D2.4
MONITORING PLAN LIFE WATERSOURCE

101113621 – LIFE22-CCA-NL-LIFE WATERSOURCE

DELIVERABLE

The monitoring plan of LIFE WATERSOURCE (Deliverable 2.4 and Task 2.2) consists of five topics (Tasks 5.1 up to .5), which includes the monitoring of:

T5.1) LIFE key performance indicators;
T5.2) Performance on water quality and quantity in relation to water stress;
T.5.3) Ecological impact indicators;
T.5.4) Socio-economic impact indicators;
T.5.5) Ecosystem services impact indicators.

The topics are divided into multiple chapters. At the start of each chapter a *reading guide* indicates the information which is stated in the specific chapter.

DISSEMINATION LEVEL

Public

DATE

January 2025

0. INTRODUCTION

The LIFE WATERSOURCE project demonstrates the potential of a nature-based solution (NBS) for drinking water production from surface water in Lake IJsselmeer to counter the emerging risk of surface water salination due to climate change, whilst boosting lake's ecology. This project demonstrates:

1) Securing the source for drinking water, regardless of present and future water stress due to climate change, whilst adding essential ecotopes.
2) A nature-based solution that can compete economically with technological alternatives to secure drinking water production – most notably desalination and the importation of water from other sources.
3) That the LIFE WATERSOURCE solution is more sustainable, and that securing drinking water availability can even substantially benefit the wider environment.

This demonstration project serves as a guideline to generate insights for the full scale implementation of the nature-based solutions (NBS) of the Climate Reservoir/Buffer (in Dutch: Klimaatbuffer IJsselmeer (KIJ)) concept and the potential for replication at other locations.

This document is the monitoring plan of the LIFE WATERSOURCE project (Deliverable 2.4) and consists of the five different topics (Taks 5.1 up to .5) as indicated in the Grant Agreement: T5.1) LIFE key performance indicators; T5.2) Performance on water quality and quantity in relation to water stress; T.5.3) Ecological impact indicators; T.5.4) Socio-economic impact indicators; T.5.5) Ecosystem services impact indicators. All monitoring efforts as described in this document are focusing on the LIFE WATERSOURCE demonstration project.

PROJECT CONTEXT

PWN, the drinking water supplier for the province of North Holland, relies on Lake IJsselmeer as its source for over 70% of its drinking water production. However, climate change increasingly threatens this critical resource with extreme weather events such as droughts, heavy rainfall, and heat waves. These events exacerbate salinization risks, reduce water availability, and degrade water quality due to algal blooms, organic pollutants, and contaminants of emerging concern (CECs), such as pesticides, microplastics, and pharmaceuticals. Projections for 2050 suggest salinization events could occur every eight years, with water shortages every five years (Pouwels et al., 2021).

To address these challenges and to improve PWN's resilience and increase sustainability, the Klimaatbuffer IJsselmeer (KIJ) project proposes an innovative system of deep water storage reservoirs surrounded by natural purifying landscapes, created from the excavated sand from the reservoirs (Figure 1). These interconnected reservoirs aim to enhance water pre-treatment, increase storage capacity, and improve ecology. Furthermore, the reservoirs are designed to allow fluctuating water levels, enabling flexibility in the intake of IJsselmeer source water for selective intake. The LIFE WATERSOURCE (LWS) project serves as a demonstration of this concept, testing the feasibility and effectiveness of these nature-based purification techniques on a smaller scale. Additionally, the project will assess the impact of fluctuating water levels on surrounding water systems, by means of a hydrological study.

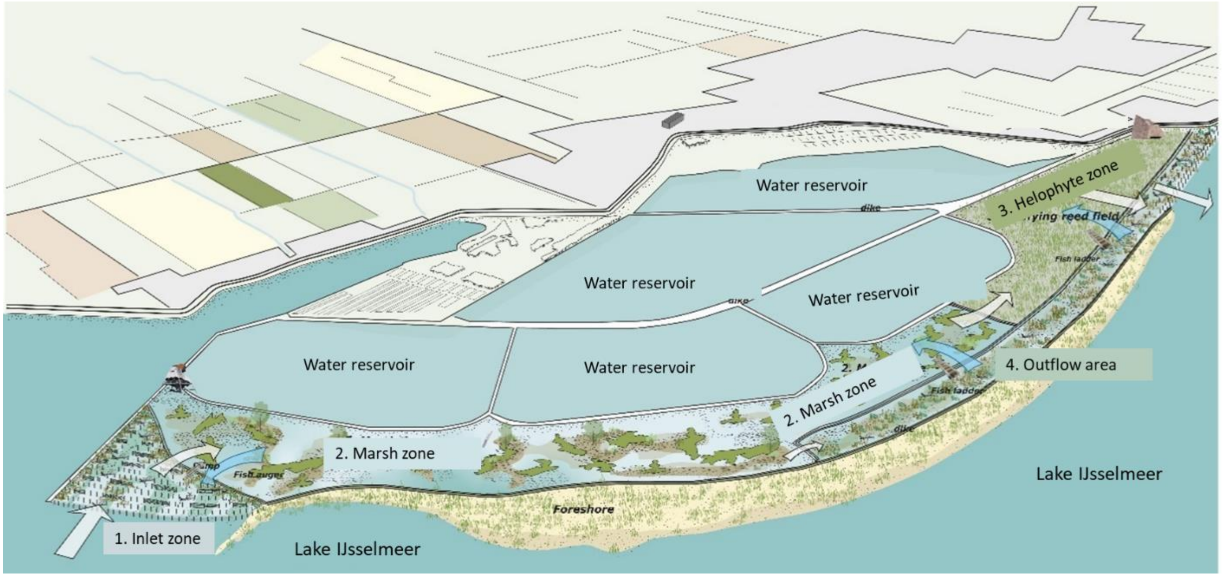


Figure 1. Conceptual view of the Klimaatbuffer IJsselmeer (KIJ), featuring a purifying landscape designed for water purification. This design serves as inspiration for the LWS demonstration setup including an inlet zone with mussels, a shallow marsh zone and a dense helophyte section.

LIFE WATERSOURCE DEMONSTRATION

The LWS demonstration showcases the use of a purifying landscape as a nature-based solution (NBS) for pre-treating Lake IJsselmeer water. The demonstration site integrates various NBS approaches, which are planned to be implemented in the KIJ, to improve water quality and enhance ecological resilience (Figure 1). Key components include:

- **Mussel zone:** Enhances water quality through filtration by mussels.
- **Purifying landscapes:** Utilizes wetlands for natural filtration.
- **Constructed wetlands:** Improves purification efficiency with engineered systems.
- **Pilot reservoir with bank filtration:** Provides a final purification step before water abstraction.

Additional non-NBS research conducted during the LWS demonstration includes:

- **Hydrological study:** Investigates the effects of fluctuating water levels on surrounding groundwater using existing PWN reservoirs, PSA and WPJ.

All information from this study will feed into a digital twin—a dynamic, virtual representation continuously updated with monitoring data. This digital twin supports predictive modelling, scenario testing, and potential replication in regions like Barcelona. The LWS project began in 2023, with construction planned for 2025, and monitoring continuing through at least 2028.

D2.4. MONITORING PLAN T5.1 KEY PERFORMANCE INDICATORS

101113621 – LIFE22-CCA-NL-LIFE WATERSOURCE

READING GUIDE

This chapter of the monitoring plan (D2.4) contains the Key Performance Indicators of the LIFE WATERSOURCE project (**T5.1**).

For every EU LIFE project several Key Performance Indicators (KPIs) are identified which indicate progress of the project and the contribution to goals from the European Union. For LIFE WATERSOURCE multiple indicators are chosen and the progress will be updated at the end of the project (in 2028). Following the guidelines, this will be done via the KPI portal.

The numbers and headings of the chapters in this report are copied from the KPI portal. The data which is saved in the KPI portal is stated and the methods to measure the impact are described per indicator. The text behind the arrow indicates the action which is needed to monitor the specific KPI. The names and numbers of the indicators are copied from the KPI portal as well.

1. KEY PERFORMANCE INDICATORS

PROJECT INFORMATION

In the Table below general project information on the LIFE WATERSOURCE is provided (copied from the KPI portal).

FIELD	VALUE
REFERENCE	LIFE22-CCA-NL-LIFE-WATERSOURCE/101113621
TITLE	LIFE WATERSOURCE: Demonstrating a Climate-Resilient Drinking Water Source, Adopting Nature-Based Solutions
ACRONYM	LIFE22-CCA-NL-LIFE WATERSOURCE
BENEFICIARY NAME	NV PWN WATERLEIDINGBEDRIJF NOORD-HOLLAND
LEVEL	Public Provincial/District
ENTITY TYPE	Private commercial
SIZE	Large (250+)
START DATE	01/07/2023
END DATE	30/09/2028
PERIOD AFTER PROJECT END	5
COMMENTS	Initial import from eGrants
TOTAL COST	4999594,26
ELIGIBLE COST	4999594,26
EC CONTRIBUTION	2999756,56
CA CONTRIBUTION	1799961,7
AA CONTRIBUTION	199876
CF CONTRIBUTION	0
COMPLEMENTARY FUNDING	0

The (thematic) priority area of the project is MAWP21-24 Climate Change Adaptation.

SUMMARY

The main objective of LIFE WATERSOURCE (LWS) is to demonstrate large-scale, nature-based drinking water production adapted to climate change. Specifically, the aims are to:

1. Demonstrate a nature-based solution (NBS) to water stress and salinisation, securing drinking water production.
2. Demonstrate sustainable improvement in the drinking water production and treatment process.
3. Demonstrate improvements in the ecological quality of Lake IJsselmeer.
4. Promote nature-based management of drinking water resources.

LIFE WATERSOURCE is a steppingstone towards the full-scale implementation of a 250 ha purifying ecotope and climate reservoir, to be realised over the next 10 year.

The objectives will be achieved by the construction of a demonstration site of about 1 hectare on our premises in Andijk. Here, water from Lake IJsselmeer will flow through a purifying landscape and other nature-based treatment steps where natural processes purify the water, before it will enter the regular (and current) drinking water production process. We will monitor (amongst other things) the water quality changes and impact on the ecology. On top of these measurements the impact of the project, by means of the KPIs, will be monitored.

INDICATOR CONTEXT

C.1.1. Territorial extents

The project will be implemented in the Netherlands, NL (NUTS code NL328, 'Alkmaar en omgeving'). The replication study will be performed in España, ES (NUTS code ES511 Barcelona).

C.1.2. Water bodies

The project will be implemented adjacent to Lake IJsselmeer (NL92_IJsselmeer).

C.2 Specific context

The implementation of LIFE WATERSOURCE will be adjacent to Lake IJsselmeer (NL328, Nederland/Rijn/IJsselmeer). The feasibility study for replication and implementation of LIFE WATERSOURCE technique will take place near the Rubi river in Barcelona (ES511).

PROJECT SPECIFIC SETTINGS AND INDICATOR SELECTION

Below the project specific settings and indicator selection are stated. Here the start, end value and beyond end value is provided, which are copied from the KPI portal. The beyond end value describes the situation after 5 years after the project ends. Unless stated otherwise, these are formulated for the implementation of the LIFE WATERSOURCE technique adjacent to the Lake IJsselmeer (NL).

D. Project setting, area/length and population

The indicators which are selected are 1.5 B Project work area and 1.6 B Humans impacted by the project, are described below.

1.5 B. Project work area

Descriptor	Start value	End value	Beyond end value	Unit	Context

Area of environmental/climate implementation actions (e.g. development, testing, demonstration, application of best practices/innovations).	0	1	150	ha	LIFE WATERSOURCE will create a 1 ha purifying landscape, which will have a positive impact on water quality and nature and biodiversity. This will create habitat for species that is currently absent. The consortium will also study the impact of the natural purification for water treatment on other water bodies, based on this demonstration. Within 5 years after project end, a large-scale implementation is planned.

Descriptor	Start value	End value	Beyond end value	Unit	Context
Area of monitoring activities to assess the outcomes/impacts of project environmental/climate actions (e.g. through sensors, surveys, visits, etc).	0	1	1	ha	LIFE WATERSCOURCE will monitor the effect of the purifying landscape on water quality, nature and biodiversity.

- As described in the tables above the demonstration site which will be constructed for the LIFE WATERSOURCE project is about 1 ha. The constructed area will be measured before and after the project construction is finished. This will be done via a digital terrain model (DTM, a digital measurement). This will also be used to construct the BIM model of the demonstration site.
- Five years after project end, the large scale implementation of the LWS technique with the 'climate reservoir' is planned to be operational. This will be 150 hectares of newly created nature where water purification will take place. Additionally, water reservoirs totalling 100 ha will be created. For the large scale implementation the area will also be measured prior and after the project realization. This information will be used for the (final) design and the DTM and BIM model of the large scale implementation.

1.6 B. Humans impacted by the project

Descriptor	Start value	End value	Beyond end value	Unit	Comment
Type of impact: Persons reached (via dissemination or awareness raising project-actions). Type of persons: Residents within or near the project area.	0	627520	947020	Number of persons impacted	Website - expected unique visitors - 12500 project end - 25000 5 years after project end 2 technical publications @ 700 readers each - 1 more publication 5 years after project end 3 seminars @ 300 visitors each 2 opening events @ 60 visitors each 4 press releases + 2 popular scientific publications @ 100,000 readers each - 3 more publications 5 years after project end

- The persons reached via dissemination and awareness raising activities will be monitored. The reach of the publications will be estimated based on the standards of the (online) magazines.

- The visitors of the LIFE WATERSOURCE webpage and views on posts (of articles on the webpage and on social media, e.g. LinkedIn) will be tracked.
- We will keep track of the people present at every dissemination activity.

Descriptor	Start value	End value	Beyond end value	Unit	Comment
Type of impact: Persons whose quality of life was positively impacted by CLIMATE CHANGE ADAPTATION-related project actions. Type of persons: Residents within or near the project area.	0	63316	1700000	Number of persons impacted	LIFE WATERSOURCE will positively impact the quality of life for the inhabitants of the municipalities of Medemblik and Enkhuizen (incl. Andijk), as they will have more access to nature. Five years beyond project end, the entire population of the province of North Holland will be positively impacted, as their access to clean drinking water is assured for years to come, and they will be able to recreate in the large nature area created. The most substantial benefit will be that these citizens are less vulnerable to climate change, as their drinking water supply and enjoyment of nature will no longer be negatively impacted by climate change. The quality of the drinking water will be carefully monitored during the project. Monitoring indicators include S.S., TOC, NO3, PO4, EC, Cl, O2, SO4, turbidity, PH, UVT, and FeCl3, as will be described in detail in the monitoring plan.

- The persons whose quality of life is positively impacted by the LIFE WATERSOURCE project is measured by the inhabitants who live nearby PWN in Andijk and the construction of the project. These inhabitants can experience more nature in their surroundings.
- A successful implementation of the LIFE WATERSOURCE project strongly enhances the chance that the climate reservoir (Klimaatbuffer IJsselmeer) of 250 ha will be implemented. This allows people to access (certain parts) of this newly created natural surroundings of the climate reservoir.
- In addition, when the climate reservoir is implemented beyond project end, the drinking water production is significantly more robust, more sustainable and resilient for the coming decades. All persons which PWN supplies will be positively impacted.

E. Environmental and climate action outputs and outcomes

2 B. Water

2.2 B. Reduction in area of length of surface freshwater bodies or volume of groundwater bodies whose status is affected by issues addressed by the project

Within the LIFE WATERSOURCE project the current reservoir of 45 ha will be improved in terms of quality and quantity. The reservoir will have a flexible water level and will demonstrate the impact of flexible water intake on securing good water quality intake to prevent poor water quality intake. Five years after project end, the plan is to have implemented 100 ha new reservoirs as with the large-scale LIFE WATERSOURCE replication of the climate buffer.

Hydromorphological alterations include the creation of different habitats and fluctuation of water levels, which should improve the water quality and sustainable water quantity, also in times of drought or bad water quality in the adjacent IJsselmeer. The storage capacity created in the reservoir will make the area less prone to flooding and water scarcity. The fish passage (siphon fish ladder) that is part of this project allows fish to enter the reservoirs freely and use it as a nursery.

First level descriptor of this KPI is 'Lake'. The table below provides the data for the specific KPI per second level descriptor.

