European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Water quality management in the Netherlands

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Setting the Scene

Joanna, 16 years old, woke up very excited this morning of the summer 2013. She would go to Lauwersmeer, the largest lake in the region known for its national park, beautiful landscape and peaceful beaches. They would enjoy with her two friends, Jan and Lotte, sunbathing, picnicking, swimming and most importantly learn to windsurf. As they were setting up on the sandy beach, a safeguard told them that it was not possible to swim because of blue-green algae in the water. Frustration of Joanna was high as she was wondering how sudden algal appearance would not let them enjoy the lake and she decided to ask further explanation to the safeguard. He explained that such algae can pose serious health risks, as it can produce toxins harmful to humans. He also explained that such problem is becoming more recurrent every year because of warmer summers due to climate change and the surrounding intensive agriculture having livestock manure, fertilisers and pesticides runoffs into nearby rivers and lakes. Such phenomenon also represents a disaster for biodiversity in and around the lake. Through toxic blooms and oxygen depletion, such algal bloom harms aquatic biodiversity by killing or displacing species and disrupting food webs.

Joanna made a promise to herself on that day, she decided she would be involved, in the future, in preserving and restoring water quality in her country.

This is how, 10 years later, Joanna is now an active member of an environmental activist group which has recently launched a first legal initiative to force a water board and the provincial government to step up their actions against polluters (mainly from agriculture).

If the case has to go to court, her friend Lotte, who is an environmental scientist, showed her how to use satellite data to provide evidence of the water deterioration during the past years and its direct link with agriculture. She thinks it would be enough to put pressure on stakeholders to align with Dutch government who has pledged to improve the water quality by 2027 when signing the EU Water Framework Directive. Lotte also told Joanna that she was working on a project to automate warnings of blue green algae bloom through Earth Observation data. It means that with a simple app, anyone will be soon able to know before going to a lake if the lake is infested or not, so that they would never experience the same frustration they had 10 years ago.

These Earth Observation technologies gave some hope to Joanna and appeased her frustrations. She now knows that things can finally change as water quality along with factors influencing it can be better monitored.

Whilst the character in this story is entirely fictional, the situation is inspired by real events based on our knowledge gained through the case interviews.

Executive Summary

Lakes hold a crucial role in our society and the natural environment. A sound and well-maintained lake ecosystem not only offer numerous environmental advantages but also have a substantial impact on people's well- being and strengthen the economy. This study examines how water quality management is improved in Dutch lakes through the use of data coming from Copernicus Sentinels and other satellites the management.

Since centuries, the Dutch have been reclaiming land – the polders – from the sea and other water bodies. By effectively controlling water levels and preventing flooding, polders have created fertile, predictable landscapes ideal for intensive agriculture. Such agricultural practices combined with high population density and shallow lakes are greatly affecting water quality in the Netherlands. In this matter, water quality management in the Netherlands faces important challenges although this country is one of the most innovative countries in the world with regards to water management and ecology.

These challenges are related to enhancing the monitoring of water quality, which, in turn, results in more effective measures being taken. Advanced monitoring techniques such as Earth Observation (EO) and optical sensors are therefore strongly needed to collect real-time data on parameters like nutrient levels, algae blooms, and pollutant concentrations. The main follow-up actions have to do with sustainable agricultural practices (accompanied with stricter regulation) and innovative actions to improve water quality.

Policy makers, both at national and EU level, have recognised all these aspects and several national and regional actors are involved in the process of maintaining or improving water quality.

In the Netherlands, these actors benefit from satellite data to monitor water quality. This technology complements in-situ water analyses. It provides extremely valuable information that could hardly be obtained by other means, such as extensive measurements in terms of surface monitoring, access to historical measurements and (almost) real-time variations. Hence the data coming from the satellites provides a much better spatial picture of the water conditions than traditional sampling monitoring techniques, which are typically constrained to a few locations within a lake.

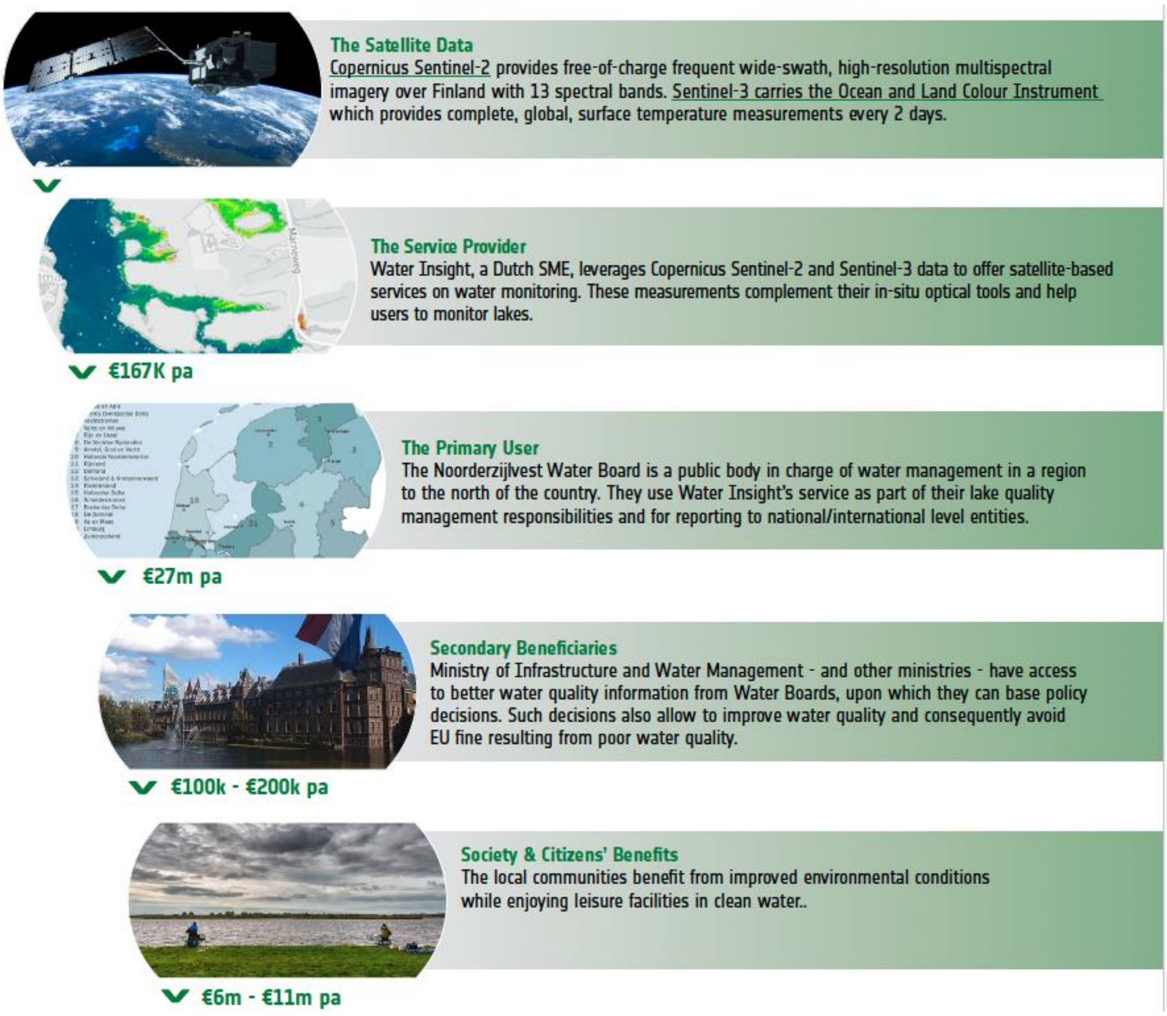
Such services utilising satellite data were developed since 2005 by **Water Insight** (a Dutch SME). It uses mainly Copernicus Sentinel observations to provide information on water quality.

The primary user of Water Insight's services is the **Noorderzijlvest Water Board**, the public body in charge of water management in the North of the country. It is one of the 21 water boards in the Netherlands.

One of the common issues it faces is the presence of fertilizers and other chemicals in the water coming from agriculture. Excess nitrogen and phosphorus in the water can lead to algal bloom and especially, to Harmful Algal Blooms (HABs) which can be dangerous to wildlife and humans. In this specific case, Water Insight's EO service enables the regular monitoring of large lakes. In addition, it offers the possibility to go back in time to analyse the evolution of the algal bloom. In order to prevent algal bloom in lakes, the **Noorderzijlvest Water Board** together with other authorities take initiatives to limit the use of nutrients in agriculture areas. Additionally, the water board reports to the **Ministry of Infrastructure and Water Management** – as well as other ministries - who has access to better information on which to base new policy decisions. At the end of the value chain, citizens and society greatly benefit from better quality water and better information.

The data provided by Copernicus Sentinels is especially relevant for a country like the Netherlands where many large water bodies combined with poor water quality requires the most advanced technologies to improve water quality. Poor quality water has indeed negative repercussions on life of citizens, environmental sustainability (and biodiversity) and other economic variables.

The ***economic benefits of the use of EO quantified in this case are estimated at 33,46 to 37,81 million euros per year*** *(all figures explained in Chapter 5) and are mainly derived from water boards saving monitoring costs (because in-situ monitoring is extremely costly) as well as citizens having access to cleaner water.*



This use of Sentinel satellite data in the Netherlands generates positive impact on the environment, economic variables, society, innovation, and science. These benefits are going to grow significantly in the next five to ten years. Such growth should be induced by the adoption of EO across the entire country while national and EU regulation should implement the use of EO data as reporting method in the relevant regulations. Benefits will also improve in the near future thanks to additional AI tools to predict, prevent and provide early warnings for events such as HAB and other phenomena requiring special attention, data integration with in-situ measurements, more accurate satellite data/images from Copernicus and private satellites, long-term trends analysis to overcome polluting events as well as improvements of the underlying scientific knowledge (e.g. relevant algorithms).

1 Introduction & Scope

1.1 The Context of this study

The analysis of the case study *'Water Quality management in the Netherlands"* is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This 5-6 year study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

1.2 What is the case all about?

Lakes are a key feature in our natural environment. Whilst some lakes are natural, others are manmade, but all play an essential role in our society. They are a source of drinking water and irrigation for crops, they provide leisure facilities, and they are a strong factor in maintaining biodiversity and sustaining both flora and fauna.

In the Netherlands, the quality of the water in lakes is controlled by European regulations and reflected in national laws as well as feeding down to regional level. After taking and analysing water samples, agencies in the regions compile reports on the quality of the water in their area which are sent to the federal agency each year. Water Insight, an SME providing unique optical instruments and earth observation information services derived from the use of data from Sentinel 2 and 3 satellites, plays a unique role in complementing the official measurement samples. This allows more frequent measurements to be made and more water surface to be monitored. In turn this helps to better identify problems, so enabling better corrective action.

Our case looks at the management of the water quality of lakes in the Netherlands using Water Insight services as a reference, and how overall decision making is improved through the use of data coming from the Sentinels and other satellites. Water Insight supports the Dutch Water Boards in their legal responsibility to protect the lakes and rivers of their region. For instance, it allows the detection of Harmful Algal Bloom (HAB) which is dangerous for both swimmers and for wildlife including fish. It also allows the access to historical data which provides valuable insights into long-term trends and understanding the impacts of human activities effect on water quality which help in implementing actions to improve water quality.

1.3 How does this case relate to others?

This case is one of the portfolio cases being developed and analysed within the frame of the SeBS project. It is the third case which explores water quality. The first two cases on this subject were conducted over Germany and Finland. These cases investigated the various and important benefits of data coming from both Sentinel-2 and Sentinel-3. More specifically, for the Germand case, the focus was on the region of Baden-Württemberg where the largest lake, the Bodensee (Lake Constance), attracts visitors from all over Germany, and from neighbouring countries, bringing income to the region. Additionally, the region has over 260 lakes of a significant size (>10ha) and the health of the lakes and the quality of the water is of primordial importance. The case on water quality in Germany brought forward invaluable information on the added value generated by Sentinels. The Finnish case not only confirmed several of the key findings of the German case, but also brought to light additional information, especially with its geographic specificities (57K lakes covering 10% of its territory (compared to 2.2% of German territory covered by water) and its EO platform which is accessible to all its citizens. The case of the Netherlands also confirmed key findings and brought to light others because of specific features in the Netherland, such as high population density, shallow lakes and intensive agricultural practices (which add more pressure on the fragile lakes ecosystems).

In terms of satellite data, whilst Sentinel-2 has prominently featured in many previous reports, especially linked to agriculture and farm management, Sentinel-3 becomes particularly relevant for the water quality cases.

1.4 More About the Study

Each case study analysed in SEBS focuses on products and services which use data coming from Sentinel satellites, measuring the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally friendly operations, economic gains and improved quality of life, among others. The evaluated and demonstrated benefits can be used by:

- **Decision makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards areas that most matter in their country or organisation.
- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.
- **Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective

marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project, more than 20 case studies are developed with reports to be published on each one. The study has started in March 2017 and will end in June 2024.

1.5 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders. They helped us navigate across the various aspects of lake monitoring and water quality measurements. In particular, we wish to thank Marnix Laanen (Water Insight) who introduced us to a number of the experts we have consulted. We also would like to thank him for her very useful insights and his time dedicated to this case. We also wish to thank the following persons for their time spent talking with us to develop the case.

- Annelies Hommersom, Project Manager, Water Insight.
- Jannes Schenkel, Coordinator Hydrology, Noorderzijlvest Water Board.
- Vincent Hovinga, Project Manager, Noorderzijlvest Water Board.

2 Water quality management in the Netherlands

Despite the Netherlands' reputation for innovative water management, it faces ongoing challenges in maintaining water quality. This is particularly due intensive agricultural practices and high population density. To address these concerns, it is imperative to explore the factors influencing water quality, regulatory frameworks, and effective interventions.

2.1 Overview of water bodies

The Netherlands is a country renowned for its relationship with water since its early history. As a quarter of the Netherlands is below mean sea level, many ingenious solutions have been created to outsmart the water in all sorts of ways across centuries. As a result, an extensive network of water management systems has been created.

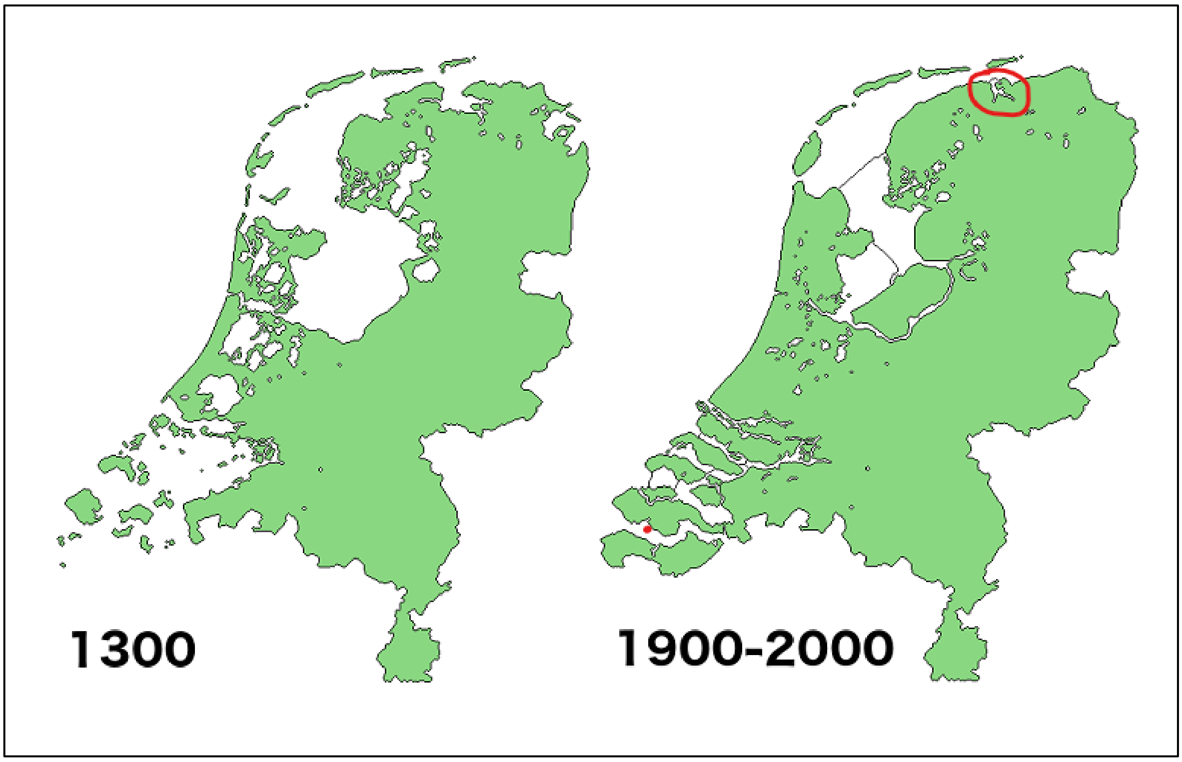


Figure 2-1 Land reclamation in the Netherlands, 1300 vs. 1900-2000[1]

The best illustration of such system is the polders which are very typical in the Netherlands. The polders are areas of land reclaimed from the sea or rivers through the construction of dikes, drainage channels, and pumping stations. They form a vast network of fertile agricultural lands. Many lakes as well as inland waterways are found across the polders, serving as drainage channels, irrigation sources, and recreational spaces. These waterways contribute to the unique charm of Dutch cities like Amsterdam, where canals are an integral part of the urban landscape.

[1] Source of the picture: https://brilliantmaps.com/netherlands-land-reclamation/

Large-scale dredging and removal of peat during the 17th century have formed most lakes in the Netherlands. Most of them are generally found in the catchment areas of the major rivers: the Rhine, the Maas and the Schelde in the northern and western part of the country. These lakes are usually very shallow (<2m) and vary from a few hectares to a few thousand hectares. About 16% of the total area (Dutch territory surface is equal to 41 864 km2) of the Netherlands is covered by water, mostly classified as wetlands, includes riverine, estuarine and coastal ecosystems (Wadden Sea), freshwater lakes. The total combined surface area of the lakes larger than 50 hectares is about 2,500 square kilometers.[2]

Figure 2-2 Wetlands in the National Park Weerribben-Wieden[3]

One of the numerous lakes in the Netherlands, which will be further analysed in this study, is the Lauwersmeer (highlighted in a red circle in the picture above, see figure 2-1). For fear of flooding after the flood disaster in 1953, this lake was formed in 1969 when the Lauwerszee was separated from the Wadden Sea with a 13-kilometer-long dike. The salty Lauwerszee (Meaning Lauwer-see) became fresh water Lauwersmeer (meaning Lauwer-lake).

[2] https://en.wikipedia.org/wiki/List_of_lakes_of_the_Netherlands

[3] Source of the picture: https://www.holland.com/global/tourism/getting-around/interests/land-of-water/water-story.htm

Figure 2-3 Lauwersmeer[4]

This closure initially led to a dead area as all marine animals died. But soon after, the first plants and animals settled down in this new area. As the years passed, a number of (partly very rare) species developed rapidly. As a result, a beautiful and diverse landscape with various species was created. In less than fifty years, nature has transformed the Lauwersmeer area into a beautiful natural reserve, which became an official National Park in 2003. Lauwersmeer offers as well high-quality bathing sites.

2.2 Water quality in the Netherlands

Despite being one of the most innovative countries in the world with regards to water management and ecology, the water quality in the Netherlands faces challenges, particularly in areas affected by agricultural runoff and urban pollution, where additional measures are being implemented to improve water quality. The Netherlands continues to work towards attaining the WFD's objective of achieving "good ecological status" for all its water bodies.

