar as for N retention, two indicators for Impact I Provision have been developed:

A) Potential P retention in-stream

B) Potential P retention in the floodplains (i.e. without the river bed)

All of the indicators are based on the State parameters mentioned above and standard P retention values obtained from scientific literature (for explanations see Annex).

A) Potential P retention in-stream

Methods

Indicator A was calculated based on stream bed profiles and retention rates reported in literature. The calculations were conducted in the Excel-tool as described in 5.1. A macrophyte cover of 80% or 20% was assumed for restored streams (AFTER) with high and low macrophyte growth, respectively. For unrestored streams (BEFORE), we assumed a cover of 5% resembled by growth of algae. Literature data was derived from Scholz et al. (2012).

Upscaling to catchment level and evaluating the retention BEFORE the restoration were also conducted as described in 5.1. Further details can be obtained from the Annex.

Results & discussion

The in-stream P retention increased from 0.88 t per year BEFORE the restoration to 4.23 t per year AFTER (Figure 22). This positive effect is due to a larger stream bed surface as well as a larger surface of macrophytes available for particulate P retention after the reconversion.

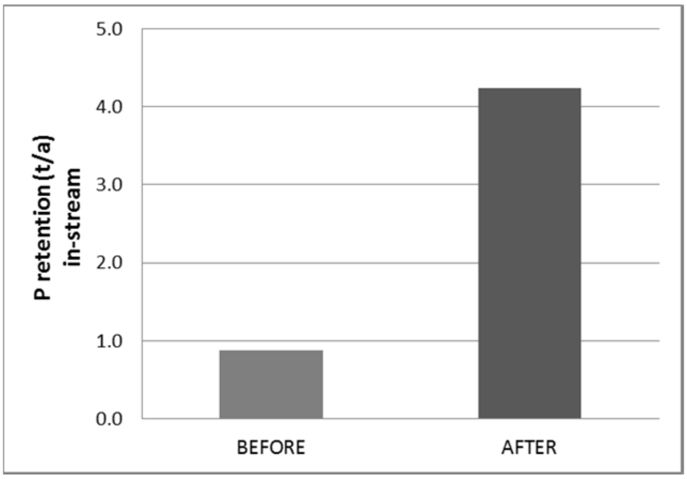

Figure 22: Total in-stream P retention in the Emscher basin BEFORE and AFTER the Emscher re-conversion. Calculation based on stream bed profiles and literature data on P retention rates (Source Excel tool: UDE, data source: EG).

B) Potential P retention in the floodplains

Methods

For the calculation of indicator B, we applied a rule of thumb based calculation using literature data on P retention rates for different land use types according to Scholz et al. (2012). Land use type is applied as a proxy for vegetation type. P retention was estimated for each of the DESSIN focus streams, using the area of a certain vegetation type and the specific P retention for this vegetation type. Upscaling to the entire Emscher catchment was conducted as for N retention. Further details can be obtained from the Annex.

Results & discussion

Total P retention in the floodplain increased from 0.66 to 1.41 t per year (Figure 22), resulting from the increase in the part of forested area within the HQ50 area.

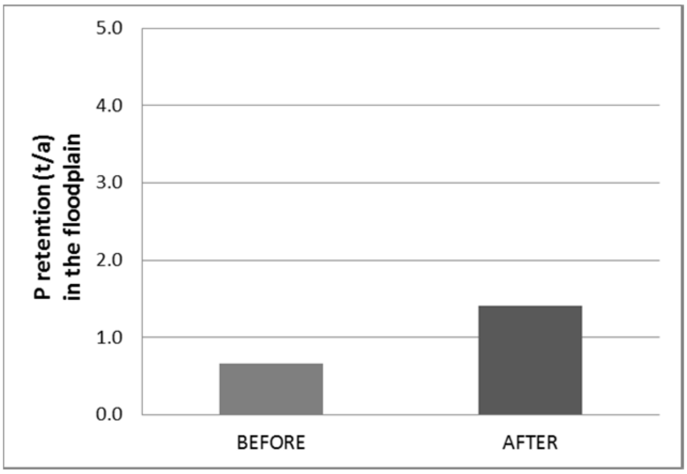

Figure 23: Total P retention in the floodplains of the Emscher basin BEFORE and AFTER the Emscher re-conversion. The calculation is based on the HQ50 areas and literature data on P retention rates (Source Excel tool: UDE, data source: EG).

The results indicate that P retention in the streams happens in a similar range as in the floodplains. Even though in-stream retention rates are reported to be 10 times higher than in floodplains, the projected surface area we identified is 8 times smaller than the floodplain area. In total, a similar retention level can be observed. In both cases, retention AFTER the reconversion is higher than BEFORE.

The combined P retention in streams and in the floodplains sums up to 1.54 t/a BEFORE and 5.64 t/a AFTER the reconversion.

5.2.3 IMPACT II – Use & resulting benefit (IESS # 2)

There is no direct Impact II for this service, as it is an Intermediate service. It is also a prerequisite for the final Cultural services FESS # 2-5.

Uncertainty

The methodological constraints are similar as for N retention. Furthermore, not all relevant processes could be assessed. For instance, in reality P elimination from the water column occurs not only via retention of particulate P but also via uptake of dissolved P into the macrophytes (for biomass). Due to a lack of literature data on uptake rates per area of macrophyte growth, however, the latter process could not be considered in our calculations. Thus, we only consider the particle-bound P held back by macrophytes on the stream bed and by vegetation in the floodplain. Note that even though this leads to a removal of P from the water column, accumulation in and potential resuspension from the sediment will occur.

To validate the results, we compared them to those obtained by Scholz et al. (2012) for the 25 rivers with the largest floodplains in Germany. P retention in the Ruhr and Lahn basins account for approximately 10 t/a. This includes retention in the floodplain and retention along the shoreline of the rivers. The values obtained are again comparable to the combined P retention in-stream and in the floodplains assessed for the Emscher basin. These add up to 5.64 t/a. These results are also in a similar range.

5.3 IESS # 3: Self-purification: C retention

The service of organic carbon retention investigated in this study is subdivided: The C retention process assessed in streams (A) is provided by biofilms via uptake for biomass (growth) and energy supply (respiration), while the process evaluated in the floodplain (B) resembles carbon stock in the soil (underground) and in vegetation (aboveground). The in-stream process takes place at the water-sediment surface while the process during flooding takes place at the land-water interface. In-stream, the wetted surface as well as the initial C concentration in the water are relevant parameters. In the floodplain, the potentially wetted surface area and its soil type are of importance, as well as land use as a proxy for vegetation types.

Similarly to N and P retention, we expect an increased C retention capacity in sections where stream profiles are widened and secondary floodplains are developed (i.e. where the restoration is completed).

5.3.1 STATE (IESS # 3)

The relevant parameters of State are adopted from 5.1.1 and 5.2.1, being

- water-sediment surface area (in-stream, i.e. in the river bed) and
- area of land-water interface (in the floodplain, without the river bed).

Furthermore, initial C concentrations, specifically mean values of total organic carbon (TOC) transferred by a correlation factor to chemical oxygen demand (COD), were obtained from monitoring campaigns.

5.3.2 IMPACT I - Provision (IESS # 3)

Again, two indicators for Impact I Provision have been developed, one for the in-stream process and one for the process in the floodplain:

A) Potential C retention in-stream

B) Potential C stock in the floodplains (i.e. without the river bed)

A) Potential C retention in-stream

Methods

The in-stream method applied for C retention is similar as for N and P retention with specific carbon retention rates from scientific literature (Niemann 2001).

Results & discussion

The in-stream C retention per year scaled up to the entire Emscher basin (Figure 23) shows an increase in C retention from 416.4 t/a BEFORE restoration to 736.06 t/a AFTER the restoration due to an increase in the wetted surface area.

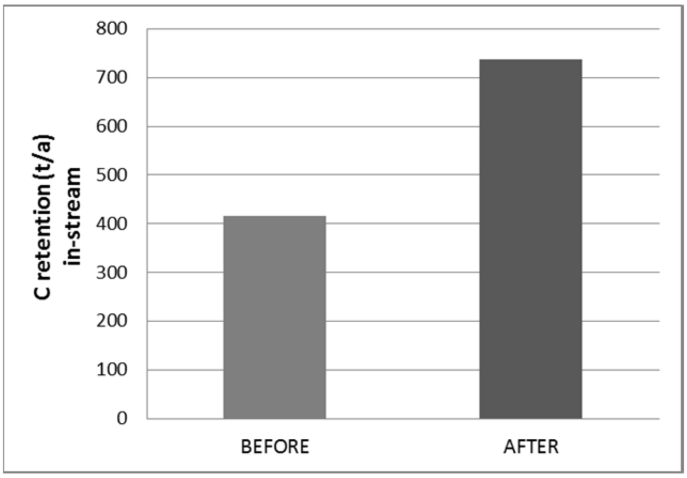

Figure 24: Total in-stream C retention in the Emscher basin BEFORE and AFTER the Emscher re-conversion. The calculation is based on stream bed profiles and C retention rates obtained from literature (Source Excel tool: UDE, data source: EG).

B) Potential C stock in the floodplains

Methods

This indicator is based on organic carbon stock values for different vegetation types according to Cierjacks et al. (2010), defined as „Total C stocks aboveground and belowground". We used the values reported for softwood and meadows (grassland). The specific C stock was determined for each focus stream. Upscaling to catchment level was conducted as for N and P retention.

Results & discussion

Total above and belowground carbon stock in the floodplain increases by 38 megatons (Figure 24), resulting from the larger floodplain area (HQ50 area) and a larger part of forested area within the HQ50 area AFTER re-conversion.

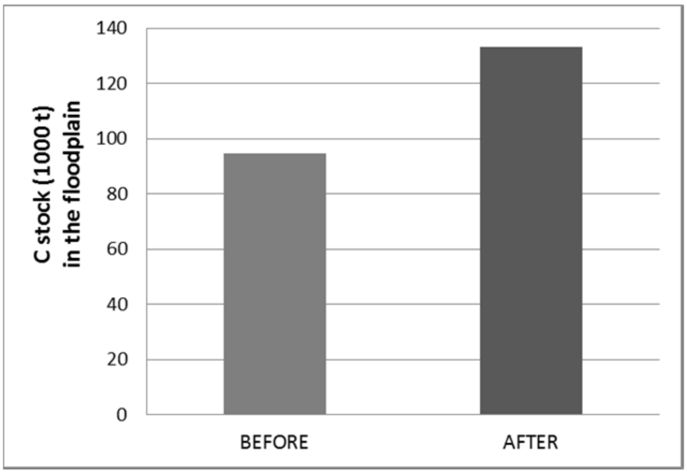

Figure 25: Total C stock in the floodplains of the Emscher basin BEFORE and AFTER the Emscher re-conversion. The calculation is based on the HQ50 areas and literature data on C retention rates (Source Excel tool: UDE, data source: EG).

With regard to carbon, in-stream C retention in the Emscher basin cannot be compared to the C stock in the floodplains. The first process describes a retention rate per year, while the second represents the existing C stock above and below ground. The two processes cannot be summarized.

5.3.3 IMPACT II – Use & resulting benefit (IESS # 3)

As all self-purification services, carbon retention is also an intermediate service and a prerequisite for FESS # 2-5.

Uncertainty

The methodological differences in this case are similar as for N and P retention.

The relatively high C stock of 133,160 t determined for the entire Emscher basin (168 ha, AFTER) is due to high literature values on C stock (Scholz et al. 2012) for the land use/vegetation types grassland and woodland.

5.4 IESS # 4: Biodiversity

Biodiversity is an important IESS for Cultural services but also for other Regulating & Maintenance services. It is based on the availability of habitats and is reflected by biological communities of bacteria, algae, macrophytes, macroinvertebrates, fishes, etc. in rivers. Concrete endpoints for macroinvertebrates are for instance: the number of different taxa, the number of red list taxa, and indicators such as the ecological status of a river. Biodiversity as a Regulating & Maintenance service does not have a direct beneficiary, however, it is part of the provision of final Cultural services – in our case these are FESS # 2-5.

5.4.1 STATE (IESS # 4)

The State of an ecosystem under study can be described by the

- number of different habitats (not assessed).

5.4.2 IMPACT I - Provision (IESS # 4)

For the assessment of Impact I Provision we applied proxies, being standard measures of biodiversity in ecology. We focus on aquatic macroinvertebrate communities, not taking into consideration algae, macrophytes, fishes or terrestrial plants and animals. The indicators we applied were:

A) Taxa richness/ number of species

B) Number of red list species (i.e. endangered aquatic macroinvertebrate species)

C) Saprobic index (i.e. an indicator of the level of organic pollution, based on the composition of the macroinvertebrate community)

D) Assessment of the ecological potential according to the EU Water Framework Directive

The biological indices reported below are derived from monitoring data (Source: EG, UDE). The stage AFTER is derived from monitoring results in restored streams at various stages (1 to 18 years) after restoration. The time after restoration (1-2 years versus 3-9 years versus <10 years), however, did not have a significant influence on taxa richness at the streams sampled. For this reason, only the two stages BEFORE and AFTER are reported. BEFORE values are derived from three monitoring campaigns at the unrestored Emscher main stream.

A) Taxa richness/ number of species

The number of aquatic invertebrate taxa rose from an average of 9 to 18 species per sample between BEFORE and AFTER the re-conversion (Figure 26).

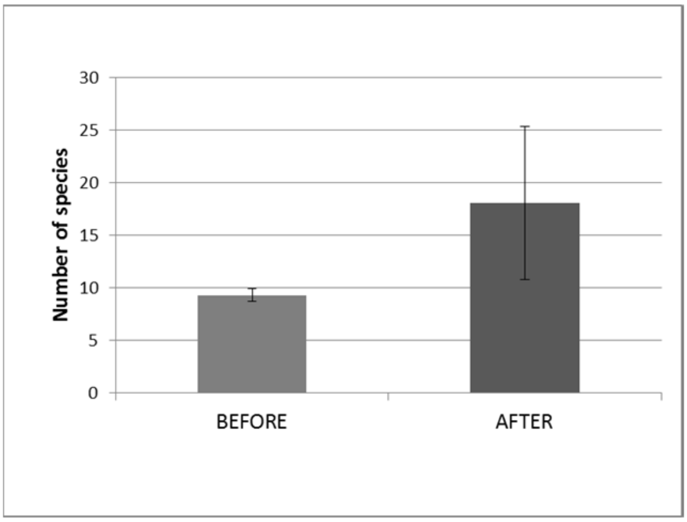

Figure 26: Taxa richness, given as average number (with standard deviation) of aquatic macroinvertebrate species at sampling sites in the DESSIN focus streams BEFORE and AFTER restoration (Data source: EG, UDE).

B) Number of red list taxa

No red list taxa of aquatic invertebrates were found BEFORE the restoration, while a maximum of four red list species were present at the sites sampled AFTER the restoration (Figure 27).

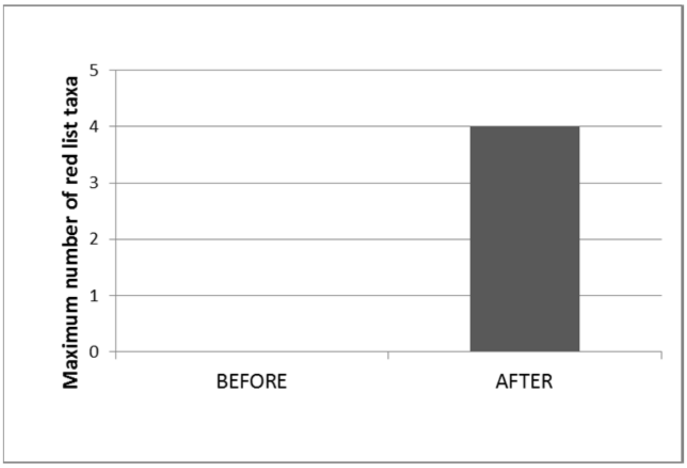

Figure 27: Maximum number of red list taxa occurring at sampling sites in the DESSIN focus streams BEFORE and AFTER restoration (Data source: EG, UDE).

C) Saprobic index

The Saprobic index (SI) is reported as ecological quality ratio (EQR). The EQR standardizes biological quality values (Rolauffs et al. 2002; Birk, Hering 2006). The calculation is conducted according to the formula based on the Saprobic index derived from the composition of the aquatic macroinvertebrate community:

EQR_{SI} =1 – ((observed SI value - reference SI value) – (maximum SI value - reference SI value)) An EQR value of one represents (type-specific) reference conditions and a value close to zero indicates a bad ecological status. The EQR AFTER the restoration is considerably closer to 1 than the EQR BEFORE (Figure 28).

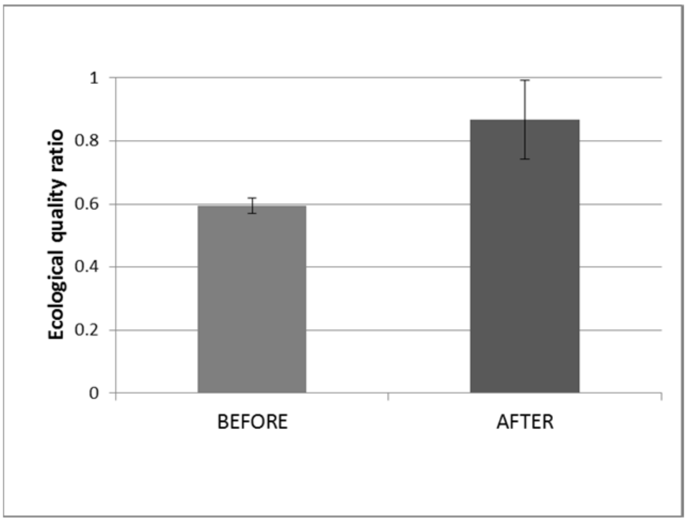

Figure 28: Ecological quality ratio on the Saprobic index based on the composition of the aquatic macroinvertebrate community occurring at sampling sites in the DESSIN focus streams BEFORE and AFTER restoration, with standard deviation (Data source: EG, UDE).

D) Ecological potential

The ecological potential (Döbbelt-Grüne et al. 2015) at the stage BEFORE restoration has not been monitored in tributaries of the Emscher but only in the main stem. Nevertheless, we adopted bad potential for all streams in the Emscher basin for the BEFORE stage, as all unrestored streams were in fact open wastewater channels with a concrete bed and sewage water (except for short upstream sections in a few tributaries) (Figure 29).

We categorized the streams' ecological potential according to the status observed at the latest monitoring campaign and, if several sites were sampled per stream, selected the most representative site by expert opinion.

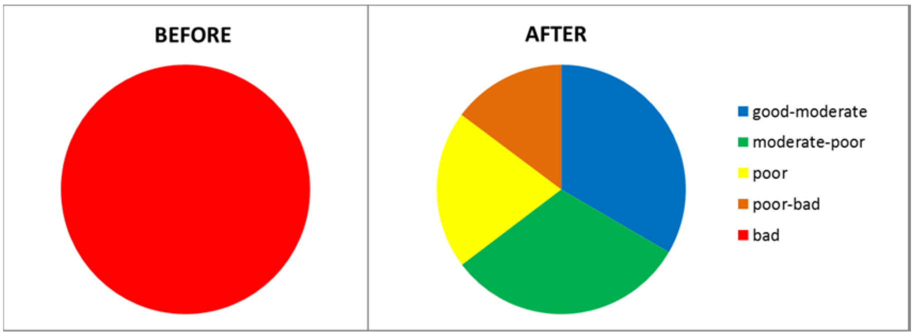

Figure 29: Ecological potential of the Emscher basin BEFORE and AFTER restoration. Fractions are plotted in km of total stream length (297 km) (Data source: EG, UDE).

5.4.3 IMPACT II – Use & resulting benefit (IESS # 4)

Similarly as the Regulating & Maintenance service self-purification, also biodiversity is an intermediate service, however, with high importance for the provision of the final Cultural services FESS # 2-5.

Uncertainty

Few monitoring results were available on the state BEFORE the ecological improvement of the streams. However, a bad potential and a very poor aquatic invertebrate community (as observed in the Emscher main stream before restoration) can be adopted for all streams before restoration.

Upscaling the results from the focus streams to the entire Emscher basin was only done for the ecological status. As taxa richness, number of red list species, etc. are given as average or maximum, it is more challenging to transfer the results to basin level. Especially since these endpoints depend on diverse factors shaping biological communities, which can hardly be approximated with similarity of stream types. The results for the ecological status are scaled up to basin level according to the similarity of stream types weighted by stream length. Note that in reality, also here further factors than only similarity of stream type determine the community.

5.5 FESS # 1: Opportunity for placement of infrastructure and reduced risk of flooding

Flood protection in the basin is achieved via two approaches:

- Natural water retention is realized by restoration of the streams and their floodplains.
- Technical flood protection is assured via the construction of rain and flood retention basins.

Furthermore, the de-coupling of rainwater from the combined sewage system decreases the amount of water reaching the sewers and the streams.

As the Emscher River length was shorted by 30% during the first Emscher conversion, the discharge rate was augmented accordingly. This fact in combination with a growing subsidence area, gave flood protection a high significance.

Nowadays and due to the intensive anthropogenic utilization of the area, the part of sealed surface in the Emscher basin is extremely high (60%). Thus, during rain events large volumes of rainwater are discharged into the sewers. Also in the streams, rainwater input results in high discharge peaks regarding water level and flow rate. Hardly any natural floodplains were present before the Emscher re-conversion, because the artificial land cover reaches close to the streams. Space restriction is still a major limitation of the re-conversion success (Figure 30).

Figure 30: Low water level and restricted space for the development of the Deininghauser Bach in the city of Castrop-Rauxel.

Where the conditions allow, stream profiles are widened as part of the restoration efforts and secondary floodplains are attached (Figure 31). This increased the retention volume inside the stream bed which can delay the flood wave and reduce the water level (Impact I Provision).

Figure 31: Emscher re-conversion at the Berne (left side: technical state, right side: one year after restoration) (Source: Johann & Frings, 2016).

Additionally, 40% of the Emscher basin is polder area which constantly needs to be protected from flooding. Therefore, technical flood protection is provided through dikes (a total of 129 km of dikes along the Emscher and its tributaries). Pumping stations keep the polder areas dry and flood retention basins (Figure 32) buffer discharge peaks. Rain retention basins serve as additional storage volume for combined sewage in order to delay discharge from CSO facilities into water bodies.

Figure 32: Vegetated flood retention basin Dortmund-Mengede (Source: EGLV Blog).

5.5.1 STATE (FESS # 1)

The following information on parameters of State needed to be obtained for the stages BEFORE and AFTER restoration for later on assessing Impact I Provision:

- stream profiles
- water holding volumes in floodplains (not assessed)
- water holding volumes in basins
- the area at risk of flooding

Furthermore, knowledge on the level of flood protection to be provided throughout the basin as a regulatory threshold was required.

Figure 33 shows the level of flood protection throughout the Emscher basin BEFORE the re-conversion. In the source section, the Oberlauf der Emscher, a level of only HQ20 is required, followed by HQ50 and HQ100 sections. The major part of the Emscher River has a protection level of HQ200. This means that only flood events of the intensity which statistically occur once in 200 years can cause flooding beyond their embanked secondary floodplains. AFTER the restoration, and already completed, all HQ50 sections of the Emscher have an increased flood protection level of HQ100. The central and Western section will continue with a level of HQ200, however, with reduced discharge.

The improvements in the flood protection levels result from the construction of the flood retention basins Lake Phoenix, Mengede and Ellinghausen in the upper Emscher section around the city of Dortmund. Furthermore, a culvert in the Emscher channel downstream of Dortmund Dorstfeld helped improve the flood protection. Note that no changes in height or position of the dikes along the Emscher had to be made.

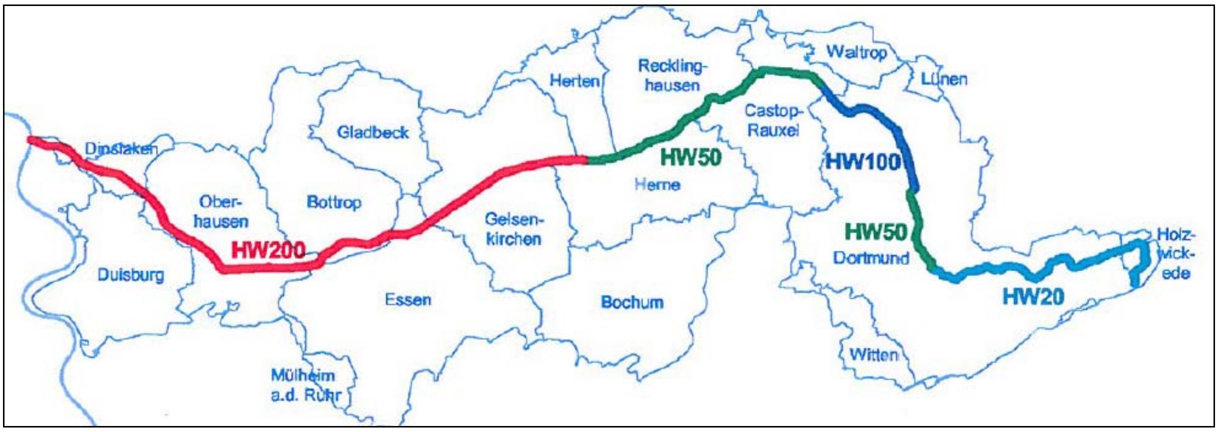

Figure 33: Level of flood protection (HQ) valid BEFORE the re-conversion (Source: Hydrotec 2004).

In case of flood events with an intensity stronger than HQ100 events, the areas along the Emscher marked in turquoise in Figure 34 will be flooded, while the yellow areas will only be flooded in case of dike failure during HQ200 events.

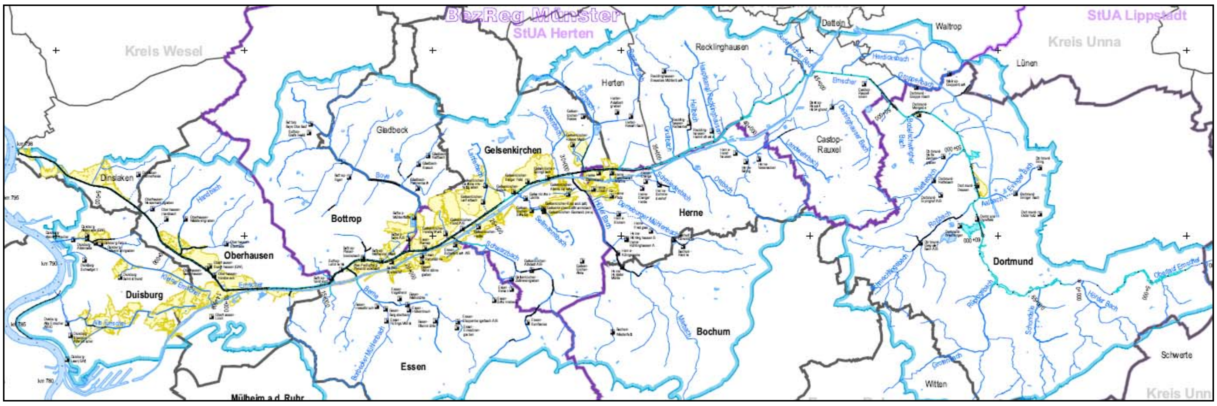

Figure 34: Flooded areas at HQ100 (turquoise) and potentially flooded areas at HQ200 in case of dike failure (yellow) BEFORE the re-conversion (Source: Hydrotec 2004).

5.5.2 IMPACT I - Provision (FESS # 1)

In order to assess the water retaining capacity in the Emscher basin, various indicators were selected:

A) Stream bed's water retaining capacity (not reported)

B) Floodplain's water retaining capacity (not reported)

C) Vegetated basin's water retaining capacity

D) Discharge reduction

C) Vegetated basin's water retaining capacity

One aim of the Emscher re-conversion is also to augment the retention capacity within retention basins in the upper sections of the Emscher in order to lower the flood risk for downstream sections. A total of 23 flood retention basins with a total storage volume of 3.3 M m³ (EG, planning status 2005) are to be in place after the re-conversion (Figure 35). A considerable part of the basins are vegetated and represent nature-based solutions or artificial secondary floodplains with a number of additional benefits. Apart from flood retention, these benefits are: habitat for animals and plants, carbon sequestration via plants, recreational potential for people living in the area, local climate improvement via evaporation and evapotranspiration.

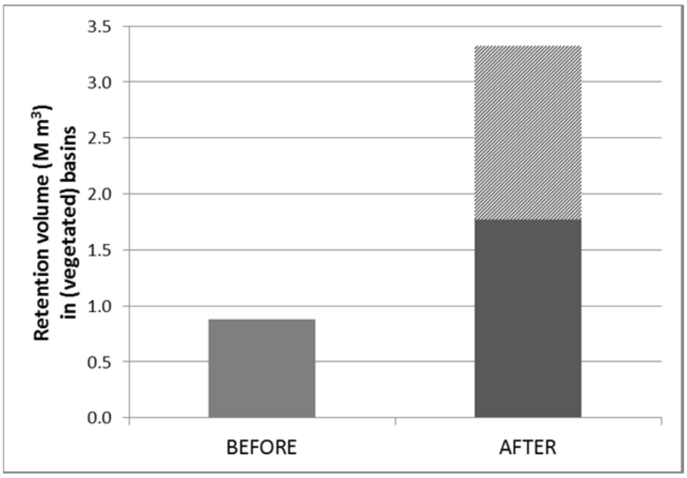

Figure 35: Retention volume inside flood retention basins BEFORE and AFTER the Emscher re-conversion. Fraction of vegetated basins hatched (Data source: Emschergenossenschaft 2014; EG, planning status 2015).

D) Discharge reduction

Method

Empirical discharge data for 60 years (1950-2010) were available from EG. A model for the BEFORE and AFTER status was developed (Beysiegel 2015) for 17 exemplary tributaries and the Oberlauf der Emscher in the program "Timeview 2.5.0". The model was based data records of precipitation, temperature and evapotranspiration, and on two types of stream cross-sections: a near-natural profile and a trapezoidal profile. The near natural profile has a higher retention factor compared to the trapezoidal one due to higher turbulences, higher friction losses, and thus, lower water speed. A number of distribution functions have been calculated (Figure 36) and the distribution which fitted the empirical distribution best was chosen.

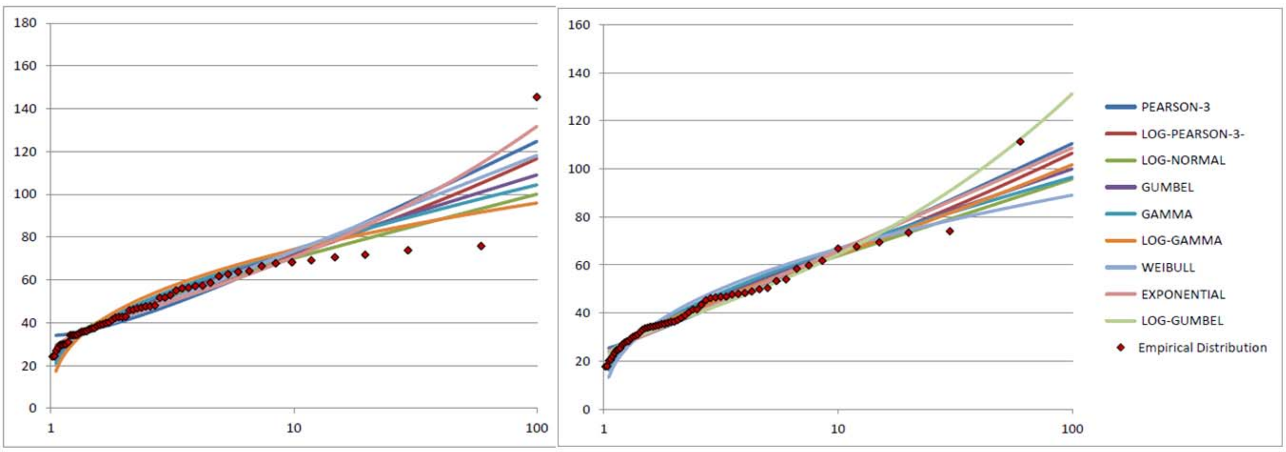

Figure 36: Modelled discharge distribution curves for the Oberlauf der Emscher (Source: Beysiegel 2015).

Results & discussion

The model showed that discharge in the state AFTER restoration was considerably lower for most of the tributaries and the Oberlauf der Emscher (Figure 37). For 100 year events, there was an average decrease of 27% and for 2 year events of 44% from BEFORE to AFTER restoration for the exemplary streams. Note, however, that considering single events, this was not always the case; at times, also higher discharge rates occurred.

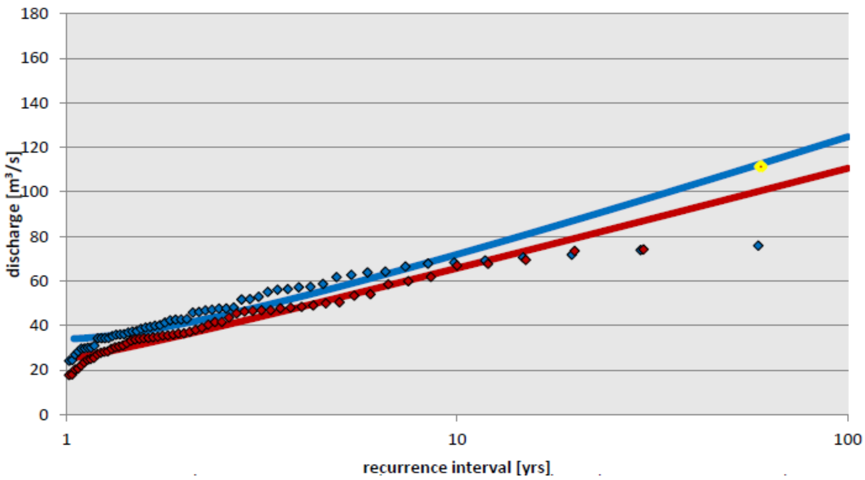

Figure 37: Probability distributions (Pearson-3, solid line) and empirical distribution (dots) for discharges in the Oberlauf der Emscher for the BEFORE (blue) and AFTER (red) for recurrence intervals HQ1 to HQ100 (Source: Beysiegel 2015).

Discharge AFTER the ecological restoration proved to be lower in all exemplary tributaries than BEFORE the restoration for both 100 year and 2 year events (Figure 38).

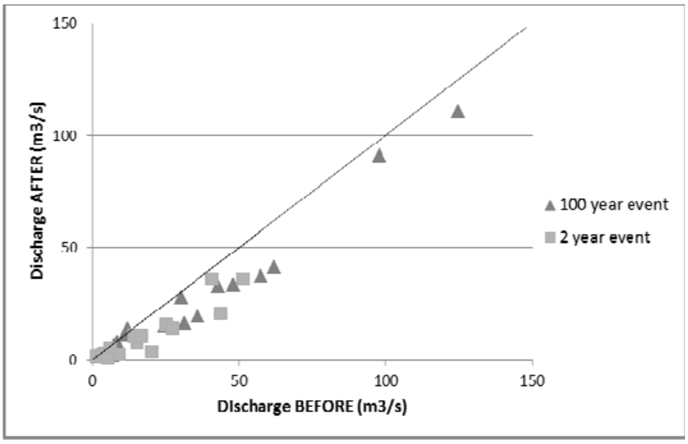

Figure 38: Discharge BEFORE and AFTER during a 100 year and 2 year event for the exemplary tributaries (Source: Beysiegel 2015)

The results for the exemplary tributaries were transferred to the DESSIN focus streams and were scaled up to catchment level by weighting the average discharge with stream kilometers according to similarity of stream profiles. Discharge AFTER was 24% and 43% lower than BEFORE for 100 year and 2 year events, respectively (Figure 39).

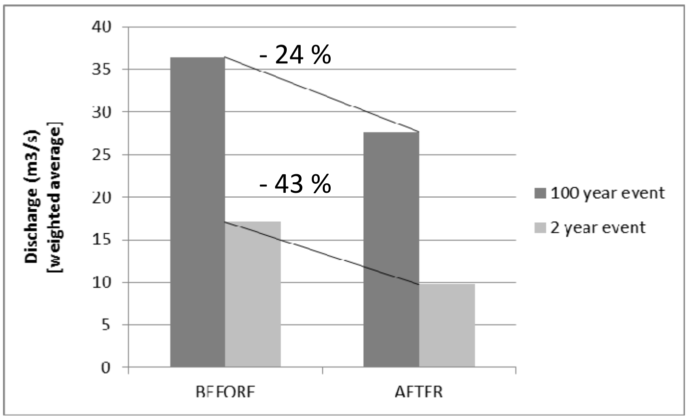

Figure 39: Reduction in average discharge in the basin BEFORE and AFTER for a 100 year and 2 year event, weighted by stream length for the entire basin, based on five focus streams (Data source: Beysiegel 2015).

The model also demonstrated an effect on the Emscher River itself, showing a peak decrease of up to 15% in the Emscher stream AFTER the restoration of the tributaries, i.e. even without the restoration of the Emscher River itself.

5.5.3 IMPACT II – Use & resulting benefit (FESS # 1)

The use of the flood protection service by beneficiaries is equal to its provision, i.e. if a protection level of HQ50 is provided, this provision is also entirely used; similarly with HQ100 or 200.

A monetarization of the benefit is conducted with regard to the avoided costs from flood damage.

Method

In the flood action plan (Hydrotec 2004), the flood damage is assessed concerning flooded areas at HQ100, HQ200, and HQ>500 events. Furthermore, the damage occurring in case of dike failure during flood events stronger than HQ200 and HQ>500 (hence called “potentially flooded areas”) was assessed in the flood action plan. Here, flooded areas were identified for different flood scenarios based on the flooding statistics of 1993 and 1995, discharge amounts, water levels for HQ100, HQ200, and HQ>500, and a digital elevation model. Subsequently, damage costs were calculated for objects, cars, land use, and infrastructure by applying damage functions (HOWAS). Also objects especially susceptible to flooding such as industry facilities, power plants, mining sites and underground railways were considered. The damage costs are directly depending on the water level.

A summarization of damage costs of the potentially flooded areas at HQ100 and HQ200 is not possible, because dike failure cannot occur at several spots – or, if it does, there is not enough water to fill several polder areas.

Results & discussion

BEFORE the re-conversion, a HQ100 flood event would have flooded an area of approx. 415 ha. Excluding the area within dikes and the backwater zones of the tributaries, the remaining area accounted for 126 ha, which was almost entirely (123 ha) within the municipality of Dortmund. The estimated damage costs for objects, cars, land use, and infrastructure within this area are about 178 M €. These damage costs were indexed according to the building cost index of the German Federal Statistical Office (Statistisches Bundesamt; category maintenance of residential buildings). The damage costs almost entirely stroke the city of Dortmund with minor costs in Castrop-Rauxel and Recklinghausen and no costs in the remaining basin. For a HQ200 event, the damage costs would have increased by 1.7 M € and at an extreme event (HQ>500) by 7.1 M €. AFTER the re-conversion, these damage costs are avoided due to the measures mentioned above (Figure 40). As by definition the damage costs for a HQ100 event are only expected to occurs once in 100 years statistically, the annual costs avoided are estimated to be about 1.78 M €/a. As discussed in chapter 5.11, climate change effects can result in flood events with a reoccurrence interval of 100 years (i.e. HQ100) to occur more often (e.g. every 80 years). This would, for instance, increase the avoided costs to 2.22 M €/a.

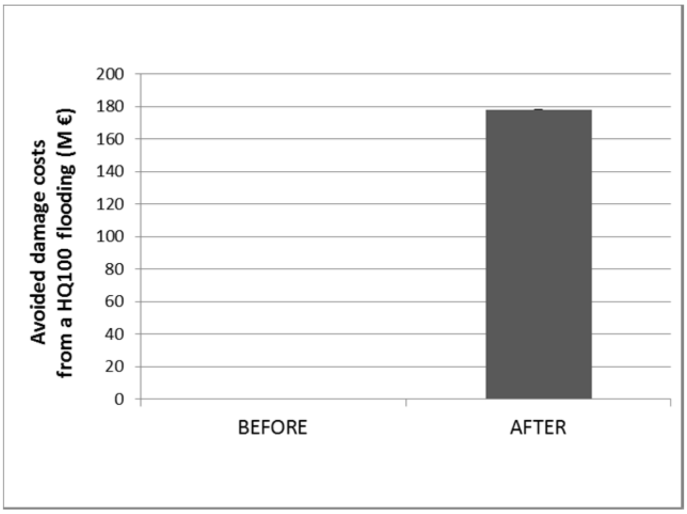

Figure 40: Avoided damage costs from a HQ100 flooding (Data source: Hydrotec 2004).

For the case of dike failure, the damage costs for the time BEFORE the re-conversion for potentially flooded areas at HQ100 and HQ200, can be assessed for single cities. The city districts with the highest estimated damage costs at HQ100 are: Gelsenkirchen Erle (656 M €), Duisburg Alte/Kleine Emscher (489 M €), and Gelsenkirchen Karnap (434 M €). For a HQ200 event, the costs account for 764 M €, 553 M €, and 449 M €, respectively. Also here, the damage costs were indexed. A summarization of the damage costs for various cities is not valid, as outlined above.

Currently, no data are available for damage costs in potentially flooded areas at HQ100 and HQ200 for single cities AFTER the re-conversion; they are currently investigated.

Uncertainty

In the assessment of discharge reduction, it has to be noted that the retention effect observed in the models is due to the combination of technical flood protection and natural retention: the construction of rain and flood retention basins and the ecological restoration. The single effects could not be partially assessed.

Note also that in the estimation of avoided damage costs, economic follow-up costs in the consequence of flood events are not taken into account.

5.6 FESS # 2: Opportunity for placement of infrastructure in environment

This final Cultural service describes how the attractiveness/aesthetics of a landscape/environment influences the prices for buildings with a view on these landscapes. The provision (Impact I) of an environment suitable for placement of infrastructure can either be assessed using landscape aesthetics metrics or by considering a number of intermediate services that act as preconditions for such a suitable environment. In our case these are the IESS # 1-4. Landscape aesthetics were not assessed, as not all information was available.

In the Emscher case, we have identified two beneficiaries for service "*Opportunity for placement of infrastructure in environment*":

A) Resources-dependent businesses (cafés and restaurants) and

B) Residential property owners.

Therefore, we will focus on the use (Impact II) of this service in terms of

A) Commercial places with view on restored river and

B) Flats/houses with view on restored river.

Both types of use can be monetized with the willingness to pay (WTP) for commercial places or flats/houses, respectively. For the assessment, we adopted results of the rwi study (Barabas et al. 2013) and the price increases they detected throughout the New Emscher valley.

Figure 41: Creation of Lake Phoenix (left: steel processing plant at the area of Phoenix East, center: Phoenix East area after plant dismantling, right: completed creation of Lake Phoenix) (Source: EGLV, Hans Blossey)

5.6.1 STATE (FESS # 2)

As this FESS relies on the provision of several intermediate ESS, it also depends on the parameters of STATE that were assessed for these IESS. The State parameters to be assessed for the IESS "*Self-purification potential (N, P, C)*" were reported in 5.1.1, 5.2.1, and 5.3.1, and those for the IESS "*Biodiversity*" in 5.4.1. The Landscape aesthetics metrics (not assessed) relies on a number of single parameters of State. For a list of these single parameters see Factsheet FESS # 2 and # 3 in the Annex.

5.6.2 IMPACT I - Provision (FESS # 2)

The FESS "*Opportunity for placement of infrastructure in environment*" relies on the provision of several intermediate ESS:

- *Landscape aesthetics*
- *Self-purification potential (N, P, C)*
- *Biodiversity.*

Note that a quantitative link between Impact I assessed for IESS # 1-4 and Impact II assessed for FESS # 1-5 is not possible. As there is a multitude of factors that influence prices of real estates and the appreciation of an environment, no direct link can be drawn. However, we assume that a river environment which has a high self-purification capacity and can deal well with occasional pollution via CSO events is visually cleaner, shows less turbidity, less smell, less signs of eutrophication such as mass growth of algae or the creation of foam, and accordingly, is more attractive to people.

5.6.3 IMPACT II – Use & resulting benefit (FESS # 2)

The quantification of the use of the service is represented by A) the commercial and B) the housing area and the resulting benefit is analyzed for the two different types of beneficiaries A) Resources-dependent businesses (cafés, restaurants) and B) Residential Property Owners.

The monetization of the "*Opportunity for placement of infrastructure in environment*" was calculated by hedonic pricing via two methods, presented below. The first method focused on the already restored Lake Phoenix area and covers both types of beneficiaries, while the second method focused on residential property owners in the entire New Emscher Valley.

Method 1

The benefit assessment focused on Lake Phoenix with no consideration of the remaining basin. Data were obtained from the City of Dortmund, the Chamber of Commerce and Industry, the Statistical Bureau, and an online real estate portal. In the use assessment, the area of commercial or housing places was applied as indicator for demand for working or living space, respectively. The monetary benefit arising from this is given in € rent/cost per year for the direct Lake Phoenix surroundings.

A transfer of these results to the entire Emscher basin is not appropriate, as similar restoration projects as the creation of Lake Phoenix are currently not planned. If they were to be realized in the future, similarly positive effects on real estate and rental prices as around Lake Phoenix can be expected.

Results & discussion of method 1

A) Resources-dependent businesses (cafés, restaurants)

As this method focusses on Lake Phoenix, which did not exist until its creation and flooding in 2010, the BEFORE values for use and benefit account for 0.

The area of commercial places with view on the created Lake Phoenix and the Oberlauf der Emscher flowing along the lake is presented in Figure 42 and the subsequent assessment via hedonic pricing in Figure 43. Data on the used area was obtained from the City of Dortmund. For the monetary evaluation we obtained the number of restaurants along the lake shore, the rental cost for commercial area, and the yearly turnover per restaurant (Data sources: German Chamber of Commerce and Industry, German Federal Statistical Office).

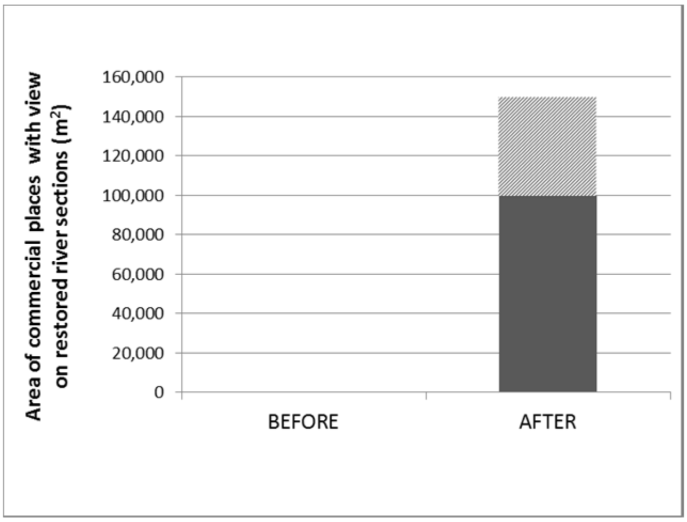

Figure 42: Area of commercial places with view on the created Lake Phoenix and the Oberlauf der Emscher. The range of results based on different assumptions is hatched (Data source: City of Dortmund).

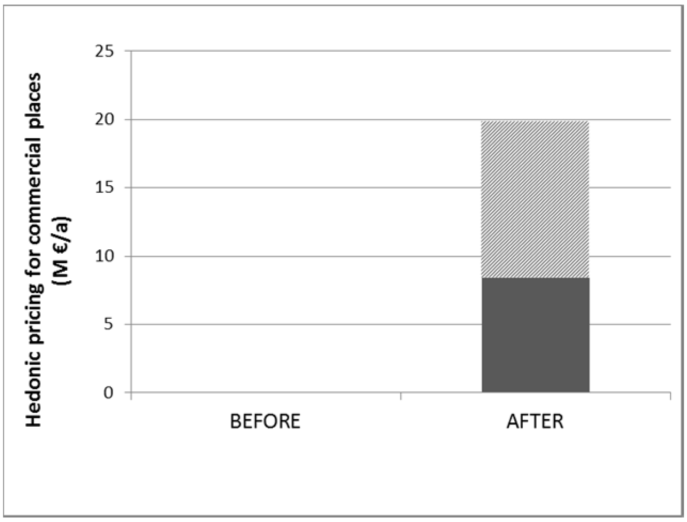

Figure 43: Hedonic pricing method applied to commercial places with view on the created Lake Phoenix and the Oberlauf der Emscher. The range of results based on different assumptions is shown hatched (Data source: German Chamber of Commerce and Industry, German Federal Statistical Office).

B) Residential Property Owners

Similarly as for resources-dependent businesses, also for residential property owners we assume use and benefit at Lake Phoenix BEFORE its creation to be 0.

The area of flats and houses with view on the created Lake Phoenix and the Oberlauf der Emscher flowing along the lake is presented in Figure 44 and the assessment via hedonic pricing in Figure 45. Again, the used area is obtained from the City of Dortmund; the monetization was conducted based on the rental cost for housing area from the online real estate portal “wohnungsboerse.net”.

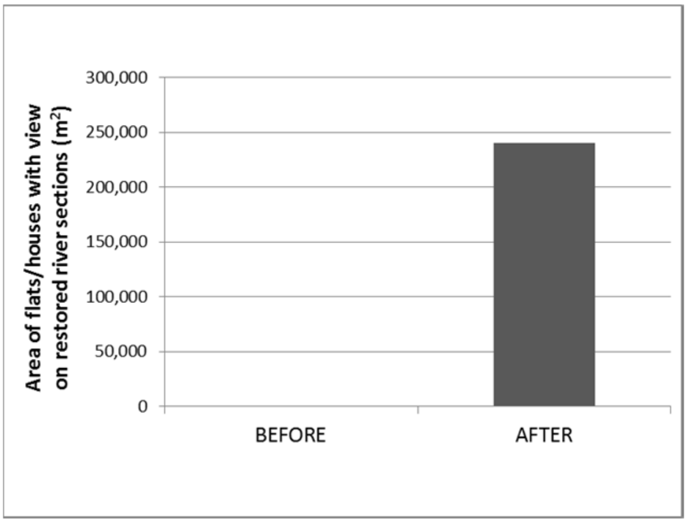

Figure 44: Area of flats/houses with view on the created Lake Phoenix and the Oberlauf der Emscher. The range of results based on different assumptions is shown hatched (Data source: City of Dortmund).

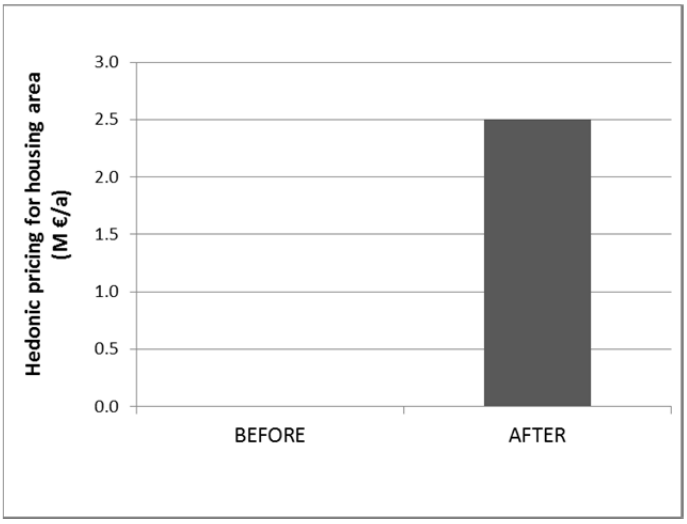

Figure 45: Hedonic pricing method applied to flats/houses with view on the created Lake Phoenix and the Oberlauf der Emscher (Data source: online real estate portal “wohnungsboerse.net”).

Method 2

The rwi study (Barabas et al. 2013) was the basis for applying this method. The study revealed an increase in certain types of real estate and rental prices in the New Emscher Valley. This can be due to the already progressed conversion to the New Emscher Valley in that area.