Start value	End value	Beyond end value	Unit	Second level descriptor
100	55	0	ha (reservoir, lake or transitional waters)	Reduction in length of river (except reservoirs) or area of surface body (reservoir, lake or transitional waters) or volume of groundwater body whose ecological/chemical status or volume are affected by issues addressed by the project (this may be less than the total area/length/volume of the surface water body or groundwater body addressed).
0	45	100	ha (reservoir, lake or transitional waters)	a. Part of the total area/length of the surface water body where physical alterations were addressed
0	45	100	ha (reservoir, lake or transitional waters)	b. Part of the total area/length of the surface water body where hydromorphological alterations were addressed.
0	0	0	Did not achieve pollution reduction	c. Part of the total length of river turned into free flowing river (please also report in 2.4.1B).
0	45	100	ha (reservoir, lake or transitional waters)	d. Part of the total length/area of surface water bodies where other connectivity improvements were made excluding free flowing river (e.g. connectivity improvements due to fish passes). Please also report in 2.4.1B.
0	0	0	Did not achieve pollution reduction	e. Part of the total area/length of surface water bodies or part of the total volume of groundwater where pollution was reduced (Please also report in KPI 2.4.3B)
0	45	100	ha (reservoir, lake or transitional waters)	f. Part of the total area/length of surface water bodies or part of the total volume of groundwater where water quantity issues were addressed (e.g. flooding or scarcity).
0	45	100	ha (reservoir, lake or transitional waters)	g. Part of the total area/length of surface water bodies or volume of groundwater where other improvements were made - specify in comment box

- The water which is impacted by the project will be expressed in terms of surface area. Dependent on the second level descriptor the area of impact will be determined. This mainly concerns the already existing reservoirs in Andijk (of 45 ha) which will be positively impacted by the project. After project end, this concerns the new reservoirs (of 100 ha) which will be created.

2.4 B Pressure(s) or risk(s) addressed:

2.4.1 B Connectivity of Water bodies

Descriptor	End value	End value	Beyond end value	Unit	Comments
Modification of barriers improving water body connectivity but not resulting in a free flowing river (please report the length or area of water body in 2.2B.d). Connectivity issues due to other drivers/causes.	1	0	0	Number of barriers that need to be modified to improve connectivity (not free flowing river)	The project includes the realisation of a fish passage between Lake Ijsselmeer and the climate reservoir. This fish passage will help important species to move freely between the water bodies, ensuring they can use the newly created nature area as a nursery. The fish passage will be maintained during the large-scale implementation of the LIFE WATERSOURCE concept after project end.

- With LIFE WATERSOURCE project a new water body is created. The modification of barriers improving water body connectivity is included in the design of the project. Here the number on the connectivity towards Lake IJsselmeer will be quantified.

4 B. Resource efficiency and Waste (including energy, circular economy and forests)

4.1.1 B Primary energy consumption reduction

Descriptor	Start value	End value	Beyond end value	Unit	Comments
Electric	25	24.99	24	GWh/year	Total energy use at PWN for UV treatment is 25 GWh. Within the project duration, it is expected that at the demonstration rate of 20 m3/h, NO3 will be reduced by 20%. This leads to a 4% reduction in energy usage. Compared with the full production rate at the drinking water plant of 25Mm3 per year, this means a reduction of 0.03% for the entire plant. The UV installation uses 0.36 kWh. A 0.03% reduction equals 0.0025 GWh per year. Five years after project end, we plan to have realised the large-scale replication of the LIFE WATERSOURCE project. Then, a 4% energy reduction will result in the following reduction in energy usage: 4% * 0.36 * 70 Mm3/j = 1,008,000 kWh/y = 1008 MWh/y = 1 GWh/y.

					The energy used by the installation is monitored automatically by PWN and is included in the mid- and final report.

- The energy which is currently used for the drinking water production with UV is quantified. The aim is to reduce this amount with the LIFE WATERSOURCE project, which will be expressed in the concentration of NO3 in the water. Due to the natural treatment NO3 is expected to reduce which serves as indicator for the reduction of energy which is required in the treatment plant. The NO3 concentration of the water is measured at the inlet (from Lake IJsselmeer) and when the water passed through the LIFE WATERSOURCE demonstration site. The reduction will be related to the reduction in necessary energy for the UV treatment.

7 B. Nature and Biodiversity

7.2 B Natural and semi-natural habitats

Within the project, we create 3 'missing ecotopes' in the Lake IJsselmeer Region: floodable grasslands (floodplains); helophyte marge (H6430, hydrophilous tall herb fringe communities); shallow water plants (H3260 water courses with aquatic plants) in ratio 1:2:4. Within the LIFE WATERSOURCE demonstration project, we connect 1 ha shallow ecotope Lake IJsselmeer; 5 years after project end, this will amount to 150 ha (as part of the Climate reservoir. The 1 ha created does not fall under the Habitat Directive.

Start value	End value	Beyond end value	Unit	Descriptor
0	1	150	ha	a. Area/Length of habitat where loss of biodiversity is being halted and reversed due to your project (due to existing habitat restored and/or newly created/developed habitat)
0	1	150	ha	b. Part of the Area/Length of habitat indicated in line "a" which is newly created/developed habitat (ex-novo)
0	0	0	km2	c. Part of the Area/Length of habitat (existing habitat restored or newly created/developed) indicated in line "a" which is within a Nat2K Site

- The area (of currently missing ecotopes in the lake IJsselmeer region) of the LIFE WATERSOURCE project will be measured. Every year a map of the vegetation/ecotopes will be created (based on expert judgement).
- Images (with camera's and drones) of the project will be made to see the development of the demonstration site, which includes the vegetation.
- After project end the natural area which will be created in the large scale project will be designed and the area will be indicated.

7.3 B Wildlife species

At the moment, there are very limited numbers of fish and birds, as there is no shallow ecotope near the envisaged demonstration and large scale project site in Lake IJsselmeer. For the fish, the baseline is on average 50 kg/ha. In the demonstration project, we improve and monitor the presence of at least 3 fish species: perch (Perca fluviatilis), pike perch (Stizostedion lucoperca), and roach (Rutilus Rutilus), increasing this to 75 kg/ha. For the birds, this applies to at least 4 typical bird species: great cormorant, (Phalacrocorax carbo), common tern (Sterna hirundo), helophyte bunting (Emberiza schoeniclus), and yellow wagtail (Motacilla flava). 5 years after (in the large project of the climate buffer/reservoir), we expect this to include smelt (Osmerus eperlanus) and bream (Brama brama), and little and little ringed plover (Charadrius dubius and Charadrius hiaticula), pied avocet (Recurvirostra avosetta), small and potentially great helophyte warbler (Acrocephalus scirpaceus and Acrocephalus arundinaceus), black tern (Chlidonias nigra), greater scaup (Aythya marila) and goosander (Mergus merganser).

The unit for the descriptor is provided in the table below (which was not added before in the KPI portal).

First level descriptor	Second level descriptor	Third level descriptor	Start value	End value	Beyond end value	Unit
Annex I Birds Directive	Chlidonias niger/Birds	Population count in the project context				Individuals
Annex I Birds Directive	Chlidonias niger/Birds	Species Range Area				ha
Annex I Birds Directive	Chlidonias niger/Birds	Total species population count in the Member States included in the context				Individuals
Annex I Birds Directive	Recurvirostra avosetta/Birds	Population count in the project context				Pairs
Annex I Birds Directive	Recurvirostra avosetta/Birds	Species Range Area				ha
Annex I Birds Directive	Recurvirostra avosetta/Birds	Total species population count in the Member States included in the context				Pairs
Annex I Birds Directive	Sterna hirundo/Birds	Population count in the project context				Individuals
Annex I Birds Directive	Sterna hirundo/Birds	Species Range Area				ha
Annex I Birds Directive	Sterna hirundo/Birds	Total species population count in the Member States included in the context				Individuals
Annex II Birds Directive	Aythya marila/Birds	Population count in the project context				Individuals
Annex II Birds Directive	Aythya marila/Birds	Species Range Area				ha
Annex II Birds Directive	Aythya marila/Birds	Total species population count in the Member States included in the context				Individuals
Annex II Birds Directive	Mergus merganser/Birds	Population count in the project context				Individuals
Annex II Birds Directive	Mergus merganser/Birds	Species Range Area				ha
Annex II Birds Directive	Mergus merganser/Birds	Total species population count in the Member States included in the context				Individuals

First level descriptor	Second level descriptor	Third level descriptor	Start value	End value	Beyond end value	Unit
European Red List: Birds	Acrocephalus/ arundinaceus	Population count in the project context				Pairs
European Red List: Birds	Acrocephalus/ arundinaceus	Species Range Area				ha
European Red List: Birds	Acrocephalus/ arundinaceus	Total species population count in the Member States included in the context				Pairs
European Red List: Birds	Acrocephalus/ scirpaceus	Population count in the project context				Pairs
European Red List: Birds	Acrocephalus/ scirpaceus	Species Range Area				ha
European Red List: Birds	Acrocephalus/ scirpaceus	Total species population count in the Member States included in the context				Pairs
European Red List: Birds	Charadrius/dubius	Population count in the project context				Pairs
European Red List: Birds	Charadrius/dubius	Species Range Area				ha
European Red List: Birds	Charadrius/dubius	Total species population count in the Member States included in the context				Pairs
European Red List: Birds	Charadrius/hiaticula	Population count in the project context				Individuals
European Red List: Birds	Charadrius/hiaticula	Species Range Area				ha
European Red List: Birds	Charadrius/hiaticula	Total species population count in the Member States included in the context				Individuals
European Red List: Birds	Emberiza/schoeniclus	Population count in the project context				Pairs
European Red List: Birds	Emberiza/schoeniclus	Species Range Area				ha
European Red List: Birds	Emberiza/schoeniclus	Total species population count in the Member States included in the context				Pairs
European Red List: Birds	Motacilla/flava	Population count in the project context				Pairs
European Red List: Birds	Motacilla/flava	Species Range Area				ha

First level descriptor	Second level descriptor	Third level descriptor	Start value	End value	Beyond end value	Unit
European Red List: Birds	Motacilla/flava	Total species population count in the Member States included in the context				Pairs
European Red List: Birds	Phalacrocorax/carbo	Population count in the project context				Individuals
European Red List: Birds	Phalacrocorax/carbo	Species Range Area				ha
European Red List: Birds	Phalacrocorax/carbo	Total species population count in the Member States included in the context				Individuals
European Red List: Fresh Water Fishes	Osmerus/eperlanus	Population count in the project context				Individuals
European Red List: Fresh Water Fishes	Osmerus/eperlanus	Species Range Area				ha
European Red List: Fresh Water Fishes	Osmerus/eperlanus	Total species population count in the Member States included in the context				Individuals
European Red List: Marine Fishes	Brama/brama	Population count in the project context				Individuals
European Red List: Marine Fishes	Brama/brama	Species Range Area				ha
European Red List: Marine Fishes	Brama/brama	Total species population count in the Member States included in the context				Individuals

- Birds: the types of birds which are present in the project area will be monitored.
  - Experts will visit the demonstration site at least 4 times a year to monitor the type of bird species present.
  - In addition to the measurements we will make use of citizen sciences to monitor the birds in the area. We will ask persons passing by the project site to indicate the type of birds they monitor and save this in a digital environment (digital twin).
  - Observations on the website 'www.waarneming.nl' will be used as source of information on the bird species present in the area.
- Fish
  - A fish friendly construction will make sure fish can enter and leave the LIFE WATERSOURCE demonstration site. A fish camera will be installed in this construction, which can identify and count the fish which are swimming towards and leaving the landscape using AI algorithms.

- Visual observations of fish species present in the landscape will be made incidentally when visiting the demonstration site and saved online.
- In addition to visual monitoring water samples will be taken to measure the eDNA. One sample will be taken from the water entering the landscape from Lake IJsselmeer and one sample at the end of the landscapes. With the difference in results the fishes which are present in the landscape of LWS can be deduced.
- For a certain amount of time a fishnet will be installed where the fish can enter the landscape in order to monitor the species. The fish will be trapped and a fisherman will observe the specie. A distinction will also be made in the fish which are younger or older than 1 year. After saving this information the fish will be allowed to swim freely in the landscape.

Regarding the third level descriptor of the fishes and birds present, the '*Population count in the project context'* will be zero at the start since there is no natural habitat of these species before construction of the demonstration site. After project implementation the landscapes of the demonstration serve as habitats for the species. After the project end it is expected that these species will remain occurring in the area and therefore are expected to be present in the large scale implementation after the LIFE project ends.

Regarding the fish, the start value will be 0 since there is no water, ergo habitat for fish, at the demonstration site before project implementation.

Above in the table the information as stated in the KPI portal is shown. Currently, there is a table available with the expected species and number of birds and fish at project end and 5 years beyond (when the large scale climate reservoir is implemented).

8.1 Climate Change Mitigation

8.1 B. Reduction of greenhouse gas emissions

Descriptor	Start value	End value	Beyond end value	Unit	Comments
Reduction of greenhouse gas emissions	9950	9937.17	7450.25	Tons of CO2eq / year	The GHG emissions of PWN is largely due to of the use of chemicals for the drinking water production (FeCl3). The demonstration project will reduce this with (at least) 25%. With a total use of 9.950 ton CO2, this leads to a reduction of 12.83 tonnes in the course of the demonstration project and 2486.92 tonnes 5 years after project end. This is a conservative estimate, as we expect a reduction of up to 75% is feasible. Calculation: The CO2 reduction is based on the lesser use of chemicals at the plant (FeCl3 and NaOH). The demonstration capacity is 20 m3/h = 175200 m3/yr, which comprises 0.7% of the total water flow (2.50E+07 m3/yr) towards the plant. Here a 25% decrease in chemicals is expected due to water quality improvement. On the entire flow, this is (19.08 tons/yr) converted to CO2eq by a factor of 0.628= 11.98 tons for FeCl3 and (3.76 tons/yr) 0.85 tons for NaOH (with the factor 0.225). In sum, this is a reduction of 12.83 CO2eq/yr, whereas at the moment, 9,950 tons of CO2 eq/yr is emitted, meaning 9,950,000/175,200 = 56.79 kg per m3

					produced drinking water. By project end, this will be (9,950,000-12,830)/175200 = 56.72 kg per m3 drinking water produced. For the large-scale implementation 5 years after project end, it will eventually be 360% of the total water flow (also due to plant expansion) (9.00E+07 compared with to the current 2.50E+07 m3/yr, again with a 25% decrease in chemicals), which in an equal calculation (savings of 3267.23 tons/yr = 2.052 tonsCO2eq/yr on FeCl3 and for NaOH at 1933.75 tons CO2/yr and 435.09 tons CO2eq/yr) comes down to a reduction of 2486.92 tonnes CO2eq/yr. The savings per m3 drinking water produced will remain the same. The chemicals used at the plant are monitored daily by PWN. CO2 emission reductions can be calculated accordingly for the Final Report.
	56,79	56,72	56,72	kg CO2eq / unit (Define unit in comment box)	"

- Water quality will be monitored both before and after it enters the LIFE WATERSOURCE demonstration site. An improvement in water quality is expected, particularly a reduction in suspended particles . Coagulation tests will be used to measure this reduction, which is anticipated to lower the need for chemical usage in drinking water production. Based on these measurements, the corresponding reduction in CO_2 emissions (in tons per year) will be calculated, highlighting the environmental benefits of the system.

8.2 B. Carbon sequestration increase

Descriptor	Start value	End value	Beyond end value	Unit	Context
Aquatic natural	0	2,2	370	Tons of CO2eq sequestrated / year	Helophyte marsh is known to fixate 2 ton CO2 per ha per year (https://research.wur.nl/en/publications/ecosysteemdiensten-van-natuur-en-landschap-aanpak-en-kennistabell). This amounts to 7.4 ton CO2/year. There is currently no ecotope, and hence no GHG sequestration. Within the demonstration project, a total of 0.3 ha helophyte marsh will lead to the sequestration of 2.2 ton CO2 per year. Full-scale implementation will result in around 50 ha of helophyte marsh, resulting in 370 ton CO2sequestration per year. The proof of evidence submitted in the Final Report is the development of ha helophyte marches created by the project.

- The vegetation and therefore helophyte marshes which will develop in the demonstration site will be measured (based on images of the vegetation and expert judgement). The amount of CO2 sequestrated will be calculated.

9.1 Climate Change Adaptation

9.1 B. Adaptation area – Reduction of areas vulnerable to climate change.

Descriptor	Start value	End value	Beyond end value	Unit	Context
Adaptation of particularly vulnerable area. Particularly vulnerable - Flood management area	1.62	1.61	0	km2	The whole PWN area at Andijk is vulnerable to higher lake levels as a result of climate change (sea level rise). This is 1.62 km2. The ecotopes created in the project form a 'lake barrier' to prevent flooding. Whilst within the demonstration project, this will have limited impact, after 5 years, full-scale implementation will make the full 1.62 km2 less vulnerable. An extra 2.5 km2 yet to be created climate reservoir will also be less vulnerable to climate change, resulting in a total of 4.1 km2 that will be less vulnerable in total. Proof of evidence will be lack of flooding at the premises of beneficiary PWN.