2.2.1 State of water quality

Regarding bathing water quality, the Netherlands is situated as 23d EU country, with 75% of excellent bathing sites (for which criteria are based on two microbiological parameters[5]). Inland waters are around the same number with 73,5% of excellent bathing sites. This number is not bad

[4] Source of the picture: https://www.np-lauwersmeer.nl/het-lauwersmeer/natuur-landschap/

[5] The bathing waters quality is classified according to the two microbiological parameters (Escherichia coli and intestinal enterococci) defined in the Bathing Water Directive. Based on the levels of bacteria detected, bathing water quality is then classified as 'excellent', 'good', 'sufficient' or 'poor'.

considering the high population density and intensive agricultural practices in this country - the Netherlands being the highest populated country in the EU after Malta.[6]

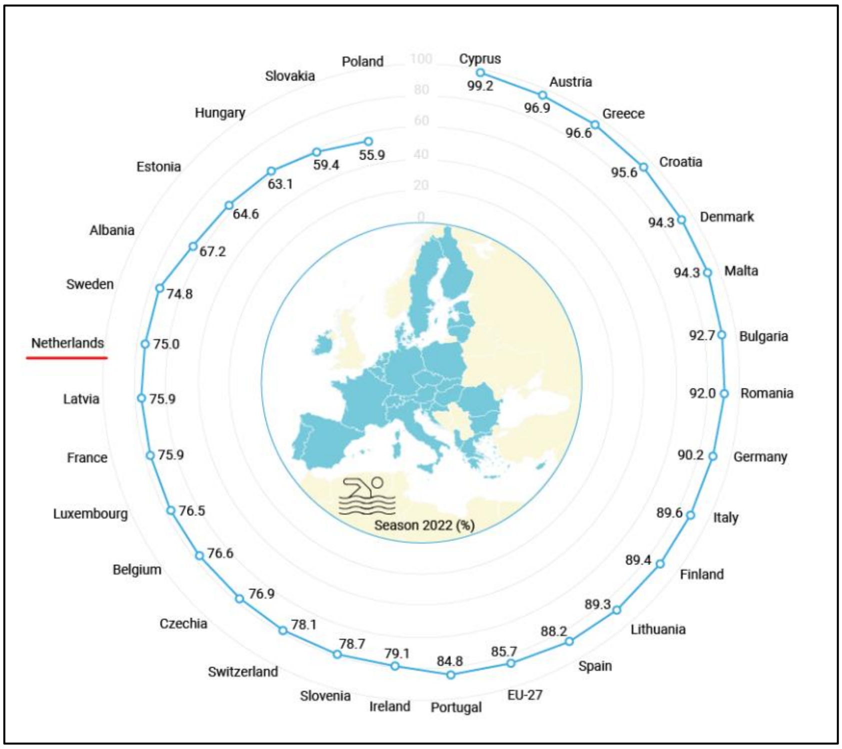


Figure 2-4 Proportion of bathing waters with excellent quality in European countries in 2022

6 https://en.wikipedia.org/wiki/Demographics_of_the_European_Union#:~:text=82.5%20years%20(2021%20est.)&text=3.5%20deaths%20per%201%2C000%20live%20births%20(2021%20est.)&text=The%20population%20density%20of%20the%20EU%20is%20117%20people%20per%20km2.

Figure 2-5 Bathing water quality in the Netherlands (dark blue = Excellent, light blue = good, green = sufficient, red = poor)[7]

The evolution of the quality of bathing water is rather stable as seen in figure 2-6 below since the beginning of the years 2000.

[7] Source: https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/state-of-bathing-waters-in-2022

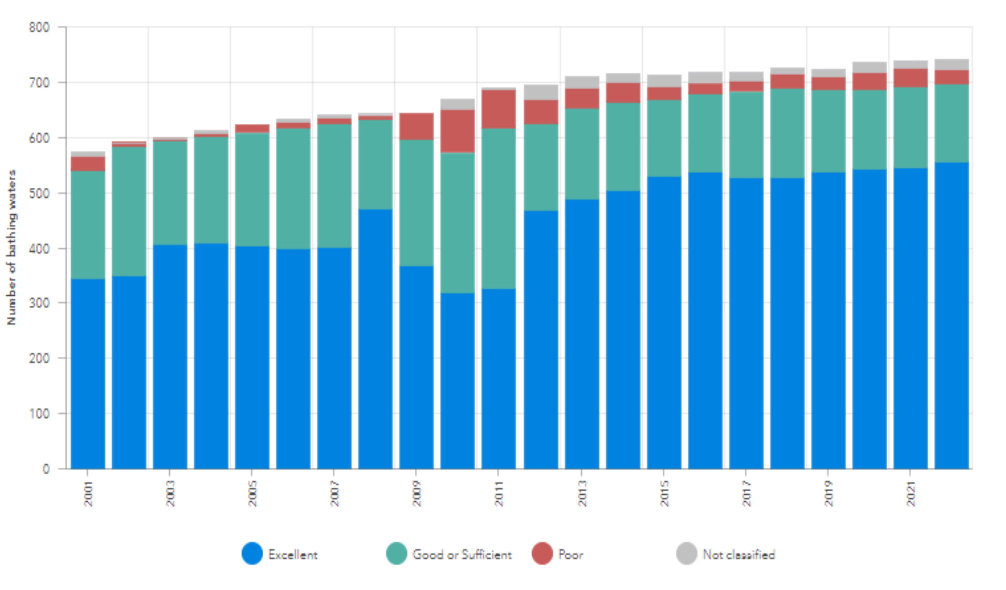


Figure 2-6 evolution of bathing water quality in the Netherlands

However, a more comprehensive assessment of the status of waters is conducted in all EU Member States every six years through the Water Framework Directive (WFD). The last assessment done in 2019 (for the period spanning 2012-2017) is not positive about the Netherlands as the country reports more than 90% of water bodies that are not in good ecological status (see figure below).

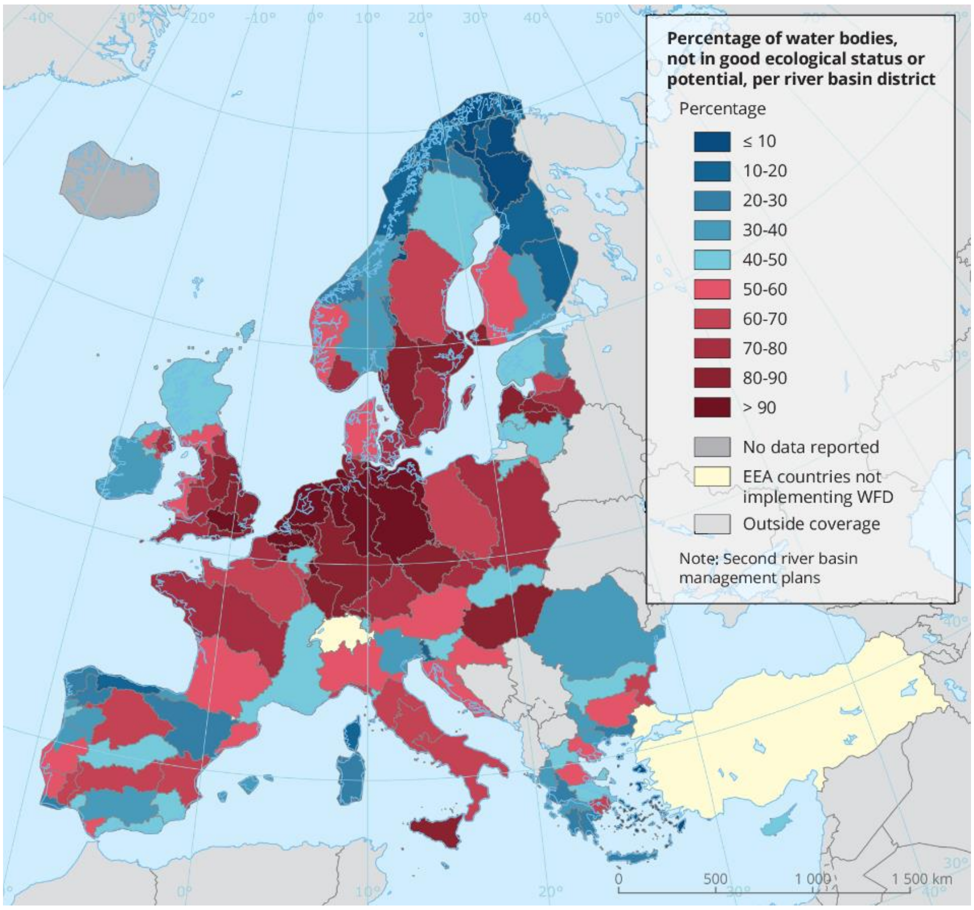


Figure 2-7 Ecological status of EU water per river basin district[8]

2.2.2 Relevance of lakes and good quality water

Lakes serve more than just as recreational spots for activities like water sports, fishing, and tourism or places for residential living. They play a vital role in preserving biodiversity in both the water bodies and their surrounding areas, while also replenishing groundwater resources. In addition to their environmental significance, healthy lakes and their shores contribute to the economy by serving as water sources for industrial and agricultural purposes, as well as providing drinking water for communities.

The Netherlands has been shaped by its relationship with water, making it an integral part of the Dutch identity and cultural heritage. To showcase the importance of water's quality in the Netherlands, we take the example of Lauwersmeer which is depicted in section 2.1.

[8] Source: https://www.eea.europa.eu/data-and-maps/figures/proportion-of-classified-surface-water-7/percentage-of-number-of-water/FIG02-129538-Country-comparision_v4.eps.75dpi.png/download

Figure 2-8 Lauwersmeer[9]

With its surface of 57 square kilometres[10], Lauwersmeer provides various **ecosystem services** that benefit both the environment and citizens. First, Lauwersmeer is home to a diverse range of plant and animal species, including numerous bird species that use the area for breeding, nesting, and as a stopover during migration.[11] Additionally, healthy wetlands of Lauwersmeer act as natural filters, removing pollutants and excess nutrients from the water before it enters the Wadden Sea while wetlands play an important role in carbon sequestration.[12]

Recreational use of the lake is also well developed. With regards to citizens, Lauwersmeer National Park offers numerous recreational opportunities, including hiking, birdwatching and cycling. Bathing in the clean and clear waters of Lauwersmeer is a popular activity, especially during the summer. Tourists and locals alike can safely swim in designated areas, taking advantage of the picturesque surroundings of the national park. Other water-based recreation, such as boating, fishing, and kayaking, are popular on the lake's clear waters.

On top of bringing tourists in the area which contributes to the **economic development** of the region, Lauwersmeer also offers clean water to irrigate agriculture fields around the lake. Sustainable agricultural practices are also encouraged to maintain a balance between farming and

[9] Source of the figure: https://en.wikipedia.org/wiki/Lauwersmeer#/media/File:Lauwersmeer.png
[10] https://en.wikipedia.org/wiki/List_of_lakes_of_the_Netherlands
[11] https://www.np-lauwersmeer.nl/english-information/
[12] https://www.waddensea-worldheritage.org/sites/default/files/2009_Ecosystem25_QSR%202009.pdf

the protection of the park's ecological resources, ensuring the harmonious coexistence of both sectors in the Lauwersmeer area.[13]

2.2.3 Factors affecting water quality

Lakes are subject to influences and pressures from their surroundings. The composition of the biotic communities is determined by environmental factors and, above all, by the degree of pollution. Even relatively low concentrations of excess nutrients, acidic deposition or other harmful contaminants can easily disrupt their sensitive aquatic ecosystems.[14]

Many lakes suffer from various unsustainable practices. Rivers and streams absorb pollutants from the landscape which then concentrate in lakes and other ponds. Aquatic species - e.g. fishes - can contain high concentrations of contaminants as some pollutants do not dissolve and dilute in water and are instead taken up into organisms. As lakes drain their catchment areas, they reflect the processes and actions that take place around them. When chemicals are used by farmers to their fields, they can leach into streams and are transported downstream into lakes.

One of the most pressing issues is the release of chemicals from pesticides[15] and fertiliser such as nitrates and phosphates from nearby **agricultural fields** that – if applied more than the plants are able to absorb – can run into the lakes via rivers and ground-water and ultimately lead to algae blooms and **eutrophication** that are harmful to aquatic and human life. Excessive livestock manure is also an important problem, especially in the Netherlands as it can release nutrients and bacteria into water bodies, leading to water quality degradation. This process is also accelerated by climate change, because of more heavy rain in short periods and increasing water temperature. Large algae blooms reduce lake clarity and impede the growth of other aquatic plants. As a result, it can reduce oxygen levels and harm fishes. This process is called eutrophication. Eutrophication together with brownification (due to increased leaching of terrestrial humic matter to aquatic ecosystems) also reduce the proportion of essential omega-3 fatty acids in fishes. **Algal blooms** and **brownification** are also very unpleasant for swimming and boating activities.[16] Furthermore, extensive sourcing of water from lakes for irrigation purposes on nearby fields can affect the sustainability of the lake.

A typical algal phenomenon is called **Harmful Algal Blooms (HAB)**. Cyanobacteria blooms are the most common type of Harmful Algal Blooms (HAB) in lakes, ponds, and other freshwater systems. Although they can occur in brackish and saltwater environments, too. Cyanobacteria are, as the name suggests, bacteria—but they perform photosynthesis, like algae do, and are often referred to as blue-green algae. They create toxins that may cause various health problems for the exposed

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[13] https://www.noorderzijlvest.nl/_flysystem/media/rapport-gebiedsproces-krw-lauwersmeer-van-zorgen-naar-zekerheid-rond-zoet-en-zout.pdf

[14] Seen | Umweltbund https://www.umweltbundesamt.de/themen/wasser/seen#wissenswertesesamt

[15] Pesticides most often causing exceedance in surface waters are the insecticides imidacloprid and malathion, and the herbicides MCPA, metolachlor and metazachlor, all of which were approved for use in plant protection products during the monitoring period, though some are no longer approved (source: https://www.eea.europa.eu/ims/pesticides-in-rivers-lakes-and)

[16] https://www.intechopen.com/chapters/62471

wildlife, home animals, and humans, e.g., skin irritation and mild to serious gastro-intestinal disorder. Pets and children are the most vulnerable regarding symptoms.[17]

Figure 2-9 Cyanobacteria blooms on a lake[18]

In the **Netherlands**, the fact that the water quality, in many cases, is still not at "good" level is caused primarily by **intensive agricultural activities** but also legacies from the past (industrial substances remaining for a long time in the ground and water), diffuse pollution (small sources of pollution that occur in large numbers, e.g. pollutants found in the exhaust of cars washed into the water by rainfall) and treated discharges (even treated, discharges are still a type of pollution) and sewage overflow.[19] All these causes are obviously linked to the high population density in this country.

In addition, the **shallowness of lakes** in the Netherlands can lead to increased sensitivity to water quality issues. Shallow lakes tend to heat up more quickly, promoting excessive algae growth, which can result in eutrophication and decreased water quality.

To improve water quality, a variety of restoration techniques have been employed in the Dutch lakes such as hydrological management, reduction of phosphorus in the external loads, in-lake reduction or immobilisation of phosphorus, and complementary ecological management.[20]

[17] https://www.epa.gov/cyanohabs/health-effects-cyanotoxins

[18] Source of the picture: https://www.lgsonic.com/cyanobacterial-blooms/

[19] https://www.government.nl/topics/water-management/water-quality/towards-better-water-quality

[20] https://www.researchgate.net/publication/227265518_Lakes_in_the_Netherlands_their_origin_eutrophication_and_restoration_State-of-the-art_review

In parallel, strict regulation on industrial discharges, enhanced wastewater treatment methods and the promotion of sustainable agricultural practices are showing good results.

Very recently, the Dutch government had opened a €500m pot for smaller-scale farmers to stop or reduce their impact. Additionally, in Veluwe, where emissions are nine times the threshold cited in a Dutch policy, about 3,000 "peak polluter" livestock farmers are offered voluntary buy-outs from a €975m pot. The main idea is to reduce nitrogen emission (which is an important source of water eutrophication), while at the same time providing farmers the opportunity to end their activities in a sound and dignified manner.[21] This pot is part of a larger Dutch strategy to reduce nitrogen pollution. [22]

2.3 Regulatory framework and water management

In Europe, the EU Water Framework Directive (EU WFD) has played a pivotal role in promoting water quality and ecological preservation. This directive has not only reinforced environmental awareness but has also spurred European countries to streamline monitoring activities and counteract the escalating pollution of their water bodies. This section also explores how the Netherlands has adapted its legislation and implemented the Dutch Water Act and the Pollution of Surface Waters Act to achieve the WFD goals.

2.3.1 EU water framework directive

The **EU Water Framework Directive (EU WFD)**[23] - adopted in 2000 - has given it a push to many European countries to streamline monitoring activities and improve water quality. This has led to increased environmental awareness and increased demand to counteract the accelerating pollution of European lakes.

The EU WFD sets a number of objectives towards protecting the quality of water. The key ones at European level are general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water. All these objectives must be integrated for each river basin (figure bellow illustrates river basin in the Netherlands). It is clear that the last three - special habitats, drinking water areas and bathing water - apply only to specific bodies of water (those supporting special wetlands; those identified for drinking water abstraction; those generally used as bathing areas). In contrast, ecological protection should apply to all waters.[24,25]

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[21] https://www.theguardian.com/environment/2023/jun/25/farmers-on-frontline-as-dutch-divided-by-war-on-nitrogen-pollution

[22] https://www.government.nl/topics/nature-and-biodiversity/the-nitrogen-strategy-and-the-transformation-of-the-rural-areas

[23] https://ec.europa.eu/environment/water/water-framework/index_en.html

[24] https://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

[25] "A set of procedures for identifying that point for a given body of water, and establishing particular chemical or hydro-morphological standards to achieve it, is provided, together with a system for ensuring that each Member State interprets the procedure in a consistent way (to ensure comparability). The system is somewhat

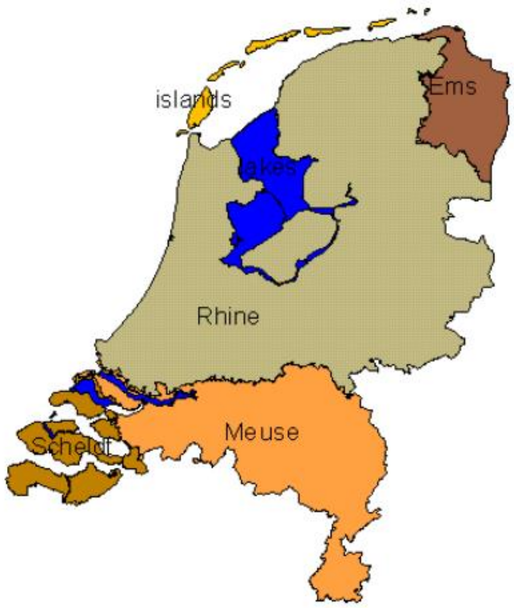

Figure 2-10 the 4 river basins in the Netherlands[26]

Several other relevant directives also exist in the EU and are worth mentioning here:

- The **EU Nitrates Directive** seeks to protect water quality across Europe by preventing excess nitrates used in agriculture from polluting ground and surface waters such as lakes and by promoting the use of good farming practices.[27]
- The **EU Bathing Water Directive** seeks to safeguard public health and protect the aquatic environment in coastal and inland waters from pollution, providing a more proactive approach to informing the public about water quality and focuses mainly on the monitoring and managing of specific types of bacteria; Intestinal enterococci and Escherichia coli.[28]
- The **EU Wastewater Directive** aims at tackling the root cause of lake water quality problems originating from urban wastewater collection, treatment and discharge as well as the treatment and discharge of wastewater from certain industrial sectors by protecting the environment from adverse effects thereof.[29]
- The **EU Drinking Water Directive** achieves the objectives of the WFD and aforementioned linked directives will facilitate reaching the objectives of the Drinking Water Directive which focuses more on distribution systems.[30]

complicated, but this is inevitable given the extent of ecological variability, and the large number of parameters, which must be dealt with." EU WFD

[26] https://www.researchgate.net/figure/The-Netherlands-split-up-into-four-main-river-basins-as-distinguished-in-the-WFD_fig1_242216128

[27] https://ec.europa.eu/environment/water/water-nitrates/index_en.html

[28] https://ec.europa.eu/environment/water/water-bathing/summary.html

[29] https://ec.europa.eu/environment/water/water-urbanwaste/index_en.html

[30] https://ec.europa.eu/environment/water/water-drink/index_en.html

2.3.2 Dutch regulatory framework on lake management

To be able to achieve the goals of the WFD, the fragmented Dutch legislation on water management needed to be simplified. In this context, the **Dutch Water Act**[31] was implemented in 2010. The main objectives of the Water Act are flood protection, ensuring sufficient water supply, and preserving water quality. It also defines responsibilities for water boards, municipalities, provinces, and the central government in managing water resources.[32]

Additionally, the **Pollution of Surface Waters Act**[33] addresses the prevention and control of pollution in surface waters within the Netherlands and sets limits on the discharge of substances that could degrade water quality and harm aquatic ecosystems in the country. It is one of the key pieces of legislation related to water quality management at the national level in the Netherlands.