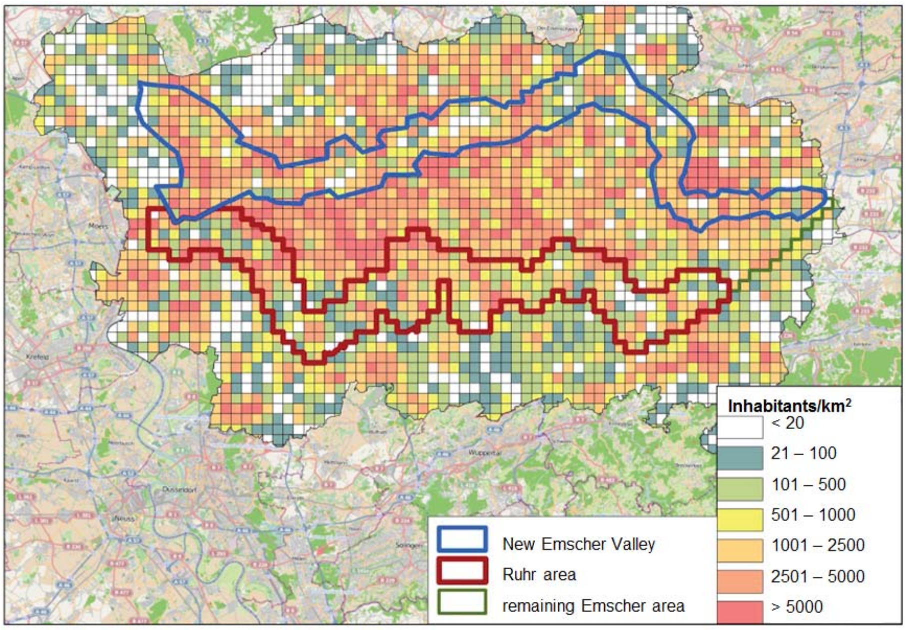

Figure 46: Map of the entire Ruhr area showing the subareas compared within the rwi study: The New Emscher Valley, the Ruhr Valley, and the remaining Emscher area as well as the number of inhabitants per km² , status 2000 (Source: microm in Barabas et al. 2013).

In order to transfer these results to the entire Emscher basin after full restoration, i.e. the entire New Emscher Valley restored, we took the following approach: The change in value for flats for sell and rental flats (€/m²) for those areas where the restoration had already taken place (at Lake Phoenix) was transferred to the total used housing area (m²) of owner-occupied flats (not reported due to data constraints) and total used housing area (m²) of rented flats for the entire New Emscher Valley. The same was done for the remaining Emscher area.

Note that this calculation focusses on the New Emscher Valley, and as such, only on the Emscher main stem without taking into consideration the increase in value along the tributaries as well.

Results & discussion of method 2

By applying method 2, we estimated the changes in residential rents (Figure 47) for the total housing area for the New Emscher Valley (NE) and the remaining Emscher region (Emscher) for BEFORE and AFTER the ecological restoration of the Emscher. For the renting offers, we detected price increases for both the NE (11.81 to 35.97 M €/a) and the remaining Emscher (40.38 to 86.08 M €/a), each for the total housing area. The price increase we detected is a result of two developments: a price change due to the restoration and an increase in the number of rental flat offers. This increase in the number of flats with various sizes was observed both in the NE (from 3062 to 5590) and the remaining Emscher (9434 to 21896) (Barabas et al. 2013). The reason for the increase in the number of flats is not clear.

For flat purchase offers, we could not make a prediction, as no data on price changes in flat purchase offers resulting for the restoration was available. Furthermore, effects on flat purchase offers are one-time effects only.

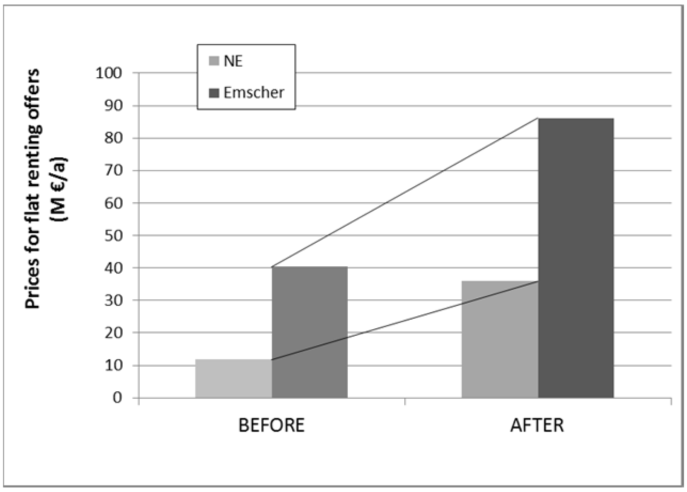

Figure 47: Prices for flat renting offers, BEFORE and AFTER re-conversion in the New Emscher Valley (NE) and the remaining Emscher area (Emscher) in M € per year (Data source: Barabas et al. 2013).

The observed effect was differentiated into price effect and area effect in order to specify the effect caused by the restoration. We see that the price effect is positive for the NE (from 11.81 to 20.44 M €/a) and constant for the remaining Emscher (40.38 to 40.33 M €/a; Figure 47). The area effect is positive in both the NE and the remaining Emscher, as explained above (increase in number of flats).

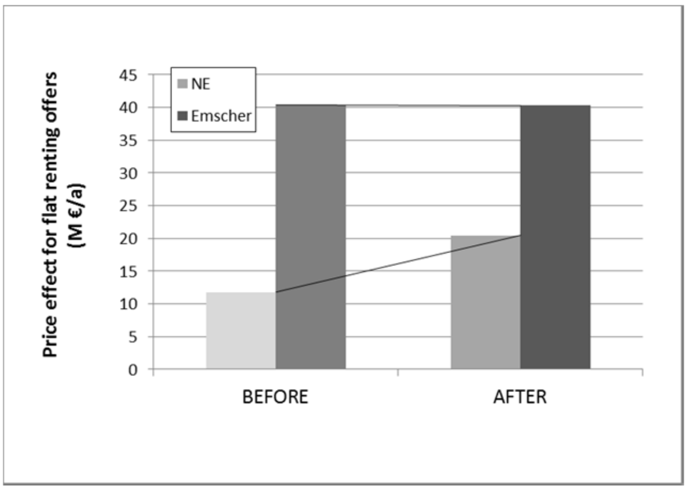

Figure 48: Price effect (i.e. without area effect) for flat renting offers, BEFORE and AFTER re-conversion in the New Emscher Valley (NE) and the remaining Emscher area (Emscher) in M € per year (Data source: Barabas et al. 2013).

Uncertainty

Method 1

Due to the fact that the values for the total area for retail businesses and residential buildings had to be taken from planning reports, there is some uncertainty linked to the final results. But as the leasing prices are real data sets, the calculated economic impact is assumed to be a good estimation of the real economic impact.

Method 2

The calculation of the increase in renting prices needs to be seen as a rough estimation only due to the different data sources for the states BEFORE and AFTER. Furthermore, it is not clear if the observed area effect is a result of the Emscher re-conversion or other factors.

5.7 FESS # 3: Opportunity for biking & recreational boating

This final Cultural service describes how an environment is suitable for recreational activities, in our case biking & recreational boating. The provision (Impact I) of an environment suitable to provide this opportunity can either be assessed using landscape aesthetics metrics and/or the intermediate services IESS # 1-4 which are preconditions for such a suitable environment.

In the Emscher case, we have identified two beneficiaries for this service:

A) Bikers and

B) Boaters.

Therefore, we will focus on the use (Impact II) of this service in terms of

A) Biking activity and

B) Boating activity.

5.7.1 STATE (FESS # 3)

Besides the parameters of State required for providing the intermediate services IESS # 1-4 (See 5.1.1, 5.2.1, 5.3.1., 5.4.1.), further cultural parameters of State are required. In our case, these are

- presence of bike paths (Figure 49)
- presence of lake for sailing/boating.

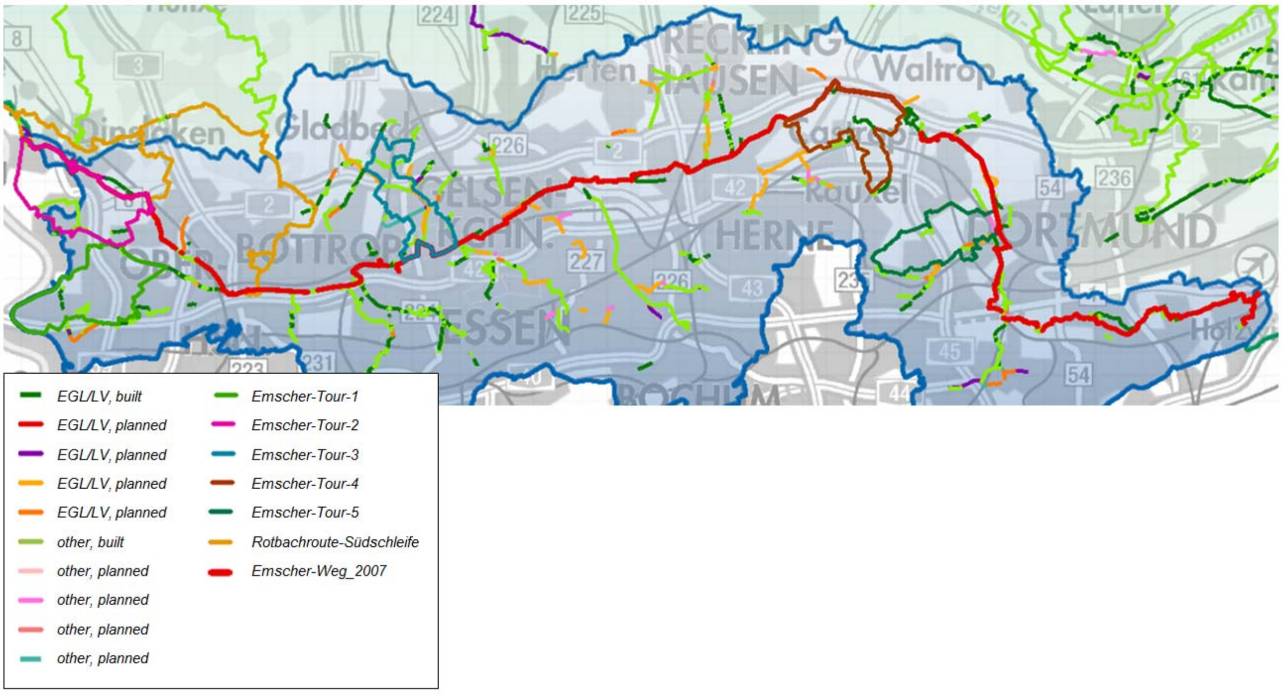

Figure 49: Network of biking paths in the Emscher basin (Source: EG, WebGIS).

The total length of biking paths increases from less than 40 to more than 120 km (Figure 50) from BEFORE to AFTER the Emscher re-conversion.

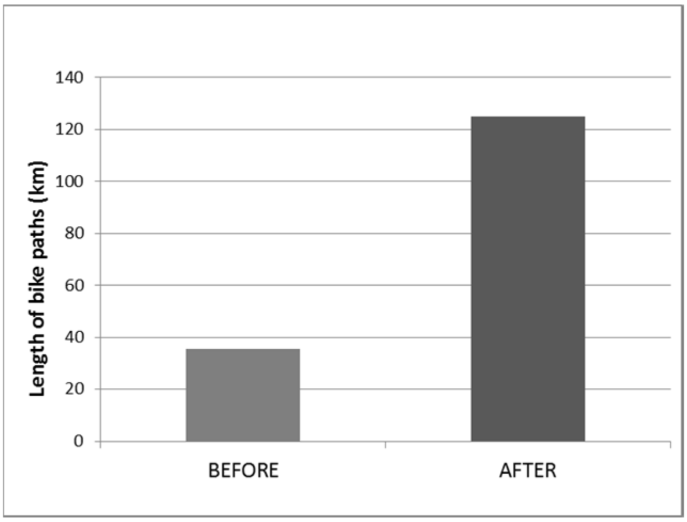

Figure 50: Length of biking paths in the Emscher basin (Source: EG).

Lake Phoenix represents the only lake present in the Emscher region that offers the opportunity for sailing (Figure 53).

5.7.2 IMPACT I - Provision (FESS # 3)

See 5.6.2.

5.7.3 IMPACT II – Use & resulting benefit (FESS # 3)

The FESS "*Opportunity for biking & recreational boating*" was assessed for two types of beneficiaries:

A) Bikers

B) Boaters

A) IMPACT II – Use & benefit: Biking

Method

To evaluate the use and economic value of biking in the Emscher basin, we transferred the results of a study on the economic effects of the Römer-Lippe bike route in the Lippe basin (Radschlag, IGS 2013) to the Emscher area. The basins and the expected number of bikers are comparable. The total spending per biker on a day trip or a several day bike tour was multiplied with the number of bikers per year, representing the WTP of the users of the bike paths.

Results & discussion

BEFORE the Emscher re-conversion, only 28% of the 125 km of bike paths that will be available by 2020 were present. Thus, the number of bikers (Figure 51) and the total economic value originating from biking activities were both approx. 72% lower at that time (Figure 52).

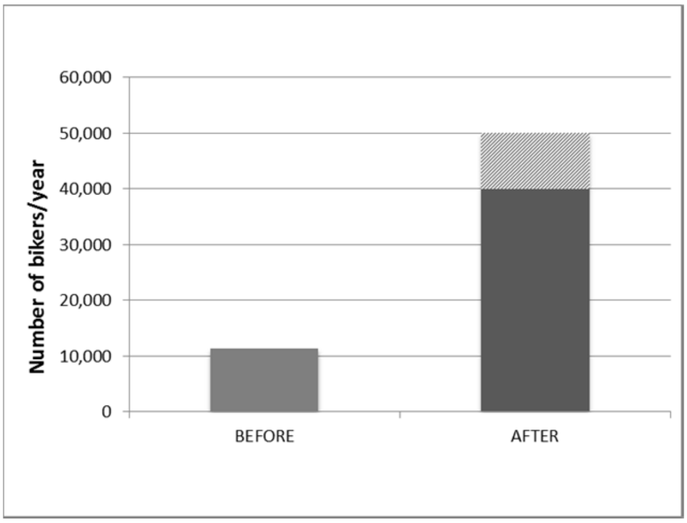

Figure 51: Expected number of bikers per year on the bike paths in the Emscher basin, range hatched (Data source: Radschlag, IGS 2013)

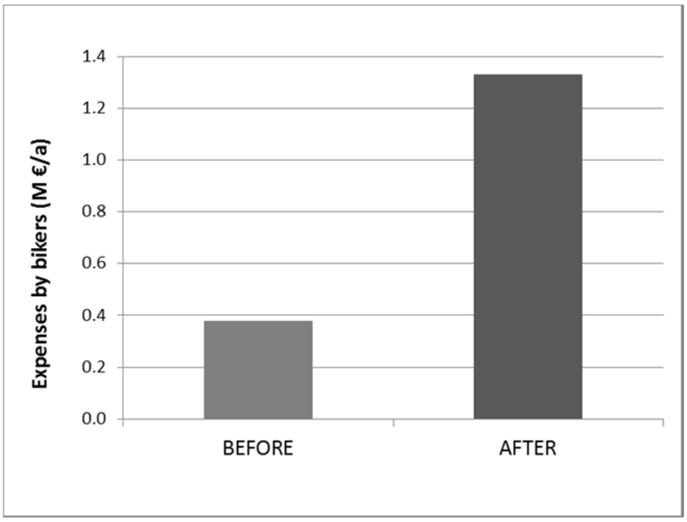

Figure 52: Expected expenses by day-trip and bike route bikers per year in the Emscher basin (Data source: Radschlag, IGS 2013)

A) IMPACT II – Use & benefit: Boating

Figure 53: View of Lake Phoenix as a recreational area (Source: EGLV, Gabi Lyko)

The recreation activity boating is only possible on Lake Phoenix and not on other water bodies within the Emscher basin. Furthermore, this kind of activity is only possible as a result of the creation of Lake Phoenix. As there was no lake before, the use and the recreational benefit accounted to 0 BEFORE the conversion (Figure 54, Figure 55, Figure 56, Figure 57). The total expected expenses by boaters at Lake Phoenix are more than 50,000 €/a.

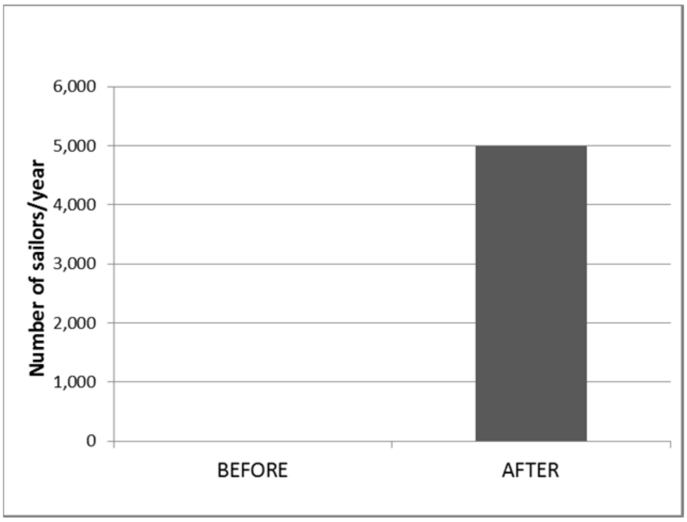

Figure 54: Number of sailors on Lake Phoenix per year (Data source: Lake Phoenix boat rental)

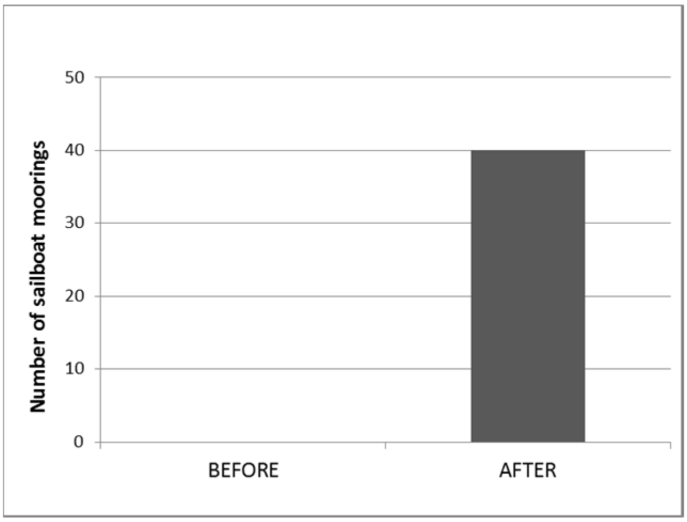

Figure 55: Number of sailboat moorings on Lake Phoenix (Data source: Lake Phoenix boat rental)

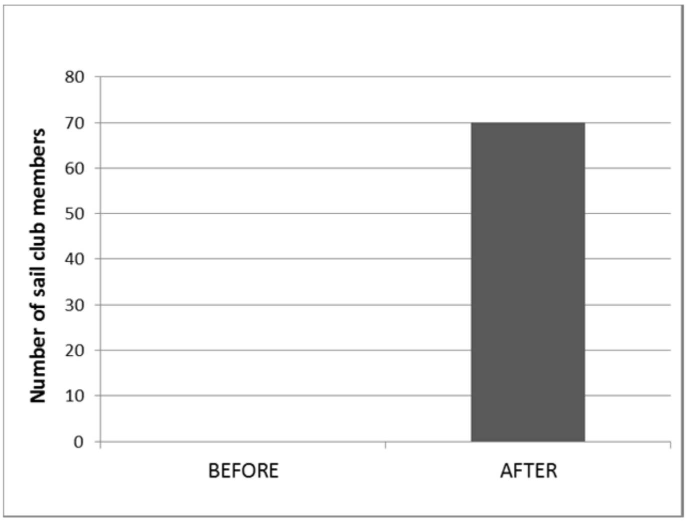

Figure 56: Number of sail club members at Lake Phoenix (Data source: Lake Phoenix boat rental)

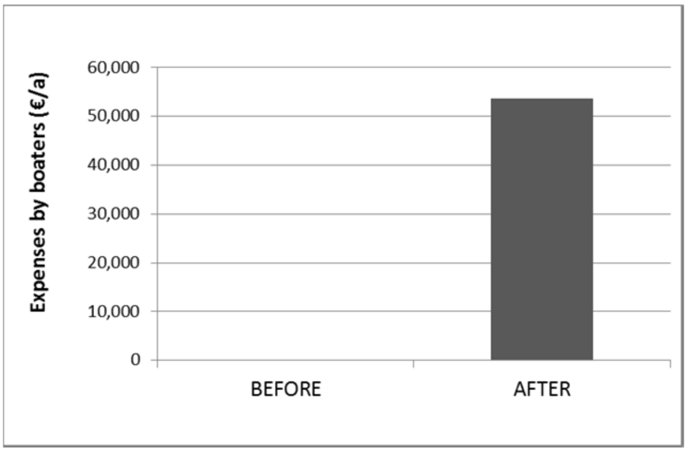

Figure 57: Expected expenses by boaters at Lake Phoenix (Data source: Lake Phoenix boat rental)

Uncertainty

This FESS is present at only one site in the Emscher case and, thus, cannot be scaled up to basin level. However, it is an interesting example of possible effects from innovative restoration measures.

5.8 FESS # 4: Opportunities to understand, communicate, and educate

This final Cultural service describes how an environment is suitable for educational activities. Similarly as for FESS # 2-3, the provision (Impact I) of an environment suitable to provide this opportunity can either be assessed using landscape aesthetics metrics and/or the intermediate services IESS # 1-4 which are preconditions for such a suitable environment.

In the Emscher case, we have identified educators and students as beneficiaries for this FESS.

5.8.1 STATE (FESS # 4)

See 5.1.1, 5.2.1, 5.3.1., 5.4.1.

5.8.2 IMPACT I - Provision (FESS # 4)

The provision of a suitable environment is essential for educational activities. The FESS "*Opportunities to understand, communicate, and educate*" relies on the provision of several intermediate ESS, being e.g. *Landscape aesthetics, Self-purification potential (N, P, C)* and *Biodiversity*.

Note, however, that there is no direct link between Impact I and Impact II.

5.8.3 IMPACT II – Use & resulting benefit (FESS # 4)

For the use of this FESS we have identified three potential indicators:

A) Offer: educational offers linked to the environment
The offer could not be quantified, because no data are available on this metric.

B) Acceptance: participation in excursions

C) Outcome: persistence of knowledge and environmental awareness
The outcome could not be quantified, because no data are available on this metric for success of the educational units.

Figure 58: Educational excursion along Lake Phoenix and the new Oberlauf der Emscher with its new floodplain bypassing the lake.

B) Acceptance: participation in excursions

The number of participants in excursions at Lake Phoenix and in excursions along streams within the Emscher basin are shown in Figure 59 and Figure 60. The price paid by participants in an excursion to Lake Phoenix (during a scientific conference) is depicted in Figure 61.

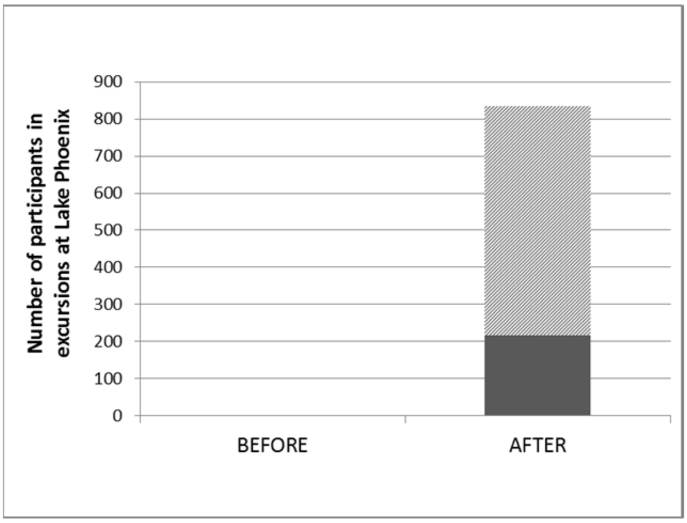

Figure 59: Number of participants in excursions at Lake Phoenix, range hatched (Data source: EG).

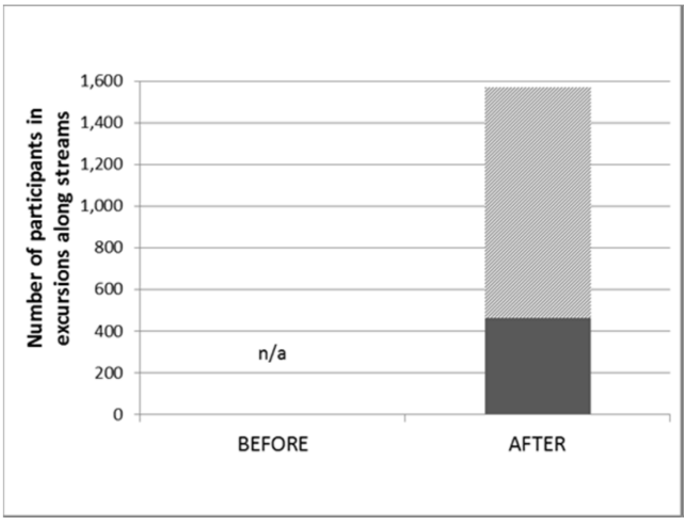

Figure 60: Number of participants in excursions along streams within the Emscher basin, range hatched (Data source: EG).

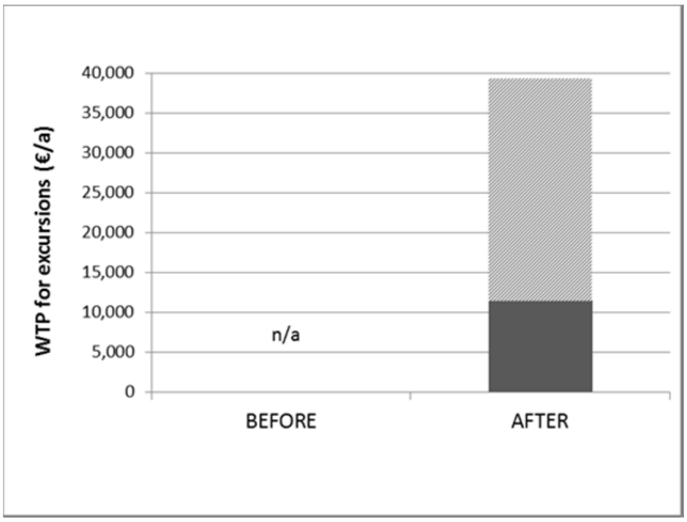

Figure 61: Willingness to pay for excursions within the Emscher basin, range hatched (Data source: UDE, DGL – Deutsche Gesellschaft für Limnologie e.V. conference).

Uncertainty

Also pupils, students, etc. are participants in educational excursions, possibly having a different WTP than guests of conferences. However, due to data constraints, the WTP was transferred from the costs of a conference excursion only.

5.9 FESS # 5: Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)

FESS # 5 describes the "*Knowledge that a restored river area exists, with suitable water quality*". In our case, we define suitable water quality with the goal to reach the good ecological potential (GEP), the regulatory threshold of the WFD. The provision (Impact I) of such a river environment suitable to reach this goal is also reflected by the intermediate services IESS # 1-4 as preconditions.

The beneficiaries for this final service are people who care.

5.9.1 STATE (FESS # 5)

See 5.1.1, 5.2.1, 5.3.1., 5.4.1.

5.9.2 IMPACT I - Provision (FESS # 5)

The FESS "*Knowledge that a restored river area exists, with suitable water quality*" depends on the provision of the IESS *Self-purification potential (N, P, C), Biodiversity* and others.

In this case, a quantifiable link between Impact I and Impact II is possible by comparing the final nutrient concentrations in a given water body with a given self-purification potential with the regulatory thresholds of the WFD concerning maximum nutrient concentrations. Similarly, biodiversity indicators could be compared to biodiversity goals of the WFD. We conducted the latter comparison by means of the ecological potential (see 5.4.2).

5.9.3 IMPACT II – Use & resulting benefit (FESS # 5)

An indicator of use is, in this case, not required and not appropriate.

The indicator for monetizing the value derived from the "*Knowledge that a restored river area with suitable water quality exists*" was taken from literature using the benefit transfer approach.

Benefit transfer was conducted from a WTP study for achieving the good ecological status (GEP) of the River Wupper by Hecht et al. (2015), as primary valuation research was not feasible within the DESSIN project. Wupper and Emscher are comparable in terms of length, area, location, affected beneficiaries, and market construct (see Annex for further information). The total WTP for restoring the Emscher was finally calculated by taking the WTP for reaching the GEP of the River Wupper and transferring it to the population structure in the Emscher catchment (Figure 62).

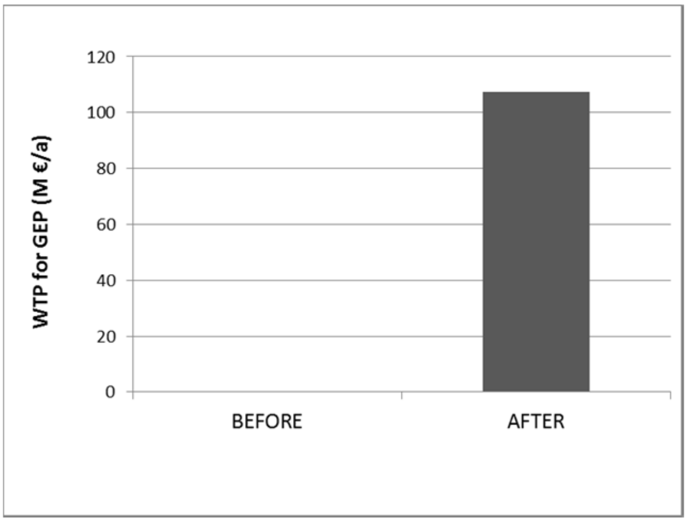

Figure 62: Willingness to pay for river environment to reach the good ecological potential (Data source: Hecht et al. 2015)

Uncertainty

The benefit transfer method is always linked to some uncertainty, as the benefit was not evaluated in the area under study. Nevertheless, a transfer was regarded appropriate, as both the Wupper and Emscher are tributaries to the River Rhine, have nearly the same length and catchment area. Also the affected beneficiaries and market construct are comparable and both rivers were historically used for (industrial) sewage disposal.

5.10 Further ESS not assessed quantitatively

The following ESS could not be assessed quantitatively due to data constraints. In this chapter, they are, therefore, briefly described qualitatively.

5.10.1 ESS: CO_2 sequestration (Global climate regulation by reduction of greenhouse gas concentrations)

Ongoing restoration activities have an effect on greenhouse gas concentration via several processes. These are discussed in the sustainability assessment in Part V (En124 and EG 213). One of these processes is the increased CO_2 sequestration by vegetation which is developing in the newly restored floodplains and river banks. These floodplains are either newly created or re-connected. Within these floodplains, the share of the land use types grassland and forested area shifts towards forested area. As forested area is capable in fixing more CO_2 compared to grassland, an increase in carbon sequestration is to be expected from BEFORE to AFTER restoration.

5.10.2 ESS: Local climate regulation (Micro and regional climate regulation)

Positive effects on local climate have been observed and studied in various cases, where green spaces have been created in urban areas (Elmqvist et al. 2015). For evapotranspiration by plants, energy is abstracted from the air, resulting in a decline in air temperature. Furthermore, the air is humidified via this process. Shading is, of course, also a positive effect of green spaces. These effects are valuable benefits for the inhabitants of cities. Especially during heat periods in summer they reduce temperature in urban heat islands. The effect can, for instance, be monetized as it saves large amounts of energy used in air conditioning. Additionally, pollution removal takes place at the surface of plants/trees. The monetary benefit for people can e.g. be assessed in terms of positive health effects.

5.10.3 ESS: In-stream cooling effect

Vegetated or forested stream shores considerably reduce in-stream water temperature by shading. It has been observed (Refresh project, Piet Verdonschot, personal communication) that shading results in average temperature being 2°C lower with 6°C lower maximum temperatures. From the land use within the HQ50 areas of restored DESSIN focus streams, we derived that on average 54% of the banks are vegetated, and thus, have the potential to contribute to the cooling effect.

5.10.4 ESS: Research opportunities (Educational)

Open wastewater channels are not of interest for conducting research. Natural streams are much more often object of research, investigating ecological functions and processes. Also restored streams offer a wide variety of topics to be investigated, especially concerning the development of newly restored streams and the establishment of communities of plants and animals. Also the self-development of restored stream beds and shores is often object of research studies.

5.10.5 ESS: Drinking water provision in the downstream Rhine catchment

As mentioned in the beginning, the downstream Rhine catchment is beyond the spatial limitation of the present case study, and therefore, not assessed here. However, due the restoration and the re-establishment of ecological functions and services such as the self-purification capacity of the water bodies (IESS # 1-3), positive effects are expected even beyond the study area. One of these effects is the improved water quality of the Emscher discharging into the River Rhine. This will facilitate drinking water provision conducted via river bank filtration of Rhine water and reduce additional water treatment costs. After completion of the Emscher re-conversion, the WWTP at the Emscher mouth in Dinslaken will not anymore treat the entire river like it has before the re-conversion. Thus, CSO discharges into receiving water during rain events will need to be eliminated or retained by the river itself. This elimination/retention is stronger if the self-purification capacity of the streams is high.

5.11 Possible impacts of climate change on ESS provision and use

Climate change scenarios for North Rhine-Westphalia for 2046-2055 predict an increase in temperature in the Emscher region (Figure 63) (MUNLV NRW 2007). At the same time, total precipitation in the summer months will decline while in winter it will increase. The probability for extreme precipitation events is expected to increase throughout the whole year (Figure 64).

The effects of climate change on the weather conditions in the Emscher region have also been analyzed in the research project dynaklim. Mean annual air temperature has already increased and is expected to increase more, especially in the summer months. Concerning extreme temperatures, hot days are expected to increase in frequency and intensity while cold days are expected to decrease. Annual precipitation is forecasted to remain at a level as today. In the far future a decline in precipitation during the summer term is anticipated. Furthermore, dry periods with a longer duration are expected to occur more often with more dry days during the summer term. A higher number of heavy rain events has already been observed and more intensive heavy rain events are expected to occur more often (Quirmbach et al. 2012).

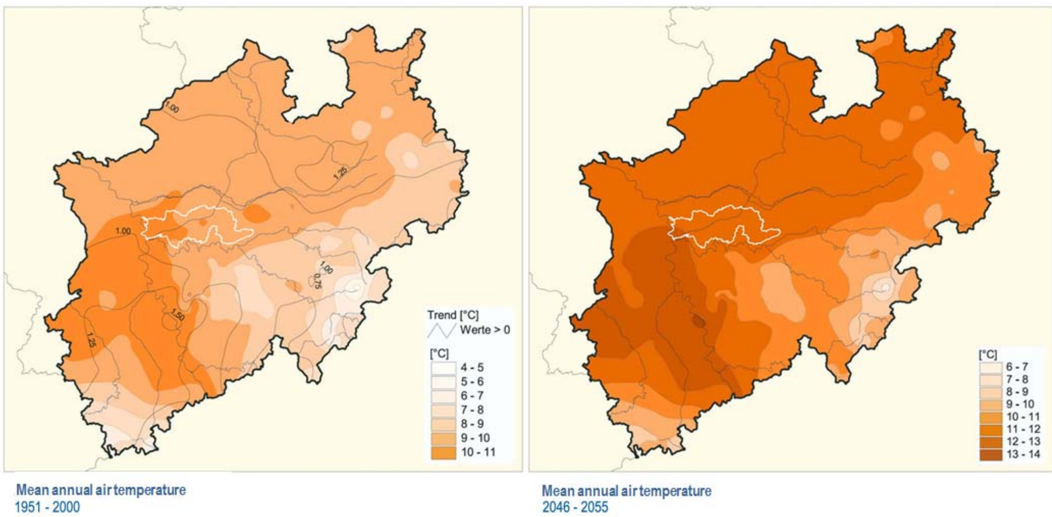

Figure 63: Forecast for temperature increase in North Rhine-Westphalia (left: mean annual air temperature 1951-2000, right: mean annual air temperature 2046-2055 (Source: MUNLV NRW 2007)

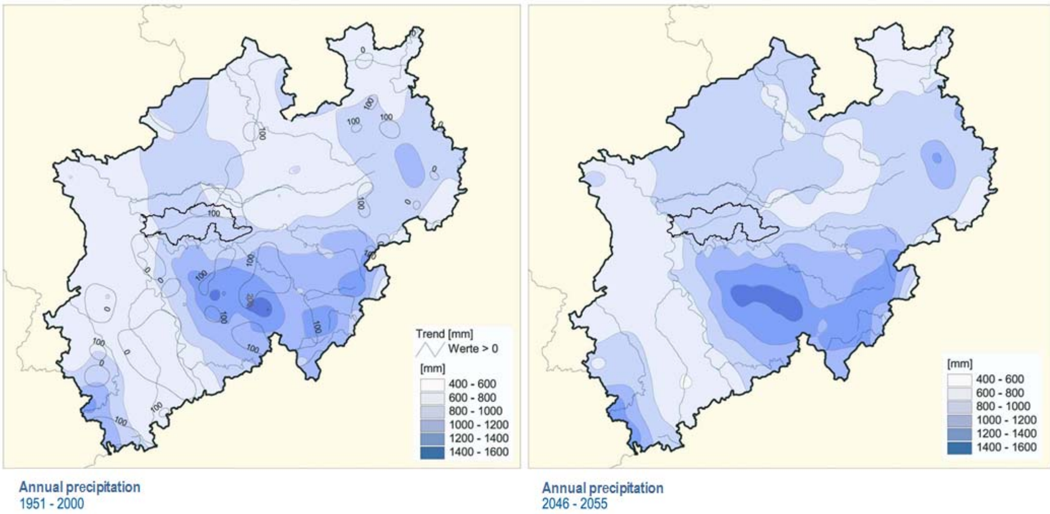

Figure 64: Forecast for precipitation increase in North Rhine-Westphalia (left: annual precipitation 1951-2000, right: annual precipitation 2046-2055 (Source: MUNLV NRW 2007)

These climatic changes have implications for the provision and use of ESS. The following effects on aquatic ecosystems are probable: Increases in air temperature will also lead to higher in-stream water temperatures, especially in shallow, slow flowing water bodies. Higher water temperatures can affect biological communities, both plants and animals. Plant growth could be enhanced with higher temperatures and more sunlight up to a maximum level. Aquatic invertebrates and fishes might, on the other hand, be stressed by high temperatures. Invasive species, however, might be able to better cope with these conditions than local species. Furthermore, conversion processes provided by bacterial communities such as denitrification could be enhanced by a temperature increase – at least up to an optimum (above which a decrease will follow). These potential effects have implications on the IESS "*Self-purification*" and "*Biodiversity*".

Extreme heat days in urban areas will have effects on local climate, rising the importance of the ESS "*Local climate regulation"* as well as of measures (e.g. parks, water bodies) promoting this ESS.

The changes in precipitation can affect several ESS. With less rain in the summer months coinciding with high temperatures, it is more probable that streams periodically fall dry. This, of course, is detrimental for "*Biodiversity*" but also for "*Self-purification*". Furthermore, enhanced precipitation in the winter term and more regular heavy rain events will affect the ESS "*Flood protection*". Natural water retention inside stream beds, floodplains and vegetated basins will gain importance in order to prevent damage by flooding. Flood events of a certain intensity and reoccurrence interval (e.g. HQ100) are expected to occur more often in the future due to climatic changes, e.g. once in 80 years instead of 100 years.

Cultural ESS might also be affected by both climatic developments. The directions of the trends need to be considered distinctively. Flooded areas or streams that fell dry will probably not be a destination for *recreational activities* anymore. Parks and water bodies in the cities will, however, become a location for recreation during hot summer periods. *Research and education* might become more relevant in ecosystems affected by climate change. And the "*Knowledge that ecosystems with a good ecological status*" exist might be valued higher by people who care.

Therefore, climate change can lead to an enhancement of provision and use of several ESS. At the same time, however, a decline in other ESS is anticipated.

5.12 Conclusions & recommendations

5.12.1 Summary

As only final services can be reported in the same unit (€/a) but not intermediate services, only FESS can be shown in one overview graphic. The spider plot below (Figure 65) presents the changes in the monetary benefit for each of the FESS in the same plot. The change in benefit ranges from 53,600 €/a ("*Opportunity for boating*") to 107,335,717 €/a ("*Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)*"). As this range is quite large, the benefits had to be log10 transformed to appear in one plot.

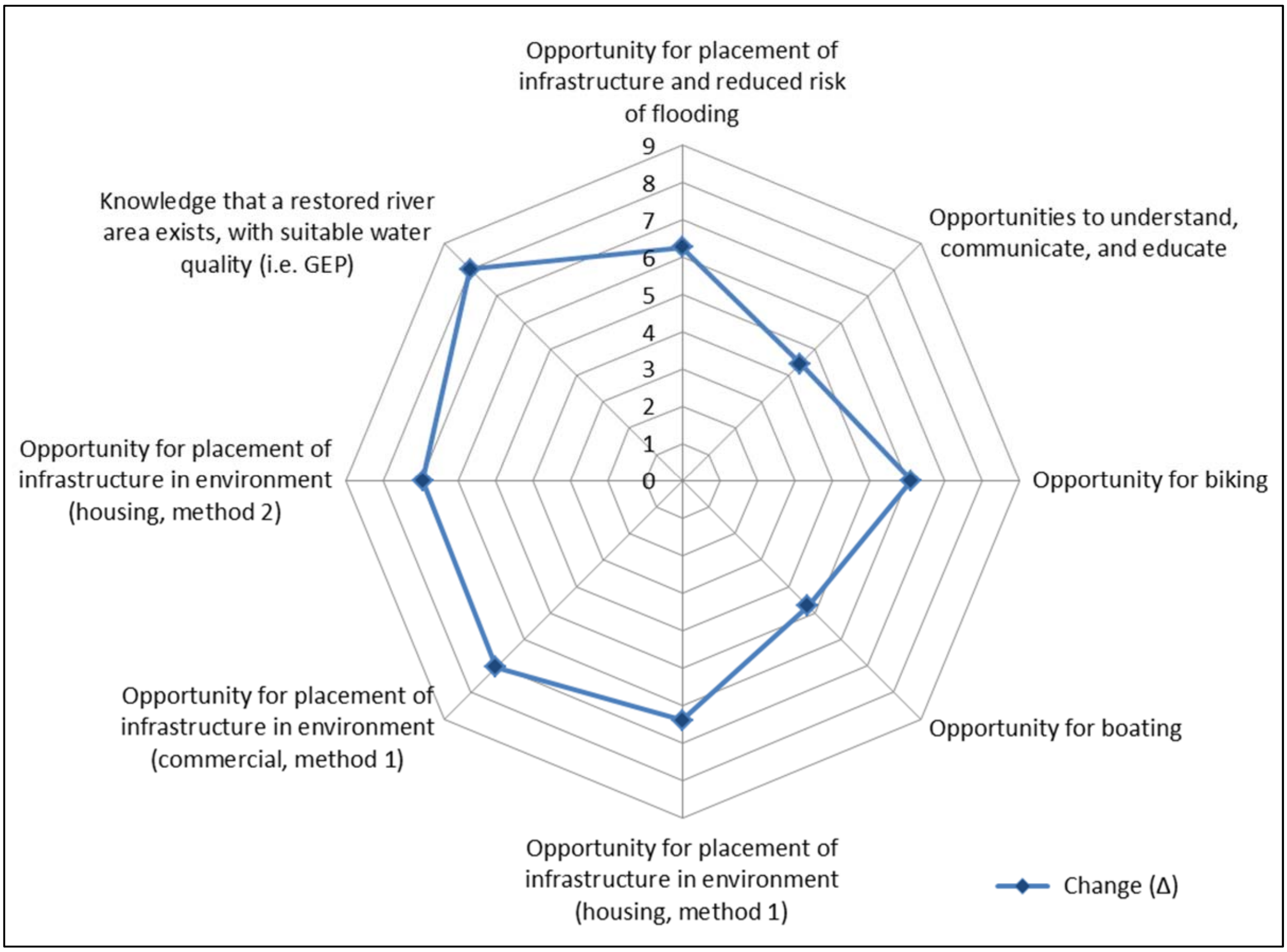

Figure 65: Spider plot showing all FESS evaluated in the Emscher mature case, axis: log10 transformed €/a (red points: BEFORE, blue points: AFTER).

5.12.2 Conclusion

All in all, it can be stated that the Emscher re-conversion has led to an improvement in all of the IESS and FESS assessed.

The fact that these benefits are available to all of the 2.2 million inhabitants in the Emscher catchment as well as to tourists travelling to the area has to be considered in a positive way.

For a comparison of ESS provision and the resulting benefits with the costs of the restoration project (4.5 billion €), some restrictions have to be considered. First of all, not all ESS can be included in this comparison since only FESS are reported in monetary terms (€/a). Thus, the IESS "*Self-purification*" (retention of N, P, and C) as well as "*Biodiversity*" cannot be considered. Also those ESS not assessed quantitatively (*CO_2 sequestration, Local climate regulation, In-stream cooling effect, Research opportunities, Drinking water provision in the downstream Rhine catchment*) cannot be accounted for. Secondly, it has to be noted that those FESS that were quantified and monetized represent only a part of all the ESS relevant in the study area. Thirdly, due to data constraints, several assumptions and estimations had to be made during the assessment process. And finally, not all of the assessed benefits result in a direct economic impact. For example, the WTP for GEP is a theoretical value; this economic impact does not occur in reality. Therefore, only a very roughly calculated cost-benefit comparison can be made.

If the hypothetical value derived from WTP is excluded and benefits from all other FESS are summed up, the annual benefits resulting from the Emscher conversion are estimated to be about 25.73 M €/a. This benefit could be compared to the annualized investment costs of 150 M € per year (4.5 billion € investment costs spent over 30 years). Thus, the benefit for a lifetime of 80 years can be calculated: For those ESS that could be monetized, being *educational and recreational ESS*, *flood protection* and the *opportunities for placement of housing and commercial buildings* the benefit accumulates to 2.06 billion €, excluding, however, the ESS *self-purification*, *biodiversity*, *CO_2 sequestration*, *local climate regulation*, *in-stream cooling effects*, *research opportunities*, and *drinking water provision in the downstream Rhine catchment*, which could not be quantified. Furthermore, it should be highlighted that the benefits are not expected to occur only for 80 years which equals the expected lifetime of the sewage system (see Part V, E.5). The ecological improvement of the streams is supposed to last for eternity, as long as maintenance is assured (see Part V, E.5). With a longer lifetime for the positive effects resulting from the restored streams, the cumulative benefit will be correspondingly higher. Note also that no inflation or price increases are assumed.

Again, it should be highlighted that this cost-benefit-comparison is very rough and incomplete. Further positive and negative effects of the measure which are not included in the ESS evaluation have to be considered in such an assessment as well. Such positive and negative effects are e.g. avoided CO_2 emission costs but also additional pumping costs in the restored system. Some of these aspects are discussed within the sustainability assessment (see Part V).

Concluding, it has to be emphasized that the Emscher re-conversion was a necessity. It was imperative in order to fulfil legal requirements and assure regulated discharge conditions in an area exposed to the consequences of a mining history. In the present study we evaluated extra benefits resulting from the Emscher re-conversion in addition to the fulfillment of the legal responsibilities.

5.12.3 Recommendations

Recommendations by WP13 to WP11 concerning the ESS Evaluation Framework were made throughout the developmental process in order to improve its applicability. In phone conferences and meetings, recommendations were given based on the application and testing of the Framework in the mature cases. These recommendations are reported in the Minutes of Meeting, which are available in the combined Milestones 21 & 26.

STEP A: Definition of the assessment and decision case

The objective of the SA for the Emscher case was to test the developed SA framework. As the reconstruction process of the Emscher is already at a very advanced stage, this assessment can only be seen as an ex-post evaluation of the Emscher conversion measures highlighting benefits and negative side effects in social, environmental, governance, assets and financial terms. As there was no alternative measure to be considered in the decision making process, once the final decision on renaturalizing the Emscher stream and creating Lake Phoenix was made, there will be no alternative considered in the SA. This means that only two scenarios have been compared by using a set of indicators for different assessment criteria:

- a "**BEFORE**" scenario, dealing as a baseline to the assessment, assuming that no measures have taken place at all and
- a future-oriented "**AFTER**" scenario with all measures of the Emscher conversion finished.

The timeframe of the assessment is set in accordance with the duration of the Emscher restoration of 30 years (from 1990 to 2020). The effects considered refer (if not explicitly stated otherwise) to the local area of the Emscher catchment. Please be aware that this choice of system boundaries implies that positive and/or negative effects occurring outside the focus area are not included in the assessment results. The results presented below have to be interpreted with the system boundaries in mind.

In order to avoid redundancy of previous work and reduce the working effort for the Emscher SA, a comprehensive literature review was done by EG and IWW beforehand in order to gather a detailed overview of assessments and other studies performed in the Emscher region so far. Main contributing studies and documents to the SA were the study on regional economic effects of the Emscher conversion by RWI (Barabas *et al.*, 2013) and measurements/monitoring reports as well as management reports by EG.

STEP B: Selection of indicators

In the second step of the assessment process the DESSIN sustainability indicator list was filtered according to the characteristics of the system and the assessment purpose. Therefore, all indicators relating to a water supply system have been excluded since there is (currently) no water extracted from the Emscher for (drinking) water treatment. The same could have been done for the indicators requiring an alternative technology as reference. But as is the review of recent reports and studies information for some of these indicators had been found without considerable efforts, these indicators will be presented as well. However it must be highlighted that these indicators need to be interpreted differently as no reference value is available. Nonetheless, they can give a valuable impression of the dimensions and characteristics of the system under consideration.

Unfortunately, data availability was a critical (but manageable) issue within this assessment. The rating of appropriate indicators for this case study led to a very condensed list of indicators available for quantitative assessment. Furthermore, due to a lack of data in the environmental dimension, only four of the five dimensions proposed by this framework can be addressed in a quantitative way. Nevertheless, all other indicators, suitable but not quantitatively assessable, are described qualitatively in order to fill this gap.

A detailed list of all indicators selected for assessment can be found in the annex to this chapter (Annex, Part V, Step B).

Step C: Definition of additional indicators

Due to the fact that there was no further data available which had not already been covered by one of the indicators selected in Step B, this step has been skipped within the assessment process of this case study.

Step D: Data collection and assessment

As intended in the DESSIN SA framework, some of the data required for the SA was derived from the ESS Evaluation. In the case of the Emscher restoration, several Impact I and Impact II indicators fit specific criteria of the SA. These parameters and metrics do not require further description as this information can be obtained from Part IV (Table 2).

Table 2: SA data derived from ESS evaluation

FESS/ IESS ID	DESSIN ESS	unit	before	after	SA metric/indicator
FESS # 1	Avoided costs from flooding	[€/a]	0	1.78 M	→ F113
FESS # 2	Economic impact of hedonic pricing	[€/a]	n/a	16,599,840	→ S151
FESS # 3	Economic impact of biking	[€/a]	0	1,330,000	
FESS # 3	Economic impact of boating	[€/a]	0	53,600	
FESS # 4	Economic impact of educational excursions	[€/a]	0	25,400	→ S152
IESS # 1	Potential denitrification rate in total Emscher basin	[t/a]	2.99	4.12	→ A151
IESS # 2	Potential P-retention rate in total Emscher basin	[t/a]	1.54	5.64	
IESS # 3	Potential C-stock in total Emscher basin; Potential C-retention in total Emscher basin	[1000t]; [t/a]	95.53; 416.40	133.16; 736.06	

Further data for the SA of the Emscher case study was obtained by EG and IWW from (Barabas *et al.*, 2013) and the management reports by EG. Whenever possible and suitable, data was expressed in annual values in order to be in accordance with the ESS evaluation and to allow an overall life cycle analysis over the lifetime of the solution – if desired in further research.

All SA indicators that have been assessed quantitatively for this mature case study and which have not been reported in the ESS evaluation part of this document before are summarized in Table 3 below.

Table 3: Overview of additional SA data

SA metric/ indicator	DESSIN ESS	unit	before	after	source
S121	Economic impact derived from initial spending	[-]	0	0.62	RWI study
S131	Employment created by implementation of solution	[1/a]	0	1,400	RWI study
S141	Number of beneficiaries affected	[-]	2,210,557	2,210,557	EG
F111	Investment expenditure	[€]	-	4,500,000,000	RWI study
F112	Operational expenditure (between 1991-2020)	[€]	-	450,000,000	RWI study
F114	Other sources of financing (e. g. subsidies)	[%]	-	100	EG
G111	Compliance improvement w/ relevant EU standards	[%]	0	33	EG
A111	MTTF	[a]	-	80 (sewers) ∞ (other)	EG
A221	lifetime of solution/start up time	[-]	-	2.7	EG

The quantitative assessments summarized in Table 2 and Table 3 as well as further qualitative descriptions to those indicators lacking data for calculation are presented in the following chapter.

Step E: Results and discussion

E.1 Social dimension

Besides the two indicators that deal with data from the ESS Evaluation, four additional indicators have been assessed for the Emscher re-conversion in the social dimension.