- The area of the premises of PWN which are vulnerable to climate change (by flooding) is known. With the new natural area which will be created with LIFE WATERSOURCE will be reduced.
- After project end the climate reservoir will result in a decreasing vulnerability of climate change since a new barrier to prevent the area from flooding will be created.

F. Societal outputs and outcomes

11. B Information and awareness

11.1 B Website

Descriptor	Start value	End value	Beyond end value	Unit	Comments
No. of unique visits	0	12500	25000	Number of unique website visits	We estimate that during the project, the webpage will attract 2500 of unique visitors per year. During the project, this means an estimated total of 12500 visitors. We estimate that after 5 years, this will at least have doubled.

- The number of visitors who visit the webpage of the LIFE WATERSOURCE project will be tracked.

11.2 B Other tools of reaching/raising awareness

Descriptor	Start value	End value	Beyond end value	Unit	Comments
Number of different displayed information created (posters, information boards)	0	2	2	Number of outcomes (e.g. nr of reports,	During the project we will place 2 boards, 1 at the demonstration location and 1 at the entrance of PWN's facilities.

				events, etc)	
Number of different publications made (Journal/conference)	0	2	3	Number of outcomes (e.g. nr of reports, events, etc)	During the project, we plan 2 technical publications reaching 7000 individuals each in sector-specific media. After project end, we consider it realistic to publish at least one more publication about the large-scale replication of the project.
Number of events/exhibitions organised	0	5	5	Number of outcomes (e.g. nr of reports, events, etc)	During the project, we will organise 3 seminars with 300 attendees each; and 2 opening events with 60 attendees each.
Number of articles in print media (e.g. newspaper and magazine articles)	0	6	9	Number of outcomes (e.g. nr of reports, events, etc)	During the project, we plan 4 press releases and 2 popular scientific publications, reaching 100,000 individuals per publication. Five years after project end, we deem it realistic we have published at least 3 further publications about the large-scale implementation of the project.

- The deliverables which are organized or products which are written are being counted. The reach of the specific deliverable is being tracked or estimated based on the reach of the specific media.

12 B. Networking and synergies

12.1 B. Networking and synergies with projects/initiatives

First level descriptor	Start value	End value	Beyond end value	Unit	Comments
LIFE projects	0	2	5	No. of projects/initiatives	LIFE WATERSOURCE will seek synergy with at least two other LIFE projects.
Other projects or initiatives (nationally/regionally/privately funded; to be specified in the comments box...)	0	2	4	No. of projects/initiatives	LIFE WATERSOURCE will seek synergy with project Markerwadden, visiting knowledge exchange events. In addition, the consortium will visit the Sere 2024 conference on habitat restoration and plans to seek more synergies there.

- During the LIFE WATERSOURCE project connection with other LIFE projects will be established. Demonstration sites will be visited, and knowledge will be exchanged.

G. Economic outputs and outcomes

13 B. New jobs created

	Descriptor	Start value	End value	Beyond end value	Unit	Comments
Implementation of the LIFE WATERSOURCE technique adjacent to the Ijsselmeer (NL)	New jobs created within the project consortium	0	5	115	No. of FTE	"This project creates both nature and data, which is measured and needs to be processed (and implemented in an innovative digital method). As a result, employment is created. Within the demonstration project, we create 5 fte at PWN alone (3.5 fte specialist; 1.5 fte operations). For full implementation, this will be 30 fte for PWN (10 fte specialist; 20 fte engineering) and a further 80 fte for external employment (20 fte engineer; 60 fte construction). These are conservative estimates. PWN has a policy for also hiring people with a distance to the job market.
Feasibility Study for implementation of LIFE WATERSOURCE technique at the Rubi river in Barcelona (ES)	New jobs created within the project consortium	0	0	38	No. of FTE	For implementation in Spain, we estimate the creation of 7 fte at CETAQUA (5 fte specialist; 2 fte engineering) and 7 at Aigues de Barcelona (4 fte specialist; 1 fte operations; 2 fte engineering), with a further 24 fte for external employment (4 fte engineering; 20 fte construction).

- The number of jobs created for the construction and operation of the LIFE WATERSOURCE project and the full scale implementation at PWN will be quantified.
- The number of jobs created for (after project end) implementation of the LIFE WATERSOURCE technique in Spain will be determined.

14 B. Economic sustainability and Catalytic effect

14.1 B. Revenue during or after project end, due to project outcomes

Descriptor	Start value	End value	Beyond end value	Unit	Comments
Revenue from a mix of sources or from other sources	0	30112	7696057	€	"In the course of the project, chemicals and energy are saved, as they are no longer required because of the natural purification that takes place in the project area. During the project: 19.08 tonnes of FeCl3 is saved per year @ 230 EUR per ton. For NaOH, this is 376 tonnes per year @ 300 EUR per ton. 2522.9 kWh/m3 is saved per year on the UV installation in

					Andijk @ 0.20 EUR per kWh. For 5 project years, this leads to a revenue of 30,112 EUR. 5 years after project end: the full scale implementation of the LIFE WATERSOURCE concept will result in a reduction of 751,464 tonnes of FeCl3 per year @ 230 EUR per ton. For NaOH, this is 580,125 tonnes per year @ 300 EUR per ton. 1,008,000 kWh/m3 is saved per year on the UV installation in Andijk @ 0.20 EUR per kWh. For 5 project years, this leads to a revenue of 7,665,945 EUR + the 30,112 EUR generated during the project itself.

- The water quality will be monitored when it passes the LWS demonstration. The reduction of particles in the water will be measured and will lead to a reduction in the necessary amount of FeCl3 and NaOH. This will be determined with coagulation tests. The costs of these chemicals are known; therefore the reduction will be calculated.
- The same accounts for the amount of energy necessary for the water treatment with UV. This reduction will decrease the energy costs, which will be calculated.
- The exact reduction in costs will be calculated at project end and estimated for 5 years after the project ends based on the water flow and expected water quality improvement, for when the large scale project will be implemented.

14.2 B. Catalytic effect – Financial – Cumulative investments triggered or finance accessed

Descriptor	Start value	End value	Beyond end value	Unit	Context
Other sources	0	0	152000000	€	Five years after project end, the large-scale implementation of LIFE WATERSOURCE is estimated at 147 million EUR. The exact financing structure is yet to be determined, and the project outcomes of LIFE WATERSOURCE will be instrumental in determining the financing strategy. In addition to large scale implementation in the Netherlands, the implementation in Spain is likely to take place 5 years after project end, if the feasibility study is successful. This will require an investment similar to the investment in this demonstration scale (5 million EUR).

- After the LIFE WATERSOURCE project ends the large scale project will be implemented. These costs are estimated and updated based on a cost calculation.
- The costs of the implementation of the LIFE WATERSOURCE technique in Spain after the project end will be estimated.

14.3 B. Continuation/replication/transfer after the project period

14.3.1 B Continuation after the project-end in the same premises/area(s) as those used during the project

Descriptor	Comment
Continuation at higher scale (compared to the	After project end, the 1 ha purification zone will be expanded to a 150 ha nature area. The original 1 ha will be included here and continues to be maintained.

scale during project implementation).	

- After project end the 1 ha demonstration site will continue to exist. Certain parameters will continue to be monitored. The continuation after project end is the full scale implementation of the climate reservoir where an area of 150 ha nature will be realised.

D2.4. MONITORING PLAN T5.2 & T5.3 PERFORMANCE ON WATER QUALITY AND QUANTITY IN RELATION TO WATER STRESS & ECOLOGICAL IMPACT INDICATORS

101113621 – LIFE22-CCA-NL-LIFE WATERSOURCE

READING GUIDE

The following chapter of the monitoring plan (D2.4) contains the performance of the LIFE WATERSOURCE demonstration regarding:

- **T.5.2**: Monitoring water quality and quantity in relation to water stress;
- **T.5.3**: Monitoring ecological impact indicators.

It outlines the methodology for evaluating water quality, ecological health, and hydrological impacts, in alignment with the project's goals and the tasks specified in the grant agreement. This chapter is divided into multiple sub-chapters which address the different aspects of the LIFE WATERSOURCE demonstration and is organized as follows:

- Section 2.1: introduces the monitoring aims and objectives of the various NBS components of the demonstration.
- Section 2.2: details the hydrological study, focusing on how fluctuating water levels in the water reservoir affect groundwater levels.
- Section 2.3: explains the digital twin, which is designed to store, analyze, and model data from the demonstration.
- Section 2.4: addresses the climate impact being investigated through the demonstration.
- Section 2.5: concludes with a preliminary schedule of the demonstration and monitoring efforts efforts.

2. MONITORING WATER QUALITY, QUANTITY AND ECOLOGY DEMONSTRATION

AIMS AND OBJECTIVES

The primary aim of the LWS demonstration project is to demonstrate the effectiveness of NBS components for pre-treating source water for drinking purposes and to provide insights for upscaling these solutions in the future KIJ. The specific objectives for each component include:

1. **Assess water quality changes:**
   Monitor key parameters such as total suspended solids (TSS), dissolved organic carbon (DOC), nitrogen compounds (e.g., NO_x), and other nutrients to evaluate the performance of NBS in improving water quality.

2. **Monitor microbial water quality:**
   Measure bacterial counts, faecal indicators (e.g., E. coli and enterococci), and ATP levels to assess whether the NBS effectively maintain or improve microbial stability, and to determine if the presence of fauna (e.g., birds, fish) introduces pathogens that could compromise water quality.

3. **Evaluate ecological impact:**
   Track changes in biodiversity, focusing on vegetation, fish, insects, and birds, to understand how NBS affect biodiversity and ecological value. This includes assessing habitat creation and niche development.

4. **Evaluate purifying landscape effectiveness:**
   Analyse contaminant removal by NBS, and determine their impact on reducing the requirements for conventional drinking water treatment.

5. **Develop and utilize a Digital Twin:**
   Create and apply a digital twin to store, analyse, and model data. This tool will enable real-time monitoring, inform decision-making, and support scaling NBS solutions.

Timeline
Monitoring will begin as the demonstration site components become operational. The purifying landscape is expected to be functional by May 2025. However, as a natural system, the landscape's biological development may take years to fully mature, meaning functionality will evolve over time which will be monitored. The mussel zone, constructed wetlands, and pilot reservoir will follow later in 2025, where the monitoring will be starting as soon as these are realized.

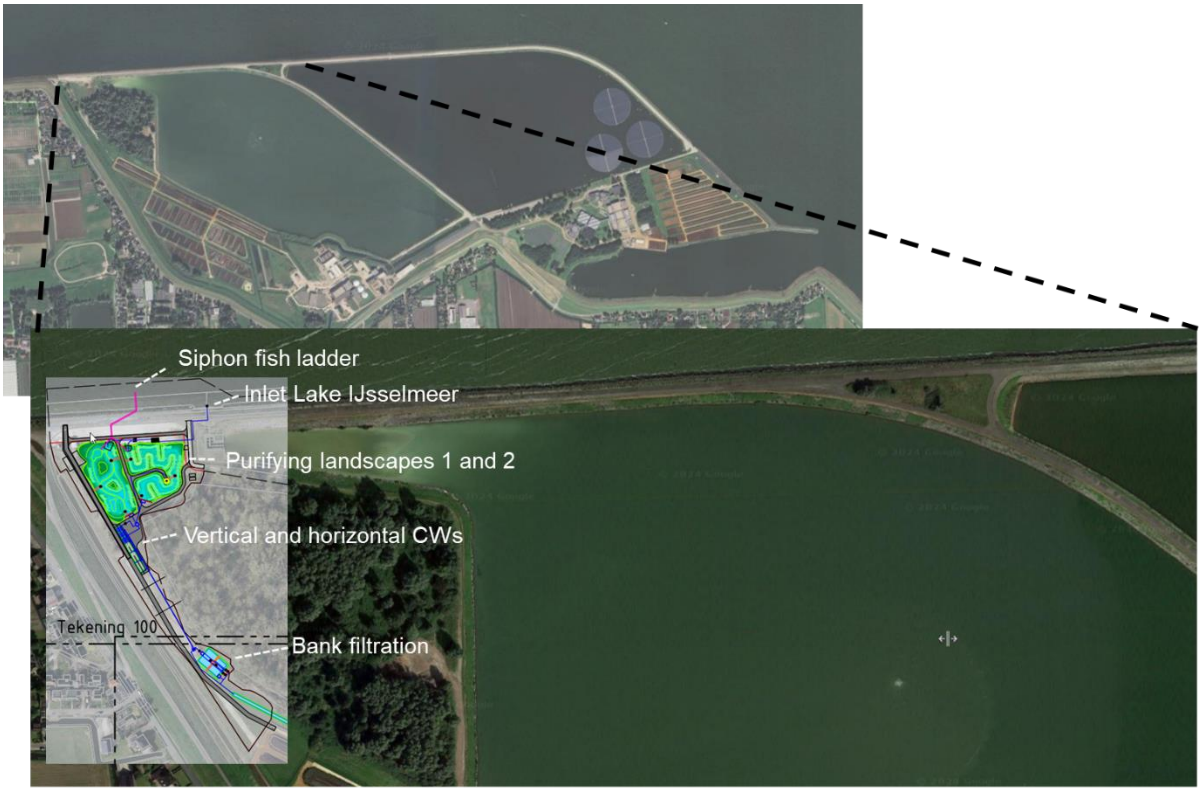


Figure 2. Overview of the LWS demonstration site at the PWN premises. Key features include a siphon fish ladder, allowing fish to swim in and out; an inlet for water from Lake IJsselmeer; and two purifying landscapes: Purifying Landscape 1 (left), designed as a traditional wetland, and Purifying Landscape 2 (right), designed as a constructed free-water-surface wetland. Below these landscapes, three vertical and three horizontal constructed wetlands will be installed. At the base, a bank filtration system is indicated.

2.1 DEMONSTRATION

The LIFE WATERSOURCE demonstration site consists of multiple interconnected components (Figure 3). These components necessitate distinct monitoring strategies, tailored to their technical goals and roles within the system.

To provide clarity, Table 1 summarizes the technical goals, monitoring objectives, and main indicators for each component. This structured overview highlights the rationale behind the varied monitoring approaches and ensures a comprehensive evaluation of the demonstration site.

The subsequent sections describe each component in detail, elaborating on their design, operation, and associated monitoring strategies.

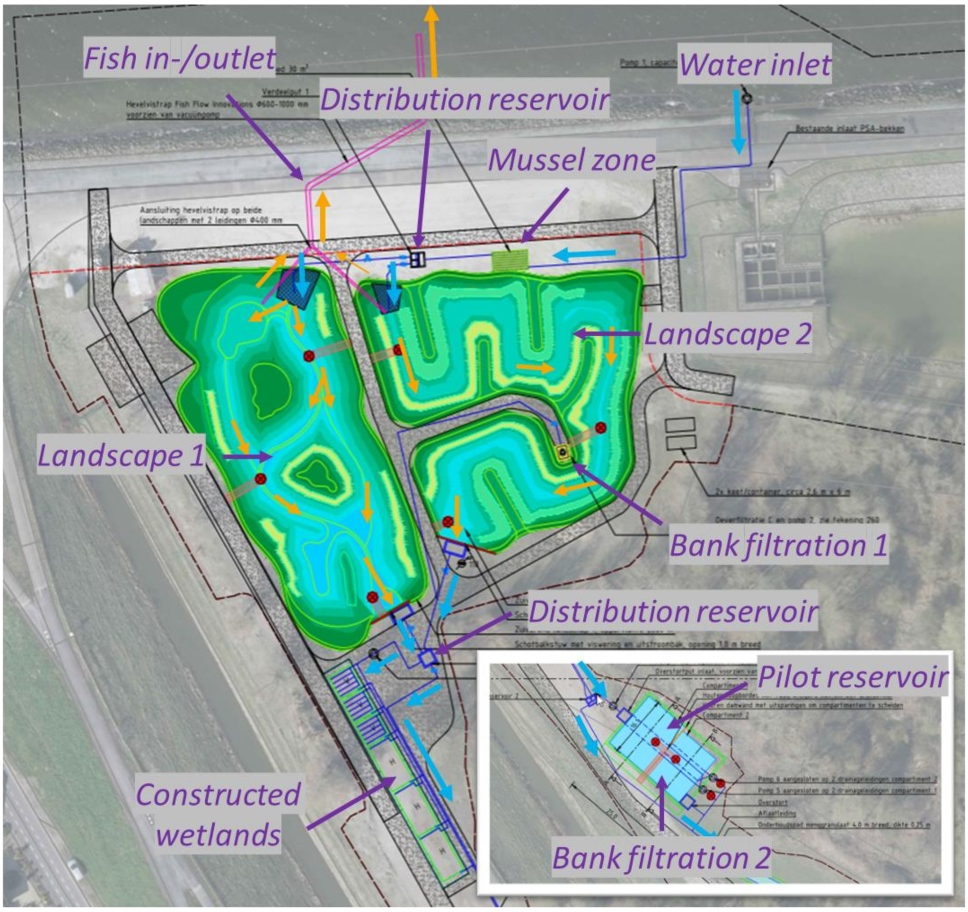


Figure 2. Design LWS demonstration. This figure shows the following components: Inlet water from Lake IJsselmeer, mussel zone, siphon fish ladder, Purifying landscapes 1 and 2, Three vertical and horizontal constructed wetlands, and a pilot reservoir with bank filtration on the bottom. Orange arrows indicate fish-friendly water flow directions, while blue arrows indicate fish-unfriendly flow directions. Red dots in both landscapes mark the locations of sampling jetties.

