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 1: Aarhus case

Lead Author: DHI,

April 2016, revision October 2017

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

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.

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**.

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.

DELIVERABLE NUMBER	**WORK PACKAGE**
D13.1	WP13
LEAD BENEFICIARY	**DELIVERABLE AUTHOR(S)**
DHI	Niels Riegels (DHI)
QUALITY ASSURANCE	
Anders Lynggaard-Jensen (DHI)	Rikke Margrethe Closter (DHI)
PLANNED DELIVERY DATE	**ACTUAL DELIVERY DATE**
15/04/2016	15/04/2016 (revision 23/10/2017)
DISSEMINATION LEVEL	

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

Table of contents

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

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

List of tables

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

List of figures

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

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

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

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.

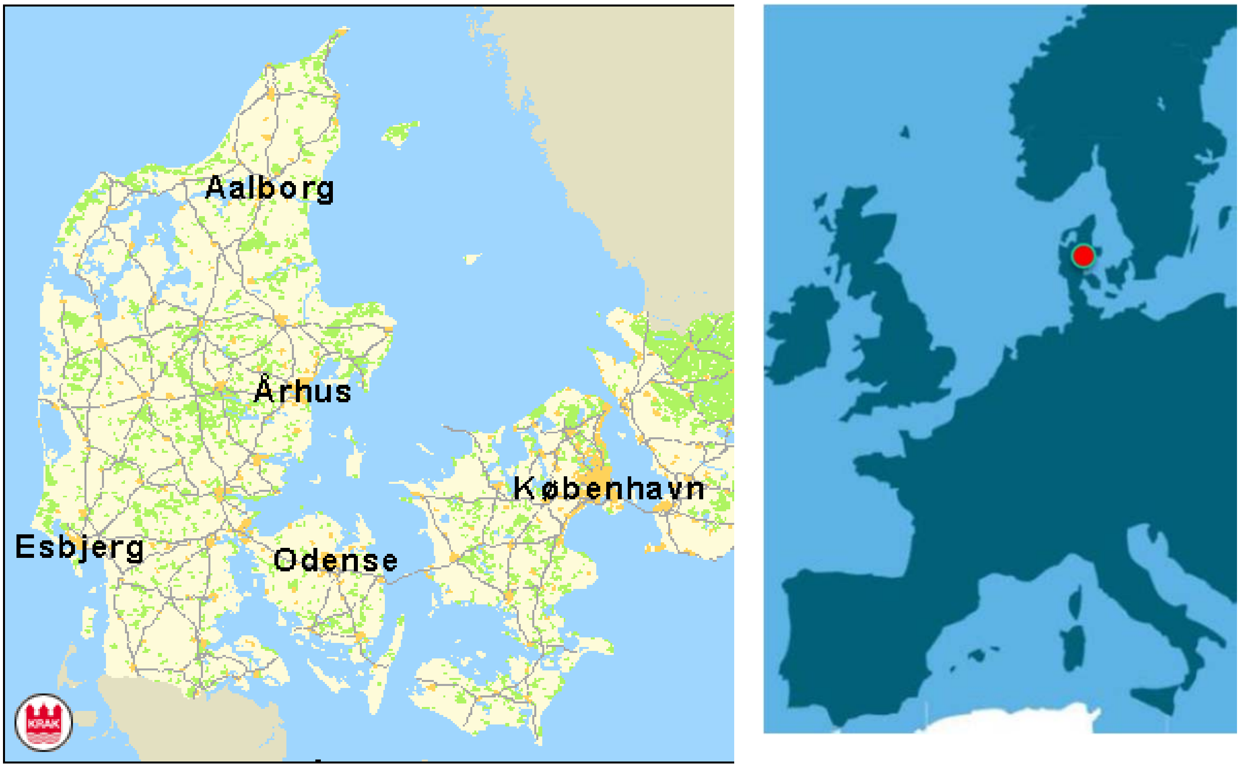


Figure 1 Location of Aarhus in Denmark and in Europe

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 km^2 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.

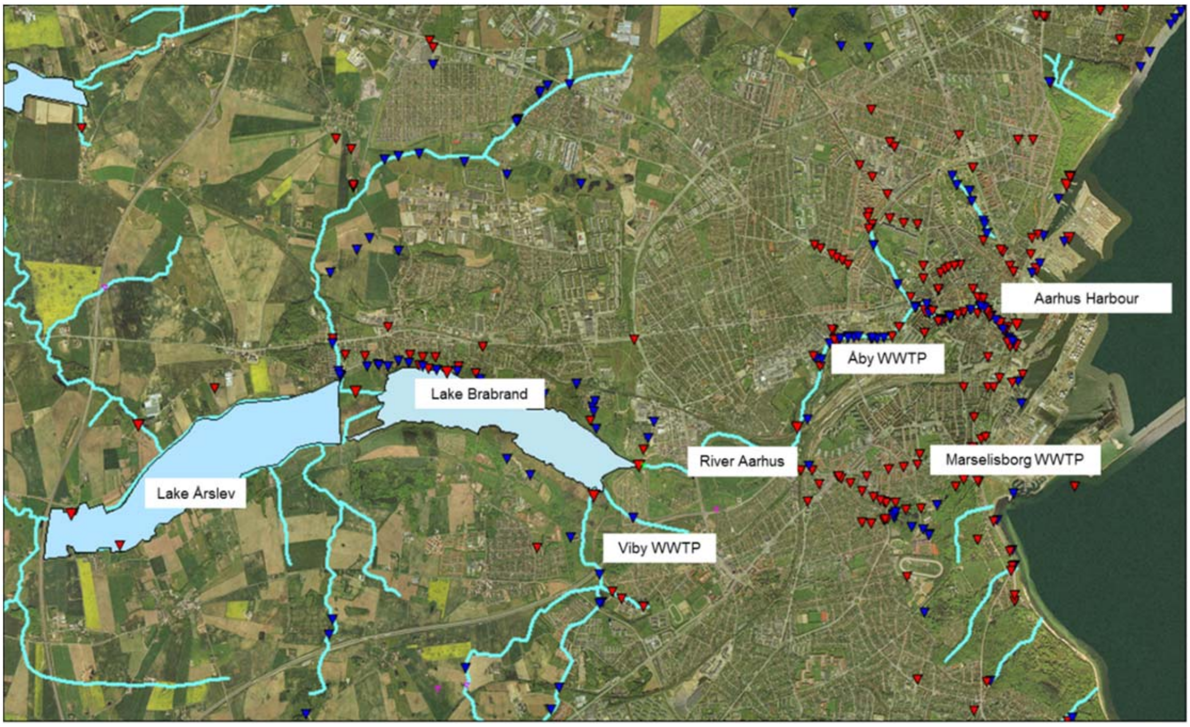


Figure 2 Lake Brabrand, the Aarhus River, and the Aarhus harbor

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.

The ECOLAB add-on to MIKE 11 is a generic software tool for customizing aquatic ecosystem models to simulate water quality, eutrophication, heavy metals, ecology, and other variables or processes of scientific or regulatory interest. The software provides a generic framework for describing processes and interactions between chemical and ecosystem state variables. ECOLAB is coupled to the advection-dispersion module of MIKE 11 so that transport mechanisms based on advection-dispersion can be integrated in the simulation.

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.

