European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Water quality in Finland

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Setting the Scene

It is Saturday afternoon in July and Tuomas just arrived with his family to their summer cabin near lake Saimaa, the largest lake in Finland and also known to be one of the most beautiful lakes in the world. Like most Finns, for him, summer vacation is not complete without spending time at a summer cottage by the lake where sauna, swimming, barbecuing, reading books on the pier and fishing are the most common activities. The perspective of spending a week in complete peace and solitude together with his family fills him up with joy and harmony.

While chopping firewood for the sauna, he is preparing the expedition of the next day in his mind. He promised Aurora, his 6-year-old daughter, to teach her how to fish. The two of them will travel on their old boat to a nearby shore. Yesterday, his friend Jo, who works at the Regional Centre for the Environment, showed him how to find the perfect spot using satellite imagery. Since a couple of years, Jo uses a service called TARKKA (which means “exact”) to evaluate water quality for his work. He explained that this tool was made publicly available by the Finnish Institute for the Environment, SYKE. Thanks to TARKKA, he can check whether there is algal bloom in the lake that could impede their fishing activity or a swim. He can also check if the nearby forest remains intact to pick some berries for their picnic. Jo also laughingly tells Tuomas that if he had internet in his cottage, he could use TARKKA to get accurate information on the weather conditions for the day.

Back to the lake in this perfect day, Tuomas showed his daughter flowers called water lobelia. He explained that these flowers would not be there if there was any kind of pollution in the lake. He told her that it was specifically the job of his best friend Jo to maintain the quality of lakes for people like them to enjoy the lakes as well as to preserve fish and other animals. He added that Jo can do that thanks to satellites that are far away in the sky and carry big cameras that take pictures of the lakes.

Once back to his house in Helsinki, where he has high-speed internet connection, Tuomas will share his experience in using TARKKA with his fishers’ group peers on social media. As Jo also told him that it was a great tool to find the perfect spot for ice-fishing, he cannot wait to use it during the winter to detect the thickness of the ice and hence stay safe while teaching his daughter the tricks of the trade.

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 play an essential role in our society and environment. Healthy lakes and their shores not only provide citizens with a number of environmental benefits, but they influence their quality of life and strengthen the economy. This case looks at the management of water quality of lakes in Finland and how this is improved through the use of data coming from Copernicus Sentinels and other satellites.

Finland is widely known as the "land of a thousand lakes". In fact, Finland has more than 187K lakes and ponds larger than 500 m2 - and its land surface is covered by about 10% of water. Lakes are therefore culturally very important for most Finnish people who can, for example, enjoy a summer break at a cottage by a lake or go ice-fishing to one of the many Finnish lakes. Additionally, lakes replenish groundwater and supply drinking water in parts of the country. Healthy lakes are also essential to preserve biodiversity both in water bodies and in the surrounding areas.

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 (especially coming from agriculture) or other harmful contaminants can easily disrupt their sensitive aquatic ecosystems.

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 Finland, these actors can 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 the number of lakes monitored and variations within larger lakes. Hence the data coming from the satellites provides a much better overall picture of the water conditions than in-situ monitoring techniques, which are typically constrained to a few locations within a lake. This allows a more precise understanding of the state of any particular lake or water body.

In Finland, such service utilising satellite data was developed in 2018 by SYKE, the environmental institute of Finland. Thus, the TARKKA service uses mainly Copernicus Sentinel observations coupled with machine learning processes to provide information on water quality and water temperature with visual satellite true colour imagery. The results are visualised on a user-friendly and intuitive platform, which SYKE has opened up to the public so that anyone can have access to it.

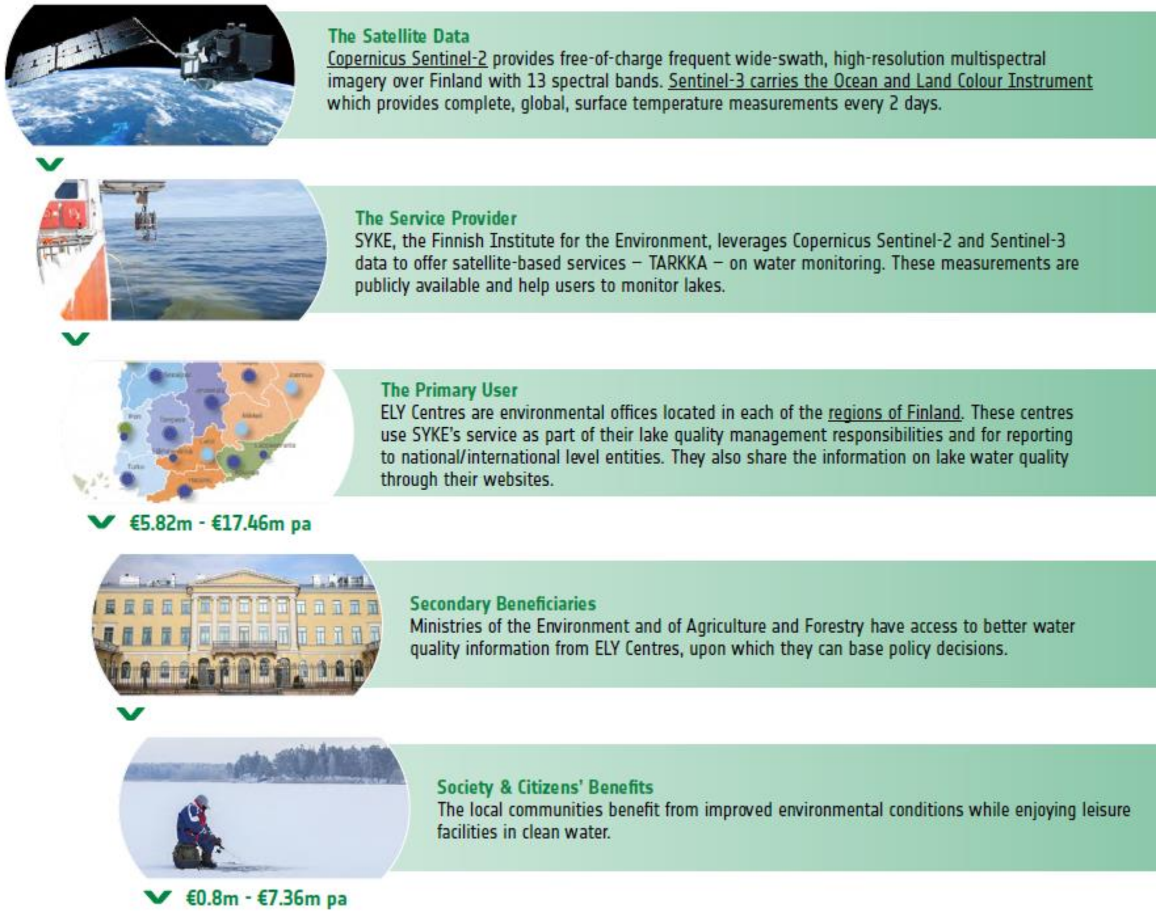
SYKE is using the TARKKA service for its own research and monitoring tasks, but also supports other actors along the value chain enabling significant benefits. The primary users of SYKE's services are the Regional Centres for Economic Development, Transport and the Environment (ELY Centres). The ELY Centres are local offices of the Finnish government placed in each of the regions of Finland.