Before the Emscher re-conversion was initiated, all Emscher tributaries as well as the Emscher River itself were open wastewater channels. Raw wastewaters from households and industry as well as mining effluent were flowing in these channels together with the original river water (groundwater) and rainwater. Thus, high concentrations of pathogens (*E. coli*, Enterococci) and chemicals were transported in the river network. After the construction of an underground sewer network, the first step of the Emscher re-conversion, all communal and industrial wastewater is conducted underground. Therefore, the concentration of pathogens and pollutants in the streams is considerably lower (**S111, 112, 113**). However, during rain events, discharge of CSO can still lead to occasional input of wastewater into the streams. Also run-off during rain events as well as sewage from brownfields and waste deposits causes input of pollutants.

As the economic impact creation of the measure has already been calculated within the RWI study (Barabas et al. 2013), the resulting production effect of 11 billion euro can easily be transformed to the indicator **S121** proposed in the DESSIN indicator list. As there was neither an initial spending nor a resulting economic impact before the measure had been implemented, there was no economic impact creation to be observed BEFORE. AFTER the construction works are completed, there will be a return on initial spending via economic impact creation of 0.62 (on a scale from 0 to 1). This value might seem to be low with regard to the optimum value of 1 for a "perfect investment". But as there is no comparable measure available, this value can only be taken as an indication that the Emscher restoration works have resulted in a high economic impact creation in the Emscher catchment and beyond.

This becomes evident as well when considering the second indicator metric assessed belonging to the criteria of job creation (**S131**). Barabas et al. (2013) determined the number of jobs that are secured and created by the measures themselves on an annual basis. The final value of 1,400 jobs emphasizes that the Emscher re-conversion is a very large-scale project. Although information on jobs derived from improved Cultural services was not available at the time of assessment, based on the fact that there are several retail stores newly located in the Emscher catchment (especially at Lake Phoenix) after the Emscher re-conversion, a positive effect in this indicator can be assumed.

The annual economic impacts derived from hedonic pricing for commercial places (e. g. cafés, restaurants) (**S151**) and the newly built housing area at Lake Phoenix as well as educational excursions have already been assessed and discussed in the previous chapters on ESS evaluation. As no use of these Cultural ESS existed before the Emscher re-conversion, these can be seen as pure benefits to human well-being resulting from the solution.

All in all, it can be stated that the Emscher re-conversion has led to an improvement in all of the social criteria assessed. The fact that these benefits are available to all of the 2.2 million inhabitants in the Emscher catchment as well as tourists travelling to the area gives further emphasis to this.

E.2 Environmental dimension

As mentioned above, unfortunately, there was no data available on the environmental effects of the Emscher restoration measures besides those affecting ESS provision and use. Thus, the environmental dimension can only be described qualitatively by highlighting tendencies in the indicators' developments.

The Emscher re-conversion is only feasible with intensive excavating, transport, and building activities. These activities go along with a high energy demand (**En125**), and with this, high emissions of CO_2 (**En213**) throughout the 30 year conversion period. The activities are conducted by EG itself as well as by external companies. However, currently no data on CO_2 emissions resulting from these activities is available. The EG management summary states that the main construction works where executed by external contractors (Emschergenossenschaft 2015). But also in the EG statistics, an increase in energy consumption can be observed since the beginning of the Emscher re-conversion (Emschergenossenschaft 2015). Unfortunately, the part which is consumed specifically for the re-conversion measures and not for standard operation tasks cannot be identified.

Energy consumed for WWTP operation is one of the main factors concerning energy demand (Figure 66). Nine WWTPs were in place in the Emscher area BEFORE the re-conversion, while AFTER the re-conversion only four WWTPs remain. Thus, a reduction in energy demand of 10.6% could already be achieved from 2002 to 2015 (Figure 67). Furthermore, the energy recovery rate in the system (**En122**) by EG (mainly from bio gas) has increased by 15.5% over the years. Additionally, a wind power plant has been installed on one of the WWTP sites with an expected annual return of 4,500 – 8,000 MWh/a. Several pumping stations have been newly created during the re-conversion, plus, large-scale underground pumping stations still need to be put in place. The latter are required for transporting wastewater through the newly built sewage system to the WWTPs. The pumping costs cannot be quantified yet because the amount of water reaching these stations cannot yet be exactly forecasted. This forecast is hindered because the future development of the population in the area, the share of rainwater in the combined sewer, and the amount of groundwater infiltrating into the sewers are factors of uncertainty.

Figure 66: WWTP in Bottrop in the Emscher area, one of the largest WWTPs in Germany, with an electricity consumption of 40 M kWh per year.

Another impact concerning CO_2 emissions from the construction works is not caused by energy but by fuel consumption by trucks for moving excavated material.

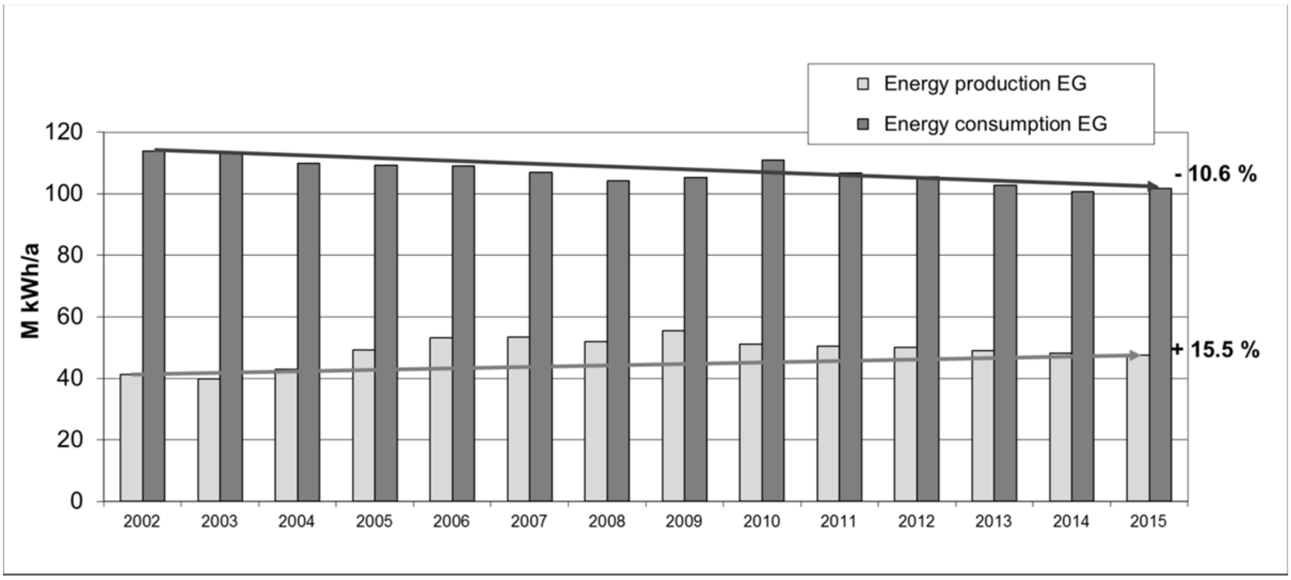

Figure 67: Energy consumption and production at WWTPs in the Emscher area from 2002 to 2015 (Source: Frehmann 2015).

One more source of climate relevant gas emissions are CH_4 and N_2O emissions from WWTPs, digestion towers, sludge drying sites, and from the Emscher River itself (BEFORE) or the underground sewers (AFTER) (**En213**). These emissions can be transferred and be reported as CO_2 equivalents for the state BEFORE and AFTER the re-conversion (Figure 68). To get an idea of the current monetary value of these avoided carbon emissions in terms of CO_2 certificates, current trading prices were adopted (Source: http://www.finanzen.net/rohstoffe/co2-emissionsrechte/Chart). An amount of 95,47 M kg CO_2 equivalents avoided per year as observed in Figure 68, thus, corresponds to avoided costs of 477,350 to

763,760 €/a (with a price of ~ 5 €/a (Feb-Mar 2016) or ~ 8 €/a (Aug-Dez 2015) per ton of CO_2 equivalents, respectively).

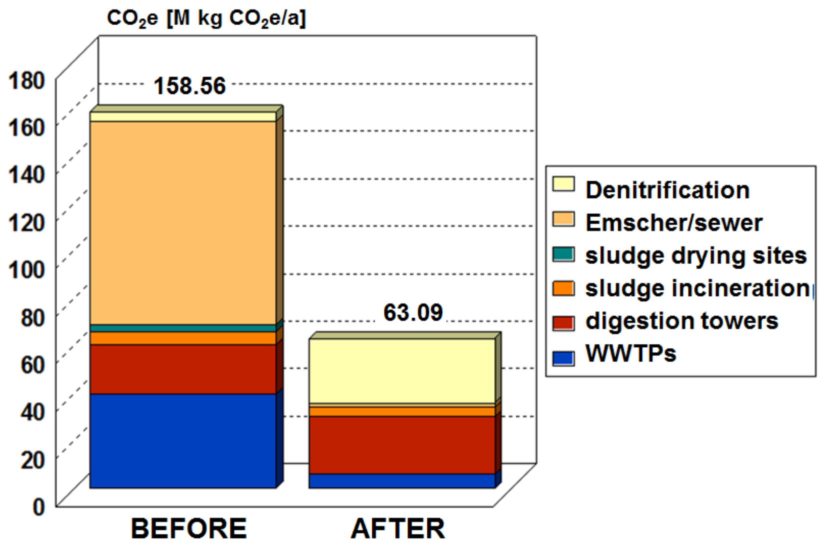

Figure 68: CO_2 equivalent emissions from CH_4 and N_2O emissions from WWTPs, digestion towers, sludge drying sites, from the Emscher River itself (BEFORE) or from the underground sewers (AFTER) (Source: Grün et al. 2013).

Thus, the energy consumption and climate relevant gas emissions during the construction phase may have caused negative environmental effects. These will continue to a smaller extent during operation in the future. EG is aware of these effects and is trying to further reduce energy consumption in the future. Therefore, internal investigations about the effects caused so far and the effects to be expected in the future have started.

On the other hand, the Emscher re-conversion also leads to changes in the CO_2 sequestration in the area (**En213**) resulting from the restoration, re-connection and creation of floodplains along the restored streams. These floodplain areas are relevant for carbon fixation as a result of growing vegetation. The areas have increased in size from approx. 70 to 121 ha in the years 2007 to 2015 (Source: Emschergenossenschaft 2015; EG, unpublished results) and are expected to increase further with ongoing restoration activities. The various aspects mentioned above regarding carbon sequestration (ESS: CO_2 sequestration, 5.10.1) and carbon release (**En213**) can be summarized as follows: Beneficial climate effects are resulting from CO_2 sequestration and avoided CO_2 emissions in the restored system (from greenhouse gas releases from the open wastewater channel) while CO_2 emissions due to digging and construction activities are unfavorable.

The type of energy used is another important factor that has to be taken into account discussing energy consumption. The energy used for construction works done and the additional energy required for sewage pumping in the future was and will be taken from the public electricity system. Therefore, the share of green energy usage (**En123**) will depend on the German energy mix. In 2015, the share of renewable energy was about 33 % which is a major increase compared to the year the reconstruction measures in the Emscher catchment began (1990: 3% renewables; AGEB 2016). Although there is additional energy for pumping required in the future, the share of green energy consumed in the Emscher catchment might be increased due to this positive change in Germany´s energy system.

Of course, restoring a river catchment can generally be seen as a process reducing the usage of artificial and man-made material (**En13**). But the construction process of renaturalizing a river bed might also require bringing back some "natural material" to the Emscher catchment that was used to be in this area but removed long time ago when the concrete channel was build. Besides, building an underground sewage system makes use of further artificial material. The real extent of this material consumption cannot be estimated at the moment, but surely, there is a certain negative impact on the environment linked to this factor as well.

Due to the fact that the sewage will not be discharged into the Emscher streams anymore, the amount of waste recovered should be further increased in the future. The extent of this increase, however, requires further investigations.

E.3 Financial dimension

The Emscher re-conversion was a capital-intensive and costly measure. In total, the investment costs (**F111**) – only those directly related to the measure – were about 4.5 billion €. Furthermore, there was and will be operational expenditure (**F112**) caused in the on-going construction works between 1991 and 2020. These are estimated to be about 0.45 billion € (Barabas et al. 2013). Besides, in the future, additional costs for sewage pumping inside the newly built sewer system are expected to occur but these costs cannot yet be quantified. The reason is that the amount of water that will need to be pumped cannot yet be estimated. In contrast, the expected costs savings in the form of avoided costs of flooding (**F113**) were calculated within the ESS assessment to be about 1.78 M € per year (178 M € per 100 years).

It is clear that it would take a very long time for the investment to amortize just by future cost savings. But in the case study under investigation, cost coverage (**F11**) is not a question since the investment and other expenditure related to the re-construction works are already covered by private-public partnership investments (e.g. subsidy by federal government of NRW). Thus, the only costs that have to be considered for financial sustainability are the additional costs for pumping and whether they are "covered" by the avoided costs from flooding. Since these additional costs cannot be estimated to date, this question cannot be answered exclusively.

E.4 Governance dimension

Regarding sustainability from a governance dimension´s perspective, the Emscher re-conversion supports the compliance with relevant EU standards sustainably (**G111**). The Ecological Potential has come closer to the WFD thresholds. The distance to the GEP has been 100% BEFORE and is expected to be 67% AFTER completion of the restoration efforts. So even though the WFD threshold will not yet be met, there is still an improvement achieved by the measures.

Stakeholder involvement (**G12**) has been given special attention over the whole course of the project. Several relevant actors/stakeholders were involved in planning and implementing the solution from the very beginning. The level of information dissemination aimed to be reached via communicative events can be denoted rather high.

E.5 Assets dimension

The lifetime of the system (**A111**) under investigation can be considered very long. Aside from the sewer system which is planned to last for at least 80 years (after which reinvestment is expected), the ecological improvement at the streams are expected to last for eternity (given maintenance work is conducted). Thus, for the sewer system, the mean time to failure (MTTF) of the solution is 80 years, while the ecological restoration and recreation of near natural stream beds and profiles is not expected to fail at all. With regard to the eternal lifetime of the Emscher conversion measures (except of the sewer system) even the starting (i.e. implementation) time of 30 years which seems to be very high at first glance becomes acceptable (lifetime – start up time ratio: 2.7 for sewer piping / ∞ for the environmental system) (**A221**). In this case it was not considered, that apart from sewage channels, technical facilities might require reinvestment already before 80 years after construction. As the frequency of flooding events and resulting damage costs will be noticeably reduced in the future (see FESS # 1), the capacity of the solution (**A121**) is expected to fit well to projected future needs.

Due to the fact that the sewer network (incl. CSOs) was rebuilt so that the river stream will be waste-water free from now on, the number of complaints (**A211**) due to noise and landscape aesthetics will decline strongly. ~~Recent~~ Future complaints about such unwanted side-effects caused by the solution itself are not expected.

Besides these performance indicators of the solution itself, the Emscher restoration will also increase the potential of nitrogen, phosphor and carbon retention (**A151**) of the River Emscher itself (for detailed information about these indicators: see IESS # 1-3).

As most of the indicators proposed in this assets dimension are dedicated to be used for decision cases to compare two or more technological alternatives, a final evaluation of the sustainability from an assets point of view cannot be made. Nonetheless, these examples show how the stated indicators can be reported and how they could be taken into account in another decision case e.g. for a comparison with alternative technologies.

E.6 Discussion

From the previous explanations for each of the DESSIN sustainability dimensions, it can be concluded that the Emscher re-conversion has many positive effects in social and governance terms. Especially the newly created opportunities for enjoying the Cultural ESS of the Emscher catchment and the improvement of Emscher water quality will bring sustainable benefits for the society. Regarding the environmental dimension, two contradicting effects can be observed: During the Emscher restoration works various negative environmental effects have to be accepted. But once the construction work is completed, there will be mainly positive environmental impacts on ESS and energy demand for operating the system. The financing of the project itself was successfully managed using public-private partnerships. But since the additional costs for pumping in the new system were not available, it cannot be exclusively stated whether the project was financially sustainable for EG. With regard to the assets dimension, a comparable solution is missing, therefore, a final conclusion on the performance of the system cannot be made.

Step F: Decision Support

The objectives of the SA for the Emscher case were to test the developed SA framework, to evaluate the Emscher re-conversion measures ex-post and to highlight benefits and negative side effects. A decision support is not required anymore, as the measure is already implemented. Step F of the Cookbook should be conducted when a decision is not yet taken and support is to be provided. In the Emscher case, it is not needed anymore.

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ANNEX: REPORTING TABLES - EMSCHER MATURE CASE

PART I

A.0 Study description

Element of Part I	Instructions	User entries
Administrative details	1. Provide general information about: • the entity/ies involved in carrying out the assessment • the provider/s of information for the assessment • - the provider/s of funding for the assessment	• *Emschergenossenschaft (EG),University of Duisburg-Essen (UDE), IWW Rheinisch-Westfälisches Institut für Wasser (IWW)* • *EG* • *EU FP7 project*
Objectives of the assessment	2. • Define the intended audience of the results (*Who will be the main recipient of the outcome report?*) • Define and explain the specific purpose and the expected outcomes of carrying out the assessment (*What do you want to achieve by assessing changes in ESS in your area?*).	• *Intended audience: Researchers, practitioneers* • *Objectives: The assessment is conducted with the aim of (i) testing the ESS Evaluation Framework proposed and (ii) identifying the benefits resulting from the Emscher re-conversion project for subsequently conducting a cost-benefit analysis.*
Overview of the study area	3. Provide a detailed description of the study area considering: • geographical location (e.g. Mediterranean region, Western Europe, Nordic region) • spatial extent • environmental attributes (e.g. climate type, topography, water quality levels, water availability)	• *Northwest Europe* • *The Emscher catchment basin covers 865 km^2* • *temperate seasonal climate, 150 m above sea level (source) to 25 m (mouth)*

	• economic activities taking place in the area (e.g. land use, land use transitions, comparison of activities by share of GDP) • socioeconomic profile (e.g. population density, average household income, age profile) • sociocultural aspects (e.g. value systems, role of landscape and land use in identity formation).	• *The former land use was mainly urban settling, coal mining, steel production and steel processing. A shipping channel and a network of roads was built for that purpose. Today's land use is a very densely populated area with 17 cities that are apparently merged into one metropole conglomerate. There is hardly any agriculture; business has shifted towards service companies. The total built-up area is ~50%, agricultural land ~18%, natural area (incl. forested area) ~ 22%.* • *2.2 M inhabitants live in the Emscher basin with a mean population density of 2,775 inhab./km^2.* • *The people are used to avoiding the streams in the area since 1900, when creeks and rivers turned into a system of open wastewater channels. In a densely populated area, places for local recreation are highly demanded.*
Stakeholder list	4. Elaborate an exhaustive list of the stakeholders present in the area.	• *People living in the area;* • *Recreators (boaters, bikers, walkers);* • *Researchers, environmental educators;* • *Industry;* • *Mining companies;* • *Industrial forestry;* • *NGOs;* • *Water board (= WWTP operator, CSO operator);* • *Chambers of commerce;* • *Industrial memorial tourism*
Terminology	5. If necessary after going carefully through the DESSIN Glossary, include the definitions of any additional case-specific terminology here.	*NR*

A.1 Drivers

1. Characterisation Table for Drivers

The list of drivers is based on MARS, 2014.

DRIVER	SPECIFICATION (to be input by the user)
Flood protection	Flood protection – along with the need to discharge wastewater – was the most important driver for the first Emscher conversion, resulting in a manmade open wastewater system. Though the second Emscher conversion aims at renaturalizing the streams, flood protection has to be guaranteed at any time.
Industry	Industry is an important factor since the 1860s, when coal mining, steel production and steel processing started. Now it has shifted towards service providers.
Tourism & recreation	Tourism in the Ruhr area is not relevant except for some industrial/cultural heritage sites. Local recreation, however, is very important for the inhabitants of the Emscher cities.
Transport	A dense network of roads and highways, the most travelled railway route in Germany and a shipping channel are characteristic for the Ruhr area.
Urban development	The urban development in the Emscher basin started in the 1860s and the basin is now one of the world's most densely populated areas.

A.2 Pressures

2. Characterisation Table for Pressures

The relation between the pressure categories and the drivers is based on IMPRESS Guidance No. 3 and MARS, 2014

DRIVER IDENTIFIED IN THE STUDY AREA	PRESSURE CATEGORY	SPECIFICATION
Flood protection	Morphological	The flood protection requirements in the area lead to channelized streams encased by dikes.
Flood protection	Other anthropogenic	Pumping stations and other manmade structures were installed for maintaining the discharge function of the Emscher and its tributaries.
Industry	Diffuse source	Diffuse sources of industrial pollution can result from deposition of air emission.
Industry	Point source	Point sources of pollution (after completion of the Emscher re-conversion) will be CSO facilities and WWTPs (4).
Industry	Activities using specific substances	Due to the dense population and the high variety of industry branches, all kinds of substances can be found in the wastewater.
Industry	Morphological	The morphology of the landscape was changed as a result of the industrialization.
Industry	Other anthropogenic	The industrialization shaped the area in all kinds of aspects.
Tourism & recreation	Morphological	The aim of improving recreational opportunities at the streams will lead to a change in their morphology after completion of the Emscher re-conversion.
Tourism & recreation	Other anthropogenic	
Transport	Diffuse source	Diffuse sources of pollution are run-off from roads and sealed surface (as well as from agricultural areas).
Transport	Point source	As there is a combined sewage system in the Emscher region, point sources of pollution resulting from transportation (after completion of the Emscher re-conversion) will also be CSO facilities and WWTPs (4).
Transport	Morphological	The dense network of transport routes through the area shaped the

		landscape and often runs alongside of the Emscher or its tributaries.
Transport	Other anthropogenic	
Urban development	Diffuse source	Diffuse sources of pollution are run-off from roads and sealed surface (as well as from agricultural areas).
Urban development	Point source	Point sources of pollution (after completion of the Emscher re-conversion) will be CSO facilities and WWTPs (4).
Urban development	Morphological	The intensive urban development shaped the Emscher region in all kinds of aspects.
Urban development	Other anthropogenic	

A.3.1 Description of the proposed measure

The Emscher re-conversion is a project stated in 1990 and expected to be completed in 2020. Its main aims are the creation of sewer net-work incl. CSOs, resulting in waste-water free streams. This first step is followed by the ecological restoration of the waste-water free streams by recreation of near natural stream beds/profiles.

A.3.2 Claimed/expected capabilities of the Proposed Measures

Proposed Measure	Claimed/expected capability	Qualitative description	Quantitative description
Emscher re-conversion: *- creation of sewer net-work incl. CSOs* *- waste-water free streams* *- ecological restoration* *- recreation of near natural stream beds/profiles (technical measure)*	*- reduction of point and diffuse pressure (tested)* *- reduction in the frequency of overflow events (tested)* *- reduction of morphological constraints (tested)*	*- reduction* *- reduction* *- reduction*	*n/a*

A.3.3 Driver, Pressure, and/or State affected by the capabilities

Proposed Measure	Capability		
	Effect on DRIVER *(from D catalogue)*	**Effect on PRESSURE** *(from P catalogue)*	**Effect on STATE** *(from S catalogue)*
Emscher re-conversion: *- creation of sewer net-work incl. CSOs* *- waste-water free streams* *- ecological restoration* *- recreation of near natural stream beds/profiles (technical measure)*	*n/a*	*- reduction of point and diffuse pressure (tested)* *- reduction in the frequency of overflow events (tested)* *- reduction of morphological constraints (tested)*	*1. Biological* *- Macrophytes + Phytobenthos* *- Benthic invertebrates* *- Fish fauna* *2. Hydromorphology* *2.1 Hydrology* *- Quantity + dynamics of water flow* *- Water residence time* *2.2 Morphology* *- Depth and width variation* *- Structure and substrate of the water body bed* *- Structure of the water body shoreline* *3. Physiochemical* *3.1 General* *- Transparency* *- Thermal conditions* *- Oxygenation conditions* *- Salinity* *- Nutrient conditions*

			3.2 Priority hazardous substances *- Pollution by all priority substances identified as being discharged into the body of water* *3.3 Other pollutants* *- Pollution by other substances identified as being discharged in significant quantities into the body of water* *4. Cultural* *all*

A.3.4 Case-relevant ESS

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
Biological	*Bio-remediation by micro-organisms, algae, plants, and animals*	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Maintaining nursery populations and habitats	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
Hydrology	*Hydrological cycle and water flow maintenance*	*Liquid flows*	*Mediation of flows*	*Regulation & Maintenance*
Morphology	*Flood protection*	*Liquid flows*	*Mediation of flows*	*Regulation & Maintenance*
	Maintaining nursery populations and habitats	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*

	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Decomposition and fixing processes	*Soil formation and composition*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
	Mass stabilization and control of erosion rates	*Mass flows*	*Mediation of flows*	*Regulation & Maintenance*
Physiochemical	*Surface water for drinking*	*Water*	*Nutrition*	*Provisioning*
	Surface water for non-drinking purposes	*Water*	*Materials*	*Provisioning*
	Bio-remediation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*

	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Decomposition and fixing processes	*Soil formation and composition*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
	Chemical condition of freshwaters	*Water conditions*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
	Maintaining nursery populations and habitats	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
all	*all cultural*	…	…	*Cultural*

A.4.1 Comparison of case-relevant ESS with potential beneficiaries and FEGS

CICES Class *(restricted to ecosystem type)* *(from Step 3)*	**Beneficiary** *(Categories and Sub-Categories)*	**FEGS** *(Importance of FEGS to the Beneficiary)*
Surface water for drinking	*Water Subsisters*	*• water suitable for drinking (i.e., human consumption)*
Surface water for non-drinking purposes	*Agricultural,* *Commercial / Industrial,* *Municipal Drinking Water Plant Operators*	*• e.g. water for growing and maintaining crops* *• e.g. water suitable for cooling or processing industrial products* *• e.g. water suitable for processing by a municipal drinking water plant*
Flood protection	*Resource-Dependent Businesses, Residential Property Owners*	*• opportunity for placement of infrastructure and reduced/increased risk of flooding, erosion, and pest infestation on the property*
Hydrological cycle and water flow maintenance	*none*	*none*
Filtration/ sequestration/ storage/ accumulation by micro-organisms, algae, plants, and animals	*Industrial Dischargers,* *Waste Water Treatment Plant Operators*	*• Opportunity to discharge into the environment* *• Medium for discharging [treated municipal wastewater] into the environment*

Filtration/ sequestration/ storage/ accumulation by ecosystems	*Industrial Dischargers,* *Waste Water Treatment Plant Operators*	*• Opportunity to discharge into the environment* *• Medium for discharging [treated municipal wastewater] into the environment*
Bio-remediation by micro-organisms, algae, plants, and animals	*Industrial Dischargers,* *Waste Water Treatment Plant Operators*	*• Opportunity to discharge into the environment* *• Medium for discharging [treated municipal wastewater] into the environment*
Decomposition and fixing processes	*Industrial Dischargers,* *Waste Water Treatment Plant Operators*	*• Opportunity to discharge into the environment* *• Medium for discharging [treated municipal wastewater] into the environment*
Dilution by atmosphere, freshwater and marine ecosystems	*Industrial Dischargers,* *Waste Water Treatment Plant Operators*	*• Opportunity to discharge into the environment* *• Medium for discharging [treated municipal wastewater] into the environment*
Mass stabilization and control of erosion rates	*Resource-Dependent Businesses, Residential Property Owners*	*• opportunity for placement of infrastructure and reduced/increased risk of flooding, erosion, and pest infestation on the property*
Chemical condition of freshwaters	*Water Subsisters,* *Agricultural,* *Commercial / Industrial,* *Municipal Drinking Water Plant*	*• water suitable for drinking (i.e., human consumption)* *• e.g. water for growing and maintaining crops* *• e.g. water suitable for cooling or processing*

	Operators	*industrial products* *• e.g. water suitable for processing by a municipal drinking water plant*
Maintaining nursery populations and habitats	*Food Extractors* *Pharmaceutical and Food Supplement Suppliers*	*• edible organisms (i.e., flowers, plants, etc.) or associated products (i.e., fruit, greens, tubers, berries, sap) for commercial use or sale• edible organisms (i.e., birds, mammals, reptiles, etc.) for commercial use or sale* *• organisms (i.e., flowers, plants, etc.) or associated products (i.e., fruit, greens, tubers, berries, sap) used in medicines or sold for medicinal purposes* *• organisms (i.e., birds, mammals, reptiles, etc.) or products associated with organisms (i.e., oils, fats, keratin, etc.) used in medicines or sold for medicinal purposes*
all cultural	*Recreational (e.g. Experiencers and Viewers; Boaters)* *Inspirational* *Learning (e.g. Researchers; Educators and Students)* *Non-Use (e.g. People who care)*	

A.4.2 List of stakeholders (Part I) compared to list of beneficiaries (US EPA)

List of stakeholders *(from Part I, Step 0)*	**List of beneficiaries** *(from Step 4.1)*	**FEGS appropriate?**
People living in the area	*Residential Property Owners* *People who care*	*yes*
Recreators (boaters, bikers, walkers)	*Experiencers and Viewers* *Boaters*	*yes*
Industrial memorial tourism	*Experiencers and Viewers*	*yes*
Researchers, environmental educators	*Researchers* *Educators and Students*	*yes*
NGOs	*People who care*	*no*
Industry	*none*	*no*
Mining companies	*none*	*no*
Industrial forestry	*none*	*no*
Water board (= WWTP operator, CSO operator)	*none*	*no*
Chambers of commerce	*none*	*no*

A.4.3 Intermediate and final ESS table

Measure	Capability	ESS affected (use CICES and US EPA catalogue!)					Beneficiaries (use US EPA categorization!)[1]
		CICES section	CICES division	CICES group	CICES class	DESSIN ESS (use US EPA nomenclature where applicable)[2]	(no beneficiary = only intermediate service)
Emscher re-conversion: - creation of sewer network incl. CSOs - waste-water free streams - ecological restoration - recreation of near natural stream beds/profiles	- improvement of water quality - reduction in the frequency of overflow events - improvement of the physical structure of watercourses	**Regulation & Maintenance services**	Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Filtration/sequestration/storage/ accumulation by ecosystems	**Self-purification: N retention** (DESSIN) **IESS Fact sheet # 1** **Self-purification: P retention** (DESSIN) **IESS Fact sheet # 2** **Self-purification: C retention** (DESSIN) **IESS Fact sheet # 3** **→ ISS for FESS # 2-5**	*No direct beneficiary, but potential savings to the* ***water board*** *that must meet water quality standards for measures against CSO discharge*
			Mediation of waste, toxics and other nuisances	Mediation by ecosystems	Dilution by atmosphere, freshwater and marine ecosystems		
			Mediation of flows	Liquid flows	Hydrol. cycle + water flow maintenance		
			Maintenance of physical, chemical, biological conditions	Soil formation and composition	Decomposition and fixing processes		
			Mediation of flows	Liquid flows	**Flood protection**	**Opportunity for placement of infrastructure and reduced risk of flooding**	**Residential Property Owners**

						(US EPA/DESSIN) **FESS** **Fact sheet # 1**	
			Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	**Maintaining nursery populations and habitats**	**Biodiversity** (DESSIN) **IESS** **Fact sheet # 4** **→ ISS for FESS # 2-5**	*No direct beneficiary*
			Maintenance of physical, chemical, biological conditions	Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	*only intermediate ESS:* CO_2 sequestration	*no beneficiary (US EPA)/* Humanity?
			Maintenance of physical, chemical, biological conditions	Atmospheric composition and climate regulation	Micro and regional climate regulation	*only intermediate ESS:* Local climate	*no beneficiary (US EPA)/* Residential Property Owners?; Experiencers and Viewers? (Health effect on citizens)
		Cultural services	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	**Experiential use of plants, animals and landscapes in different environmental settings**	**Opportunity for placement of infrastructure in environment** **FESS** **Fact sheet # 2**	**Resources-dependent businesses (operators of cafés and restaurants along the restored riverfront);** **Residential Property Owners**

					Physical use of landscapes in different environmental settings	**Opportunity for biking** (DESSIN) & **Opportunity for recreational boating** (US EPA) **FESS** **Fact sheet # 3**	**Bikers** **&** **Boaters**
			Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Intellectual and representative interactions	Educational	Research opportunities (US EPA)	Researchers
						Opportunities to understand, communicate, and educate (US EPA) **FESS** **Fact sheet # 4**	**Educators and Students**
			Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Other cultural outputs	Existence	**Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)** (DESSIN) **FESS** **Fact sheet # 5**	**People who care;** **Residential Property Owners**

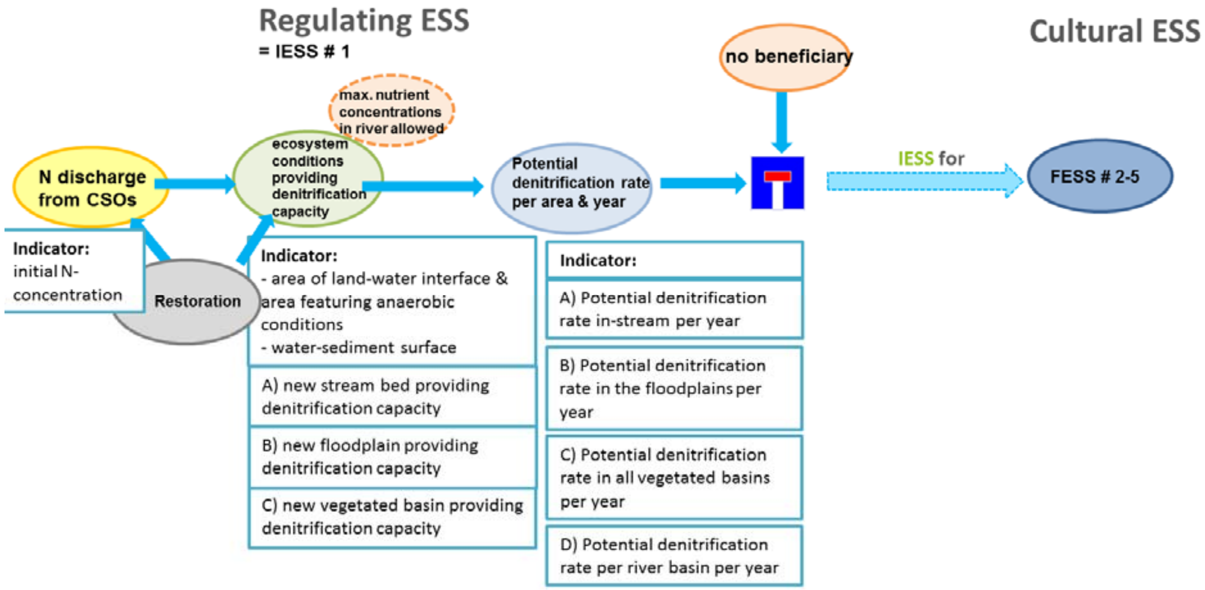
A.4.3 Categorization of case-relevant ESS into intermediate ESS and final ESS

Intermediate ESS (IESS)	Final ESS (FESS)
Self-purification: N retention (DESSIN) **IESS # 1**	**Opportunity for placement of infrastructure and reduced risk of flooding** (US EPA) **FESS # 1**
Self-purification: P retention (DESSIN) **IESS # 2**	**Opportunity for placement of infrastructure in environment** (US EPA) **FESS # 2**
Self-purification: C retention (DESSIN) **IESS # 3**	**Opportunity for biking** (DESSIN) & **Opportunity for recreational boating** (US EPA) **FESS # 3**
Biodiversity (DESSIN) **IESS # 4**	**Opportunities to understand, communicate, and educate** (US EPA) **FESS # 4**
	Knowledge that a restored river area exists, with suitable water quality (i.e. GEP) (DESSIN) **FESS # 5**

STEPs 5, 6, 7 and 8

The overview graphics below are structured according to the Cookbook and Companion document. Color codes: yellow = Pressure, grey = Response, green = STATE, light blue = Impact I, dark blue = Impact II, orange = Beneficiaries, orange with dotted line = Regulatory thresholds. Indicators required for assessing the single elements are given below the elements.

IESS # 1: Self-purification: N retention



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses
CICES Section	Regulation & Maintenance services
CICES Division	Mediation of waste, toxics and other nuisances
CICES Group	Mediation by ecosystems/ Liquid flows/ Soil formation and composition
CICES Class	**Filtration/sequestration/storage/accumulation by ecosystems/ Dilution by atmosphere, freshwater and marine ecosystems/ Hydrol. cycle + water flow maintenance/ Decomposition and fixing processes**
ESS *(use US EPA nomenclature!)*[2]	**Opportunity to discharge into the environment/ Medium for discharging [treated municipal wastewater] into the environment** (US EPA)**/** **Self-purification: N retention** (DESSIN)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Rivers and streams
	B) Wetlands
	C) Lakes and ponds
Temporal scope	A) per year

	B) per year
	C) per year
Spatial scope	A) per river basin
	B) per river basin
	C) per river basin
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	Intermediate Service
For FESS: Intermediate ESS required *(use CICES catalogue!)*	no
For Intermediate services: FESS affected & other IESS required	FESS # 2-5
Regulatory Threshold	Water quality standards (WFD) ?
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	no

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Box XX!)*	**Data quality** *(see catalogue in Box XX!)*
DRIVER *(From*	1) Industry: CSO discharge 2) Transport: run-off, CSO	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

IMPRESS/WISE) (only those addressed by the capability??)	discharge 3) Urban development: CSO discharge					
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions **3) Point source: pollution through CSO discharge of municipal waste water + rainwater** 4) Activities using specific substances??	1) Stream profile 2) Concentration of N in the water 3) Concentration of N in the water 4) -	1) ? 2) mg/L 3) mg/L 4) -	?	direct indicator	
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) construction of a piped sewer network (2) newly created physical structure of watercourses, floodplains, and basins				
STATE *(only those relevant for the assessment of Impact I)*	A) stream bed conditions providing denitrification capacity	(1) water-sediment surface (2) initial N-concentration	(1) m², (2) kg/m³	(1) EGLV planning data/measurement data: stream profiles, water-sediment surface, (2) EGLV monitoring data: N conc	proxy	planning data/ measurement data, monitoring data → “B data”
	B) new floodplain providing denitrification capacity	(1) area of land-water	(1) ha,	(1) ?, EGLV planning	proxy	planning data/

		interface (i.e. HQ50 area), (2) stream length (3) soil types,	(2) km, (3) – ,	data/measurement data: stream profiles, water-sediment surface, (2) GIS (3) GIS		measurement data, GIS data → "B data"
	C) new vegetated basin providing denitrification capacity	(1) water-sediment surface (2) frequency of flooding	(1) m² (2) 1/a	(1) EGLV planning data: basin profiles, water-sediment surface	proxy	planning data/ measurement data, monitoring data → "B data"
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	A) Potential denitrification rate in-stream per year	potential denitrification rate	kg/a N removed in total stream length in the Emscher basin	see State parameters, literature data	proxy	modelled data, literature data → "B data"
	B) Potential denitrification rate in the floodplains per year	potential denitrification rate	kg/a of total floodplain area in the Emscher basin	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	C) Potential denitrification rate in all vegetated basins per year	potential denitrification rate	kg/a in all vegetated basins per year	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	D) Potential denitrification rate per river basin per year	=A+B+C	kg/a in total Emscher basin			
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

INDICATOR TABLE - Further explanation

Further information on IMPACT I – PROVISION indicator "*Potential denitrification rate in-stream per year*":

The developed tool is a simple Excel-based calculation to estimate the turnover of carbon and nutrients (N, P) in a given river reach. It calculates carbon and nutrient loads that are retained/eliminated over in a given time in a given river reach. The results provide a rough estimation of the self-purification capacity for aerobic river systems. The tool does not claim correctness; e.g. the tool does not consider changing turnover rates due to temperature changes or changes related to sunlight exposure or other dynamic variables. Furthermore, it is assumed that there is no further input or output within the time period.

Central information is stream geometry (wetted surface, cross section area). Information about the profile shape, location as well as the water level (e.g. dry weather flow which is reached 50% of the year) was entered. For each profile the overall wetted surface, the projected surface area as well as the total water volume are calculated. Subsequently, literature turnover rates for in-stream retention are applied (COD and N retention rates were taken from Niemann (2001); P retention rates were taken from Scholz et al. (2012)).

	N-retention (kg/ha/a)	P-retention (kg/ha/a)	C-retention (t/ha/a)
In-stream	10.95	53	4.38

The turnover of COD and N is assumed to be performed by the biomass on the wetted surface of the river stretch. For P, we assume that particulate P is held back by macrophytes determined via an estimated percentage of the projected surface area.

The tool was applied to four rivers stretches within the Emscher catchment and, subsequently, scaled up to basin level based on similarity of profiles. Water levels for each profile section were derived using an existing 1D-model and based on median discharge and water level of one year (source: EG). The initial concentrations used were mean values of TOC (transferred by a correlation factor to COD), NH_4-N and Total P (monitoring data source: EG). For the status BEFORE the re-conversion, a standard concrete profile was used, while for the status AFTER, profile geometry was taken from restoration plans; both were implemented into the 1-D model. As river profiles BEFORE restoration were made out of concrete, there were no macrophytes. Nevertheless, we assume a retention of P in algae and biofilms that equals a macrophyte density of 5%. High macrophyte density (80%) of the projected river surface/cross section area is assumed for half of the focus streams and low density (20%) for the other half for the stage AFTER re-conversion.

Further information on IMPACT I – PROVISION indicator "*Potential denitrification rate in the floodplains per year*":

This indicator applies a rule of thumb based calculation using the denitrification rates for different soil types according to Scholz et al. (2012). Various soil types are assigned denitrification rates, given as levels, each corresponding to a range of nitrogen retention rates. Literature values for denitrification rates are adopted from Scholz et al. (2012)(based on Gäth et al., 1997; modified by Höper, 2000; NLfB working group " Bodenkundliche Beratung" and modified by Scholz et al. (2012).

	Denitrification (kg/ha/a)	P-retention (kg/ha/a)	C-stock (t/ha)
Grassland	5	0.75	212
Woodland	5	5	357
Artificial land cover	0	0.75	0

The product of the area [ha] having a certain soil type with its respective nitrogen retention level [kg/ha/a] results in the nutrient retention [kg/a] in the area of a floodplain having this certain soil type. The sum of the retention rates of the areas with individual soil types within a floodplain gives the total potential retention in the entire floodplain of the examined water body/ stream section. The actual floodplain in the Emscher area is defined as the area that is statistically flooded every 50 or 100 years (HQ50 or HQ100). This potential retention is extrapolated to the entire Emscher catchment.
The size of the HQ50 areas was obtained from maintenance and development plans for each stream in GIS (Atkis; EG, Pflege- und Entwicklungspläne) for the state AFTER restoration. The respective area sizes BEFORE restoration were derived from the sizes AFTER restoration with consideration of information from the ecological development potential evaluated for each water body in the Emscher basin (Semrau et al. 2007; Semrau et al., internal documents 2013). The ecological development potential categorizes each stream according to the availability of space for development into (i) a group of streams with no space available, and thus, an area BEFORE restoration similar in size as AFTER. One group (ii) has space for development along 10-40% of its stream

length, and thus, the BEFORE area is assumed to be 85% of the AFTER area. The last group of streams (iii) has space for development along > 40% of its stream length, from which we derive that the BEFORE area was only 70% of the AFTER area.
Furthermore, we assume a land use within the HQ50 areas BEFORE reconversion of 75% grassland, 20% woodland, and 5% concrete bed (EG, expert opinion). For the state AFTER reconversion we derived a partitioning of 45% grassland and 55% woodland from land use data (Atkis, UDE) evaluated for the DESSIN focus streams.
Upscaling to basin level was done according to stream length and the category of availability of space for development.
According to Scholz et al. (2012), the potential denitrification was calculated only for the land use types of woodland and grassland; arable land and sealed surfaces were not considered. A problem in applying this indicator was that during the restoration the channelized streams' concrete beds were removed down to the ground rock. As soil formation has not yet taken place, currently there is no proper soil type. Thus, we chose the soil type with the lowest denitrification rate (i.e. brown earth, regosols, rendzinas) (Scholz, personal communication). The soil that is newly developing along the restored water bodies is most likely rendzinas/ cambisol. Furthermore, the groundwater level in the Emscher area is very low. Since dry, and thus, aerobic soils have low denitrification rates, all other soil types could be ruled out.

RESULTS TABLE

	Case-relevant Element	Output	Output unit	Comments
PRESSURE	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions 3) Point source: pollution through CSO discharge of municipal waste water + rainwater 4) Activities using specific	no results yet	(1) ? (2) mg/L (3) mg/L -	

<table>
<tr><td></td><td>substances??</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">STATE</td><td>A) new stream bed providing denitrification capacity</td><td>(1) water-sediment surface:
BEFORE: 95 ha (entire Emscher basin)
AFTER: 168 ha (entire Emscher basin)

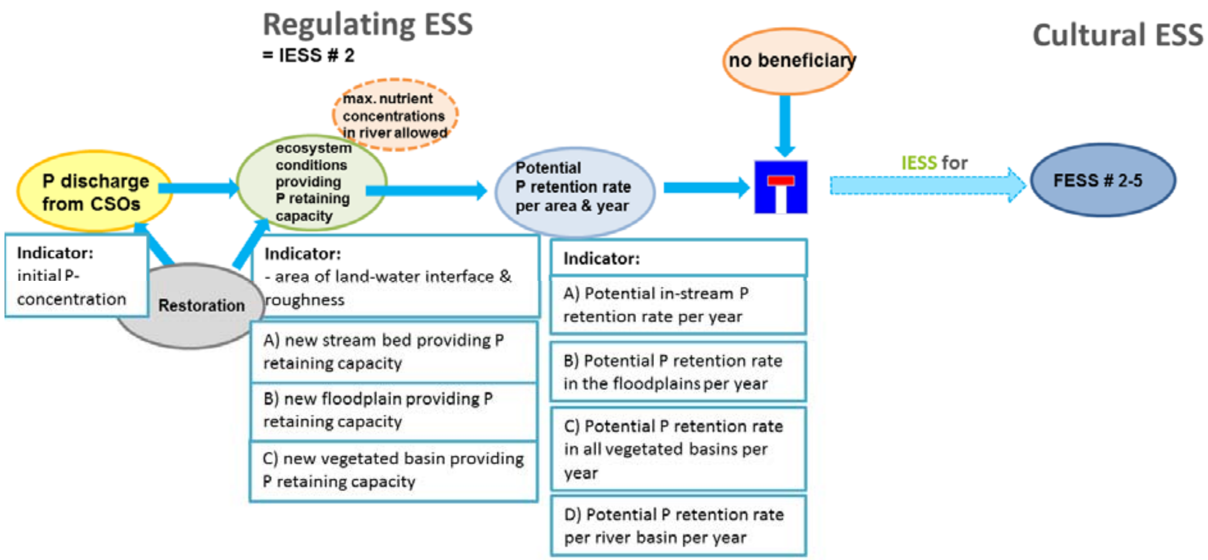
(2) initial nutrient concentrations (for 5 focus streams):
<table>
<tr><td></td><td>COD [mg/l]</td><td>N [mg/l]</td><td>P [mg/l]</td></tr>
<tr><td></td><td>COD</td><td>NH4N</td><td>PO4 solute</td></tr>
<tr><td>Kirchschemmsbach</td><td>14.02</td><td>0.02</td><td>0.024</td></tr>
<tr><td>Deininghauser Bach naturnah</td><td>20.58</td><td>2.16</td><td>0.057</td></tr>
<tr><td>Deininghauser Bach uh naturn</td><td>20.58</td><td>2.16</td><td>0.057</td></tr>
<tr><td>Emscher_OL</td><td>14.69</td><td>0.3</td><td>0.093</td></tr>
<tr><td>Vorthbach</td><td>15.68</td><td>0.07</td><td>0.034</td></tr>
</table></td><td>(1) m^2 or ha,
(2) kg/m^3 or mg/l</td><td></td></tr>
<tr><td>B) new floodplain providing denitrification capacity</td><td>(1) area of land-water interface (i.e. HQ50 area):
BEFORE: 410 ha (entire Emscher basin)
AFTER: 456 ha (entire Emscher basin)

(2) stream length (entire Emscher basin):
252 km
(3) soil types: brown earth, regosols, rendzinas</td><td>(1) m^2 or ha,
(2) km,
(3) –</td><td></td></tr>
<tr><td>C) new vegetated basin providing denitrification capacity</td><td>(1) water-sediment surface (m^2):
BEFORE: 28 ha
AFTER: 66 ha
(2) frequency of flooding: not available</td><td>m^2
1/a</td><td></td></tr>
<tr><td>IMPACT I - PROVISION</td><td>A) Potential denitrification rate in-stream per year</td><td>BEFORE: 1.04 t/a
AFTER: 1.84 t/a</td><td>kg/a of total stream length in the Emscher basin</td><td></td></tr>
</table>

	B) Potential denitrification rate in the floodplains per year	BEFORE: 1.95 t/a AFTER: 2.28 t/a	kg/a of total floodplain area in the Emscher basin	BEFORE: concrete bed, no denitrification AFTER: Method according to Scholz et al., 2012
	C) Potential denitrification rate in all vegetated basins per year	not assessed	kg/a in all vegetated basins per year	
	D) Potential denitrification rate in total Emscher basin per year	= A+B+C not assessed	kg/a in total Emscher basin	
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*

RESULTS TABLE - Description

IESS # 2: Self-purification: P retention



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses
CICES Section	Regulation & Maintenance services

CICES Division	Mediation of waste, toxics and other nuisances
CICES Group	Mediation by ecosystems/ Liquid flows/ Soil formation and composition
CICES Class	**Filtration/sequestration/storage/accumulation by ecosystems/ Dilution by atmosphere, freshwater and marine ecosystems/ Hydrol. cycle + water flow maintenance/ Decomposition and fixing processes**
ESS *(use US EPA nomenclature!)*[2]	**Opportunity to discharge into the environment/ Medium for discharging [treated municipal wastewater] into the environment** (US EPA)**/** **Self-purification: P retention** (DESSIN)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Wetlands
	B) Lakes and ponds
Temporal scope	A) per year
	B) per year
Spatial scope	A) per river basin
	B) per river basin
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	Intermediate Service
For FESS: Intermediate ESS required *(use CICES catalogue!)*	no
For Intermediate services: FESS affected & other IESS required	FESS # 2-5
Regulatory Threshold	Water quality standards (WFD) ?

Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	no

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	1) Industry: CSO discharge 2) Transport: run-off, CSO discharge 3) Urban development: CSO discharge	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions **3) Point source: pollution through CSO discharge of municipal waste water + rainwater** 4) Activities using specific substances??	1) Stream profile 2) Concentration of P in the water 3) Concentration of P in the water 4) -	1) ? 2) mg/L 3) mg/L 4) -	?	direct indicator	
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) construction of a piped sewer network				

		(2) newly created physical structure of watercourses, floodplains, and basins				
STATE *(only those relevant for the assessment of Impact I)*	A) stream bed conditions providing P retention capacity	(1) water-sediment surface (2) initial P-concentration	(1) m², (2) kg/m³	(1) EGLV planning data/measurement data: stream profiles, water-sediment surface, (2) EGLV monitoring data: P conc	proxy	planning data/ measurement data, monitoring data → "B data"
	B) new floodplain providing P retention capacity	(1) area of land-water interface (i.e. HQ50 area), (2) stream length (3) landuse and vegetation types,	(1) ha, (2) km, (3) –	(1) ?, EGLV planning data/measurement data: stream profiles, water-sediment surface, (2) GIS (3) GIS	proxy	planning data/ measurement data, GIS data → "B data"
	C) new vegetated basin providing P retention capacity	water-sediment surface	m²	EGLV planning data/measurement data: basin profiles, water-sediment surface,	proxy	planning data/ measurement data, monitoring data → "B data"
IMPACT I - PROVISION *(quantify if necessary for the assessment of*	A) Potential P retention rate in-stream per year	potential P retention rate	kg/a P removed of total stream length in the Emscher basin	see State parameters, literature data	proxy	modelled data, literature data → "B data"

Impact II, otherwise describe qualitatively)	B) Potential P retention rate in the floodplains per year	potential P retention rate	kg/a of total floodplain area in the Emscher basin	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	C) Potential P retention rate in all vegetated basins per year	potential P retention rate	kg/a in all vegetated basins per year	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	D) Potential P retention rate per river basin per year	=A+B+C	kg/a in total Emscher basin			
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

INDICATOR TABLE - Further explanation

Further information on IMPACT I – PROVISION indicator "*Potential P retention rate in-stream per year*":

See explanation for "*Potential denitrification rate in-stream per year".*

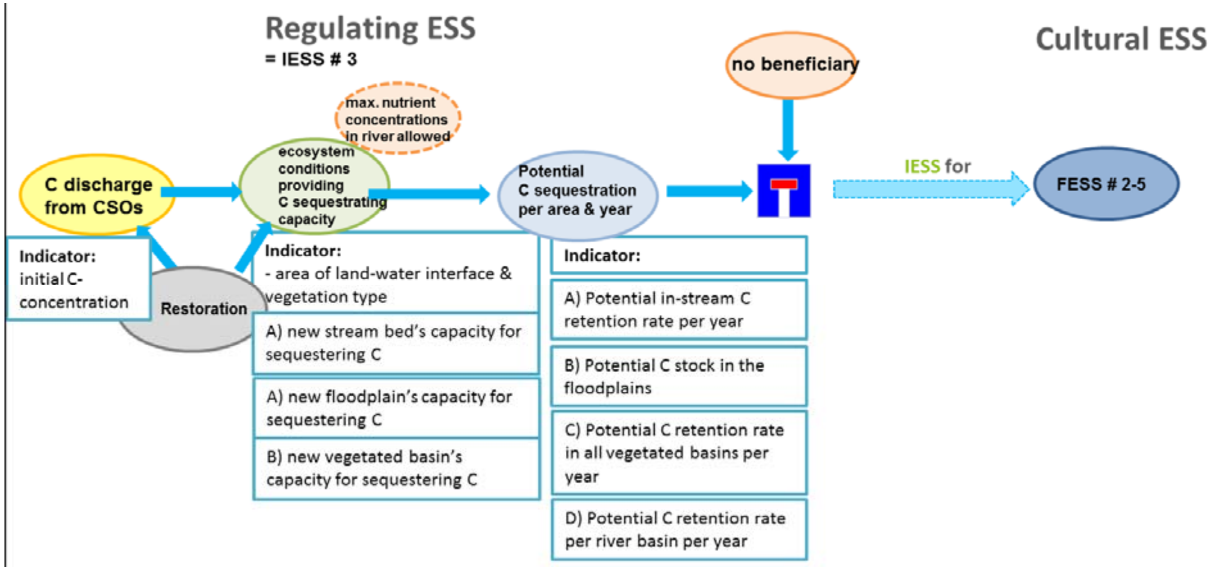
Further information on IMPACT I – PROVISION indicator "*Potential P retention rate in the floodplains per year*":

This indicator applies a rule of thumb based calculation using the phosphorous retention rates for different **roughness values** according to Scholz et al. (2012). Literature values for phosphorous retention rates are adopted from Scholz et al. (2012)(based on Brunotte et al. 2009, Koenzen et al. 2005 and modified by Scholz et al. (2012)). Various **land use and vegetation types** are assigned *Kst* values, each corresponding to a range of potential phosphorous retention rates [kg/ha/a]. The product of the area [ha] having a certain land use and vegetation type with its respective phosphorous retention level [kg/ha/a] results in the nutrient retention [kg/a] in the area of a floodplain having this certain land use and vegetation types.
The potentially wetted area (HQ50) BEFORE and AFTER restoration as well as the respective land use in these areas were derived as described for N retention. Also upscaling of the respective land use areas from stream to basin level was done according to the method described in the Annex section "*Potential denitrification rate in the floodplains per year*".

RESULTS TABLE				
	Case-relevant Element	Output	Output unit	Comments
PRESSURE	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions 3) Point source: pollution through CSO discharge of municipal waste water + rainwater 4) Activities using specific substances??	no results yet	(4) ? (5) mg/L (6) mg/L -	
STATE	A) stream bed conditions providing P retention capacity	See results table of IESS # 1		
	B) new floodplain providing P retention capacity	See results table of IESS # 1		
	C) new vegetated basin providing P retention capacity	See results table of IESS # 1		
IMPACT I - PROVISION	A) Potential P retention rate in-stream per year	BEFORE: 0.88 t/a AFTER: 4.23 t/a		
	B) Potential P retention rate in the floodplains per year	BEFORE: 0.66 t/a AFTER: 1.4 t/a		

	C) Potential P retention rate in all vegetated basins per year	not assessed		
	D) Potential P retention rate per river basin per year	= A+B+C not assessed		
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
RESULTS TABLE - Description				

IESS # 3: Self-purification: C retention



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses

CICES Section	Regulation & Maintenance services
CICES Division	Mediation of waste, toxics and other nuisances
CICES Group	Mediation by ecosystems/ Liquid flows/ Soil formation and composition
CICES Class	**Filtration/sequestration/storage/accumulation by ecosystems/ Dilution by atmosphere, freshwater and marine ecosystems/ Hydrol. cycle + water flow maintenance/ Decomposition and fixing processes**
ESS *(use US EPA nomenclature!)*[2]	**Opportunity to discharge into the environment/ Medium for discharging [treated municipal wastewater] into the environment** (US EPA)**/** **Self-purification: C sequestration** (DESSIN)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Rivers and streams
	B) Wetlands
	C) Lakes and ponds
Temporal scope	A) per year
	B) per year
	C) per year
Spatial scope	A) per river basin
	B) per river basin
	C) per river basin
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	Intermediate service

For FESS: Intermediate ESS required *(use CICES catalogue!)*	no
For Intermediate services: FESS affected & other IESS required	FESS # 2-5
Regulatory Threshold	Water quality standards (WFD) ?
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	no

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	1) Industry: CSO discharge 2) Transport: run-off, CSO discharge 3) Urban development: CSO discharge	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	1) Morphological: stream profile 2) Diffuse source: pollution with organic substances through run-off **3) Point source: pollution through CSO**	1) Stream profile 2) COD/BOD/SI 3) COD/BOD/SI 4) -	1) ? 2) mg/L 3) mg/L 4) -	?	direct indicator	

	discharge of municipal waste water + rainwater 4) Activities using specific substances??					
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) construction of a piped sewer network (2) newly created physical structure of watercourses, floodplains, and basins				
STATE *(only those relevant for the assessment of Impact I)*	A) stream bed conditions providing C retention capacity	(1) water-sediment surface (2) initial C-concentration	(1) m^2, (2) kg/m^3	(1) EGLV planning data/measurement data: stream profiles, water-sediment surface, (2) EGLV monitoring data: C conc	proxy	planning data/ measurement data, monitoring data → "B data"
	B) new floodplain providing C retention capacity	(1) area of land-water interface (i.e. HQ50 area), (2) stream length (3) vegetation types	(1) ha, (2) km, (3) –	(1) ?, EGLV planning data/measurement data: stream profiles, water-sediment surface, (2) GIS (3) GIS	proxy	planning data/ measurement data, GIS data → "B data"
	C) new vegetated basin providing C retention capacity	water-sediment surface	m^2	EGLV planning data/measurement data: basin profiles, water-sediment surface	proxy	planning data/ measurement data, monitoring data → "B data"

IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	A) Potential C retention rate in-stream per year	potential C retention rate	kg/a C removed of total stream length in the Emscher basin	see State parameters, literature data	proxy	modelled data, literature data → "B data"
	B) Potential C stock in the floodplains per year	potential C stock	kg/a of total floodplain area in the Emscher basin	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	C) Potential C retention rate in all vegetated basins per year	potential P retention rate	kg/a in all vegetated basins per year	see State parameters, literature data	proxy	GIS data, literature data → "B data"
	D) Potential C retention rate per river basin per year	=A+B+C	kg/a in total Emscher basin			
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

INDICATOR TABLE - Further explanation

Further information on IMPACT I – PROVISION indicator "*Potential C retention rate in-stream per year*":

See explanation for "*Potential denitrification rate in-stream per year*".

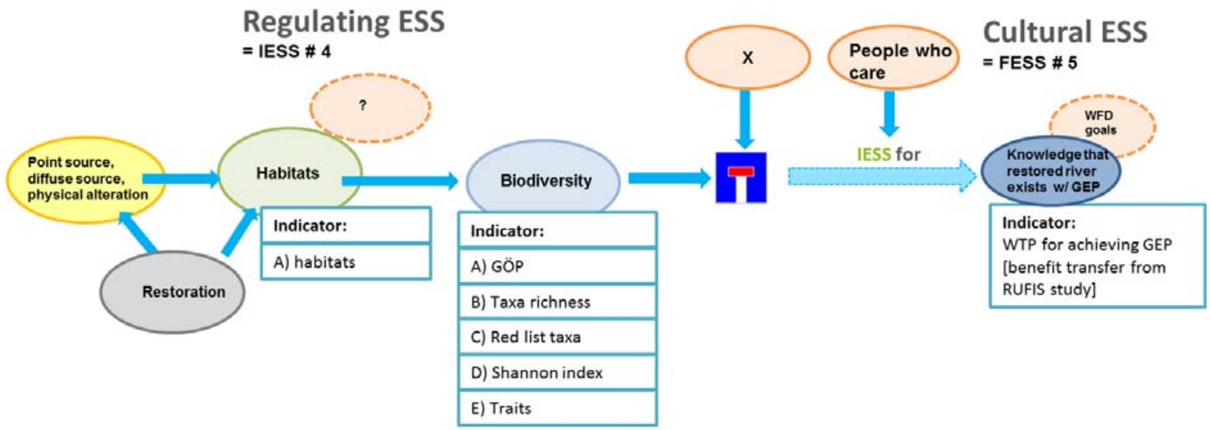
Further information on IMPACT I – PROVISION indicator "*Potential C stock in the floodplains per year*":

This indicator applies a rule of thumb based calculation using the organic carbon stock values for different **vegetation types** according to Cierjacks et al. (2010) in Scholz et al. (2012), defined as „*Total C stocks aboveground and belowground*". We used those values for softwood and meadows (grassland). The

product of the area [ha] having a certain vegetation type with its respective C stock value [t/ha] results in the C stock [kg/a] in the area of a floodplain having this certain vegetation types. The potentially wetted area (HQ50) BEFORE and AFTER restoration as well as the respective land use in these areas were derived as described for N retention. Also upscaling of the respective land use areas from stream to basin level was done according to the method described in the Annex section "*Potential denitrification rate in the floodplains per year*".				
RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions 3) Point source: pollution through CSO discharge of municipal waste water + rainwater 4) Activities using specific substances??	no results yet	(7) ? (8) mg/L (9) mg/L -	
STATE	A) stream bed conditions providing C retention capacity	See results table of IESS # 1		
	B) new floodplain providing C retention capacity	See results table of IESS # 1		
	C) new vegetated basin providing C retention capacity	not assessed		
IMPACT I -	A) Potential C retention rate in-	BEFORE: 416.40 t/a		

PROVISION	stream per year	AFTER: 736.06 t/a		
	B) Potential C stock in the floodplains per year	BEFORE: 94.53 megatons AFTER: 133.16 megatons		
	C) Potential C retention rate in all vegetated basins per year	not assessed		
	D) Potential C retention rate per river basin per year	= A+B+C not assessed		
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
RESULTS TABLE - Description				

IESS # 4: Biodiversity



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses
CICES Section	Regulation & Maintenance services
CICES Division	Maintenance of physical, chemical, biological conditions
CICES Group	Lifecycle maintenance, habitat and gene pool protection
CICES Class	**Maintaining nursery populations and habitats**

ESS *(use US EPA nomenclature!)*[2]	**Biodiversity & habitats** (DESSIN)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Rivers and streams
Temporal scope	point in time
Spatial scope	per river basin
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	Intermediate service
For FESS: Intermediate ESS required *(use CICES catalogue!)*	no
For Intermediate services: FESS affected & other IESS required	FESS # 2-5
Regulatory Threshold	Water quality standards (WFD) ?
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	no

INDICATOR TABLE						
	Case-relevant Element	Indicator	Output unit	Data sources & data availability	Indicator quality *(see explanation in Framework Box*	Data quality *(see catalogue in Framework p.XX!)*

					XX!)	
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	1) Industry: CSO discharge 2) Transport: run-off, CSO discharge 3) Urban development: CSO discharge	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	1) Morphological: stream profile 2) Diffuse source: pollution through run-off from fertilizer application/ transport emissions **3) Point source: pollution through CSO discharge of municipal waste water + rainwater** 4) Activities using specific substances??	1) Stream profile 2) Concentration of N in the water 3) Concentration of N in the water 4) -	1) ? 2) mg/L 3) mg/L 4) -	?	direct indicator	
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) construction of a piped sewer network (2) newly created physical structure of watercourses, floodplains, and basins				
STATE *(only those relevant for the assessment of Impact I)*	Habitats	1) Ecological potential 2) Taxa richness 3) Red list taxa				

		4) Saprobic index 5) Traits				
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Biodiversity	A) Taxa richness B) Red list taxa C) EQR (Saprobic index) D) Ecological potential	A) mean number of taxa B) max. number of taxa C) - D) km	monitoring data	direct indicator	→ "A data"
IMPACT II - USE	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

INDICATOR TABLE - Further explanation

RESULTS TABLE

	Case-relevant Element	Output	Output unit	Comments
PRESSURE	1) Morphological: stream profile 2) Diffuse source: pollution	not yet quantified		

<table>
<tr><td></td><td>through run-off from fertilizer application/ transport emissions
3) Point source: pollution through CSO discharge of municipal waste water + rainwater
4) Activities using specific substances??</td><td></td><td></td><td></td></tr>
<tr><td>STATE</td><td>Habitats</td><td>not assessed</td><td></td><td></td></tr>
<tr><td>IMPACT I - PROVISION</td><td>Biodiversity</td><td>A) Taxa richness
BEFORE: 9.33
AFTER: 18.10

B) Red list taxa
BEFORE: 0
AFTER: 4

C) EQR (Saprobic index)
BEFORE: 0.59
AFTER: 0.87

D) Ecological potential:
<table>
<tr><th>km</th><th>good-moderate</th><th>moderate-poor</th><th>poor</th><th>poor-bad</th><th>bad</th></tr>
<tr><td>BEFORE</td><td>0.00</td><td>0.00</td><td>0.00</td><td>0.00</td><td>297.11</td></tr>
<tr><td>AFTER</td><td>99.23</td><td>92.93</td><td>61.04</td><td>43.90</td><td>0.00</td></tr>
</table></td><td>A) mean number of taxa

B) max. number of taxa

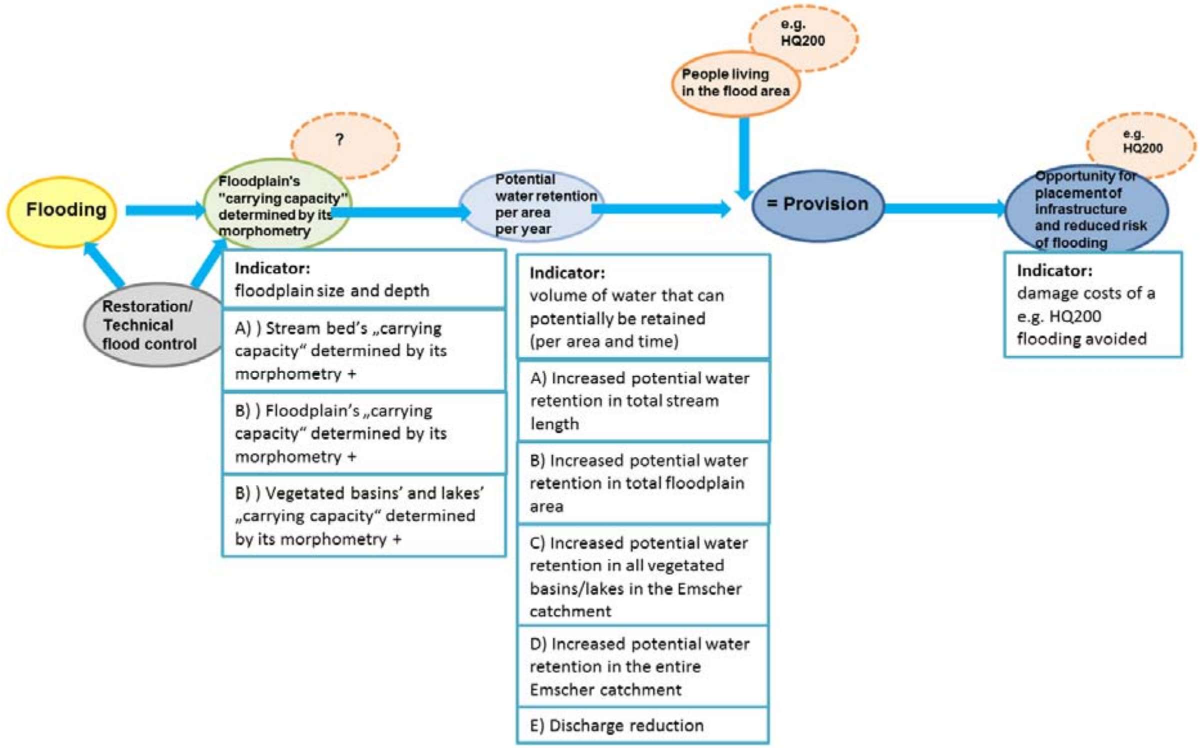
C) -

D) -

E) km</td><td></td></tr>
<tr><td>IMPACT II - USE</td><td>IESS
→ see FESS # 2-5</td><td>not to be quantified</td><td>not to be quantified</td><td>not to be quantified</td></tr>
</table>

IMPACT II – resulting benefit	IESS → see FESS # 2-5	*not to be quantified*	*not to be quantified*	*not to be quantified*
RESULTS TABLE - Description				

FESS # 1: Opportunity for placement of infrastructure and reduced risk of flooding



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events

	(3) improvement of the physical structure of watercourses
CICES Section	Regulation & Maintenance Services
CICES Division	Mediation of flows
CICES Group	Liquid flows
CICES Class	Flood Protection
ESS *(use US EPA nomenclature!)*[2]	**Opportunity for placement of infrastructure and reduced risk of flooding** (US EPA/DESSIN)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** A) Rivers and streams
	B) Wetlands
	C) Lakes and ponds
Temporal scope	A) Per year
	B) Per year
	C) Per year
Spatial scope	A) per river basin
	B) per river basin
	C) per river basin
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS

For FESS: Intermediate ESS required *(use CICES catalogue!)*	none
For Intermediate services: FESS affected & other IESS required	NR
Regulatory Threshold	e.g. HQ200
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Residential Property Owners: People living in the flood area

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	(1) Flood protection (2) Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE)* *(only those addressed by the*	(1) Other anthropogenic: Flooding	Volume of stormwater during flood event HQ50/HQ100	m^3	?	direct indicator	

capability??)						
RESPONSE *(describe in detail)*	Emscher re-conversion: Natural flood control through near natural stream beds/profiles	1) Estimation of the reduction in the frequency of overflow events?? 2) Estimation of the substitution of technical flood protection infrastructure by green infrastructure?	?			
STATE *(only those relevant for the assessment of Impact I)*	A) Stream bed's „carrying capacity" determined by its morphometry	Stream bed's profile	m^3	EGLV planning data/measured data	direct indicator	planning data/measured data → "B data"
	B) Floodplain's „carrying capacity" determined by its morphometry	Floodplain size and depth	m^3	EGLV planning data/measured data; GIS	direct indicator	planning data/measured data → "B data"
	C) Vegetated basins'/lakes' „carrying capacity" determined by its morphometry	Vegetated basins'/lakes' profile	m^3	EGLV planning data/measured data	direct indicator	planning data/measured data → "B data"
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	A) Increased potential water retention in total stream length (per year?)	Volume of water that can potentially be retained	m^3 (/a?) in total stream length	EGLV planning data/measured data	proxy: status-related indicator	planning data/measured data → "B data"
	B) Increased potential water retention in total floodplain area (per year?)	Volume of water that can potentially be retained	m^3 (/a?) in total floodplain area	EGLV planning data/measured data; GIS	proxy: status-related indicator	planning data/measured data → "B data"
	C) Increased potential water retention in all vegetated	Volume of water that can	m^3 (/a?) in all	EGLV planning	proxy: status-related	planning

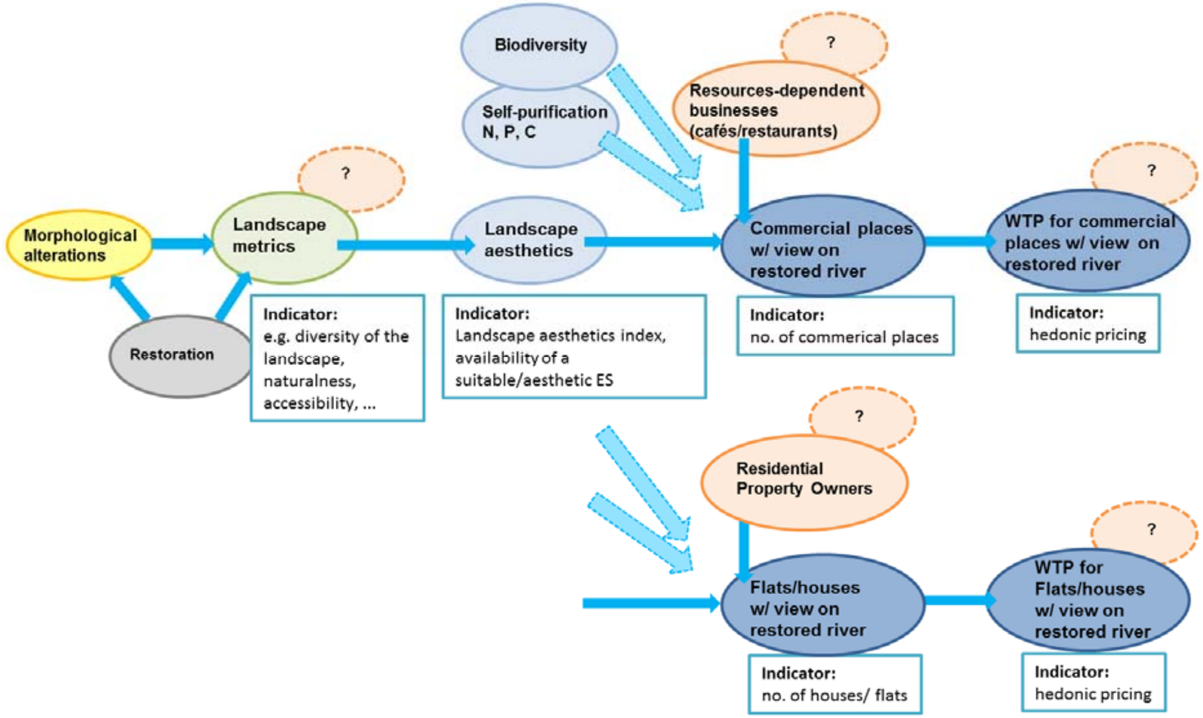
	basins/lakes in the Emscher catchment (per year?)	potentially be retained	vegetated basins/lakes	data/measured data	indicator	data/measured data → "B data"
	D) Increased potential water retention in the entire Emscher catchment (per year?)	= A+B+C	m³ /a in the entire Emscher basin			
	E) Discharge reduction	Discharge inside streams	m³/s → %	Master thesis Wiebke Beysiegel (Beysiegel 2015)	direct indicator	modelled data → "B data"
IMPACT II - USE	Equal to Provision	see Impact I Provision				
IMPACT II - resulting benefit	Avoided costs of flood damage		€	Hochwasser-Aktionsplan Emscher (Hydrotec 2004)		
Further explanation						

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	(1) Other anthropogenic: Flooding	no results yet	m³	
STATE	A) Stream bed's „carrying capacity" determined by its morphometry		m³	

<table>
<tr><td rowspan="2"></td><td>B) Floodplain's „carrying capacity" determined by its morphometry</td><td></td><td>m^3</td><td></td></tr>
<tr><td>C) Vegetated basins'/lakes' „carrying capacity" determined by its morphometry</td><td></td><td>m^3</td><td></td></tr>
<tr><td rowspan="5">IMPACT I - PROVISION</td><td>A) Increased potential water retention in total stream length (per year?)</td><td>not assessed</td><td>m^3 (/a?) in total stream length</td><td></td></tr>
<tr><td>B) Increased potential water retention in total floodplain area (per year?)</td><td>not assessed</td><td>m^3 (/a?) in total floodplain area</td><td></td></tr>
<tr><td>C) Increased potential water retention in all vegetated basins/lakes in the Emscher catchment (per year?)</td><td>BEFORE: 881,500 m^3 (0 m^3 vegetated)
AFTER: 3.3 M m^3 (1.55 M m^3 vegetated)</td><td>m^3 (/a?) in all vegetated basins/lakes</td><td></td></tr>
<tr><td>D) Increased potential water retention in the entire Emscher catchment (per year?)</td><td>= A+B+C</td><td>m^3 /a in the entire Emscher basin</td><td></td></tr>
<tr><td>E) Discharge reduction</td><td><table><tr><th>weighted average [m^3/s]</th><th>BEFORE</th><th>AFTER</th></tr><tr><td>100 year event</td><td>36.41</td><td>27.66</td></tr><tr><td>2 year event</td><td>17.16</td><td>9.80</td></tr></table>CHANGE:
- The discharge for a two-year-event is on average reduced by 44%.
- The average percentage of improvement for a flood event with a recurrence interval of 100 years is 27%.</td><td>m^3/s → %</td><td></td></tr>
<tr><td>IMPACT II - USE</td><td>Equal to Provision</td><td>see Impact I Provision</td><td>$m^3/km/a$</td><td></td></tr>
</table>

IMPACT II - resulting benefit	Avoided costs of flood damage	BEFORE: 178,550 €/100 years AFTER: 0 €/100 years	€/100 years	
RESULTS TABLE - Description				

FESS # 2: Opportunity for placement of infrastructure in environment



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events

	(3) improvement of the physical structure of watercourses
CICES Section	Cultural Services
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Physical and experiential interactions
CICES Class	**Experiential use of plants, animals and landscapes in different environmental settings**
ESS *(use US EPA nomenclature!)*[2]	**Opportunity for placement of infrastructure in environment**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Rivers and streams + Wetlands
Temporal scope	per year
Spatial scope	along water body
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS
For FESS: Intermediate ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance **(2) Filtration/sequestration/storage/ accumulation by ecosystems ← Intermediate ESS # 1-3** **(3) Maintaining nursery populations and habitats ← Intermediate ESS # 4** (4) Chemical condition of freshwaters (5) Mediation of smell impacts Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds
For Intermediate services: FESS affected & other IESS	NR

required	
Regulatory Threshold	?
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	A) Resources-dependent businesses (operators of cafés and restaurants along the restored riverfront) B) Residential Property Owners

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	(1) Flood protection (2) Industry (3) Tourism & recreation (4) Transport (5) Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	(1) Morphological (2) Other anthropogenic (3) Diffuse source (4) Point source (5) Activities using specific substances	no results yet				
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) improvement of water quality (2) reduction in the				

		frequency of overflow events (3) improvement of the physical structure of watercourses				
STATE *(only those relevant for the assessment of Impact I)*	Landscape aesthetics: 1. Presence of surface water 2. Water clarity status 3. Extent to which sound of flowing water can be heard 4. Algae status 5. Odor status 6. Extent of experiential facilities 7. Number of experiential users	1. Percentage of analysis period that surface waters are visible 2. Water clarity metric 3. Percentage of analysis period during which flow rate is sufficient for sound of flowing water to be heard 4. Frequency of algal blooms 5. Odor metric 6. Experiential facilities metric 7. Persons likely to make close-to-home visits	1. Percentage (dimensionless) 2. Water clarity metric 3. Percentage (dimensionless 4. Number of blooms during analysis period 5. Odor metric 6. Experiential facilities metric 7. Number of people living with 8 km of restored reach	1. Monitoring data 2. Monitoring data 3. Discharge monitoring 4. Monitoring data 5. ? 6. ? 7. Population density data, road network maps (from publications on urban density distribution in Ruhrgebiet)	direct indicator: status-related indicator	1. Monitoring data 2. Monitoring data 3. Monitoring data 4. Monitoring data 5. ? 6. ? 7. Literature
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds *Note: no direct link between I1 and I2*	Beauty of the landscape (Composite indicator that aggregates indicators 1-6 in the list above); IESS # 1-4	Dimensionless index		proxy: status-related indicator	see State

IMPACT II - USE	A) commercial places with view on restored river sections	commercial area (at Lake Phoenix)	m²	City of Dortmund		
	B) flats/houses with view on restored river sections	housing area (houses/flats) (at Lake Phoenix)	m²	City of Dortmund		
IMPACT II - resulting benefit	A) Hedonic pricing for commercial place (cafés, restaurants, …)	(1) Rental cost for commercial area per m² (2) (exemplary) business turnover for commercial place	(1) €/m²/a (2) €/a	BEFORE: 0 AFTER: (1) German Chamber of Commerce and Industry (2) German Federal Statistical Office		→ "B data"
	B) Hedonic pricing for housing area	Rental cost for housing area per m² (at Lake Phoenix, in New Emscher Valley)	€/m²/a	BEFORE: 0 (1) AFTER: online real estate portal "wohnungsboerse.net",		→ "B data"

INDICATOR TABLE - Further explanation

Further information on IMPACT II – resulting benefit indicator "Hedonic pricing for housing area":

Method 1:

The area for commercial or flat/housing use and the rental cost for commercial/ housing area per m² resulted in the total rental costs at Lake Phoenix. No upscaling to basin level was conducted.

Method 2:

Total prices for buying and rental flats were available for 2007 and 2011. Buying offers for flats have in averaged decreased in price between 2007 and 2011 by -8% both for the New Emscher Valley and the remaining Emscher area. Renting offers for flats have, however, increased by +3.5% in the New Emscher

Valley while they stayed constant in the remaining Emscher area.

In order to forecast prices per m^2 for the restored Emscher valley, we assumed constant prices for the Emscher area but increased prices for the New Emscher Valley. These were derived from the price increases observed at Lake Phoenix. Price change from BEFORE (0 €/m^2) to AFTER (8.68 €) was used but an average rental price (mean price in the New Emscher valley and remaining Emscher basin in 2011 = 5.22 €/m^2) was distracted, resulting in an increase by 3.46 €/m^2 for rental flats. The area for apartments/flats AFTER re-conversion was assumed to be the same as in 2011. Price estimates were conducted based on total area of flats (calculated from the number of flats of various sizes) and price per m^2. Note that this is only valid for rental flats.

Price effect was differentiated from area effect by assuming a constant number of flats, and thus, total housing area from 2007 through 2020 when calculating the price change.

RESULTS TABLE

	Case-relevant Element	Output	Output unit	Comments
PRESSURE	(1) Morphological (2) Other anthropogenic (3) Diffuse source (4) Point source (5) Activities using specific substances	No results yet		
STATE	Landscape aesthetics	No results yet		
IMPACT I - PROVISION	Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds	No results yet	Dimensionless index	
IMPACT II - USE	A) commercial places with view on	Method 1:	m^2	

<table>
<tr><td></td><td>restored river sections</td><td>BEFORE: 0 m²
AFTER: 100,000 – 150,000 m²</td><td></td><td></td></tr>
<tr><td></td><td>B) flats/houses with view on restored river sections</td><td>Method 1:
BEFORE: 0 m²
AFTER: 240,000 m²

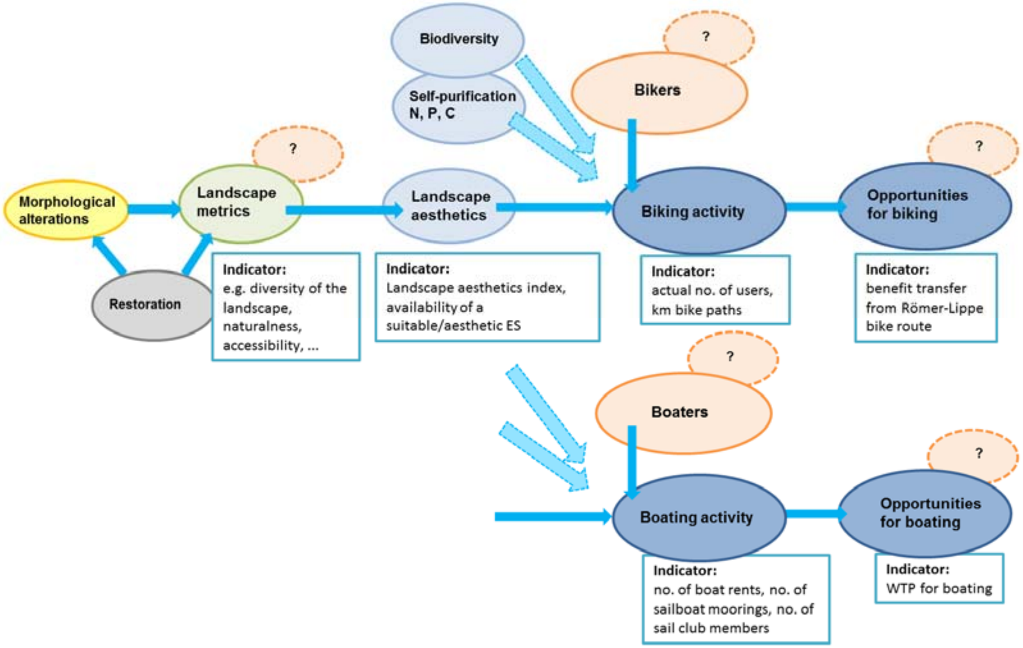
Method 2:<table><tr><th colspan="3">Number of rental flat offers</th></tr><tr><th></th><th>BEFORE</th><th>AFTER</th></tr><tr><td>NE</td><td>3,062</td><td>5,590</td></tr><tr><td>Emscher</td><td>9,434</td><td>21,896</td></tr></table></td><td>Method 1: m²

Method 2: count</td><td></td></tr>
<tr><td rowspan="2">IMPACT II – resulting benefit</td><td>A) Hedonic pricing for commercial place (cafés, restaurants, …)</td><td>Method 1:
BEFORE: 0 €/a (only Lake Phoenix!)
AFTER: 8,4 - 19,8 M €/a (only Lake Phoenix!)

Method 2: not assessed</td><td>€/a</td><td>Economic impact</td></tr>
<tr><td>B) Hedonic pricing for housing area</td><td>Method 1:
BEFORE: 0 €/a (only Lake Phoenix!)
AFTER: 2,5 M €/a (only Lake Phoenix!)

Method 2:<table><tr><th colspan="3">Price effect for rental flat offers (M €/a)</th></tr><tr><th></th><th>BEFORE</th><th>AFTER</th></tr><tr><td>NE</td><td>11.81</td><td>20.44</td></tr><tr><td>Emscher</td><td>40.38</td><td>40.33</td></tr></table></td><td>€/a</td><td>Economic impact</td></tr>
<tr><td colspan="5">RESULTS TABLE - Description</td></tr>
<tr><td colspan="5"></td></tr>
</table>

FESS # 3: Opportunity for biking & recreational boating



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events

	(3) improvement of the physical structure of watercourses
CICES Section	Cultural Services
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Physical and experiential interactions
CICES Class	**Physical use of landscapes in different environmental settings**
ESS *(use US EPA nomenclature!)*[2]	**(A) Opportunities for biking** (DESSIN) **(B) Opportunity for recreational boating** (US EPA)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Rivers and streams + Wetlands
Temporal scope	per year
Spatial scope	along water body
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS
For FESS: Intermediate ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance **(2) Filtration/sequestration/storage/ accumulation by ecosystems ← Intermediate ESS # 1-3** **(3) Maintaining nursery populations and habitats ← Intermediate ESS # 4** (4) Chemical condition of freshwaters (5) Mediation of smell impacts
For Intermediate services: FESS affected & other IESS required	NR

Regulatory Threshold	?
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	A) Bikers (leisure time bikers/ everyday & workday bikers) (FESS not applicable) B) Boaters

INDICATOR TABLE

	Case-relevant Element	Indicator	Output unit	Data sources & data availability	Indicator quality *(see explanation in Framework Box XX!)*	Data quality *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	(6) Flood protection (7) Industry (8) Tourism & recreation (9) Transport (10) Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	(6) Morphological (7) Other anthropogenic (8) Diffuse source (9) Point source (10) Activities using specific substances	no results yet				
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) improvement of water quality (2) reduction in the frequency of overflow				

		events (3) improvement of the physical structure of watercourses				
STATE *(only those relevant for the assessment of Impact I)*	Landscape aesthetics: 8. Presence of surface water 9. Water clarity status 10. Extent to which sound of flowing water can be heard 11. Algae status 12. Odor status 13. Extent of experiential facilities 14. Number of experiential users	8. Percentage of analysis period that surface waters are visible 9. Water clarity metric 10. Percentage of analysis period during which flow rate is sufficient for sound of flowing water to be heard 11. Frequency of algal blooms 12. Odor metric 13. Experiential facilities metric 14. Persons likely to make close-to-home visits	8. Percentage (dimensionless) 9. Water clarity metric 10. Percentage (dimensionless 11. Number of blooms during analysis period 12. Odor metric 13. Experiential facilities metric 14. Number of people living with 8 km of restored reach	8. Monitoring data 9. Monitoring data 10. Discharge monitoring 11. Monitoring data 12. ? 13. ? 14. Population density data, road network maps (from publications on urban density distribution in Ruhrgebiet)	direct indicator: status-related indicator	8. Monitoring data 9. Monitoring data 10. Monitoring data 11. Monitoring data 12. ? 13. ? 14. Literature
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds *Note: no direct link between I1 and I2*	Beauty of the landscape (Composite indicator that aggregates indicators 1-6 in the list above) ; IESS # 1-4	Dimensionless index		proxy: status-related indicator	see State
IMPACT II - USE	A) Recreational use by bikers	(1) actual no. of bikers, (2) km of bike paths	(1) no. per year (2) km	(1) Römer-Lippe-bike route study	(1) direct indicator; (2) proxy	→ "B data"

				(Radschlag, IGS 2013); (2) bike paths built		
	B) Recreational use by boaters	(1) no. of sailors (2) no. of sailboat moorings (3) no. of sail club members	(1) count sailors (2) count sailboat moorings (3) count sail club members	(1) Lake Phoenix boat rental (2) Lake Phoenix boat rental (3) Lake Phoenix boat rental	(1) proxy (2) proxy (3) proxy	→ "B data"
IMPACT II - resulting benefit	A) Recreational benefits for bikers	economic impact for this type of recreation	€	Römer-Lippe-bike route study (Radschlag, IGS 2013)		→ "B data"
	B) Recreational benefits for boaters	economic impact for this type of recreation	€			→ "B data"
INDICATOR TABLE - Further explanation						

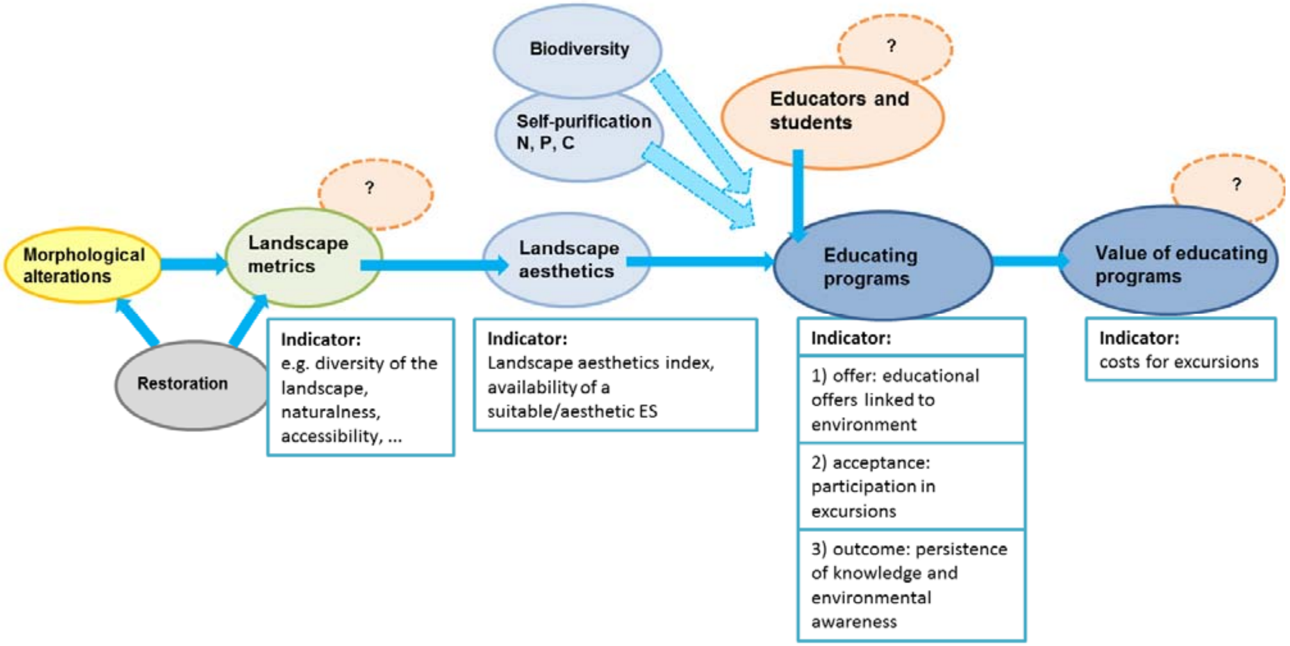
RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	(6) Morphological (7) Other anthropogenic (8) Diffuse source	No results yet		

	(9) Point source (10) Activities using specific substances			
STATE	Landscape aesthetics	No data available		
IMPACT I - PROVISION	Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds	No data available	Dimensionless index	
IMPACT II - USE	A) Recreational use by bikers	(1) BEFORE: 11,392 bikers/year AFTER: 40,000 – 50,000 bikers/year (2) BEFORE: ca. 35 km of bike paths AFTER: 123 km of bike paths	(1) count bikers/year (2) km of bike paths	estimation of the number of bikers based on the length (km) of bike paths present BEFORE in relation to AFTER
	B) Recreational use by boaters	(1) BEFORE: 0 sailors/year AFTER: 5,000 sailors/year (2) BEFORE: 0 sailboat moorings AFTER: 40 sailboat moorings (3) BEFORE: 0 sail club members AFTER: 70 sail club members	(1) count sailors (2) count sailboat moorings (3) count sail club members	
IMPACT II – resulting benefit	A) Recreational benefits of bikers	BEFORE: 378,784 €/year AFTER: 40,000 – 50,000 bikers per year - day trippers: 80 % - touring cyclist: 20 % - day trippers: 14.50 € p.P./day - touring cyclist: 75 € p.P./day = 1,330,000 €/year	€/year	benefit transfer from Radschlag, IGS (2013)
	B) Recreational benefits of boaters	BEFORE: 0	€	

		AFTER: 5,000 sailors per year * 5 € p. P./day + 40 moorings * 5 € p. M./year + 70 sail club members * 180 € p.M./year = 53,600 €/year		

RESULTS TABLE - Description

FESS # 4: Opportunities to understand, communicate, and educate



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses

CICES Section	Cultural Services
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Intellectual and representative interactions
CICES Class	Educational
ESS *(use US EPA nomenclature!)*[2]	**Opportunities to understand, communicate, and educate** (US EPA)
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Rivers and streams + Wetlands
Temporal scope	per year
Spatial scope	per catchment
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS
For FESS: Intermediate ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance **(2) Filtration/sequestration/storage/ accumulation by ecosystems ← Intermediate ESS # 1-3** **(3) Maintaining nursery populations and habitats ← Intermediate ESS # 4** (4) Chemical condition of freshwaters (5) Mediation of smell impacts Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds
For Intermediate services: FESS affected & other IESS required	NR
Regulatory Threshold	NR

Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Educators and students

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	(11) Flood protection (12) Industry (13) Tourism & recreation (14) Transport (15) Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE)* *(only those addressed by the capability??)*	(11) Morphological (12) Other anthropogenic (13) Diffuse source (14) Point source (15) Activities using specific substances	no results yet				
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses				

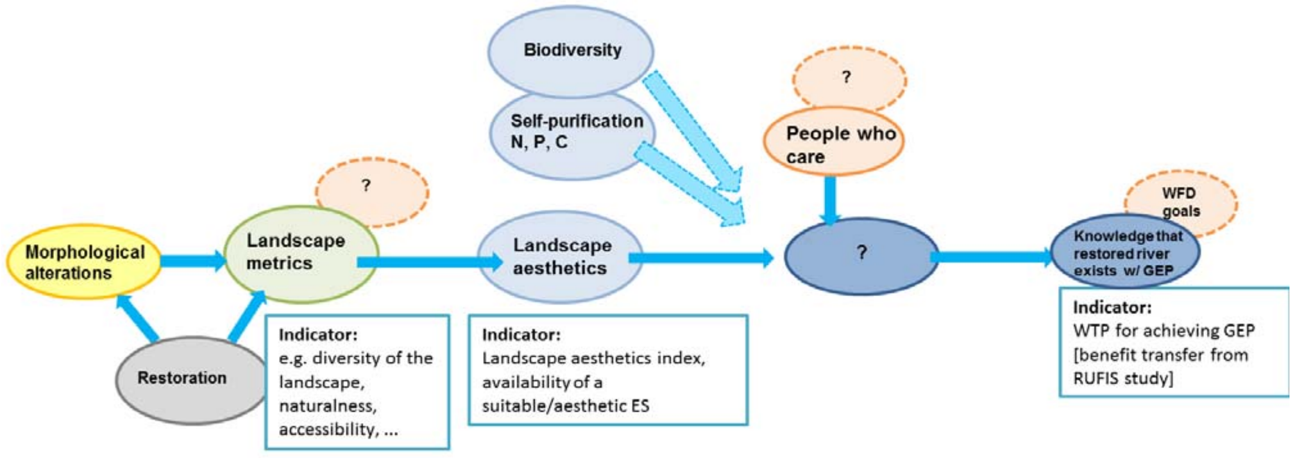
STATE *(only those relevant for the assessment of Impact I)*	← Intermediate ESS # 1- 4	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	← Intermediate ESS # 1-4 Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - USE	1) offer: educational offers linked to environment	number of educational offers linked to environment	count			
	2) acceptance: participation in excursions	number of participants in excursion (to Lake Phoenix and to streams)	count	EG, Marc Franke	direct	→ "B data"
	3) outcome: persistence of knowledge and environmental awareness	metric for success of educational unit	dimensionless			
IMPACT II - resulting benefit	costs for excursions	cost for participating in excursion	€	DGL excursion (UDE, personal communication) as proxy for WTP	proxy	→ "B data"
INDICATOR TABLE - Further explanation						

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE				
STATE	← Intermediate ESS # 1-4	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT I - PROVISION	← Intermediate ESS # 1-4	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - USE	1) offer: educational offers linked to environment	No data available		
	2) acceptance: participation in excursions	BEFORE: a) Lake Phoenix: 0 b) Course of the stream: n/a AFTER: a) Lake Phoenix: 218-834 b) Course of the stream: 465-1549	count	
	3) outcome: persistence of knowledge and environmental awareness	No data available		
IMPACT II – resulting benefit	costs for excursions	BEFORE: n/a AFTER: a) 218-834 visitors per year * 10 € p. P. + b) 465-1,549 visitors per year * 20 € p. P.	€/a	

		= 11,480-39,320 €/year		

RESULTS TABLE - Description

FESS # 5: Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)



ESS HEAD	
Measure influencing the ESS	(1) creation of sewer net-work incl. CSOs (2) waste-water free streams (3) ecological restoration
Capability influencing the ESS	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses
CICES Section	Cultural Services
CICES Division	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environ-mental settings]

CICES Group	Other cultural outputs
CICES Class	**Existence**
ESS *(use US EPA nomenclature!)*[2]	Knowing that the environment exists (US EPA) / **Knowledge that a restored river area exists, with suitable water quality (i.e. GEP) (DESSIN)**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Rivers and streams + Wetlands
Temporal scope	per year
Spatial scope	per catchment
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS
For FESS: Intermediate ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance **(2) Filtration/sequestration/storage/ accumulation by ecosystems ← Intermediate ESS # 1-3** **(3) Maintaining nursery populations and habitats ← Intermediate ESS # 4** (4) Chemical condition of freshwaters (5) Mediation of smell impacts Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds
For Intermediate services: FESS affected & other IESS required	NR
Regulatory Threshold	Water Framework Directive
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	People who care/ Residential Property Owners

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Framework Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	(16) Flood protection (17) Industry (18) Tourism & recreation (19) Transport (20) Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	(16) Morphological (17) Other anthropogenic (18) Diffuse source (19) Point source (20) Activities using specific substances	no results yet				
RESPONSE *(describe in detail)*	Emscher re-conversion	(1) improvement of water quality (2) reduction in the frequency of overflow events (3) improvement of the physical structure of watercourses				
STATE *(only those relevant for the*	← Intermediate ESS # 1-4	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*

assessment of Impact I)						
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	← Intermediate ESS # 1-4	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - USE	???					
IMPACT II - resulting benefit	Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)	WTP by people in the area for achieving GEP	€/year	benefit transfer from Hecht et al. (2015)	proxy	→ "B data"

INDICATOR TABLE - Further explanation

Further information on IMPACT II – resulting benefit indicator "*WTP by people in the area for achieving GEP*":

As primary valuation research was not feasible within the DESSIN project, the indicator for monetizing the value derived from the "*knowledge that a restored river area with suitable water quality exists*" had to be taken from literature using the benefit transfer approach. The study chosen for that purpose is the WTP study for achieving a GEP of River Wupper by Hecht et al. (2015) which can be at least used for an adjusted unit value transfer for the Emscher case since it fulfills the following criteria: The ESS studied in the Wupper case is the same as in the Emscher case. Wupper and Emscher are both tributaries to the River Rhine of nearly the same length and catchment area so that location, affected beneficiaries and market construct are comparable. As both rivers were historically used for (industrial) sewage disposal it can be assumed that the change in ESS required to achieve a GEP is similar in both cases. Although the study is not published in a peer-review journal it is the best available source for benefit transfer.
The total WTP for restoring the Emscher was calculated by taking the WTP for reaching GEP of the River Wupper and transferring it to the population

structure in the Emscher catchment. WTP was transferred based on average WTP with regard to gender, with regard to the total number of inhabitants, and with regard to the age structure of the inhabitants. As in Hecht et al. (2015), only inhabitants > 18 years were considered. The results of the three scenarios (gender, total, age) range from 104 to 108 M € per year.

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE				
STATE	← Intermediate ESS # 1-4	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT I - PROVISION	← Intermediate ESS # 1-4 Provision of opportunity to experience and view a landscape that provides a sensory experience, including sights and sounds	*not to be quantified*	*not to be quantified*	*not to be quantified*
IMPACT II - USE	???			
IMPACT II – resulting benefit	Knowledge that a restored river area exists, with suitable water quality (i.e. GEP)	BEFORE: 0 €/a AFTER: 2,686,079 inhabitants (> 18 years old) WTP = 39.96 € per person and year = 107,335,717 € per year	€/a	benefit transfer from RUFIS study
RESULTS TABLE - Description				

A.B Selection of indicators

F	G	H	J	K	N	O	P	Q
							Data Availability	
ID	Metric	Indicator	Unit	System	Alternativ		yes	no
S111	Presence of microbial pathogens			WW/WS	no			x
S112	Presence of cyanobacteria and cyanotoxins			WW/WS	no			x
S113	Presence of toxic chemicals			WW/WS	no		x	
S121	Economic impact (incl. Indirect and induced	(Economic impact - initial spending) / economic	[I] or [-]	WW/WS	no		x	
S131	Number of jobs, amount of employment created by implementation of technology/solution		[1/a]	WW/WS	yes		x	
S132	Number of jobs, amount of employment derived from improved cultural services		[1/a]	WW/WS	yes			x
S141	Number of beneficiaries affected		[-]	WW/WS	yes		x	
S142	Categories of beneficiaries affected			WW/WS	yes			x
S151	Experiential and physical use of landscapes in		I/a	WW/WS	yes		x	
S152	Intellectual and representative interactions (Educational)		I/a	WW/WS	yes		x	
En121		Efficient use of energy	[%]	WW/WS	no			x
En12		Energy recovery rate	[%]	WW/WS	no			x
En12		Green energy usage	[%]	WW/WS	no			x
En12	Energy consumed		[kWh/m^3]	WW/WS	yes			x
En131	Materials, chemicals and other consumables		[kg/m^3] or [kg/a]	WW/WS	yes			x
En13		Recovery of wastes	[%]	WW/WS	no			x
En211	Cumulative energy demand of fossil resources		[MJ]	WW/WS	yes			x
En21	Cumulative energy demand of nuclear resources		[MJ]	WW/WS	yes			x
En21	Global warming potential (100a)		[kg CO_2-eq]	WW/WS	yes			x
En21	Terrestrial acidification potential (100 a)		[kg SO_2-eq]	WW/WS	yes			x
En21	Freshwater eutrophication potential		[kg P-eq]	WW/WS	yes			x
En21	Marine eutrophication potential		[kg N-eq]	WW/WS	yes			x
En21	Particulate matter formation		[kg PM_{10}-eq]	WW/WS	yes			x
En21	Human toxicity (non-cancer)		[CTU_h]	WW/WS	yes			x
En21	Human toxicity (cancer)		[CTU_h]	WW/WS	yes			x
En22	Freshwater ecotoxicity		[CTU_e]	WW/WS	yes			x
F111	Investment expenditure		[I]	WW/WS	yes		x	
F112	Annual operational expenditure		[I]	WW/WS	yes		x	
F113	Avoided costs and/or additional monetary benefits from: - Opportunity to discharge into the environment - Opportunity for placement of infrastructure and		[I]	WW/WS	yes		x	
F114	Other sources of financing (e. g. subsidies) aligned to the solution		[%]	WW/WS	yes		x	
G111	Compliance improvement w/ relevant EU standards (WFD, BWD)	water status reached / water status level required		WW/WS	no		x	
G112	Compliance with relevant national, local standards			WW/WS	no			x
G121	Number of actors/stakeholders involved in planning, implementation, operations, and			WW/WS	yes			x
G122	Communicative events			WW/WS	yes			x
G131	Monitoring			WW/WS	yes			x
G132	Information dissemination			WW/WS	yes			x
A111		MTTF	[year/1 failure]	WW/WS	yes		x	
A112		MTBF	[years/1 failure]	WW/WS	no			x
A121		Sufficient capacity of the technology/solution to the expected use	[%]	WW/WS	no			x
A131		Adaptive capacity as: The probability that the item is able to function at time t (availability at time t) for any given loads	[0-1]	WW/WS	no			x
A141		[Hours of exposed or "dirty work""! on the site/total hours of work per year]*100	[number/reference time]	WW/WS	no			x
A142		Risk episodes, injuries on the site/total hours of work in test period	[number/reference time]	WW/WS	no			x
A151		percentage of load removed	[kg N/a]	WW	no		x	
A211		Number of complaints about the technology (due to for instance Noise, Dust, Estetics,	[number/reference time]	WW/WS	no			x
A221		lifetime of solution/start up time		WW/WS	no		x	
A231	training hours for staff operating the solution			WW/WS	yes			x

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

www.dessin-project.eu

D13.1: Quantified ESS for 3 mature sites including recommendations for application

Part 3: Llobregat case

Lead Author: Cetaqua, April 2016

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This publication reflects only the author's views and the European Union is not liable for any use that may be made of the information contained therein.