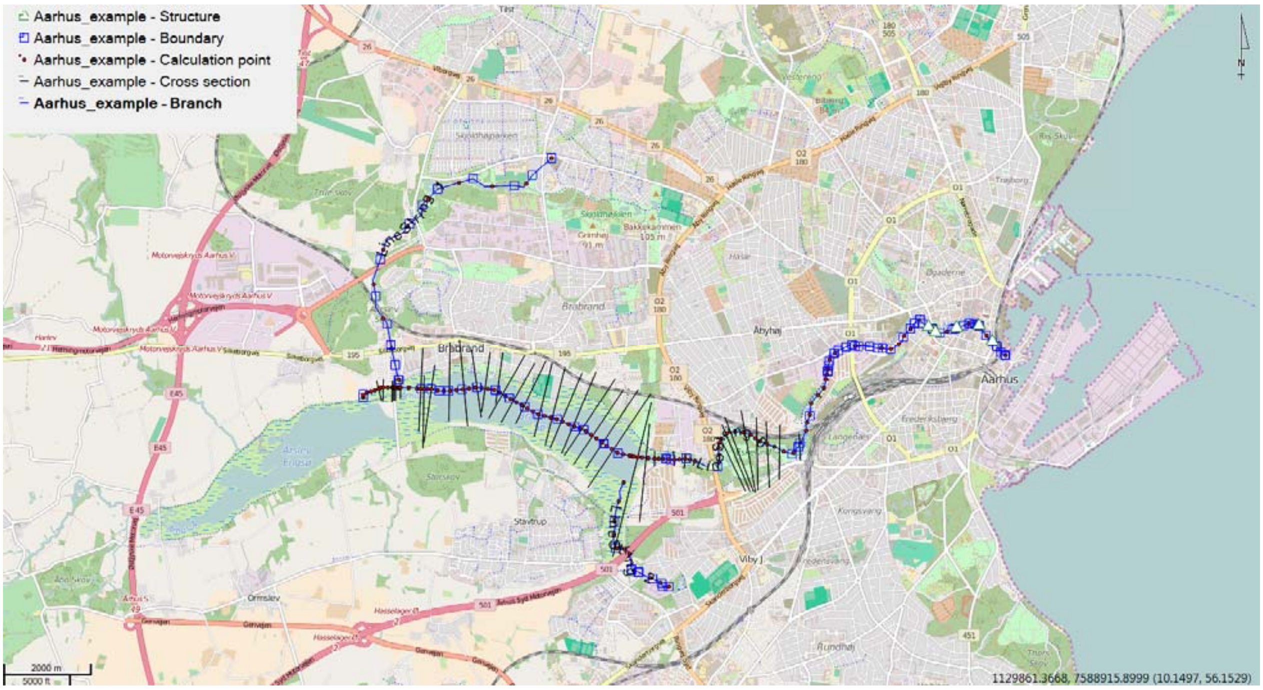


Figure 6 Schematic of MIKE 11/ECOLAB representation of Lake Brabrand and the Aarhus River

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.

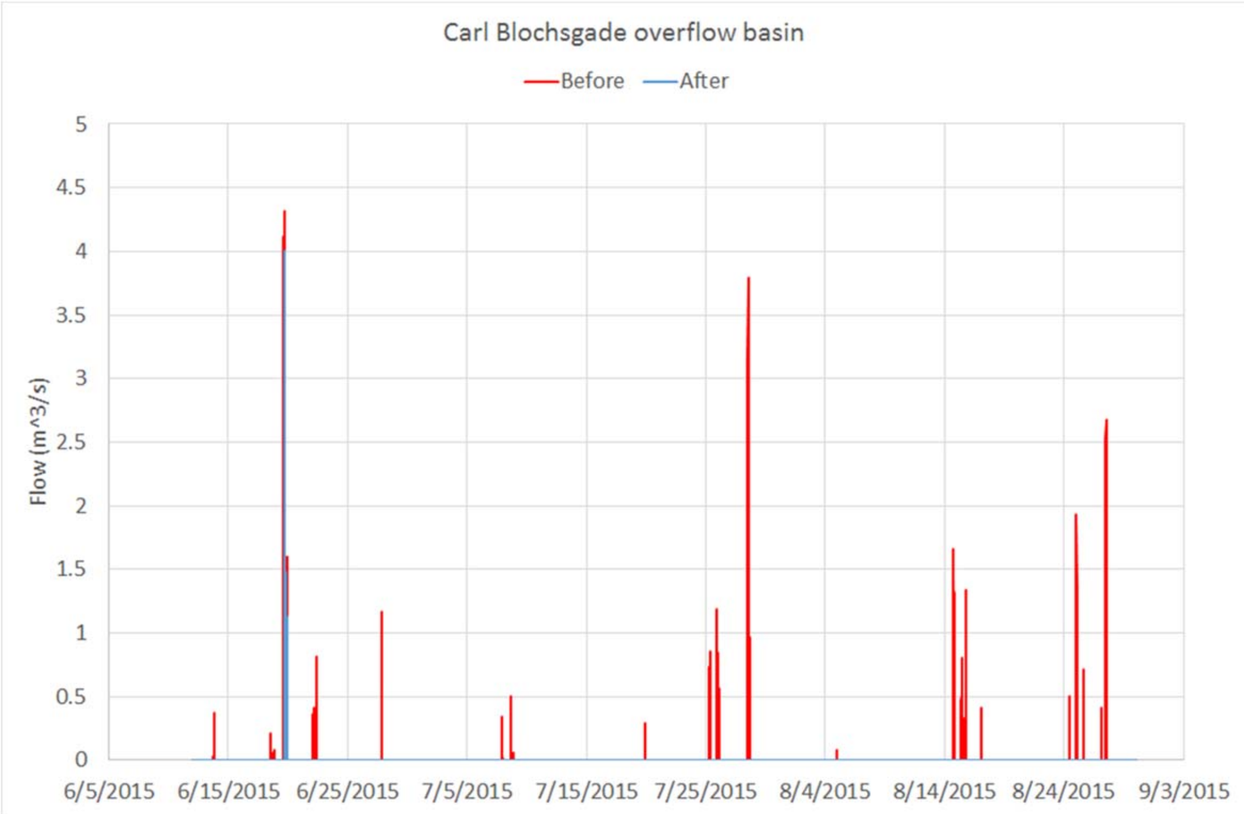


Figure 7 Comparison of inflows to Aarhus River from the Carl Blochsgade CSO basin

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.

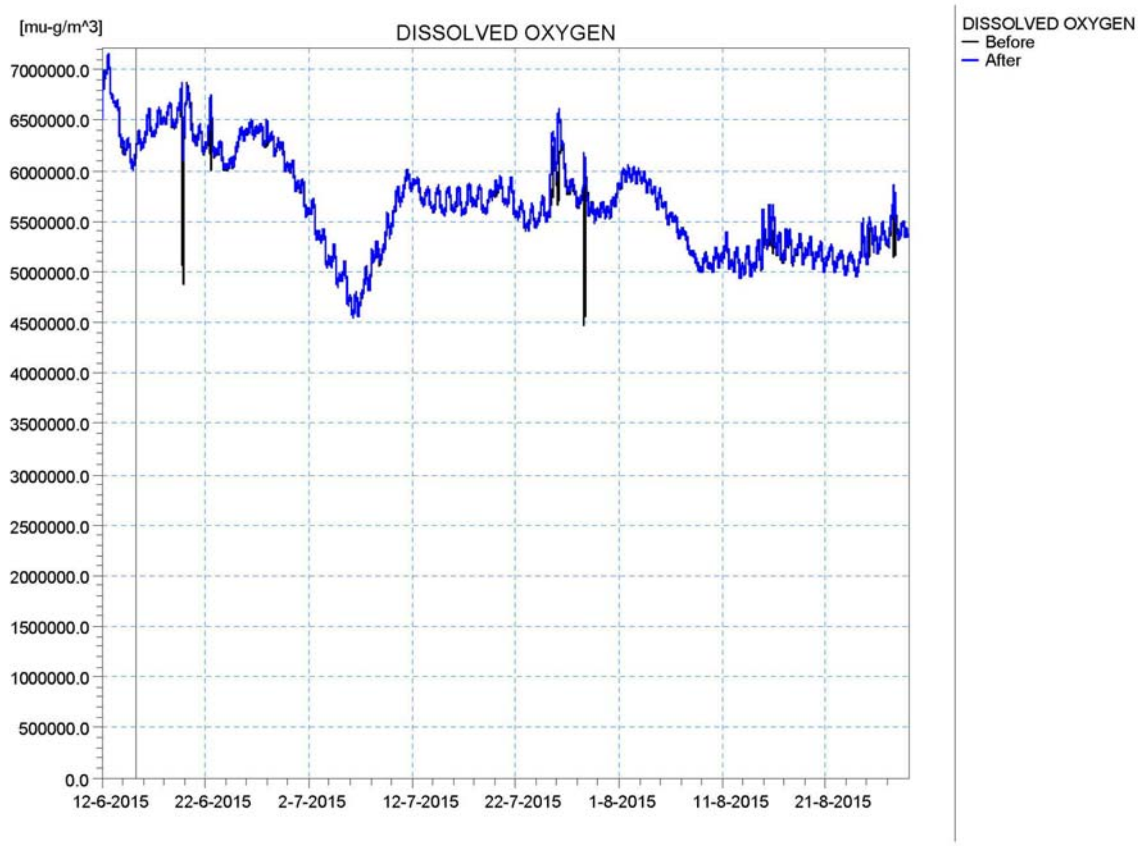


Figure 8 Dissolved oxygen concentrations, just upstream of the mouth of the Aarhus River

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.