The use of TARKKA outputs in the different districts varies. For instance, one of the common issues they face 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, SYKE's

TARKKA service enables the regular monitoring of most lakes (greater than one hectare). In addition, it offers the possibility to go back in time to analyse the evolution of the algal bloom. TARKKA images also help ELY Centres (together with SYKE) to communicate to the general public (through local newspapers or websites). This helps citizens to avoid going to infested lakes for recreational activities. In order to prevent algal bloom in lakes, ELY centres and other authorities also take initiatives (e.g. use of gypsum) to limit the use of nutrient in nearby agriculture areas. Additionally, regional centres report to Ministries of Environment and of Agriculture and Forestry who have access to better information – thanks to satellite imagery – 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 Finland where the enormous amount of water bodies would require complex logistics and significant costs for local authorities if they were to use only in-situ monitoring methods. This would inevitably reflect on a poorer quality water and hence quality of life of citizens, environmental sustainability (and biodiversity) and other economic variables. Additionally, the TARKKA service does not only serve water quality, but also the monitoring of a wide range of events such as watercourse restorations and its impact on nearby fields, litigations over specific dredging events, winter floods prevention, fishing opportunities, etc.

*The **economic benefits quantified in this case range from €6,62 million to €24,82 million per year** (all figures explained in Chapter 5) and are mainly derived from regional centres saving monitoring costs (because in-situ monitoring of most Finnish lakes would be extremely costly) as well as citizens having access to cleaner water and better information which result in time saving (e.g. going directly to the best place for ice-fishing).*



This exemplary use of Sentinel satellite data in Finland generates positive impact on the environment, economic variables, society, innovation and science are going to grow significantly in the next five to ten years. Such growth should be induced by regulation foreseeing the wide adoption of satellite data (i.e. the use of EO data as reporting method in the relevant 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 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 in Finland"* 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 Finland, 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. The environment institute of Finland, SYKE, has created a platform (TARKKA) with measurements derived from the use of data from Sentinel 2 and 3 satellites to complement the official measurement samples. This allows more frequent measurements to be made and many more lakes to be monitored. In turn this helps to identify problems earlier, so enabling more rapid corrective action.

Our case looks at the management of the water quality of lakes in Finland using TARKKA as a reference, and how overall decision making is improved through the use of data coming from the Sentinels and other satellites. TARKKA is a public service that provides regional centres and other authorities statistics and images indicating the quality of the water over the whole country at an almost daily frequency. This supports the regional centres in their legal responsibility (in collaboration with SYKE) to protect the lakes and rivers of their region. For instance, TARKKA allows the detection of Harmful Algal Bloom (HAB) which is dangerous for both swimmers and for wildlife including fish. TARKKA is available to anyone and hence can also be particularly useful for local citizens having leisure activities related to lakes.

The use of TARKKA is also expected to inform future revisions of applicable legislation, recognising the importance of using satellite-based observations for the maintenance of water quality in Finland.

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 second case that looks at water quality. The first case on this subject was conducted over Germany and showed the various and important benefits of data coming from both Sentinel-2 and Sentinel-3. More specifically, 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, studied here, not only confirms several of the key findings of the German case, but also brings to light additional information. Overall, the comparison of the two cases yields the following observations:

- Finland is one of the countries in the world with most water bodies and its surface is covered by significantly more lakes than Germany. To compare, about 2,2% of German territory is covered by water, while about 10% of Finnish territory is covered by water. Additionally, we can count about 57K lakes in Finland greater than 1 hectare (and 187K lakes greater than 500 square metres) compared to 12K lakes in Germany. As a result, the use of EO is very relevant for monitoring the water bodies in Finland as it allows important amounts of monitoring costs savings (regular in-situ monitoring of most water bodies would be extremely expensive). Additionally, this important number of lakes of all sizes also makes Finnish culture greatly focused on lake activities as most Finns regularly benefit from lakes through leisure activities.
- Satellite observation derived services developed by SYKE (the Finnish Environment Institute) are publicly available as they are open-source services. In Germany, this service is provided by a private company and is therefore not publicly available. This fact allows Finnish citizens (and other institutes) to check water quality and other variables before enjoying a lake for a swim or other activities.

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 2023.

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 **Jenni Attila** (SYKE) who introduced us to a number of the experts we have consulted. We also would like to thank her for her very useful insights and her time dedicated to this case. We also wish to thank the following persons for their time spent talking with us to develop the case.

- Petri Liljaniemi, Ministerial Adviser (Department of the Natural Environment, Water resources and marine protection).
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- Harri Helminen, Centre for Economic Development, Transport and the Environment of the Southwest Finland.
- Marjo Tarvainen, Centre for Economic Development, Transport and the Environment of the Uusimaa region.
- Jouni Törrönen, hydrobiologist, Centre for Economic Development, Transport and the Environment for Southeast Finland.

2 Water quality in Finland

The heart of this story revolves around water quality in Finland, therefore it is important to understand the natural landscape in Finland as well as the relevance of good water quality and the factors affecting it. The following sections address these topics.

2.1 Overview of water bodies

Finland is known as the land of a thousand lakes. Finland can be indeed counted as the/a country with the most lakes in Europe depending on the definition of a lake in terms of size. There are about 187,000 lakes and ponds larger than 500 square metres in Finland. Even if we count just the larger lakes, with the size of one hectare or larger, there are 57,000 lakes in Finland.[1] Most lakes are rather small, and 309 lakes are larger than 10 km^2. The total area of inland waters is about 10% of the total area of the country. There is also a total of 25,000 km of rivers in length and the territorial area of Finland in the Baltic Sea is about 36,000 square kilometres.[2]

[1] https://www.stat.fi/tup/suoluk/suoluk_alue_en.html

[2] https://www.eea.europa.eu/soer/2010/countries/fi/freshwater-state-and-impacts-finland-1#:~:text=Currently%2C%20the%20ecological%20quality%20status,Finland's%20lakes%20is%20generally%20better

Figure 2-1 Finland – inland waters cover 10% of the territory[3]

Lakes dominate the landscape of Finland. This extraordinary amount of water is caused from geological conditions many thousands of years ago. During the last major Ice Age period, continental glaciers covered a vast majority of the country. Approximately 10,000 years ago the glaciers began to melt and left behind physical evidence of their presence in the forms of mountains, valleys and craters that filled up with melted waters.

All these lakes are subject to interactions with their surroundings. The presence of so much fresh water has helped make Finland abundant in resources and tourism. For example, there is a rich agriculture activity in the whole country thanks to the accessibility of water. The majority of farms and agricultural land in Finland lies between the 60th and 65th parallel, making it one of the countries with the largest agricultural sector so far in the north.[4] The percentage of farms

[3] Source : https://sites.google.com/site/finlandbylouise/mountains-rivers-and-lakes.

[4] The claim can be verified by a comparison of national agricultural statistics from Canada, Norway, Russia, Sweden and the United States. Source : https://en.wikipedia.org/wiki/Agriculture_in_Finland#Geography

concentrating on animal production increases towards the north and east. Regarding tourism, the picturesque sight of the land of a thousand lakes is attractive.