D13.1: Quantified ESS for 3 mature sites including recommendations for application
PART 3 – Llobregat case

SUMMARY	
This Deliverable reports the results of the application of the ESS Evaluation Framework (D11.2) for the Llobregat mature case.	
DELIVERABLE NUMBER	**WORK PACKAGE**
13.1	WP13
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
Cetaqua	Amorós Puigmal, Jaume (Cetaqua) Hernández García, Marta (Cetaqua) Termes Rifé, Montserrat (Cetaqua) Strehl, Clemens (IWW) Wencki, Kristina (IWW)
QUALITY ASSURANCE	
Cetaqua	Marín, Desirée (internal Cetaqua)
PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
15/04/2016	15/04/2016
DISSEMINATION LEVEL	X PU = Public □ PP = Restricted to other programme participants □ RE = Restricted to a group specified by the consortium. Please specify: _______________________________ □ CO = Confidential, only for members of the consortium

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Table of contents

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List of Figures

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List of tables

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List of Acronyms and Abbreviations

AB	Aigües de Barcelona Drinking Water Supply company
ACA	Catalan Water Agency
AMB	Àrea Metropolitana de Barcelona public administration
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage Transfer and Recovery
CICES	Common International Classification of Ecosystem Services
CUADLL	Association of groundwater users in the Llobregat aquifer
DPSIR	Drivers, Pressures, State, Impacts and Response scheme
DWTP	Drinking Water Treatment Plant
ESS	Ecosystem Services
FESS	Final Ecosystem Services
GDP	Gross Domestic Product
ICTM	Individual Travel Cost Method
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MAR	Managed Aquifer Recharge
MPN	Most Probable Number (unit of microbiological concentration)
MTTF	Mean Time To Failure
MTBF	Mean Time Between Failures
SA	Sustainability Assessment
SCC	Santa Coloma de Cervelló
SJD	Sant Joan Despí facility of Drinking Water Treatment Plant (Barcelona)
SVH	Sant Vicenç dels Horts
WHO	World Health Organisation
WTP	Willigness To Pay

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Executive summary

This report is included in task T13.1 of the DESSSIN project, aiming at applying the DESSIN ESS assessment methodology to existing data from measures already implemented in the water basins. Three European sites have been selected: Emshcher river restoration (Germany), rehabilitation of a coastal area including the river as part of the city in Aarhus (Denmark) and the construction of large infiltration ponds for aquifer replenishment in Baix Llobregat area (Barcelona). The methodology for ESS evaluation developed within the DESSIN project is based on DPSIR scheme (drivers, pressures, state, and impact and response). The cookbook describes the method to be applied, and contains standard lists for classification of drivers, pressures, beneficiaries and type of services (intermediate or final), for instance. To know more about the methodology developed in the cookbook, it is hardly recommended to consult it (Anzaldúa *et al.* 2016).

Specifically, this report evaluates the ESS linked to the infiltration system planned in Santa Coloma de Cervelló (SCC). SCC inifiltration system is designed to occupe 13 ha of surface placed and an infiltration capacity of 10 Mm^3/year. This is one of the top priorities for the future investments 2015 – 2020 of the Catalan Water Agency (ACA). The investment for its construction is 8 M€. For the biophysical approach and the evaluation of expected impacts in hydrogeology and biophysical indicators, the system of SVH has been taken as a reference, with an annual infiltrated volume of 1 Mm^3/year in average. SVH represents a 10% of the amount of water that could be recharged in SCC, but can illustrate perfectly the changes in native groundwater quality and the changes along soil-aquifer passage in terms of pollutants removal. SCC has been selected as mature site in the Llobregat area due to the high impact in groundwater resources and the previous experience gathered in Sant Vicenç dels Horts (SVH) system. Results obtained will be directly applied by ACA to the cost-benefit analysis in their starting plan of investments in hydraulic infrastructures linked to the water cycle.

The first part of the document explains the **drivers and preassures** which contextualize the construction of the infiltration ponds. Industry and urban development have been the two drivers identified, causing a list of inter-connected pressures in groundwater: local industrial pollution as solvents, PAHs… ; municipal and industrial waste water treatment discharges, increase of extraction rates for industry and drinking water production and hydrological alteration caused by the urbanization of areas in the river basin.

The complexity of the ESS assessment of SCC is due to: (1) assumption of the similar effectiveness of SCC system to SVH system in terms of water quality and operational regime; (2) evaluation of research opportunities and cultural services of a very specific nature-based infrastructure, (3) uncertainty of the effects of piezometric level rise and salinity decrease for the groundwater users and (4) determination of added value of groundwater for the users in the aquifer. To deal with these uncertainties, the work started with a series of interviews with hydrogeologists and water managers of the area in order to identify the main beneficiaries of groundwater and the area of influence of SCC system. Once identified drinking water operators and industries as the main groundwater end-users, Aigües de Barcelona (AB) and DAMM Company were selected as the most representative beneficiaries due to their large volume of pumped groundwater compared to other drinking water opeators (e.g. Aigues del Prat) and industries, respectively. Moreover, the numerical model developed by CUADLL simulating the groundwater level rise in the aquifer after the implementation of SCC system has been used to determine the groundwater level expected in the pumping wells evaluated.

Four ecosystem services linked to the infiltration ponds have been identified and assessesed: (1) water for drinking purposes (selected beneficiary: Aigües de Barcelona); (2) water for non-drinking purposes (selected beneficiary: DAMM); (3) research opportunities (selected beneficiary: scientific community); (4) cultural services (selected beneficiary: population living in the surroundings and Barcelona Metropolitan Area).

There has been defined a **list of biophysical indicators of state** whose value change before and after the implementation of the SCC system. There have been classified in: physical parameters related to water quantity (e.g. groundwater level), quality parameters in native groundwater (e.g. salinity); quality parameters in recharge water that will improve during SAT (e.e. micropollutants), other parameters naturally occurring in groundwater (e.g. constant temperature) and biological aspects related to ponds implementation (e.g. number of bird species watched).

Authors realized that despite the large number of indicators of state that can be quantified, few of them are **key indicators for end-users** of groundwater interviewed (Aigües de Barcelona and DAMM). Specifically, DAMM restricts the parameters to the salinity reduction (linked to the membranes for water pre-treatment) and groundwater level (linked to the wells power consumption). Aigües de Barcelona agrees with the importance of groundwater level rise and specific physico-chemical parameters affecting the water production (turbidity, temperature, ammonium) and the relevance of having additional groundwater to use as input water instead of river water (savings in the conventional treatment). Then, the biophysical impacts indicators that are related the changes in state and cause the economic impacts are assessed using the key indicators for the end-users.

Finally, the impacts on the ESS are assessed. First the **biophysical impact**, impact I, and later the **economic impact**, impact II. Due to data and time constraints different valuation methods are applied; avoided costs, travel cost and revealed preferences. These valuation methods were applied in the assessment of four different ESS (1) water for drinking purposes, (2) water for non-drinking purposes, (3) educational and (4) experiential use of landscapes in different environmental settings. The benefits and the respective beneficiaries resulting of the assessment are AB with 220k€, Damm Company with 217k€, researchers with 484k€ and, finally, experiencers and viewers with 20k€. These figures derived from different kinds of benefits per each beneficiary, a more detailed explanation is done in step 8 of this document and the information is summarized in Table 33.

The aggregation of the different figures resulting from the assessment is not technically recommended due to the use of different valuation methods, recommendations on how to carry on the economic assessment are done in the cookbook and the companion document (Anzaldúa *et al*. 2016). However, while the implementation of the measure, 8M€ projected, is not economically profitable for Agència Catalana de l'Aigua (ACA), the entity responsible of the response construction; it seems that from a wider perspective, taking into account all the beneficiaries, the response will be economically and environmentally positive. To ensure the economic viability, a Cost Benefit Analysis is highly recommended in order to facilitate the aggregation of all the benefits, and accounting the whole costs.

Last but not least, a **sustainability assessment (SA)** is done. Different indicators are selected in four dimensions: social, environmental, financial and assets. While the DESSIN assessment is about the impacts on the changes of ESS, the sustainability assessment is aimed to assess the sustainability of the solution or technology. Thus, the SA is a complementary tool for decision makers that allow comparing alternative technologies. Results of the SA highlilgh the benefit of auto-depuration of the infiltrated water along the soil aquifer passage (reduction of 10^6 microbial pathogens fron the river to the extraction wells) and shows the economic effort of the investment and the operational expenditure.

In general, this report illustrates the application of the valuation methods of ecosystem services using a common methodology developed in DESSIN project, while it is a valuable document at regional scale to open the discussion about the implementation of MAR systems to increase water guarantee in a scarcity area.

PART I – STUDY DESCRIPTION

Step 0: Setting the scene

Llobregat River basin

Llobregat River is located in the North-East of Spain and has typical Mediterranean climate regime. The total length of the river is 170 Km, and the surface of the river basin is 4948 km^2. Administratively, it is located in Catalonia region, and the management is carried out by the Water Catalan Agency (ACA by its Catalan name). The river basin is characterised by irregular and heavy rain periods, followed by periods of severe droughts which occur in an interval of 8 – 10 years. Different pressures appear along the course of the river. While in the upper course it is characterised by the high quality of water and biodiversity, this worsens gradually due to anthropic activities.

Llobregat river course has been historically modified. 3 reservoirs (dams) named "*La Llosa del Cavall*" (80 Hm^3 of capacity), "*Sant Ponç*" (24 Hm^3 of capacity) and "*La Baells*" (109 Hm^3 of capacity) have a total storage capacity of 213 Hm^3 and regulate artificially the flow according to (1) water needs in the low valley area where the drinking water treatment plants (DWTP) are located and (2) meteorological alerts which indicate a need of extra storage capacity (this is called preventive discharge). As an orientation data, in Martorell, near to the Abrera DWTP has an average flow of 20.7 m^3/s.

Figure 1: Fresh water management infrastructures in the Llobregat river basin
Source: https://hacdoso.wordpress.com/ (Modified)

Several valuation studies have been conducted in the river basin. Most of them are based in the following ecosystem services provided by the Llobregat River:

- **Drinking water provision:** including the metropolitan area of Barcelona.
- **Sediment retention:** reduction of costs in sediments removal in the dams, and enlargement of their expected lifetime.
- **Energy production:** using hydropower generation.
- **Water purification:** avoiding costs of treatment in drinking water treatment plants downstream.

Table 37 summarises main scientific papers already published about valuation of ecosystem services in the Llobregat River basin. Recent studies carried out by ICRA (Catalan Water Research Institute) revealed a total of 1000 M€ per year of ecosystem services provided by the Llobregat river basin[1].

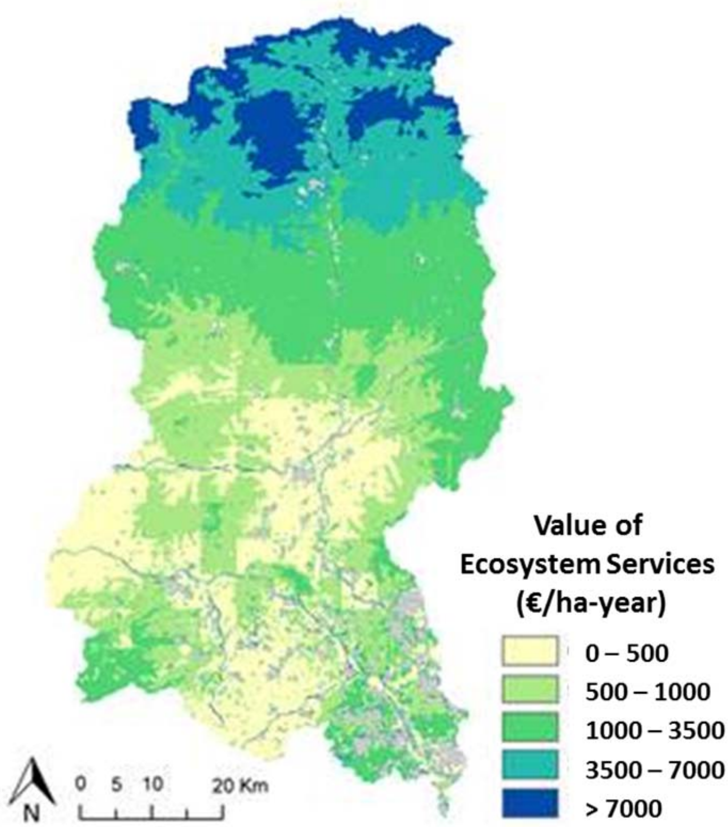

Figure 2: Valuation of ESS in the Llobregat river basin
Source: http://www.clipmedia.net/galera/ICRA

Given the practical approach of the selected mature sites of DESSIN project, the theoretical estimations of the ecosystem services provided in the Llobregat basin do not fit exactly with the aim of the mature sites exercise itself. As a result, a project carried out in the Llobregat lower valley has been selected as demonstration site. The project that application of EES methodologies is going to be carried out is about Managed Aquifer Research (MAR) techniques.

[1] http://www.clipmedia.net/galera/ICRA/Dossiers_premsa/2011/091311_memoria10/Llobregat.html

Infiltration ponds in the lower valley of Llobregat River

The economic development of the Barcelona metropolitan area caused several pressures in the the low course of the Llobregat River and the delta of the Llobregat River. Some factors that will be exposed in this report (construction of transport infrastructures, industry, urbanisation…) caused increasing loss of permeable soil due to the growing of the urban area, causing a hydrogeological direct impact on the aquifers. The available soil surface for natural infiltration has been reduced notably. This fact, joined with the continuous growth of groundwater extractions along time, caused a decrease in the groundwater availability. Saline intrusion increased, affecting urban and industrial wells inland.
The solution to these problems was no simple, and consisted in a package of measures to assure the sustainability of the area in terms of hydraulic resources. In this context, Catalan Water Agency (ACA) projected two artificial recharge systems located in two municipalities: Sant Vicenç dels Horts and Santa Coloma de Cervelló. Sant Vicenç dels Horts was constructed in 2007 and has been operated for more than 6 years, with an annual capacity of injection of 1 Mm^3. Santa Coloma de Cervelló system is projected (not yet constructed), and the annual capacity is expected to be 10 Mm^3. In this context, Sant Vicenç dels Horts system will be used as training area to test the effectiveness and positive effects on the aquifer of this technique. Results will encourage ACA to construct the new system at bigger scale, learning also from failures in Sant Vicenç dels Horts.

A combination of **both systems will be used as "mature site"** in the DESSIN project. Data available of Sant Vicenç dels Horts will allow the quantification of the impacts obtained in groundwater quality, while the big size of Santa Coloma de Cervelló will allow the quantification of the impacts in the population visiting the site, as well as an increase in groundwater resources for end users in the aquifer.

Table 1: Summary of main properties of the infiltration ponds in the Lower Valley of Llobregat

	Sant Vicenç dels Horts	Santa Coloma de Cervelló
Infiltration volume	1 Mm^3/year	10 Mm^3/year
Occupied surface (water)	1 ha	13 ha
Year of construction	2007	Not constructed
Type of infiltration water	River / Reclaimed	River / Reclaimed
Data of water quality	Yes	No (similar to Sant Vicenç)
Expected visitors / cultural services	No – closed to the public	Yes – open to the public
Expected habitats creation	Limited (small surface)	High (large surface)
Expected impact in groundwater users (drinking water operators & industries)	Limited (small surface)	High (large surface)

Sant Vicenç dels Horts infiltration system

The infiltration system of Sant Vicenç dels Horts consists of an infiltration ponds system in the right margin of Llobregat River. It was finished in 2007. This infrastructure was projected as a compensation measure for the construction of the railway in the area. The infiltration system was built by the high speed train public company ADIF (national), and its property was transfer to the Catalan water agency ACA (regional).

The system consists mainly in two ponds: settling pond of 6000 m^2 (reduction of sediments) and infiltration pond of 5600 m^2 (percolation in the aquifer). From 2008 the system has infiltrated 4 Mm^3 in the aquifer, with maximum volume infiltrated of 1.16 Mm^3 in 2011. The main objective of the system is to introduce additional freshwater into the aquifer to gain an average extra volume of 1 Mm^3/year. The operation consists in a direct intake of Llobregat river water 2 km upstream of the ponds. The catchment area is an intake channel that has to be reconstructed from time to time according to rainy periods that can destroy totally or partially the intake channel. Collected water circulates downstream by a concrete pipe of an inner diameter of 1000 mm. All the system is controlled manually by CUADLL (Association of Users of the aquifer) according to quality alerts and meteorological forecast.

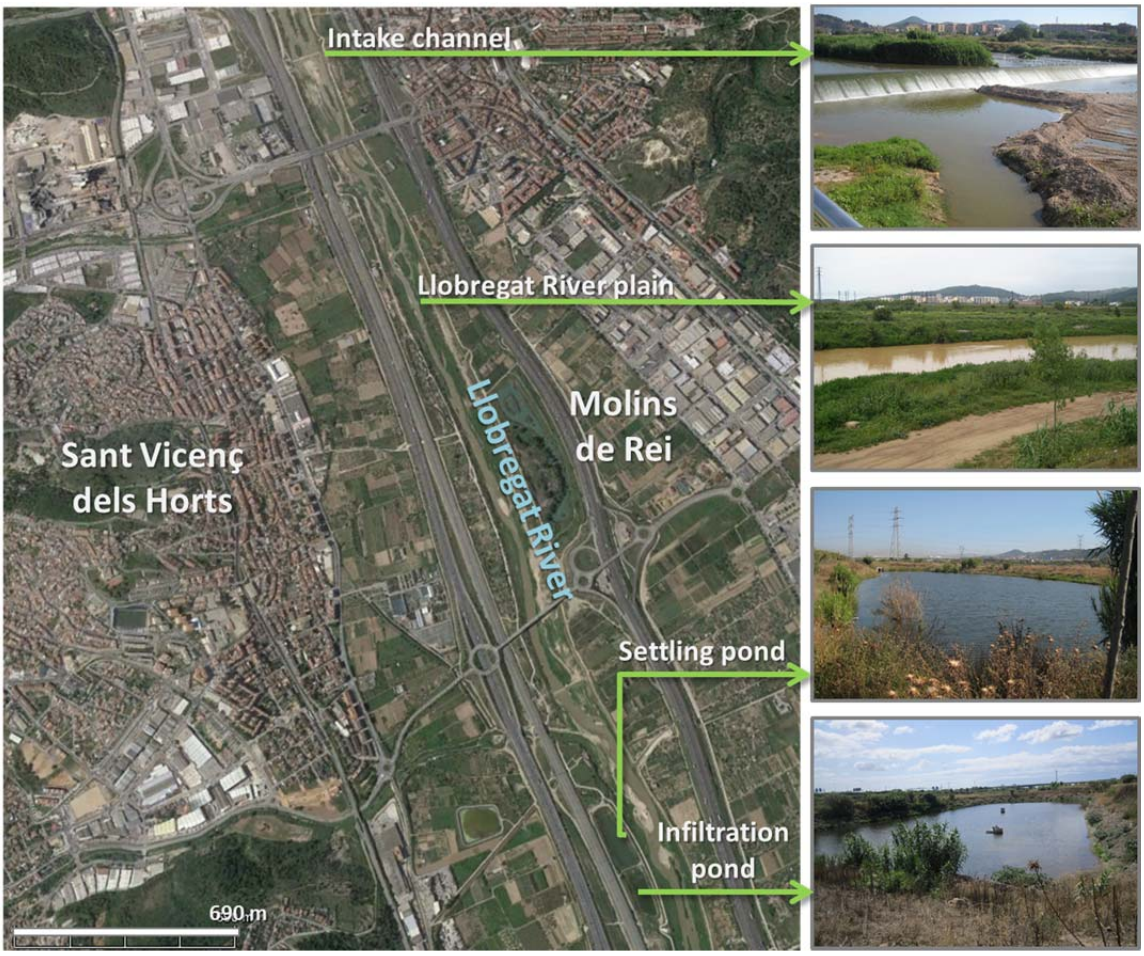

Figure 3: Location of Sant Vicenç dels Horts infiltration ponds

Previous R+D projects and PhD thesis have studied the site. The most important are listed below:

- **GABARDINE**: FP6 project which proposed Sant Vicenç dels Horts as a demonstrative site. The GABARDINE project (Groundwater Artificial recharge Based on Alternative sources of wateR: aDvanced INtegrated technologies and managEment) is a Specific Targeted Research Project, which develops innovative technologies for alternative water sources. It is undertaken in the FP6 priority "Global Change and Ecosystems ". The project implementation is being developed by a consortium of 14 partners. The consortium is co-ordinated by the University of Göttingen in Germany. Final reports and publications related to Sant Vicenç dels Horts are not reported in the website: http://cordis.europa.eu/publication/rcn/13034_en.html

- **ENSAT**: Life+ Project whose main objective was to assess the improvement of retention of emerging pollutants in the MAR system using a reactive organic layer made with vegetal compost. It has been the most complete project in improving the knowledge of the hydrogeological and hydrochemical aspects of the aquifer recharge system. Cost-effectiveness analysis of the reactive layer implementation was carried out. http://www.life-ensat.eu/

- **PREPARED:** FP7 project aiming at evaluating the preparedness of urban water facilities to deal with climate change impacts. Sant Vicenç dels Horts was proposed as a demonstrative site to evaluate the impact of high turbidity values in recharge water, and improve maintenance techniques. LCA – LCC analysis of the system and measures carried out was done. http://www.prepared-fp7.eu/

- **DEMEAU**: FP7 project that aims at assessing innovative technologies in water and wastewater sector to deal with emerging pollutants. Sant Vicenç dels Horts is one of the demonstrative sites of the project, as it was included in the LCA – LCC analysis of MAR sites. Pharmaceuticals concentrations have been also assessed, as a continuation of the results of ENSAT. The effectiveness of the reactive layer has been assessed by conducting leaching tests. http://demeau-fp7.eu/

- **MARSOL**: Water Inno-Demo project based on Managed Aquifer Recharge Techniques. Sant Vicenç dels Horts has been proposed as a test site to evaluate the importance of microorganisms in degradation of organic pollutants and biofilm formation. http://www.marsol.eu/

Main parts of the research done have been focused on the natural capacity of the aquifer passage to improve water quality along the so-called soil-aquifer treatment. Nonetheless, the positive impact of the existence of this infiltration system in the area goes beyond. The ecosystem services impacted positively by the construction and operation of this MAR facility are:

- Increase of groundwater resources in the aquifer.
- Improve water quality along aquifer passage.
- Reduction of anthropic pollutants in the aquifer (organic contaminants).
- Creation of a bird and micro fauna habitat.
- Increase of interest of local people in water resources in the Llobregat (noticeboard for runners, bikers and trekkers in the pathways). Identification of the place as "interesting point" in the area[2].
- Technical visits to the facility (study tours, project visits in workshops…).

Santa Coloma de Cervelló infiltration system

The selected location of this large infiltration system was the municipality of Santa Coloma de Cervelló (Baix Llobregat region, Barcelona), in a 13 ha of surface area placed in the right plane of Llobregat River between the river bed and the high speed train (AVE) platform, owned by ADIF (public Spanish rail company). This is an ambitious project with a total estimated cost of 8.0 million euros that will provide an extra infiltrated volume of 10 Mm^3 to the Llobregat aquifer. The construction project was presented in 2008, but it is still not constructed due to financial constraints in ACA. Nevertheless, this is one of the top priorities for the future investments 2015 – 2020.

This system has been selected as mature site in the Llobregat area due to the high impact in groundwater resources and the previous experience gathered in Sant Vicenç dels Horts (SVH) system. The SVH infiltration system works at smaller scale, infiltrating $1Mm^3$/year. It has been considered that the working scale to evaluate the ecosystem services will be Santa Coloma de Cervelló and results obtained will be directly applied by ACA to the cost-benefit analysis in their starting plan of investments in hydraulic infrastructures linked to the water cycle.

[2] http://www.parcriullobregat.cat/puntsdinteres.php

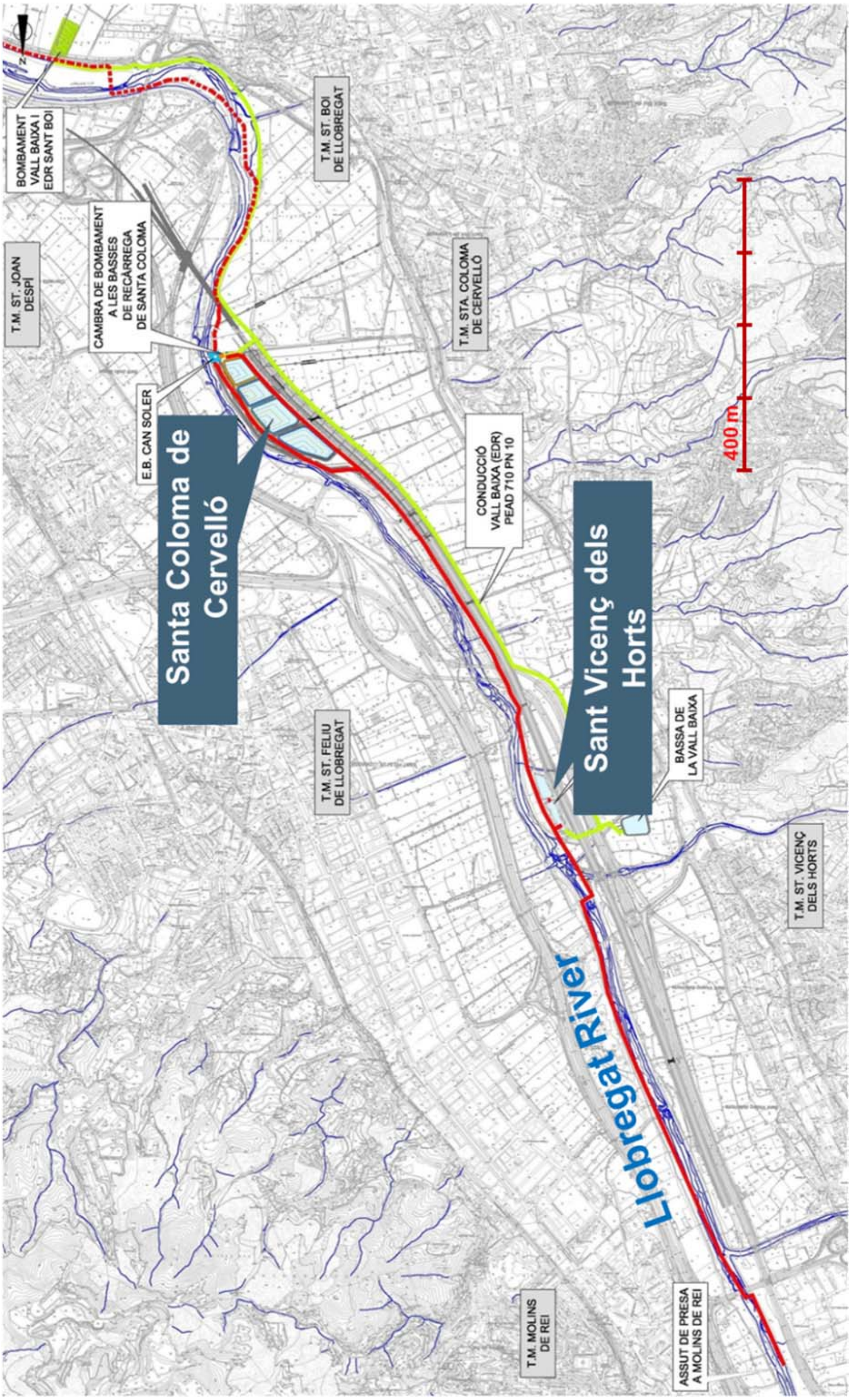

Figure 4: Location of Santa Coloma de Cervelló infiltration ponds

PART II – PROBLEM CHARACTERISATION

Step 1: Description of drivers

One of the difficulties to present the context of the infiltration ponds and the drivers and pressures which justified their construction is the geographical definition of the impacted area. The infiltration ponds (Sant Vicenç and Santa Coloma) are placed in the lower valley of the river, in the south of the Metropolitan Area of Barcelona (36 municipalities). The administrative division corresponds to The Baix Llobregat region (30 municipalities).

Metropolitan Area of Barcelona: The Metropolitan Area of Barcelona (AMB) is the public administration of the metropolitan area of Barcelona, which occupies 636 km² and is made up with 36 municipalities with more than 3.2 million inhabitants with a mean density of 5.093 inhabitants per km^2. The metropolitan area is also the nucleus of the economic activity in Catalonia, its gross domestic product (GDP) was 99.174 M€ in 2012, that is about 51% of the Catalan GDP.

Baix Llobregat region: The administrative division in Catalonia comprises 41 regions. Baix Llobregat region is constituted by 30 municipalities around the Llobregat River. Some of them are included in the Metropolitan area of Barcelona (see Figure 5):

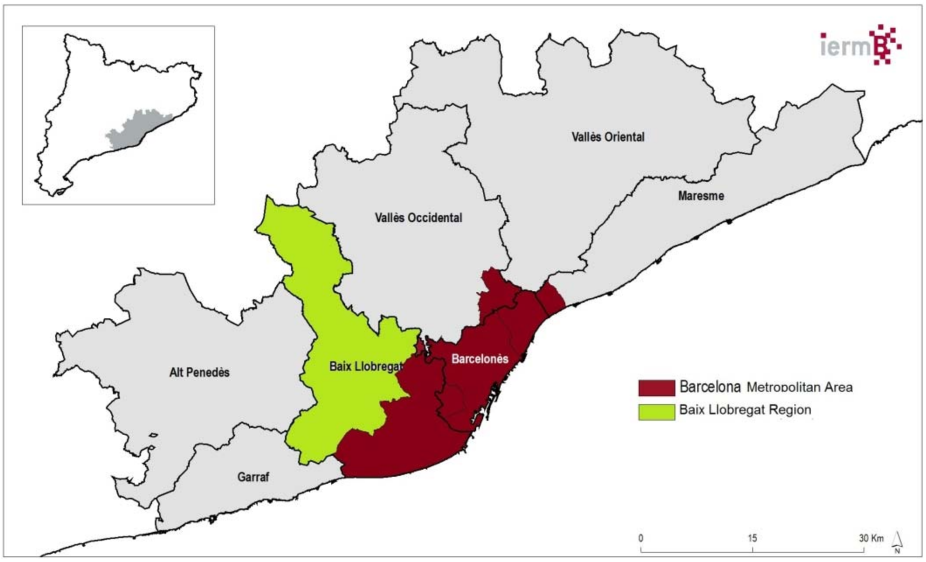

Figure 5: Administrative borders of AMB and Baix Llobregat region

Within DESSIN project, a driver is defined as a human activity that may produce an environmental effect on the ecosystem. Examples for drivers are agriculture or industry (MARS Project Terminology, 2014)[3]. In the study area of the Llobregat River two drivers were identified: industry and urban development.

DRIVER Industry: Industrial bad practices in the past: solvents and PAHs in groundwater and river. Industries increase in the metropolitan area: WWTP discharges

During the last quarter of the XIXst century the industry in Catalonia switched their location from the coastline near ports to the river courses. The aim was to find cheaper sources of energy; changing the British coal that powered the steam boilers, for the water that powered the waterwheels. The Llobregat river course, as one of the main

[3] Source: http://www.freshwaterplatform.eu/index.php/glossary.html

rivers in the area, attracted numbers of industries. This fact carried a growing urban development, which pushed the creation of cities and infrastructures along the river course.

But the river was not only used as a resource; it also became the way to get rid of the waste. An authorization for discharging into the river was not mandatory since 1985, when the national government enacted the 29/1985 Law about water. So, the industries were discharging pollutants without control. Furthermore, a unique salt mine in Europe was placed near the river course. The intensive mining activities last from 1920 to 1990.

Last decades, the industry weight in the economy of Baix Llobregat is decreasing. In 2004, the industry represented a 34.3% of the GDP against the 47.6% of 1991. Even though, the 34.3% is higher than the average weight of the industry in Catalonia region, which was about 27% in 2004. As it is shown in the Table 2 below, the main industries in the Baix Llobregat region are transport equipment, chemical and metallurgy. The impact of the discharges and pollutants of these industries are quantified in the following pressures section.

Table 2: Industrial sector GDP structure, year 2004, in percentage
Source: Caixa Catalunya, adapted from Pons i Novell (2005)

	Baix Llobregat	Catalunya
Energy, water and abstractives	2.2	12.9
Food, drinks and tobacco	9.1	11.0
Textile, leather and footwear	3.9	7.0
Wood and cork	0.9	1.4
Paper and graphic arts	9.9	8.9
Chemical	12.9	13.8
Rubber and plastics	6.3	4.9
Other minerals non metals	5.9	4.8
Metallurgy and metallic products	11.6	9.5
Machinery and mechanical equipment	7.5	6.3
Electric, electronic and optical equipment	8.4	8.5
Transport equipment	19.0	7.8
Other manufacturing industries	2.5	3.2
Industry	**100.0**	**100.0**

DRIVER Urban development: (Intensive use the land in new urbanised areas). Inhabitants increase in the metropolitan area: WWTP discharge, intensive use of the river

Along the low course of the river, Baix Llobregat region is a fast growing area in terms of population since XIXst century. As it is explained in the section before, the industrialization along the river created some population nucleus that were further developed as the cities that are near the river nowadays. In last decades, the proximity with Barcelona and the impossibility of the capital to grow caused the cities to increase the raising in population. Actually, from 1975 to 2014 the population has increased more than 50%. It causes lots of consequences in the water cycle. For first, the drinking water demand has increased as drinking water is directly related to number of inhabitants. It also means that waste water production has increased in this period, following the same relation as for drinking water; the more population, the more production. During this period, the land uses within the area has changed a lot. There is a substitution from the agricultural uses to urbanized uses, the agricultural surface has decreased in more than 3,000ha that the majority of it is becoming urban.

All in all, the result of the urbanization of the area is stressing at maximum the water resources. The water demand is increasing; the permeable surface water is decreasing; so the aquifer groundwater level is under more pressures than ever.

Table 3: Population, from 1981 to 2004, number of inhabitants
Source: Idescat, adapted from Pons i Novell (2005)

	Baix Llobregat	Catalunya	Baix Llobregat/Cat.%
1981	573,461	5,956,414	9.6
1986	583,354	5,978,638	9.8
1991	610,192	6,059,494	10.1
1996	643,419	6,090,040	10.6
2001	692,892	6,343,110	10.9
2004	741,024	6,813,319	10.9
Growth 1986/1981	1.7	0.4	
Growth 1991/1986	4.6	1.4	
Growth 1996/1991	5.4	0.5	
Growth 2001/1996	7.7	4.2	
Growth 2004/2001	6.9	7.4	
Growth 2004/1981	29.2	14.4	

Step 2: Description of pressures

This section explains the pressures identified as a result as applying the DPSIR scheme proposed by the DESSIN framework. The pressures are directly related with the drivers identified in the previous step. This relationship is shown in the Table 4. Following, an explanation per each pressure is done, as well as an identification of at least one indicator to monitor the evolution of the pressures in time, and how are they impacting in the system. In the DESSIN project is considered a pressure the direct environmental effect of the driver, such as an effect that causes a change in water flow or a change in the water chemistry (MARS project terminology, 2014)[4]. Examples are the abstraction of water for industrial processes or an increased nutrient load caused by agricultural use of fertilizers.

Table 4: Description of the drivers and pressures relationship

Drivers	Pressures
Industry	• Diffuse source: Contaminated sites/abandoned industrial sites. Groundwater pollution (solvents, PAHs, industrial pollutants).
	• Point source: Industrial waste water.
	• Abstraction: Abstraction from industry.
Urban development	• Diffuse source: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).
	• Point source: Urban waste water.
	• Abstraction: Abstraction urban development
Other	• Hydrological alteration: Reduction of permeable surface for precipitation infiltration.

[4] Source: http://www.freshwaterplatform.eu/index.php/glossary.html

PRESSURE: Contaminated sites/abandoned industrial sites. Groundwater pollution (solvents, PAHs, industrial pollutants) (Diffuse source)

Lot of industries settled in Baix Llobregat region because the strategic location of the area in terms of communication network and the access of River water. The Llobregat Basin, specifically the sub-basin of the Anoia River overpasses the quality objectives of the Water Framework Directive in the following parameters: Chromium, trichloroethylene, perchloroethylene and mercury. Map in Figure 6 illustrates how the Baix Llobregat region has been found one of the most polluted sites in Catalonia, especially by the episodes of pollution caused by heavy metals and volatile compounds.

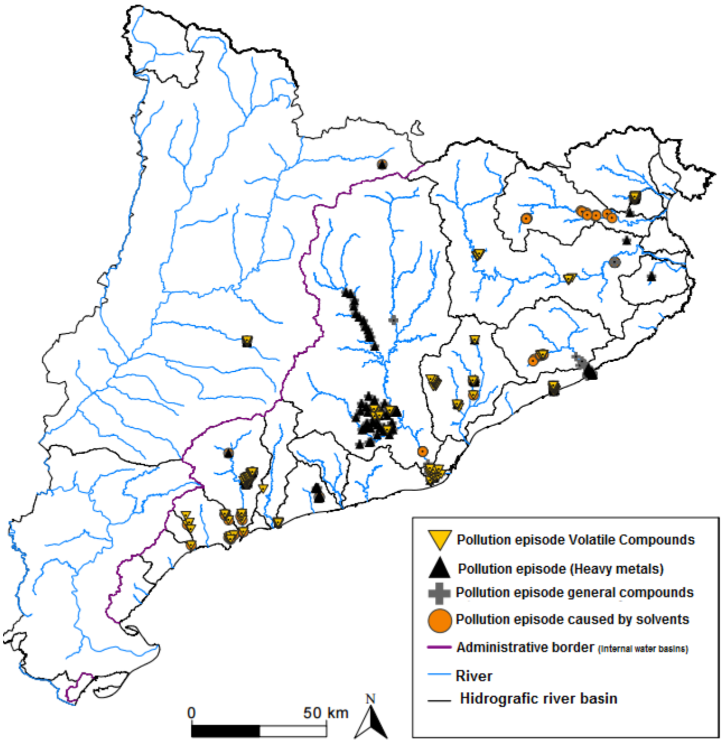

Figure 6: Location of pollution episodes in Catalonia internal water basins
Source: ACA (2005)

INDICATOR: Organic volatile compounds found in the aquifer. Selected indicator compound: Trichloroethane (chlorinated compound largely used as solvent removing grease from machined metal products, in textile processing and dyeing and in aerosols).

Indicator units: µg/L of trichloroethane
Indicator value before the implementation of infiltration ponds: 500 µg/L of trichloroethane
Expected trend once implemented the infiltration pond: reduction

PRESSURE: Industrial waste water (Point source)

River courses have historically attracted industrial activity in the surroundings. This trend can be easily viewed in Figure 7, which locates the discharge points of industrial effluents biodegradable and non-biodegradable respectively. There a high concentration of discharge points around Barcelona area. Final disposal of treated wastewater or industrial wastewater below threshold values are streams and rivers near the factories. In these sense, there were lot of industrial settlements with final disposal of waste water near the Llobregat River and its streams and creeks.

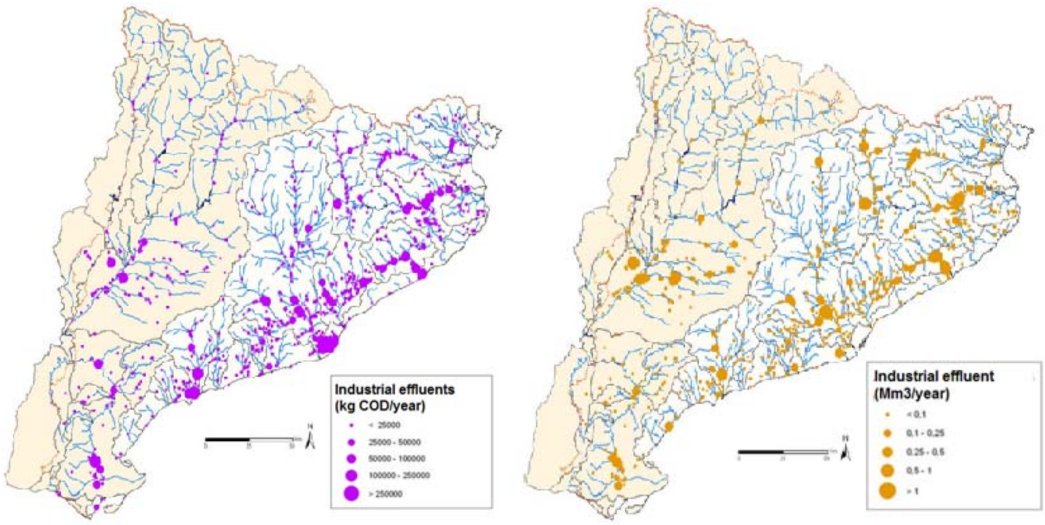

Figure 7: Spot map of industrial effluents in Catalonia
(Left) Biodegradable Industrial effluents of waste water to the environment in kg of COD per year and
(Right) Non-Biodegradable Industrial effluents of waste water to the environment in volume per year.
Source: ACA (2005)

Low Llobregat river area and Delta of Llobregat have been classified as high pressured areas by industrial effluents. ACA establishes both groundwater bodies (Llobregat aquifer and Delta aquifer) as groundwater bodies in high risk by the presence of industrial effluents. Figure 8 illustrates this classification.

INDICATOR: Amount of effluents from industries with final disposal in the Llobregat river course.

Indicator units: m^3 of industrial waste water
Indicator value before the implementation of infiltration ponds: 873.176 m^3/year
Expected trend once implemented the infiltration pond: indicator value will be not directly affected by the construction of infiltration ponds.

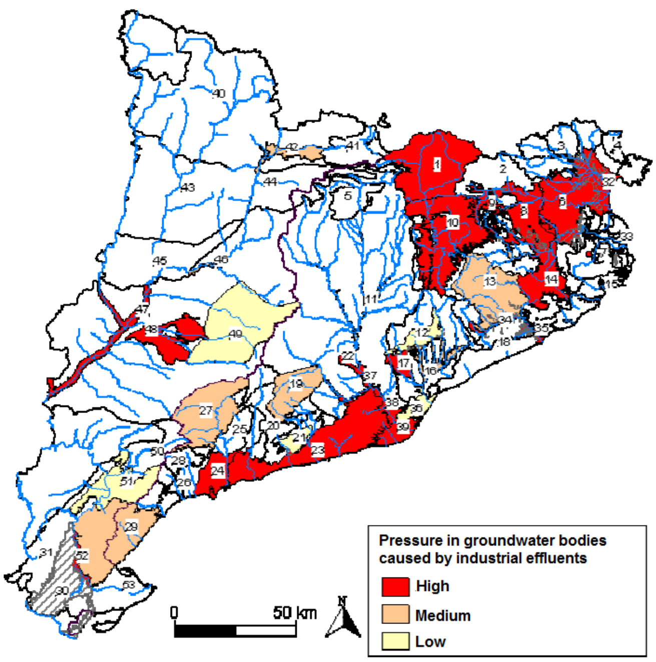

Figure 8: Map of areas with pressure in groundwater bodies caused by industrial effluents
Source: ACA

PRESSURE: Abstraction from industry (Abstraction)

The attraction of industries in the surroundings of the river course causes not only an increasing pressure in industrial waste water but an increase in water demand as an input. Moreover, water availability is one of the reasons that make river course surroundings attractive.

In Figure 9 a record of total abstractions as well as disaggregation per types of users is shown. Concretely, looking at the industrial users, a shrink between 1970 and 2010 extractions can be seen. Following a similar trend, the total amount of abstractions has gone down from 1970 to nowadays. As it is going to be explained in next sections, also a decrease in the permeable surface happened in the area during these years. It carries depletion in the groundwater level in the 1970 that last to nowadays, due to the amount of abstractions.

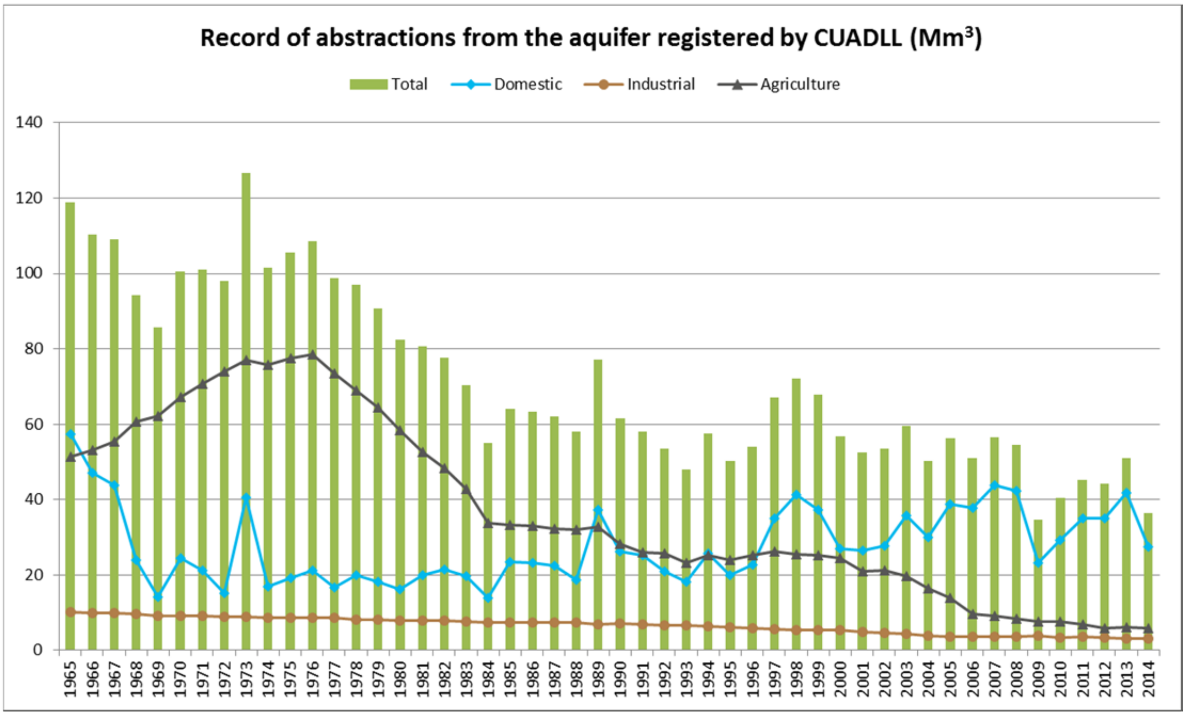

Figure 9: Record of abstractions from the aquifer registered by CUADLL
Source: CUADLL

In the end, the use of total annual volume of extractions from industries in the aquifer as an indicator is necessary to track the groundwater level in a sustainable level.

INDICATOR: Total annual volume of extractions from industries in the aquifer.

Indicator units: hm^3 of aquifer water
Indicator value before the implementation of infiltration ponds (2006): 3.66 Mm^3/year
Expected trend once implemented the infiltration pond: indicator value will be not directly affected by the construction of infiltration ponds.

This effect has a direct relation with groundwater level for industrial users and drinking water operators. Figure 10 illustrates this pressure in El Prat del Llobregat, an area representative of the effect of over extractions in the Delta area. Historical maximum of low groundwater levels was recorded in 1975. In that year, differences between minimum level and maximum level were more than 7 meters, according with the extraction needs of the factories and drinking water production operators. From 2005, the aquifer management has suffered a change of paradigm, obtaining a difference of level around 4 meters (see annual values in

Table 5).

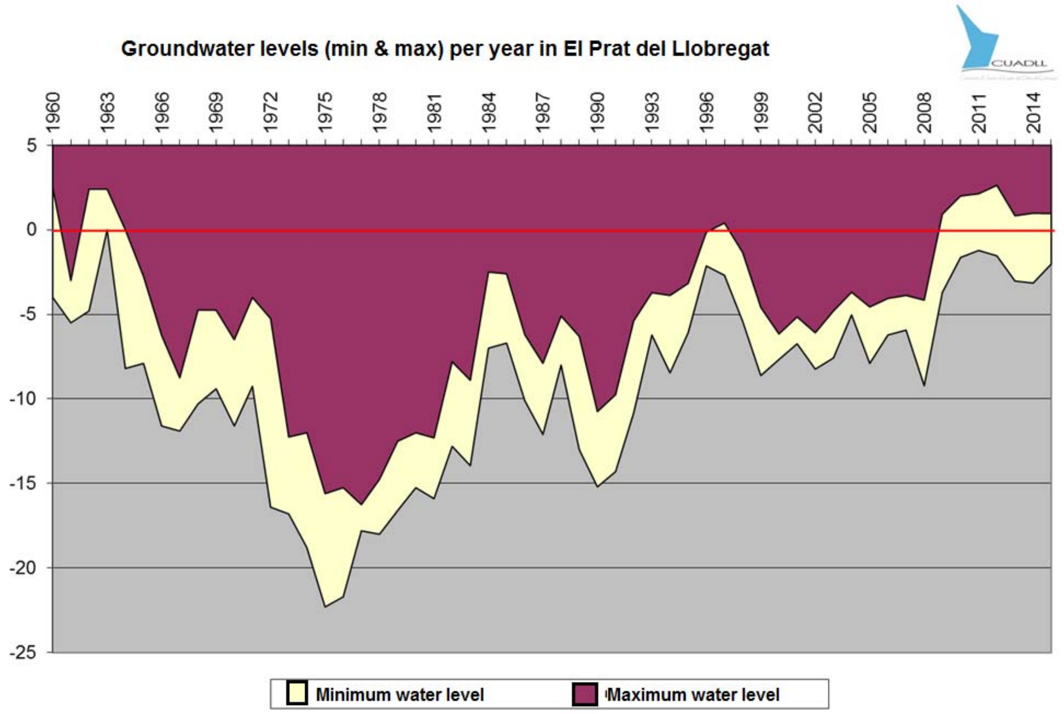

Figure 10: Groundwater levels (min& max) per year in El Prat del Llobregat

Table 5: Maximum differences in groundwater level per year

Year	Difference of level (min – max) [m]	Year	Difference of level (min – max) [m]
2005	3.34	2011	3.35
2006	2.16	2012	4.17
2007	2.05	2013	3.86
2008	5.06	2014	4.13
2009	4.62	2015	2.98
2010	3.64		

In the coastal line, this evolution of groundwater level impacts directly in salinity. Saline intrusion appears in inland wells when phreatic level is low, so sea level penetrates inland. In that sense, electrical conductivity measured in production wells can be an additional indicator of this pressure in coastal zones (Delta of Llobregat, for example). Figure 11 shows the increase of chloride concentration in mg/L in four industrial wells in the Delta aquifer of Llobregat, with a very high peak in 2009, corresponding to the drought period in Barcelona. As groundwater alteration it is one of the most relevant and direct pressures affecting the Llobregat mature site, two indicators have been designed to quality them.