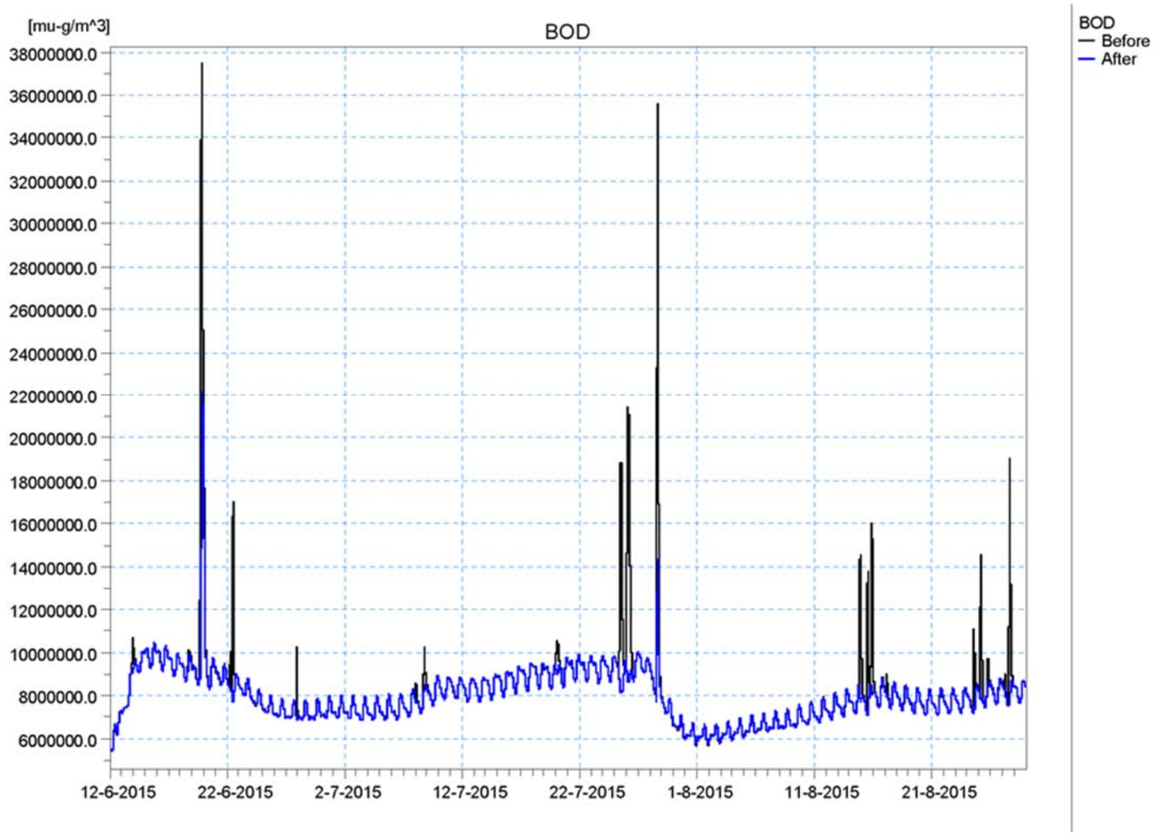


Figure 9 BOD concentrations, just upstream of mouth of Aarhus River

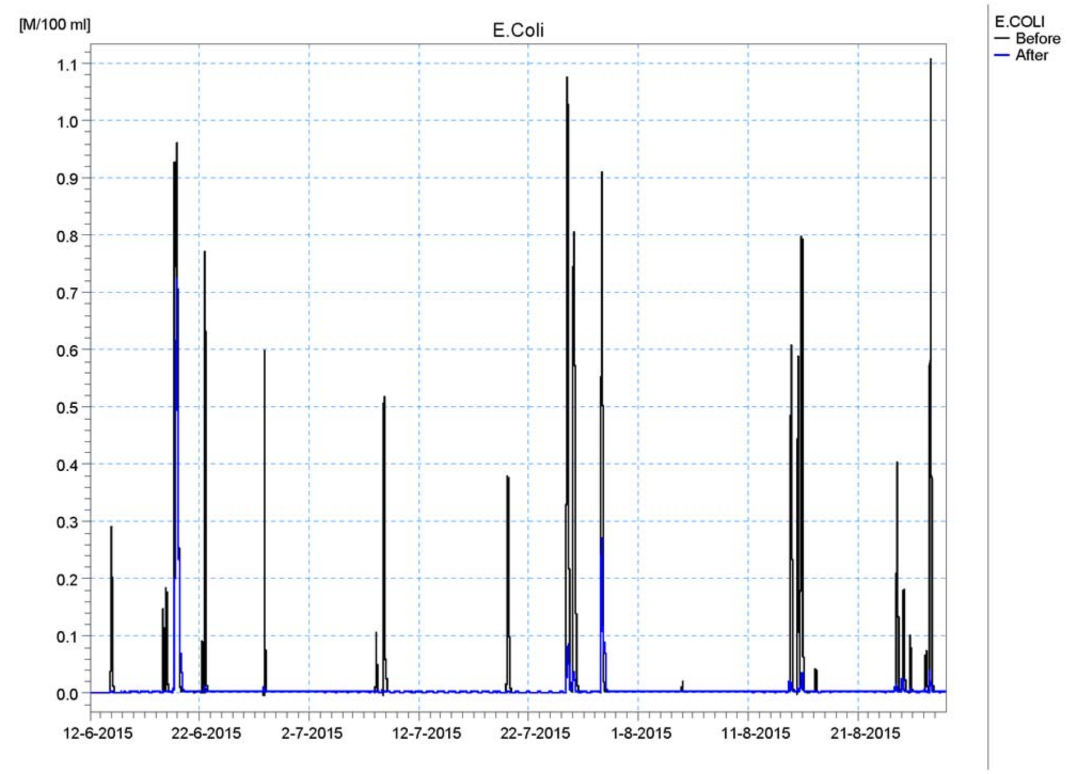


Figure 10 E.Coli concentrations, just upstream of mouth of Aarhus River

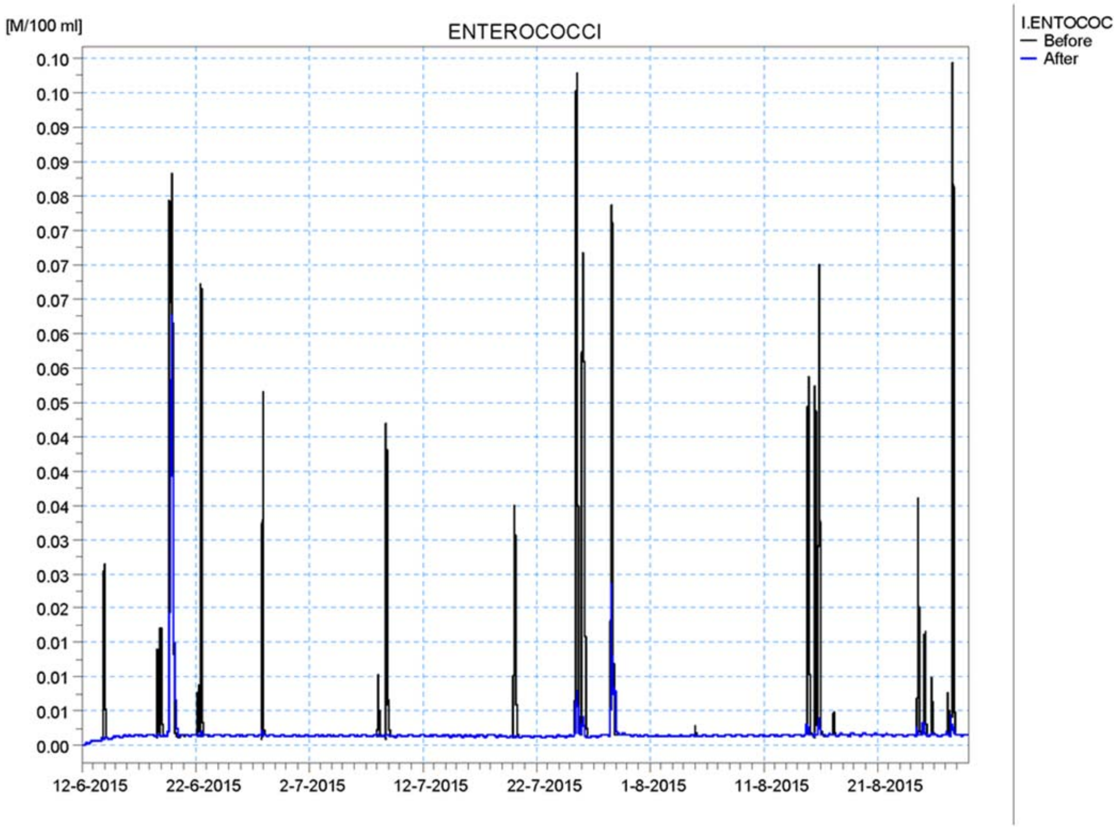


Figure 11 Enterococci concentrations, just upstream of mouth of Aarhus River

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 inTable 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 **Fehler! Verweisquelle konnte nicht gefunden werden.**.

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 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.

Box 1

LIFE CYCLE ASSESSMENT (LCA)

Stakeholder feedback

Although no stakeholder feedback activities took place as part of WP13, stakeholders involved in the Aarhus case study projects were interviewed as part of WP12. A summary of interviews with these stakeholders can be found in DESSIN deliverable D12.1, “Governance regime factors conducive to innovation uptake in urban water management”.

Two observations emerged during the WP12 stakeholder interviews that are relevant for the Aarhus case study, and both are referenced in the conclusions section.

The first relevant observation is that natural degradation of pollutants in the river was not considered in the initial design of the Aarhus real-time control system. While the length of the river is probably not long enough for natural degradation processes to make a substantial contribution to water quality improvements, it is possible that natural degradation could have played a small role in the technical solution and reduced the need for new infrastructure.

The second relevant observation is that formal cost-benefit analysis did not play a role in ensuring public acceptance of the cost of the Aarhus real-time control project and river opening. Instead, political support and public acceptance appear to have resulted from a commitment from the Aarhus city government to brand itself as a so-called ‘green city’, along with public support for achieving this goal and creating an attractive environment for companies and residents.

Both observations suggest that the ESS approach was not decisive for uptake of innovation in Aarhus. A possible interpretation is that the ESS approach is not needed to stimulate uptake of innovation. Another possible interpretation is that application of the ESS approach has potential to increase awareness of the benefits of using or enhancing ESS, which could increase the use of ESS as part of an innovative solution, or help gain support for innovation in communities where public support may be lacking.

Conclusion

The Aarhus mature case study functioned as a test of the DESSIN ESS framework and sustainability assessment (SA). Because the innovations used in the Aarhus case study have already been implemented, the innovations provided an opportunity to test the ESS framework and SA, and to provide feedback on how these methodologies may provide value to decision makers and others involved in the development and application of innovative technologies in the water sector.

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. Therefore, the Aarhus case study has also served as a initial test of the hypothesis.

- The Aarhus case study application suggests that the systematic approach used in the DESSIN ESS framework offers two important benefits to decision makers:The systematic approach could encourage decision makers to incorporate ESS in innovative solutions by increasing awareness of the potential of regulatory and supporting services. In the Aarhus case, for example, natural degradation processes taking place in the Aarhus River were not a consideration in the design of the real-time control system. It may be that more active consideration of these services would not have resulted in changes to the final design because the length of the river is relatively short, limiting the extent to which natural degradation takes place. None the less, the Aarhus case study demonstrates that the natural degradation capacity of the river was improved by the project, and application of the DESSIN approach at the outset of a project would certainly promote integration of ESS into technical measures.