The northern geographical situation of Finland makes its water landscape very peculiar. During the springtime, melting snow makes the landscape radically change while it causes also important floods. Winter floods also happen in Southern and Central Finland. Some of these flood frequencies may increase in the future due to climate change. This issue can partly be solved by regulating water levels of lakes. [5]

[5] www.syke.fi/en-US/Current/We_already_have_climate_solutions__How_(61302)

2.2 Water quality in Finland

2.2.1 State of water quality

Regarding bathing water, Finland is situated in the top-EU countries with 88.8% of excellent bathing sites.[6] Inland waters are even cleaner with 94,7% of excellent bathing sites – compared to 71,8% of excellent coastal bathing sites (mostly due to polluted areas in Baltic Sea).

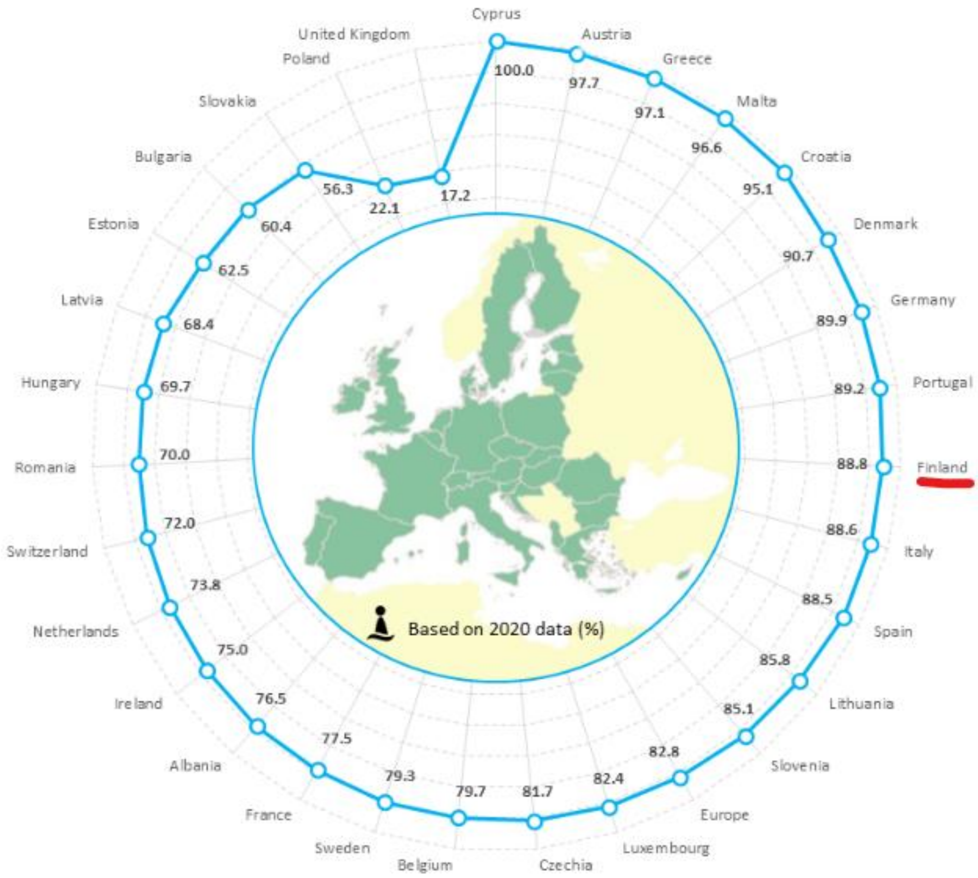

Figure 2-2 Proportion of bathing waters with excellent quality in European countries in 2020.[7]

[6] The bathing waters quality is classified according to the two microbiological parameters (Escherichia coli and intestinal enterococci) defined in the Bathing Water Directive. 97% of all reported bathing waters (includes those that could not be quality classified due to lack of samples) are in line with the minimum quality standards of the Directive, thus classified "sufficient" or better. Source: FI_Bathingwater_Country reports_2021 on https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/state-of-bathing-water/state-of-bathing-water-4

[7] Source : https://ec.europa.eu/environment/water/water-bathing/index_en.html

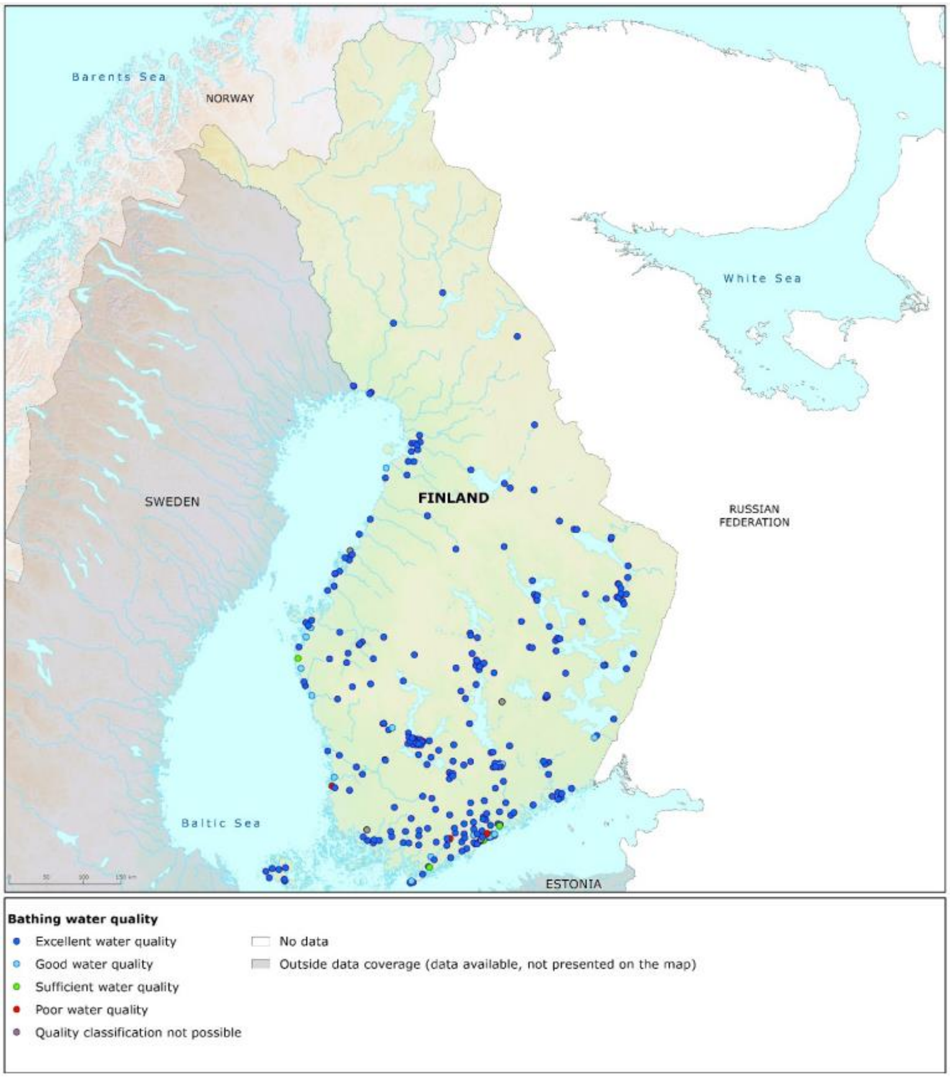

Figure 2-3 Bathing waters quality in Finland in 2020[8]

The evolution of the inland quality of water is also rather remarkable a seen in figure 2-4 below where poor bathing water quality has almost disappeared beginning of the years 2000.