To ensure the implementation of the above regulations, **the National Water Programme (NWP)**[34] is a strategic plan developed by the Dutch government to safeguard sustainable water management, protection against flooding, and preservation of water quality in the country. The NWP is designed to cover a 6-year period (the current plan considers the years 2022-2027), and it is typically updated every 6 years to adapt to changing circumstances and needs. In its objective of preserving and improving the quality of surface water and groundwater, this programme includes measures to reduce pollution, encourage sustainable water use, and ensure the protection of ecosystems and biodiversity. To achieve these goals, it establishes quality standards and indicators as well as a comprehensive monitoring network to collect data from various water bodies.

The national governing body in charge of water management is the **Rijkswaterstaat (RWS)**[35] which is the executive agency of the **Dutch Ministry of Infrastructure and Water Management**. It is responsible for the management and maintenance of the main waterways, including large lakes and rivers. RWS plays a crucial role in monitoring water quality, water levels, and flood protection measures.

Expert knowledge and know-how about water quality issues is available at the expert institutes **RIZA (Institute for Inland Water Management and Wastewater Treatment)** and RIKZ (Institute for Coast and Sea). RIZA and RIKZ duties are to: (1) provide advice on policy and management; (2) gather information at the national level; and (3) coordinate water quality issues.[36] Additionally, the **Netherland Institute of Ecology (NIOO)** is the main centre of ecological water research in the Netherlands. It performs leading ecological research on individual organisms, populations, ecological communities and ecosystems, including water bodies.[37]

31 https://www.helpdeskwater.nl/secundaire-navigatie/english/legislation/
32 https://www.government.nl/topics/water-management/water-quality/towards-better-water-quality
33 https://wetten.overheid.nl/BWBR0002682/2009-12-03
34 https://open.overheid.nl/documenten/ronl-0c5086b3029ab6a4ab28d52838ce44d5e6285d1a/pdf
35 https://www.rijkswaterstaat.nl/
36 https://www.eea.europa.eu/publications/92-9167-001-4/page014.html
37 https://nioo.knaw.nl/en/who-we-are

The local governing body for surface water management in the Netherlands are **Water Boards** (*Waterschap* in Dutch). These water boards are responsible for managing water levels, water quality, and flood protection within their respective regions in the Netherlands. Water boards are independent from administrative governing bodies like provinces and municipalities. The different regions allocated for the different water boards are represented in the figure 2-11 below. We find the Noorderzijlvest Waterschap at the northern part of the map (1). This is the water board of interest in this study.

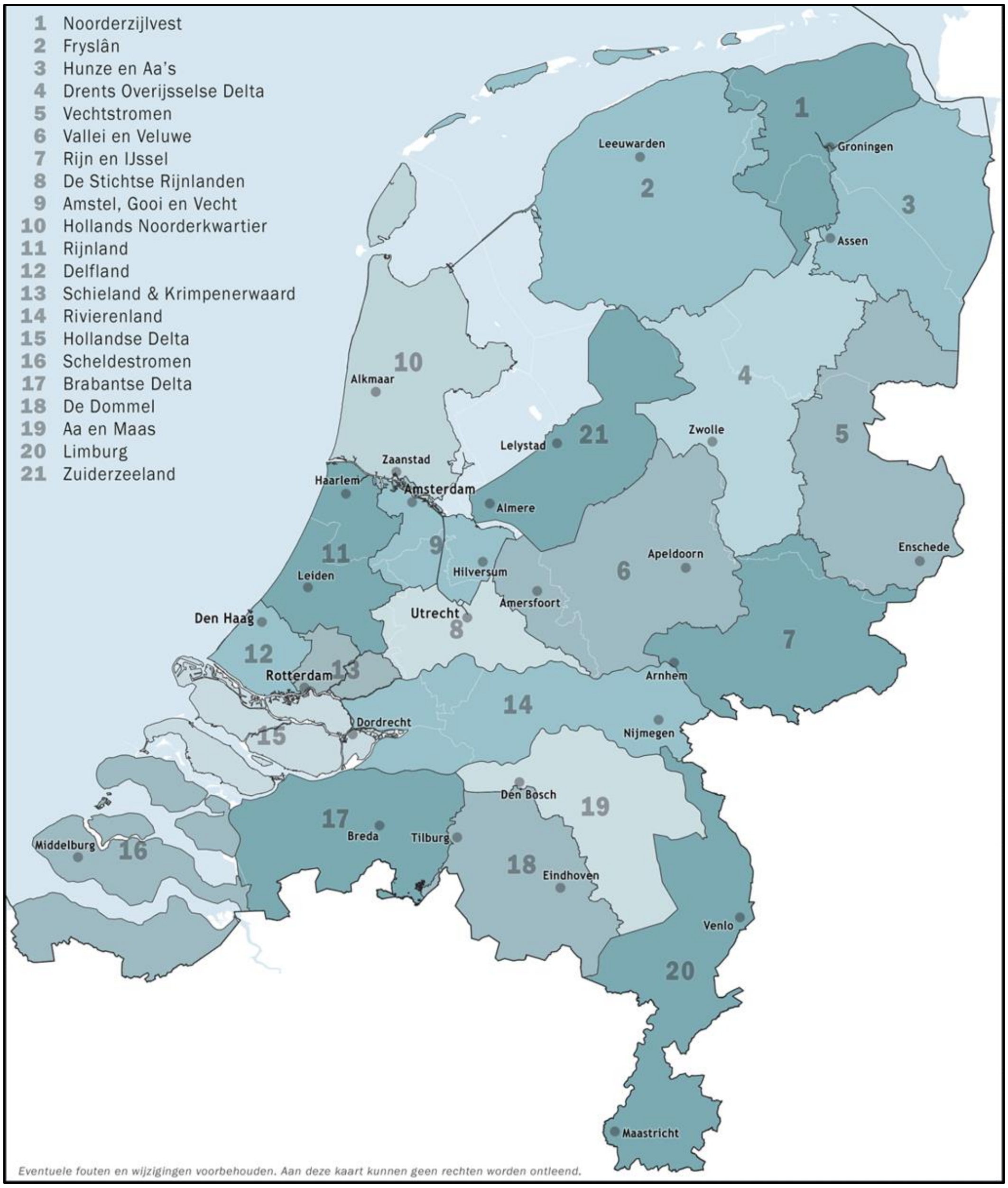

Figure 2-11 water boards regions in the Netherlands[38]

In its territory a water board is responsible for:

- Innovation, building, management and maintenance of water barriers: dunes, dikes, quays and levees;
- Innovation, building, management and maintenance of water pumping systems, locks for the navigation of water;
- Management and maintenance of waterways and water drainage systems;
- Maintenance of a proper water level in polders and waterways;
- Maintenance of surface water quality through prevention of waste-dumping and wastewater treatment.[39]

2.4 Informed decisions, coordinated actions and effective interventions

Preventing, reducing and mitigating the adverse impacts of water pollution and its impact on water quality is of paramount importance given the various economic and environmental functions of lakes in general. To enforce regulation around water quality in the Netherlands, data must be collected at many stages of the value chain.

2.4.1 Collecting the necessary data

The monitoring network of local water boards operates at a regional level and covers several thousands of locations. The frequency of water quality observations and the factors under analysis vary according to local needs. Monitoring of fresh water in the Netherlands involves an assessment of the ecological - aquatic plants, fish and other aquatic life - and chemical status – the presence of various harmful substances - of water.

Depending on the objectives of the study, samples can be collected at **different depths, locations, and times**.

Specialized equipment is used to measure water quality. Common tools include a water sampling bottle, a secchi disk for measuring water clarity, a conductivity and temperature probe, and a pH meter. In addition, containers for sample preservation and transport are prepared.

Through this equipment, various types of indicators are monitored:

- The quantity of **nitrate and phosphate** are indicators of algae biomass as the latter are the most important nutrients for plants and algae to grow.

[38] Source of the figure: https://nl.wikipedia.org/wiki/Lijst_van_Nederlandse_waterschappen#/media/Bestand:2019-Waterschap-prov-1200.png

[39] https://www.waterschappen.nl/; https://en.wikipedia.org/wiki/Water_board_(Netherlands)#:~:text=In%20the%20Netherlands%2C%20a%20water,surface%20water%20in%20the%20environment.

- Eutrophic waters have fluctuating amounts of **dissolved oxygen** which makes it a good indicator as well. During the day, autotrophic algae and cyanobacteria produce oxygen, like plants. However, in the night they consume oxygen, and also when a large algal bloom dies and sinks to the bottom, the decay of the algal biomass can lead to very low concentrations of oxygen in the water, sometimes so low that even fish cannot survive.
- A third indicator is **water transparency**. Many algae do not allow much light to penetrate the water causing an increase of turbidity (and the other way around, if the water is turbid due to sediments in the water, there is not much light for algae growth). The Secchi disk is a common method for measuring this effect. The disk is being lowered into the water and the depth at which the disc is no longer visible, is a measure of the clarity of the water.
- **Chlorophyll** (Chl a) is a green pigment found in algae and plants. The measurement of the Chl-a level in the water is a good proxy for estimating the concentration of Phytoplankton, which forms the basis of the aquatic food pyramid within the water column.
- The presence of organisms in terms of species and numbers also indicates the **biological water quality** (i.e. plankton composition, algae density, bacterial presence).
- **Water temperature** impacts various water components.

The main methodology to collect data and monitor water quality parameters is the traditional sampling method. Additionally, the Noorderzijlvest Water board (described below in section 4.2.2) – as well as other water boards in the Netherlands - uses innovative in-situ methods to monitor water quality. An example of these is the portable WISP-3 optical tool which is developed by Water Insight (WI - company described below in section 4.2.1) for quick scanning and monitoring of water quality in water supply reservoirs, swimming water locations, lakes, ditches, rivers and the sea. Additionally, the WISPstation provides high-frequency accurate water quality measurements at a single location. Both methods base their measurement on the colour of the surface water, it determines the most important bio-physical water quality parameters, such as chlorophyll, cyanobacteria pigment, suspended matter, presence of scums and transparency.[40]

2.4.2 Limitations of conventional methods

In-situ sampling measurements in the lakes provide high precision estimates of the various biological, physical and chemical parameters as required by the EU WFD and the EU Bathing Directive. They however only provide information about the status of the water quality in that precise location of the in-situ station site and for a specific moment in time. This way of sampling and analysing in the laboratory is very time-consuming, very expensive due to the large amount of labour and capital-intensive infrastructure. While conclusions can be drawn regarding nearby locations, this type of monitoring is bounded by certain limitations. These limitations give rise to important challenges and high potential costs (that current budgets would not be able to cope with) faced by the authorities. In-situ sampling measurements are disadvantaged with regards to:

[40] https://www.waterinsight.nl/

- **Constructing a broader picture**: lakes are dynamic systems with spatial variations in water quality parameters. In-situ sampling at a single location may not fully represent the entire lake's condition, leading to potential inaccuracies in the overall assessment of water quality.
- **Real-time monitoring:** in-situ sampling typically provides discrete data points at specific sampling times. It may not offer real-time or continuous monitoring capabilities required to detect rapid changes or pollution events.
- **Facilitating common understanding**: communicating on the evolution of water quality is important both between the corresponding public authorities (federal, regional and local level), but also to the public, media and political hierarchy. This cannot be easily achieved with a limited number of station samples.

These limitations can – to a large extent – be addressed by the use of satellite data.

We will look into this service in the next chapter, followed by a thorough account of how it was used by the different actors (chapter 4) and the concrete value it brought (chapter 5).

3 The Use of Sentinel satellite Data

The utilization of satellite data for monitoring water quality represents a transformative advancement in environmental observation. Satellites, specifically Sentinel-2 and Sentinel-3, have become indispensable tools for observing lakes and assessing water quality parameters. Before delving into the specifics of their application in the Netherlands, it's essential to grasp how these satellites capture Earth's surface changes, providing invaluable insights for water monitoring. The advantages and limitations of EO, including its wide geographical coverage and temporal resolution, are discussed in this section.

3.1 How can satellites help with lake monitoring?

Satellites are increasingly being used to support water bodies monitoring. Data coming from Sentinel-2 and Sentinel-3 are used to observe lakes and to measure the quality of the water.

Before entering into the specificities of this case and water bodies monitoring services implemented in the Netherlands, it is important to understand how satellites can capture changes on the surface of the Earth giving rise to information that is extremely valuable to entities involved in the monitoring of water.

Broadly speaking there are two main classes of Earth Observation satellites[41]:

- Those carrying **passive sensors** able to detect the sun’s energy as it is reflected from the Earth’s surface. These “optical” satellites are affected by cloud coverage (as it hinders solar radiation) and can only observe during daytime. Typically used sensors in this category are radiometers (incl. imaging and spectro-radiometers) and spectrometers.
- Those carrying **active sensors** capable of emitting their own energy (in the form of electromagnetic radiation) to illuminate the scene (and objects therein) they observe. Such satellites send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Typically used sensors in this category are radar, scatterometers and lidar. Satellites carrying such sensors – for example Synthetic Aperture Radar (SAR) satellites – are unaffected by cloud coverage.

Active and passive sensors emit/collect electromagnetic signals of different wavelengths. In practice, different materials on the Earth’s surface reflect electromagnetic waves in various manners. These reflectance differences allow Earth Observation (EO) satellites to distinguish between grasslands, water surfaces, forests, buildings, etc. When more than two wavelengths are used, the separation among objects is even more evident. Thus, satellites equipped with multispectral sensors (i.e. utilising different bands of the spectrum) can provide data that allow the quantitative classification of different types of land cover in a given scene.

[41] A nice overview of passive and active instruments on board earth observation satellites is provided in https://earthobservatory.nasa.gov/Features/RemoteSensing/remote_08.php

Passive sensor principles are used to monitor for example water surface temperature, salinity and water quality while active sensors are used for example to detect sea level and wave height.

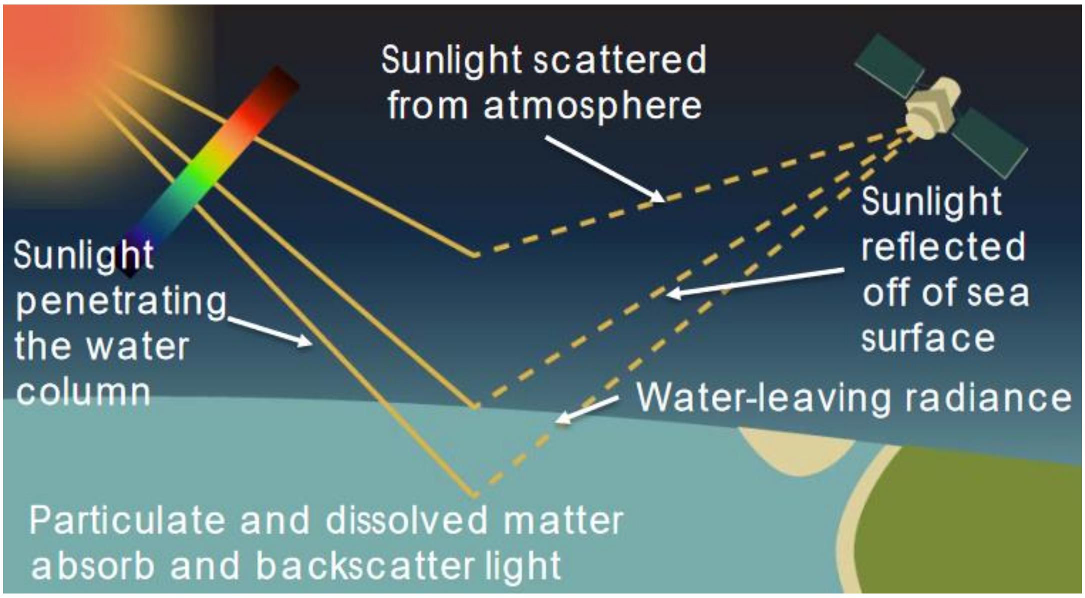

Figure 3-1 Principles of satellite-based water quality measurement[42]

Water bodies show specific reflectance characteristics measured at differing wavelengths of light, based on the absorption and scattering properties of particular constituents. These are directly related to relevant water quality parameters such as turbidity and suspended matter, phytoplankton and its main pigment Chlorophyll, and detritus and dissolved coloured organic matter. By knowing their optical characteristics, it is possible to retrieve quantitative values for the concentration of these water constituents solely based on the light reflectance measured by satellite sensors. Multi-spectral satellite sensors are capable of measuring these water constituents using the reflected sunlight as it penetrates the water body.

The following satellite-based measurements support the management of lakes by providing information on a number of critical parameters, all being indicators of the water quality:

- **Chlorophyll-a levels**: The level of Chlorophyll-a (Chl-a) - a pigment included in phytoplankton provides a proxy for the level of algae in natural waters.
- **Turbidity** is a key parameter of water quality and is linearly related to the backscatter of natural light by organic and non-organic suspensions in the water. Light in the range of 450nm to 800nm wavelength provides the best results.
- **Total Absorption** is a measurement of the absorption of light at 440nm, indicating the level of organic material.
- The **Harmful Algal Bloom Indicator (eoHAB)** is an indicator of the presence of specific pigments associated with HAB's. Measurement does not yet indicate the quantity which is

[42] Source: https://appliedsciences.nasa.gov/sites/default/files/S2P1SDG6.pdf

provided by typical in-situ measurements but provides an indicator of the presence of these pigments.

- Cyanobacteria can be detected by satellite, separated from the broader pigment group with **Phycocyanin** as an additional indicator.[43]
- **Surface Water Temperature** is calculated from thermal infrared channels recorded by optical satellites – Sentinel 3 and Landsat 8. It measures the top skin temperature of the water body.

3.1.1 Advantages

Freely available data from spatially high-resolution satellites (e.g. Sentinel-2: 10m) opens up new possibilities for monitoring the water quality of lakes and ponds. This comes with additional advantages too. The great advantage of satellite imagery is its wide geographical coverage that allows for monitoring much larger surfaces than can practically be achieved with traditional methods. For instance, it is possible to obtain **better information on spatial inhomogeneities** of Chl-a distributions (patchiness) in large lakes. This kind of spatial information cannot be covered by in-situ measurements at reasonable costs, because the single in-situ measurements at individual points are often not representative of the whole lake. To have a better idea on how many sampling stations are needed in lakes, a study was performed by El Alem et Al. (2012)[44] comparing in-situ techniques versus satellite-based earth observation for monitoring of lakes. They used 168 sampling stations to monitor comprehensively four lakes (with a total of 92 square kilometres). This illustrates the advantage of using satellite-based EO for lake monitoring as it would be very costly to deploy so many sampling stations; nonetheless it should be underlined that the comparison is not absolute since the in-situ monitoring approach focusses on specific patches of the lake that have higher interest or importance.

The fact that satellite imagery offers a broad picture also facilitates **common understanding**, making it easier for everyone involved in decision-making to understand the situation. The comprehensive nature of the images ensures that all decision-makers have access to the same information, enabling them to quickly grasp the relevant details. As a result, this type of imagery greatly facilitates the decision-making process, as it provides a clear and common basis for discussion and analysis.

Furthermore, EO data can be used to achieve **better temporal resolution** i.e. more frequent measurements than traditional sampling methods.[45] This is a great advantage, especially in case of sudden changes in lake ecology such as upcoming harmful algal blooms. In this way, existing in-situ

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[43] https://www.epa.gov/cyanohabs/health-effects-cyanotoxins
[44] https://www.researchgate.net/figure/Water-sampling-stations-on-the-four-studied-lakes_fig2_237008495
[45] Although it depends on the lake. Well sampled lakes such as in many areas of the Netherlands are sampled weekly or at least every two weeks in summer. With sentinel-2 (about every 5 days, but half of these cloudy) this is comparable, but not better.

sampling programs and evaluation methods can be usefully supplemented with satellite measurements.[46]

A last advantage of Earth Observation in monitoring water quality is the **access to historical data**. Such data provides valuable insights into long-term trends, identifying patterns, and understanding the impacts of human activities and natural processes on water bodies. It provides an important source of information for research, decision-making and effective water resource management. In this regard EO can also improve the understanding of climate change and its effect on water quality, aiding in the development of adaptive strategies to mitigate negative impacts.

All in all, EO allows quantifying elements of environmental status such as frequency, onset, duration and extend of algal blooms as well as measuring inter-annual variability. It also allows better standardisation of monitoring methods.

To concretely illustrate some of these advantages, below are some satellite-based observations provided by Water Insight.