- The focus on beneficiaries has the potential to contribute to cost-benefit analysis of innovative solutions. The systematic approach used to identify changes to state, ESS provision, ESS use, and economic benefits encourages users of the framework to identify beneficiaries of ecosystem services and then apply quantitative tools to estimate how beneficiaries are affected in economic terms. The approach encourages a rigorous approach to cost-benefit analysis of innovations affecting ESS, which could provide important economic arguments encouraging uptake of innovation.

References

Aarhus Kommune. (2006). Bedre vandkvalitet I Brabrand Sø, Åarhus Å og Århus Havn: Scenarier, konsekvenser og muligheder (in Danish). Aarhus, Denmark.

Clavreul, J., H. Baumeister, T. H. Christensen and A. Damgaard (2014). "An environmental assessment system for environmental technologies." Environmental Modelling and Software 60: 18-30.

European Environment Agency (EEA). (1999). Environmental indicators: Typology and overview. Copenhagen, Denmark: Smeets, E., & Weterings, R.

Godskesen, B., M. Hauschild, M. Rygaard, K. Zambrano and H. J. Albrechtsen (2012). "Life cycle assessment of central softening of very hard drinking water." Journal of Environmental Management 105(0): 83-89.

Göteborgs Stad, Kretsloppskontoret (2007) Systemstudie avlopp (In Swedish). Pdf available from http://www17.goteborg.se/kretslopp/BinaryLoader.aspx?ObjectID=578&PropertyName=FileList&PropertyValueIndex=3&CollID=File

Haines-Young, R., & Potschin, M. (2013). CICES V4.3-Revised Report Prepared Following Consultation on CICES Version 4, August-December 2012. EEA Framework Contract No EEA/IEA/09/003.

Institut for Fødevare- og Ressourceøkonomi (IFRO), Københavns Universitet. (2013). IFRO Rapport nr. 216c: Værdisætning af bykvaliteter – fra hovedstad til provins. Appendiks (in Danish). Frederiksberg, Denmark: Lundhede, T. H., Panduro, T. E., Kummel, L., Ståhle, A., Heyman, A., Thorsen, B. J.

ISO (2006) ISO 14044 Environmental management - Life cycle assessment - Requirements and guidelines.

Jensen, I.H., Lynggaard-Jensen, A., Petersen, S.O. (2014) Demonstration of Integrated real time control of sanitation systems incl. early warning for WQ in receiving waters in Aarhus. PREPARED report 2014.047.

Landers, D., Nahlik, A. (2013). Final Ecosystem Goods and Services Classification System (FEGS-CS) (No. EPA/600/R -13/ ORD - 004914). U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

La Rosa, D., Spyra, M., & Inostroza, L. (2015). "Indicators of cultural ecosystem services for urban planning: A review." Ecological Indicators, doi:10.1016/j.ecolind.2015.04.028

Malmqvist, P.-A., G. Heinicke, E. Kärrman, G. Svensson and T. A. Stenström. (eds.) (2006) Strategic planning of sustainable urban water management. IWA Publishing, London. ISBN: 1843391058

Paracchini, M. L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J. P., Termansen, M., . . . Bidoglio, G. (2014). "Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU." Ecological Indicators, 45, 371-385. doi:10.1016/j.ecolind.2014.04.018

Rygaard, M., B. Godskesen, C. Jørgensen and B. Hoffmann (2014). "Holistic assessment of a secondary water supply for a new development in Copenhagen, Denmark." Science of The Total Environment 497–498(0): 430-439.