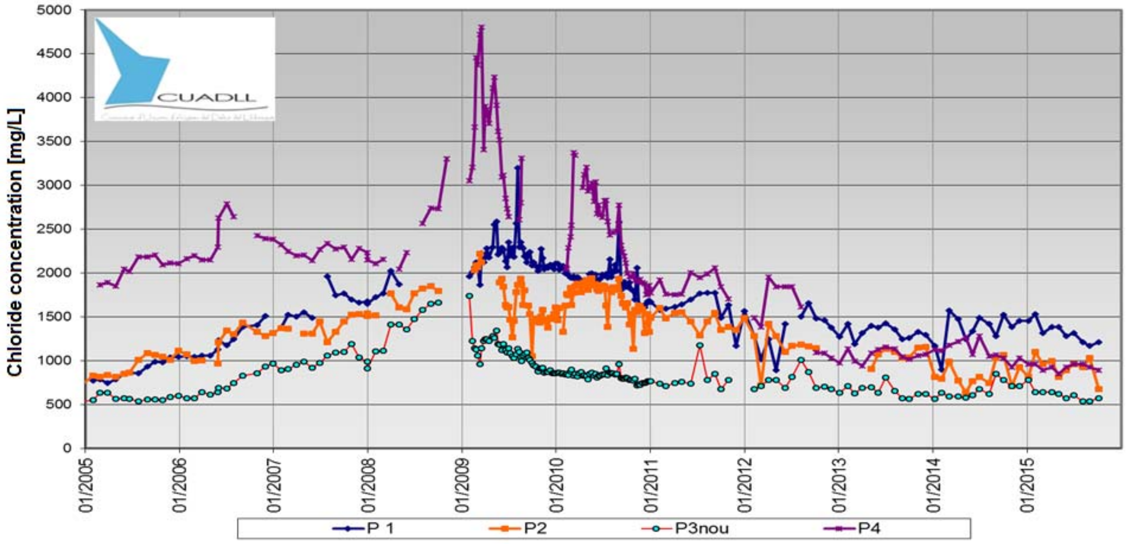

Figure 11: Chloride concentration in industrial wells
Source: CUADLL

PRESSURE: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium) (Diffuse source)

The large amount of waste water produced in heavy rain episodes affects the treatment capacity of waste water treatment plants. Sewerage networks receive large volume of waste water in a short space of time. If the rainy event is long enough, waste water is directly bypassed to the Llobregat River. This discharge has high concentrations of ammonia and low concentration of dissolved oxygen, causing a strong impact on the fauna of the river. Fortunately, the biggest WWTPs in the Barcelona Metropolitan area are discharging to the sea, avoiding the impact in the River ecosystem. Nonetheless, in Baix Llobregat region, there are some WWTP discharging directly to the Llobregat River or to one of its tributaries (streams and creeks). Table 6 lists the WWTPs in the Baix Llobregat region. Regarding the problem of the bypass of not completely treated waste water, Abrera, Martorell and Sant Feliu del Llobregat are the WWTPs which could cause higher impact in the river water quality. As an example, Table 7 presents typical values of input water in Sant Feliu.

Table 6: WWTPs in Baix Llobregat region and fate of effluent discharge

WWTP	Design Flow [m^3/day]	Equivalent inhabitants	Effluent discharge
ABRERA	34500	115000	Llobregat River
BEGUES	1200	7000	Stream
CASTELLVÍ DE RONSANES	400	1667	Stream
GAVÀ-VILADECANS	64000	384000	Mediterranean sea
LLEDONER	472	3149	Stream
MARTORELL	10500	61250	Stream
OASIS-AMETLLER	9	56	Stream
OASIS-CAN MIQUEL AMAT	60	400	Stream
OASIS-JAUME	42	280	Stream
EL PRAT LLOBREGAT	420000	2275000	Mediterranean Sea
SANT FELIU DE LLOBREGAT	64000	673333	Llobregat River

Table 7: Waste Water characterisation in the inflow of WWTP Sant Feliu del Llobregat
Source: Alcobé (2009)

Parameter	Concentration [mg/L]	Parameter	Concentration [mg/L]
Total Solids	308.1	Ammonium	36.9
BOD_5	325.5	Orthophosphate Phosphorus	5.2
Nitrate	3.7	Organic Phosphorus	1.3
Organic nitrogen	3.3	Phytoplankton Phosphorus	0
Phytoplankton nitrogen	0		

INDICATOR: Discharges of waste water not completely treated in WWTP in Baix Llobregat region.

Indicator units: number of episodes per year
Indicator value before the implementation of infiltration ponds (2006): not available information. This information is currently being required by a new Spanish regulation RD 1290/2012 for the accomplishment of the Water Framework Directive 2000/60/CE.
Expected trend once implemented the infiltration pond: the impact in this indicator of the infiltration ponds in Santa Coloma de Cervelló is not directly related.

PRESSURE: Urban waste water (Point source)

As it is pointed before, river courses have historically attracted industrial activity in the surroundings. And it carries urban growing and urban development. Due to the increase in population, an increase of waste water production occurred. It is shown in the construction of new WWTP in the area in the last years. A list of the six plants operating in the area is shown in Table 8 as well as the treatment capacity and equivalent population. In this sense, in Figure 12: Total of waste produced in Waste Water Treatment Plants in Catalan regions, is shown the Baix Llobregat region as one of the top waste producers in Catalonia with more than 50 thousand tons per year.

Table 8: Capacity of Waste Water treatment plants in El Baix Llobregat region
Source: ACA website

Municipality	Year of implementation	Treatment capacity [m3/day]	Equivalent population
Abrera	1994	34,500	115,000
Begues	2004	1,200	7,000
Gavà-Viladecans	1986	64,000	384,000
Martorell	1984	10,500	61,250
El Prat del Llobregat(*)	2002	420,000	2,275,000
Sant Feliu del Llobregat (*)	1989	64,000	373,333

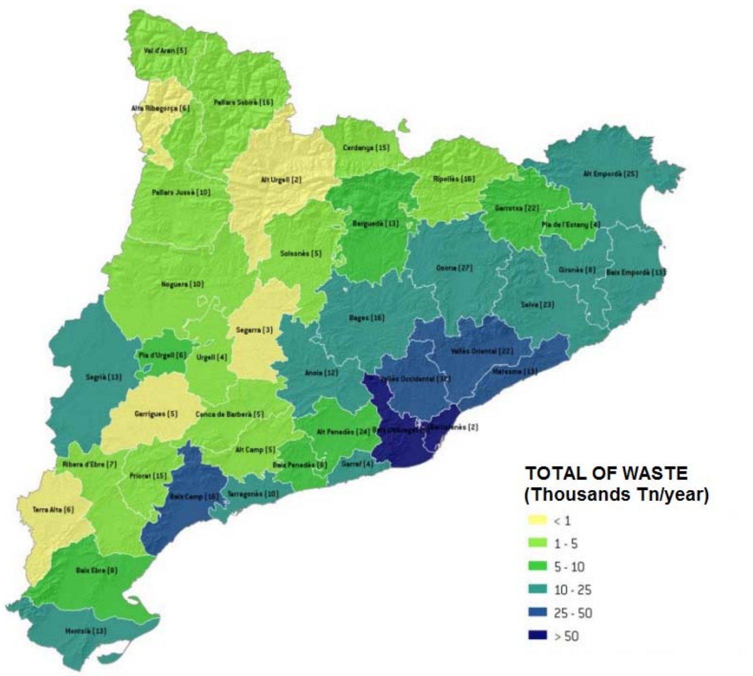

Figure 12: Total of waste produced in Waste Water Treatment Plants in Catalan regions
Source: ARC (2013)

Furthermore, the production of urban waste water is directly related with the population in the surrounding area (Mateo-Sagasta *et al*. 2015). Due to this strong relationship between urban waste water production and population, the number of inhabitants in the Baix Llobregat region is chosen as the indicator per this pressure. As it is shown in Figure 13; the increase in population in the last 40 years is about 57.5%. It is the same amount of increase of the density, due to the surface is always the same, but it is also shown in the figure to understand the level in which density is. All the data is shown in Table 36 in the Annex.

INDICATOR: Number of inhabitants in the Baix Llobregat region.

Indicator units: inhabitants (inh.)
Indicator value before the implementation of infiltration ponds: 771,516 inh.
Expected trend once implemented the infiltration pond: indicator will no change

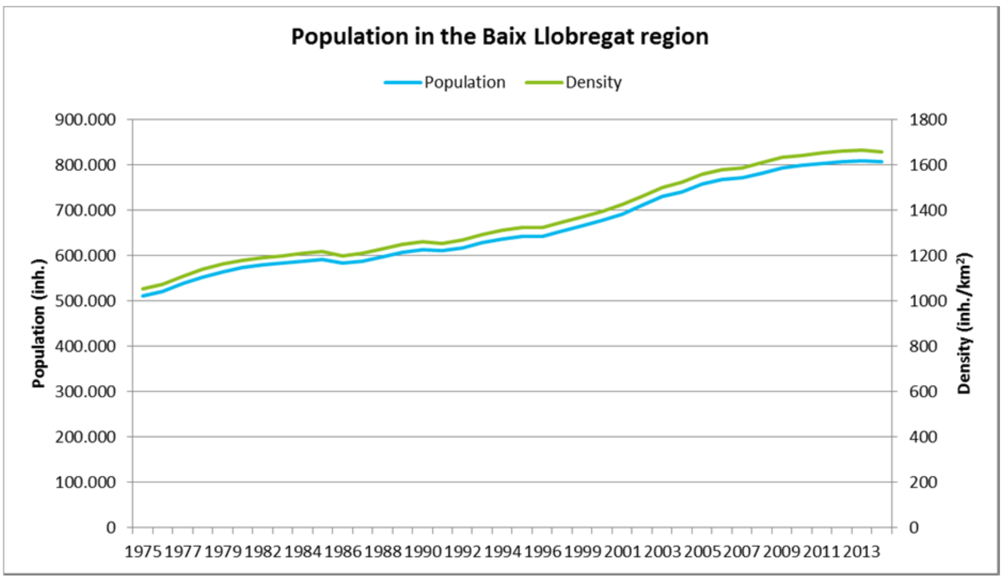

Figure 13: Population in the Baix Llobregat region
Source: Idescat

PRESSURE: Abstraction urban development (Abastraction)

Following the same scheme as per industrial uses, the urban growing along the river course not only causes an increase in the waste water production but an increase in the drinking water demand. And, in a region such as Catalonia where the stress in potable water is high, it becomes crucial to have different sources of pre-potable water to ensure the supply of drinking water.

As it is explained in the previous section, the population has grown over 50% in the last 40 years. It carries an increase in the drinking water demand that is reflected in the abstractions for supply in Figure 9.

In the figure, high variability in the abstractions for supply between years is shown. It is because it depends on different factors such as river water quality (the other source available), river water availability and precipitations. However, it is clear that the trend is growing along time.

Moreover, the substitution of the use of the aquifer water from an industrial use to a drinking use means that the quality of the aquifer water becomes more important. Also the quantity, as the continuity in the supplement of water becomes crucial.

Equally to the volume of extractions from industries, the use of total annual volume of extractions in the aquifer for supply drinking water as an indicator is necessary to track the groundwater level in a sustainable level.

INDICATOR: Total annual volume of extractions in the aquifer for supply drinking water.

Indicator units: hm^3 of aquifer water
Indicator value before the implementation of infiltration ponds (2006): 37.68 hm^3/year
Expected trend once implemented the infiltration pond: indicator will no change

PRESSURE: Hydrological alteration: Reduction of permeable surface for precipitation infiltration

As a result of the increasing population, and as another indicator of the urban development, the change in the land uses in the Baix Llobregat region is shown in Table 9. It can be seen in the figures that a substitution from agriculture soil to urbanized soil is happening. The reduction in the agricultural surface is 35% from 1993 to 2013. In the same period, the forestry surface is almost the same. It means that what is growing is the urbanized surface.
The substitution from agriculture to urbanized surface carries less permeability in the region due to tarmac is not as permeable as agriculture surface, causing less recharged volume of water in the aquifer. Adding the increasing demand of groundwater level, the result is a high stress in the aquifer.

Table 9: Change in land uses in the Baix Llobregat region.
Source: Idescat

	Forestry surface		Agriculture surface		Urbanized surface	
1993	24,187	49.86%	10,121	20.86%	14,200	29.27%
2013	24,868	51.19%	6,541	13.46%	17,172	35.35%
Difference	3%	-	-35%	-	21%	-

INDICATOR: Weight of urbanized land use in the Baix Llobregat region

Indicator units: hectares (ha)
Indicator value before the implementation of infiltration ponds (1993): 14.200 ha
Expected trend once implemented the infiltration pond: indicator will no change

PART III: RESPONSE CAPABILITIES AND POTENTIAL BENEFICIARIES

Step 3: Description of proposed measure and its capabilities

Description of the proposed measure: construction of infiltration ponds Santa Coloma

As stated in initial chapters of this document, one of the responses to deal with such complex pressures was the design and execution of infiltration ponds in the surrounding areas of the Llobregat River. Santa Coloma de Cervelló is the biggest system designed, and it is designed to allow the infiltration of three types of waters with different origins:

- Llobregat River water (surface water) (upstream)
- Desalinated water treated in the electrodialysis treatment in Sant Boi (downstream)
- Reclaimed water treated in the regeneration plant of El Prat (downstream)

Table 10 summarises main characteristics of Santa Coloma de Cervelló MAR system:

Table 10: Design parameters of infiltration system in Santa Coloma de Cervelló

Parameter	unit	Estimation
Occupied area	ha	13
Settling surface	m^2	88,600
Infiltration surface	m^2	56,300
Total infiltrated volume	Mm^3/year	10
Operation	Percentage of time (%)	75
Design flow	m^3/s	0.5
Infiltration rate	m/d or m^3/ m^2/day	1.0
Electrical Conductivity of Infiltration water	µS/cm	Surface water (Llobregat River) = variable Desalinated water (Sant Boi) = 1,200 (20ºC) Reclaimed Water (El Prat) = 3,000 20ºC
Estimated settling time	days	Surface water (Llobregat River) = 6 days Desalinated water (Sant Boi) = 0 days Reclaimed Water (El Prat) = 0 days

Capabilities and expected impact description

Main capabilities are listed below:

- Enhancing water infiltration by additional permeable surface
- Increasing groundwater resources in the aquifer
- Improving water quality via soil-aquifer treatment
- Reducing pollutants in the aquifer
- Creation of a new surface water body (aquatic ecosystem)

ANNEX of Part III of this document summarises expected impacts in drivers and pressures after its implementation. The impact evaluation of the measure will be evaluated in the following section of the document (Part IV) in detail.

Step 4: Identification of expected beneficiaries of the changes introduced by the proposed measure

The construction, maintenance and operation of the infiltration ponds will benefit multiple actors in the Llobregat area. Table 11 matches the capabilities listed with the potential beneficiaries. This matching will be very useful in Step 7 of the methodology, for the calculation of the human wellbeing indicators, as they have to be related to a final beneficiary. This table has been completed after the interviews with the most relevant stakeholders in the case study.

Table 11: Identification of beneficiaries linked to system capabilities

	Industries using groundwater	Drinking water operators	Students and Researchers	General population
Enhancing water infiltration by additional permeable surface	X	X		X
Increasing groundwater resources in the aquifer	X	X		
Improving water quality via soil-aquifer treatment		X	X	
Reducing pollutants in the aquifer	X	X		
Creation of a new surface water body (aquatic ecosystem)			X	X

PART IV: RESPONSE EVALUATION

The response evaluation is done through the quantification of impacts generated due to the response application. Impacts are the effects on ecosystem services (Impact I) and on human wellbeing (Impact II) resulting from changes in ecosystem state due to response application. In this section each ecosystem service is described, followed by the corresponding assessment of impact I and II. In addition, the state of the ecosystem is the baseline that generates the impacts either to ecosystem or the population. A further explanation of the state before and after the implementation is done in step 5 and 8a. And impacts are assessed in steps 6, 7 and 8b.

Regarding the results of the quantitative IMPACT II assessments it shall be noted, that no aggregation of the different calculated economic figures was pursued. This is due to the fact that the results partly do express figures with different "economic meanings", since different economic evaluation methods have been used for each calculation. The aggregation would need a careful interpretation and adjustment process which was out of scope of this mature case study. For additional information on this topic it shall be referred to the explanations in Step 7 of the DESSIN Cookbook and in chapter 5 of the Companion Document (Anzaldúa et al. 2016).

Step 5: Identification of parameters stablishing the "state"

Taking into account the proposed measure of the construction and equipment of an infiltration pond system, there are the list of indicators that can define the state before and after its implementation. The parameters listed below are all the indicators that can be applied to assess the changes occurring at ecosystem level by the implementation of the infiltration ponds system. Most of them have been already characterised in the infiltration system of Sant Vicenç dels Horts and the results are going to be presented in Step 8 of this section:

Table 12: State parameters identified in the infiltration ponds

Parameter	State parameters
Physical parameters related to water quantity (before / after the implementation of the system)	Infiltration area
	Infiltration capacity – permeability of the soil
	Groundwater level NOTE: it can be measured in several observation points of the aquifer, including the saturated zone under infiltration system itself. For the evaluation of the impact of the measure, it will be especially important to evaluate it in the location of pumping wells of the users of groundwater.
	Volume of groundwater replenishment by surface infiltration NOTE: this parameter can be globally considered by the local managers of groundwater resources.
Quality parameters in native groundwater (before / after the implementation of the system)	Natural attenuation: the presence of an additional source of water in the water balance will mean the natural attenuation by mixing infiltration water and groundwater. This effect will be applied to salinity and chlorinated compounds to determine the state before and after.
	Electrical conductivity / Salinity NOTE: it can be measured in several observation points of the aquifer, including the saturated zone under infiltration system itself. For the evaluation of the impact of the measure, it will be especially important to evaluate it in the location of pumping wells of the users of groundwater.
	Chlorinated compounds in the aquifer
Quality parameters in	Nitrate concentration

recharge water that improve during Soil-Aquifer-Treatment	Organic content (Dissolved organic carbon)
	Micropollutants (pharmaceuticals, pesticides…)
Other parameters naturally occurring in groundwater	Ammonium concentration
	Temperature
	Turbidity
Biological aspects related to ponds implementation	Number of bird species watched in the area
	Volume of surface water available for amphibians and aquatic species

Step 6: Selection of biophysical indicators (defined as impact I)

Impact I measures the change of biophysical indicators. These indicators are part of the list of the parameters defining state in the previous Step 5. In fact, Table 13 describes the relation between state parameters and impact I indicators.

Table 13: Link between state parameters and impact I

Parameter	State parameters	Impact I indicator
Physical parameters related to water quantity (before / after the implementation of the system)	Infiltration area	Area available able to be actively infiltrating water during managed aquifer recharge [m^2]
	Infiltration capacity – permeability of the soil	Infiltration rate [$m^3/m^2/d$]
	Groundwater level	Increase of groundwater level in the extraction area of the groundwater user (for drinking and non-drinking purposes) [m]
	Volume of groundwater replenishment by surface infiltration	Additional amount per year in groundwater reservoir provided by the infiltration system [Mm^3/year]
Quality parameters in native groundwater (before / after the implementation of the system)	Natural attenuation	Percentage of mixing ratio in certain observation Wells according to distance and travel time
	Electrical conductivity / Salinity	Reduction in groundwater salinity in the extraction area of the groundwater user (for drinking and non-drinking purposes) [µS/cm]
	Chlorinated compounds in the aquifer	Reduction of selected chlorinated compounds of concern for drinking water [µg/L]
Quality parameters in recharge water that improve during Soil-Aquifer-Treatment	Nitrate concentration	Reduction of nitrate concentration along the unsaturated zone passage [mg/L]
	Organic content (Dissolved organic carbon)	Reduction of nitrate concentration along the unsaturated zone passage [mg/L]
	Micropollutants (Pharmaceuticals, pesticides…)	Percentage of reduction of micropollutants in infiltration process (average value according to their type) [% elimination]

Other parameters naturally occurring in groundwater	Ammonium concentration	Difference between ammonium concentration in groundwater and ammonium concentration in river water taking into account seasonal variations in the river [µg/L]
	Temperature	Difference between temperature in groundwater and temperature river water taking into account seasonal variations in the river [°C]]
	Turbidity	Difference between turbidity values in river water and groundwater (extreme values and average values) [NTU]
Biological aspects related to ponds implementation	Number of bird species watched in the area	Number of species watched related to wetlands and surface water [list]
	Volume of surface water available for amphibians and aquatic species	Additional volume of surface water considering the construction of the infiltration system in Santa Coloma [m^3]

Step 7: Selection of human wellbeing indicators (defined as impact II)

Impact II measures the change of human wellbeing after the implementation of the proposed measure. To this end, end users have been identified the following ESS described in Table 14. As shown in the table below, there are to type of uses, new uses due to the creation of ponds infiltration system and improved uses. Adding both, the impact II is obtained per each beneficiary.

Table 14: Definition of beneficiaries and correspondants Impact II

Beneficiaries	Impact II	
Drinking Water Treatment Plant Operators. AB example.	Improved ESS.	Energy cost for pumping.
		Energy cost for membranes system.
	Created ESS.	Breakdowns cost.
		Energy cost for pumping.
		Water treatment.
		Maintenance.
Industrial Processors. DAMM example.	Improved ESS.	Energy cost for pumping.
		Energy cost for membranes system.
		Membranes purchasing cost.
Researchers.	Created ESS.	Research studies value.
		PhDs conducted at the ponds value.
		Technical visits value.
Experiencers and viewers.	Created ESS	Visitors' value.

Step 8(a): Quantification of state level before and after the implementation of infiltration ponds system

Infiltration area (before/after)

The total surface occupied by Santa Coloma de Cervelló recharge system is around 13 ha. The surface includes settling ponds, infiltration ponds, paths and auxiliary zones (services, etc…). This indicator is quantified in 56300 m^2 of infiltration available.

Santa Coloma de Cervelló infiltration system provides **56,300 m^2** of new infiltration area.

Infiltration capacity – permeability of the soil (before/after)

The implementation of Santa Coloma de Cervelló system will allow the maximisation of infiltration rate, as the place has been selected according to preliminary studies (boreholes and numerical modelling) to determine the optimum infiltration rate. Taking into account the experience gained in the system located in Sant Vicenç dels Horts, an average infiltration rate of $1m^3/m^2$/day is expected.

Santa Coloma de Cervelló infiltration system provides an infiltration capacity of **$1m^3/m^2$/day**.

Groundwater level (before/after)

One of the direct effects of the implementation of the infiltration ponds in Santa Coloma de Cervelló is the increase of groundwater level in the surroundings of the infiltration system. The quantification of the state before and after the implementation of the ponds is not easy, as the reference values vary according to irregular regime of precipitation. For the standardisation of the calculations of the effect of the aquifer replenishment, CUADLL developed a scenario using the numerical model for the low Valley and Delta of Llobregat aquifer. The scenario modelled consisted in a constant recharge of surface water in the aquifer, having an annual volume recharged of 10 Mm^3. Figure 14 shows the relative increase of groundwater level calculated.

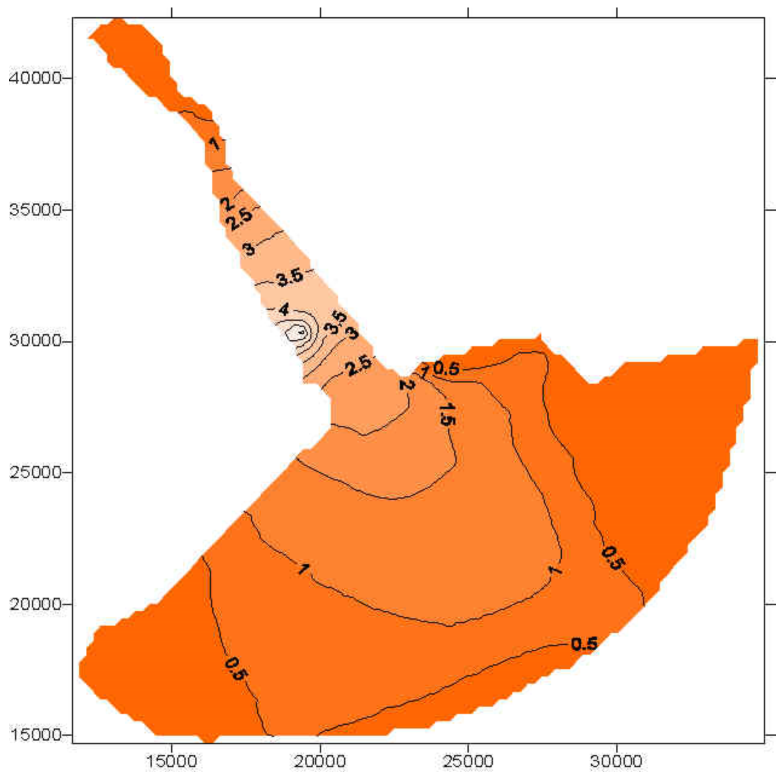

Figure 14: increase in groundwater level (modelled) after the implementation of SCC system

NOTE: lines represent the relative increase in groundwater level (in meters) caused by infiltration of additional 10 Mm^3/year in Santa Coloma de Cervelló. Source: CUADLL.

Santa Coloma de Cervelló infiltration system generates an increase in groundwater level variable depending on (i) the distance (ii) the direction of flow and (iii) hydrogeological parameters of the aquifer, but in general the model predicts a **maximum of 4-5 meters** increase of groundwater level in the surroundings and a **measurable effect up to 0.5 meters** in the major part of the Lower Valley aquifer and Llobregat Delta aquifer.

Volume of groundwater replenishment by surface infiltration (before/after)

Volume of groundwater replenishment has been established in 10 Mm^3, which will be added as input in the groundwater balance in the aquifer. This volume could vary depending on the operational regime of the system.

Santa Coloma de Cervelló infiltration system provides additional groundwater input of **10 Mm^3/year**.

Natural attenuation (before/after)

Infiltration water will act as an additional volume of water that will be naturally mixed with native groundwater circulating in the aquifer (Figure 15 represents the concept of natural attenuation). As most of the parameters of state in the aquifer, the degree of natural attenuation achieved will depend on the location of the observation well (distance, travel time, hydrogeological properties, and preferential paths among others). A rough estimation of the natural attenuation in Santa Coloma can be given (see Table 15). This information is key to quantify the local benefits of natural attenuation of hazardous pollutants (chlorinated solvents, for instance) in abstraction wells located near the infiltration facility.

Table 15: Natural attenuation depending on observation wells

Observation well	Total depth [m]	Filter screen depth [m below surface]	Distance to infiltration pond [m]	Approximate travel time or recharged water [days]	Proportion of infiltrated water (conservative tracer test)*
BSV-8.1	16.0	13-15	0*	N.A.	57%
BSV-8.3	10.0	7 - 9	0*	4	88%
BSV-5	21.5	5-23	10	6	98%
BSV-9	26.6	9.5 – 24.4	100	13	96%
BSV-10	22.5	6-20	200	17	98%

(*) zero distance means that observation well BSV-8.1 and BSV-8.3 are located inside the infiltration pond

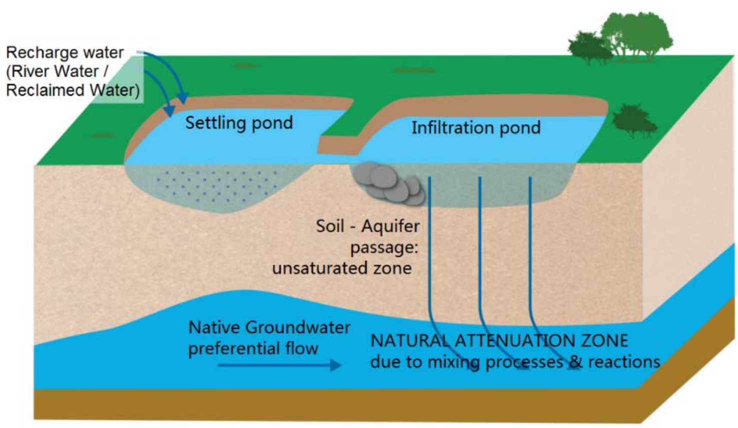

Figure 15: Illustration of natural attenuation taking into accoung groundwater flow

Natural attenuation depends on the location of the observation well, but in general, attenuations **between 90% and 98%** are expected in the surroundings downstream of the infiltration system (distance of 200 meters). In deep, the **natural attenuation can be limited to 60% below the pond**. Long distances attenuations have not been assessed[5].

Electrical conductivity / Salinity (before / after)

Salinity in the Llobregat aquifer is very variable depending on the distance to the sea and depending of the extraction regime. In fact, in 2008 the hydraulic barrier against sea water intrusion was started, and the operation continued until 2011, where the hydraulic barrier injection was stopped due to financial restrictions. Moreover, the drought periods without rain make the aquifer more vulnerable to saline intrusion. Natural recharge decreases, while extraction regime continues with constant or at least independent regimes of operation. This disequilibrium causes groundwater intrusion locally, where extraction cones pull along brine water. To calculate salinity reduction caused by increase of groundwater replenishment using managed aquifer recharge, we can do the comparison between native groundwater before infiltration and infiltration water, as electrical conductivity is a conservative parameter.
Locally, as native groundwater has less salinity than Llobregat river water, there is an increase in salinity. There are 2 parameters that provide similar information:

- Electrical conductivity: measured in micoSiemens/cm =[µS/cm]
- Chloride concentration: measured in milligrams of chloride per litre = [mg Cl^-/L]

Table 16: Salinity values of native groundwater and influence of aquifer recharge

	Electrical Conductivity	Chloride concentration
Average salinity in the Llobregat river	1,136 µS/cm (SVH) 1,260 µS/cm (ETAP SJD)	230 -270 mg/L (SVH) 230 v (ETAP SJD)
Average salinity in reclaimed water (Tertiary treatment)	2,140 µS/cm	-
Average salinity in native groundwater in Santa Coloma de Cervelló *(same values than in Sant Vicenç dels Horts)*	1,330 µS/cm	200 mg/L
Average salinity in native groundwater AB extraction wells *(constant value not affected by sea water intrusion – located inland)*	1,850 µS/cm	270 mg/L
Average salinity in native groundwater DAMM extraction wells *SCENARIO 1: drought period – extreme values*	10,000 µS/cm	-
Average salinity in native groundwater DAMM extraction wells *SCENARIO 1: wet period – extreme values (similar to MAR in operation)*	6,500 µS/cm	-

Salinity of native groundwater and Infiltration water is very similar, around **1100 – 1300 µS/cm**. The impact of the implementation of Santa Coloma de Cervelló Infiltration system will have low impact in **Aigües de Barcelona extration wells (potential reduction from 1850 µS/cm to 1300 µS/cm)**. Other groundwater users located downstream and affected by seawater intrusion (as the DAMM factory with peaks of 10,000 µS/cm) will find a hight impact in their salinity levels, reaching **values around 6000 – 7000 µS/cm**. These users will notice the reduction of salinity in their extraction wells due to (i) natural attenuation (not very relevant) and (ii) in increasing of piezometric level and displacement of seawater intrusion.

[5] CUADLL developed the numerical model for the assessment of groundwater level increase. Using conservative transport, a simulation of natural attenuation could be provided if neeed.

Chlorinated compounds in the aquifer (before / after)

This document described the presence of organic solvents in groundwater due to industry bad practices. Figure 6 stablishes the locations where pollution episodes have been detected, most of them located in the Llobregat lower valley. Trichloroethane has been found a good indicator (see this compound in tables as 1.1.2 Trichloroethane). The quantification of this pressure has been characterised around 500 µg/L of Trichloroethane, but locally they has been found in peaks of 700 – 900 µg/L. Specifically, experience performed in Sant Vicenç dels Horts recharge system, demonstrated that the infiltration plume has an attenuation factor of almost 100% during a continuous recharge period.

Taking into account the model of flow and the natural attenuation in Sant Vicenç dels Horts, Figure 16 and Figure 17 represents 1.1.2 Trichloroethane obtained in same period of time (and same sampling campaign from C1 to C19) along 2011 and 2012. While BSV-1 (located upstream) maintain 1.1.2 Trichloroethane concentrations between 200 and 700 µg/L before and after the recharge period, BSV-8.1 (located inside the infiltration pond) shows a rapid decrease in the concentration of this compound due to the natural attenuation. Obviously, the 1.1.2 Trichloroethane is not naturally found in river water nor reclaimed water. The evidence of reduction

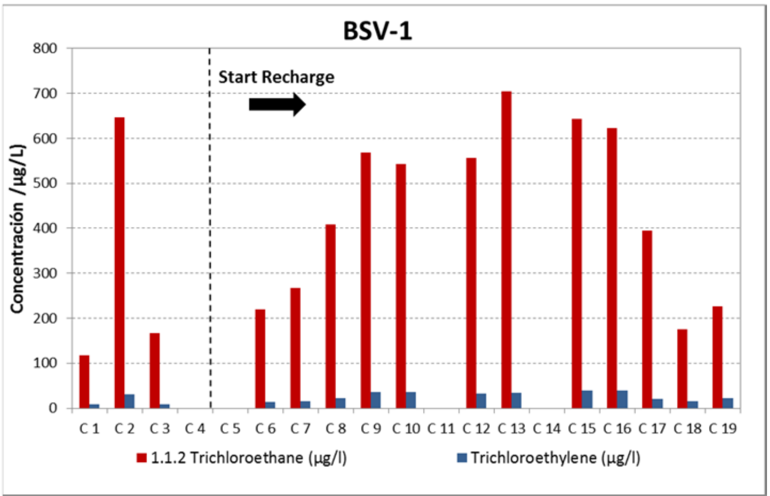

Figure 16: 1.1.2 Trichloroethane in groundwater not influenced by recharge (before and after)
NOTE: BSV-1 is an observation well located upstream the infiltration system of SVH and used as control point of native groundwater conditions during recharge periods.

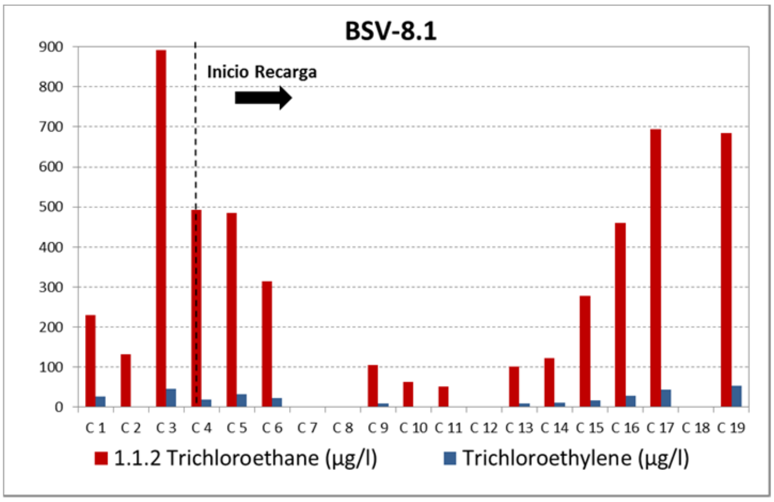

Figure 17: 1.1.2 Trichloroethane in groundwater influenced by rechage (before and after)
NOTE: BSV-8.1 is an observation well located in the infiltration pond of SVH.

Chorinated compounds in the aquifer are related with buried waste from bad practices in the past. Chlorinated solvents are not present naturaly in Infiltration water (river water or reclaimed water). The promotion of aquifer replenisment using infiltration ponds could reduce the concentration around the sistem from peaks of **700 – 900 µg/L to below the detection limit**.

Nitrate concentration (before / after)

Nitrate concentration in the aquifer is not a pollutant of concern. Average concentration in infiltration water is around 6 mg/L, with peaks of 10-12 mg/L of nitrate, while nitrate concentration in the aquifer varies enormously depending on the zone. In the observation network of Sant Vicenç dels Horts, nitrate concentration varies from 5 to 17 mg/L, with an average concentration around 8 mg/L

Baix Llobregat region is not classified as vulnerable area of nitrates (up to 50 mg/L). The vulnerable areas in Catalonia are located mainly in the North, and directly related to farming. Nitrate concentration evolution in the aquifer is unknown. There are no vulnerable zones identified (> 50 mg/L). As nitrate is not a conservative compound, it is difficult to predict the evolution. There are not simulations about that. The reduction of nitrate concentration in groundwater is not a key issue in the area for any of the groundwater users that have been surveyed.

In the surroundings of the infiltration pond, nitrate concentration (8mg/L) is almost the same than in infiltration water (12 mg/L), so a priori **no changes in nitrate concentration are expected**.

Organic content (Dissolved Organic carbon) (before / after)

Organic content in infiltration water is around 3 – 4 mg/L of dissolved organic carbon, corresponding to the same concentration of the raw Llobregat river water in the water intake for the wastewater treatment plant. Settling ponds have not any effect in the concentration of DOC before infiltration. Due to soil-aquifer processes, organic carbon is being degraded by adsorption and biodegradation processes. Thus, despite river water has an average concentration of 3-4 mg/L, groundwater is characterised by DOC values between 1.0 and 1.5 mg/L. The effect of having the infiltration ponds in operations leads to faster this process, changing infiltration water composition from 3-4 mg/L to 1-1.5 mg/L.

With the infiltration ponds in operation, recharge water will reduce the organic content, passing **from 3-4 mg/L to 1-1.5 mg/L.**

Micropollutants (pharmaceuticals, pesticides…) (before / after)

Micropollutants include a broad list of substances almost infinite. There are evidences of the potential removal of emerging pollutants as pharmaceuticals, pesticides and personal care products along the infiltration process, including unsaturated zone and saturated zone. The effectiveness of the removal rates depends on multiple factors: initial concentration, DOC content in water, temperature, redox conditions and of course, travel time. Studying the same system with identical conditions, the removal rates of emerging pollutants have been quantified from 0% to 100% depending on their molecular weight, polar behaviour, specific chemical groups, etc. this is a field under exploration. In the case of Sant Vicenç dels Horts, there are insights based in several experiments about the removal of some pharmaceuticals, pesticides and hormones along soil-aquifer passage. Moreover, the infiltration pond of Sant Vicenç dels Horts demonstrated the feasibility of increase micropollutants removal using an organic layer of vegetal compost installed in the bottom of the infiltration pond. Figure 18 and Figure 19 illustrates examples of differences in elimination along the infiltration system of Sant Vicenç dels Horts (at laboratory and field scale).

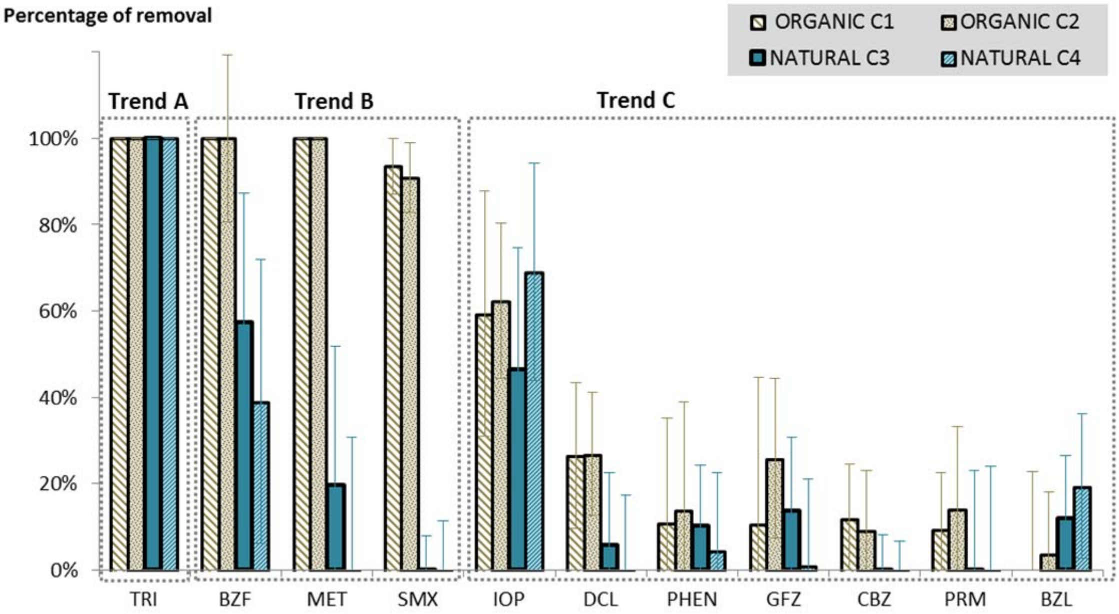

Figure 18: Trends of micropollutants removal in Llobregat infiltration system (laboratory results)

NOTE: TRI = Trimethoprim; BZF = Bezafibrate; MET = Metrprolol; SMX = Sulfamethoxazole; IOP = Iopromide; DCL = Diclofenac; PHEN = Phenazole; GFZ = Gemfibrozil; CABZ = Carbamazepine; PRM = Primidone; BZL = 1-H Benzotriazole. Trend A, Trend B and Trend C correspond to the classification of different behaviours found in emerging pollutants according DEMEAU project classification (http://demeau-fp7.eu/)

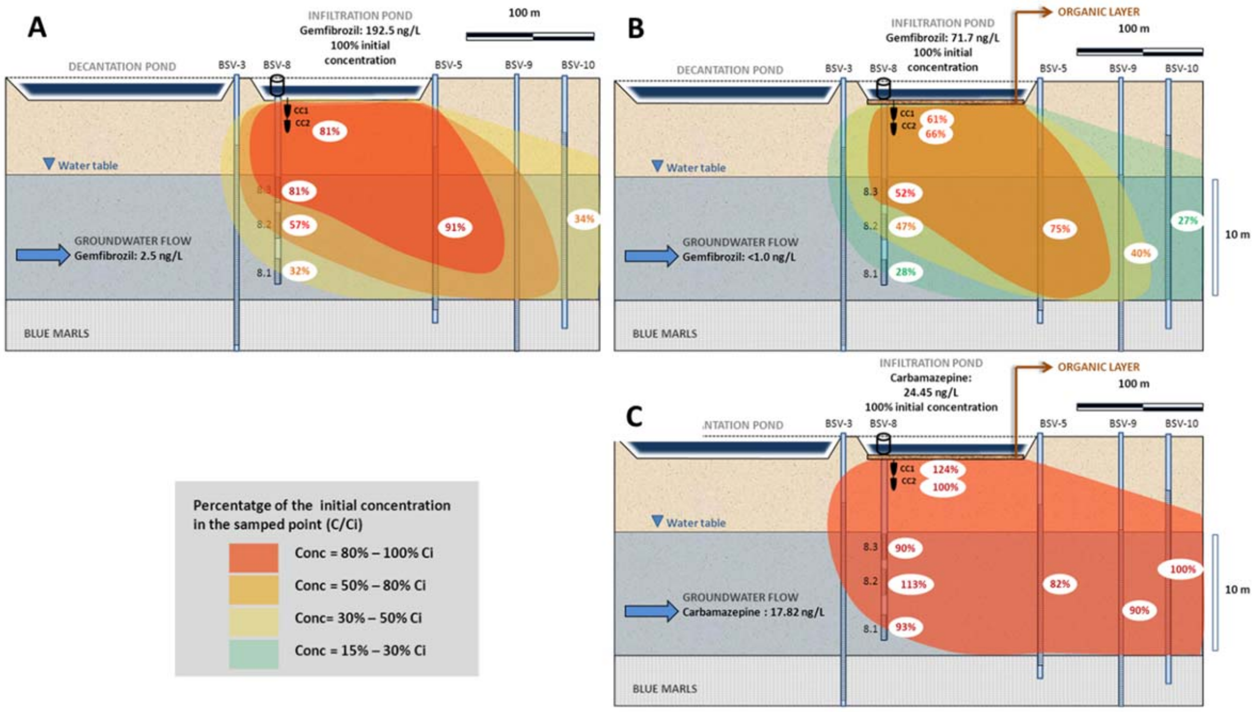

Figure 19: Trends of micropollutants removal in Llobregat infiltration system (field results)

Micropollutants are commonly present in Llobregat river water and reclaimed water at very low concentrations (ng/L to µg/L). The infiltration process along unsaturated and saturated zone has been proved to be an **effective technique for the removal of some micropollutants**. These substances are not naturally present in the aquifer.

Ammonium concentration (before / after)

Normally, ammonium concentration in the aquifer is below detection limit. River water can present peaks of ammonium, especially in winter, when the performance of WWTP is not totally completed. Ammonium is not a conservative compound, which means than an additional entrance of ammonium via infiltration could react depending on the redox conditions, presence of organic matter and total nitrogen in the aquifer.

Regarding the comparison between ammonium concentration in river water and groundwater as fresh water resource for drinking water production, low ammonium concentration in groundwater is one of the most valuable parameters of this input water. It is going to be taken into consideration in the impact I and impact II evaluation for drinking water operators.

Ammonium is not present in groundwater. River water can have peaks of ammonium, but this will be a control parameter to stop their operation. The implementation of the infiltration ponds is not expected to increase ammonium concentration in the aquifer, as it is transformed.

Temperature (before / after)

Groundwater in Llobregat aquifer is around 18ºC all the year (winter and summer). The infiltration of river water with a higher or lower temperature in the infiltration system of Sant Vicenç dels Horts is not going to affect aquifer temperature in general (only very locally). Infiltration water temperature will evolve to groundwater temperature according heat transfer laws.

Regarding the comparison between temperature in river water and groundwater as fresh water resource for drinking water production, constant temperature of groundwater is one of the most valuable parameters of this input water. It is going to be taken into consideration in the impact I and impact II evaluation for drinking water operators.

Temperature of groundwater is constant along the year **(18ºC). Temperature will remain constant** after the implementation of infiltration system.

Turbidity (before / after)

Turbidity of groundwater is normally below 5 NTU. Infiltration water is higher (5 to 50 NTU have been the range of values of turbidity of infiltration water in Sant Vicenç dels Horts. Fine particles are retained in a thin surface layer that will be periodically cleaned. It is not expected to have an increase in groundwater turbidity due to infiltration water.

Regarding the comparison between turbidity in river water and groundwater as fresh water resource for drinking water production, low turbidity of groundwater is one of the most valuable parameters of this input water. It is going to be taken into consideration in the impact I and impact II evaluation for drinking water operators.

Turbidity in groundwater is very low (less than 5 NTU). The implementation and operation of infiltration ponds will not bring additional turbidity to groundwater, as the settling pond will eliminate most of turbidity and top layer of the pond will act as a filter.

Number of bird species watched in the area (before / after)

The construction of the large system in Santa Coloma de Cervelló will attract numerous bird species that have been already identified in smaller systems (Sant Vicenç dels Horts system and Castellbisbal system). The amount of species is very difficult to be estimated, so a list of the bird species identified in the infiltration ponds upstream is provided in Annex IV: List of bird species identified in SVH infiltration system, of this document. There is more information available, as the birds in the natural wetlands of the Delta del Llobregat, but this comparison would overestimate the attraction effect of Santa Coloma de Cervelló.

52 bird species already identified in Sant Vicenç and Castellbisbal infiltration system could be watched in the infiltration system of Santa Coloma de Cervelló.

Volume of surface water available for amphibians and aquatic species (before / after)

With the implementation and normal activity of the settling and infiltration ponds, there will be a new surface water area near to the river able to be colonized by amphibians and aquatic species. The settling surface is about 86,600 m^2, while infiltration surface is 56,300 m^2. Taking into account an average of 75 cm of water column, the new volume of water available will be 107,000 m^3.

Total new volume available of surface water is estimated in **107,000 m^3**, corresponding to water in the settling ponds and infiltration ponds.

Percentage of days with surface water available (before / after)

Infiltration system is a nature-based solution using groundwater replenishment to alternative water source to increase water availability. The system operation will depend on climatic conditions (flooding episodes can damage partially the facilities), and maintenance tasks. Based on previous experiences in Sant Vicenç dels Horts, is feasible to stablish and operation percentage of 75% of days, when settling ponds and infiltration ponds will have surface water inside. It is expected than in this situation, infiltration system will be more attractive to visitors and population in the surroundings.

The percentage of days with surface water available in the settling ponds and/or infiltration ponds is estimated around **75%.**

Step 8(b): Quantification of changes impact I and impact II

Impact I and Impact II have been evaluated from the perspective of the end users. To this end, following information in this section is going to be presented in sub-sections, taking into account an example of beneficiary.

Assessment of impact I & II for drinking water operators: Aigües de Barcelona

Two drinking operators are extracting water for drinking from the aquifer: Aigües de Barcelona and Aigües del Prat. The former uses the aquifer water as a complementary source of the river water. The latter only uses the aquifer water to supply drinking water to the whole city of el Prat, about 60,000 inhabitants. For the impact I & II Aigües de Barcelona is going to be assessed due to more data is available.
Aigües de Barcelona (AB) extracted 114 Mm^3 since 2009. But the extractions in case of AB are very variable. It depends on the river water quality, the water level in the aquifer, and it is limited by a total annual amount imposed by ACA (Catalan water public agency). Due to this variability, the average from 2009 to 2015, which is 16.3 Mm^3, is going to be considered as the annual extraction volume. This number is taken as the annual extraction volume in order to do the calculations below.

Impact I

Impact I has been assessed as the changes in state (before / after the infiltration ponds implementation) that changes the ecosystem services of provision or regulation and impacts in one or several beneficiaries.

1. **Increase of groundwater level nearby pumping wells:** according to numerical modelling carried out by CUADLL, groundwater level is expected to increase around 3 metres in the pumping wells located in Estrella area and 2 metres in the pumping wells located in Cornellà area. There are fieldwell for drinking water purposes in both locations. Impact II will quantify the economic benefits of this additional increase of groundwater level.

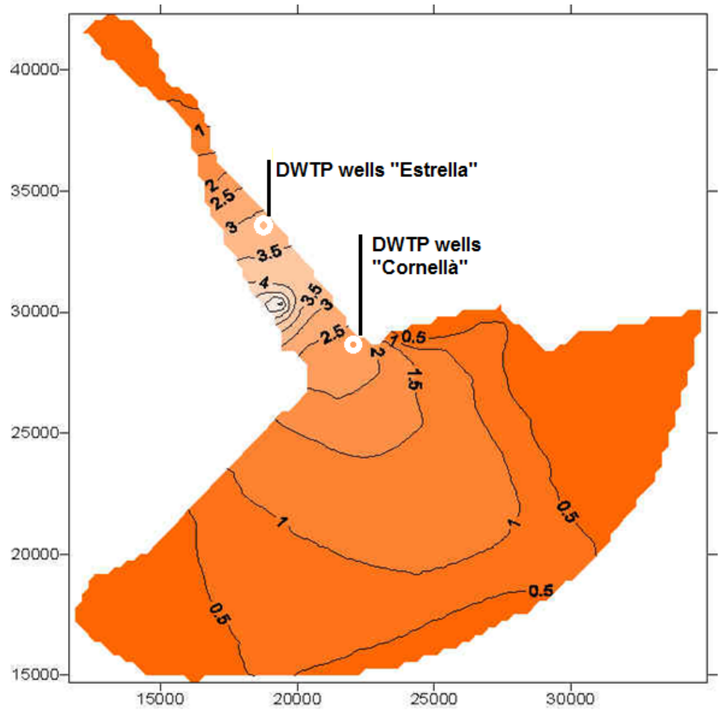

Figure 20: Modelling of groundwater level increase after the implementation of SCC in AB wells

NOTE: black lines represent the relative increase in groundwater level (in meters) caused by infiltration of additional 10 Mm^3/year in Santa Coloma de Cervelló and AB wells location.
Source: CUADLL

2. **Ammonium elimination:** in winter, WWTP performance upstream the DWTP can be limited due to temperature. Main secondary treatment of WWTP is activated sludge. If ammonium concentration in river is above 2.5 mg/L, intake of water is stopped (with concentration up to 1.8 mg/L there is an alert situation). In this case, the use of groundwater becomes critical, as this is the only available resource to maintain the full production of the plant. Ammonium is not present in groundwater (in general), so the increase of groundwater available due the infiltration in Santa Coloma de Cervelló will allow having an additional volume of groundwater available to deal with ammonium peaks in the river catchment.