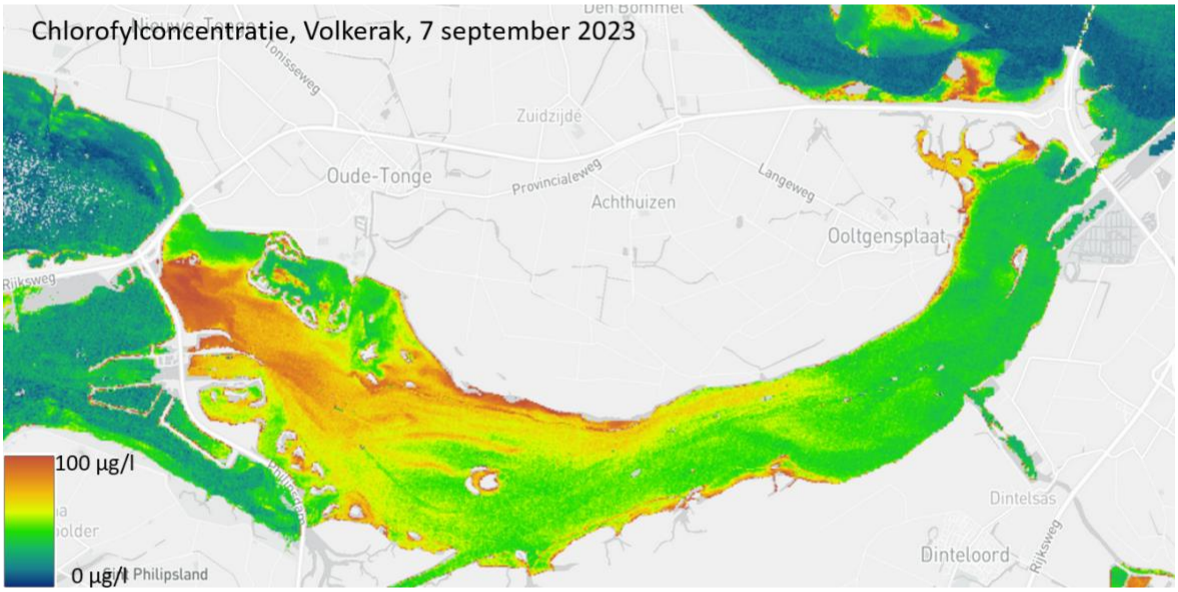


Figure 3-2 Cyanobacterial bloom in Lake Volkerak-Zoommeer observed by Sentinel-2 (detected as chlorophyll-a) for the Dutch Government (RWS).

Drones could also be an alternative solution to in-situ monitoring but this is not considered in this case. Although drones can offer high spatial resolution and quality, it would still be much more expensive to monitor water quality. Moreover, drones are typically used to perform very-high resolution surveying/monitoring which is of no immediate value for this case. In that sense, satellite-based observation offers the best solution in terms of efficiency.

46 https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11156/111561Q/Satellite-remote-sensing-of-chlorophyll-and-Secchi-depth-for-monitoring/10.1117/12.2533233.short?SSO=1

3.1.2 Limitations

Satellites offer incredibly valuable information for water monitoring but **not for all lakes and not all the time**.

Not all the time because whilst satellite observations are available every few days, some of the images are obscured by clouds. Fortunately, using several satellites, most of the time images of the lakes can be obtained regularly enough (around 5 days when there is no cloud) to detect problems in time to respond.

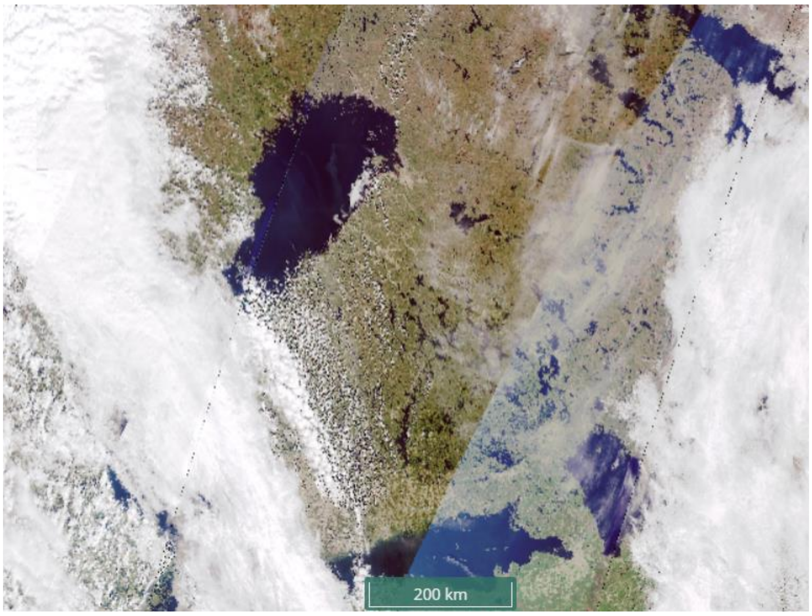


Figure 3-3 Sentinel image partly covered with clouds[47]

Not for all lakes as **smaller lakes** may have prohibitive size for a meaningful observation. This is because for smaller lakes, the spatial resolution of the satellite observations may not be enough to discern (inside a single pixel) what is water and what is land. **Shallow waters** can also lead to measuring errors as the seafloor is still noticeable, but it is not really a problem in the Netherlands because of high turbidity making seafloor usually not noticeable. The standard water quality products are therefore only applicable for optically deep surface waters with a minimum depth typically between 1m and 15m, depending on water turbidity or the amount of humic materials/transparency of the water.

For lakes greater than about 10ha in size, the measurements made are quite reliable and accurate. For lakes down to a minimum surface area of 1ha, depending on the purpose, satellites can still be useful, providing between 20 and 50 good measurement points over the lake. This is valid if all small-scale adjacent land corrections and atmospheric impacts are correctly accounted for in the

[47] Source: https://wwwi4.ymparisto.fi/ (25 May 2022)

data analysis process. As an example, we can observe that the image is blurred when we use the 200m scale with Sentinel-2[48] (see image below).

Figure 3-4 Observation of a lake showing resolution limitation with a scale of 1000m in the first picture and a scale of 200m in the second picture.[49]

Furthermore, on-site surveys in particular offer information about water chemistry and physical properties at different depths which cannot as of yet be fully replicated with satellites.

3.2 Copernicus and the Sentinels

Imagery used to support the monitoring of lakes in the Netherlands is coming from optical satellites carrying sensors with multiple imaging bands (i.e., observing different parts of the light spectrum). These include the Sentinel-2 and Sentinel-3 satellites which are part of the EU Copernicus Programme and Landsat 8 which is a USGS (U.S. Geological Survey) satellite.

[48] Image sourced from Tarkka, a platform made freely available by Syke, the environmental institute in Finland.
[49] Source: https://syke.fi/TARKKA/EN (22 July 2022)

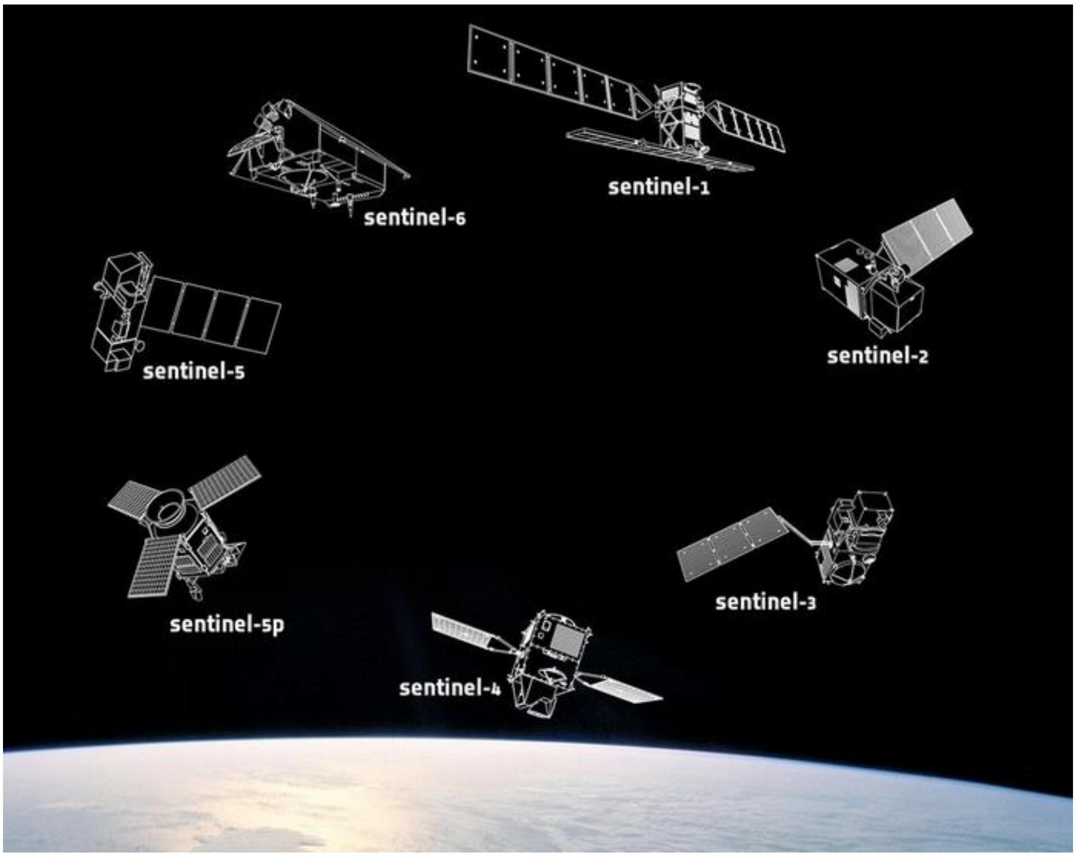
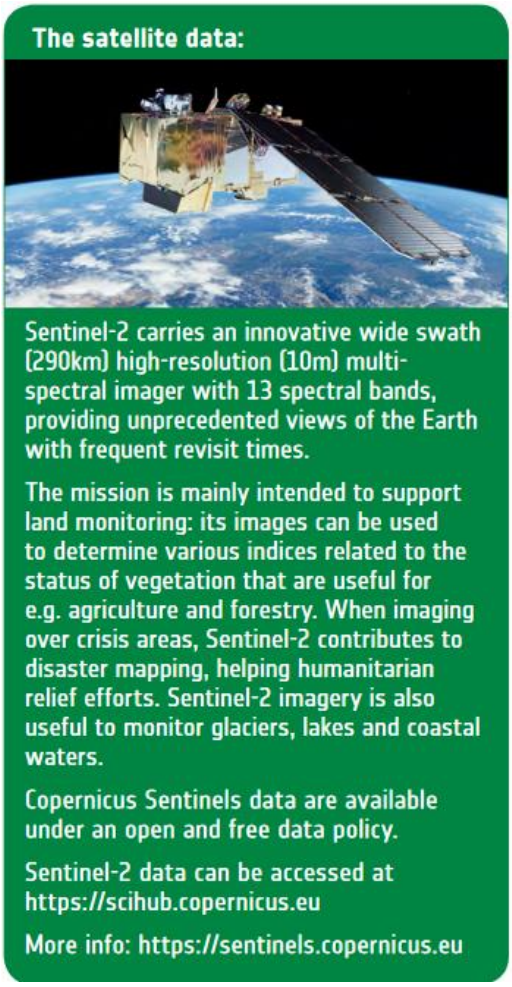


Figure 3-5 Current Sentinel satellites

Copernicus is an EU flagship Programme[50] with the goal of meeting European geo-information needs. At its heart is the most complete, operational satellite system in the world; owned by the EU and operated by ESA and Eumetsat and currently comprising six types of satellites, see above.

Our case is defined by Sentinel-2[51] and Sentinel-3 satellites (see the info boxes).

[50] https://www.copernicus.eu/en
[51] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2



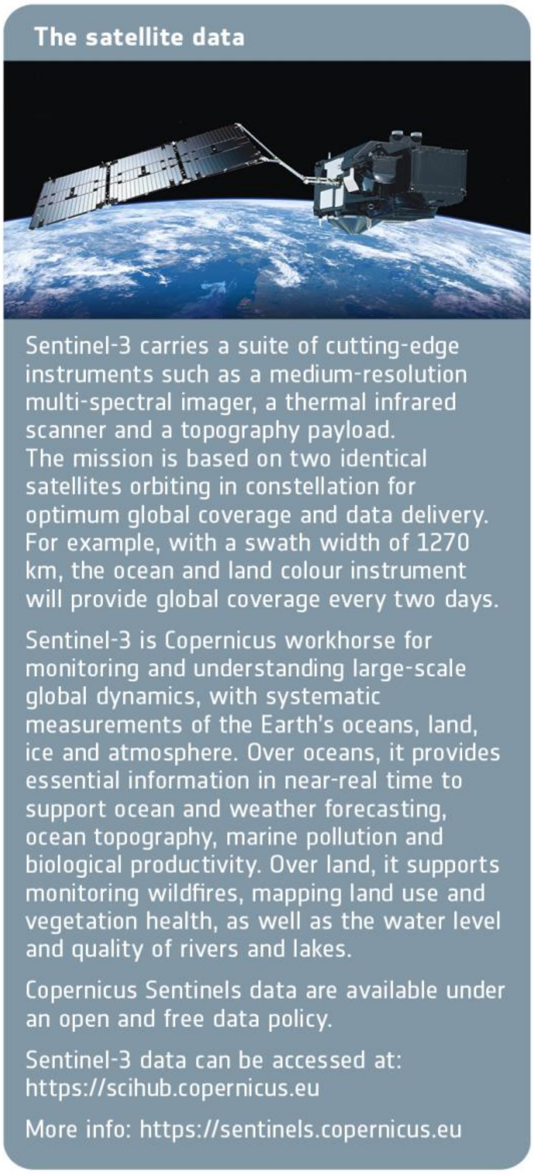


Figure 3-6 Sentinel-2 and Sentinel-3 Satellites

Sentinel-2: there are 2 identical Sentinel-2 satellites in orbit. The twin satellites are flying in the same orbit but phased at 180°, in order to give a high revisit frequency of 5 days at the Equator. Sentinel-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. The orbital swath width is 290 km. Both the spatial resolution and the frequency of measurement are critical for lake monitoring.

Sentinel-3: there are 2 identical Sentinel-3 satellites in orbit The main objective of the Sentinel-3 mission[52] is to measure sea-surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission definition is driven by the need for continuity in provision of ERS[53], ENVISAT[54] and SPOT[55] vegetation data, with improvements in instrument performance and coverage. The Sentinel-3 mission is jointly operated by ESA and EUMETSAT to deliver operational ocean and land observation services.

Sentinel-2 and sentinel-3 data are complementary. The satellites with the most sensitivity to the environmental parameters due to its large number of measurement bands are Sentinel-3 but their resolution is rather coarse (~ 300 m). Hence it can be used only for the larger lakes. On the other hand, Sentinel-2 can measure down to 10m resolution on the ground, but it is less sensitive for detecting the environmental parameters. It can be used for smaller lakes, but with reduced sensitivity, especially at low concentration levels. A further factor is the frequency with which measurements can be taken. Sentinel-3 provides one image every day, whilst Sentinel-2 only every 5 days. These intervals are made even longer during cloudy weathers as clouds make pictures worthless. To take the example of the Netherlands, observations are obtained at medium resolution (300m-1km) daily and more precisely (10-60m) approximately every five days.

3.3 Water Insight Services

Water Insight, a company based in the Netherlands, is an EU pioneer in developing water monitoring services based on satellite data and in-situ optical tools. They offer three different types of services (two optical in situ tools and a third service based on earth observation):

1. *WISPstation*

The WISPstation is an autonomous water quality spectrometer which is based in a fixed position in the lake or river. This optical device analyses the colour of the surface water to determine the most important bio-physical water quality parameters, such as chlorophyll, cyanobacteria pigment, suspended matter, presence of scums and transparency. Its great strength resides in the high frequency (e.g. every 15 minutes) of the measurement which considerably improves the insights about the ecological processes. The results are directly available through an API which allows alerts to be issued or additional measurements to be taken immediately. It can be combined with a weather station or a water temperature sensor for a comprehensive analysis of water parameters. Below is an image of the WISPStation with an example of data it provides, i.e. a Chl-a time series from the WISPstation in Paterswoldsemeer.

52 https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-3
53https://earth.esa.int/eogateway/missions/ers
54 https://earth.esa.int/eogateway/missions/envisat
55 https://earth.esa.int/eogateway/missions/spot

Figure 3-7 WISPstation, constantly monitoring water quality on Paterswoldsemeer[56]

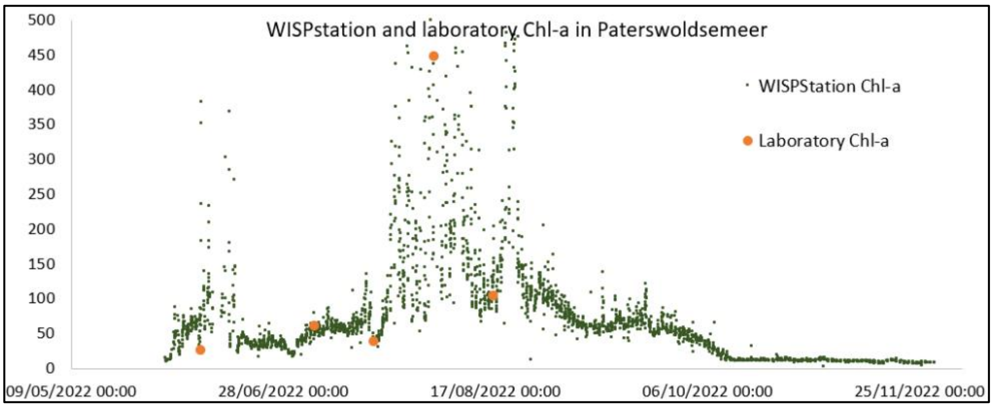


Figure 3-8 Example of a Chl-a time series from the WISPstation in Paterswoldsemeer[57]

2. *WISP-3*

The WISP-3 is a portable water quality spectrometer that scan surface water quality (with pretty much the same technology as the WISPstation). It contains three radiometers that measure the reflectance ('the colour') of the water. Its strength is to be a hand-held instrument which means it can take measurements anywhere we bring it. It instantly derives the concentrations of water quality indicators such as chlorophyll and suspended matter, without the need for laboratory analyses.

56 Picture taken by L. Dewulf (Author)
57 Graph provided by Water Insight

Figure 3-9 WISP3 Spectrometer[58]

3. *Satellite observation*

Satellites that Water Insight often uses are the Sentinel-2 and Sentinel-3 satellites which are part of the EU Copernicus Programme[59] and Landsat 8 which is a USGS (U.S. Geological Survey) satellite. The combined product has a resolution up to 10 m and measures the typical parameters detailed in section 3.1. Very recently, Water Insight also started to include high resolution imagery from private satellites. Below are images of the final product of Water Insight derived from Sentinel-2 at Lauwersmeer and Paterswoldsemeer, i.e. true colour imagery and derived Chlorophyll concentration scale 0-200 µg/l.

[58] Source of the image: https://www.dutchwatersector.com/news/estonia-tartu-observatory-buys-awarded-wisp-3-portable-spectrometer-for-monitoring-surface

[59] https://www.copernicus.eu/en

Figure 3-10 Lauwersmeer 30 May 2020 (left), 13 August 2020 (right), Sentinel 2 – True color.