Weber, M. A., & Ringold, P. L. (2015). "Priority river metrics for residents of an urbanized arid watershed." Landscape and Urban Planning, 133, 37-52. doi:10.1016/j.landurbplan.2014.09.006

Yoshida, H., J. Clavreul, C. Scheutz and T. H. Christensen (2014). "Influence of data collection schemes on the Life Cycle Assessment of a municipal wastewater treatment plant." Water Research 56: 292-303

DHI. (2017). ECOLAB: User manual. Retrieved from http://manuals.mikepoweredbydhi.help/2017/General/ECOLab_UserGuide.pdf.

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 DESSIN 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*
<u>*Physiochemical*</u> 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*	*medium for discharging [treated municipal*

	operators	*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		

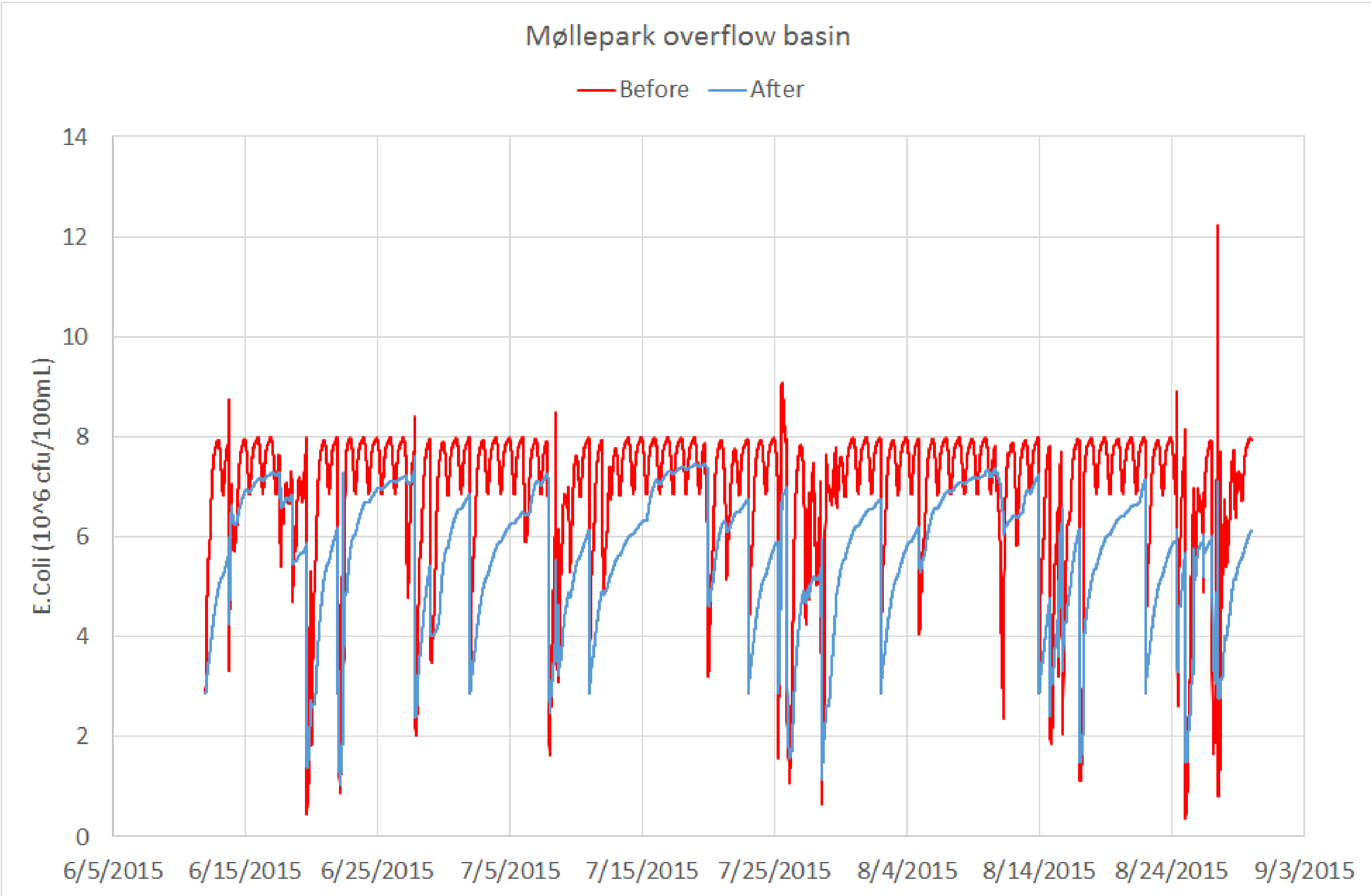
	Morphological disturbance	Length of covered river section	m	GIS analysis		
RESPONSE *(describe in detail)*	Real-time control system and associated infrastructure	1. Concentrations of bacteria in CSO discharges 2. Concentrations of BOD in CSO discharges 3. Flows rates from CSO discharge locations 4. Concentrations 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						
…						

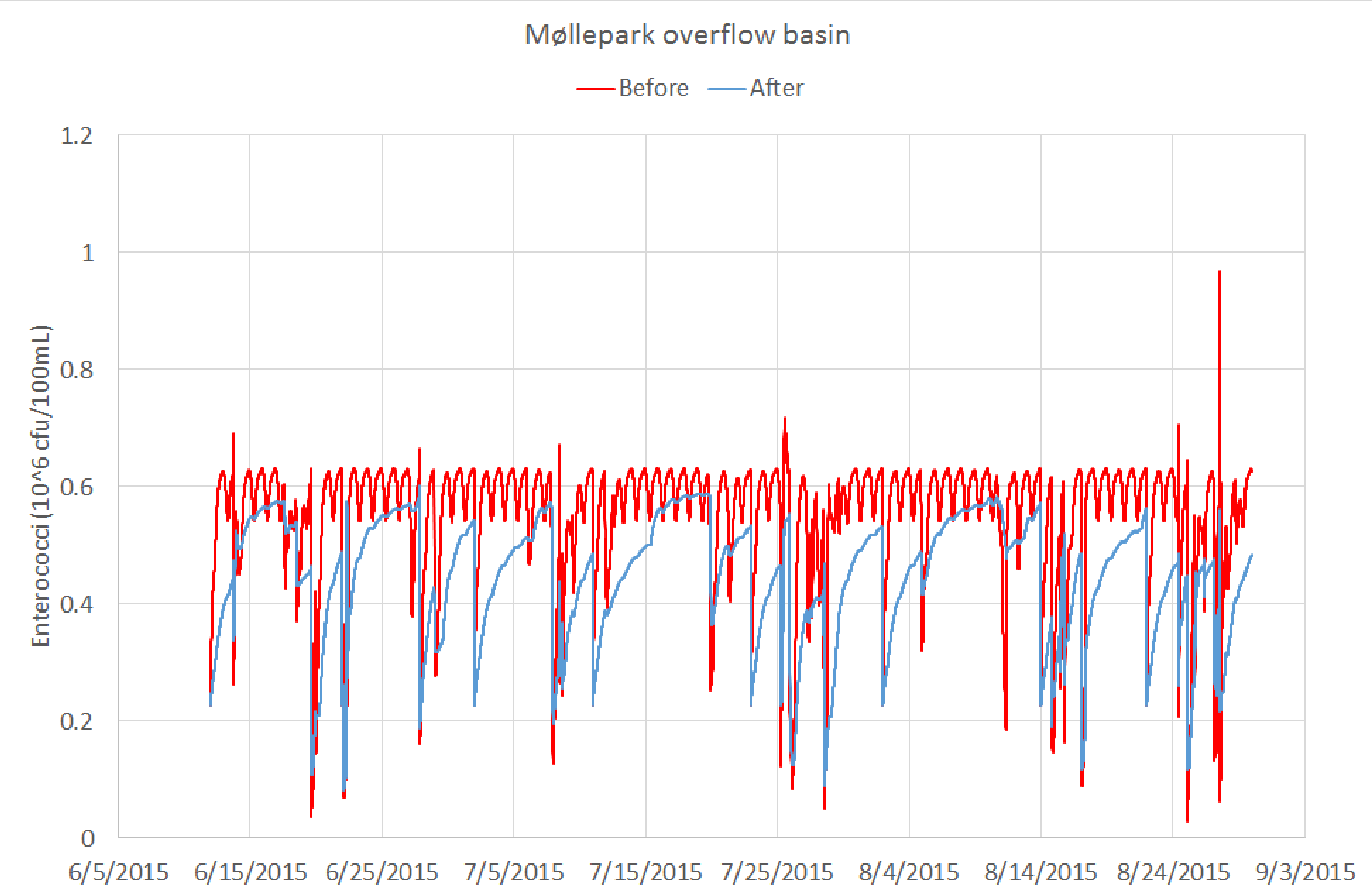
RESULTS TABLE				
	Case-relevant Element	Output	Output unit	Comments
PRESSURE	Diffuse source pollution: E.Coli concentration in CSO discharges	Timeseries ouput, see representative plots below	cfu/100mL	
	Diffuse source pollution: Enterococci concentration in CSO discharges	Timeseries ouput, see representative 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*