3. **Turbidity reduction:** Groundwater presents naturally low turbidity. This is a warranty to use groundwater in case Llobregat river water presents turbidity values above 500 NTU. An increase in groundwater resources due to the additional 10 Mm^3 in the aquifer, will allow Aigues de Barcelona to dispose of additional groundwater resources to deal with turbidity peaks.

4. **Temperature regulation:** as stated, DWTP in Sant Joan Despí can switch from surface water to groundwater. Water input can be mixed (after the primary treatment) or can be one of the two options (100% river water or 100% groundwater). In winter, with low temperatures in river water (5ºC to 10 ºC), abrupt changes from groundwater (18ºC) to river water caused damages in the piping system. The distribution network engineers detected more pipe breakages in winter due to this effect. Aigues de Barcelona studied this effect and calculated the number of breakages due to temperature contrast, and since then they uses groundwater to prevent this effect.
   Warm temperature of groundwater in winter has another positive effect in the drinking water treatment. When water temperature is higher, membrane porous dilates, which allow working with smaller pressure than in cold water conditions. This effect can be also measured economically.

Impact II of infiltration ponds in AB abstraction wells: economic assessment
The monetisation of impact II in water for drinking purposes is done in five axes. First, the avoided costs in energy for pumping; then, avoided costs in pipes network breakdowns reparation; and, third, the substitution from surface water to groundwater, that includes increased costs in energy for pumping, avoided costs in water treatment and change in maintenance costs. The first two are changes in the actual use of groundwater due to the change in quality and quantity, while the lasts are due to the substitution of 8Mm^3 from surface water to groundwater. This substitution is due to the more water available in the aquifer. All the values are assessed using avoided costs valuation method (Zografos, 2010). Note that the pipes network is made of the transportation network and the distribution network. The former are the network from the treatment plants to the cities, high volume pipes; while the latter is the network within the cities, small and medium pipes. The avoided costs are assessed for the distribution network only since no data is found for the assessment of the avoided breakdowns in transportation network. However, it is known by the operator that using more groundwater will reduce breakdowns in the transportation network that are more expensive to maintain than the distribution breakdowns.

Regarding the avoided costs in energy for pumping, due to the increase in water level due to the more volume infiltrated, the catchment levels will increase at about 2-2.5 metres. This is shown in Figure 20. A difference of 4-5kwh per well is assumed. The working time is equivalent to three wells working full time, every day of the year. Thus, a difference in consumption of 12 kWh per hour resulted. This difference in energy consumption is converted in avoided costs in Table 17. The annual avoided costs in energy for pumping for AB beneficiary is 9,586.80€/year.

Table 17 Avoided costs in energy for pumping in AB

Avoided costs in energy for pumping	unit	
Difference in energy consumption by the pump at x+2 metres.	kWh/hour	12
Number of hours of use in the whole year.	hour/year	8,760
Energy cost.	€/kWh	0.091
Annual avoided costs in energy for pumping.	€/year	9,586.80

Regarding the avoided costs in pipes network breakdowns reparation, the indicators needed are the total number of breakdowns, the average cost per breakdown and the percentage attributable to the use of groundwater. In case of the number of breakdowns, it is taken from the DSO (2014) report. The average cost per breakdown is the result of dividing the total cost of breakdowns by the total amount of breakdowns. And, finally, it is assumed that 10% of the reduction in breakdowns is due to the use of groundwater. It is a conservative assumption taking DSO (2014) report as reference. The annual avoided costs in pipes network breakdowns reparation is 64,400€/year, as it is shown in Table 18.

Table 18: Avoided costs in pipes network breakdowns reparation in AB

Avoided costs in pipes network breakdowns reparation	unit	
Difference in the number of breakdowns.	units/year	230
Average cost per breakdown.	€/unit	2,800
Percentage attributable to the use of groundwater.	%	10%
Annual avoided costs in pipes network breakdowns reparation.	€/year	64,400

Finally, due to the substitution between surface water and groundwater, three diferent changes are accounted. The first is the increase in costs due to the energy for pumping needed for the groundwater capitation. The energy consumption is 0.11 kWh/m^3, with an increase in the water pumped of 8 Mm^3/year and an energy cost of 0.091 €/kWh. These result with an increased cost of 82,954.97€/year summarized in Table 19.

Secondly, there are the avoided costs in water pretreatment. Due to the aquifer soil eliminates some pollutants; the pretreatment is not needed in case of groundwater. These treatment cost is 0.034 €/m^3 that with the substitution of 8 Mm^3/year, means an annual avoided costs of 296,600€/year wraped up in Table 20.

Finally, due to the change of the source per these 8 Mm^3, a change in the maintenance costs is expected. This chance is supposed to affect the corrective costs rather than the preventive ones. In fact, a ratio €/Mm^3 is calculated for the corrective maintenance. Thus, the change in corrective maintenance suppose an increase of 63,803.68 €/year in the pumping wells and a decrease in pre-treatment corrective maintenance of 22,857.14 €/year. The difference between they, suppose an increase of costs about 40,946.54 €/year extracted from Table 21.

All in all, the net result of the substitution from surface water to groundwater is 145,698.49 €/year.

Table 19: Increased costs in energy for pumping in AB

Substitution from surface water to groundwater:	unit	
Increased costs in energy for pumping		
Difference in energy consumption between groundwater and surface water	kWh/m^3	0.113701
Water quantity.	Mm^3/year	8
Energy cost.	€/kWh	0.091199
Annual increased costs in energy for pumping (catchment)	€/year	82,954.97

Table 20: Avoided costs in water treatment in AB

Avoided costs in water treatment		
Total amount of water treated substituted by groundwater.	Mm^3/year	8
Treatment cost.	€/m^3	0.034
Annual avoided costs in water treatment	€/year	269,600

Table 21: Change in costs in maintenance in AB

Change in costs in maintenance	unit	
Corrective maintenance costs in pumping wells	€/year	130,000
Corrective maintenance costs in pre-treatment	€/year	280,000
Total amount of groundwater abstracted before measure implementation.	Mm^3/year	16.3
Total amount of groundwater pre-treated before measure implementation.	Mm^3/year	98

Corrective maintenance costs in pumping wells per Mm^3	€/Mm^3	7,975.46
Corrective maintenance costs in pre-treatment per Mm^3	€/Mm^3	2,857.14

Water pre-treated substituted per groundwater	Mm^3/year	8

Increased costs in corrective maintenance in pumping wells	€/year	63,803.68
Avoided costs in corrective maintenance in pre-treatment	€/year	22,857.14

Change in costs in maintenance	€/year	40,946.54

The total annual benefits for AB are 219,685.29 € per year, which is the sum of all the values reported above.

Assessment of impact I & II for industrial users of groundwater: DAMM factory

DAMM is the main industrial user of groundwater in terms of extracted water. DAMM factory is located in the municipality of El Prat Del Llobregat. The strategic location of the factory responds to the need of fresh water available as a raw material for the production of beer. The factory has a quite constant production, around 435,000 m^3/year (period 2010-2014). DAMM gets all the water needed for the industrial processes from the aquifer. Four wells provide enough groundwater for direct and indirect water uses. Total consumption of DAMM is around 2.3 Mm^3/year, which represents a half of total industrial consumption in the aquifer.

Because it has a considerable influence on the organoleptic characteristics of the beer, the water used must be pure, sterilised and devoid of extraneous tastes or smells. Therefore, the factory installed a purification system consisting in reverse osmosis. Between 2005 and 2008 the factory faced a critical situation, due to the high salinity of the aquifer (Figure 21). The company installed a new reverse osmosis scheme, to deal with high levels of electrical conductivity, having a high investment in equipment and additional costs related to electrical consumption. Moreover, groundwater level rise decrease in that period represented high power consumption to raise groundwater with the pumping system, installed in the four wells.

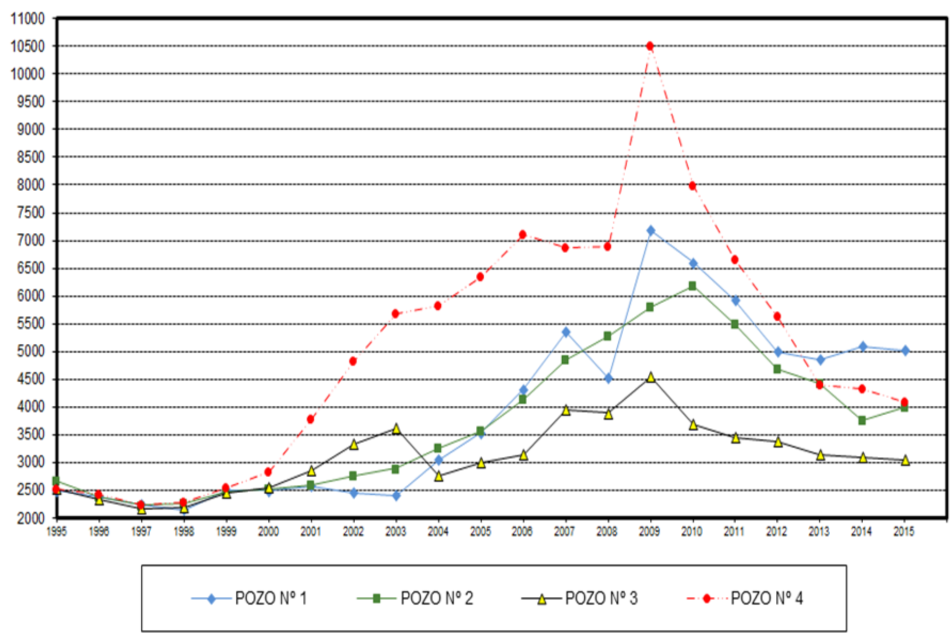

Figure 21: Electrical conductivity in the extraction wells (unit µS/cm)

DAMM factory has been selected as an example of the industrial end user that will be directly favoured by the increase of groundwater resources with the implementation of the infiltration system in Santa Coloma the Cervelló, In fact, despite there are some kilometres from the ponds to the factory, a raise of 1.5 meters in phreatic level has been predicted by the simulations. Regarding quality parameters, as water for industry needs a very exhaustive quality control; most of factories have their own purification system. In the case of DAMM, only salinity is a parameter of concern that can affect their production costs.

Using data from 2014, results obtained in this case study would represent approximately 65% of the results obtained for the industrial users consuming groundwater for their production and auxiliary processes. There is, of course, the uncertainty of the values of the indicators used for the calculations, which are based in DAMM data.

Impact I

1. **Increase of groundwater level nearby pumping wells**

According to the model developed by CUADLL, a relative increase of 1.5 meters of groundwater is expected nearby the location of the 4 pumping wells of DAMM factory in the municipality of El Prat de Llobregat.

Figure 22 illustrates the location of SCC infiltration system, with maximum groundwater level rise of 5 meters around the infiltration focus, and the isopiezometric values caused by infiltration. The 4 pumping wells of DAMM (named P1, P2, P3 and P4) will be impacted similarly due the proximity between them.

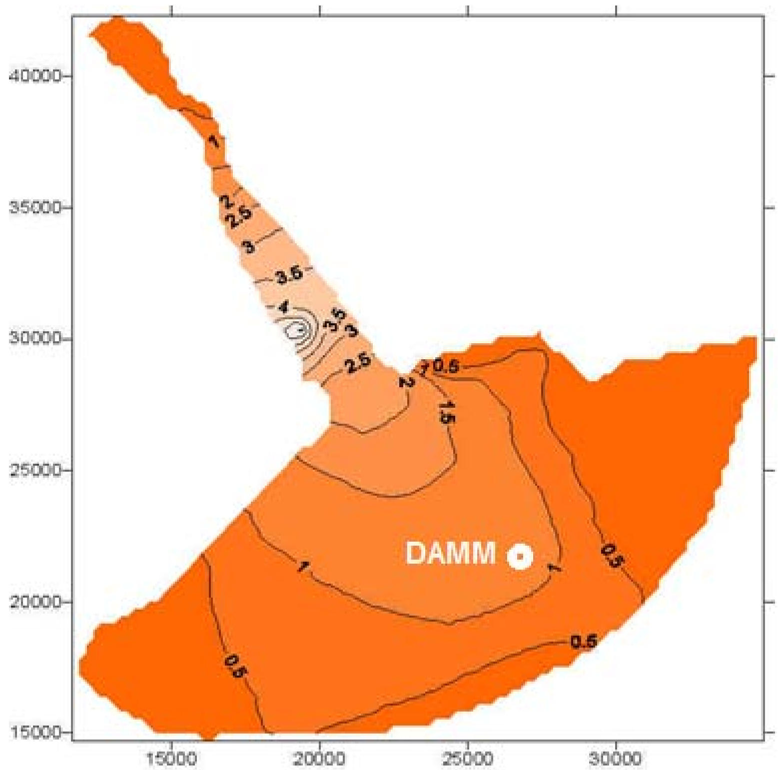

Figure 22: Modelling of groundwater level increase after the implementation of SCC in DAMM wells

NOTE: Blac line represent the relative increase in groundwater level (in meters) caused by infiltration of additional 10 Mm^3/year in Santa Coloma de Cervelló and DAMM location
Source: CUADLL

2. **Salinity decrease in groundwater for brewery**

Groundwater salinity has been considered the key indicator of groundwater quality. High conductivity values (around 10,000 µS/cm) are the maximum electrical conductivity registered in the area, which conditioned the factory to the installation of a more robust reverse osmosis scheme. A scenario of a half of this value (5,600 µS/cm) is considered as optimal situation to change the reverse osmosis scheme, having less power consumption. This value will be reached with the infiltration ponds of Santa Coloma de Cervelló in operation.

Impact II of infiltration ponds in DAMM abstraction wells: economic assessment

As it is explained above the three avoided costs to be monetized are the difference in energy costs for pumping, in energy costs for running the membranes systems, and the difference in the price of purchasing and installing the membranes system itself.

Firstly, for the monetization of the avoided costs in energy for pumping two scenarios are taken, the current scenario that is the actual groundwater level, and a future scenario where the groundwater level will raise 1 meter. This future scenario is consistent with the results of the CUADLL model of groundwater level showed in

Figure 22.

For the future scenario a less powerful pump is needed and the energy consumption is lower than for the actual scenario. The calculation is shown in the following table:

Table 22 Avoided costs in energy for pumping in DAMM

Avoided costs in energy for pumping	unit	
Energy consumption for the pump at "x" metres	kWh/m^3	0.26
Energy consumption for the pump at "x + 1" metres	kWh/m^3	0.17
Energy cost	€/kWh	0.1
Water flow	m^3/h	250
Hours of use per year	h/year	8,454
Avoided cost per hour	€/h	2
Avoided cost per year	€/year	17,753

As it is shown in the table, the total avoided cost per year in energy for pumping will be 17,753€ per year. Considering that the annual cost of pumping is 54,951€, it means a 32% reduction in costs annually.

Secondly, for the monetization of the avoided costs in energy for running the membranes system two different scenarios are taken. Scenario 1 is with the actual salinity, and scenario 2 is considering a decrease in the salinity about 39.3%. In scenario 1 there is a system with membranes from Koch. In this case the membranes used are DESAL-CE8040-F. These membranes need a pressure of 21 bars to be efficient. On the other hand, the system of scenario 2 is built from Dow BW30HR-440i membranes; and the pressure needed to run the system is 11 bars. The difference between the pressures needed in the first and the second causes the avoided costs in energy. In the following table the calculation is shown:

Table 23: Avoided costs in energy for membranes system in DAMM

Avoided costs in energy for membranes system	unit	
Membranes consumption scenario 1	kWh/m^3	1.10
Membranes consumption scenario 2	kWh/m^3	0.57
Energy cost	€/kWh	0.1
Water flow	m^3/h	250
Hours of use per year	h	8,454
Avoided cost per hour	€/h	13
Avoided cost per year	€/year	112,016

As it is shown in the table, the total avoided cost per year in energy for membranes system will be 112,016€ per year. Considering that the annual cost of pumping is 232,485€, it means a 48% reduction in costs annually.

Finally, for the monetization of the membrane systems avoided costs the two salinity scenarios above are taken into account. There are 696 membranes per each system and the lifetime expected is 5 years. As an annual discount rate we consider 3%. The calculation is shown in the table below:

Table 24: Avoided costs in membranes system purchasing in DAMM

Avoided costs in membranes system purchasing	unit	
Membrane unitary cost scenario 1	€	1,100
Membrane unitary cost scenario 2	€	525
Total number of membranes	units	696
Lifetime of the membranes	years	5
Lifetime avoided cost	€/5 years	400,200
Annual avoided cost	€/year	87,385
Discount rate	%	3%

As it can be seen in the table, the total avoided cost is 400,200€, that is 87,385€ per year with a discount rate of 3%. This 3% is taken from the Cookbook step 8 recommendations. It is a decrease of 52% of the annual cost in respect to the scenario 1.

All in all, the sum of all the avoided costs due to the improve either in quality and in quantity is 217,154€ per year, which is a depletion in costs of 47.71%.

Table 25: Total annual avoided cost in DAMM in euros per year

Total annual avoided cost	217,154
Avoided costs in energy for pumping	17,753
Avoided costs in energy for membranes system	112,016
Avoided costs in membranes system purchasing	87,385

A recommendation on the Cookbook part IV step 7 (Anzaldúa et al. 2016) regarding the addition of different figures is done. The recommendation is not to sum results of different valuations. However, as the valuation method, the data sources and the beneficiary is the same the addition of this figures is found appropriate.

Additionally, a benefit transfer is done to assess the avoided costs for the other industrial users. Damm is chosen as the example because is the main industrial user but there are other industrial users in the area. Due to the lack of data, a benefit transfer using DAMM figures is proposed. The only avoided cost that is assessed is the energy for pumping. The whole industrial abstractions in the Aquifer area is 3.17Mm^3 annually[6]. A total of 1.06Mm^3 correspond to the other industrial uses. And this quantity using the same assumptions than in DAMM case will represent an avoided cost of 8,864.84€/year. The figures are summarized in the following Table 26.

Table 26: Avoided costs in energy for pumping in other industrial users

Avoided costs in energy for pumping	unit	
Groundwater abstracted by DAMM	Mm^3	2.11
Groundwater abstracted by other industrial users	Mm^3	1.06
Avoided cost per year at DAMM	€/year	17,753
Avoided cost per Mm^3 per year at DAMM	€/Mm^3*year	8,399.77
Avoided cost per year at other industries	€/year	8,864.84

[6] 2014 data, source CUADLL.

Assessment of impact I & II for researchers & scientists

Sant Vicenç dels Horts infiltration system started its operation in 2008. Since then, several R+D projects have used this facility as demonstration site to evaluate the properties of MAR systems (Managed Aquifer Recharge) and to know more about the capabilities of natural purification, clogging processes and other physico-chemical processes occurring. MAR systems are nature-based solutions increasingly applied.

The case of Sant Vicenç dels Horts, jointly with the facilities located in Segovia (Santiuste and Carracillo ponds[7]) has been included as demonstration site in several European EC funded projects. The construction and start-up of a new and bigger system in the Baix Llobregat region, will lead some research groups to continue exploring these systems in a multidisciplinary approach. Specifically, Catalan research groups and institutes are specialised in MAR systems, being an international reference, with some scientific publications and continuous participation in public European projects.

Moreover, this kind of facilities attracts the interest of foreigners as students, scientists and water managers. The infiltration system of Sant Vicenç dels Horts has been visited as technical visit of some international conferences as AQUACONSOIL (2013)[8] or EIP Water meeting (2014)[9].

Figure 23: pictures to illustrate the research opportunities of infiltration ponds

Impact I evaluation

The selection of the indicators to calculate the educational services and the research opportunities provided by the infiltration pond is not an easy task. Scientifics are attracted by these nature-based solutions for passive-

[7] http://www.eip-water.eu/sites/default/files/MAR4FARM-workshop-Santiuste-en-v8.pdf
[8] http://www.aquaconsoil.org/
[9] http://www.eip-water.eu/5th-6th-november-2014-eip-water-conference-barcelona-es

depuration through soil-aquifer treatment. Regarding educational services, it can be estimated the number of water professionals interested in this kind of systems that would take advantage of the existence of Santa Coloma de Cervelló system. In that sense, Sant Vicenç dels Horts system can serve as an example (with smaller area) about how many researchers, scientists and students have visited and/or studied the managed aquifer recharge system.

Impact II evaluation

There are three impacts in human wellbeing generated because of the infiltration ponds construction in terms of research. These three impacts are the technical visits, the PhDs and the research projects conducted in the ponds. Following, the valuation of these impacts is done.

First, the infiltration ponds are an innovative solution that captures the attention of technicians. Since the infiltration ponds construction several international conferences about water were done in the area of Barcelona. The attendants had the opportunity to visit the infiltration ponds into the conference context. The overall number of technical visitors during the 8 years of life was 232. As the infiltration ponds are out of the city and had not a public transport connection, a private bus was hired to go to the ponds. The cost per visitor to go from Barcelona to the ponds and come back is 13€. This is the result of dividing the total cost of the bus hiring by the amount of visitors per trip. In the following Table 27, the total value of the visits is calculated.

Table 27: Value of the technical visits conducted at the infiltration ponds

Technical visits value		
Average cost from Barcelona to the ponds	€/visitor	13.00
Number of visitants	visitors	232
Total value of the technical visits	€	3,016.00
Lifetime of the ponds	years	8
Discount rate	%	2%
Annual value of the technical visits	€/year	411.71

The total value of the technical value is annualized in order to make able the aggregation of all the quantities per each ESS. The annual value of the technical visits is 411.71€ per year.

Second, the infiltration ponds also give the opportunity to research more in deep in numerous subjects. In the 8 years of ponds life 6 PhDs were been conducted in it. Each PhD will be impossible to be done without the ponds existence, so we valued the whole grant per student as the created value. In the following table, all the calculations are shown.

The total value of the PhDs conducted at the ponds amount to 369,264€. As it is done in all of the valuations, the total amount is annualized in order to permit the aggregation of all the values. The annual value of the PhDs is 50,408.15€ per year.

Table 28: Value of the PhDs conducted at the infiltration ponds

PhD values		
Grant per PhD student	€/PhD	61,544.00
Number of PhD students	students	6
Total value of the PhDs	€	369,264.00
Lifetime of the ponds	years	8
Discount rate	%	2%
Annual value of PhDs conducted at the infiltration ponds	€/any	50,408.15

Last but not least, the assessment of the research projects value is done. A total of 5 different projects, apart of DESSIN, were conducted, almost partially, in the infiltration ponds. Each project budget and the percentage attributable to ponds existence are listed in the Table 29. Regarding ENSAT project, it is fully attributable to the ponds existence. GABARDINE's and MARSOL's percentages are due to the ponds are a case study. In case of GABARDINE is one over four case studies and one over eight case studies in MARSOL. Finally, the percentage in case of DEMEAU and PREPARED is the weight of Cetaqua's budget over the global project budget. Thus, the total value in research projects conducted at the ponds is 3,173,777.06 and the annual value of it is 433,251.67 € per year.[10]

Table 29: Value of the research projects conducted at the infiltration ponds

Research projects value		
ENSAT budget	€	1,240,358
Percentage attributable to ponds existence	%	100%
GABARDINE budget	€	3,286,579
Percentage attributable to ponds existence	%	25%
DEMEAU budget	€	4,618,591.6
Percentage attributable to ponds existence	%	3%
PREPARED budget	€	10,657,756
Percentage attributable to ponds existence	%	3%
MARSOL budget	€	5,200,000
Percentage attributable to ponds existence	%	12,5%
Total value of the research projects conducted at the ponds	€	3,173,777.06
Lifetime of the ponds	years	8
Discount rate	%	2%
Annual value of the research studies conducted at the ponds	€/year	433,251.67

All in all, the total annual value due to research, which is the aggregation of the three values, is 484,071.53.

[10] The values and calculations per these three ESS are done in current euros.

Assessment of impact I & II for experiencers and viewers

Barcelona Metropolitan Area presents a high density of population, and the green per habitant in the city of Barcelona is aroud 6 m^2/inh, very distant from the optimum of 15 m^2/inh recommended by WHO. This is a key factor to explain how valuable green areas are in the city and in the surrounding areas. The Llobregat delta wetlands are a natural area protected that is permanently visitied by scholars, families and ornithologists.

Infiltration pond project in SCC includes some paths connecting transversely the settling and infiltration ponds, and will be opened to the public, so runners, bikers and visitors could come near to the water. The already constructucted infiltration system in SVH has been perimeter fenced to protect the measurement equipement, so people can only get closer to the fence. To imagine how could be the relation of the citizens with an open infiltration system, it is necessary to consider also public health issues, as the prevention of direct contact with reclaimed water, and the protection of the equipement. So at the end, it will be solution of compromise consisting in having large lagoons that will attact birds, and the prevention mesures to maintain the population safe of not disinfected reclaimed water.

Impact I evaluation

To analise the potential impact in terms of visitors of SCC system and existing water bodies in the surroundings, a selection has been done taking into account some criteria. Finally, Murtra wetland and Maiola pine area have been chosen due to:

- Size of water body: Murtra is a coastal wetland around 22 Ha.
- Accessibility: there are not public announcements nor indications to reach the site. It is only known by local people (from Gavà and Viladecans) and local biologists. In the case of SCC, it is not expected to reach the infiltration system by car.
- Public services: there are no public services as a parking area, bathroom or restaurants.
- Poor biodiversity: la Murtra coastal lagoon is nowadays suffering from eutrophisation and salinisation, which makes it a water body without a big amount of bird species. Moreover, there are not activities of identification of birds programmed. SCC will attact birds (according to those observed already in Annex IV of the document), but it can be temporally, taking into account the maintenance periods (25% of the days).

Figure 24: Pictures to illustrate the cultural services of infiltration ponds (similar to Murtra system)

Impact II evaluation

The main indicator of the impact II use is the number of visitors, which are estimated through a survey done in the whole Delta area. The result of the survey for Murtra wetland and Maiola pine area, which are chosen due to the similarity to the ponds, are 250 visitors for the Murtra and 5,000 visitors for the Maiola per year. The results are shown in the following table.

Table 30: Estimated visitors in the Murtra and Maiola areas

Estimated visitors			
Visitable places	**Free visitors (not organised)**	**Scholar visitors**	**Total Visitors**
Murtra wetland	250	0	**250**
Maiola pine area	5,000	0	**5,000**
Total			**5,250**

But more indicators are needed in order to make able the monetisation of the visitors. Thus, the indicators needed are the distance to the ponds, the travel time to reach it, the average wage or gain per hour and the fuel cost. The indicators are quantified and explained along the monetisation application.

The monetisation of the impact II is done through the Individual Travel Cost Method (ICTM). ITCM is a standard methodology applied in several projects to determine the monetary surplus value of visitors (Langemeyer 2015). ITCM includes two values, the cost of the transportation and the time invested in it, as an opportunity cost.

Transport cost

The transport chosen to do the calculation is the car due to there is no public transport available to reach the ponds area. For the calculation of the cost, an average distance is calculated assuming that the majority of the people come from the surroundings of the ponds. The closer cities are Santa Coloma de Cervelló, Sant Feliu de Llobregat, Sant Joan Despí, Sant Vicenç dels Horts, Sant Boi, Cornellà, Esplugues and Molins de Rei. This assumption is consistent with the results of a survey conducted to the whole area of Delta del Llobregat shown in Table 31. An equal distribution is supposed among the municipalities, thus the average distance to the ponds is 6.0875 km. The fuel consumption is calculated with 7l/100km of fuel consumption with a fuel cost of 1.25€/L.

Table 31: Visitors origin

Coming from? (survey done to 16337 visitors)			
Catalonia region	**Europe**	**rest of Spain**	**Other countries (excluding Europe)**
97%	1.90%	0.90%	0.20%

Travel time

As it is done in Langemeyer (2015), the travel time was determined as hourly wages multiplied by a factor 0.5. Then, hourly wages are taken from the national institute of statistics (Idescat), the national average benefit in €/h is taken, 15.63 €/h. Using the same assumptions as per transport cost, the average travel time resulted in 0.18 hours per journey. Finally, the total travel cost is multiplied by 2, because the return is also included. All the calculations are summarized below in Table 32.

Table 32: Value of the visitors to the infiltration ponds

Visitors value		
Transport cost	€/visitor	0.53 €
Number of visitors	visitor/year	5,250
Travel time	hours	0.18
Time value	€/hour	7.815
Annual value of visitors	€/year	20,477.30 €

The annual value of visitors is 20,477.30€/year.

Summary of Impact II assessments

In conclusion, the whole values assessed due to the creation of the infiltration ponds are summarised in the following Table 33. A wider sort of beneficiaries is found impacted by the measure and in general in a positive way. However, the beneficiaries identified correspond to a specific point of time; it could change along the infiltration ponds lifetime as there are a lot of external conditions affecting each beneficiary. Furthermore, the actual use of ESS per each beneficiary could change during the lifespan of the measure too. As it is expressed before and on step 7 of the Cookbook (Anzaldúa *et al*. 2016) it is not recommended to aggregate the different values. However, as broader analised in Financial Dimension of the Sustainability Assessment (SA), it seems that the balance between benefits and costs is positive if all the beneficiaries are taken into account. The aim of the methodology application, to assess the wider value created by the measure, is reached. And, finally, as expressed in SA, a cost-benefit analysis is recommended to ensure the financial affordability of the measure.

Table 33: Summary of the values assessed due to the infiltration ponds creation

Final ESS type	Beneficiary	Valuation method	Assumptions/comments/references	Values[11] (€/year)	Uncertainty
FESS1: Water for drinking purposes	AB	Avoided costs	Energy for pumping	9,586.80	🟡
FESS1: Water for drinking purposes	AB	Avoided costs	Breakdowns reparation	64,400	🟡
FESS1: Water for drinking purposes	AB	Avoided costs	Energy for pumping. Assumption: water source substitution from surface water to groundwater	-82,954.97	🟡
FESS1: Water for drinking purposes	AB	Avoided costs	Water treatment. Assumption: water source substitution from surface water to groundwater	269,600	🟡
FESS1: Water for drinking purposes	AB	Avoided costs	Maintenance costs. Assumption: water source substitution from surface water to groundwater	-40,946.54	🟡
FESS2: Water for non-drinking purposes	DAMM	Avoided costs	Energy for pumping	17,753	🟡
FESS2: Water for non-drinking purposes	DAMM	Avoided costs	Energy for membranes system	112,016	🟡
FESS2: Water for non-drinking purposes	DAMM	Avoided costs	Membranes system purchase	87,385	🟡
FESS2: Water for non-drinking purposes	Other industrial users	Avoided costs	Energy for pumping. Assumption: same pumping costs per m^3 as DAMM; benefit transfer for the whole water abstractions	8,864.84	🔴
FESS3: Educational	Researchers	Travel cost	Technical visits value	411.71	🟡
FESS3: Educational	Researchers	Revealed preferences	PhDs value	50,408.15	🟡
FESS3: Educational	Researchers	Revealed preferences	Research projects value	433,251.67	🟡
FESS4: Experiential use of landscapes in different environmental settings	Experiencers and viewers	Travel cost	Visitors' value	20,477.30	🟡

[11] Positive sign is a gain or a save, in contrast negative sign is a loss or a cost.

PART V: SUSTAINABILITY ASSESSMENT

Step A: Definition of the assessment and decision case

The objective of the sustainability assessment (SA) for the Llobregat case was to test the developed SA framework developed in DESSIN project. The decision to implement the MAR facility in Santa Coloma de Cervelló has already been made, as discussed above. Therefore, the SA described below is simply an ex-post assessment for the fictive decision case where one has to decide if the MAR facility in Santa Coloma de Cervelló is an appropriate and viable solution to improve water availability in the area without having too many negative "side effects", e.g. on the society and the environment, or not. For this, the DESSIN SA framework proposes to use a set of indicators, enlightening the effects from the social, environmental, governance, assets and financial perspective.

Consequently the task of this mature case test was to identify potentially interesting indicators from the different DESSIN SA dimensions from the decision maker's point of view, quantify them and exemplify how they could have produced valuable decision relevant results for the past decision on implementing the MAR solution. In other words two scenarios have been compared by using a set of indicators for different assessment criteria: The (fictive) scenario without the existence of the infiltration ponds in Santa Coloma de Cervelló, and the scenario with the existence of the system.

Step B: Selection of indicators

The application of Steps B.1 until B.3 lead to a set of indicators for the social, environemental, financial and assets dimension. Due to a lack of data it was not possible to identify fitting indicators for the governance dimension. Futhermore no additional indicators where identified to be relevant for the decision case. A detailed list of all indicators selected for assessment can be found in the annex to this chapter (see ANNEX-PART V).

Step C: Definition of additional indicators

No further data was found to be available and thus no additional indicators relevant for the decision case were derived.

Step D: Data collection and assessment

The data collection was conducted by Cetaqua using data from Sant Vicenç dels Horts in terms of technical performance and data of the constructive project of the system in Santa Coloma de Cervelló (ACA, 2011).

Moreover as few indicators from the ESS Evaluation could be identified to be usefull in the SA, the following table summerarizes them. How they could be integrated in the SA is discussed in the next section. Details about their calculation are explained above in the chapter of PART IV, the response evaluation. For the assessment the timeseries where annualized making an extrapolation for a life cycle assessment possible, to cover all effects until the end of the lifetime of the solution, which is after 18 years.

Table 34: SA data for the Llobregat case derived from ESS evaluation

FESS/ IESS ID	DESSIN ESS	unit	before	after	Potential SA metric/indicator
FESS #1	Net Avoided costs for the municipal DWTP from using groundwater instead of surface water (more expensive treatment)	[k€/a]	0	331	→ F113
FESS #2	Avoided costs for industrial producers from using cheaper groundwater from the aquifer instead of drinking water	[k€/a]	0	215	

FESS/ IESS ID	DESSIN ESS	unit	before	after	Potential SA metric/indicator
FESS #3	Economic impact of research opportunities due to the MAR solution	[k€/a]	0	484	→ S152
FESS #4	Economic impact from visiting and experiential / interllectual interactions with MAR solution	[k€/a]	0	20	

Step E: Results and discussion

Social dimension

The social dimension covers effects of the solution on society and how it influences the quality of life. Numerous indicators from the SA framework in this dimension are most meaningful if the decision case is to choose between alternative solutions. But due to positive data availability and for illustrative reasons the indicators S111 and S152 have been assessed for the Llobregat case and are discussed below.

It was found, that the infiltration ponds in Santa Coloma de Cervelló lead to a decrease of the presence of microbial pathogens (S111) in the water abstracted from the aquifer compared to the water infiltrated from the river. For instance the total coliform is reduced from 322,880 MPN (annual average in Llobregat river water 2014) to 6.8 MPN (annual average of AB abstraction wells 2015). This in turn is an indication for an improvement for the assessment criteria of health and safety. Still the water abstracted does not reach drinking water quality, for which the threshold of 0 MPN total coliform.

Additionally it was possible to take into account results from the ESS evaluation for the SA, as mentioned above. So from the impact II assessment an annual value for the intellectual and representative interaction (S152) could be derived. The travel cost method was used therefore, as explained above in the response evaluation chapter of the ESS evaluation. The annual value of visitors at the infiltration ponds is calculated to be 20 k€. This result indicates a positive value added for human wellbeing in the area due to the ponds. To estimate the definite economic value added for human wellbeing the transport cost and opportunity cost (lost labour income) of visitors would need to be substracted from their WTP to enjoy the recreational experience of the visit to the ponds. Still the calculated value can be said to be the lower bound of the WTP of people enjoying the ponds. Furthermore a value from the impact II ESS for research opportunities could be derived also to be accounted for S152. The research opportunities were estimated to account for 484 k€ annualy as explained above. This is a rather optimistic estimation, assuming continuing research projects and PhD studies based on the infiltration ponds to take place in the future, as well as a continuous flow of interested visitors from the areas nearby.

Environmental dimension

Regarding the environmental dimension one potentially decision relevant indicator was identified, the water use efficiency (EN111), since the solution deals with water supply. The indicator is headed under the objective Dn1 Efficient use of water, energy and materials. Thus the indicator should reflect any losses or waste of natural ressources within the utilisation of it. For the infiltration pond data was available for the evapotranspiration loss during the water storage in the pond. Thus the water use efficiency indicator was calculated in this case as percentage of water infiltrated, which equals to water in ponds minus net loss from evapotranspiration). Using timeseries the annual average percentage was calculated as the range of 99.63%-99.78%. In other words the MAR technology has quite a good efficiency in the use of water. Eventhough if compared to the situation before, where water from the river was directly transmitted to the drinking water treatment system and hence no evapotranspiration losses have happened, a loss of less than one percentage can not be seen as negligible environmental degradation.

Financial dimension

For the financial dimension the affordability of the infiltration ponds was estimated by calculating the cost coverage from the point of view of the organisation in charge for the investment and the operation, which is the Catalan Water Agency (ACA). Here it turned out, that from the point of view of the ACA the project is not financially sustainable. The results showed that the investment needed 8,000 k€ plus the maintenance costs estimated 103k€ per year will not produce additional incomes for ACA. However, it must be noted, that from a broader point of view, taking into account other stakeholders, there are additional financial benefits resulting from enhanced provisioning ecosystem service use to be expected. Those are the water suitable for processing by the municipal DWTP in the region (AB). It was estimated that AB could benefit with 331 k€ annualy from avoided costs - additional costs (compare the evaluation for the Impact II in the ESS evaluation section above). Also the beer factory Damm benefits from water suitable for cooling of processing industrial products with an expected amount of avoided costs due to groundwater use instead of drinking water purchace from AB as high as 215 k€ annualy (compare the ESS evaluation results above). In other words the infiltration ponds might not be financially sustainable for ACA, but eventually sustainable from an economic point of view, covering all financial implications to (external) stakeholders affected. To answer this question and cover all externalities a cost-benefit analysis could be additionally envisaged, aiming to cover all relevant economic implications of the solution not only relevant for the organisation in charge of the solution but also for the wider society and thus other stakeholders.

Assets dimension

In relation to the assets dimension there has been quite some data available for indicators informing about the solutions reliability, adequacy and resilience. Most of them are proposed to be used for decision cases where the aim is to compare two or more technological alternatives. Nevertheless resuling values for indicators with data available are summarized and interpreted here. For instance the lifetime of the facility is expected to be 18 years. This means the mean time to failiure (A111) is 18 years. Also data for an estimation of the average interval for the top layer removal in the ponds was available, which is to done every 2 years. This means a value of 2 for the indicators A112 mean time between failures. Also the Start up time (A22) was available, which is just one year. This means the indicator “lifetime of solution / start up time” can be calculated as 18. Futhermore data was available on the turbidity levels of the infiltration water from the river. These data can be used as an indicator for the adaptive capacity of the solution to changes (A131). So in the Llobregat case the “percentage of days per year at which the solution is in use” was found to be depending on the turbidity. Due to the regulative threshold the water can only be infiltrated if the turbitiy is below 50 NTU. According to timeseries from 2010-2012 this threshold was meat in 43% of the time on an average basis. Thus it can be concluded that only in 43% of a year the solution can operate properly. All of these mentioned indicators are examples of performance indicators to characterize the solution and could be taken into account to compare it with the performance of an alternative technology. The following table summarizes all SA indicators used to complement the ESS Evaluation indicators.

Table 35: Overview of additional SA data complementing ESS Evaluation indicators

SA metric/ indicator	DESSIN ESS	unit	before	after	source
S111	Presence of microbial pathogens	[MPN]	322,000	7	Cetaqua (based on SVH data)
S152	Economic impact from intellectual and representative interactions (Educational)	[k€]	0	20	Cetaqua (DESSIN ESS)
En111	Water use efficiency	[%]	100	99.63-99.78	Cetaqua (based on SVH data)
F111	Investment expenditure	[k€]	-	8,000	ACA
F112	Operational expenditure	[k€]	-	103.05	ACA

F114	Other sources of financing (e. g. subsidies)	[€]	-	0	ACA
A111	MTTF	[a]	-	18	ACA
A112	MTBF	[a]	-	2	ACA
A131	Adaptive capacity	[0-1]	1	0.43	Cetaqua
A221	lifetime of solution/start up time	[-]	-	18	ACA

Concluding from this test of the mature case Llobregat the SA framework was applicable and offered reasonable assessment results valuable for decision support. Nevertheless it becomes obvious, that it is sometimes necessary to define the boundaries of an indicator carefully and eventually necessary to expand or redefine them. Here this became obvious in the financial dimension, where the SA framework originally was meant to check the financial sustainability from the perspective of the organisation financially in charge for implementation and operation. But this narrow definition might leave out valuable financially positive implications of a solution to other external stakeholders benefiting from it. Thus in case there are financially relevant positive effects from a solution, not fitting to the social dimension in terms of economic impact and also not directly relevant for the organisation implementing the solution, it is recommended to expand the SA integrating these additional monetary benefits as indicators in the analysis.

Conclusions

The application of the ESS DESSIN methodology in the case study of the infiltration ponds in Santa Coloma de Cervelló (SCC) has been challenging. Groundwater is an invisible part of the water cycle, despite in some areas, as in Barcelona, it constitutes an alternative to surface water for drinking water production. Specifically in the Llobregat area the presence of fresh groundwater available, made the Llobregat Delta area and Lower Valley the selected placement for multiple water-dependent industries. Thus, in some way groundwater allowed the industrial and urbanistic growth of this part of the Barcelona Metropolitan Area.

This report is one of the first documents evaluating the ESS linked to managed aquifer recharge, going deeper to the general groundwater approach for ecosystem valuation (some references can be found in Qureshi *et al*. 2012; EA, 2007; Marsden Jacob Associates, 2012, among others.). In this case, the aquifer recharge through infiltration ponds is the mesure that has been evaluated (before and after) using an innovative methodology based in DPSIR analysis, and using standard lists for classification of drivers, pressures, beneficiaries and type of services (intermediate or final). The detailed methodology can be found in Anzaldúa *et al.* 2016.

As result of the implementation of the DESSIN framework in SCC system some conclusions have arisen:

- The result of the framework application is taking into account certain conditions that could change along time. The assumptions validity as well as the results needs to be revised in case of changes in the beneficiaries' types and the use of ESS.

- The DESSIN framework permits to incorporate wider beneficiaries and types of benefits allowing understanding the whole impact of the measure.

- Due to the limitations of the valuation methods and caused by the lack of data, an aggregation of the different beneficiaries is not recommended. However, the balance between impacts and costs seems positive.

- There is a need of a multidisciplinary team and local experts to deal with complex water management systems. In this case, hydrogeologists and economists have worked together to reach a common language able to join a MAR project and the economic impact. In more complex scenarios, biologists, sociologists and other professionals will be hardly recommended to participate.

Specifically, in the case study of SCC, main results have been:

- Four beneficiaries have been identified: industrial users, drinking water operators, researchers and expericers and views. Despite the high protagonism of agriculture in other schemes, in Llobregat aquifer the irrigation with groundwater is very limited, and located upstream the SCC system.

- Lot of benefits in terms of improvement of native groundwater quality and infiltration water quality have been demonstrated and evaluated. In this report, the list of indicators are included in Step 8(a) *Quantification of state level before and after the implementation of infiltration pond system*. Along the interviews with groundwater users (DAMM and AB), authors realized that most of the benefits are not perceived by the beneficiaries, and only a short list of parametres are strategic for their operation (salinity, groundwater level, groundwater temperature and ammonium concentration).

- For groundwater users located near the coast, in the Delta area, salinity is the key factor that compromises their activity. In that sense, the installation of SCC system or other control mesure could mean the replacement of current membranes system, as the salinity will decrease and remain more or less constant. SCC system will be as a guarantee against sea water intrusion. In the case of DAMM, the scenarios of salinity reduction from a maximum of 10,000 µS/cm to 6,500 µS/cm and the groundwater level increase of one meter has been quatified with a total annual benefit of 217 k€/year.

- Aigues de Barcelona benefits from the use of groundwater in the drinking water production partially, as the groundwater consumption representents between 10% and 15% of the total supplied water. Despite the increase of an additional amount of 10 Mm3/year in the aquifer (80% of this amount could be pumped by AB wells), there are lots of administratives restrictions and conditions in the current water management. Advantatges of use more groundwater have been listed and quantifiedby the operators: the savingns in the use of the pre-treatment (groundwater is directly introduced in the advanced treatment after sand-filtration), constant groundwater quality (ammonim and turbidity and the frequent liming factors of the river water) and regulation of temperature in the transport and distribution network. As a drawback, the increase of groundwater pumping would suppose an additional cost of wells maintenance. Total annual benefit of the SCC system scenario has been quantified for AB in 220 k€.

- The most theoretical approach has been the quantification of benefits for educational and cultural services. SVH is close to the public, so it is not possible to stimate the potential number of visitors in SCC system. Comparing with similar systems in the Llobregat Delta Park, it is feasible to stimate 20€ due to the application of travel costs methodologies. Moreover, scientific production based in SVH system have been very prolific, so it is expected that SCC will attract the interest of students, public founds and rearch projects estimated in 484k€.

The challenge of the evaluation of ESS linked to the infiltration ponds in SCC is that the system is not already constructed, so the operation in terms of infiltration rate, dilution capacity and elimination of pollutants through Soil Aquifer Treatment (SAT) has been evaluated considering similar effectiveness than the monitored system in Sant Vicenç dels Horts (SVH). Regarding the impact in terms of groundwater level increase due to the additional 10 Mm^3 infiltrated annualy by the SCC MAR system, the model of flow and conservative transport developed by CUADLL has been extremely useful to quantify the rise in specific pumping wells. This effort on assumptions will be useful for the future execution of the SCC MAR system, budgeted in 8 M€, and pending to be executed by ACA in the coming time.

The infiltration system is expected to be constructed and operated by Catalan Water Agency to improve water resources in the Llobregat area. The cost will be included in the public budget as investment in hydraulic infraestructure. Financially, it is not expected any type of in-kind contribution or cofinancing, as there is a public interest. The document shows the existence of potential beneficiaries of the additional replenishment of the aquifer. Despite it is a very theoretical exercise, the ESS methodology developed could be a practical method to identify and quantify end-users of a public good. The resulting analysis is a powerful tool for decision-makers. But the alternative solutions need to be evaluated using the same framework if a decision will be taken based on it.

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ANNEX I - PART I: Reporting tables of Llobregat mature case (infiltration pond)

Element of Part I	Instructions	User entries
Administrative details	1. Provide general information about: - the entity/ies involved in carrying out the assessment - the provider/s of information for the assessment - the provider/s of funding for the assessment	• *Cetaqua* • *Cetaqua, CUADLL, DAMM, ACA* • *EU FP7 project*
Objectives of the assessment	2. Define the intended audience of the results (*Who will be the main recipient of the outcome report?*) Define and explain the specific purpose and the expected outcomes of carrying out the assessment (*What do you want to achieve by assessing changes in ESS in your area?*).	*Intended audience: Researchers* *Objectives: The assessment is conducted with the aim of (i) testing the ESS Evaluation Framework proposed and (ii) identifying the benefit resulting from the ponds construction.*
Overview of the study area	3. Provide a detailed description of the study area considering: • geographical location (e.g. Mediterranean region, Western Europe, Nordic region) • spatial extent • environmental attributes (e.g. climate type) • economic activities taking place in the area (e.g. land use, land use transitions, comparison of activities by share of GDP) • socioeconomic profile (e.g. population density)	• *Mediterranean region* • *Aquifer area (115 km^2)* • *Typical Mediterranean climate regime* • *Agriculture 0.075%, Industry 22.78%, Construction 6.43% and Services 70.72% (2012 data[12]).* • *5,093 inh/km^2*
Stakeholder list	4. Elaborate an exhaustive list of the stakeholders present in the area.	*People living in the area;* *Industry;* *City councils;* *AB (Private company – drinking water suppier)* *Aigües del Prat (Public company – drinking water suppier)* *Aquadom (Private company – consultancy)*

[12] Source: http://www.idescat.cat/emex/?id=11&lang=es#h1fe000000

		Aqualogy (Private company – consultancy) *AQUATEC (Private company – consultancy)* *AGBAR (Private holding)* *ACA(Public entity)* *AMB (Public entity)* *Agència de Salut Pública (Public entity)* *CUADLL (Public entity)* *CDTI (Public research institution – management)* *ACC1Ó (Public research institution – management)* *CSIC (Public research institution – scientific)* *UPC (Public research institution – scientific)*

ANNEX I - PART II: Tables of drivers and pressures

1. Characterisation Table for Drivers

The list of drivers is based on MARS, 2014.

DRIVER	SPECIFICATION (to be input by the user)
Industry	Industrial bad practices in the past: solvents and PAHs in groundwater and river. Industries increase in the metropolitan area: WWTP discharge.
Urban development	Inhabitants increase in the metropolitan area: WWTP discharge, intensive use of the river.

2. Characterisation Table for Pressures

The relation between the pressure categories and the drivers is based on IMPRESS Guidance No. 3 and MARS, 2014

DRIVER IDENTIFIED IN THE STUDY AREA	PRESSURE CATEGORY	SPECIFICATION
Industry	Diffuse source	Contaminated sites/abandoned industrial sites. Groundwater pollution (solvents, PAHs, industrial pollutants).
Industry	Point source	Industrial waste water.
Industry	Abstraction	Abstraction from industry.
Industry	Other anthropogenic	Groundwater alterations of water level or volume.
Urban development	Diffuse source	Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).
Urban development	Point source	Urban waste water.
Urban development	Abstraction	Abstraction urban development
Other	Hydrological alteration	Reduction of permeable surface for precipitation infiltration.