Table 1. Overview of the components in the LIFE WATERSOURCE demonstration site, detailing their technical goals, monitoring objectives, and key indicators used to evaluate performance.

Component	Technical Goal	Goal of Monitoring	Main Indicators
Inlet with Lake IJsselmeer water	Pump a portion of water from Lake IJsselmeer into the demonstration.	Serve as a reference site for monitoring water inflow.	Flow rate, water quality parameters (e.g., temperature, turbidity).
Mussel zone	Cultivate mussels for natural water purification.	Assess mussel filtration efficiency and its impact on water quality.	Mussel biomass, water quality (e.g., nutrient levels, turbidity), larvae stages.
Fish-friendly outlet (siphon fish ladder)	Facilitate fish movement in and out of the demonstration site.	Monitor fish movement, species, age, and size.	Fish movement (fish camera), species diversity, size distribution.
Purifying landscapes	Enhance water quality through natural landscape features and boost ecology.	Evaluate water quality improvements and ecological impacts.	Water quality (e.g., NH_4, DOC, NO_x, TSS), biodiversity (fish, birds, flora, fauna), maintenance strategies.
Vertical and horizontal wetlands	Further purify water using constructed wetland systems.	Monitor water treatment efficiency across different wetland designs.	Water quality (e.g., NH_4, DOC, NO_x, TSS), maintenance requirements.
Pilot reservoir with bank filtration	Simulate water storage and natural purification through bank filtration.	Assess bank filtration performance as a final filtering step.	Filtration efficiency, biological stability, clogging rates, maintenance strategies.
Hydrological model development	Study the effect of level variations in PWN reservoirs on surrounding groundwater.	Developing a hydrological model and implementing monitoring system.	Groundwater level variations, hydrological model accuracy.
Digital twin	Create a digital simulation environment to store data and model scenarios.	Integrate data from all components, analyse data and simulate future scenarios.	Data integration quality, simulation accuracy, system performance metrics.

2.1.1 Inlet IJsselmeer water

Water from Lake IJsselmeer first enters PWN's PSA reservoir as part of the drinking water production process. This inlet will also serve as the LWS inlet. Routine water quality samples are taken at various intervals from the PSA reservoir inlet (Table 2), providing critical baseline data for assessing water quality at the LWS demonstration site. This monitoring will establish reference values for key parameters, which will be integrated into the digital twin system. If elevated concentrations of specific parameters are detected, the system will issue a warning, prompting an increase in sampling frequency at the LWS site.

Research question:

1. What is the initial water quality of Lake Ijsselmeer?

Table 2. Monitoring parameters at current WPJ reservoir inlet used as baseline reference for the LWS project

PARAMETER	UNIT	ANALYSIS CODE	FREQUENCY (YEARLY)
NUTRIENTS			
AMMONIUM	mg/L	NH4	26
NITRITE	mg/L	NO2	4
NITRATE	mg/L	NO3	26
ORTHOPHOSPHATE	mg/L	PO4-O	26
TOTAL PHOSPHATE	mg/L	PO4-T	26
IRON TOTAL	mg/L and µg/L	FE-TOT	26
MANGANESE TOTAL	mg/L and µg/L	MN-TOT	26
IONS AND HARDNESS			
CALCIUM	mg/L	CA	52
CHLORIDE	mg/L	CL	26
CARBONATE	mg/L	CO3	52
HYDROGENCARBONATE	mg/L	HCO3	52
TOTAL HARDNESS	mmol/L	HH-TOT-BER	52
MAGNESIUM	mg/L	MG	52
SODIUM	mg/L	NA	52
SULFATE	mg/L	SO4	13
WATER QUALITY PARAMETERS			
DISSOLVED ORGANIC CARBON	mg/L	DOC	26
ELECTRICAL CONDUCTIVITY	mS/m	EGV	52
PH	-	PH	52
TEMPERATURE	°C	TEMP	52
SUSPENDED SOLIDS	mg/L	SUSP-ST	52
TOTAL ORGANIC CARBON	mg/L	TOC	13
CARBON DIOXIDE	mg/L	CO2-BER	52
UV TRANSMITTANCE (254 NM)	%	UV	52
BIOLOGY			

CHLOROPHYLL FLUORESCENCE	µg/L	CHL-FLUO	26
ALGAE (GENUS)	Cells/mL	FYT-N-OW-G	13
ZOOPLANKTON (GENUS)	Individuals/L	ZOO-N-OW-G	13

2.1.2 Fish in- and outlet

Research questions:

1. Does the fish siphon effectively facilitate fish movement in and out of the LWS demonstration site?
2. How does the siphon fish ladder influence the overall ecological connectivity between the LWS demonstration site and Lake IJsselmeer?

To facilitate water flow to the LWS demonstration site, pumps are required. However, these pumps prevent fish from entering the area. To enable fish to move in and out of the landscape, a siphon fish ladder will be built (Figure 3). This structure is designed to allow water to flow from the LWS demonstration site toward Lake IJsselmeer. The water connected to the landscape enables fish to swim upstream against the current into the landscape, and to exit when swimming downstream in the same direction as the water flow toward the lake.

Monitoring
The siphon fish ladder enables fish to swim in and out of the landscape in both directions. A fish camera will be installed in this structure to capture videos of the fish. These videos will be analysed using artificial intelligence software to determine the size, species, and swimming direction of the fish. The collected data will be stored in the digital twin. Additionally, the videos will be displayed in real-time on a publicly accessible dashboard associated with the digital twin.

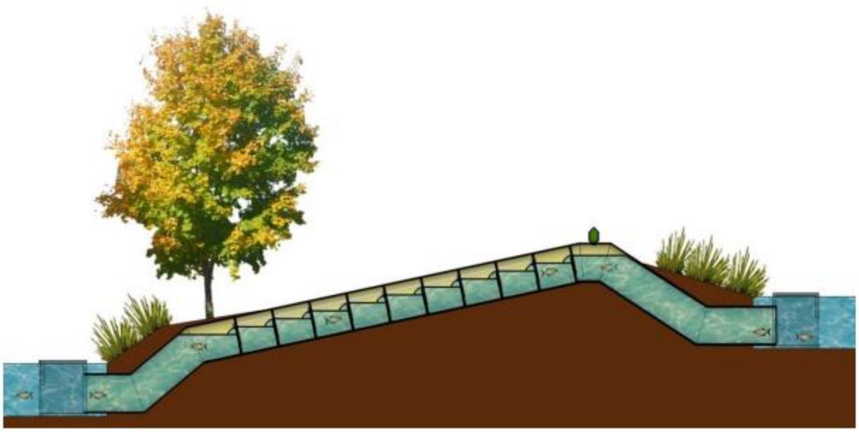


Figure 3. Illustration siphon fish ladder. Water flows from downstream while fish are able to swim upstream.

2.1.3 Mussel zone

Research questions:

1. What is the impact of mussels on water quality enhancement?
2. What are the system-wide challenges posed by mussel larvae?

The mussel species *Dreissena polymorpha*, *Dreissena bugensis*, and *Corbicula fluminea* (Zebra mussels, Quagga mussels and Asian clams) will be grown on ropes placed in the mussel reservoir, a rectangular basin with a volume of 20 - 30 m³ (Figure 4). The setup aims to feature 10 horizontal ropes, each with 10 vertical ropes of about 80 cm, resulting in a total of 100 ropes. Initially, half of the ropes will remain mussel-free, while the other half will hang in the existing reservoirs for several months prior to the demonstration where mussel growth is expected. Assuming an average filtration rate of 1.5 Liters per mussel per day, each rope will house an estimated 500 mussels. This setup will accommodate a total of 50,000 mussels across the system. At the estimated rate of 1.5 Liters per mussel per day, the system will achieve a maximum filtration capacity of 75,000 Liters per day, which constitutes approximately 6% of the total incoming water volume from Lake IJsselmeer daily.

This configuration enables us to monitor mussel colonization and growth within a controlled environment. The mussel reservoir will also act as the first sampling point after the reference inlet from Lake IJsselmeer, facilitating comparisons with the current IJsselmeer inlet water quality. This comparison will help evaluate the impact of mussel-based filtration on water quality. To protect the mussels and ensure efficient harvesting, protective nets will be installed to shield them from bird predation.

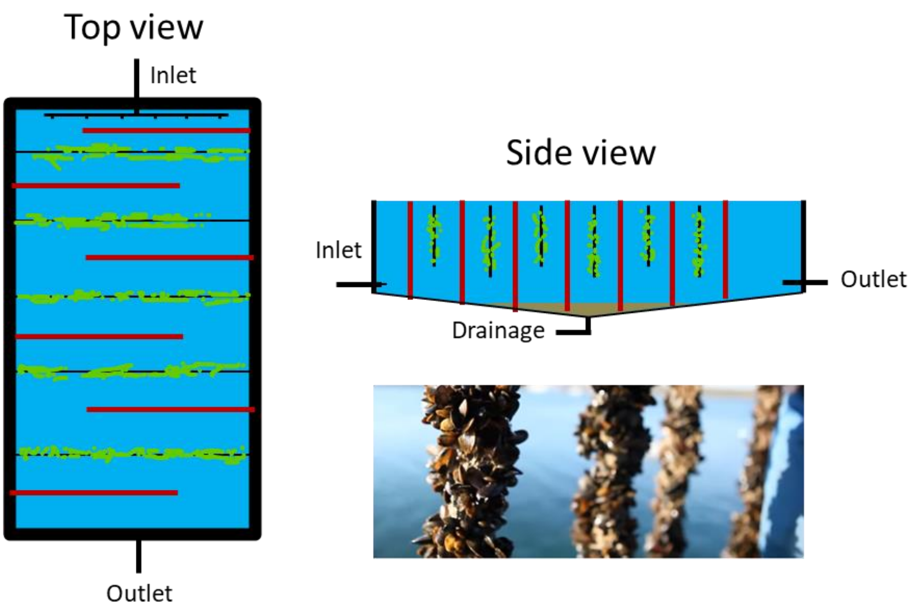


Figure 4. Illustration of mussel zone Layout. Mussels will grow on ropes and not touching the bottom where sedimentation takes place.

Monitoring Mussels

Manual monitoring will track the distribution and size of bivalves, including *Dreissena polymorpha*, *Dreissena bugensis*, and *Corbicula fluminea* (Zebra mussels, Quagga mussels, and Asian clams). The different mussel larvae stages (Table 3) will be monitored quarterly through zooplankton sampling and cell counting near the inlet and outlet of the mussel zone. Juveniles and adults will be tracked through visual inspections of ropes within the mussel zone, which serve as settlement substrates. Shell size and weight will be measured quarterly to assess growth and distribution patterns. Biomass and density on ropes and walls will also be determined, along with evaluations of the condition index (the relationship between shell length and meat content) and population structure through length-frequency analysis. These measurements, conducted four times a year, will provide comprehensive insights into population dynamics and overall health.

In addition to the growth ropes, other solid structures within the mussel zone, such as pipes and walls, will be monitored for settlement. These structures can act as additional substrates for juvenile and adult mussels, presenting risks of biofouling and potential obstruction. In a later section on landscapes, the monitoring of solid structures outside the mussel zone will also be addressed, ensuring a comprehensive assessment of settlement risks and ecosystem impacts.

Table 3. Mussel larvae stages and settling relevance

Larval Stage	Description	Monitoring Method	Relevance to Settling
Glochidia	Microscopic larvae.	Zooplankton sampling and cell counting.	Low: Cannot settle directly in pipes or solid structures but important for understanding reproduction and dispersal.
Juvenile Stage	Free-living young mussels settling on substrates.	Visual inspections of settlement ropes and solid structures, including pipes.	High: Critical stage, as juveniles can attach to pipes and structures, initiating biofouling.
Adult Stage	Fully developed mussels capable of reproduction and sustained growth.	Visual inspections of settlement ropes, solid structures, and pipes.	Medium: Adults contribute to long-term biofouling.

Monitoring mussels and water quality in mussel zone

As mussel growth density increases, water quality monitoring will be intensified. Handheld sensors will measure parameters such as dissolved oxygen, turbidity, pH, and conductivity. Additionally, nutrient concentrations, including nitrogen compounds (e.g., nitrate and ammonium) and phosphorus (e.g., phosphate), will be measured before and after the mussel zone to assess the mussels' impact on water quality. All collected data—including larval counts, settlement on substrates, and water quality measurements—will be saved in the digital twin for detailed analysis and predictive modelling.

Online monitoring

The mussel zone is equipped with a robust structure that facilitates the installation of an online monitoring system, serving as the starting/reference point for water quality and biological monitoring within LWS. A UV-VIS sensor (s::can spectro::lyser) will continuously measure key organic parameters and suspended particles. These parameters include, turbidity, nitrate, dissolved organic carbon (DOC), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), UV254, and total organic carbon (TOC).

In addition, a multiparameter sensors (EXO 3) will be deployed to monitor environmental variables, such as electrical conductivity (EGV), pH, dissolved oxygen, turbidity, temperature, and algae concentration, with measurements taken automatically every 10 minutes. Data from both sensors will be transmitted via Wi-Fi to a local data hub and stored in the digital twin for analysis and monitoring. Figure 5 shows the sensor locations: one of each sensor in the mussel zone and one of each at the outlets of both landscapes. The relevant parameters, their units, and the measurement intervals are listed in Table 4.

In addition to the permanently installed EXO3 system, an EXO1 handheld multiparameter sensor will be used for on-demand spot checks and short-term measurements. This portable sensor can measure conductivity (EGV), pH, temperature, dissolved oxygen, and turbidity in real time. This allows additional measurements within the landscapes and monitoring of the pilot reservoir water. The EXO1's flexibility makes it particularly valuable for investigating specific areas or following up on anomalies revealed by the continuous monitoring network. All collected data will be uploaded to the digital twin for further analysis and integration with other water quality parameters.

Table 4. Overview of online monitoring parameters and associated sensors. The table highlights which sensors measures which parameter. Interval can be changed in case necessary.

Parameter	Unit	Range	Interval	Sensor
Total suspended solids (TSS)	mg/L	0 – 1200	10 min	spectro::lyser
Dissolved organic carbon (DOC)	mg/L	0 – 180	10 min	spectro::lyser
UV254	Abs/m	0 – 500	10 min	spectro::lyser
Nitrate (NO3)	mg/L	0 – 120	10 min	spectro::lyser
Biochemical Oxygen Demand (BOD)	mg/L	0 – 300	10 min	spectro::lyser
Chemical Oxygen Demand (COD)	mg/L	0 – 300	10 min	spectro::lyser
Total Organic Carbon (TOC)	mg/L	0 – 210	10 min	spectro::lyser
Turbidity	NTU	0 - 4000	10 min	spectro::lyser
Conductivity	µS/cm	0 - 100	10 min	EXO3 + EXO1
Temperature	°C	0 – -40	10 min	EXO3 + EXO1
pH	pH	0 - 14	10 min	EXO3 + EXO1
Dissolved Oxygen (DO)	mg/L	0 - 50	10 min	EXO3 + EXO1
Total Algae (chlorophyll & blue-green algae)	µg/L	0 - 100	10 min	EXO3

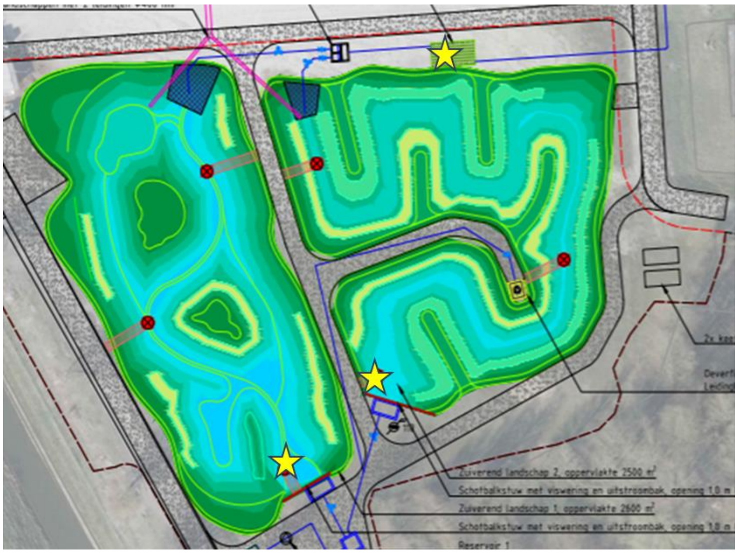


Figure 5. Locations of online monitoring systems. Yellow stars indicate the positions of the sensors, with one sensor located in the mussel zone and one at the outlets of each landscape.