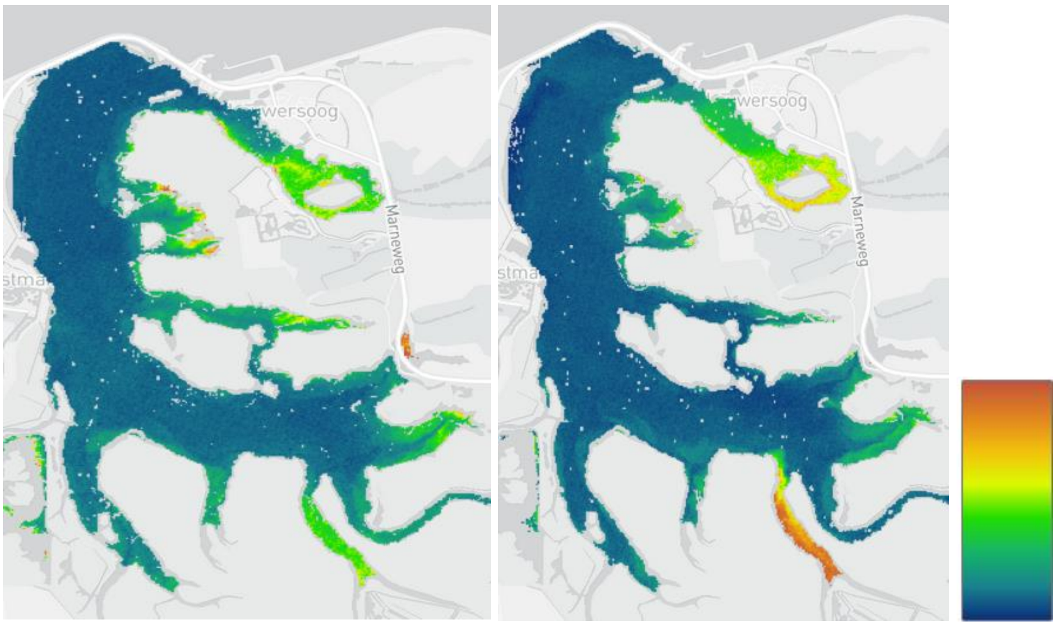


Figure 3-11 Lauwersmeer 30 May 2020 (left), 13 August 2020 (right), - Derived Chlorophyll concentration scale 0-200 µg/l.

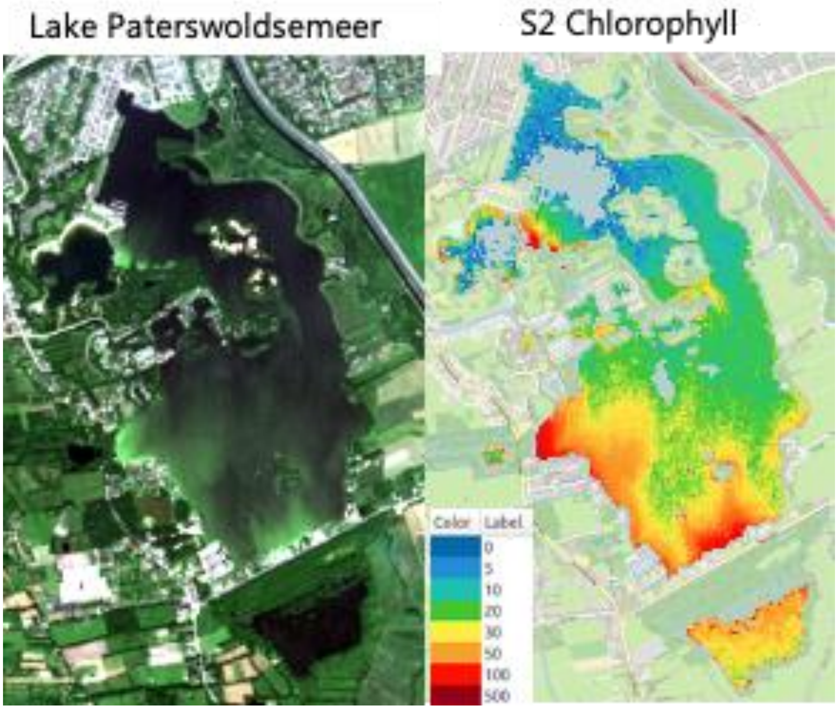


Figure 3-12 True colour images compared with Derived Chlorophyll concentration on Paterswoldsemeer.[60] Algal bloom is clearly identified on both pictures.

3.3.1 Future Evolution of the Service

Water Insight is working on a more advanced integration of satellite data and field measurements. Such integration would allow a more comprehensive overview of water bodies thanks to detailed in situ measurements at strategic points complemented with a full earth observation overview of any water body.

Another significant aspect of this integration allows the **automated atmospheric correction** of Sentinel-2 satellite images by providing water leaving radiance reflectance data. It also contributes to **continuous validation** of satellite products through the concentration data derived from WISPstation measurements.

In ongoing projects, Water Insight is developing operational **early warning systems** for algal blooms. These systems are essential for timely responses to the emergence of harmful algal blooms, contributing to effective water quality management.

Furthermore, Water Insight is developing algorithms designed to measure additional parameters beyond the scope of traditional water quality assessment. These parameters include the identification and quantification of **floating vegetation** types and abundance, the detection of **(macro)plastics** in water bodies, and the estimation of **Chemical Oxygen Demand** (COD), providing a more comprehensive view of water health.

[60] Source: Water Insight

In addition to these technological advancements, Water Insight is finalizing the development of a new handheld sensor, designed to replace the existing WISP-3. This innovative sensor promises ease and flexibility in monitoring water bodies, facilitating more efficient data collection and analysis.

3.4 Complementarity between different services

A summary of the main pros and cons of each service would be beneficial to better assess the complementarity between the different services:

- *In situ – sampling*

Pros: This method offers very precise observations across a wide spectrum of variables, encompassing pH, nutrient levels, dissolved oxygen, plankton composition, algae density, bacterial presence, and pollutant levels. Additionally, samples can be collected at different depths, locations, and times.

Cons: It is not adapted for urgent situations as it takes time (usually more than a week) for the sample to be analysed. It is also a time-consuming and a costly method. Although robust, this method falls short in providing a comprehensive overview of expansive areas.

- *In situ – spectrometer*

Pros: The hand-held WISP-3 allows to gather quick and easy data at different locations and times while the WISPstation allows to gather real-time information for a fixed location. It makes it adapted to respond quickly to several urgent situations such as sudden HABs thanks to its high frequency measurements (knowing that HABs show important evolution in a single day). Spectrometers allow to gather information about the most important bio-physical water quality parameters. It is – much - less time-consuming and less costly than the traditional sampling method.

Cons: The analysis is conducted for the surface water and does not allow to gather chemical information and it is more limited on gathering data on bio-physical parameters than the sampling methodology. It does not offer a full picture of large areas.

- *Earth Observation*

Pros: it offers a full picture of large areas. It also offers the possibility to make historical analysis. Data can be collected once every few days (depending on which satellite is considered and the clouds affecting the picture) which is better than traditional sampling (but not as efficient as the in-situ spectrometer). It makes it therefore more adapted than traditional sampling for urgent situations.

Cons: the analysis is conducted on surface water. It does not allow to gather chemical information while it is more limited for the analysis of bio-physical parameters than the two previous methodologies.

This summary provides a good grasp of the complementarity between the three services. Generally, coupling several methods can improve cost-efficiency of the water quality assessment while offering a better overview of water bodies. This view on complementarity is also shared by Papathanasopoulou, E., Simis, S. et al. (2019) in their study on "Satellite-assisted monitoring of water quality to support the implementation of the Water Framework Directive":

> *"Satellite observation is not, cannot and should not be seen as a means to replace existing monitoring practises. While cost-savings or increased cost-efficiency can be found, there is far more to be gained in terms of product confidence when both satellite and in situ observations are in place, with in situ efforts organised to support satellite validation."*

The authors also mention that using EO to support the implementation of the WFD would allow quantifying elements of environmental status that are currently not or under-reported by Member States (e.g. frequency, onset, duration and extend of algal blooms); it would also increase representativeness of the natural diversity of waterbodies that are monitored (e.g. inter-annual variability); it would achieve much improved spatial coverage of medium (several square kilometres) and larger waterbodies; and it would allow better standardisation of monitoring methods.

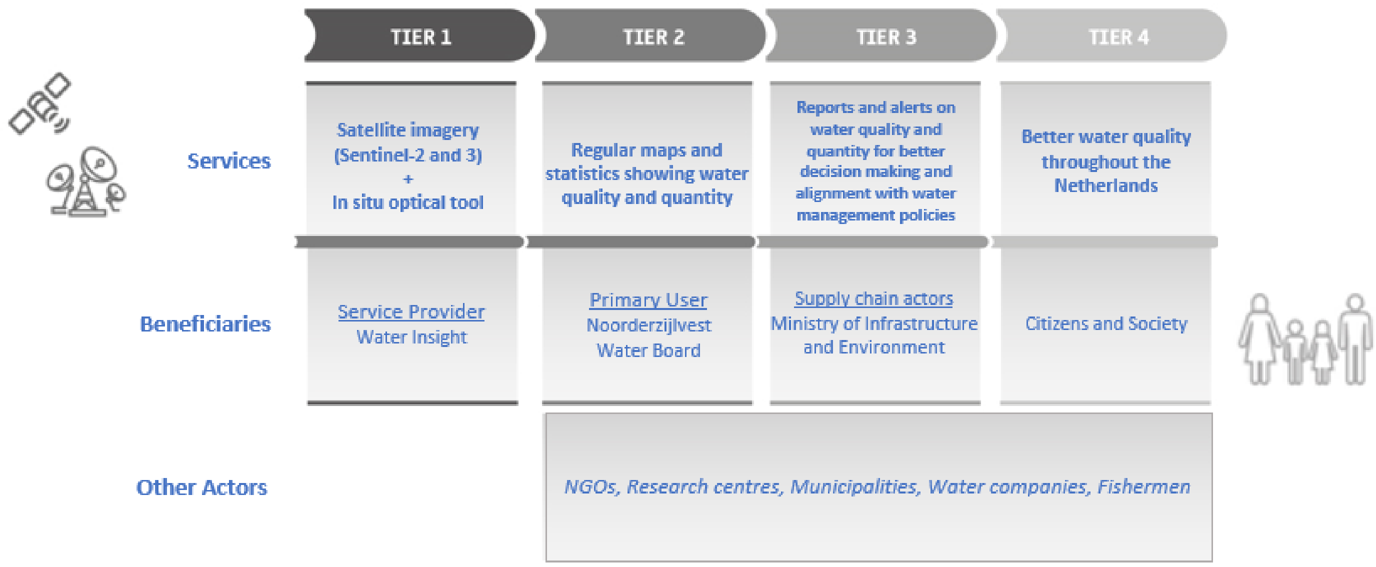
Outside the framework of the WFD, decision-making can be optimised using jointly several monitoring services. For example, decisions/policies on nutrients usage in agriculture could greatly benefit from both field data on nutrients level (data made available through sampling methods) and/or eutrophication at specific spots in lakes (data made available with traditional sampling and/or thanks to the quick use of the spectrometer) while benefiting from the overall picture and historical evolution of eutrophication in water bodies in a large geographical region (made available through earth observation).

Additionally, spectrometers and sampling methods can also be used for ground-truthing earth observation data and calibrate earth observation algorithms while EO helps in indicating the best spot to perform is situ observation and/or to place a sampling or a spectrometer station.

4 Understanding the Value Chain

The use of satellite data at the entry point of the value chain, results in enhanced information or improved operations that bring value for each link further down the chain. Ultimately, better water quality (from an environmental, social, and economic point of views) results in benefits experienced by our society at large. But before we dive into the individual links and attempt to quantify the benefits (this is done in chapter 5) it is instructive to understand how the use of satellite data helps actors along the value chain to address the challenges that shape their own operational reality. Thus, in the following sections we provide details on the interests and responsibilities of the stakeholders in each tier.

4.1 Description of the Value-Chain



4.2 The actors

4.2.1 Tier 1: Service Provider – Water Insight

The main focus of Water Insight services is to provide unique optical instruments and earth observation information services for more cost-effective digital monitoring of water quality, allowing for real-time mitigation measures. The WI water quality service has a strong research pedigree arising from Institute for Environmental Studies (IVM) of the VU University Amsterdam, see WI story below.

In 2014, WI initiated a collaboration on water quality jointly with the Noorderzijlvest Water board (see next section). Both institutions, being keen to develop innovative approaches to monitor water quality, are well fitted to work together. Both of them understood the added value of modernising traditional methods by introducing satellite and in situ optical monitoring as well as the impact it can have on water quality and its contribution to safeguarding public health, preserving ecosystems, and ensuring sustainable water resource management.

The Water Insight Story

Water Insight started in 2005 as a spin-off of the Institute for Environmental Studies (IVM) of the VU University Amsterdam. Marnix Laanen (CEO) and Steef Peters (CTO) are the co-founders of the company. Marnix, who holds a PhD in Earth Sciences, previously worked for Fugro (the world's largest geodata specialist). Steef, who holds a PhD in hydrogeology remote sensing, worked for almost twenty years at the Institute for Environmental Studies. Since 2005, Water Insight has developed services in various projects to support the monitoring of water quality in larger areas (large lakes and coastal waters).

At first, their services focused mainly on Earth Observation. In 2010, the company achieved a significant milestone with the development of a portable spectral measurement instrument named the WISP-3. This achievement was praised with the prestigious Netherlands Enterprise Agency Partners for Water Award (2011), cementing Water Insight's status as a pioneer in the field. Building on this success, the company also created a modular optical measuring instrument, the WISPstation, which autonomously collected high-frequency data at fixed positions.

Water Insight's philosophy extends beyond technological innovation as it also aims at unburdening customers (scientists, water managers, etc.). This is how the company created its own IT infrastructure providing a user-friendly platform that consolidates essential project data on water quality.

To develop state-of-art services and tools, Water Insight is also involved (as coordinator or contributor) in many national and international research projects, including the FP7 projects GLaSS and AQUA-USERS and H2020 projects EOMORES, CoastObs, TAPAS, MONOCLE, e-Shape and Water-ForCE.

As a result of a strong business model coupled with key expertise and important R&D, Water Insight has grown continuously since its inception, gaining more projects each year. Marnix and Steef still remain at the head of the company which has grown entirely organically, and together they hold 100% of the equity.

Today, Water Insight prides itself on its flexibility to respond to customers’ needs. The company is now in a decisive moment where it has brought instruments and services to the market on a small scale and is ready to step in a larger-scale market.

4.2.2 Tier 2: Primary User – Noorderzijlvest (NZV) Water board.

Water Boards (Waterschappen) are autonomous bodies responsible for managing water levels, quality, and flood protection in specific regions. They operate independently from administrative entities like provinces and municipalities. Water Boards oversee tasks such as safeguarding the quality of surface water by limiting improper waste disposal and implementing wastewater treatment processes but also building and maintaining water barriers, pumping systems, locks, waterways and drainage systems.

The Noorderzijlvest water board (NZV) is one of the 21 water boards (see figure 2.9 above) in the Netherlands. Its responsibilities cover the region represented in the figure below.

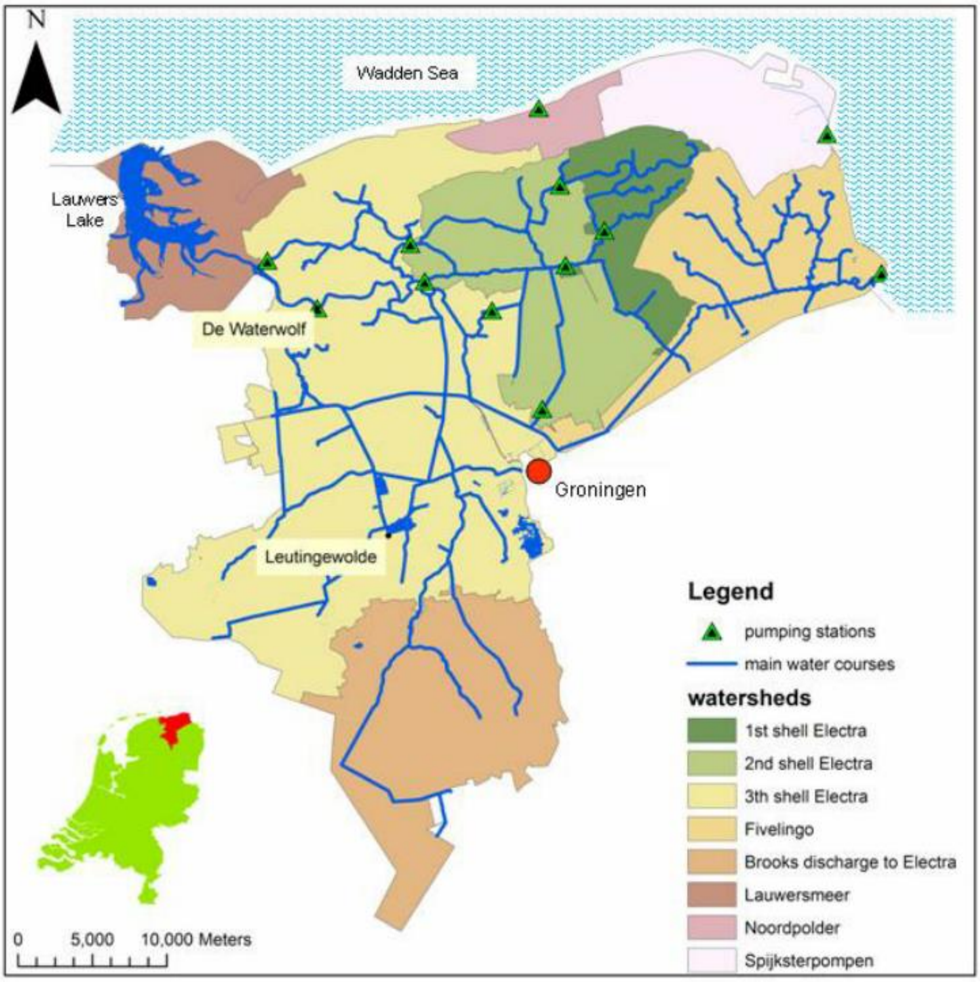


Figure 4-1 Region covered by the Noorderzijlvest water board

Lauwersmeer (north-east) is the largest lake in this region which is under the responsibility of the Noorderzijlvest water board and will be analysed in further details in the next section. Another important lake in the region is the Paterswoldsemeer which is situated south of Groningen and attracts many citizens for recreational activities.

Figure 4-2 Water Insight & NZV water board checking the WISPstation[61]

While Water Insight provides EO services to NZV waterboard, the application of EO varies according to the lake. The most present issues they are dealing with are **algal bloom**. When algal blooms occur in a lake, it is often detected in-situ and it is confirmed by EO. The added value of satellite based-EO services is materialised in both complementing in-situ observations by providing a full picture of lakes and providing the ability to go back in time to analyse the evolution of the algal bloom. Such information also provides useful insights on where to find the best spot for next samples and/or next optical view to be taken or on where to install a sampling/spectrometer station.

Having access to the full picture of the lake coupled with the opportunity to go back in time also allows NZV water board to gather enough data in order to find innovative ways to improve water quality such as the possibility of reversing a pumping station (which is under discussion).

Additionally, NZV water board manages ecological restoration of watercourses which is an important way to improve the status and habitats of lakes, rivers and small waters degraded by human actions. The NZV water board also use EO to monitor ground water quantity.

Some services are also planned but not yet operational. As EO could also help citizens to avoid going to cyanobacteria infested lakes for recreational activities, automated communication to the public about the current status of the bathing water is planned. In fact, automated communication will allow to be much faster than the current practice. An example of this was witnessed recently by WI when having a meeting at one of the recreational bathing area exploitation companies. Upon arriving, the exploitation company was putting up signs warning for a fresh cyanobacteria bloom, while people from the Provincial government announced at the meeting they had just informed the local media (web sites, newspaper) the water was cleared from the previous cyanobacteria bloom.

[61] Picture taken by the author, L. Mamais

NZV water board is also planning to use EO observation to support Regional State Administrative Agencies in **dredging permits**, dredging activities monitoring, industrial permits and **industrial activities monitoring** (when there are consequences on water quality).

Knowing the incredible benefits of using EO to monitor water in the Netherlands, NZV Water Board is using different triggers to implement such tool in the National Water Programme (NWP) with regards to water monitoring.[62]

4.2.3 Tier 3: Ministry of Infrastructure and Water Management

While Water Boards are primarily responsible for regional water management, flood protection, and water quality within their specific areas, the Ministry of Infrastructure and Water Management holds a broader national perspective on water-related policies, strategies, and legislation. Both entities collaborate to ensure a cohesive approach to water management and to address broader issues that may transcend regional boundaries.

More specifically, the **Rijkswaterstaat (RWS)**[63] which is the executive agency of the **Dutch Ministry of Infrastructure and Water Management** is responsible for the management and maintenance of the main waterways, including large lakes and rivers. RWS plays a crucial role in monitoring water quality, water levels, and flood protection measures.

Generally, the Ministry of Infrastructure and Water Management sets the overarching policies, regulations, and guidelines for water management at the national level. These policies provide a framework within which Water Boards operate and make decisions.

Water boards mainly report to the Ministry of Infrastructure and water Management with regards to compliance with water quality regulation. This ministry takes decisions and adapt legislation based upon the relevant water quality reports.