ANNEX I - PART III Tables of the quantification of infiltration system capabilities

Capabilities of the Proposed Measures:

Proposed measure	Claimed / expected capability	Qualitative description	Quantitative description
Construction and equipment of infiltration ponds	Enhancing water infiltration by additional permeable surface	Increase of infiltration surface available for the infiltration processes.	56,300 m^2 1 m^3/m^2/day
	Increasing groundwater resources in the aquifer	River water is disconnected of the aquifer due to fine particles acting as clogging in the river bed. Infiltration ponds will increase groundwater resources by the infiltration of river water and/or reclaimed water. Periodic maintenance will allow maintaining infiltration surface available.	10 Mm^3/year
	Improving water quality via soil-aquifer treatment	It has been proved an effective reduction of turbidity (sediment retention) and a reduction in chemical compounds.	Sediment retention Denitrification Organic matter reduction Micropollutants degradation (See PART III for specific evaluation of water quality improvement)
	Reducing pollutants in the aquifer	Anthropogenic substances as chlorinated solvents are present in groundwater. By the infiltration of non-polluted water, a plume of clean water is expected to dilute undesirable substances.	(See PART III for specific evaluation of water quality improvement)
	Creation of a new surface water body (aquatic ecosystem)	The implementation of infiltration system (settling ponds and infiltration ponds) in a dry area will generate several impacts in terms of new ecosystem creation.	13 ha

Capabilities of the Proposed Measures and their effects on DRIVERS, PRESSURES:

		Effect on DRIVER (from D catalogue)		Effect on PRESSURE (from P catalogue)							
Proposed measure	**Claimed / expected capability**	Industrial bad practices in the past & WWTP	Urban development: (Intensive use the land	Groundwater pollution	Industrial waste water (Point source)	Abstraction from industry (Abstraction).	Groundwater alteration of water level	Discharges not connected to WWTPs	Urban waste water	Abstraction for urban uses & development	Reduction of permeable surface
Construction and equipment of infiltration ponds	Enhancing water infiltration by additional permeable surface										X
	Increasing groundwater resources in the aquifer					X	X			X	
	Improving water quality via soil-aquifer treatment	X		X							
	Reducing pollutants in the aquifer	X		X							
	Creation of a new surface water body (aquatic ecosystem)		X								

Capabilities of the Proposed Measures and their effects on STATE:

		Effect on STATE (from S catalogue)														
Proposed measure	**Claimed / expected capability**	Infiltration area	Infiltration capacity (Permeability)	Groundwater level	Volume of groundwater replenishment by surface infiltration	Natural attenuation	Electrical conductivity / Salinity	Chlorinated compounds in the aquifer	Nitrate concentration	Organic content	Ammonium concentration	Temperature	Turbidity	Number of birds species watched in the area	Volume of surface water available for amphibians and aquatic species	Percentage of days with surface water available
Construction and equipment of infiltration ponds	Enhancing water infiltration by additional permeable surface	X	X													
	Increasing groundwater resources in the aquifer			X	X											
	Improving water quality via soil-aquifer treatment					X			X	X	X	X?	X			
	Reducing pollutants in the aquifer						X	X	X		X					
	Creation of a new surface water body (aquatic ecosystem)													X	X	X

ESS from the CICES list associated to the affected parameters of STATE:

STATE Parameter influenced by measure	CICES Class *(restricted to ecosystem type)*	CICES Group	CICES Division	CICES Section
Biological	*Maintaining nursery populations and habitats*	*Lifecycle maintenance, habitat and gene pool protection*	*Maintenance of physical, chemical, biological conditions*	*Regulation & Maintenance*
Hydrology	*Hydrological cycle and water flow maintenance*	*Liquid flows*	*Mediation of flows*	*Regulation & Maintenance*
Physiochemical	*Surface water for drinking*	*Water*	*Nutrition*	*Provisioning*
	Surface water for non-drinking purposes	*Water*	*Materials*	*Provisioning*
	Bio-remediation by micro-organisms, algae, plants, and animals	*Mediation by biota*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Filtration/ sequestration/ storage/ accumulation by ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*
	Dilution by atmosphere, freshwater and marine ecosystems	*Mediation by ecosystems*	*Mediation of waste, toxics and other nuisances*	*Regulation & Maintenance*

List of stakeholders (Part I) merged with list of beneficiaries (US EPA):

List of stakeholders	List of beneficiaries
People living in the area; *Industry;* *City councils;* *AB (Private company – drinking water suppier)* *Aigües del Prat (Public company – drinking water suppier)* *Aquadom (Private company – consultancy)* *Aqualogy (Private company – consultancy)* *AQUATEC (Private company – consultancy)* *AGBAR (Private holding)* *ACA(Public entity)* *AMB (Public entity)* *Agència de Salut Pública (Public entity)* *CUADLL (Public entity)* *CDTI (Public research institution – management)* *ACC1Ó (Public research institution – management)* *CSIC (Public research institution – scientific)* *UPC (Public research institution – scientific)*	*Municipal Drinking Water Treatment Plant Operators* *Industrial processors* *Researchers* *Experiencers and viewers*

ANNEX I - PART IV: Overview table of ESS classification and list fo Fact sheets

Overview table:

Measure	Capability	ESS affected *(use CICES and US EPA catalogue!)*					Beneficiaries *(use US EPA categorization!)*[1]
		CICES section	**CICES division**	**CICES group**	**CICES class**	**DESSIN ESS** *(use US EPA nomenclature where applicable)*[2]	*(no beneficiary = only intermediate service)*
Construction and equipment of infiltration ponds	- enhancing water infiltration by additional permeable surface - increasing groundwater resources in the aquifer - improving water quality via soil-aquifer treatment - reducing pollutants in the aquifer - aquatic ecosystem creation	Provisioning services	Nutrition	Water	**Groundwater for drinking**	Water suitable for processing by a municipal drinking water treatment plant (DWTP). **FESS** **Fact sheet # 1**	Municipal Drinking Water Treatment Plant Operators
			Materials	Water	**Groundwater for non-drinking purposes**	Water suitable for cooling or processing industrial products. **FESS** **Fact sheet # 2**	Industrial processors
		Cultural services	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Intellectual and representative interactions	**Educational**	Research opportunities. **FESS** **Fact sheet # 3**	Researchers
				Physical and experiential interactions	**Experiential use of landscapes in different environmental settings**	(1) Opportunity to view the environment and organisms* within it, and groundwater phenomena. (2) Landscape that provides a sensory experience. (3) Sounds and scents that provide a sensory experience. * Organisms (i.e., flowers, plants, birds, mammals, reptiles, etc.) that can be viewed. **FESS** **Fact sheet # 4**	Experiencers and Viewers

[1]The US EPA categorization of beneficiaries can be found in the appendix (pages 46-70) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.
[2]The US EPA nomenclature of ecosystem services can be found in the appendix (pages 46-70) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

ANNEX I - PART V: Sustainability assessment table of indicators

Step A:

Proposed measure	Claimed / expected capability	Comparative Technology(ies)
Construction and equipment of infiltration ponds	Enhancing water infiltration by additional permeable surface	n/a
	Increasing groundwater resources in the aquifer	
	Improving water quality via soil-aquifer treatment	
	Reducing pollutants in the aquifer	
	Creation of a new surface water body (aquatic ecosystem)	

Step B: List of selected indicators

ID	Metric	Indicator	Unit	System	Alternative needed?		Data Availability yes	no
S111	Presence of microbial pathogens		[MPN] [MPN] [CFU/100ml] [CFU/ml]	WW/WS	yes		x	
S112	Presence of cyanobacteria and cyanotoxins			WW/WS	no			x
S113	Presence of toxic chemicals			WW/WS	no			x
S121	Economic impact (incl. Indirect and induced impacts) derived from initial spending for the solution itself	(economic impact - initial spending) / economic impact		WW/WS	no			x
S131	Number of jobs, amount of employment created by implementation of technology/solution		[1/a]	WW/WS	yes			x
S132	Number of jobs, amount of employment derived from improved cultural services		[1/a]	WW/WS	yes			x
S141	Number of beneficiaries affected		[-]	WW/WS	yes			x
S142	Categories of beneficiaries affected			WW/WS	yes			x
S151	Experiential and physical use of landscapes in different environmental settings		€/a	WW/WS	yes			x
S152	Intellectual and representative interactions (Educational)		[€]	WW/WS	yes		x	

							Data Availability	
ID	Metric	Indicator	Unit	System	Alternative needed?		yes	no
En111		Water Use Efficiency (WUE)	[%]	WS	no		x	
En112		Water Resources Availability	[%]	WS	no			x
En113	Treated wastewater for reuse	Recycle rate	[m³] or [%]	WS	no			x
En121		Efficient use of energy	[%]	WW/WS	no			x
En122		Energy recovery rate	[%]	WW/WS	no			x
En123		Green energy usage	[%]	WW/WS	no			x
En124	Energy consumed		[kWh/m³]	WW/WS	yes			x
En131	Materials, chemicals and other consumables		[kg/m³] or [kg/a]	WW/WS	yes			x
En132		Recovery of wastes	[%]	WW/WS	no			x
En211	Cumulative energy demand of fossil resources		[MJ]	WW/WS	yes			x
En212	Cumulative energy demand of nuclear resources		[MJ]	WW/WS	yes			x
En213	Global warming potential (100a)		[kg CO_2-eq]	WW/WS	yes			x
En214	Terrestrial acidification potential (100 a)		[kg SO_2-eq]	WW/WS	yes			x
En215	Freshwater eutrophication potential		[kg P-eq]	WW/WS	yes			x
En216	Marine eutrophication potential		[kg N-eq]	WW/WS	yes			x
En217	Particulate matter formation		[kg PM_{10}-eq]	WW/WS	yes			x
En218	Human toxicity (non-cancer)		[CTU_h]	WW/WS	yes			x
En219	Human toxicity (cancer)		[CTU_h]	WW/WS	yes			x
En220	Freshwater ecotoxicity		[CTU_e]	WW/WS	yes			x
F111	Investment expenditure		[€]	WW/WS	no		x	
F112	Annual operational expenditure		[€/year]	WW/WS	no		x	
F113	Avoided costs and/or additional monetary benefits from:		[€/year]	WW/WS	no		x	
F114	Other sources of financing (e. g. subsidies) aligned to the solution		[€]	WW/WS	no			x

							Data Availability	
ID	Metric	Indicator	Unit	System	Alternative needed?		yes	no
G111	Compliance improvement w/ relevant EU standards	water status reached / water status level required		WW/WS	no			x
G112	Compliance with relevant national, local standards			WW/WS	no			x
G121	Number of actors/stakeholders involved in planning, implementation, operations, and monitoring			WW/WS	yes			x
G122	Communicative events			WW/WS	yes			x
G131	Monitoring			WW/WS	yes			x
G132	Information dissemination			WW/WS	yes			x
A111		MTTF	[year/1 failure]	WW/WS	yes		x	
A112		MTBF	[years/1 failure]	WW/WS	yes		x	
A121		Sufficient capacity of the technology/solution to the expected use	[%]	WW/WS	no			x
A131		Adaptive capacity as: The probability that the item is	[0-1]	WW/WS	no		x	
A141		[Hours of exposed or "dirty work"*) on the site/total hours of work per year]*100	[number/reference time]	WW/WS	no			x
A142		Risk episodes, injuries on the site/total hours of work in test period	[number/reference time]	WW/WS	no			x
A151		percentage of load removed	[%]	WW	no			x
A211		Number of complaints about the technology (due to for instance Noise, Dust, Estetics, landscape)/reference time	[number/reference time]	WW/WS	no			x
A221		lifetime of solution/start up time		WW/WS	yes		x	
A231	training hours for staff operating the solution			WW/WS	yes			x

FESS FACTSHEET # 1

ESS HEAD	
Measure influencing the ESS	(1) construction and equipment of infiltration ponds
Capability influencing the ESS	(1) enhancing water infiltration by additional permeable surface (2) increasing groundwater resources in the aquifer (3) improving water quality via soil-aquifer treatment (4) reducing pollutants in the aquifer
CICES Section	Provisioning Services
CICES Division	Nutrition
CICES Group	Water
CICES Class	Groundwater for drinking
ESS *(use US EPA nomenclature!)*[2]	**Water suitable for processing by a municipal DWTP.**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Groundwater
Temporal scope	Per year
Spatial scope	Local along the aquifer area
FESS or Intermediate Service?	FESS

(for Intermed. Service stop after Impact I)	
Intermediary ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance (2) Filtration/sequestration/storage/ accumulation by ecosystems
Regulatory Threshold	RD1620/2007 (reclaimed water) RD140/2003 (drinking water standards) (Spanish government regulation) ACA threshold (quality of infiltrated water and abstraction permits)
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Municipal Drinking Water Plant Operators E.g. AB

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	Industry Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those*	Diffuse source: Contaminated sites/abandoned industrial sites. Groundwater pollution (solvents, PAHs, industrial	Organic volatile compounds found in the aquifer. Selected indicator	µg/L	Cetaqua: sampling campaigns in ENSAT project	Direct indicator	Local scale study required by project

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
addressed by the capability??)	pollutants)	compound: Trichloroethane				
	Point source: Industrial waste water.	Amount of effluents from industries with final disposal in the Llobregat river course.	m^3	ACA: data pending	Direct indicator	Public data from Catalan Water Agency
	Abstraction: Abstraction from industry.	Total annual volume of extractions from industries in the aquifer.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Diffuse source: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).	Number of not treated discharges in municipal WWTPs in Llobregat river	Number of episodes	AB: operator of WWTP Sant Feliu	Direct indicator	Public data from operator
	Point source: Urban waste water.	Number of inhabitants in the Baix Llobregat region.	Inhabitants (inh.)	Idescat	Direct indicator	Public data from national statistical institute
	Abstraction: Abstraction urban development.	Total annual volume of extractions in the aquifer for supply drinking water.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration.	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
RESPONSE *(describe in detail)*	Construction and equipment of infiltration ponds.	Area	m^2	ACA		Local scale study prior to the project.
		Infiltrated volume	m^3/year			
STATE *(only those relevant for the assessment of Impact I)*	Groundwater available for abstraction.	Groundwater level	m	CUADLL		
	Groundwater capacity of pollution attenuation.	Natural attenuation	%	Cetaqua		
	Salinity of groundwater.	Electrical conductivity/Salinity	µS/cm	CUADLL		
	Antropogenic pollution.	Chlorinated compounds in the aquifer	µg/L	Cetaqua		
	Organic pollution.	Organic content (Dissolved Organic Carbon)	mg/L	Cetaqua		
	Incomplete waste water treatment (denitrification).	Amonium concentration	mg/L	Cetaqua		
	Temperature fluctuations summer – winter.	Temperature	ºC	AB		
	Phisical particles in dissolution.	Turbidity	NTU	Cetaqua		
IMPACT I - PROVISION *(quantify if necessary for the*	Quality of available water.	Groundwater salinity	µS/cm (electrical conductivity)	CUADLL		Local scale study required by project.
	Volume of water available.	Groundwater availability	Mm^3	ACA		

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
assessment of Impact II, otherwise describe qualitatively)		nearby catchment point.				
IMPACT II - USE	Pump energy consumption:					
	Pump energy consumption.	Difference in energy consumption by the pump at x+1 metre.	kWh/hour			
	Hours of use.	Total amount of hours of use before measure implementation.	Hour/year			
	Energy cost.	Energy cost per kWh.	€/kWh			
	Pipes network breakdowns reparation:			AB		
	Number of breakdowns.	Difference in the number of breakdowns.	units/year			
	Breakdowns avoided due to the use of groundwater.	Percentage attributable to the use of groundwater.	%			
	Cost per breakdown.	Average cost per breakdown.	€/unit			
	Substitution from surface water to groundwater: 1) Pump energy consumption					

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
	Pump energy consumption.	Difference in energy consumption between groundwater and surface water	kWh/m^3			
	Water substituted.	Water quantity.	m^3			
	Energy cost.	Energy cost per kWh.	€/kWh			
	2) Pre-treatment needed in case of surface water:					
	Water treated.	Total amount of water treated substituted by groundwater.	m^3			
	Treatment cost.	Difference in treatment cost for groundwater.	€/m^3			
	3) Maintenance:					
	Corrective maintenance costs in pumping wells.	Relative corrective maintenance cost in pumping wells.	€/m^3*year			Private data from stakeholders.
	Corrective maintenance costs in pre-treatment.	Relative corrective maintenance cost in pre-treatment.	€/m^3*year			
	Water substitution.	Surface water substituted by groundwater.	Mm^3/year			
INDICATOR TABLE - Further explanation						

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources & data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
A further explanation is done in the respectives parts of the text description.						

RESULTS TABLE

	Case-relevant Element	Output	Output unit	Comments
PRESSURE	Organic volatile compounds found in the aquifer. Selected indicator compound: Trichloroethane.	500	µg/L	
	Amount of effluents from industries with final disposal in the Llobregat river course.	873,176	m^3	
	Total annual volume of extractions from industries in the aquifer.	3.66	Mm^3	
	Number of not treated discharges in municipal WWTPs in Llobregat river.	n/a	Number of episodes.	
	Number of inhabitants in the Baix Llobregat region.	771,516	Inhabitants (inh.).	
	Total annual volume of extractions in the aquifer for supply drinking water.	37.68	Mm^3	
	Total surface not urbanised nor industrialised (Permeable soils).	14,200	ha	
STATE	Groundwater level	3	m	
	Natural attenuation	90%	%	
	Electrical conductivity/Salinity	1,850-1,300 reduction	µS/cm	
	Chlorinated compounds in the aquifer	700-900	µg/L	
	Organic content (Dissolved Organic Carbon)	1-1.5	mg/L	
	Amonium concentration	1.8	mg/L	

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
	Temperature	18	ºC	
	Turbidity	5	NTU	
IMPACT I / PROVISION	Change in salinity in groundwater.	1,850-1,300 reduction	µS/cm	
	Change in groundwater availability nearby pumping wells.	10	Mm^3	
IMPACT II - USE	Avoided costs in energy for pumping:			
	Difference in energy consumption by the pump at x+3 metres.	12	kWh/hour	
	Number of hours of use in the whole year.	8,760	hour/year	
	Energy cost.	0.091	€/kWh	
	Avoided costs in pipes network breakdowns reparation:			
	Difference in the number of breakdowns.	230	units/year	
	Average cost per breakdown.	2,800	€/unit	
	Percentage attributable to the use of groundwater	10	%	
	Substitution from surface water to groundwater: 1) Increased costs in energy for pumping.			

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
	Difference in energy consumption between groundwater and surface water	0.11	kWh/m^3	
	Water quantity.	8	Mm^3/year	
	Energy cost.	0.091	€/kWh	
	2) Avoided costs in water treatment.			
	Total amount of water treated substituted by groundwater.	8	Mm^3/year	
	Treatment cost.	0.033	€/m^3	
	3) Increased costs in maintenance:			
	Corrective maintenance costs in pumping wells per Mm^3	7,975.46	€/Mm^3	
	Corrective maintenance costs in pre-treatment per Mm^3	2,857.14	€/Mm^3	
	Total amount of water treated substituted by groundwater.	8	Mm^3/year	
IMPACT II - Monetization	Avoided costs in energy for pumping.	9,586.80	€/year	**Valuation method:** Avoided costs
	Avoided costs in pipes network reparation breakdowns.	64,400		
	Substitution from surface water to groundwater: 1) Increased costs in energy for pumping.	-82,954.97		

RESULTS TABLE				
	Case-relevant Element	Output	Output unit	Comments
	2) Avoided costs in water treatment.	269,600		
	3) Increased costs in maintenance.	-40,946.54		

RESULTS TABLE - Description

A further explanation of the results is done in step 8 of the text description.
Negative figures express a loss or an increased cost.

FESS FACTSHEET #2

ESS HEAD	
Measure influencing the ESS	(1) construction and equipment of infiltration ponds
Capability influencing the ESS	(1) enhancing water infiltration by additional permeable surface (2) increasing groundwater resources in the aquifer (3) improving water quality via soil-aquifer treatment (4) reducing pollutants in the aquifer
CICES Section	Provisioning Services
CICES Division	Materials
CICES Group	Water
CICES Class	Groundwater for non-drinking
ESS *(use US EPA nomenclature!)*[2]	**Water suitable for cooling or processing industrial products.**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Groundwater
Temporal scope	Per year
Spatial scope	Local along the aquifer area
FESS or Intermediate Service?	FESS

(for Intermed. Service stop after Impact I)	
Intermediary ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance (2) Filtration/sequestration/storage/ accumulation by ecosystems
Regulatory Threshold	RD1620/2007 (reclaimed water) RD140/2003 (drinking water standards) (Spanish government regulation) ACA threshold (quality of infiltrated water and abstraction permits)
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Industrial Processors E.g. Damm

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	Industry Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE)*	Abstraction: Abstraction from industry.	Total annual volume of extractions from industries in the aquifer.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box)*	**Data quality** *(see catalogue in Framework p.XX!)*
(only those addressed by the capability??)	Abstraction: Urban development	Total annual volume of extractions in the aquifer for supply drinking water.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute
	Diffuse source: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).	Number of not treated discharges in municipal WWTPs in Llobregat river	Number of episodes	AB: operator of WWTP Sant Feliu	Direct indicator	Public data from operator
	Point source: Urban waste water.	Number of inhabitants in the Baix Llobregat region.	Inhabitants (inh.)	Idescat	Direct indicator	Public data from national statistical institute
	Abstraction: Abstraction urban development.	Total annual volume of extractions in the aquifer for supply drinking water.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration.	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute
RESPONSE	Construction and	Area	m^2	ACA		Local scale study

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box)*	**Data quality** *(see catalogue in Framework p.XX!)*
(describe in detail)	equipment of infiltration ponds.	Infiltrated volume	m^3/year			prior to the project.
STATE *(only those relevant for the assessment of Impact I)*	Groundwater available for abstraction.	Groundwater level	m	CUADLL		
	Groundwater capacity of pollution attenuation.	Natural attenuation	%	Cetaqua		
	Salinity of groundwater.	Electrical conductivity/Salinity	µS/cm	CUADLL		
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	Quality of available water.	Groundwater salinity	µS/cm (electrical conductivity)	DAMM		Local scale study prior to the project.
	Volume of water available.	Groundwater availability nearby catchment point.	Mm^3	CUADLL		
IMPACT II - USE	Volume of water abstracted.	Annual groundwater abstracted.	Mm^3	DAMM		
IMPACT II - Monetization	Pump energy consumption:			DAMM		Private data from stakeholders.
	Pump energy consumption.	Difference in energy consumption by the pump at x+1 metre.	kWh/m^3			
	Water flow.	Water flow.	m^3/h			

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box)*	**Data quality** *(see catalogue in Framework p.XX!)*
	Hours of use per year.	Hours of use per year.	h/year			
	Energy cost.	Energy cost per kWh.	€/kWh			
	Membranes system energy consumption:					
	Membrane system energy consumption.	Difference in energy consumption by each membrane system.	kWh/m^3			
	Water flow.	Water flow.	m^3/h			
	Hours of use per year.	Hours of use per year.	h/year			
	Energy cost per kWh.	€/kWh	Energy cost.			
	Membranes system purchasing:					
	Number of membranes.	Number of membranes.	units			
	Lifetime of the membranes.	Lifetime of the membranes.	years			
	Membranes system cost.	Difference in the cost of membranes system.	€/membrane			

INDICATOR TABLE - Further explanation

A further explanation is done in the respectives parts of the text description.

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	Organic volatile compounds found in the aquifer. Selected indicator compound: Trichloroethane.	500	µg/L	
	Amount of effluents from industries with final disposal in the Llobregat river course.	873,176	m^3	
	Total annual volume of extractions from industries in the aquifer.	3.66	Mm^3	
	Number of not treated discharges in municipal WWTPs in Llobregat river.	n/a	Number of episodes.	
	Number of inhabitants in the Baix Llobregat region.	771,516	Inhabitants (inh.).	
	Total annual volume of extractions in the aquifer for supply drinking water.	37.68	Mm^3	
	Total surface not urbanised nor industrialised (Permeable soils).	14,200	ha	
STATE	Groundwater level	1	m	
	Natural attenuation	90%	%	
	Electrical conductivity/Salinity	1,300-1,800	µS/cm	
IMPACT I / PROVISION	Change in salinity in groundwater.	3,500	µS/cm (electrical conductivity) (peaks)	
	Change in groundwater availability nearby pumping wells.	10	Mm^3	

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
IMPACT II - USE	Annual groundwater abstracted.	2.113	Mm^3	
IMPACT II - Monetization	<u>Avoided costs in energy for pumping:</u>			
	Difference in energy consumption by the pump at x+1 metre.	0.084	kWh/m^3	
	Water flow.	250	m^3/h	
	Hours of use per year.	8,454	h/year	
	Energy cost	0.1	€/kWh	
	<u>Avoided costs in energy for membranes system:</u>			
	Difference in energy consumption by each membrane system.	0.53	kWh/m^3	
	Water flow.	250	m^3/h	
	Hours of use per year.	8,454	h/year	
	Energy cost.	0.1	€/kWh	
	<u>Avoided cost in membranes system purchasing:</u>			
	Number of membranes.	696	Units	
	Lifetime of the membranes.	5	Years	
	Difference in purchasing cost by each membrane.	575	€	
IMPACT II -	Avoided costs in energy for pumping.	17,753	€/year	**<u>Valuation method:</u>**

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
Monetization	Avoided costs in energy for membrane system.	112,016		Avoided costs
	Avoided costs in membranes system purchasing.	84,906		

RESULTS TABLE - Description

A further explanation of the results is done in step 8 of the text description.

FESS FACTSHEET #3

ESS HEAD	
Measure influencing the ESS	(1) construction and equipment of infiltration ponds
Capability influencing the ESS	(1) enhancing water infiltration by additional permeable surface (2) increasing groundwater resources in the aquifer (3) improving water quality via soil-aquifer treatment (4) reducing pollutants in the aquifer (5) aquatic ecosystem creation
CICES Section	Cultural services
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Intellectual and representative interactions
CICES Class	Educational
ESS *(use US EPA nomenclature!)*[2]	**Research opportunities**
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Lakes and ponds
Temporal scope	per year
Spatial scope	Ponds and surrounding area

FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS
Intermediary ESS required *(use CICES catalogue!)*	(1) Hydrological cycle and water flow maintenance (2) Filtration/sequestration/storage/ accumulation by ecosystems
Regulatory Threshold	Non applicable
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Researchers

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	Industry	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
	Urban development					
PRESSURE *(From IMPRESS/WISE) (only those*	Abstraction: Abstraction from industry.	Total annual volume of extractions from industries in the aquifer.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Abstraction: Urban	Total annual volume of	Mm^3	CUADLL	Direct indicator	Private data form

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
addressed by the capability??)	development	extractions in the aquifer for supply drinking water.				stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute
	Diffuse source: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).	Number of not treated discharges in municipal WWTPs in Llobregat river	Number of episodes	AB: operator of WWTP Sant Feliu	Direct indicator	Public data from operator
	Point source: Urban waste water.	Number of inhabitants in the Baix Llobregat region.	Inhabitants (inh.)	Idescat	Direct indicator	Public data from national statistical institute
	Abstraction: Abstraction urban development.	Total annual volume of extractions in the aquifer for supply drinking water.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration.	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute
RESPONSE *(describe in*	Construction and equipment of infiltration ponds.	Area	m^2	ACA		Local scale study prior to the project.
		Infiltrated volume	m^3/year			

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
detail)						
STATE *(only those relevant for the assessment of Impact I)*	Permeable surface available for aquifer replenishment.	Infiltration area	m^2	ACA		
	Transmissive unsaturated area able to infiltrate water.	Infiltration capacity	m^3/m^2/day	ACA		
	Groundwater available for abstraction.	Groundwater level	m	CUADLL		
	Groundwater capacity of pollution attenuation.	Natural attenuation	%	Cetaqua		
	Salinity of groundwater.	Electrical conductivity/Salinity	µS/cm	CUADLL		
	Antropogenic pollution.	Chlorinated compounds in the aquifer	µg/L	Cetaqua		
	Agricultural pollution.	Nitrate concentration	mg/L	Cetaqua		
	Organic pollution.	Organic content (Dissolved Organic Carbon)	mg/L	Cetaqua		
	Not regulated pollution (emerging contaminants).	Micropollutants (pharmaceuticals, pesticides…)	µg/L	Cetaqua		
	Incomplete waste water treatment (denitrification).	Amonium concentration	mg/L	Cetaqua		
	Temperature fluctuations	Temperature	ºC	AB		

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
	summer – winter.					
	Phisical particles in dissolution.	Turbidity	NTU	Cetaqua		
	Birds biodiversity.	Number of bird species watched in the area	Bird species	Cetaqua		
	Natural environment enriched for aquatic species.	Volume of water available for amphibians and aquatic species	m^3	ACA		
	Capacity of attraction of visitors by a water system.	Percentage of days with surface water available	days	CUADLL		
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*
IMPACT II - USE	Research studies value:			CETAQUA		Local scale study prior to the project.
	Research studies conducted at the infiltration ponds.	Number of research projects based on infiltration ponds.	Projects			
	PhDs conducted value:					

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
	PHDs conducted at the infiltration ponds.	Number of PHDs based on infiltration ponds.	PHD students			
	Technical visits value:					
	Technical visits conducted at the infiltration ponds.	Number of visitors at the infiltration ponds.	People			
IMPACT II - Monetization	Suitability of an ecosystem or a green infrastructure for acquiring research budget.	Research studies value	€/year	CETAQUA		
	Suitability of an ecosystem or a green infrastructure to be studied in PhDs	PhDs conducted value	€/year	CETAQUA		
	Suitability of an ecosystem or a green infrastructure to receive technical visits	Technical visits value	€/year	CETAQUA		
INDICATOR TABLE - Further explanation						
A further explanation is done in the respectives parts of the text description.						

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	Organic volatile compounds found in the aquifer. Selected indicator compound: Trichloroethane.	500	µg/L	
	Amount of effluents from industries with final disposal in the Llobregat river course.	873,176	m^3	
	Total annual volume of extractions from industries in the aquifer.	3.66	Mm^3	
	Number of not treated discharges in municipal WWTPs in Llobregat river.	n/a	Number of episodes.	
	Number of inhabitants in the Baix Llobregat region.	771,516	Inhabitants (inh.).	
	Total annual volume of extractions in the aquifer for supply drinking water.	37.68	Mm^3	
	Total surface not urbanised nor industrialised (Permeable soils).	14,200	ha	
STATE	Infiltration area	56,300	m2	
	Infiltration capacity	1	m3/m2/day	
	Groundwater level	1-4	m	
	Natural attenuation	90%	%	
	Electrical conductivity/Salinity	1,850-1,300 reduction	µS/cm	
	Chlorinated compounds in the aquifer	700-900	µg/L	

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
	Nitrate concentration	8	mg/L	
	Organic content (Dissolved Organic Carbon)	1-1.5	mg/L	
	Micropollutants (pharmaceuticals, pesticides…)	0	µg/L	
	Amonium concentration	1.8	mg/L	
	Temperature	18	ºC	
	Turbidity	5	NTU	
	Number of bird species watched in the area	52	Bird species	
	Volume of water available for amphibians and aquatic species	107,000	m3	
	Percentage of days with surface water available	75	%	
IMPACT I / PROVISION	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*
IMPACT II - USE	Value of research studies conducted at the infiltration ponds:			Projects: Gabardine, MARSOL, DEMEAU, PREPARED, and Life + ENSAT.
	Number of research projects based on infiltration ponds.	5	Projects	
	Total research budget attributable to ponds existence.	3,173,777.06	€	
	Lifetime of the ponds.	8	Years	

RESULTS TABLE	Case-relevant Element	Output	Output unit	Comments
	<u>Value of PhDs conducted at the infiltration ponds:</u>			Students: Manuela Barbieri, Marco Barahona, Danielle Pedretti, Cristina Valhondo, Carme Barba and Albert Carles.
	Number of PhDs based on infiltration ponds.	6	Students	
	Grant per PhD student.	61,544.00	€	
	Lifetime of the ponds.	8	Years	
	<u>Value of technical visits conducted at the infiltration ponds:</u>			
	Number of visitors at the infiltration ponds.	232	Visitors	
	Average travel cost from Cetaqua to the ponds.	13	€	
	Lifetime of the ponds.	8	Years	
IMPACT II - Monetization	Annual value of research studies conducted at the infiltration ponds.	433,251.67	€/year	**<u>Valuation method:</u>** Revealed preferences
	Annual value of PhDs conducted at the infiltration ponds.	50,408.15		
	Annual value of the technical visits conducted at the infiltration ponds.	411.71		**<u>Valuation method:</u>** Travel costs

RESULTS TABLE - Description

A further explanation of the results is done in step 8 of the text description.

FESS FACTSHEET #4

ESS HEAD	
Measure influencing the ESS	(1) construction and equipment of infiltration ponds
Capability influencing the ESS	(5) aquatic ecosystem creation
CICES Section	Cultural services
CICES Division	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]
CICES Group	Physical and experiential interactions
CICES Class	Experiential use of landscapes in different environmental settings
ESS *(use US EPA nomenclature!)*[2]	**(1) Opportunity to view the environment and organisms* within it, and groundwater phenomena.** **(2) Landscape that provides a sensory experience.** **(3) Sounds and scents that provide a sensory experience.** * Organisms (i.e., flowers, plants, birds, mammals, reptiles, etc.) that can be viewed.
Ecosystem *(use US EPA classification!)*[3]	***Class:*** Aquatic. ***Sub-class:*** Lakes and ponds
Temporal scope	per year
Spatial scope	Ponds and surrounding area
FESS or Intermediate Service? *(for Intermed. Service stop after Impact I)*	FESS

Intermediary ESS required *(use CICES catalogue!)*	(3) Maintaining nursery populations and habitats
Regulatory Threshold	Non applicable
Beneficiary *(From USEPA[1]/NACE)* *(continue after Impact I only if beneficiary is present)*	Experiencers and viewers

[3]The US EPA classification of ecosystems can be found in the appendix (page 42) of:
DH Landers and Nahlik AM. 2013. Final Ecosystem Goods and Services Classification System (FEGS-CS). EPA/600/R-13/ORD-004914. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
DRIVER *(From IMPRESS/WISE) (only those addressed by the capability??)*	Urban development	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*	*not to be quantified*
PRESSURE *(From IMPRESS/WISE) (only those addressed by the capability??)*	Diffuse source: Discharges not connected to sewerage network: River water pollution (pesticides, pharmaceuticals, TOC, ammonium).	Number of not treated discharges in municipal WWTPs in Llobregat river	Number of episodes	AB: operator of WWTP Sant Feliu	Direct indicator	Public data from operator

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
	Point source: Urban waste water.	Number of inhabitants in the Baix Llobregat region.	Inhabitants (inh.)	Idescat	Direct indicator	Public data from national statistical institute
	Abstraction: Abstraction urban development.	Total annual volume of extractions in the aquifer for supply drinking water.	Mm^3	CUADLL	Direct indicator	Private data form stakeholders
	Hydrological alteration: Reduction of permeable surface for precipitation infiltration.	Total surface not urbanised nor industrialised (Permeable soils)	Km^2	Idescat	Direct indicator	Public data from national statistical institute
RESPONSE *(describe in detail)*	Construction and equipment of infiltration ponds.	Area	m^2	ACA		Local scale study prior to the project.
		Infiltrated volume	m^3/year			
STATE *(only those relevant for the assessment of Impact I)*	Permeable surface available for aquifer replenishment.	Infiltration area	m^2	ACA		Qualitative regional study.
	Incomplete waste water treatment (denitrification).	Amonium concentration	mg/L	Cetaqua		
	Birds biodiversity.	Number of bird species watched in the area	Bird species	Cetaqua		
	Natural environment enriched for aquatic species.	Volume of water available for amphibians and aquatic species	m^3	ACA		
	Capacity of attraction of visitors by a water system.	Percentage of days with surface water available	days	CUADLL		

INDICATOR TABLE						
	Case-relevant Element	**Indicator**	**Output unit**	**Data sources/ Data availability**	**Indicator quality** *(see explanation in Fw Box XX!)*	**Data quality** *(see catalogue in Framework p.XX!)*
IMPACT I - PROVISION *(quantify if necessary for the assessment of Impact II, otherwise describe qualitatively)*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*
IMPACT II - USE	Infiltration ponds visitors.	Number of visitors	Visitors/year	CUADLL		
	Transport cost	Transport cost	€/visitor	CETAQUA		
	Travel time	Travel time	hours	CETAQUA		
	Time value	Time value	€/hour	Idescat		
IMPACT II - Monetization	Suitability of an ecosystem or a green infrastructure to be visited.	Visitors value	€/year	CETAQUA		

INDICATOR TABLE - Further explanation
A further explanation is done in the respectives parts of the text description.

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
PRESSURE	Number of not treated discharges in municipal WWTPs in Llobregat river.	n/a	Number of episodes.	
	Number of inhabitants in the Baix Llobregat region.	771,516	Inhabitants (inh.).	
	Total annual volume of extractions in the aquifer for supply drinking water.	37.68	Mm^3	
	Total surface not urbanised nor industrialised (Permeable soils).	14,200	ha	
STATE	Infiltration area	56,300	m2	
	Amonium concentration	1.8	mg/L	
	Number of bird species watched in the area	52	Bird species	
	Volume of water available for amphibians and aquatic species	107,000	m3	
	Percentage of days with surface water available	75	%	
IMPACT I / PROVISION	*Non applicable*	*Non applicable*	*Non applicable*	*Non applicable*
IMPACT II - USE	Number of visitors	5,250	Visitors/year	
	Transport cost	0.53	€/visitor	
	Travel time	0.18	hours	
	Time value	7.815	€/hour	

RESULTS TABLE				
	Case-relevant Element	**Output**	**Output unit**	**Comments**
IMPACT II - Monetization	Annual value of visitors	20,477.30	€/year	Valuation method: Travel cost

RESULTS TABLE - Description
A further explanation of the results is done in step 8 of the text description.

ANNEX II: Table of population in Baix Llobregat region

Table 36: Population in Baix Llobregat region

Source: Idescat

NOTE: There is a lack of data in 1980 and 1997

Year	Population	Density [inh/Km²]	Year	Population	Density [inh/Km²]
1975	511,971	1053.44	2000	678,724	1396.55
1976	521,366	1072.77	2001	692,260	1424.40
1977	538,806	1108.65	2002	710,612	1462.16
1978	553,102	1138.07	2003	730,111	1502.29
1979	564,556	1161.64	2004	741,024	1524.74
1981	573,461	1179.96	2005	757,814	1559.29
1982	579,426	1192.23	2006	767,967	1580.18
1983	583,245	1200.09	2007	771,516	1587.48
1984	587,551	1208.95	2008	781,749	1608.54
1985	591,765	1217.62	2009	793,655	1633.03
1986	583,354	1200.32	2010	798,468	1642.94
1987	587,841	1209.55	2011	803,705	1653.71
1988	596,996	1228.39	2012	806,799	1660.08
1989	606,729	1248.41	2013	808,644	1663.88
1990	613,474	1262.29	2014	806,249	1658.95
1991	610,192	1255.54			
1992	616,595	1268.71			
1993	628,323	1292.85			
1994	637,398	1311.52			
1995	642,889	1322.82			
1996	643,419	1323.91			
1998	654,958	1347.65			
1999	666,173	1370.73			

Annex III: Tables of main publications about ESS valuation in the Llobregat river basin

Table 37: Main publications about ESS valuation in the Llobregat river Basin

River Basin management & water technologies		
Short name	**Full name (citation)**	**Abstract / relevant aspects**
Honey-Rosés, 2012 [1]	Honey-Rosés, J. (2012). Ecosystem Services in planning practice for urban and technologically advanced landscapes. Dissertation submitter in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Regional Planning in the Graduate College of the University of Illinois at Urbana-Champaign, 2012.	Chapter 3: Urban Ecosystem Services and technological change. Case study: the water treatment technologies in Barcelona (p. 94) "By choosing to install new water treatment systems downstream, water managers preference for technological strategies over ecosystems approaches for improving source water quality. And with the new sophisticated treatment system, they attained the capacity to meet output water quality standards across a much wider range of input water qualities. Therefore, according to conventional wisdom the sophisticated new technology further isolated managers from the influence of ecosystem processes. To assess the impact of technological change on the value of ecosystem services I analysed three ecosystem services before and after the adoption of new membrane treatment: - Water quality protection (affecting salinity) - Thermal regulation (affecting temperature) - Nutrient cycling (affecting ammonium)
Honey-Rosés, 2013 [4]	Honey-Rosés, J.; Acuña, V.; Bardina, M.; Brozović, N.; Marcé, R.; Munné, A.; Sabater, S.; Termes, M.; Valero, F.; Vega, A.; Schneider, D.W. (2014) Examining the Demand for Ecosystem Services: The Value of Stream Restoration for Drinking Water Treatment Managers in the Llobregat River, Spain. Ecological Economics 90 (2013) 196–205	Ecosystem services would be incorporated into decision making more often if researchers were to focus more on the demand for these services rather than the supply. This implies examining the economic, decision-making and technological context of the end-user before trying to attribute economic values to well-known biological processes. This paper provides an example of how this research approach for ecosystems services could unfold. In the Llobregat River in north-eastern Spain, higher stream temperatures require water treatment managers to switch on costly water treatment equipment especially during warm months. This creates an opportunity to align the economic interests of downstream water users with the environmental goals of river managers. A restored riparian forest or an increase in stream flow could reduce the need for this expensive equipment by reducing stream temperatures below critical thresholds. We used the Stream Network Temperature Model (SNTEMP) to test the impact of increasing shading and discharge on stream temperature at the intake of the drinking water treatment plant. The value of the stream temperature ecosystem services provided by existing forests is €79,000 per year for the water treatment facility, while additional riparian forest restoration along the Llobregat River could generate economic savings for water treatment managers in the range of €57,000–€156,000 per year. Stream restoration at higher elevations would yield greater benefits than restoration in the lower reaches. Moderate increases in stream discharge (25%) could generate savings of €40,000 per year.

Honey-Rosés, 2014 [5]	Jordi Honey-Rosés, J.; Schneider, D.W.; Brozovic, N. (2014). Changing Ecosystem Service Values Following Technological Change. Environmental Management (2014) 53:1146–1157	Research on ecosystem services has focused mostly on natural areas or remote places, with less attention given to urban ecosystem services and their relationship with technological change. However, recent work by urban ecologists and urban designers has more closely examined and appreciated the opportunities associated with integrating natural and built infrastructures. Nevertheless, a perception remains in the literature on ecosystem services that technology may easily and irreversibly substitute for services previously obtained from ecosystems, especially when the superiority of the engineered system motivated replacement in the first place. We emphasize that the expected trade-off between natural and manufactured capital is false. Rather, as argued in other contexts, the adoption of new technologies is complementary to ecosystem management. The complementarity of ecosystem services and technology is illustrated with a case study in Barcelona, Spain where the installation of sophisticated water treatment technology increased the value of the ecosystem services found there. Interestingly, the complementarity between natural and built infrastructures may remain even for the very ecosystems that are affected by the technological change. This finding suggests that we can expect the value of ecosystem services to co-evolve with new technologies. Technological innovation can generate new opportunities to harness value from ecosystems, and the engineered structures found in cities may generate more reliance on ecosystem processes, not less.
Momblanch et al, 2015 [9]	Momblanch, A.; Paredes-Arquiola, J.; Munné A.; Manzano, A.; Arnau J.; Andreu, J. (2015). Managing water quality under drought conditions in the Llobregat River Basin. Science of the Total Environment 503–504 (2015) 300–318	The primary effects of droughts on river basins include both depleted quantity and quality of the available water resources, which can render water resources useless for human needs and simultaneously damage the environment. Isolated water quality analyses limit the action measures that can be proposed. Thus, an integrated evaluation of water management and quality is warranted. In this study, a methodology consisting of two coordinated models is used to combine aspects of water resource allocation and water quality assessment. Water management addresses water allocation issues by considering the storage, transport and consumption elements. Moreover, the water quality model generates time series of concentrations for several pollutants according to the water quality of the runoff and the demand discharges. These two modules are part of the AQUATOOL decision support system shell for water resource management. This tool facilitates the analysis of the effects of water management and quality alternatives and scenarios on the relevant variables in a river basin. This paper illustrates the development of an integrated model for the Llobregat River Basin. The analysis examines the drought from 2004 to 2008, which is an example of a period when the water system was quantitative and qualitatively stressed. The performed simulations encompass a wide variety of water management and water quality measures; the results provide data for making informed decisions. Moreover, the results demonstrated the importance of combining these measures depending on the evolution of a drought event and the state of the water resources system.

Climate change impact in ESS		
Short name	**Full name (citation)**	**Abstract**
Sabater et al., 2012 [3]	Sabater, S.; Ginebreda, A.; Barceló, D. (2012) The Llobregat. The Story of a polluted mediterranean river. Book. The Handbook of environmental chemistry 21. Springer-Verlag Berlin Heidelberg 2012	**CHAPTER: Ecosystem Services in an impacted watershed. The Relevance of Hydrology, Human Influence, and Global Change (M. Terrado et al.)** Climate change previsions in the Mediterranean regions are associated with more frequent extreme climatic conditions, which could alter water availability and impact the delivery of ecosystem services. In this chapter, the vulnerability of hydrological ecosystem services to recently observed climatic extremes in the Llobregat River basin is assessed. Provisioning (water) and regulating services (erosion control and water purification) were quantified under mean climatic conditions and subsequently compared to their provision under wet and dry conditions. Results stress that in semiarid basins submitted to chronic human pressure, hydrological services are very sensitive to climatic extremes. Provisioning services are important in mean and wet climatic conditions and are the most threatened in dry conditions when their reduction can approach 100%. Conversely, water purification (regulating service) has its largest contribution to human wellbeing in dry conditions. These results constitute a lower boundary of the possible benefits provided by ecosystem services in the basin.
Bangash et al., 2013 [8]	Bangash, R.F.; Passuello, A.; Sanchez-Canales, M.; Terrado, M.; López, A.; Elorza , F.J.; Ziv, G.; Acuña, V.; Schuhmacher, M. (2013). Ecosystem services in Mediterranean river basin: Climate change impact on water provisioning and erosion control. Science of the Total Environment 458–460 (2013) 246–255	The Mediterranean basin is considered one of the most vulnerable regions of the world to climate change and such changes impact the capacity of ecosystems to provide goods and services to human society. The predicted future scenarios for this region present an increased frequency of floods and extended droughts, especially at the Iberian Peninsula. This paper evaluates the impacts of climate change on the water provisioning and erosion control services in the densely populated Mediterranean Llobregat river basin of. The assessment of ecosystem services and their mapping at the basin scale identify the current pressures on the river basin including the source area in the Pyrenees Mountains. Drinking water provisioning is expected to decrease between 3 and 49%, while total hydropower production will decrease between 5 and 43%. Erosion control will be reduced by up to 23%, indicating that costs for dredging the reservoirs as well as for treating drinking water will also increase. Based on these data, the concept for an appropriate quantification and related spatial visualization of ecosystem service is elaborated and discussed.

Risk Assessment / identification of stressors		
Short name	**Full name (citation)**	**Abstract / relevant aspects**
Gottardo et al., 2011 [2]	Gottardo, S,; Semenzin, E.; Giove, S.; Zabeo , A.; Critto, A.; de Zwart, D.; Ginebreda, A.; Marcomini, A. (2011). Integrated risk assessment for WFD ecological status classification applied to Llobregat river basin (Spain). Part I—Fuzzy approach to aggregate biological indicators. Science of the Total Environment 409 (2011) 4701–4712	Water Framework Directive (WFD) requirements and recommendations for Ecological Status (ES) classification of surface water bodies do not address all issues that Member States have to face in the implementation process, such as selection of appropriate stressor-specific environmental indicators, definition of class boundaries, aggregation of heterogeneous data and information and uncertainty evaluation. In this context the "One-Out, All-Out" (OOAO) principle is the suggested approach to lead the entire classification procedure and ensure conservative results. In order to support water managers in achieving a more comprehensive and realistic evaluation of ES, an Integrated Risk Assessment (IRA) methodology was developed. It is based on the Weight of Evidence approach and implements a Fuzzy Inference System in order to hierarchically aggregate a set of environmental indicators, which are grouped into five Lines of Evidence (i.e. Biology, Chemistry, Ecotoxicology, Physico-chemistry and Hydromorphology). The whole IRA methodology has been implemented as an individual module into a freeware GIS (Geographic Information System)-based Decision Support System (DSS), named MODELKEY DSS. The paper focuses on the conceptual and mathematical procedure underlying the evaluation of the most complex Line of Evidence, i.e. Biology, which identifies the biological communities that are potentially at risk and the stressors that are most likely responsible for the observed alterations. The results obtained from testing the procedure through application of the MODELKEY DSS to the Llobregat case study are reported and discussed.

Coastal areas related to river basin		
Short name	**Full name (citation)**	**Abstract / relevant aspects**
Brenner et al., 2010 [10]	Brenner, J.; Jiménez, J.; Sardá, R.; Garola, A. (2010). An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53 (2010) 27–38	A spatial value transfer analysis was performed to generate baseline estimates of the value of ecosystem services in the coastal zone of Catalonia, Spain. The study used the best available conceptual frameworks, data sources, and analytical techniques to generate non-market monetary value estimates that can be used to identify scarce ecosystem services among competing coastal uses. The approach focused on natural and seminatural, terrestrial and marine systems, which provide essential services that are not considered in current economic markets. Results show that in 2004 a substantial economic value of $3,195 million USD/yr was delivered to local citizens by surrounding ecosystems. In a spatially explicit manner, the approach illustrates the contribution made by natural environmental systems to the well being of communities in the coastal zone of Catalonia. It is hoped that this study will highlight the need to consider these coastal systems in future management strategies to ensure their proper maintenance and conservation..

Annex IV: List of bird species identified in SVH infiltration system

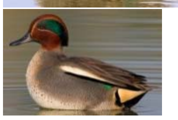
Photo	Species (Scientific name / CAT / ENG)	Photo	Species Scientific name / CAT / ENG)
	***Accipiter gentilis*** CAT: Astor ENG: Northern goshawk NOTE: Condition: near threatened		***Bubulcus ibis*** CAT: Esplugabous ENG: Cattle egret NOTE: 3 times observed in river
	***Actitis hypoleucos*** CAT: Xivitona vulgar ENG: Common sandpiper NOTE: 5 times observed		***Buteo buteo*** CAT: Aligot comú ENG: Buteo NOTE: 1 times observed in westlands
	***Alauda arvensis*** CAT: Alosa vulgar ENG: Eurasian skylark NOTE: 1 time observed in orchards along the river		***Carduelis cannabina*** CAT: Passerell comú ENG: Common linnet NOTE: 3 times observed in Llobregat river passing through the SVH
 	***Anas crecca*** CAT: Xarxet comú ENG: Eurasian teal NOTE: 4 times observed in river		***Carduelis carduelis*** CAT: Cadernera ENG: European goldfinch
	***Anas platyrhynchos*** CAT: Ànec collverd ENG: Mallard		***Cettia cetti*** CAT: Rossinyol bord ENG: Cetti's warbler NOTE: Condition: least concern
	***Anthus pratensis*** CAT: Titella ENG: Meadow pipit		***Charadrius dubius*** CAT: Corriol petit ENG: Common ringed plover NOTE: 7 times observed in a Sant Vicenç dels Horts
	***Anthus spinoletta*** CAT: Grasset de muntanya ENG: Water pipit NOTE: 1 times observed in river		***Cisticola juncidis*** CAT: Trist ENG: Zitting cisticola

Photo	Species (Scientific name / CAT / ENG)	Photo	Species Scientific name / CAT / ENG)
	***Ardea cinerea*** CAT: Bernat pescaire ENG: Grey heron NOTE: A total of 4 times observed (1 in wetlands and 3 in river)		***Columba livia*** CAT: Colom domestic ENG: Rock dove
	***Columba palumbus*** CAT: Tudó ENG: Common wood pigeon		***Falco tinnunculus*** CAT: Xoriguer comú ENG: Common kestrel NOTE: 2 times observed in river
	***Corvus corax*** CAT: Corb Corvus NOTE: Condition: least concern		***Fringilla coelebs*** CAT: Pinsà comú Common chaffinch
	***Egretta garzetta*** CAT: Martinet blanc ENG: Little egret NOTE: A total of 2 times observed (1 in wetlands and 1 in river)		***Galerida cristata*** CAT: Cogullada vulgar ENG: Crested lark NOTE: Condition: least concern
	***Emberiza cirlus*** CAT: Gratapalles ENG: Ortolan bunting NOTE: Minim 7 times observed in river		***Gallinago gallinago*** CAT: Becadell comú ENG: Common snipe NOTE: 3 times observed in river
	***Emberiza schoeniclus*** CAT: Repicatalons ENG: Common reed bunting		***Gallinula chloropus*** CAT: Polla d'aigua Common moorhen
	***Erithacus rubecula*** CAT: Pit-roig ENG: European robin		***Himantopus himantopus*** CAT: Camesllargues ENG: Black-winged stilt NOTE: 5 times observed in a Sant Vicenç dels Horts
	***Estrilda astrild*** CAT: Bec de corall senegalès ENG: Common waxbill NOTE: Condition: not applicable		***Larus michahellis*** CAT: Gavià argentat ENG: Yellow-legged gull

Photo	Species (Scientific name / CAT / ENG)	Photo	Species Scientific name / CAT / ENG)
	***Larus ridibundus*** CAT: Gavina vulgar ENG: Black-headed gull		***Phoenicurus ochruros*** CAT: Cotxa fumada ENG: Black redstart
	***Motacilla alba*** CAT: Cuereta blanca vulgar ENG: White wagtail NOTE: Condition: least concern		***Phylloscopus collybita*** CAT: Mosquiter comú ENG: Common chiffchaff
	***Motacilla cinerea*** CAT: Cuereta torrentera ENG: Grey wagtail		***Pica pica*** CAT: Garsa ENG: Eurasian magpie
	***Myiopsitta monachus*** CAT: Cotorreta de pit gris ENG: Monk parakeet		***Picus viridis*** CAT: Picot verd ENG: European green woodpecker NOTE: 1 time observed in wetlands
	***Passer domesticus*** CAT: Pardal comú ENG: House sparrow		***Psittacula krameri*** CAT: Cotorra de Kramer ENG: Rose-ringed parakeet NOTE: 8 times observed in wetlands
	***Passer montanus*** CAT: Pardal xarrec ENG: Eurasian tree sparrow		***Remiz pendulinus*** CAT: Teixidor ENG: Penduline tit
	***Phalacrocorax carbo*** CAT: Corb marí gros ENG: Cormorant NOTE: A total of 9 times observed (2 in wetlands and 7 in river)		***Tachybaptus ruficollis*** CAT: Cabusset ENG: Little grebe NOTE: A total of 3 times observed (1 in wetlands and 2 in river)

Photo	Species (Scientific name / CAT / ENG)	Photo	Species Scientific name / CAT / ENG)
	***Serinus serinus*** CAT: Gafarró ENG: Atlantic canary		***Tringa ochropus*** CAT: Xaivita ENG: Green sandpiper NOTE: 1 time observed in river
	***Streptopelia decaocto*** CAT: Tórtora turca ENG: Eurasian collared dove		***Upupa epops*** CAT: Puput ENG: Hoopoe NOTE: Condition: least concern
	***Streptopelia turtur*** CAT: Tórtora ENG: European turtle dove NOTE: Condition: least concern		***Sylvia atricapilla*** CAT: Tallarol de casquet ENG: Eurasian blackcap
	***Sturnus vulgaris*** CAT: Estornell vulgar ENG: Common starling		***Sylvia melanocephala*** CAT: Tallarol capnegre ENG: Sardinian warbler

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