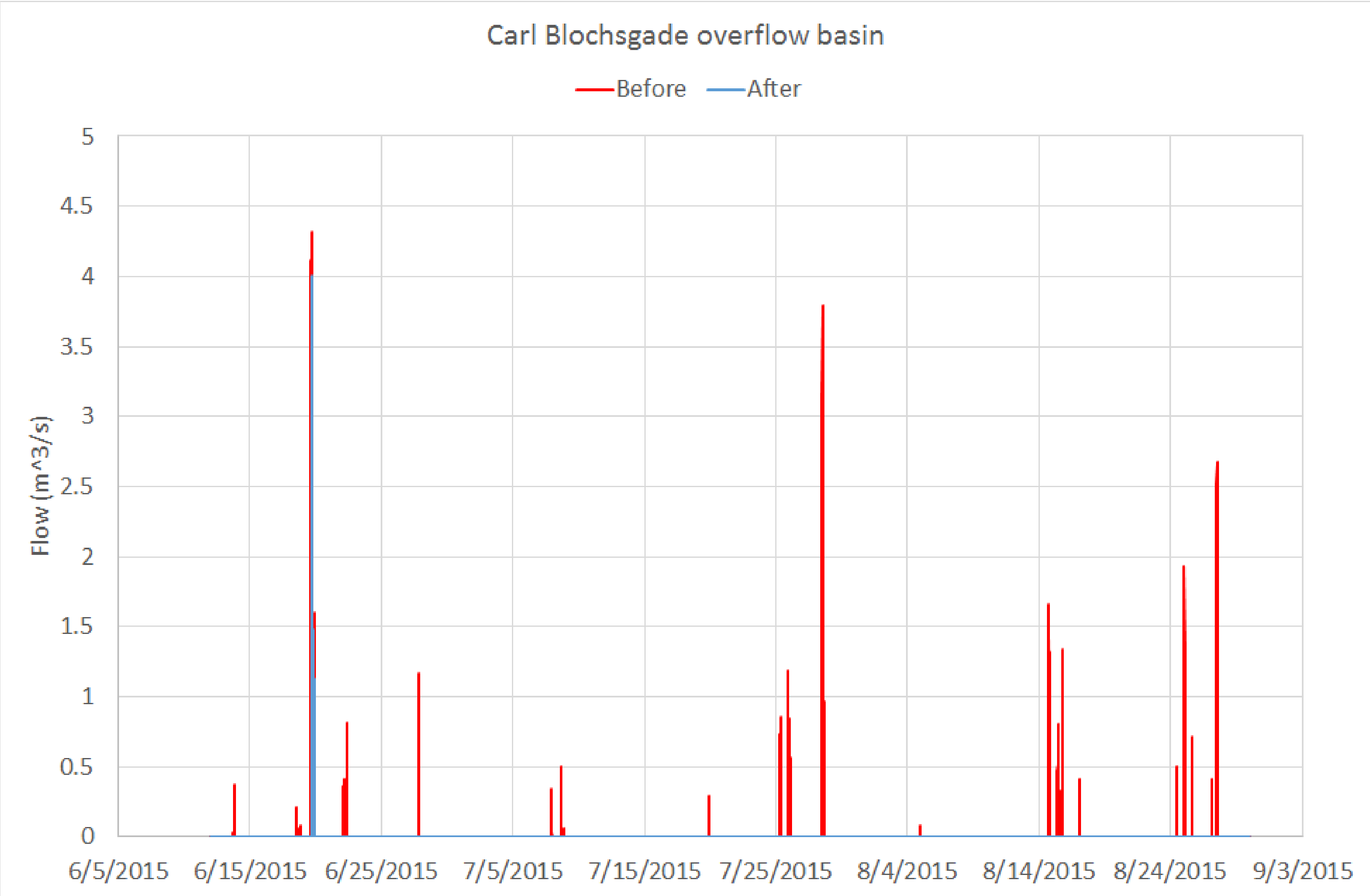
IMPACT II - Monetization		*not to be quantified*	*not to be quantified*	*not to be quantified*
RESULTS TABLE - Description				
Pressure indicator: Comparison of TS of E.Coli concentrations at Møllepark overflow basin				



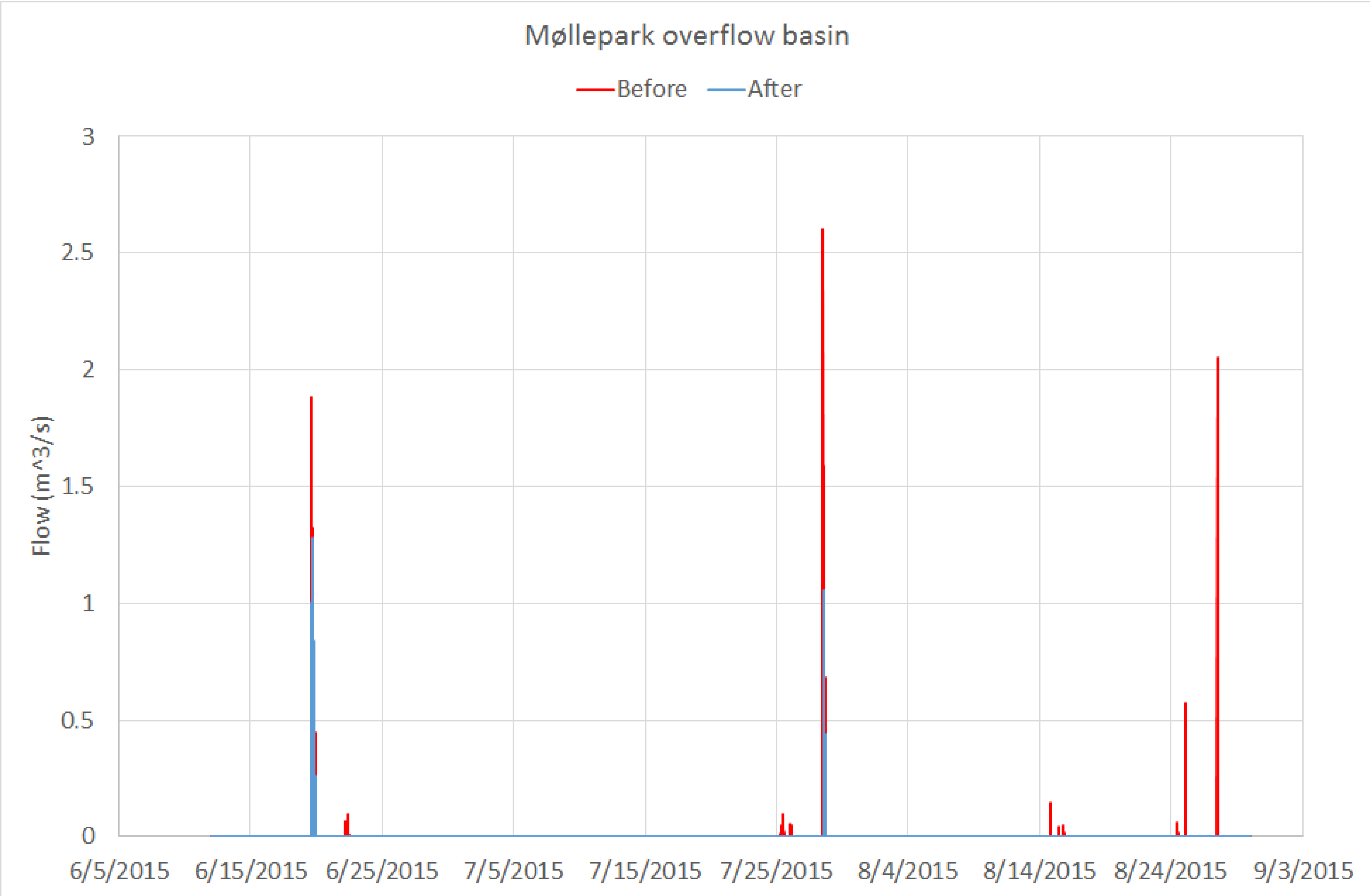
Pressure indicator: Comparison of TS of Enterococci concentrations at Møllepark overflow basin