[8] Source : https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/state-of-bathing-water/state-of-bathing-water-4

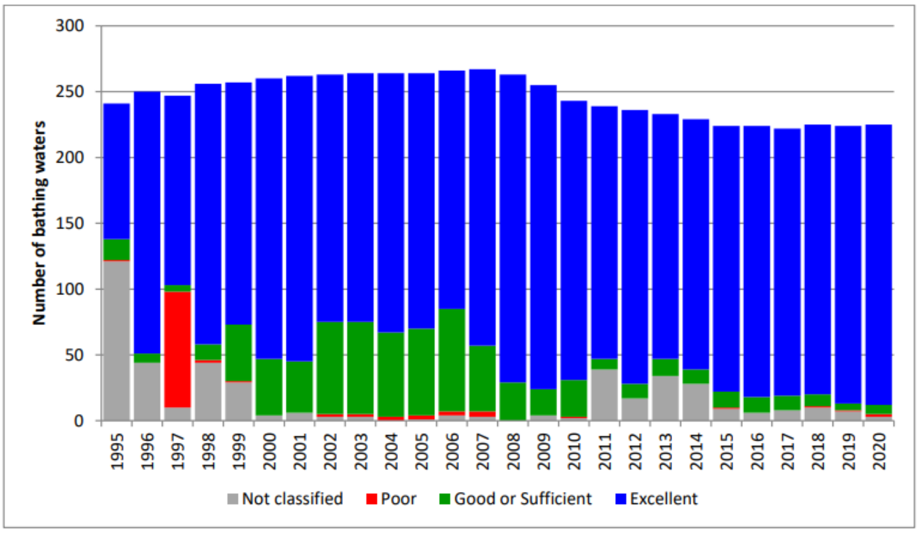

Figure 2-4 Evolution of inland bathing waters quality in Finland in 2020[9]

In fact, a more comprehensive assessment of the status of waters is conducted in all EU Member States every six years through the WFD. The last assessment done in 2019 (for the period spanning 2012-2017) confirms that the ecological quality status of most of Finland's inland waters is either good or high. Regarding evolution, it states that there have been no major changes in the status of inland waters since 2013. It adds that the status of lakes is worst for small and medium-sized lakes in agricultural areas, where problems associated with eutrophication are widespread.[10]

2.2.2 Relevance of lakes and good quality water

Lakes are not just water bodies used by many people to enjoy recreational activities such as water sports, fishing, tourism, and residential living. Healthy lakes preserve biodiversity in water bodies and their surrounding areas and replenishing groundwater. Beyond environmental benefits, healthy lakes and their shores are contributing to the economy as lakes can be used for example as a water supply for industry and agriculture as well as drinking water.

In Finland, lakes and ponds play a key role in Finnish culture and economy. To showcase the importance of lakes' quality in Finland, we take the example of lake Saimaa which is the largest lake with about 4400 square kilometres.[11] We observe in figure 2-5 below that this lake is not just a simple lake basin but a labyrinth formed by wide waters and thousands of islands. Saimaa is a national and international touristic destination highly praised by nature lovers, having been listed in the top 5 of most beautiful lakes in the world in 2014.[12]

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9 Source: https://ec.europa.eu/environment/water/water-bathing/index_en.html
10 https://www.eea.europa.eu/soer/2010/countries/fi/freshwater-state-and-impacts-finland-1#:~:text=Currently%2C%20the%20ecological%20quality%20status,Finland's%20lakes%20is%20generally%20better
11 https://nordicbackyard.com/finland/the-land-of-a-thousand-lakes-finland
12 https://www.wsj.com/articles/great-lakes-around-the-world-1405509454

Figure 2-5 Lake Saimaa[13]

The water quality in lake Saimaa is predominantly excellent and the large natural forest around the lake remains mainly untouched by man which makes it a great place for biodiversity. Many wild animals are to be found around the lake (elks, wolves, bears, …) as well into its waters such as the Saimaa ringed seal which is one of the rarest seals in the world. [14]The existence of isoetids in this lake such as isoetaceae, water lobelia (see picture below) and shoreweed is also representative of the water clarity and its bareness.[15]

Figure 2-6 Isoetids (water lobelia) representative of water quality[16]

[13] https://www.researchgate.net/figure/Location-of-Lake-Saimaa-and-some-of-the-cities-on-its-shoreline-in-Finlands-map_fig1_277669396

[14] https://www.visitsaimaa.fi/en/10-reasons-to-come-to-saimaa/

[15] https://www.saimaageopark.fi/en/environment/

[16] source: https://www.centralcoastbiodiversity.org/water-lobelia-bull-lobelia-dortmanna.html

Other lakes showcase the relevance of healthy waters in Finland. For example, lake Päijänne, the second largest Finnish lake (1,118 square kilometres) serves as the source of drinking water for millions of people in the country and is the main source of drinking water for the capital of Finland, Helsinki. It also provides tourists with the ideal fishing, sailing, boating, and canoeing location.

Lake Inari (1,040 square kilometres), the third largest lake in Finland, is located in northern Lapland and is known best for ice-fishing especially for trout, lake salmon, arctic char, white fish, grayling, perch, and pike. The forest around the lake provides a home for the largest mammals of the country, which includes bears, wolves, and moose. [17]

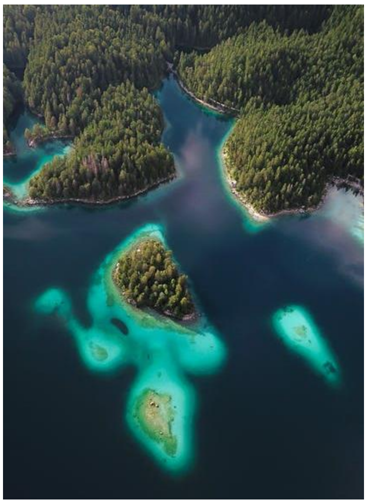

Figure 2-7 Lake Inari[18]

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.[19]

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. fish 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.

[17] https://nordicbackyard.com/finland/the-land-of-a-thousand-lakes-finland
[18] Source : https://nordicbackyard.com/finland/the-land-of-a-thousand-lakes-finland
[19] Seen | Umweltbund https://www.umweltbundesamt.de/themen/wasser/seen#wissenswertesesamt

One of the most pressing issues is the release of chemicals from pesticides[20] 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. 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.[21] 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 in this country, 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 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.[22]

Figure 2-8 Cyanobacteria blooms on lakes in Finland

[20] 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)

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

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

(Picture on the left by Jenni Attila, SYKE; picture on the right above corner by Ilkka Lastumäk; third picture by Laura Härkönen)

Although large lakes in the northern part of Finland are of good or high quality, eutrophication is still a major problem for small lakes. Important initiatives are now trying to reduce the impact of agriculture on water pollution in Finland, but it is not an easy task as agriculture is very important in the Finnish economy – agriculture fields represent 2,3 million hectares which is almost 18 percent of the whole territory.[23] For example, in 2021, a practical guide on soil improving agents aimed at farmers has been compiled. These agents are mainly gypsum, pulp mill fibre, and structural lime. These can effectively reduce the water pollution from agricultural land by affecting the aggregate structure of the soils, resulting in decreased phosphorus losses.[24] Additionally, ecological restoration of watercourses is an important way to improve the status and habitats of lakes, rivers and small waters degraded by human actions. Inland waters have been restored in Finland since the late 1960's. Restoration improves the status of the watercourse, its habitat and catchment area, and can also provide many social, economic and aesthetic benefits to the area. Since the introduction of the EU Water Framework Directive, the trend in restoration has shifted from local on-site restorations towards larger, basin-scale restoration projects. Until recently, rivers and streams have mostly been restored by the local environmental and fishery authorities, even if some restoration work has been carried out by private companies and municipalities. Non-governmental organizations and local stakeholders are now increasingly taking more responsibility for the planning and implementation of stream restorations in Finland.[25]