4.2.4 Tier 4: Citizens and Society

In tier 4, recreational users of water bodies greatly benefit from better water quality i.e. swimming, canoeing, fishing, etc. Poor water quality may affect the natural habitat and wildlife, potentially killing fish and other fauna and reducing biodiversity. Many citizens across the whole country are heading during the summer to the Lauwersmeer for recreation. In addition to the great nature reserve all around the lake, the north-east part offers important bathing sites which are highly appreciated by Dutch people (and international tourists).

Swimming is a popular pastime and a holiday activity. The EU Bathing Water Directive, described in chapter 2.3, sets out the regulatory framework to ensure swimmers enjoy pure waters.

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62 https://open.overheid.nl/documenten/ronl-0c5086b3029ab6a4ab28d52838ce44d5e6285d1a/pdf
63 https://www.rijkswaterstaat.nl/

Figure 4-3 Enjoying a swim in Lauwersmeer[64]

Fishing is another very popular pastime activity. Fishing activities are affected as well by lakes quality. The great danger for the fish is a build-up of HABs and eutrophication potentially causing a high build-up of toxins, a lack of oxygen or death.

Figure 4-4 Fishing on Lauwersmeer[65]

Kayaking and canoeing are yet another very popular pastime and tourist attraction. Lauwersmeer National Park is easy to explore by canoe. Water quality is less of an issue for these activities except when actual algae blooms make the water unpleasant to be nearby.

64 Source of the figure: http://www.promotielauwersoog.nl/negatief-zwemadvies-oostelijk-strand-lauwersmeer/
65 Source of the picture: https://www.fishinginholland.nl/bestemmingen/lauwersmeer.html

Figure 4-5 Canoeing in Lauwersmeer[66]

Enjoying the summer near a lake or the seashore is a characteristic feature of the Dutch culture. In this context, many **holidays' villages and other accommodations** are established around lakes (see figure below) and activities offered around nature and water are various.

Figure 4-6 Green holiday parc around Lauwersmeer[67]

Natural Habitats. Lakes, rivers, and their surroundings are natural habitats supporting a diversity of wildlife. Their preservation is important and also covered by several EU directives but principally the habitats directive. This, together with the EU Birds Directive, establish a network of protected sites under the common umbrella of Natura 2000. Sites identified by the EU Member States become protected and shall be managed in a sustainable manner. Birds, especially, make Lauwersmeer National Park an irresistible wilderness for every bird watcher and nature lover. More than 100 bird species breed around the lake while tens of thousands of geese spend the winter there every year. In the spring and autumn, during the bird migration, the bird festival is the largest. Lauwersmeer National Park is also a great place for unique birds (stilts and spoonbills). Or the white-tailed eagle, which has been breeding here for a number of years.

[66] https://www.np-lauwersmeer.nl/doen-zien/watersport/

[67] Source of the picture: https://www.landal.be/parken/natuurdorp-suyderoogh

Figure 4-7 birds on Lauwersmeer[68]

4.2.5 Other Beneficiaries

Outside the core value chain, research centres and environmental institutes and water companies also benefit from EO data.

An important research centre in the Netherlands is **Deltares.** It is an independent research institute that specializes in water and subsurface-related research. It collaborates with the Dutch government and other institutions to conduct scientific studies related to lake monitoring, water quality assessment, and hydraulic engineering.

The national environmental institute is **RIVM (Rijksinstituut voor Volksgezondheid en Milieu).** It is the National Institute for Public Health and the Environment and is responsible for monitoring public health and environmental issues, including water quality in lakes and other water bodies.

Other various universities and research institutions in the Netherlands are involved in scientific research related to lake monitoring, ecological assessments, and water quality studies.

Additionally, **drinking water companies** in the Netherlands benefit from good water quality in lakes because these lakes and ground water (which is alimented by lakes) serve as vital sources of raw water for their treatment processes. High water quality reduces the complexity and cost of treatment, ensuring the production of safe and clean drinking water. It also safeguards public health, upholds regulatory standards, and contributes to the sustainability of the country's drinking water supply.

[68] Source of the picture: https://www.np-lauwersmeer.nl/het-lauwersmeer/

5 Assessing the Benefits

Now that we know which effects the Sentinel-enabled water quality monitoring service is causing in the subsequent tiers of the value chain, we can establish the different types of benefits that are generated through its use. Which financial value can we attribute to the availability of the service? Which environmental or regulatory benefits can we identify? Are there any other social or scientific impacts that we can track? These are the questions we are addressing in this chapter. In this regard, it is useful to recall our value chain picture whilst adding the last two layers to it.

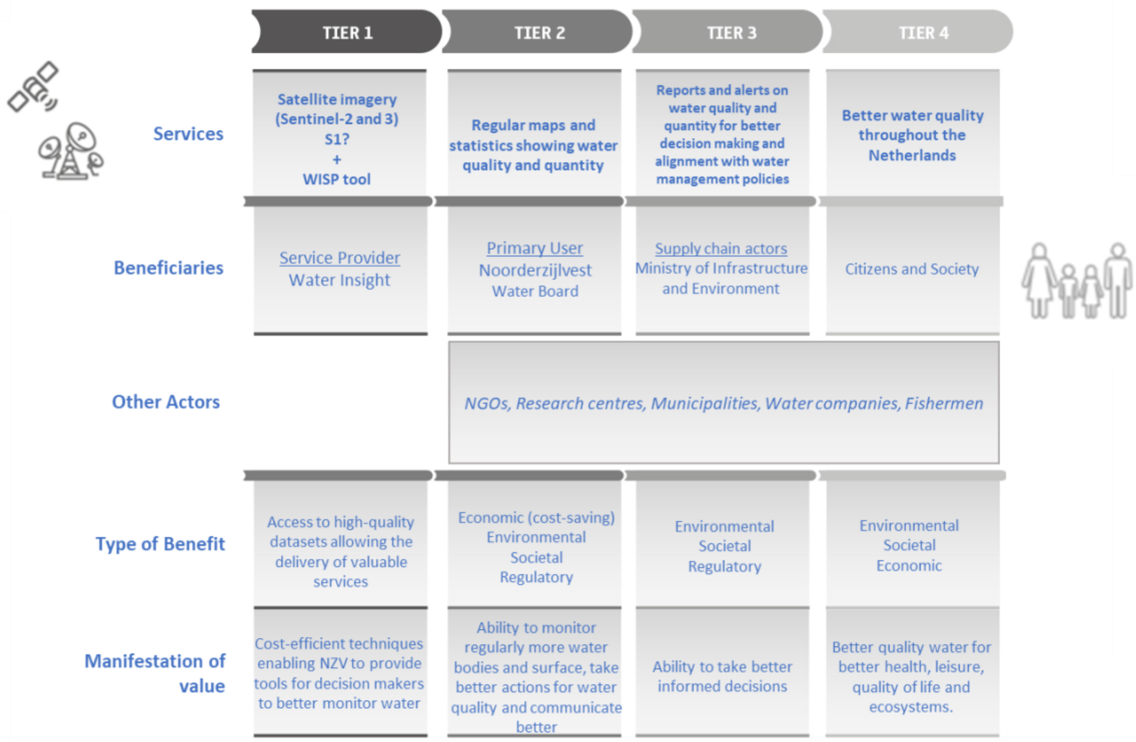

Figure 5-1 Benefits along the value chain

5.1 Overview

Before we dive into the discussion for each of the tiers it is instructive to make some high-level observations:

1. **Current benefits versus long term benefits of EO**

Benefits to the environment deriving from the use of Sentinel EO data, are being seen today but are likely to be much higher in the future. There are several reasons behind this:

- **EO measurements can become in the future recognised within reporting procedures in legislative measures** as it is highly recommended by Papathanasopoulou, E., Simis, S. et al. (2019) in their study supporting satellite-based monitoring in the framework of the WFD. It would allow quantifying elements of environmental status that are currently not or under-reported by Member States (e.g. frequency, onset, duration and extend of algal blooms); it would also increase representativeness of the natural diversity of waterbodies that are monitored (e.g. inter-annual variability); it would achieve much improved spatial coverage of medium (several square kilometres) and larger waterbodies; and it would allow better standardisation of monitoring methods. So far, none of the relevant legislations discussed earlier, currently recognise the use of satellite data as a monitoring method for reporting. The use is not banned but is not encouraged as are direct measurements. Whilst the Water Framework Directive would seem the most appropriate to reflect this enhanced ability to monitor and measure water quality across large areas, there are no plans to revise the directive in the near future. Reporting on the WFD is required every 6 years with the most recent report issued in 2018/2019 for the period spanning 2012-2017. No relevant updates to the WFD have been made so far. Consequently, the earliest possible date for a change would be after the next reporting period closes in 2024, meaning the first report using satellite data would not occur before 2030. Despite this, members of the Copernicus Management Committee have been promoting the use of Copernicus for water quality measurements with the result that a European level service should be introduced by the EEA in a very near future.[69] The Bathing Waters Directive, which is reported on a yearly basis could also provide a first vehicle to introduce satellite measurements and the European service will be relevant to meet reporting needs. This option is also promoted by the European Environment Agency (2022) in their study on "*Satellite-based monitoring of cyanobacteria in bathing waters*". Such implementation can also happen at national level as Environmental Ministries can recognise its use for monitoring and reporting purposes. Some countries, such as Finland and Germany, are starting to introduce such measurements alongside those required for reporting, but these are complementary to the formal reporting data. If and when this will change will depend on the willingness of legislators to introduce satellite-based measurements into updated directives. NZV water board is also currently strongly advocating for such implementation in the Netherlands.

- **Adapting to EO measurements and changing practices need important resources and takes time.** In the coming years, EO for water quality in the Netherlands should move from siloed experimental projects to advanced processes being used by all water monitoring bodies. While NZV is more advanced and already very actively using EO, the other water boards in the Netherlands still have to adapt their processes to EO. The younger generation may promote such change as they are usually more open to new technologies. Regarding EO services for lakes monitoring, additional AI tools will be further developed. For example, risk assessment and forecast of algal bloom (being currently developed) and automated alert systems for algal bloom could prove to be very useful to avoid late discovery. Thanks to such tools, authorities could avoid regular in-situ analysis costs while citizens could reduce their health risks by being exposed to Harmful Algal Bloom.

[69] Source: SeBS case on water quality in Germany.

- **While more lakes can be monitored more regularly thanks to EO, actions also need to be taken to observe benefits on water quality**. For example, actions to limit the nutrients in agriculture are difficult to implement as farmers are usually against such implementation. When these actions are taken, it also takes time to observe the results.

2. **Attribution to sentinel data**

In most of the previous cases which have been analysed, we face the issue of attribution, i.e., how much of the economic benefit is due to the use of the data from Sentinel satellites? In the case of lake monitoring in the Netherlands, the Water Insight service uses data from Sentinel-2 and Sentinel-3. When attributing 100% of the benefits to satellite data, we shall take 80% of this as being due to the use of the data coming from the Sentinels.

3. **Putting a Value on Nature**

As this case is focused on environmental factors, how much should we even attempt to place a monetary value on the benefits? In principle at least, every benefit can be translated into a financial one through different forms of analysis. In practice, it is often hard to place a financial value on environmental benefits such as clean air or in this case clean water, maintaining a rich flora and fauna as well as good quality of life and culture.

These high-level observations will be echoed in the detailed discussion of the economic value and other types of benefits arising from the use of Sentinel data in each Tier. These analyses have been generated thanks to the insights collected directly by the value chain actors and subsequent extensive research.

5.2 Benefits along the Value-Chain

5.2.1 Tier 1: Service Provider – Water Insight

There are three ways in which we can quantify the economic added value at the service provider level as a direct result of using Sentinel data:

1) Measuring the magnitude of WI's **revenues** which can be directly tied to the utilisation of Sentinel data;

The sources of revenues linked to sentinel data use are direct and indirect.

- Direct revenues are **direct sales** of EO services. For obvious confidentiality reasons we cannot disclose details for such measurement. However, they can disclose that roughly half of WI's turnover is linked to satellite services or projects while the other half is generated by instruments.
- Indirect benefits allow WI to have a **stronger in-situ product**. Such benefits are linked to the complementarity between WISP tools and EO data. E.g. EO data is used to find the right spot to place a WISPstation or to determine locations to take occasional measurements. EO data is also used to help target potential customers while such powerful pictures and

data help Water Insight in their communication to their potential customers. Again, for a matter of confidentiality, we cannot estimate these indirect benefits.

2) Quantifying the economic added value associated with the **number of workers** employed. currently there are 5 FTE's working at Water Insight although they are expecting to grow in the near future. Counting that half of these workers are dedicated to EO and that the average salary of a scientist in the Netherlands is 67K/year[70], **we can estimate that the added value generated by EO is 167k/year.**

3) **Additional funding received**. At the moment, WI is not receiving additional funding but they are looking into an investment round. In this context, there is a growing appeal among investors who recognize the substantial value offered by EO for various applications whereas there is an acknowledgment that the digitalization of water quality is a booming market and growth of these applications is anticipated in the future which is attractive for investors.

Beyond the economic aspects, it is important to note that WI contributes greatly to the Dutch and EU's **innovation** and entrepreneurial landscape thanks to their innovative use of Sentinel data to develop highly valuable and cutting-edge software and services. Other EU stakeholders might be inspired to develop such projects in their own country.

Furthermore, by having access to such rich data, WI and other researchers can improve their **research** on environmental issues. For example, WI services provided important help to generate the following studies published in high quality journals:

1. *Bresciani, M., et al. (2020). The use of multisource optical sensors to study phytoplankton spatio-temporal variation in a shallow turbid lake. Water, Vol. 12, No. 1. doi: 10.3390/w12010284*
2. *Giardino, C., et al. (2020). First evaluation of PRISMA Level 1 Data for Water Applications. Sensors, 20, 4553. doi: https://doi.org/10.3390/s20164553.*
3. *Jansen, H. M., van den Bogaart, L., Hommersom, A., Capelle, J. J. (2023). Spatio-temporal analysis of sediment plumes formed by mussel fisheries and aquaculture in the western Wadden Sea. Aquaculture and Environmental Interactions, 15, 145-159. doi: https://doi.org/10.3354/aei00458.*
4. *Peters, S., Laanen, M., Vaartjes, M., Oosterbaan, J., Van Druten, J. (2021). Optische metingen ter ondersteuning van het blauwalgenprotocol. H2O vakartikelen. Retrieved from www.h2owaternetwerk.nl/vakartikelen/optische-metingen-ter-ondersteuning-van-het-blauwalgenprotocol.*

[70] https://www.glassdoor.com/Salaries/netherlands-scientist-salary-SRCH_IL.0,11_IN178_KO12,21.htm

5. *Riddick, C., Tyler, A., Hommersom, A., Alikas, K., Kangro, K., Ligi, M., Bresciani, M., Antilla, S., Vaiciute, D., Bucas, M., Tiskus, E., Dionisio Pires, M., Warren, M., Simis, S. (2019). D5.3: Final Validation Report. EOMORES Project Deliverable.*

These contributions to R&D and innovation produce a snowball effect as it promotes WI as expert in their field while enriching general knowledge of various stakeholders on the benefits of EO.

It should be noted that an important upcoming mission, the [Copernicus Hyperspectral Imaging Mission for the Environment (CHIME)], expected to be launched in 2028, is foreseen to bolster the Copernicus offering even further. Carrying a novel imaging spectrometer, the CHIME mission will provide systematic hyperspectral images to map changes in land cover and help sustainable agricultural practices. It will also be used to detect different soil properties for action on improving soil health. In addition, CHIME will be used to support forest management and assessments on biodiversity, ecosystem sustainability and environmental degradation, and with relevance to this case, will support the monitoring of lake and coastal ecosystems including water quality.

5.2.2 Tier 2: Primary User – Noorderzijlvest Water board.

The primary user of WI's service, the Noorderzijlvest Water board, experiences several types of benefits. First of all, this regional centre in charge of water quality obtains for a low price an incredible amount of data and observations which are very useful for their water monitoring process. WI satellite data offers environmental status assessment (e.g. a-chlorophyl and turbidity) which provides comprehensive spatial overview in the lakes whereas samplings is just done at one point. It therefore offers better monitoring of the larger lakes (thanks to full and regular coverage). Another important feature of Earth Observation is that it provides the ability to analyse past status of water quality which allows to show the evolution of some patterns, such as algal bloom, through time.

To evaluate the **benefits,** we start with one lake, the **Lauwersmeer** (previously described) where pilots projects were undertaken.

The **first type of benefit** is the **cost saving** due to avoided in situ sampling. If in situ sampling was to be performed in Lauwersmeer with traditional sampling methods (which is still the most currently employed method in most EU countries and in other regions in the Netherlands), it would cost around €1200 per sample[71]. Typically there is a need to take around 5 samples a year for a comprehensive estimation of water quality throughout the year (which is yet under the necessary estimates for all types of urgent responses to issues such as HAB[72]). However, such sampling need is about one sampling every two weeks during summer (and less regularly during other seasons) in NZV water boards region at strategic spots (swimming areas, etc.). For the higher risk categories,

[71] Estimation made by NZV water board.
[72] Well sampled lakes such as in many areas of the Netherlands are sampled weekly or at least every two weeks in summer (source: Water Insight).

sampling is even required weekly[73]. To have an estimate of the number of spots to be evaluated, we consider a study performed by El Alem et Al. (2012)[74] comparing in-situ techniques versus satellite-based earth observation for monitoring of lakes. They used 168 sampling stations to monitor comprehensively four lakes (with a total of 92 square kilometres) which they consider as enough for a comprehensive view of the four lakes. It makes a total of 1,8 sampling station for every square kilometre. For Lauwersmeer, which has a size of 24 square kilometres[75], it means a need of a total of 43 samplings (24*1,8)[76] to cover the whole surface. As around 5 visits per year at €1200 per sample are being saved thanks to EO, **it makes a total cost saving of €258K per year for using EO in Lauwersmeer.** If we compare EO to the use of a WISP-3 tool compared to which EO brings better spatial information, the savings might be lower but as sampling is the traditional method used in most parts of the country, we keep it as the reference.

To extend these benefits at the scale of the country (considering that all water boards would use EO monitoring for water quality), we take the total combined surface area of the lakes larger than 50 hectares in the Netherlands which is 2500 square kilometres (the equivalent of 104 Lauwersmeer in terms of surface). The total benefits brought by EO in Lauwersmeer being €258K, the **extrapolation of benefits brought by EO to the whole country is €26,83m** (€258K*104).

The second type of important benefit is that an analysis of EO data has shown that the reversing of direction of a pumping station in an area (in which we find bathing sites and natural reserve sites) could greatly improve the water quality. This action, which is under discussion, is not possible without a full historical view of the lake offered by EO. Improving water quality allows NZV to reach their water quality objectives required in the framework of the EU and/or national regulation. More of these kinds of analyses are to be expected, leading to other improvements in water management.

Another action which benefits from the use of satellite imagery involves setting up a WISPstation at a strategically chosen location, enabling frequent water quality assessments throughout the day. It also helps in defining representative locations for in situ sampling. The process of identifying the optimal location is enhanced by Earth Observation (EO), thereby enhancing the efficiency of measurements.

A last benefit for NZV water board is linked to their actions on convincing the state to introduce EO measurement into the official measurement standards for water quality. Having access to satellite images provides clear and common basis for discussion which helps in convincing decision makers.

[73] This value comes from the Dutch cyanobacteria protocol. See table 1 at page 76. Risk category 0 and 1 require sampling at bathing water sites once every two weeks, for the higher risk categories they require weekly sampling https://www.rivm.nl/bibliotheek/rapporten/2020-0107.pdf

[74] https://www.researchgate.net/figure/Water-sampling-stations-on-the-four-studied-lakes_fig2_237008495

[75] https://nl.wikipedia.org/wiki/Lauwersmeer

[76] Ideally one should withdraw the samplings sites that are already in place on the lake in the calculation. However, these ones are unsignificant as it accounts for one or two sampling spot per lake.

5.2.3 Tier 3: Ministry of Infrastructure and Water Management

The Ministry of Infrastructure and Water Management obtains strong regulatory benefits as they have access to better information - more comprehensive reports and data from water boards - on which to base new policy decisions. This information may, for example, relate to the sources of pollution through the release of nitrates from farming, the magnitude of eutrophication in lakes or the impacts of HABs on local wildlife and biodiversity. This comprehensive information helps the ministry to evaluate the impact of other policies on water quality, for example policies to reduce nitrogen emissions from farms (see section 2.2.3.). Studies and reports supported by satellite-derived products are of great help in choosing the most effective measures to be supported.