Manual monitoring

In addition to the online measurements, manual water sampling will be conducted in the mussel zone and other components of LWS to evaluate water quality and biological parameters that cannot be measured online. These parameters are essential for understanding the landscapes purification capacity and maintaining the biological stability of the system. This data will be used to monitor changes in water quality at key stages: before, during, and after treatment by the purifying landscapes, constructed wetlands, and subsequent bank filtration. Biological indicators, including faecal indicators, chlorophyll, and zooplankton, will establish baseline data for system health and assess the biostability of the treatment process.

Manual sampling will also be essential for verifying and calibrating sensor data, ensuring the accuracy and reliability of the online measurements. Table 5 summarizes the parameters that will be manually sampled at the outlets of all system components, including the mussel zone and the frequency these samples will be taken annually. In emergencies, such as when inlet parameter (see section 2.1) values are elevated, the sampling frequency can be increased to address critical issues. Additionally, if online monitoring fails, the frequency of sampling key parameters such as DOC, NO_3^-, and TSS will be prioritized. For the mussel zone, mixed water samples from different depths will be collected and analysed at Het Waterlaboratorium (HWL) to guarantee precise and reliable laboratory evaluations.

Table 5. Parameters to be manually sampled at the outlet of various LWS components to assess water quality, biological stability, and verify online sensor outputs. Sampling frequency (annually) may be adjusted in emergencies at the IJsselmeer inlet or increased for key parameters.

PARAMETERS	ANALYSECODE	UNIT	MUSSEL ZONE	PURIFYING LANDSCAPES	CONSTRUCTED WETLANDS	PILOT RESERVOIR	BANK FILTRATION
Ammonium (NH_4^+)	NH4	mg/L	26	26	26	26	26
Nitrate (NO_3^-)	NO3	mg/L	26	26	26	26	26
Totaal Nitorgen	N-T-BER	mg/l	26	26	26	26	26
Phosphate (PO_4)	PO4-O	mg/L	26	26	26	26	26
Total Phosphate	PO4-T	mg/L	26	26	26	26	26
Sulfate (SO_4)	SO4	mg/L	26	26			
Natural Organic Matter (NOM)	NOM-DATA	mg/L		13			13
Metals	MET-SCAN	µg/L	13	13			13
Total Suspended Solids (TSS)	SUSP-ST	mg/L	13	13	13	13	13
Dissolved Organic Carbon (DOC)	DOC	mg/L	13	13	13	13	13
Total organic carbon (TOC)	TOC	mg/L	13	13	13	13	13
Turbidity	FTU	FTU	13	13	13	13	13
Conductivity	EGV	mS/cm	13	13		13	13
Temperature	TEMP	°C	13	13		13	13
pH	PH	pH	13	13		13	13
Dissolved Oxygen (DO)	O2	mg/L	13	13		13	13
Target Screening OMPs	UHPLC-QTOF	ng/L		8			4
Fecal indicators (coliforms and enterococci)	COLI-100; ENT-100	CFU/100 mL	13			13	
Coliforms	COLI-25L of COLI-50L	CFU/25 of 50L	13				13
Chlorophyll Fluorescence	CHL-FLUO	µg/L	13	13		13	13
Chlorophyll (a & pheophytin)	CHLOROFYL	µg/L	4	4		4	4
ATP (Total Biological Activity)	ATP-WATER	ng/L	4			4	4
Direct cell Count	DCT-TOTLEV of DCT-HNALNA	cel/ml	4			4	4
Zooplankton (Genus)	ZOO-N-OW-G	Individuals/L	4			4	4
eDNA	DNA-FIL	Copies/L	4	4			4
Mussel larvae	MOSL		13	26		13	13
Particle size distribution	PART					2	2
Coagulation tests	COG		2			2	2

2.1.4 Purifying landscapes

Water quality research questions:

1. How does water flow separation between Landscape 1 and Landscape 2 affect water quality and biodiversity?
2. How do natural water level changes affect ecological and purifying functions in both landscapes?
3. How do varying flow rates (5–20 m^3/h) impact retention times and water purification efficiency?
4. How does the management plan in Landscape 2 compare to Landscape 1 in improving water quality?
5. How do seasonal variations affect water quality dynamics in the wetland?
6. How do varying hydraulic retention times influence water quality and purification efficiency?
7. What is the impact of bank filtration on water quality within the landscape?

Ecology research questions:
Flora:

1. How does the design of Landscape 1 and Landscape 2 affect plant diversity and habitat development?
2. How does seasonal variation affect vegetation development and ecological processes in both landscapes?
3. How do maintenance strategies in Landscape 2 influence plant diversity and habitat quality compared to Landscape 1?
4. How does vegetation development vary between the two landscapes over time, and what factors drive these changes?
5. What is the role of pioneer and invasive plant species in shaping the vegetation structure and ecological balance of the landscapes?

Fauna:

6. Which bird species utilize the LWS demonstration as habitat, and how does their presence inform predictions for the larger KIJ project?
7. Which fish species are attracted to the LWS demonstration areas, and how do fluctuations in water quality (e.g., nutrient levels, dissolved oxygen) influence their abundance or diversity?
8. Which (flying) insects are present within the landscapes, and how can these communities serve as indicators for bird populations and overall ecosystem health?

After the mussel zone, water flows to the distribution well. Here the flow will be separated in two streams. One is towards landscape 1 and the other flows to landscape 2 (Figure 6).

Landscape 1 (west): This landscape features a traditional shallow wetland, with depths ranging from 0 m to 1.4 m. The inlet water from Lake IJsselmeer flows into this landscape through a controlled inlet structure, which is designed to ensure smooth water inflow. Small islands within the landscape are exposed at low water level, providing habitat for pioneering species. The focus here is on boosting ecological diversity with minimal management. The area includes a fish/spawning pond and open ground for the development of various plant species. Landscape 1 operates with little maintenance, encouraging natural ecological processes. Three wooden sampling jetties, distributed across the landscape, will allow for regular water sampling and monitoring water quality.

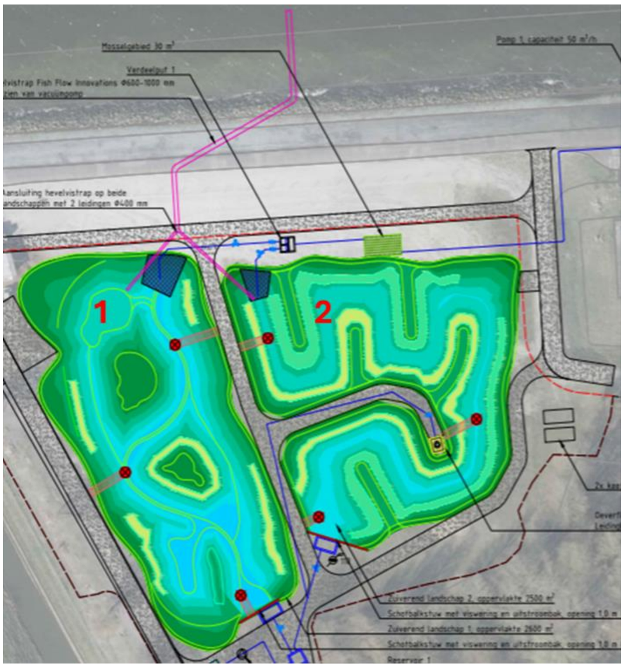
Landscape 2 (east): Landscape 2 is characterized by a meandering waterway showcasing a constructed free-water-surface wetland, stretching 180 meters, with depths ranging from 0 m to 1.2 m. A dense helophytebed lines the waterway, playing a key role in filtering and purifying the water. This landscape is designed to improve water quality and will be maintained with a clear management plan to optimize its efficiency. Like Landscape 1, three wooden sampling jetties are strategically placed for manual sampling across the landscape.

Hydrological monitoring: We will manage the system by adjusting water levels to mimic a natural hydrological regime. This strategy will support both the ecosystem and the purification process. During winter, we will set the water level to 2.20 m (NAP) to promote optimal ecological conditions and maximize the wetland's purification capacity. As the seasons change, we will gradually decrease the water level in the spring, reaching a minimum of 1.70 m (NAP) by summer. These levels will represent the baseline conditions for the system, although we may lower the minimum level further if operational needs require it.

We will regulate the flow rate between 5 and 20 m³/h to study its impact on the purification process and optimize retention time. Retention times will be calculated and determined through trace experiments, which will help assess how long water remains in the system under varying flow conditions. By adjusting the flow rate and measuring retention time, we can fine-tune the system for optimal performance.

In addition, we will use Computational Fluid Dynamics (CFD) modelling to assess and optimize flow patterns within the system. CFD will allow us to simulate different flow scenarios and adjust the system's design to maximize retention time in key areas, ensuring that the water purification process operates efficiently and effectively.

Figure 6. Schematic of the two heterogeneous purifying landscapes: Landscape 1 (west) with a shallow wetland design, featuring varied depths, small islands, and minimal management to support ecological development, and Landscape 2 (east), a meandering waterway with high-density helophyte beds, managed intensively to improve water quality.



Monitoring

Water quality

At the end of both purifying landscapes, online sensors will be installed to monitor water quality, similar to those used in the mussel zone (section 2.3). These sensors will measure the same key parameters as listed in Table 2, ensuring consistency in data collection across the system. Each landscape will have one sensor installed at the outlet, positioned on the sampling jetty for easy access and to ensure effective monitoring of the water exiting the landscapes after purification.

In addition to the automated sensors, manual sampling will be conducted following the same methodology used in the mussel zone (Table 5). Water samples will be collected from the top layer of the water, and laboratory analysis will focus on the same water quality parameters as well as biological indicators, including microbiological life and eukaryotes present in the water. This allows for a direct comparison between water quality before and after purification by the landscapes.

Multiparameter handheld sensor (EXO 1) will also be available for real-time measurements (Table 4), providing the flexibility to increase the frequency of sampling if necessary. This handheld sensor measuring parameters such as oxygen and pH, will be used at various locations across the landscapes, accessible via the three small sampling jetties (Table 2).

Coagulation tests

To evaluate the landscape effectiveness in removing suspended particles, coagulation tests will be conducted twice a year once at the end of winter and once at the end of summer. These tests will determine the optimal coagulant dosage needed to achieve the target removal efficiency for drinking water production.

Nutrient cycling monitoring

Overview

The purifying capacity of the wetland will be evaluated by analyzing water quality, focusing on nitrogen (N) and phosphorus (P) cycling. While helophyte plants take up a portion of these nutrients, other processes—such as microbial activity, sedimentation, and adsorption—play critical roles in overall nutrient removal. Consequently, rather than assuming stabilization solely from plant growth, the wetland's performance will be assessed through consistent reductions in key water quality parameters (e.g., nitrate, phosphate, dissolved organic carbon, and suspended solids). These reductions will be monitored to determine average system performance under different conditions. Analysis will begin once the plants reach maturity, estimated at approximately two years.

Harvest (Landscape 2)

- Rotational Harvesting: Landscape 2 is divided into two sections. Each year, one section is harvested, leaving the other section unharvested for two years. This approach ensures that mature plants–providing fish habitats and winter refuges for insects–remain available year-round.
- Biomass Sampling: During harvest, a representative biomass sample (1-2 kg) is dried and weighed to estimate total biomass. Its N and P content is analyzed to calculate nutrient uptake.
- Sediment Sampling: Pre-harvest sediment samples are collected to capture conditions just prior to biomass removal. Correlating sediment nutrient levels with changes in plant biomass and water quality provides a more comprehensive understanding of nutrient cycling in the system.

Comparisons of nutrient removal efficiency between different sections and plant species will help identify the most effective combinations.

Landscape Evolution

To assess initial conditions and track changes over time, sediment research will start when the purifying landscapes are established:

- At the start and end of the project, sediment samples will be collected from three representative locations in each landscape. These samples will be analyzed for nutrient content, including *Olsen-P*, total phosphorus, and various nitrogen fractions. The results will offer valuable insights into the overall functioning and nutrient dynamics of the ecosystem.
- Ongoing Monitoring: A sediment probe will measure and track sediment accumulation as the project progresses. When significant buildup is observed, additional sediment samples will be taken and analyzed, with particular attention to phosphorus binding—a key factor influencing nutrient removal efficiency.

These findings will inform further optimizations, as well as the design and scaling of future systems, ensuring that larger applications effectively cycle nutrients and minimize environmental impacts.

Ecology

Birds

Bird populations in the WATERSOURCE demonstration area will be monitored by an experts who will visit the site four times annually: twice in spring to assess breeding birds and once each in autumn and winter to track migratory species. During these visits, the expert will estimate the location and size of bird habitats to evaluate their functionality and count the number of birds. This monitoring will provide insights into how quickly the newly created habitats attract diverse species and support the establishment of nurseries and foraging areas. Special attention will be given to key species such as the great cormorant (*Phalacrocorax carbo*), common tern (*Sterna hirundo*), helophyte bunting (*Emberiza schoeniclus*), and yellow wagtail (*Motacilla flava*).

In addition to expert monitoring, citizen science will be employed to further track bird species in the area. Passersby and volunteers will be encouraged to report their observations, which can be uploaded to the digital twin. Additionally, bird sightings from websites like 'www.waarneming.nl' will be incorporated into the monitoring efforts.

Fish

The movement of fish entering and leaving the landscapes will be continuously monitored using fish cameras at the inlets and outlets. The cameras will be set up to detect fish species, monitor their size, and track the frequency of fish movements. These camera systems often use infrared or motion-sensing technology to operate 24/7, providing continuous data.

In addition to the cameras, fyke nets will be installed at intervals throughout the year, typically during high fish movement periods (spring and autumn). The nets will remain in place for approximately 2-4 days, depending on the target fish species and ecological patterns. After the netting period, a fisherman will identify, measure, and release the fish back into the landscapes. The fish will be measured by size classes, noting whether they are juveniles (younger than one year) or adults (older than one year). Special focus will be placed on species such as perch (*Perca fluviatilis*), pike perch (*Stizostedion lucioperca*), and roach (*Rutilus rutilus*).

In addition to direct fish capture methods, incidental fish observations will be made during routine visits to the site. These informal observations will be logged by project personnel and fisherman, helping to build a broader understanding of fish populations and their seasonal movements within the landscapes.

Water samples will be collected every season for environmental DNA (eDNA) analysis (Table 5). These samples are taken within the mussel zone, and each sampling jetty within the landscape and will be stored in a freezer until processed. The eDNA samples will be analysed annually to detect the presence of fish species as well as other aquatic organisms. By comparing eDNA data from the wetland areas to those from the mussel zone, we will be able to identify changes in species composition over time.

Vegetation

Vegetation and habitat development in the landscapes will be monitored through a combination of visual observations, expert assessments, and advanced techniques. Each year, before summer, the plant diversity will be assessed using the quadrant method at key locations, including herb-rich grasslands, helophyte zones, transition zones between land and water, and water vegetation areas. A vegetation map will be created based on expert input. In addition to common species such as *Phragmites australis*, narrow-leaf cattail (*Typha angustifolia*), and common cattail (*Typha latifolia*), particular attention will be given to monitoring pioneer and invasive species.

Two fixed timelapse cameras will be used to continuously document the landscape's transformation over time by generating a time-lapse video. Monthly drone imagery will further support vegetation monitoring, providing an aerial view of landscape changes and vegetation development.