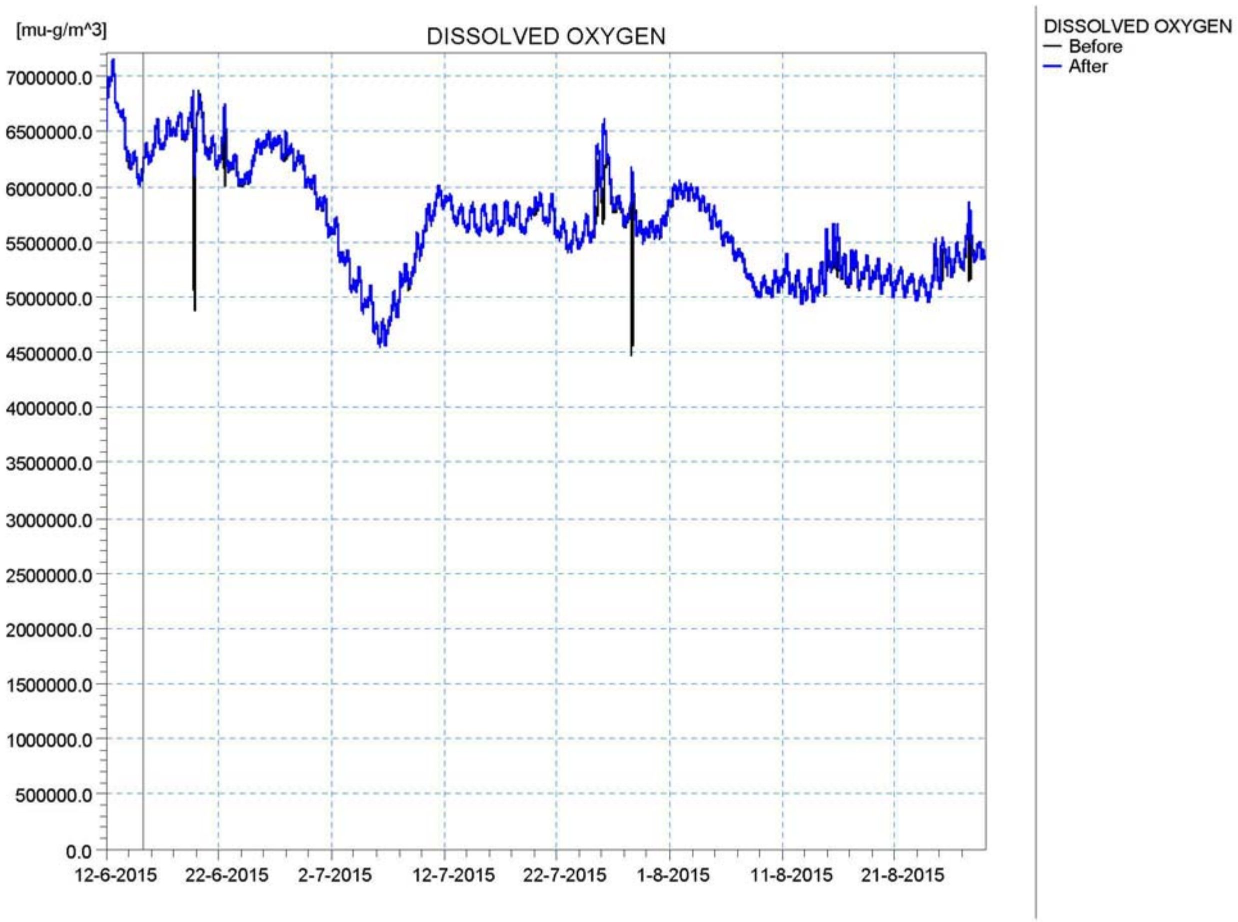
Pressure indicator: Comparison of TS of CSO discharges at Carl Blochsgade overflow basin



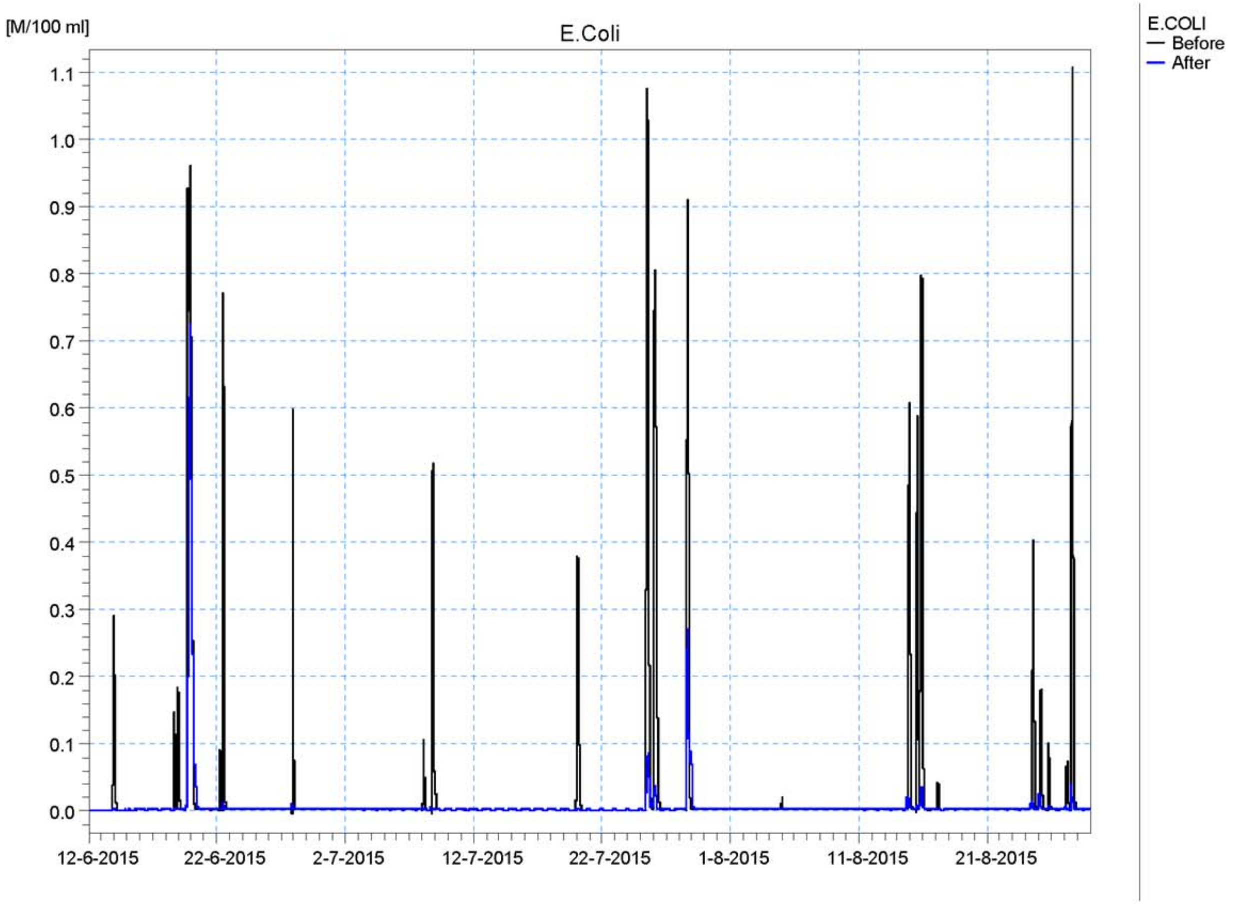
Pressure indicator: Comparison of TS of CSO discharges at Møllepark overflow basin