Industrial substances such as heavy metals including lead and mercury from construction activities or mining sites, wastewater, logging and urban run-offs or sewage seepages can also cause pollution. The pollution can cause illness or death to fish, other animals, or humans that consume them. Sediments washed away from construction activities and urban or agricultural activities can potentially enter lakes, reducing water clarity and quality, and can be lethal to aquatic organisms. Last but not least, atmospheric pollutants — from car exhaust pipes or industrial power generation – can affect lakes via acid rain or other types of acidic precipitation.[26]

Regarding the specific case of Finland, major water polluting industries in the country have been traditionally - and still are - **pulp and paper mills**. These are usually located along water bodies. Although the production of paper and paperboard has declined by one third from 2008 to 2020, production of pulp has remained more or less the same.[27] Due to regulation and increased environmental awareness in recent years in Finland, the use of water for pulp and paper production have greatly decreased, as has the pulp/paper-related pollution.

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23 https://en.wikipedia.org/wiki/Agriculture_in_Finland

24 https://www.syke.fi/en-US/Current/Soil_improving_agents_reduce_water_pollu(62072)

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

26 Ibid.

27 Managing Water and Wastewater Services in Finland, 1860–2020 and beyond. Apr 30, 2022 Tapio S. Katko.

In addition, the concentration limit set for mercury was exceeded in 2019 in approximately half of the water bodies assessed in Finland. Mercury is a long-range transported heavy metal derived from the combustion of fossil fuels, especially coal. The use of mercury and mercury emissions are restricted by international agreements. However, water recovery is expected to take decades or centuries, as current deposition is very low compared to the amount of mercury already present in soils and sediments.[28]

Dredging activities in freshwater bodies also have the potential to impact habitats and food resources that fishes depend on, and ultimately impact fishing and fisheries activities.[29] Dredging activities may also impact freshwater states and hence leisure activities taking place in or around water bodies.

The table below summarise the different sources of pollution of water in Finland.

Point-source pollution	**Phosphorus (%)**	**Nitrogen (%)**
Pulp and paper industry	3.7	3.5
Other industry	0.6	1.3
Municipalities	4.1	15.3
Fish farming	1.9	0.9
Fur farming	1.1	0.6
Peat excavation and production	0.5	0.7
Point-source pollution total	*11.9*	22.3
Diffuse pollution		
Agriculture	68.5	56.8
Scattered settlements	8.8	3.6
Forestry	5.8	4.7
Diffuse pollution total	*83.1*	*65.1*
Deposition	5.0	12.6

Table 2-1 Sources of water pollution in Finland in 2011[30]

2.3 Regulatory framework and water management

Water management in Finland is regulated through complex legislation, **linking the EU, federal and regional levels**.

Policy makers have recognised the problem of water pollution, stemming from the increased pressure on the ecologic state of surface and ground water and their impact on water quality over the last decades both at national and EU level. Several agencies and institutional actors such as regional centres, environmental agencies, research institutes and contracted companies are involved in the process to maintain or improve water quality and monitor developments to take

[28] https://www.environment.fi/en-US/Waters/The_chemical_status_of_water_bodies_rema(58392)
[29] https://environmentalevidencejournal.biomedcentral.com/articles/10.1186/s13750-018-0119-1
[30] Source: https://helda.helsinki.fi/handle/10138/39076

appropriate measures in a timely manner. This section looks more closely at the legislative framework that guides and gives the mandate to the involved stakeholders.

2.3.1 EU water framework directive

Although Finland has been monitoring a wide range of lakes since the 1960s, the **EU Water Framework Directive (EU WFD)**[31] - adopted in 2000 - has given it a push – same as for other 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 effects of the increased awareness can be shown in table 2-1 above. We can see that since 2000, water quality in lakes has greatly improved in Finland whereas the number of unclassified lakes has decreased (which is translated in a better inland water monitoring).

The EU Water Framework Directive 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 4-5 illustrates river basin in Finland). 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.[32,33]

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.[34]
- 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.[35]
- 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.[36]

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31 https://ec.europa.eu/environment/water/water-framework/index_en.html
32 https://ec.europa.eu/environment/water/water-framework/info/intro_en.htm
33 "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 complicated, but this is inevitable given the extent of ecological variability, and the large number of parameters, which must be dealt with." EU WFD
34 https://ec.europa.eu/environment/water/water-nitrates/index_en.html
35 https://ec.europa.eu/environment/water/water-bathing/summary.html
36 https://ec.europa.eu/environment/water/water-urbanwaste/index_en.html

- 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.[37]

2.3.2 Finnish regulatory framework on lake management

In Finland, a number of acts and decrees implement the EU Water Framework Directive at national level.[38]

1. The **Act on the Organisation of River Basin Management and the Marine Strategy of 2004** lays down provisions on the organisation of river basin management and development and implementation of the marine strategy. Its objective is to protect, improve and restore in-land waters and the Baltic Sea in a way that the status of surface waters and groundwater or the Baltic Sea does not deteriorate and is at least 'good'. [39]

2. The **Government Decrees on Water Resources Management** lays down provisions on the topics to be included in a water resources management plan (to be prepared for a period of six years at a time) on the assessment and monitoring of the status of waters, and on the preparation of a water resources management plan.[40]

3. The objective of the **Decree on Hazardous and Harmful Substance on Aquatic Environment** is to "*protect surface waters and improve their quality by preventing pollution and the danger caused by dangerous and harmful substances. The aim is to eliminate at once, or progressively, emissions and leaching of substances dangerous to the aquatic environment and to progressively reduce emissions and the leaching of harmful substances. For this purpose, emission prohibitions, emission limit values and environmental quality standards have been laid down*."[41]

4. **Water Resources Management in Regions** provides guidelines on regional water management in the six Finnish regions.[42,43]

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[37] https://ec.europa.eu/environment/water/water-drink/index_en.html
[38] https://ym.fi/en/legislation-on-the-protection-of-water-and-the-sea
[39] River Basin includes lakes; https://www.finlex.fi/en/laki/kaannokset/2004/en20041299_20141263.pdf
[40] https://www.informea.org/en/legislation/government-decree-water-resources-management-no-1040-2006
[41]https://www.finlex.fi/en/laki/kaannokset/2006/en20061022.pdf#:~:text=Government%20Decree%20on%20Substances%20Dangerous%20and%20Harmful%20to,Environment%201022%2F2006%20Issued%20in%20Helsinki%2023%20November%202006
[42] Region of the river Vuoksi, the water resources management region of the river Kymijoki-the Gulf of Finland, the water resources management region of the river Kokemäenjokithe Archipelago Sea-the Bothnian Sea, the water resources management region of the river Oulujoki-the river Iijoki and the water resources management region of the river Kemijoki.
[43]https://www.finlex.fi/fi/laki/kaannokset/2004/en20041303.pdf#:~:text=%281%29%20The%20water%20resources%20management%20regions%20as%20referred,water%20resources%20management%20region%20of%20the%20river%20Kemijoki.