Insects

Monitoring insects is an important component of the WATERSOURCE demonstration, as upscaling bird monitoring can be challenging. Insects, however, can offer valuable insights into the developing wetland ecosystem. As the wetland matures, the insect community is expected to transition to a more wetland-specific composition, which can be used to predict the presence of future bird species. The presence of certain insect species can serve as indicators of changes in the ecosystem and provide early signals of how the habitat may support more complex trophic interactions, including those of birds.

Flying insects will be monitored continuously using a DIOPSIS camera system (Figure 7). This device attracts insects to a fluorescent plate, which is photographed at least six times per minute whenever movement is detected. AI software then processes the images to identify the insect species. The collected data will be stored and linked to the digital twin for continuous tracking.

Figure 7. DIOPSIS camera system used to monitor flying insects. AI software processes the images to identify species.

Maintenance purifying landscapes

A key research question in this project is to assess how different maintenance intensities influence water quality. To study this, Landscape 1 is managed minimally (encouraging natural ecological development), while Landscape 2 undergoes more active interventions aimed at maximizing purification. By monitoring both systems, we can determine which maintenance strategy is most effective for improving water quality over time.

Proper vegetation and waterbed management are essential in both landscapes to maintain optimal flow and ecological function. Inadequate maintenance can degrade purification capacity, leading to flow constraints and competition for helophyte plants. Therefore, a detailed maintenance plan—covering both ecological needs and water quality goals—will be elaborated in a separate document. Below is a concise overview of the key strategies:

Landscape 1 & 2

Establishment Period

- **Young helophyte beds**: In both landscapes, newly planted helophytes require at least one (possibly two) full growing seasons without mowing to establish strong root systems.

- **Weed removal**: During this phase, unwanted vegetation is manually removed up to four times per year to prevent overgrowth and competition.

Annual Inspections

- **Visual assessments**: Both landscapes are inspected once a year to evaluate helophyte health, identify any issues (e.g., invasive species), and adjust management plans as needed.

- **Adaptive management**: Findings may prompt different approaches for each landscape—for example, more frequent mowing in Landscape 2, or selective removal of encroaching vegetation in Landscape 1.

Surrounding Grass and Trees

- Maintenance of grassland and nearby trees helps prevent shading or encroachment on wetland species, maintaining good light and flow conditions for helophyte plants.

Landscape 2 Only

Submerged vegetation

- **Annual Mowing:** Submerged vegetation in landscape 2 is cut once per year, in September or October.
- **Post-Mowing Monitoring:** Helophyte vitality is checked afterward; if signs of stress appear, mowing frequency may be reduced.

2.1.5 Constructed wetlands

Research questions:

1. How effective are horizontal and vertical constructed wetlands in improving water quality, and which design is most efficient for future scaling?
2. How does each substrates affect water quality, plant health, and maintenance efficiency?
3. What is the optimal retention time for water quality improvement, and how do different flow rates impact this duration?

Within the WATERSOURCE demonstration key water quality parameters will be monitored in the constructed wetlands: Total Suspended Solids (TSS), Dissolved Organic Carbon (DOC), phosphorus, and nitrogen compounds (Table 5). Manual sampling will occur every two weeks to assess water purification performance. In case necessary to or for research purposes the frequency can be increased for a certain period of time. This monitoring will help determine if the purifying landscapes, which may not effectively remove these compounds or could even contribute to their presence, need further treatment. In addition to the main parameters, the study may explore other pollutants such as organic micropollutants (OMPs) and natural organic matter (NOM). Bi-weekly monitoring is standard, but the frequency can be adjusted based on system needs.

Water from the purifying landscapes will flow into a reservoir, from where it will be pumped into either the constructed wetlands or directly to the pilot reservoir. This setup allows for testing of different substrates and water quality improvements. Details are provided in Table 6 and Figure 8.

Table 6 Design Vertical flow (VF) and horizontal flow (HF) constructed wetlands

Constructed wetland	Flow	Size	Expected conditions	Substrate
VF-CW 1	Vertical (batch feeding)	5 x 5 x 0.8 m	Aerobic	Sand from landscape 1 and 2 area
VF-CW 2	Vertical (batch feeding)	5 x 5 x 0.8 m	Aerobic	Sand from landscape 1 and 2 area
VF-CW 3	Vertical (batch feeding)	5 x 5 x 0.8 m	Aerobic	Mixture Sand from landscape 1 and 2 area + Iron and/or manganese granulates
HF-CW 1	Horizontal (continuous feeding)	10 x 5 x 0.5 m	Anaerobic conditions	Sand from landscape 1 and 2 area
HF-CW 2	Horizontal (continuous feeding)	10 x 5 x 0.5 m	Anaerobic conditions	Sand from landscape 1 and 2 area
HF-CW 3	Horizontal (continuous feeding)	10 x 5 x 0.5 m	Anaerobic conditions	Mixture Sand from landscape 1 and 2 area + Iron and/or manganese granulates

Each wetland operates independently, allowing comparisons of different substrates and water quality outcomes. Vertical wetlands use a sand-to-gravel substrate gradient, optimizing filtration and preventing clogging. Horizontal wetlands use a uniform sand substrate with coarse gravel at the inlet and outlet to optimize flow. A mixed substrate of manganese and iron granules, mixed with sand, will be tested in both vertical and horizontal wetlands based on previous experiments.

Each wetland unit has an independent flow path for flexibility in experimentation. Water levels are maintained via an overflow outlet system. After treatment, water from the wetlands is mixed and directed toward the pilot reservoir. Retention time and removal efficiency tests will be conducted to evaluate water treatment, focusing on the removal of TSS, DOC, phosphorus, nitrogen, and possibly OMPs and NOM.

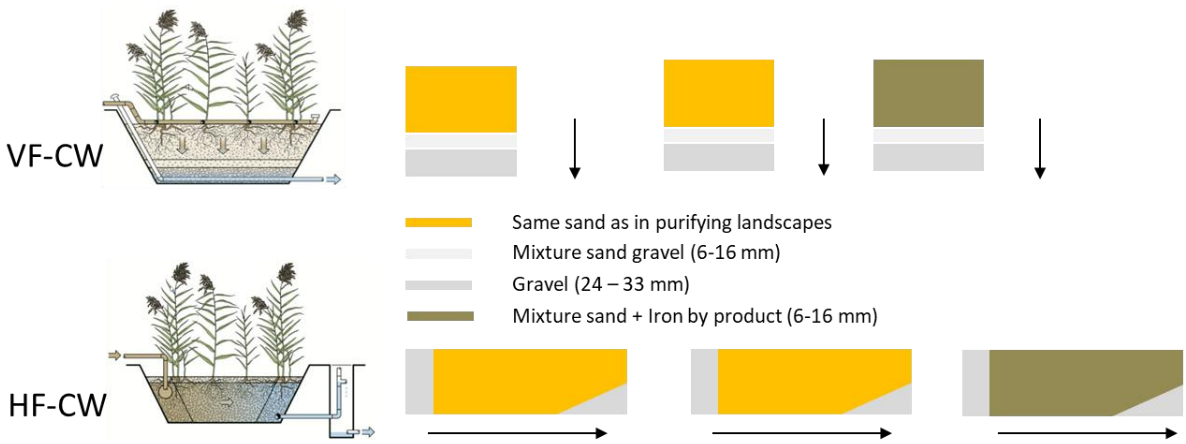


Figure 8. Overview vertical flow constructed wetland (VF-CW) (top) and Horizontal flow constructed wetland (HF-CW) (bottom).

Maintenance horizontal and vertical constructed wetlands

A maintenance plan for constructed wetlands ensures their long-term efficiency and proper functionality. For VFCWs, weekly tasks include inspecting inlets and outlets for blockages and checking the filter bed for signs of clogging. Monthly, vegetation health should be monitored, and flow distribution verified. Seasonally, plants may need trimming to avoid excessive shading, and accumulated sediment in pre-treatment areas should be removed. Annually, deep cleaning may involve replacing clogged top media layers, harvesting biomass outside bird breeding seasons, and inspecting all system components, including pipes and valves.

For HFCWs, weekly tasks focus on clearing debris from inlets and outlets and inspecting for water stagnation. Monthly, vegetation health and even water distribution across the wetland should be checked. Seasonal maintenance involves trimming overgrown plants to maintain flow paths and removing sediments from inlet zones or sediment traps. Annually, vegetation maintenance may require replacing unhealthy plants, and the gravel bed should be inspected for clogging, with partial media replacement if necessary. For both systems, keeping a record of activities, addressing minor issues early, and following safety protocols are essential. Regular monitoring and community involvement can further enhance system performance and longevity.

2.1.6 Pilot reservoir and Bank filtration

Research questions:

1. What are the changes in water quality during residence in the pilot reservoir?
2. What is the contribution of bank filtration to the final step of water quality purification?

The pilot reservoir is the final purification stage in the demonstration site, utilizing bank filtration to improve water quality before release. This step is expected to stabilize biological quality after treatment by the purifying landscapes, which may not fully remove all parameters or could even introduce certain compounds. The reservoir aims to reduce levels of nitrates (NO_3), phosphorus (P), Dissolved Organic Carbon (DOC), and Total Suspended Solids (TSS). Additionally, it may absorb and/or degrade organic micropollutants (OMPs) and natural organic matter (NOM), though this will be monitored to confirm effectiveness.

Two bank filtration locations are designed: one within Landscape 2, refer to as bank filtration 1 and another before the outlet of the demonstration site, refer to as bank filtration 2.

Bank filtration 1 is located within the last dyke before the outlet within of Landscape 2. It is designed to directly draw water from the surrounding meandering river through perforated pipe within an infiltration zone of 80 cm which is 50 cm in diameter and 200 cm long a 2-meter filter bed.

Bank filtration 2 draws water from the purifying landscapes into a reservoir, which drains at a controlled rate of approximately 4 m^3/h. Sedimentation is expected to occur within the reservoir. Water will be abstracted through drainage pipes installed at the bottom of a 3-meter sand bed, allowing natural filtration. The expected residence time for the water is 2–3 days.

The reservoir, measuring 16 x 25 x 3 meters, is split into two compartments (Figure 9):

- **Compartment A**: Sand layer with a horizontal bottom.
- **Compartment B**: Sand layer with an 8° slope.

The compartments function as a single system, with water mixing above the sand. A simple wooden jetty provides access to the two monitoring wells. After bank filtration, the treated water flows to the outlet and on to the PSA reservoir.

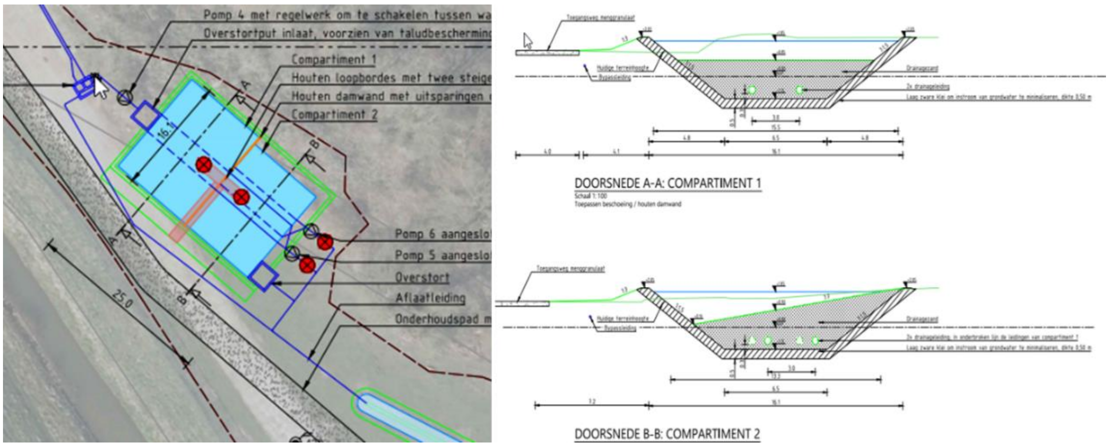


Figure 9. Schematic representation of the bank filtration B within the pilot. Compartment A features a horizontal sand layer, while Compartment B has a slight slope (~8°) to study clogging potentials. The system includes monitoring wells at two depths (2.5–2.75 m and 1.5–1.75 m) in each compartment.

UV light control

Because the pilot reservoir is only 1 m deep, algal blooms are likely during warm weather. Therefore, shading will be implemented to reduce excessive sunlight, which can accelerate algal growth and alter water quality already improved by the purifying landscapes. Potential shading methods are:

- UV-resistant floating shade cloth
- Floating wetlands
- Shade netting

We are currently evaluating which shading option best suits the reservoir's goals for water quality, ecological balance, and operational feasibility**.** Once selected, the selected shading method will be integrated into the reservoir design and monitored to ensure it meets our purification objectives.

Research Opportunities

For research purposes, the chosen shading may be temporarily removed to study algae growth under natural conditions. In such cases, a high-frequency monitoring program must be implemented, focusing on the following key parameters:

- **Daily Monitoring (Spring and Summer)**: Chlorophyll-*a* levels will be measured daily to capture the rapid growth rates of algae, especially during warmer months. Cyanotoxin analysis will be conducted if chlorophyll-a exceeds 10–20 µg/L.
- **Nutrient Analysis**: Total phosphorus (TP) and orthophosphate (PO_4^{3-}) levels will be measured weekly to evaluate the system's carrying capacity for algae growth. These nutrients are early indicators of potential algal blooms.

Monitoring

Monitoring will focus on removal efficiency and microbial water quality to evaluate system performance. Essential parameters include removal rates for NO_3, P, DOC, TSS, OMPs, and NOM within the pilot reservoir and after bank filtration (Table 5).

Microbial water quality and algae presence will also be assessed. The handheld sensor EXO1 (Table 4) will supplement this effort by providing weekly measurements of temperature, conductivity, dissolved oxygen, and pH in the reservoir.

Monitoring wells and pressure sensors

Monitoring wells and pressure sensors will be installed to assess filtration efficiency and identify potential clogging:

- Monitoring Wells: Each compartment will have two wells at different depths:
  - One well extending to 2.5 – 2.75 meters.
  - Another well extending to 1.5 – 1.75 meters.

These wells will measure redox potential and other subsurface parameters, including dissolved oxygen (DO), temperature, electrical conductivity (EC), pH, ammonium (NH_4^+), nitrate (NO_3^-), oxidation-reduction potential (ORP), and phosphate (PO_4^{3-}), at varying depths to evaluate filtration processes across the sand layer.

Pressure Sensors: Sensors will be placed at three critical points:

1. In the water column to monitor hydraulic head before entering the sand layer.
2. Below the sand layer to detect pressure as water percolates, showing filtration activity.
3. At the outlet or abstraction wells to track treated water flow and identify any resistance indicating clogging.

Pressure differentials (delta P) will be analysed:

- A pressure drop between the water column and sand layer may indicate surface clogging.
- A pressure drop between the sand layer and outlet may indicate internal sand bed clogging.

Regular analysis of pressure differentials will help track performance and signal when maintenance may be required.

Maintenance pilot reservoir and bank filtration

The pilot reservoir and bank filtration system serve as the final purification step within the LWS demonstration. Weekly maintenance includes inspecting inlets and outlets for debris or sediment buildup and verifying the functionality of pressure sensors at all three critical locations (water column, below the sand layer, and outlet). Algae levels, particularly chlorophyll-a, will also be monitored during this routine, with greater attention in warmer months. Monthly tasks focus on assessing sediment accumulation in the reservoir and bank filtration beds and analysing pressure differentials across the system to identify potential clogging.

Seasonally, vegetation around the reservoir should be managed to ensure accessibility and prevent operational interference. Bank filtration zones must be inspected for compaction or reduced flow rates, with sediment layers evaluated by draining water when necessary. Clogged filtration media should be cleaned or replaced promptly. Annually, a comprehensive inspection of all system components, including sand layers, monitoring wells, and drainage pipes, will be performed. Calibration of monitoring wells at depths of 2.5–2.75 m and 1.5–1.75 m is essential to maintain accurate measurements of redox potential, pH, and other subsurface parameters. Additionally, historical monitoring data will be analysed to detect trends and optimize overall system performance. Maintaining detailed records and addressing issues proactively will ensure.

2.2 HYDROLOGICAL STUDY

Introduction

The objective of this study is to evaluate the replication potential of the large-scale climate reservoir project by developing a comprehensive hydrological model and implementing a monitoring system. The primary focus is to assess the hydrological impacts, particularly groundwater level variations, resulting from creation of reservoirs within the climate reservoir. This groundwater model aims to provide insights into the effects of the installation and operation of the climate reservoir on its surroundings. Additionally, a practical pilot study involves fluctuating the water levels within the existing basins to determine the impact .