An important benefit for the ministry is found in **avoiding paying fines**. In fact, when a member state fails to meet their objectives linked to water quality, the European Commission can take legal action against that member state. This could result in fines or penalties imposed by the Court of Justice of the European Union (CJEU). The amount of the fines can vary depending on the severity and duration of the non-compliance.[77] To have an idea of the amount represented by such penalty, we found an example linked to the Bathing Water Directive.[78] The European Court of Justice (ECJ) imposed a penalty payment of €624 150 per year and per 1% of bathing areas in Spanish inshore waters which had been found not to conform to the limit values laid down under Directive 76/160 for the year in question. To transpose such case to the Netherlands, we take again the example of Lauwersmeer. If we consider the same type of amount as in Spain while knowing that the Netherlands has 649 inland bathing areas[79] which counts 6 of them in Lauwersmeer where water quality is improved through various measures, partly thanks to EO. These 6 bathing areas, representing almost 1% of the total bathing areas in Dutch inshore waters, **a fair estimate of the fine set by the ECJ if these waters were to be under the threshold set by the BWD would be €600K.[80] If we consider that 5% to 10% of such water quality improvement could be done thanks to sentinel satellites, it makes a saving of €30-60 K.**

To extend such benefit to the **whole country**, we consider the hypothesis that actions following EO measurements can be taken in the 3,4% of Dutch bathing sites that are of poor quality. It means that the country could save €2,04M (€3,4*600K) by improving water quality in these areas. **If we consider that 5% to 10% of such water quality improvement could be attributed to sentinels, it makes a saving of €100-200 K.**

Another example involving **possible fines from the European Commission comes from the Water Framework Directive**. By signing the WFD, the Dutch government has pledged to improve the water quality by 2027. A well-known Dutch activist committee (that also successfully went to court to force the Dutch government to adhere to nitrogen deposition reduction efforts) has recently launched a first legal initiative to force a water board and the Provincial government to step up

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77 https://ec.europa.eu/commission/presscorner/detail/en/inf_23_525

78 Unfortunately, this is the best reference we could find although it would be more representative to find a reference linked to the WFD.

79 https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/state-of-bathing-waters-in-2022

80 We note that it is not the state who pays the fine but the region.

their actions against polluters (mainly from agriculture) and carry out the WFD in full[81]. Knowing from section 2.2.1 that **90% of water bodies that are not in good ecological status** in the Netherlands, this could have enormous consequences for the level of water quality monitoring and follow-up actions in the Netherlands. However, we will not provide estimates for the possible fines related to the WFD as we do not have access to sufficient metrics.

The Ministry of Infrastructure and Water Management also benefits from additional long-term **regulatory benefits** as continuous observation of water quality helps in establishing correlation between water status and polluting industries. It in turns allows ministries to be better informed to take policy decisions.

Furthermore, thanks to the use of EO, ministries benefit from a **common understanding** as it helps them to communicate with different stakeholders on water quality using the same imagery and measurements. It is also extremely useful to communicate to the general public as EO images offer straightforward interpretations which in turns help in convincing public opinion of their actions.

Good water quality has an influence on **tourism** which in turn impacts national revenues. Before the covid period, the Netherlands hosted 20,13 million tourists (for the year 2019) which corresponded of 2.6% of their GDP.[82]

Last but not least, the Netherlands, as a pioneer country in earth observation and water quality management benefits from reputational returns for their successful innovative projects in this field. Additionally, R&D and innovation spillovers from such projects are important for the country.

5.2.4 Tier 4: Citizens and Society

With regards to the final tier of this value chain, the manifested benefits primarily relate to environmental and societal dimensions.

From the previous discussions, we consider that all or a very large part of the benefits resulting from the use of satellite data is felt by citizens and society through overall improved water quality and its impact on the ecosystem. A wider used term for it is the **value of ecosystem services**. Quality (and quantity of good quality) water is getting increased attention in most countries around the world as freshwater's goods and services are of key importance to our survival and well-being. Systematic reviews list between 20 and 32 ecosystem services (ES), the most frequently mentioned ones being recreation and tourism, water supply, water quality control, habitat provision, erosion prevention as well as food supply and climate regulation.[83]

Overall, we can summarise these services into two key types of benefits to citizens from having access to lakes with better water quality. (1) Amenity value from safer leisure activities on the lakes and (2) a better environment, offering cleaner water and greater biodiversity.

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[81] https://www.h2owaternetwerk.nl/h2o-actueel/mob-zegt-provincie-en-wetterskip-de-wacht-aan-over-beroerde-waterkwaliteit-in-friese-wateren
[82] https://www.worlddata.info/europe/netherlands/tourism.php
[83] https://link.springer.com/article/10.1007/s13280-021-01556-4

In the Netherlands, good quality freshwater benefits to

1. **658K recreational fishers from 737 fishing associations**[84]

Fishers need a fishing pass to be able to fish in most Dutch inland waters. A fishing pass is valid for one year and costs 39 euros on average.[85] It represents a market of a total of €26m (658K*€39).

This value provides an estimate of the recreational fishing market in fresh water in the Netherlands. To go one step further, the benefits brought by EO services to this market should be computed. However, as ecosystem services (which includes recreational fishing) benefits brought by sentinels on lakes quality are computed below, we will not compute such value here.

2. **Citizens enjoying the 649 inland bathing areas by lakes and rivers**[86]

A previous study[87] has looked at the value of satellite-based monitoring of water bodies in the US. At the heart of this study, the authors investigate a HAB outbreak on Lake Utah in 2017 for which they calculate that a benefit of around $370k (€300k) was made through using Landsat data to warn lake users (bathers) of the risk. By closing the lake 7 days earlier than would have been the case without the early warning, 30 bathers (out of 8000) avoided a severe illness and 400 in total were spared any illness.

Although almost all warnings of HAB in the Netherlands are currently provided by in-situ observation and citizen observations, EO services in the Netherlands allow to confirm such danger.

However, currently in the Netherlands, the water is checked every two weeks during the swimming season between May 1 and October 1. If the water of a swimming lake contains HAB, the province places a warning sign to inform swimmers about this.[88] Scientists from Wageningen University & Research have also developed a free app where citizens can report HAB.[89]

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[84] https://www.sportvisserijnederland.nl/actueel/nieuws/24034/vispas-2021-feiten-en-cijfers.html#:~:text=17%20jun%202022%20Jaarverslag%202021,maar%20liefst%20704.776%20aangesloten%20sportvissers.

[85] https://www.rijksoverheid.nl/wetten-en-regelingen/productbeschrijvingen/vispas

[86] https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/state-of-bathing-waters-in-2022

[87] Quantifying the Human Health Benefits of Using Satellite Information to Detect Cyanobacterial Harmful Algal Blooms and Manage Recreational Advisories in U.S. Lakes; Stroming et al, AGU June 2020.

[88] See protocol: https://www.rivm.nl/bibliotheek/rapporten/2020-0107.pdf; https://de-marne.nieuws.nl/knipsels/40385/waarschuwing-strand-meerkoet-en-lepelaar-lauwersmeer-blauwalg/

[89] https://www.wur.nl/en/research-results/research-institutes/environmental-research/show-wenr/report-blue-green-algae-with-the-bloomin-algae-app.htm#:~:text=Every%20summer%2C%20blue%2Dgreen%20algae,is%20less%20or%20no%20supervision.

Figure 5-2 Warning sign on Paterswoldsemeer

Generally, the Netherlands could benefit from **timely results - and hence early warning - from observation via EO** and share such precious information through the app or a website to avoid having citizens waste time by going to the lake and avoid illness.

Depending on the popularity of the site, the warning allows large numbers of potential bathers to be spared from exposure to the HABs. We do not have figures for the number of bathers and number of infected areas, but we can make the assumption that between 500 and 1000 bathers will have been spared at each bathing site where HAB occurs. Scaling from the US figures above (€300K saved for 8000 bathers) and making the hypothesis that HAB are abundant to very abundant in one site out of 10[90] leads us to conclude that the overall benefit of a potential warning across the Netherlands is therefore estimated between €1218k and €2437k.

But health issues are not the only factor which we are considering. In this case, more bathers would be saving time by being dissuaded from travelling to the lake which has been flagged as dangerous to health.

Estimating sentinel satellite data added value in this warning process would be hazardous because water boards are not yet providing the warning derived from sentinel data in the Netherlands, but the above numbers provide a good idea of future possibilities of sentinels added value.

3. **Kayakers and canoers**[91]

This category of lake user is less directly affected than the fishers or the bathers and the consequences are more limited. We shall not include any figures for an economic benefit for them but we note that there is clearly an interest for the regional centres to maintain a high level of water quality to keep attracting visitors to its lakes.

[90] This number was found in for the SeBS case in Finland.

[91] https://vesistosaatio.fi/en/finnish-fresh-waters/#:~:text=The%20status%20of%20Finnish%20fresh%20waters%20has%20improved,of%20inland%20waters%20in%20Finland%20is%20fairly%20good

4. **People enjoying their summer holidays near a lake.**

We can easily state that people would not spend their holidays near smelly lake with limited leisure possibilities. It involves that demand for accommodation around a lake is definitively correlated with good water quality and that improved ability to monitor water quality (and thus to intervene to fix it) should have a positive impact on demand for accommodation.

To have an estimate of the economic value paid by people spending a night or more around Lauwersmeer, we first need to estimate the total number of accommodations and restaurants around the lake[92]:

- About 12 hotels/B&B
- 5 Camping sites
- About 120 holiday houses
- 19 restaurants (most of them having a view on the lake)

We make the hypothesis that a hotel/B&B can host on average 30 people, a camping can host on average 100 people and a house, 6 people on average, we end up with a full capacity of 1580 people per night at Lauwersmeer. We make the second hypothesis that one person spends on average €75 on accommodation and food.[93]

To evaluate the economic added value of EO we compare two different scenarios:

1. We make the hypothesis, that **without improving water quality**, there is an average of **55% of monthly occupation rate**[94] (meaning 55% of rooms/houses/camping places are booked on average during a month), it makes a total of **€23,79m**[95] spent each year around Lauwersmeer for accommodation (and food linked to such accommodation).
2. We make the hypothesis that improving water quality allows to improve the monthly occupation rate to **60%** (instead of the previously stated 55%), it makes a total of **€25,95m**[96] spent each year around Lauwersmeer for accommodation (and food linked to such accomodation).

The difference between both scenarios represents an **economical gain of €2,16m**. To this gain, if we make the same hypothesis that **5% to 10% of such water quality improvement could be attributed to sentinels, it makes a total of €113k to €216k of gain attributed to sentinels.**

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[92] We estimate these numbers through a search on Google map.

[93] This number is much lower than the average of €175 spent by an average tourist in the Natherlands (found here: https://www.budgetyourtrip.com/netherlands) because we estimate that tourists in their own countries spend less than international tourists. Also, family tourism in camping and houses around the lake is much less expensive than tourism in a hotel in a city. A last reason for such low estimate is to stay conservative on the values to avoid overestimation.

[94] This number is based on the monthly hotel occupancy rates in Europe from 2020 to 2022, taking conservative numbers to make sure there is no over estimation (https://www.statista.com/statistics/206825/hotel-occupancy-rate-by-region/).

[95] =1580*75*0,55*365

[96] =1580*75*0,6*365

This estimate provides an idea of the economic value of the ecosystem services gained through Sentinel satellite data (which by itself allows to invert the pumping station and improve water quality) for one lake when considering only accommodation (and food). One could go further and estimate such value for the whole country but in this case we decided to keep this value only for Lauwersmeer because too many hypothesis need to be made for such extrapolation which would bias the results. However, another methodology presented below accounts for all cultural ecosystem services (recreation and tourism) in the whole country.

Putting a Price on Nature?

In order to understand what level of resource use and what level of waste can be tolerated, economists are increasingly seeking to place a value on natures contribution to human development. This is leading to a strong interest in the subject of putting a value on ecosystem services and what nature contributes to the global economy. A striking description of this can be found in the Dasgupta review[97], published in February 2021. Commissioned by the UK government, this report looks at the economics of Biodiversity saying:

> *Nature is, therefore, an asset, just as produced capital (roads, buildings and factories) and human capital (health, knowledge and skills) are assets. Like education and health, however, nature is more than an economic good: many value its very existence and recognise its intrinsic worth too.*
>
> *Biodiversity enables nature to be productive, resilient, and adaptable. Just as diversity within a portfolio of financial assets reduce risk and uncertainty, so diversity within a portfolio of natural assets increases Nature's resilience to shocks, reducing the risk to Nature's services. Reduce biodiversity and Nature and humanity suffer.*

Nevertheless, despite the various efforts described below, this is still a young scientific field with a lot of remaining work to arrive at confident valuations. It contributes strongly to the concept of sustainability since natural resources are limited yet contribute to global growth. Where the inputs are direct, the link is obvious as in the case of minerals and physical resources. However, for many other parts of the ecosystem, the link is not so evident as it is made clear in an article in the Guardian "How much is an elephant worth?"

Through better water quality and environment, local citizens can enjoy improved access to nature and its flora and fauna. How much is this worth to the average citizen? And how much preserving nature is worth to the generations to come?

A rigorous study from 2020 on Ecosystem services on Earth's largest freshwater lakes evaluates cultural services (recreation and tourism) – among other ecosystems services - for the five Laurentian Great Lakes plus two others (Baikal and Winnipeg), at $6.2 billion/year.[98]

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97 Dasgupta Review, The Economics of Biodiversity, Headlines, abridged version and Full Report. February 2021.

98 https://www.sciencedirect.com/science/article/pii/S2212041619300658

Considering that watershed population of these lakes is equal to 42 million, it means that the value of cultural services per year per watershed habitant is 149€/year. Bringing that to the Dutch population (17,8 million inhabitant, who all live close to a lake), we can estimate **lakes cultural services at 2,652 billion€/year.**

From this number we need to estimate the added value provided by sentinels derived services. First, the above value compares high quality water vs poor quality water, i.e. a situation in which a citizen must find other hobbies than the one linked to lakes because of a bad quality water to a situation with good quality water everywhere. We know that the current situation is not so extreme although. Second, we need to estimate the share attributed to the information arising from the use of satellite data. Although water quality is better monitored thanks to remote sensing, there is still a need to take actions in order to improve the quality of water (e.g. as stated above, reversing a pumping station or reduce nitrites emissions from agriculture). Actions that affect water quality are usually made in the surrounding areas such as fields and industries and take time to be implemented, to observe results and then to measure these results.

Taking these facts into account as well as the fact that EO products are rather recent, it would be too soon to compute a sound estimate of the current added value provided by sentinels derived services on water quality. We believe however that such estimate will be possible to evaluate in about 5 years, especially in Noorderzijlvest region where EO monitoring is already being used. To estimate benefits linked to EO services, it would be interesting to take two facts into account: (1) water bodies quality that have been improved thanks to EO and (2) other water bodies that should have been deteriorated with time but have been stable (or less deteriorated) thanks to EO. To make such analysis, two comparisons need to be done: (1) before and after the introduction of EO services - 5 years difference or more should be ideal to be able to observe results of actions - and (2) a comparison with similar countries or regions who did not yet introduce such kind of EO services to monitor water bodies (to account for the counterfactual, i.e. the natural evolution of water quality, due to stricter regulation for example, when only in-situ monitoring services are used).

However, we can still make the rough and uncertain estimate that EO allows an improvement of 0.3% to 0.5%[99] of the 2,652 billion€/year of lakes cultural service, it leads us to 7,96 to 13,26 million€ of ecosystem services for leisure activities brough by EO. We believe that this value will progressively increase in the coming years as the "accommodation" case above shows a much higher number in Lauwersmeer where actions based on EO measurements have already been taken, which is mostly not the case in other regions in the Netherlands. As stated at the beginning of this chapter, we compute 80% of this value to estimate sentinels' benefits among other EO providers. **It comes down to a value of 6,36 to 10,61 million euros/year of ecosystem services benefits brought by sentinels on lakes quality in the Netherlands**.

[99] This number, 0,5 corresponds to the number used in previous case. To stay conservative we put a range of values below that number.

5.2.5 Other Beneficiaries

The other beneficiaries identified in the value chain and in Section 4 are linked to research centres and NGOs that are working on water, freshwater bodies and ecosystem services, Regional State Administrative Agencies and water companies.

The transparency provided by the Sentinel-powered service allows **environmental centres** to monitor the progress of environmental and ecological targets and ultimately aids them in reaching their goals.

The availability of wide-area monitoring from satellites promises a direct impact on **research** capability. Such data is not available from other sources and hence can drive research projects looking at large scale effects or even local scale but over a wide area. This can include farming and forestry practices, future water supplies, and the contribution from nature and ecosystem services.

Good quality water also largely benefits to **drinking water companies**. 60% of Dutch drinking water comes from groundwater (partially alimented by lakes), mainly in the eastern part of the Netherlands. The remaining 40% comes from surface water, mainly in the West where water utilities pump from the Rhine and the Meuse because groundwater is salty.[100]

5.3 Summary of Benefits

In this section, we draw together the different benefits to the stakeholders identified along the value chain, grouping them by six dimensions of value-chain analysis. A summary of the degree of the benefits -based on the ratings on the sub-sections below - as applicable to this case, taking into account previously studied cases, is shown below. The assessment is subjective; the basis for it is given in Annex 2.

Economic	Environmental	Societal	Regulatory	Innovation & Entrepreneurship	Scientific & Technological
★★★★★	★★★★	★★★★	★★★★	★★★	★★★★

Table 5-1 Benefits Assessment by Category

5.3.1 Economic

Tier	Benefits identified	Lauwersmeer Annual economic value stemming from the use of Sentinel-enabled services (in €)		The Netherlands Annual economic value stemming from the use of Sentinel-enabled services (in €)	
		Min	Max	Min	Max
Tier 1	Direct sales of EO services	N/A		€167k	

[100] https://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_the_Netherlands#:~:text=60%25%20of%20Dutch%20drinking%20water,Meuse%20because%20groundwater%20is%20brackish.

(Water Insight)					
Tier 2 **(NZV Water board)**	Cost savings for avoided in-situ monitoring costs	**€258 k**		**€26,83m** (Including all water boards)	
Tier 3 (Ministries)	Avoided fine	**€30 k**	**€60 k**	**€100 k**	**€200 k**
Tier 4 (Citizens and Society)	Cultural ecosystem services	**€113k** (Accommodations only)	**€216k** (Accommodations only)	**€6,36m**	**€10,61m**
TOTAL		**€401k**	**€534 k**	**€33,46m**	**€37,81m**

Table 5-2 Summary of economic benefits

As discussed in previous sections, there are undoubtedly many additional economic benefits manifested in each tier of the value chain that have not been quantified within this table due to the many unknowns and complexity involved in performing this analysis. Therefore, it should be noted that the figures in the table are what could be more objectively quantified within this report and are considered quite conservative in terms of the actual total economic value Sentinels are bringing in this case.

We note that the high economic benefits are attributed to the fact that water quality status can be greatly improved. As stated in section 2.2, the last assessment done in the framework of the WFD in 2019 (for the period spanning 2012-2017) is not positive about the Netherlands as the country reports more than 90% of water bodies that are not in good ecological status (see figure below). Improving water quality in this country is therefore essential as it brings important benefits (especially in terms of ecosystem services). We classify the contribution to economic benefits as 5 stars.

- Cost savings from avoided in-situ monitoring (tier 2)
- Cost savings from avoided fine (tier 3)
- Cultural ecosystem services from good quality water (tier 4)

5.3.2 Environmental

As discussed in the previous sections, the Sentinel-enabled Water Insight service supports the monitoring of water quality in the Netherlands, giving rise to significant environmental actions and benefits. This includes:

- Improved ability to track the possible consequences of pollution and ultimately support reduction of pollution through fertiliser run-off or watercourse restoration.
- Possibility of reversing a pumping station (made only possible with EO imagery) improving water quality.

- Enhanced capacities to detect environmental issues connected to HABs and their evolution.
- Strengthened capacity in preserving nature and biodiversity.

All these benefits feed into the discussion of ecosystem services presented in section 5.2. Whilst the full realisation of these benefits relies on the actions taken by the competent authorities, there is strong evidence that the Sentinel-enabled information provided by Water Insight empower these authorities. Thus, 4 stars have been assigned for the environmental benefits in this case; we expect this to become 5 stars in the near future when further tools will be created (e.g. early detection of HAB) and when the capacity to react to alerts of environmental threats will be strengthened.