Water resources management is led by the **Ministry of the Environment**, together with the **Ministry of Agriculture and Forestry,** as explained below:

The key roles of the **Ministry of the Environment** regarding water management include[44]

- Preparing national objectives and legislation for water protection and river basin management.
- Implementing the Water Framework Directive and the EU Marine Strategy.
- Approving water resource management plans and assessing their implementation.
- Assessing the water bodies' conditions and factors affecting them.
- Carrying out international water protection cooperation.

The key roles of the **Ministry of Agriculture and Forestry** are to

- Prepare legislation relating to the water economy.
- Prepare and implement legislation on water supply and services, dam safety and basic drainage.
- Implement agreements on frontier rivers (transboundary watercourses).

Still at national level, there is the **Finnish Environment Institute (SYKE)** who monitors waters, undertakes societal and economic assessments for water-related decision-making and manages protection of water resources.

At regional level, the competent water resources management authorities are the regional **Centres for Economic Development, Transport and the Environment** (ELY Centres). These take on the responsibility for regional implementation of tasks defined by the central government on environment and national resources. They also support SYKE in the monitoring of water status, supervise adherence to the water permits granted by the **Regional State Administrative Agencies**, promote flood protection and prevention, supervise dam safety and support the development of water services and sewerage and supervision of water supply. The administrative agencies are also responsible for issuing licences for water abstraction, dredging and filling of a water area, laying water and sewage pipes. Other important actors are **Regional Councils** who elaborate and implement local development plans and organise regional land use planning and lead flood working groups.

On top of all these, many other different authorities and research institutes also participate in water resources management.[45]

[44] https://portal.cor.europa.eu/divisionpowers/Pages/Finland-Water-Management.aspx
[45] https://ym.fi/en/management-of-water-resources-and-marine-environments-in-finland

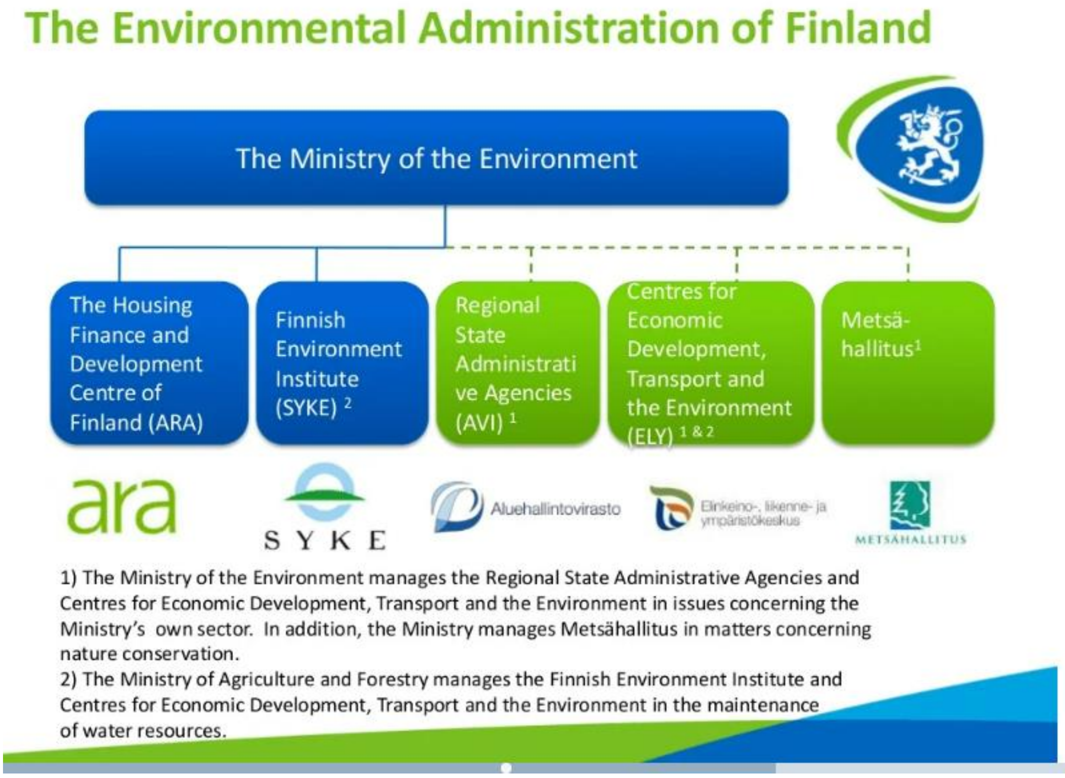

Figure 2-9 Finland's environmental administration[46]

At the level of governance, **regional governments** are the competent authorities responsible for the implementation of the WFD in the territory of its region, supported by six government departments. In parallel, **municipalities** issue and supervise environmental permits by municipal environmental protection authorities, develop water services and sewerage in their territories, monitor the quality of drinking and bathing water (see figure 2-10) and take part in river basin management planning and flood working groups.[47]

[46] Source : https://www.slideshare.net/Ymparistoministerio/facts-about-the-ministry-of-the-environment
The monitoring is composed of both administrative monitoring and compulsory inspections by industrial operators and other businesses. The frequency of water quality observations and the factors under analysis vary according to local needs. Monitoring of fresh water in Finland involves an assessment of the ecological and chemical status – defined by the presence of 42 harmful substances - of water.

[47] https://portal.cor.europa.eu/divisionpowers/Pages/Finland-Water-Management.aspx

Figure 2-10 Popular bathing water areas in/at the city of Helsinki, where municipalities follow the quality of water regularly.

Photo: left - Jenni Attila, right - city of Helsinki.

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 Finland, data must be collected at many stages of the value chain.

2.4.1 Collecting the necessary data

The monitoring is composed of both administrative monitoring and compulsory inspections by industrial operators and other businesses. The frequency of water quality observations and the factors under analysis vary according to local needs. Monitoring of fresh water in Finland involves an assessment of the ecological[48] and chemical status – defined by the presence of 42 harmful substances - of water.[49]

[48] The ecological status classification is mainly concerned with biological quality. The status of plankton algae, diatoms, aquatic plants, benthic fauna and fish stocks in the water body is compared to conditions where human activity has not caused discernible effects in flora and fauna. The lower the human influence, the better is the ecological states of the water body. The assessment also considers the chemical (total nutrient concentrations, pH, visibility) and hydromorphological (e.g. migration barriers, regulation) water quality parameters.
Source : https://www.environment.fi

[49] https://www.eea.europa.eu/soer/2010/countries/fi/freshwater-state-and-impacts-finland-1

Finland has **four national in-situ monitoring programmes** mainly focused on lakes. 71 lakes are included in the L1 programme aiming at detecting changes and time-trends in water quality of the most important waterbodies. The L2 programme focuses on the biological state of lakes with the objective of detecting the early changes in water quality by means of biological methods. Sampling of phytoplankton, periphyton, zooplankton and bottom fauna is undertaken in 71 lakes every three years.