Research questions

To assess the impact of the climate reservoir on groundwater and its surrounding environment, the study will address the following research questions:

Research questions:

1. What is the hydrological impact of the installation and operation of the climate reservoir on its surroundings?
2. To what extent is the surrounding area vulnerable to changes in groundwater levels, such as settlement sensitivity and groundwater-dependent ecosystems?
3. What is the risk of saline groundwater intrusion due to varying water levels within the climate reservoir?

Material and Methods

Monitoring system and Data collection

A monitoring system comprising four monitoring wells will be installed to collect project-specific groundwater level data with a daily frequency. These wells will be strategically placed at selected locations to provide comprehensive coverage of the study area (Figure 10):

- **Wells A & B** will be installed near the planned climate reservoir to observe fluctuations in groundwater levels directly influenced by the reservoir.
- **Well C** will be positioned near residential areas at the Oosterdijk to monitor potential impacts on housing settlements.
- **Well D** will be placed at the maximum distance where effects are to be expected. The distance is based on a theoretical assessment of the leakage factor, calculated using 'De Glee / Hantush's' formula, which considers the transmissivity of the aquifer (450m2/day) and the hydraulic resistance of the topsoil (1000 days). The resulting leakage factor indicates an effect radius of approximately 1500 meters from the source.

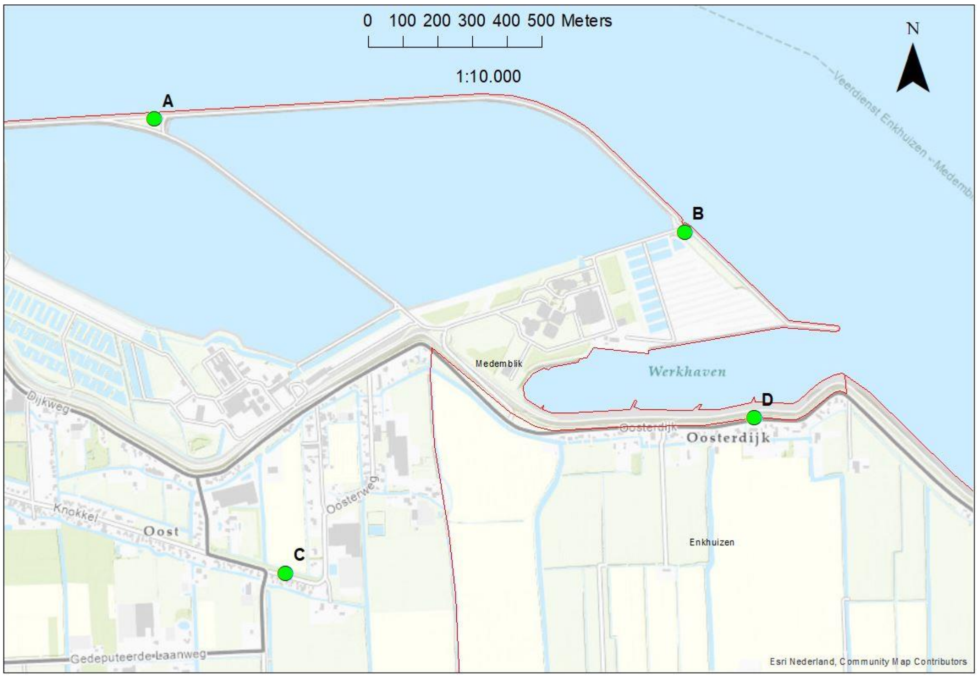


Figure 10. Planned locations of monitoring wells

Hydrological Modelling

The groundwater model will be validated using existing groundwater level data and used to predict the response of groundwater levels to the operation of the climate reservoir. Additionally, the model will simulate different scenarios involving variations in water levels to evaluate the potential risks of attracting saline groundwater and the effects on surrounding assets.

Pilot Study of Varying Water Levels

A practical study will be conducted to test different water levels in the existing reservoirs. The goal is to determine optimal water levels that minimize the negative impact on groundwater levels while maximizing the climate reservoir's efficiency. Groundwater level data collected from the monitoring wells will be used to assess the response of groundwater levels to these variations.

Depth Profile Monitoring

Each monitoring well will be equipped with three data loggers positioned at different depths to measure groundwater levels along a vertical profile:

- At –9m below NAP in the Holocene top layer
- At –26m below NAP in the Kreftenheye sand layer
- At –36m or –48m below NAP Drenthe or Urk sand layer, depending on the total well depth.

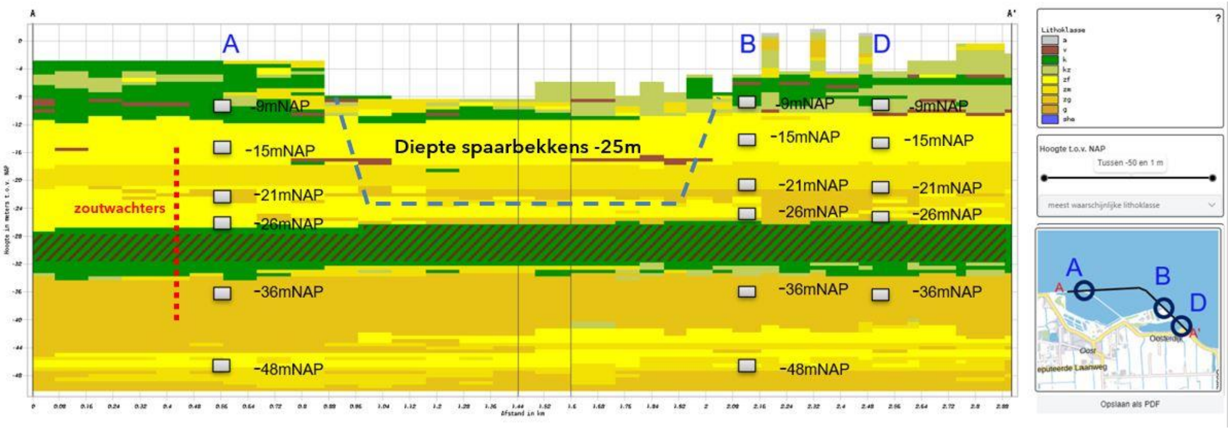


Figure 11. Depth profile filters and PEC system

This stratified monitoring approach is intended to capture variations in groundwater levels across different geological layers.

Permanent Electrode Cables System (PEC)

To capture soil water composition changes, a Permanent Electrode Cables System (PEC) will be installed in wells A and B. This system enables the measurement of soil electrical resistivity, which can indicate changes in soil water composition. The PEC system consists of a 40-meter cable with 24 pairs of electrodes spaced at intervals of approximately 1.5 meters, covering depths from –8m to –48m. A schematic example can be found in Figure 12 below. Measurements will be performed manually once or twice per year and during periods when significant changes in soil resistance are expected.

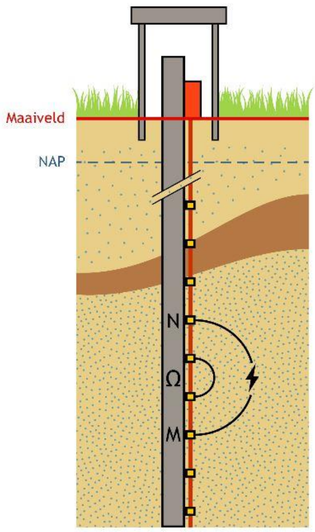


Figure 12. Schematic profile of a PEC system.

Insights

The study is expected to provide valuable insights into the hydrological effects of the climate reservoir project, including changes in groundwater levels and their potential impact on surrounding environments. The hydrological model, validated with real-time monitoring data, will help predict the response of groundwater levels to different water management strategies within the climate reservoir. The pilot study will likely identify optimal water level conditions that minimize risks such as saline groundwater intrusion while maintaining effective buffer performance. Ultimately, the findings will inform the sustainable implementation of climate reservoir in similar environments.

2.3 DIGITAL TWIN

All data gathered at the demonstration site will be stored in the digital twin, which will serve as a virtual representation of the LIFE WATERSOURCE demonstration. This digital twin will be crucial for determining the design parameters necessary for full-scale implementation, exploitation, and replication. Additionally, the processes occurring during the demonstration and the collected data will be utilized to develop a predictive model that forecasts future behaviour and runs simulations.

The digital twin will be accessible to various users, each with tailored dashboards. The personas we envision include researchers, ecologists, process technologists, higher management, government officials, and local citizens, among others. For instance, researchers will have a dashboard that stores water quality measurements, easily accessible online. This dashboard will present correlations between different measured parameters, providing more insightful data and aiding in effective interpretation. Another dashboard, aimed at citizens and available to the public, will enable the reporting of bird observations in the area.

The Digital Twin will incorporate several features focused on visualization, participation, collaboration, monitoring aspects such as water quality, quantity, biodiversity, demand and supply, efficiency, sustainability, prediction, simulation, and serious gaming. Depending on the different user personas we have in mind, this digital twin will be accessible for knowledge preservation and exchange within a protected online environment.

An example of the researcher dashboard, currently under development, is shown in Figure 13.

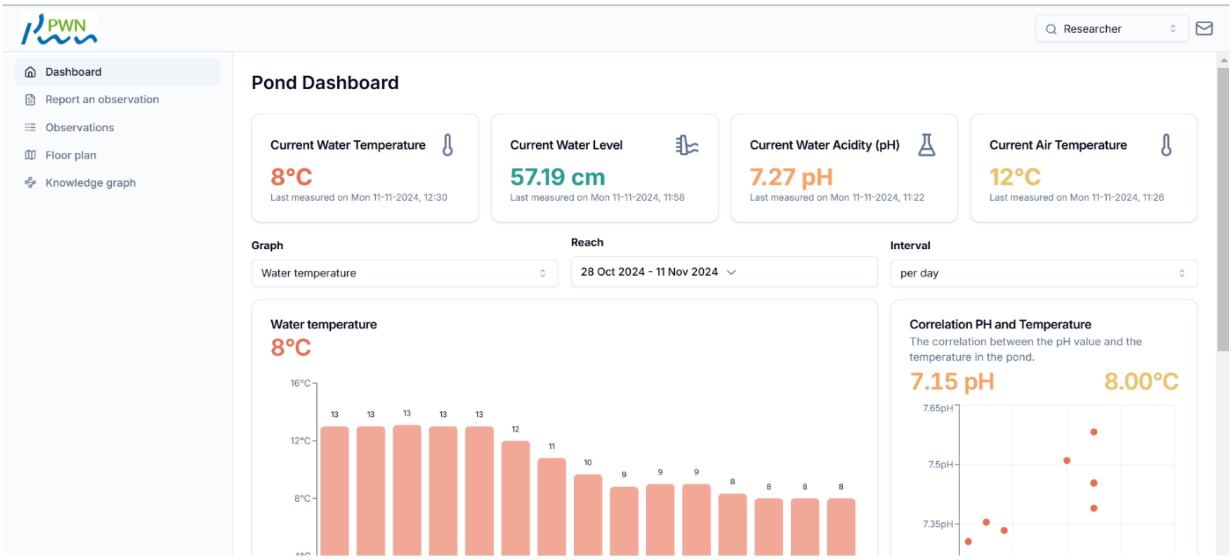


Figure 13. Example of Digital Twin dashboard

2.4. CLIMATE IMPACT

For the LIFE WATERSOURCE project LIFE key performance indicators are reported and will be monitored following the monitoring plan part I: T5.1. These monitoring efforts will generate valuable input for the following areas:

Effects of nature-based purification

We will monitor the effectiveness of nature-based purification across the purifying landscapes, constructed wetlands, pilot reservoir, and bank filtration systems. Our focus will be on tracking water quality and biological stability parameters, such as organic particles and algae, as specified in this document. These findings will guide us in assessing the potential for scaling and replicating these techniques in the larger scale climate reservoir and other replication potentials.

Our hydrological model will also examine how reservoir water level variations affect chloride concentrations and groundwater levels, offering insights into how the system interacts with local water resources.

Maintenance costs

We will conduct regular maintenance at the demonstration site, including pump upkeep, landscape maintenance, and sediment removal (bank filtration) in case of clogging. Our team will refine the frequency and methods for these tasks as we gather operational insights. We will record maintenance costs to provide an estimate for future replication of the climate reservoir.

Consumption of energy and chemicals at the plant

We will discharge water from the LIFE WATERSOURCE demonstration site into the PSA reservoir, where it will mix with Lake IJsselmeer water, the source for drinking water production. This contribution will make up about 0.1% of the total flow to the treatment plant. We will study any potential impacts on the plant's energy and chemical usage resulting from this blend.

CO2 emissions at the plant

The CO_2 emissions at the plant are mainly determined by the usage of energy and the amount of necessary chemicals for purification. We will track CO_2 emissions at the drinking water treatment plant. To measure the impact of the WATERSOURCE demonstration, we will compare the emission data from the years before the discharge into the PSA reservoir with data from the years when it operates.

Correlation between consumption and emission at the plant

To provide information for the LIFE WATERSOURCE replication and exploitation plan (D4.1), we want to know the correlation between consumption and emission at the treatment plant. Therefore, we study the impact of the LIFE WATERSOURCE demonstration on the water quality. By means of coagulation tests it will be studied whether the amount of coagulants (needed for water purification in the treatment plan) changes. The amount of coagulant is largely responsible for the CO2 footprint in the drinking water production process. If this amount reduces we can express this reduction in monetary value.

It should be taken into account that the water from LWS is only about 0.1% of the total flow of water going to the treatment plant. This means that there will not be a large impact expected in the total emission of the plant due to the LWS demonstration. However the correlation can be determined for the water flow in LWS and upscaled.

2.5 PLANNING

Timeline and Activities:

1. Establishment of Demonstration Site - Start of Monitoring - (Q2 – Q4 2025)

- Realization of LWS demonstration (D3.1, D3.2 and D3.3)
- Initiate sediment analysis to establish baseline nutrient levels.
- Deploy online sensors (UV-VIS, EXO 3) at designated locations (see Figure 5).
- Begin manual monitoring (Het Water Laboratorium).
- Start ecological monitoring, including flora and fauna.

2. Yearly Project Evaluation (**December 2026 and 2027):**

- Evaluate the effectiveness of the purifying landscapes, constructed wetlands, and the pilot reservoir/bank filtration systems.
- Assess ecological aspects, including the landscapes and the flora and fauna.
- Review data collected from both online and manual monitoring, assess sensor calibration, and analyse water quality improvements.
- Review and update the maintenance strategy as needed.
- Revise the monitoring strategy if necessary to ensure reliable data collection.
- Revise the maintenance strategy if necessary.
- Write Progress report on performance of nature-based purification zone, bank filtration and variations in water levels in the reservoir (D5.1)
- Write Progress report on ecological impact of LWS (D5.3)
- Write Progress evaluation report (D5.9).

3. End of Project (2028):

- Conduct a final round of sediment analysis to assess changes in nutrient content.
- Prepare the Final report on performance of nature-based purification zone, bank filtration, and variations in water levels in the reservoir (D5.2)
- Compare baseline and final data to evaluate ecological impacts and the effectiveness of the purifying landscapes in improving water quality and prepare Final report on ecological impact (D5.4).
- Prepare the Final evaluation report (D5.10) and data review, focusing on the long-term effects of nature-based solutions and their potential for upscaling in future projects.
- Drafting the After-LIFE plan (D1.1).

D2.4. MONITORING PLAN T5.4 SOCIO ECONOMIC

101113621 – LIFE22-CCA-NL-LIFE WATERSOURCE

READING GUIDE

This chapter of the monitoring plan (D2.4) contains **T5.4**: the socio economic impact of the LIFE WATERSOURCE demonstration. First the objectives of the socio-economic impact are described, second the indicators are described and stated in a table, which includes amongst others the monitoring method, and data source, third the data collection methods are described, and fourth, a timeline is provided.

3. SOCIO-ECONOMIC IMPACT

OBJECTIVES

The objective of the socio-economic impact plan is to conduct a comprehensive analysis of the potential socio-economic implications arising from the establishment and operation of the LIFE WATERSOURCE project. This section of the monitoring plan will capture **citizens' perceptions to evaluate the level of acceptance and engagement** with the enhanced natural and biodiversity area introduced through the project, while also **identifying and measuring both direct and indirect impacts** on the local community to assess potential changes in well-being.

The monitoring actions will commence with the establishment of the demonstration site, with completion scheduled for December 2025, as previously outlined. The LWS demonstration will include an inlet for Lake IJsselmeer water, a mussel zone, a fish-friendly outlet allowing fish movement, purifying landscapes dividing water into two streams, constructed wetlands for further treatment, and a pilot reservoir with bank filtration for final water purification. This is described in chapter 2 and shown in Figure 2.