- Maintenance of natural habitats and ecosystems (tier 4)
- Reduced pollution (less fertilizer run-off)
- Supporting tool in the detection of environmental threats such as HAB (tiers 3 and 4)

5.3.3 Regulatory

The ability to implement improved regulations seems to be a very strong potential benefit coming from the use of Sentinel data for monitoring water quality in the Netherlands but also elsewhere. In that regard, the EO services are being recognised by NZV Water Board as an effective way to improve their ability to monitor the quality of water under their legal responsibility. The data helps:

- NZV Water Board to improve their ability to carry out their own institutional monitoring tasks in accordance with their legal statutes and regional and national laws.
- NZV Water Board to advocate for the use of EO in national regulatory framework.
- NZV Water Board and ministries to improve their accountability (and thus self-confidence and sense of mission fulfilment) through better transparency and better communication. This in turns allows them to do a better job in compliance to regulation and in policy making.
- The ministry to evaluate the impact of policies on water quality.
- The ministry to improve regulations related to the water sector (including use of fertilisers, water abstraction, setting rules for polluting industries, etc…).

The further advantage that could be derived from better and streamlined reporting (at the federal and the EU levels), however, does not currently materialize because of the lack of explicit recognition of the use of EO data in the present form of the respective regulations. This potential change is subject to much debate.

We classify the contribution to the regulatory benefits as 4 stars. We do not yet assign a 5 due to the fact that the full potential of regulatory benefits is not yet realised. The score will improve when satellite observation measurements will be implemented in the regulatory framework.

- Better monitoring and enforcement sustainability commitments (tier 2)
- Better monitor impact of policies (tier 3)
- Improve policies (tier 3)

5.3.4 Entrepreneurship & Innovation

The development of the new product combining artificial intelligence, in situ optical tools, and remote sensing have strong impact for Water insight and NZV water board.

Firstly, for Water Insight, EO services represent significant research into the techniques for extracting water quality related information from satellite data. This has been followed by many steps of technical development including those mentioned earlier, to make the service more accessible by their users. Furthermore, there is still a tremendous potential of development of the service in the future.

Secondly, for NZV water board, the introduction of new processes into public agencies is never easy. Hence, the water quality software and IT infrastructure are essential tools supporting innovation inside this Dutch regional agency.

When looking at the interaction between Water Insight, NZV water board, the ministries but also society at large, the fact that water quality monitoring and associated activities are informed by a cutting-edge tool constitutes a clear case of innovative governance model.

On balance, we classify the contribution to innovation benefits as 3 stars on our qualitative scale because tremendous innovation can still be done, especially with the integration of EO data with in situ tools data, the creation of some platforms to communicate to the general public and early warnings systems.

- Creation of innovative services (tier 1)
- Championing of innovative services and changing of operational practices (tier 2)

5.3.5 Science and Technology

There is a great deal of research into the impacts of water quality on biodiversity and other environmental effects. The extensive research surrounding ecosystem services, lakes and rivers are based on this new, large-scale data derived from the satellite measurements.

A strong determinant of the scientific benefits relates to the nature of the data and its application. Whilst the knowledge on how to abstract information on water quality parameters from satellite images is quite well-developed, the regular and frequent availability of images from the Sentinel-2 satellites is unprecedented and can help to understand ecosystems at local, regional and global levels.

The data derived from satellites is unique and is not obtainable through other tools – at least not at an affordable price. Multiple measurements per week, of key water parameters, over the whole country – indeed the whole surface of the Earth – is impossible without satellites.

In consequence, three types of research are supported by the Sentinel data:

- Improved understanding about ecosystem services (and the importance of water quality) and how they contribute to the global environment and their value in economic terms.
- Understanding of water supplies and how sustainable these may be especially in fragile regions of the world,
- Improvement of water quality algorithms, where the wide-scale measurement of water quality is enabling research projects looking at how to improve the measurements made using the satellite data.

With regards to this specific case, Water Insight has been collaborating with various scientific institutions to issue new knowledge (in the form of scientific papers) on the different subjects stated above. We classify the contribution to scientific and technological research as 4 stars.

- Wide-scale nature of the measurements possible with Sentinel data is enabling research projects into ecosystems services as well as impact of water quality.

5.3.6 Societal

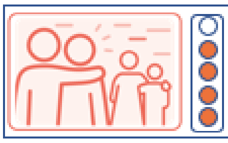
The benefits to citizens and to society are possibly the most important ones deriving from this case – and naturally, there is also a strong overlap with the environmental benefits. This highlights the circular nature that a case with strong environmental benefits has, as these benefits are further reflected into societal and regulatory benefits. This is because environmental benefits are being increasingly recognized by the public and, similarly, the impact of activities on the environment is usually subject to legislation.

The improvement in the quality of lakes and rivers translates to a pleasure shared by many whether it is for swimming, fishing or canoeing as discussed previously, or simply the appreciation of a natural landscape. Through better water quality and environment, local citizens can enjoy improved access to nature and its flora and fauna. Citizens can enjoy a better environment and diversity and hence those looking for a nature walk or just a picnic can enjoy better amenities.

How much is this worth to the average citizen? And how much preserving nature is worth to the generations to come? Sustainability is certainly to be regarded as a societal benefit. We should like to be able to place an economic value on this but lack the resources to be able to develop the necessary models or to conduct a willingness-to-pay survey.

Obtaining wide-scale data on the quality of the water in lakes and rivers is really only possible through the use of satellite imagery. Much less parameters can be analysed than that coming from in-situ measurements by water sample analysis in laboratories, but this is made up for with the ability to measure lakes across a wide geographical area. Such wide-scale data and maps can be shared internally as well as through websites, social media, and national/local press. This gives rise to important benefits such as improved coordination and communication both within organisations and vis-a-vis the general public. This in turn helps to improve reputation and accountability of environmental and regional agencies through better transparency. The society as a whole can only benefit from this trust in its public agencies which in itself represents an important pillar of a healthy and well-functioning society.

We classify the contribution to societal benefits as 4 stars although we believe it will become 5 stars in the near future when EO services will evolve and will be shared in a timely manner to citizens. Additionally, it should become 5 stars when EO effects on water quality will be clearly and significantly demonstrable.



- Improved access to amenities linked to water bodies – swimming, fishing, canoeing, etc. (tier 4)
- Better quality of life (tier 4)

5.4 Synoptic overview

Having looked at the different types of benefits and before proceeding to the conclusions extracted in this study it is instructive to provide a synoptic overview in the table below.

Tier	Benefits identified	Type	Value where **economic** (annual)
Tier 1 (Water Insight)	**Additional fundings** provided by private and public actors	Economic	
	Cost-savings from the use of free satellite data	Economic	
	Employees dedicated to EO	Economic	**€167K**
	Creation of **innovative services**	Entrepreneurship and innovation	
	Perform **better research**	Science	
	Support own **environmental mission**	Environmental	
Tier 2 (NZV Water Board)	**Cost savings** for avoided in-situ monitoring costs	Economic	**€ 26,83 m**
	Support to **other activities** (floods monitoring, ground water monitoring etc.)	Economic	
	Additional **proof of adherence** to the relevant provisions under EU and national regulation	Regulatory	
	Support own **environmental mission**	Environmental	
	Cost savings from avoided fines	Economic	**€ 100-200 k**

Tier 3 (Ministries)	Better information for **better decision-making**	Regulatory	
	Common understanding	Societal	
Tier 4 (Citizens and Society)	**Ecosystem** services	Economic	**€6,36 - 10,61 m**
	Better health and quality of life	Societal	
	Maintenance of **natural habitats and ecosystems**	Environmental	
TOTALS			**€ 33,46 – 37,81 m**

Table 5-3 Summary of benefits for each Tier

6 Key Findings and Final Thoughts

6.1 Key findings

The benefits from using Sentinel-2 and Sentinel-3 data to provide measurements of the water quality in lakes across the Netherlands are important. This technology provides detailed measurements of several parameters linked to the water quality over a large geographical area. Its utilization complements other methods to measure the quality (in-situ water analysis) and provides information that could not be obtained otherwise. The impact of this is reflected in the fact that EU countries and regions are devoting higher budgets for Sentinel-enabled services even if it is not contributing to their core reporting mission.

Such services are especially relevant in a country like the Netherlands where the large amount of fresh water is affected and threaten by pollution due to **high population density** and **intensive agriculture practices**. This country is now experimenting an important shift thanks to EO and other innovative techniques to monitor and improve water quality and there are good hopes that it will be strongly reflected in the next reporting rounds.

Like the previous cases in Germany and in Finland, one of the most striking aspects of this case is **the really strong contribution to value that is being generated across the full range of dimensions**. At the outset, we had expected that this case would be dominated by environmental issues, which indeed it is, but not that other dimensions would also feature so strongly, especially for the economic dimension. The **economic benefits** have been calculated based on a realistic current and future scenario. They are based largely on water boards saving monitoring costs, citizens having access to cleaner water and ministries avoiding EU fines for poor quality water.

Another noteworthy aspect of this case is that the **advantages will significantly expand in the coming years**, given that the Netherlands is currently in the early stages of transitioning toward more advanced tools for improved water quality monitoring. In this regard, we expect EO tools to improve while they will be extended over the full territory. Such growth will be also induced by regulation adaptation to satellite data (i.e. the use of EO data as reporting method in the current national and EU regulations), additional AI tools to predict and prevent events such as HAB and other phenomena requiring special attention, more accurate satellite data/images, long-term trends analysis to overcome polluting events and improve scientific knowledge, etc.

6.2 The Impact of Sentinel Data

Sentinel data constitutes the primary source being used to generate the EO-based measurements of water quality. Some data coming from Landsat 8 and high-resolution satellites is also used to increase the frequency and quality of the measurements. Overall, 80% of the economic benefits are attributed to Sentinel data.

But the use of data from Sentinel-2 and -3 is crucial to the success of the service. The regular and frequent observations possible on a global basis means that users can be confident in having the required information. This has driven the expansion of the service.

6.3 Widening the Perspective

Geographic Extension

Although we have demonstrated that satellite-based water quality monitoring is highly relevant for the Northen part of the Netherlands which is managed by NZV waterboard, EO is very relevant for the other parts of the Netherlands but as well other countries around the world.

With regards to the Netherlands, although EO services for public means from Water Insight are mainly provided on the NZV territory, the NZV water board is advocating for a harmonisation (through, among other things, the implementation of EO tools in the National Water Programme (NWP)[101]) and extension of such tools all over the Netherlands. Furthermore, because the geographical characteristics of the country are relatively uniform throughout the entire land, the cost of expanding such services to other water boards will not be prohibitively high.

With regards to other countries, it would be extremely valuable for other states to be inspired by the cases in Germany, Finland and the Netherlands to develop their own services which would be adapted to the geographical specificities of their own countries. Currently, such development depends on social and environmental factors outside of the regulations (since satellite observation measurements are not yet implemented in the EU WFD). We believe that as soon as regulation will be adapted, the take-off of similar services in other countries will be even more important.

From having surveyed 10 other countries (Denmark, Belgium, Germany, France, Sweden, Estonia, Norway, Irland, Latvia and Finland), we can state that such service is already developed in Finland (through the public service, TARKKA, developed by the national environmental institute, SYKE) and Germany (using EOMAP private services). Belgium is using Sentinel-2 for temporal and special monitoring of Chl-a, Ireland is very active with its project “remote Sensing of Irish Surface Waters” (INFER)[102], Sweden has a project on its way (Brockmann Geomatics has developed for a lot of lakes specific services for their customers, mostly public sector), Latvia has a strategic plan[103], and Estonia (via Tartu observatory) is very experienced in lakes water quality R&D. Additionally, R&D projects exist in Denmark, Norway and France to develop similar water monitoring services.

It is also worth noting the intent to introduce a Europe-wide water quality service under the Copernicus Land Monitoring Service. This would be paid for by the EU and under the standard license conditions, it would be available to users on a free and open basis. There is also a European lake service, but the scale is too coarse (large pixels) and not locally calibrated[104].

Increased Market Penetration

There is strong potential to increase the uptake of Water Insight services within the Netherlands as stated above. Water boards still need to adapt to these services, but we believe they will rely on it

[101] https://open.overheid.nl/documenten/ronl-0c5086b3029ab6a4ab28d52838ce44d5e6285d1a/pdf
[102] https://incubed.esa.int/portfolio/coasteo/, https://blog.vito.be/remotesensing/an-eye-on-european-waters, https://infer.ichec.ie/
[103] https://www.em.gov.lv/en/media/4109/download
[104] https://land.copernicus.eu/global/products/lwq

in the near future. Beyond this, other users of water bodies may also benefit from such service. For example, Water Insight is also developing in the private and academic sectors such as research and aquaculture. Water companies could also potentially use EO services. In addition, some regional water protection association might also be interested by such services.

Improved Technological Maturity

Water Insight services are being developed further and their visual appearance and functionalities are being updated according to users' requirements.

Short term evolutions are related to services improvements such as the use of AI methods, the integration of in situ technologies and the use of private high-resolution imagery. We believe Water Insight services will greatly improve in the near future as they are at a funding milestone which will greatly improve their capabilities. In the longer term, the plans for Copernicus program are to improve the instruments in terms of observation accuracy and capabilities which will undoubtedly impact Water Insight services.

Increased pressure from WFD and activists for better water quality

By signing the WFD, the Dutch government has pledged to improve significantly the water quality by 2027[105]. This, together with activist launching legal initiatives to pressure water boards, could have enormous consequences for the level of water quality monitoring in the Netherlands (see section 5.2.3).

[105] https://www.h2owaternetwerk.nl/h2o-actueel/mob-zegt-provincie-en-wetterskip-de-wacht-aan-over-beroerde-waterkwaliteit-in-friese-wateren

6.4 Final Thoughts

A comparison with the SeBS cases in Germany and Finland is instructive. When looking at the big picture, the overall benefits are in the same ranges of value in the 3 cases except for the economic benefits which are higher in the Netherlands. The following differences lead to such variations.

1. Geographical features of the Netherlands having much more water surface than Germany involves more cost savings from lake monitoring with in-situ techniques.
2. The very high population density in the Netherlands (especially when compared to Finland) and intensive agriculture practices involves more pollution which in turns involves more monitoring needs. It also involves more benefits from monitoring and improved water quality.

Additionally, it is essential to highlight that Sentinel-derived services have been providing, in the three cases, a rich source of information generating significant economic and environmental sustainability impact. Also in the three cases these benefits are expected to greatly grow in the future. This can serve as inspiration for the roll out of similar services in other countries and/or the launch of a pan-European service under Copernicus.

Moreover, the three cases' benefits are obtained over the full range of dimensions and it could be interesting to revisit this in a few years' time when more results of such innovation will be observed as well as after technological and regulatory changes have been implemented.

The Dutch case, likewise the Finnish case, also link to a much wider subject of ecosystem services which provide a way to consider the value of the environment to society. It is a subject gaining interest as a way to account for natural resources and how these contribute to our global economy. In this regard, it would be interesting to estimate how much water quality is worth to the average citizen through a willingness-to-pay survey.

Annex 1: References and Sources

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Note: The reader can find more references in the form of footnotes throughout the report.

Annex 2: General Approach and Methodology

This case has been analysed as a part of the Sentinel Benefits Study (SeBS), which looks at the value being created by the use of Sentinel data. It follows a methodology[106], established during a previous study, looking at a value chain for the use of a single EO service.

For each case, a value chain is established with a service provider and a primary user. The value-chain is validated with these two key players. Through a combination of desk and field research, we develop our understanding of all the actors in the value chain, the role that they play and how they may benefit through the use of the satellite-derived products.

The value-chain is divided into a number of tiers where the supplier is Tier 1, and the primary user is Tier 2. The last Tier is always "Citizens and Society". The number may vary according to the complexity of the value-chain. The benefits are then analysed against each of these tiers.

Once written, the draft report is then shared with all the persons with whom we have spoken, and their comments are incorporated, or a further discussion is held to establish a common understanding. Note that we are not asking these experts to endorse our findings but to indicate any gross errors or sensitivities which may have been introduced. At the end of this process, the report is made public.

As work has proceeded and more cases analysed, some modifications have been made to the methodology described in reference 106. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

Dimension	Definition
ECONOMIC	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
ENVIRONMENTAL	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
SOCIETAL	Impacts related to societal aspects such as increased trust in authorities, better public health or secured geostrategic position.
REGULATORY	Impacts linked to the development, enactment or enforcement of regulations, directives and other legal instruments by policymakers.
INNOVATION-ENTREPRENEURSHIP	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.

106 SeBS Methodology; June 2017 and The Six Dimensions of Value Associated to the use of Copernicus Sentinel Data: Key Findings From the Sentinel Benefits Study (https://www.frontiersin.org/articles/10.3389/fenvs.2022.804862/full)

SCIENCE-TECHNOLOGY	Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.

Table A2-1: Definitions for the benefit dimensions

For each of these, a ranking has been introduced to give an immediate, visual impression of the scale of the benefits under each dimension. To aid in the quantification of these, a guide has been introduced which is shown in Table A2-2.

Rank	Benefit status	Criteria
0	**Null**	The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.
1	**Latent**	The value chain described in the case may, in general, present potential benefits in this dimension, but none have been identified or described in this particular instance.
2	**Manifest**: At least one benefit in this dimension has been identified through the value chain within the case. Its significance in the context of the case overall is judged to be:	**Low**
3		**Moderate**
4		**High**
5		**Exceptional**

Table A2-2: The ranking of the benefits.

In order to introduce further basis for comparison, a systematic approach has been developed for the analysis of the benefits. A series of indicators have been defined for each of the benefit dimensions against which each case can be considered.

The indicators used in the case are listed in chapter 5, and a full list of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs	Alternative means to gather data
	Increased Revenues	Increased production/sales
	Reduced Inputs	Less time spent or material saved
	Improved Efficiency	Better use of resources
	Employment	Increased employment in the service provider
	Reduction of risk	Reduction of risk and consequential costs
Environmental	Reduced pollution	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health	Less toxicological risk
	Common Understanding	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency	Improved preparedness / response
	Strategic Value	Common societal value to a country or region.
Regulatory	Improved policy / regulation design/drafting	Better information (scale, accuracy) leading to better regulation
	Improved efficiency in policy/regulation monitoring	Better information available to monitor adherence to regulations.
Innovation & Entrepreneurship	Innovative products	Sentinel data leads to creation of new products / services
	New Business models	New ways to generate income.
	New markets	Global nature of sentinel data enables international business development
	New businesses	Creation of new companies; start-ups
Science & technology	Academic output	
	Research exploitation	Applied science to operational services
	Research contribution	New product enabling scientific research

Table A2-3: Complete list of indicators considered within SeBS analyses.

Annex 3: About the Authors

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Lauriane is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). Before joining Evenflow, she has worked for 5 years for an international network of universities where she has designed, launched and managed an innovative credited master program in business analytics for talented students from 24 universities worldwide. Previously, during her PhD, she made rigorous economic and analytical studies on various topics linked to R&D and Innovation.

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Lefteris is a strategy consultant with solid knowledge of programmatic, strategic and business aspects of EU Space Programmes (Copernicus and Galileo). For more than a decade, Lefteris has been extensively involved in various studies and projects related to the development, market uptake and exploitation of EO downstream applications. He has been advising clients and partners across the full spectrum of the EO value chain, including EU institutions (EC, EEA, SatCen, ESA, EUSPA), universities and private companies.

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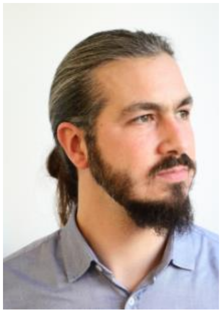
The SeBS Study Team

The SeBS study is conducted by a team of experts under the direction of ESA (the European Space Agency) and led by EARSC (the European Association of Remote Sensing Companies. The team is of a variable geometry and different experts work together on the different cases. The full team and the organisations for whom they work, is shown below.

Geoff Sawyer, BSc (Electronics), MBA

Geoff is the former Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). Geoff is now Strategic Advisor to EARSC. geoff.sawyer@earsc.org.



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Dimitrios is a strategy consultant and communication/dissemination expert with over ten years of experience in the commercialisation, uptake and exploitation of space-based data and applications, primarily as concerns the Copernicus programme and its services. He has provided expertise on a range of major market, cost-benefit and user uptake studies in the EO domain, for clients including the EC, ESA, EEA and the SatCen.

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