The L3 monitoring programme includes both lakes and rivers and aims at determining the amount of and level trends in toxic substances in the aquatic environment. The objectives of the L4 monitoring programme are to detect long-term changes in the acidification of small head-water lakes as a consequence of atmospheric deposition. The programme consists of two networks: a network including 176 lakes throughout the country in which one annual sample is taken and analysed for indicators of acidification, and a network including 200 lakes in Lapland in which samples are taken once every 2nd or 3rd year.[50]

SYKE collects long-term observations of river, lake, and groundwater water quality since the 1960s. The role of SYKE is mainly to coordinate environmental monitoring in Finland. Actual monitoring work is carried out by ELY-centres mentioned previously. These centres (together with SYKE) assess the chemical status of Finnish surface waters every six years (which is also done in all EU Member States according to the WFD). The information on water quality and biological factors that polluters are required to collect is also used for reporting purposes.[51]

Long-term observation reveals the effects of eutrophication, harmful substances, and climate change on the water systems. This information serves as a basis for overall assessments of the condition of water resources, thereby enabling predictions of the future development of water systems, assessment of the effectiveness of the protection measures taken, and recommendations for new actions. High-quality observation data are needed also for decision-making and legislative work. Up-to-date water resource information is useful in the event of a flood, for protection of the citizens and property.[52]

All these aspects are carefully monitored by SYKE, who reports the findings of its monitoring work to authorities such as the European Environment Agency and the European Commission. In addition to the official /mandatory/periodical reporting to EC /EEA, SYKE provides up-to date weekly information for regional authorities, public and press. It also usually reports on the national cyanobacterial situation on a weekly basis every Thursday from the beginning of June until the end of August. The weekly algal reporting on the national cyanobacterial monitoring was launched in 1998.[53] It provides information on lakes, coastal waters and open sea areas in the surroundings of Finland.

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50 https://www.eea.europa.eu/publications/92-9167-001-4/page007.html

51 https://www.syke.fi/en-US/Research__Development/Water/Monitoring

52 https://www.syke.fi/en-US/Research__Development/Water/Monitoring/Monitoring_related_to_the_water_theme(10027)

53 https://www.syke.fi/en-US/Current/Cyanobacterial_blooms_observed_at_only_o(60888)

A key point in this process is **measuring algae bloom and eutrophication,** a complicated task, as the aquatic ecosystem undergoes constant interactions between physical, chemical and biological components. There are various types of measurements to monitor eutrophication and algae bloom:

- 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.
- Eutrophic waters have fluctuating amounts of **dissolved oxygen** which makes it a good indicator as well. Algae consume oxygen. A great algal biomass can therefore provide 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. The Secchi disk is a common method for measuring this effect. The disc 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**.
- **Eye observations** can also detect small amount of cyanobacteria in the water. It appears as green or yellowish particles. Narrow stripes of algae can drift to a shore.[54]

2.4.2 Limitations of conventional methods

In-situ 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 point in time. 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 measurements are disadvantaged with regards to:

- **Constructing a broader picture**: the need to have a region-wide picture of the water quality in lakes requires putting in place the right measures and prioritise accordingly in-situ measurements. Achieving this on 57k lakes with the size of one hectare or larger in Finland with traditional in-situ measurement techniques would be extremely difficult and costly.

[54] https://www.syke.fi/en-US/Current/Cyanobacterial_blooms_observed_at_only_o(60888)

- **Ensuring continuous monitoring**: maintaining an accurate picture of the evolution of water quality in the lakes throughout Finland would require continuous and widespread use of in-situ measurements which is particularly resource-intensive. For example, the growth and formation of harmful algal blooms are affected by many factors, which makes it difficult to assess the development of the algal bloom in one particular lake in advance. While in-situ measurements can provide exact current data, the historical records are usually quite sparse.
- **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. Therefore, a few years ago, SYKE developed TARKKA, a monitoring system which could remotely and continuously assist water quality monitoring in Finland (and in other countries).

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 Data

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 specifics of this case and water bodies monitoring services implemented in Finland, 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[55]:

- 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.

Passive sensor principles mainly used to monitor water bodies are shown in **Error! Reference source not found.**. Other sensors detect the direct radiation from the water surface which allows the water surface temperature and salinity to be measured.

[55] 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

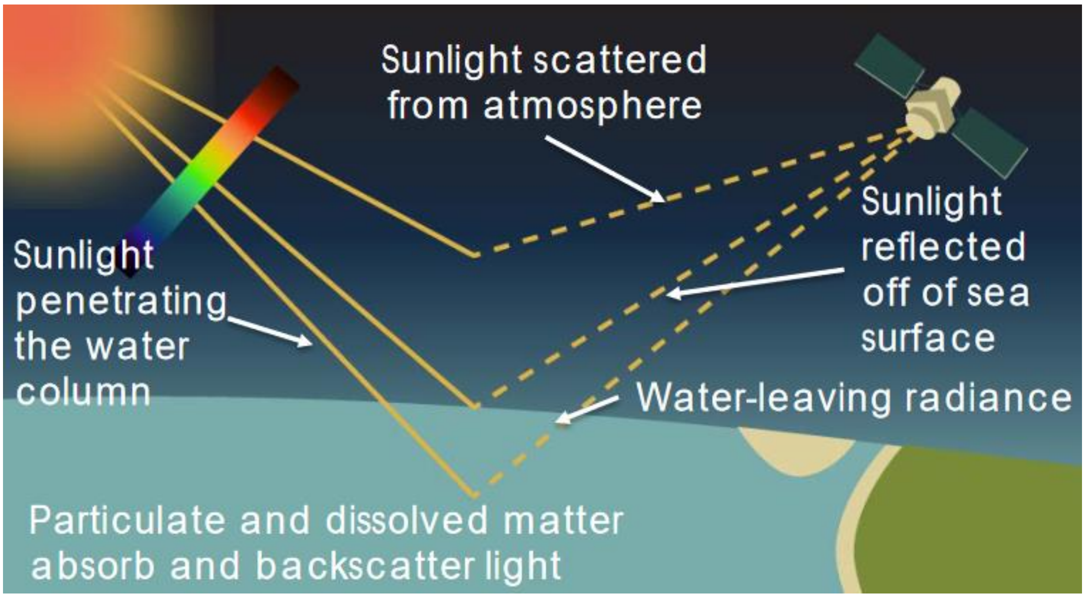


Figure 3-1 Principles of satellite-based water quality measurement[56]

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 suspended material.
- The **Harmful Algal Bloom Indicator (eoHAB)** is an indicator of the presence of specific pigments associated with HAB's. Measurement is not yet quantitative related to 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 Chlorophyll-a as an additional indicator.[57]

[56] Source: https://appliedsciences.nasa.gov/sites/default/files/S2P1SDG6.pdf
[57] https://www.epa.gov/cyanohabs/health-effects-cyanotoxins

- **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. 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, 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)[58] comparing in-situ techniques versus satellite-based earth observation for monitoring of lakes. This used 168 sampling stations to monitor comprehensively four lakes (with a total of 92 square kilometres); this corresponds to a sampling station every 1,82 square kilometres. It would represent 19714 sampling stations for the whole territory of Finland (with 36000 square kilometres of lakes surface). This illustrates the advantage of using satellite-based EO for lake monitoring; 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.

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 Finnish lakes especially when considering the remoteness of many of them. Moreover, drones are typically used to perform very-high resolution surveying/monitoring which is of no immediate value for the case of Finland. In that sense, satellite-based observation offers the best solution in terms of efficiency.

The great advantage of satellite imagery is its wide geographical coverage that allows for monitoring many more lakes than can practically be achieved with traditional methods. Satellites offer the ability to construct a broader picture of lake status which also facilitates common understanding and provides information for decision making. Monitoring the 57K Finnish lakes (greater than 1 hectare) by virtue of in-situ measurements would be in fact practically impossible.