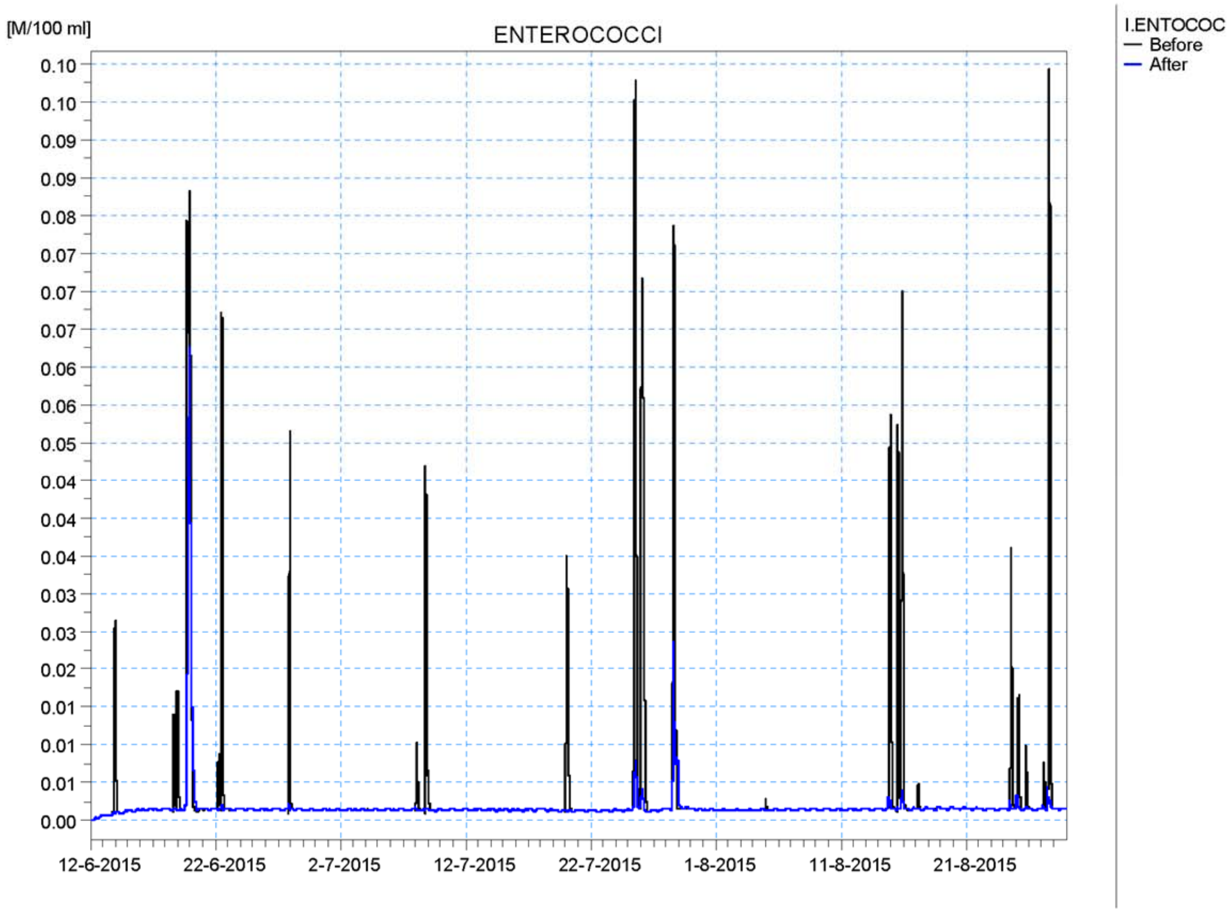
State indicator: Dissolved oxygen conditions near mouth of Aarhus River



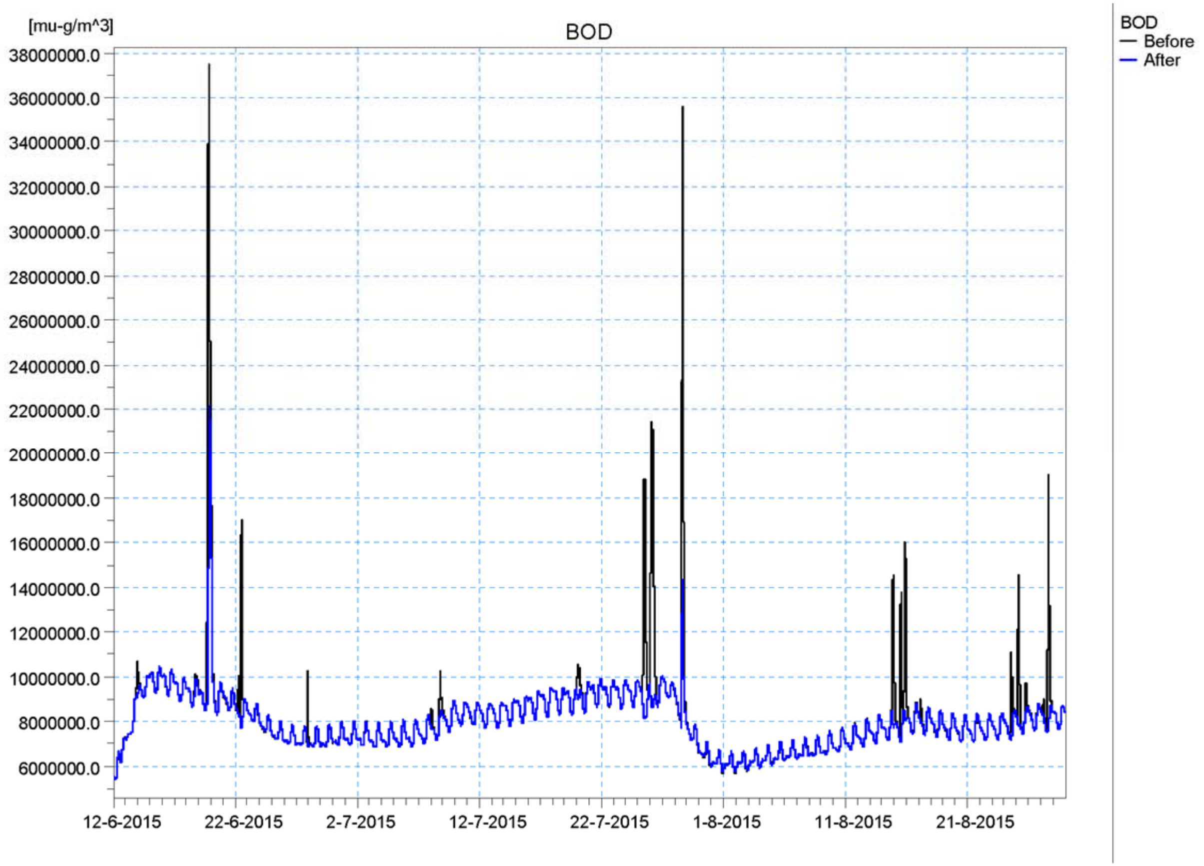
State indicator: E.Coli concentration near mouth of Aarhus River



State indicator: Enterococci concentration near mouth of Aarhus River



State indicator: BOD concentration near mouth of Aarhus River



BOD
[mu-g/m^3]
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	

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