The socio-economic plan outlined in this document will focus on evaluating the effects of the demonstration site's implementation on the local community, by collecting citizen's perceptions and attitudes regarding the site and its surrounding area. This will be primarily **assessed through surveys**, capturing how the ecological value of the newly created habitats, as well as the potential economic opportunities and water savings, influence local acceptance and well-being.

The results will provide relevant input for the implementation of the full-scale project and the Replication and Exploitation Plan (T.4.1). By evaluating the socio-economic impact and community response, the findings will contribute to **refining the strategy for scaling the climate reservoir (KIJ) project**, ensuring that it aligns with the needs and dynamics of the local population. Furthermore, the data will offer valuable insights into citizen acceptance, revealing attitudes, perceptions, and behavioural tendencies toward this type of Nature-Based Solutions (NBS) for drinking water treatment, laying the basis for further studies in Task 5.4. and Task 5.5.

INDICATORS

The table on the next pages outlines the indicators selected to evaluate the socio-economic impact of the demonstration site.

Table 7. Socio-economic impact indicators

Indicator	Description	Unit	Method	Data source	Frequency
Social Acceptance	The level of approval and support for the LIFE WATERSOURCE concept within the community. The indicator focuses on citizens' perceptions by examining the level of awareness, knowledge, and trust, influencing individuals' willingness to support the proposed solution and engage with the enhanced natural and biodiversity area.	Acceptance (1-5)	Two in-depth surveys: one administered before and one following the demonstration site guided visit.	Demonstration site visitors' responses.	Baseline and final assessment.
			Survey per individual visiting the surrounding area.	Spontaneous visitors to the surroundings of the enhanced natural area respondents.	Single assessment.

Indicator	Description	Unit	Method	Data source	Frequency
			Sentiment analysis or opinion mining through the coding and analysis of Google reviews.	Citizen's Google reviews	Four- monthly.
Citizen Engagement	This indicator measures the level of community engagement and interaction with the LIFE WATERSOURCE project, focusing on 1) the number of field visits, 2) the number of participants in each activity, and 3) participant satisfaction.	Citizen Engagement (1-5)	Once data from the three dimensions (number of activities, number of participants, and participant satisfaction) is collected, they will be normalized to generate a final composite score.	Project database tracking visitor entries and activity details. Satisfaction-related questions included in the in-depth post-visit survey.	Baseline and final assessment.
Property value	Variation in housing prices in the area resulting from the implementation of the LIFE WATERSOURCE demonstration site.	Percentual change (%)	Stated preferences: survey to estimate citizens' contingent valuation for their	(Local) demonstration site visitors and spontaneous visitors' respondents.	Single assessment.

Indicator	Description	Unit	Method	Data source	Frequency
			proximity to the (improved) natural/recreational sites.		
Job creation	Direct and indirect full-time equivalent (FTE) jobs created from the implementation of the LIFE WATERSOURCE demonstration site, and their economic value.	Monetary (€/year)	nº FTE jobs created and their wage, along with value transfer method for the employment multiplier on other sectors.	PWN operational data and existing studies.	Single assessment.

The indicator '*Housing energy cost reduction due to larger green areas that moderate temperatures*' which was indicated in the Grant Agreement has been removed from the monitoring plan. Its potential impact in the Netherlands was assessed as minimal, as the study region is not highly urbanized, contains limited cemented areas, and is predominantly green. Consequently, citizens are unlikely to experience significant changes in energy costs following the implementation of the LIFE WATERSOURCE project at Andijk. However, consumers of the PWN drinking water treatment plant may benefit from improvements in water supply security. Therefore, monitoring the indicator '*Savings in water resources*' attributed to the LIFE WATERSOURCE implementation has been deemed more relevant.

On the other hand, the indicator '*Economic damage reduction from flood risk reduction*', will also not be monitored during the project, as the likelihood of water from Lake IJsselmeer rising high enough to overflow the dyke into the demonstration site is extremely low. Therefore, no changes are expected in the frequency or magnitude of flooding in the area following the implementation of the LIFE WATERSOURCE demonstration site, nor in its economic impacts in that regard.

DATA COLLECTION METHODS

To measure the socio-economic impact of LIFE WATERSOURCE, different data sources and collection methods will be employed to support the assessment of the selected indicators.

As outlined in the table above, the project will monitor citizen engagement by tracking engagement activities, recording participant numbers, and incorporating a satisfaction evaluation to assess participants' experiences. This will include participants attending demonstration visits and other project initiatives. Along with tracking visits and participant engagement, the assessment will also **measure social acceptance to enhance the understanding of visitors' perception** and support for the LIFE WATERSOURCE concept. To collect this information, a pre-visit survey (baseline data) will be administered prior to the demonstration site visits and activities, followed by a post-visit survey upon completion, which will also include a satisfaction set of questions to enhance the assessment of citizen engagement. The administration of these two in-depth surveys will systematically gather data on citizens' understanding and attitudes towards the towards the demonstration site, providing insights into how engagement with the site affects public awareness and drives possible shifts in perceptions of the LWS project.

Another sampling group will consist of spontaneous visitors engaging with the surroundings of the enhanced natural and biodiversity area. A single short survey will be displayed in key points of the area to **gather feedback and assess the level of social acceptance** from individuals who pass by or engage with the vicinity of the enhanced natural area, including those utilizing nearby cycle lanes or walking along the dike. Surveys will be applied using a standardized questionnaire with a Likert scale (1-5) responses for each item. The response results will then be normalized and aggregated to provide a final composite score for each indicator. The project may employ **opinion mining** techniques (or sentiment analysis) to extract valuable insights from public online reviews on digital platforms (such as Google reviews) to complete the assessment. This will involve **categorizing and analysing public perceptions and attitudes towards the enhanced natural areas based on behavioural science**, providing a deeper understanding of community opinion and sentiment regarding the LWS demonstration site.

Surveys will also assess citizens' **perceptions of changes in local socio-economic well-being** by measuring their valuation of specific attributes influenced by the LIFE WATERSOURCE concept. Standardized questionnaires will collect both quantitative and qualitative data providing valuable insights for understanding public acceptance and assessing the broader socio-economic effects of the project on the local community. Surveys will be **adapted to the target audience** (considering age) and translated into the **local language** to ensure questions are accessible to all the respondents. During the translation process, the survey will be adapted to **fit the cultural context**, ensuring a meaningful and reliable data collection.

The overall approach will provide a comprehensive evaluation of social acceptance, including the level of awareness and understanding of the LWS demonstration, and the project's impact on local well-being.

Moreover, the surveys will include a question to assess **citizens' contingent valuation of their proximity to natural and recreational sites**, which will serve as a proxy for variations in housing prices in the area. Data on the number of direct jobs created during the implementation of LIFE WATERSOURCE will be sourced from PWN's records. Finally, value transfer from existing studies adapted to the context of the new study site will be used to supplement indicator values where appropriate. The results from the demonstration site will serve as a **reference for scaling up the assessment of these socio-economic impact indicators to the full-scale implementation** of the climate reservoir at IJsselmeer, **as well as at the replication site**.

TIMELINE

1. Establishment of Demonstration Site (July – December 2025)

- Design and preparation of surveys, adapting questions for different respondent age groups and translating them into the local language to ensure accessibility for all participants.
- Define and arrange all the necessary resources to establish survey distribution channels, such as placing QR codes on notice boards or other accessible locations to reach individuals visiting the surrounding area.
- Develop the database to track all engagement activities and share the tool and information with the relevant project stakeholders to ensure an effective and accurate recording of all activity-related information.

2. Yearly Project Evaluation (December 2026 and May 2028):

- Periodic administration of surveys before and after visits or engagement activities, conducted approximately eight times per year.
- Conduct sentiment analysis to categorize public perceptions derived from quarterly evaluations of online reviews.
- Translation, collection, and organization of survey results, codifying qualitative data for analysis and interpretation.

3. End of Project (2028):

- Analysis and interpretation of survey and sentiment analysis results (if any).
- Compare baseline and final survey results from demonstration visitors, and spontaneous visitors' responses, to assess the impact of community engagement with the site on public awareness and acceptance, as well as citizens' contingent valuation of the site.
- Normalize and aggregate the results to calculate the composite scores for the Social Acceptance and Citizen Engagement indicators.
- Calculate the values for job creation, property value, and savings in water resources following the implementation of the LIFE WATERSOURCE demonstration site.

D2.4. MONITORING PLAN T5.5 ECOSYSTEM SERVICES IMPACT INDICATORS

101113621 – LIFE22-CCA-NL-LIFE WATERSOURCE

READING GUIDE

This chapter of the monitoring plan (D2.4) contains **T5.5**: the ecosystem services impact indicators of the LIFE WATERSOURCE demonstration. First the objectives of the ecosystem services impact are described, second the framework of indicators is described, where the specific indicators are stated in a table, which includes amongst others the class, indicator and the data source, third the data collection methods are described, and fourth, a timeline is provided.

4. ECOSYSTEM SERVICES IMPACT

OBJECTIVES

The objective of the ecosystem services impact plan is to conduct a comprehensive analysis of the ecosystem services (ES) associated with the implementation of the LIFE WATERSOURCE demonstration site. These ES directly and indirectly contribute to human well-being and quality of life.

The goal of the monitoring plan is to define impact **indicators for ecosystem services** and identify the sources of information required to measure changes in their provision following the implementation of the LIFE WATERSOURCE demonstration site. The results from the demonstration site will serve as a **reference for scaling up the ecosystem services assessment of the full-scale implementation** of the climate reservoir (KIJ) at IJsselmeer, as well as at the **replication site in Spain**.

INDICATORS

The table on the next page outlines the indicators selected to evaluate the provision of ecosystem services associated with the demonstration site. The selected ES are **categorized according to the latest version of the Common International Classification of Ecosystem Services (CICES)**, developed by the European Environment Agency. CICES provides a standardized framework for classifying and categorizing ecosystem services, organized into three main categories: provisioning services, regulation and maintenance services, and cultural services.

The identified indicators used to measure the ES may be subject to change as continuous monitoring reveals new organisms, substances, pollutants, or as additional measures or refinements are implemented at the site.

Table 8. Ecosystem services impact indicators

Section	Class	Simple descriptor	CICES code (version 5.2)	Indicator	Source
Regulation & Maintenance (Biotic/Biophysical and Abiotic/geophysical)	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals, as well as by other chemical or physical means	*Filtering wastes or sequestering pollutants*	2.1.1.2 & 5.1.1.3	Change in water quality parameters — specified in Table 2 and Table 3)— before and after water flows through each of the different parts of the demonstration site (Mussel zone, Purifying landscapes 1 and 2, Constructed wetlands, Pilot reservoir and Bank filtration). Uptake of nitrogen (N) and phosphorus (P) by helophyte plants (*Phragmites australis, Typha latifolia and Typha angustifolia*).	On-site monitoring (in the mussel zone, purifying landscapes, constructed wetlands, pilot reservoir and bank filtration).
Regulation & Maintenance (Biotic/Biophysical)	Pollination (or 'gamete' dispersal in a marine context)	*Pollinating our fruit trees and other plants*	2.3.2.1	Abundance and species diversity of pollinators.	On-site monitoring (in the purifying landscapes).

Section	Class	Simple descriptor	CICES code (version 5.2)	Indicator	Source
Regulation & Maintenance (Biotic/Biophysical)	Maintaining or regulating nursery populations and habitats or bhelophyteing grounds (Includes gene pool protection)	*Providing habitats for wild plants and animals that can be useful to us*	2.3.2.3	Abundance and diversity of mussels species; mussel health, shell size, and weight. Zooplankton cell counting (to monitor mussel larvae). Special attention to: Zebra mussels (*Dreissena polymorpha)*, Quagga mussels (*Dreissena bugensis)*, and Asian clams (*Corbicula fluminea*). Abundance and diversity of bhelophyteing birds and migratory species. Special attention to: great cormorant (*Phalacrocorax carbo*), common tern (*Sterna hirundo*), helophyte bunting (*Emberiza schoeniclus*), and yellow wagtail (*Motacilla flava*). Fish species, size, and frequency of fish movements. Special attention to: perch (*Perca fluviatilis*), pike perch (*Stizostedion lucioperca*), and roach (*Rutilus rutilus*).	On-site monitoring (in the mussel zone, purifying landscapes, fish in- and outlet).

Section	Class	Simple descriptor	CICES code (version 5.2)	Indicator	Source
				Vegetation growth and presence of plant species. Special attention to: helophyte (*Phragmites australis*), narrow-leaf cattail (*Typha angustifolia*), and common cattail (*Typha latifolia*). Abundance and diversity of insects. Insects can also be used to predict the presence of future bird species.	
Regulation & Maintenance (Biotic/Biophysical)	Regulation of chemical composition of atmosphere and oceans, including maintaining rainfall patterns through evapotranspiration at the sub-continental scale	*Regulating our global climate*	2.3.6.1	Change in CO2 emissions at the drinking water treatment plant (from the change in energy and chemical usage). Biomass (ecotopes) sequestration of carbon per hectare.	On-site monitoring (PWN's drinking water treatment plant operations) and value transfer from existing studies.

Section	Class	Simple descriptor	CICES code (version 5.2)	Indicator	Source
Cultural (Biotic/Biophysical)	Elements of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	*Using the environment for sport and recreation; using nature to help stay fit*	3.1.1.1	Proportion of people that would increase their walking / exercising frequency in the presence of recreational green spaces associated with the LIFE WATERSOURCE concept.	Survey to (local) demonstration site visitors and spontaneous visitors.
Cultural (Biotic/Biophysical)	Elements of living systems that enable scientific investigation or the creation of traditional ecological knowledge	*Researching nature*	3.2.1.1	Number of visits by schools, university students, researchers, etc. to the LIFE WATERSOURCE demonstration site. Number of scientific studies conducted related to this initiative.	On-site monitoring (PWN's record data).
Cultural (Biotic/Biophysical)	Elements of living systems that enable aesthetic experiences	*The beauty of nature*	3.2.1.4	Citizens' contingent valuation for their proximity to the natural/recreational sites associated with the LIFE WATERSOURCE concept.	Survey to (local) demonstration site visitors and spontaneous visitors.

Section	Class	Simple descriptor	CICES code (version 5.2)	Indicator	Source
				Annual number of visitors to the site.	
Provisioning (Abiotic/geophysical)	Surface water for drinking	*Drinking water from sources at the ground surface*	4.1.1.1	Increased availability of water (m3) for drinking (water levels in the reservoirs).	On-site monitoring (LWS demonstration site).
Provisioning (Abiotic/geophysical)	Surface water used as a material (non-drinking purposes)	*Surface water that we can use for things other than drinking*	4.1.1.2	Increased availability of water (m3) for non-drinking purposes (e.g., agriculture, industry).	On-site monitoring (LWS demonstration site).

DATA COLLECTION METHODS

Data sources / Data collection tools /Sampling methods /Frequency data collection

The ecosystem services assessment will quantify changes in the provision of ecosystem services following the implementation of the LIFE WATERSOURCE demonstration site. As detailed in the table above, these ecosystem services will be evaluated using a variety of data sources and collection methods. Specifically, ecosystem service indicators will be derived from **on-site biophysical monitoring of parameters** assessed within the demonstration site, including changes in local ecology, water quality parameters, water storage capacity, and groundwater level variations. Additional indicators will be gathered from **operational data of PWN's drinking water treatment plant**, such as CO2 emissions, the number of visits to the demonstration site, and the number of scientific studies conducted in relation to the LIFE WATERSOURCE project. To measure certain cultural ecosystem services indicators, questions about citizens' contingent valuation of the site and their expected increase in exercising frequency will be **included in the surveys developed for measuring the social acceptance indicator**. Finally, value transfer from existing studies, adapted to the context of the new study site, will be used to supplement indicator values where appropriate.

TIMELINE

1. - Establishment of Demonstration Site (July – December 2025)

- Survey preparation – included in the chapter above (chapter 3 - Timeline).

2. Yearly Project Evaluation (December 2026 and 2027):

- Survey administration – included in the chapter above (chapter 3 - Timeline).
- Monitoring of biophysical indicators and PWN's drinking water treatment plant operations – included in the chapter above (chapter 2).

3. End of Project (2028):

- Analysis of survey results, on-site biophysical monitoring results and PWN's drinking water treatment plant operations to calculate the ecosystem services indicators that quantify the change in the provision of ecosystem services following the implementation of the LIFE WATERSOURCE demonstration site.

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