Furthermore, EO data can be used to achieve better temporal resolution i.e. more frequent measurements. 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 monitoring programs and evaluation methods can be usefully supplemented with satellite measurements.[59]

[58] https://www.researchgate.net/figure/Water-sampling-stations-on-the-four-studied-lakes_fig2_237008495
[59] 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

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 (sea surface temperature and HAB) showing evolution of entire lakes through time. Making the same observations via in-situ monitoring techniques would be very costly and time-consuming.

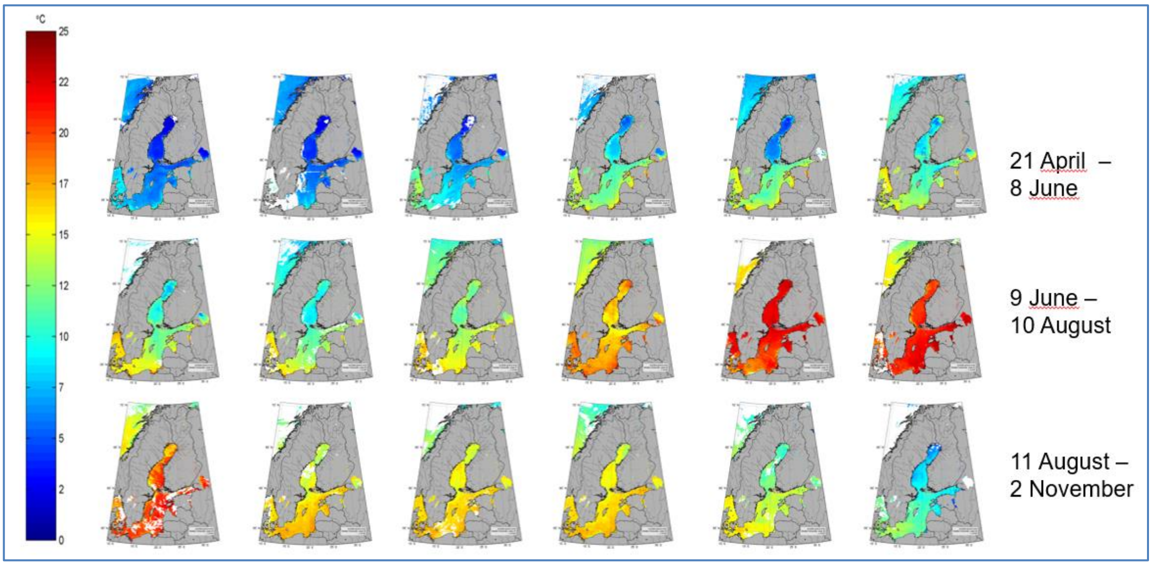


Figure 3-2 Evolution of sea surface temperature observed by SYKE.

(Source: TARKKA gallery)

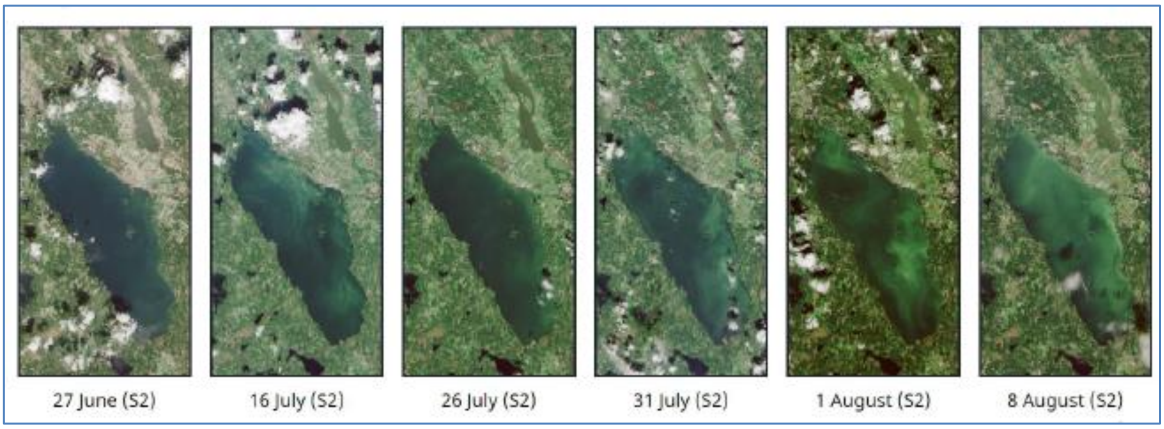


Figure 3-3 Automated observations of cyanobacteria over Finnish lake (lake Pyhäjärvi and lake Köyliönjärvi in South-West Finland).

(Source: TARKKA gallery)

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 (2 to 3 days when there is no cloud) to detect problems in time to respond.

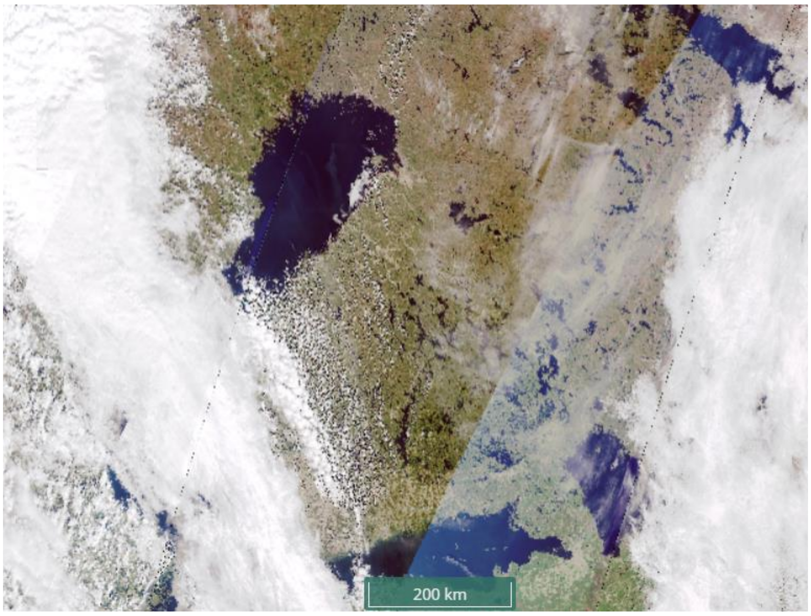


Figure 3-4 TARKKA image of Finland partly covered with clouds[60]

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. 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. In addition, dark spots in lakes may also generate biases in measurements.

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 were correctly accounted for in the

[60] 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 on TARKKA platform (see image below).

Figure 3-5 TARKKA observation of a lake in Finland showing resolution limitation with a scale of 1000m in the first picture and a scale of 200m in the second picture.[61]

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. In this regard, the picture bellow illustrates transparency from underwater.

Figure 3-6 Transparency of the water (picture by Ilkka Lastumäki).

3.2 Copernicus and the Sentinels

Imagery used to support the monitoring of lakes in Finland is coming from optical satellites carrying sensors with multiple imaging bands (i.e., observing different parts of the light spectrum). These

[61] Source: https://syke.fi/TARKKA/EN (22 July 2022)

include the Sentinel-2 and Sentinel-3 satellites which are part of the EU Copernicus programme[62] and Landsat 8 which is a USGS (U.S. Geological Survey) satellite.

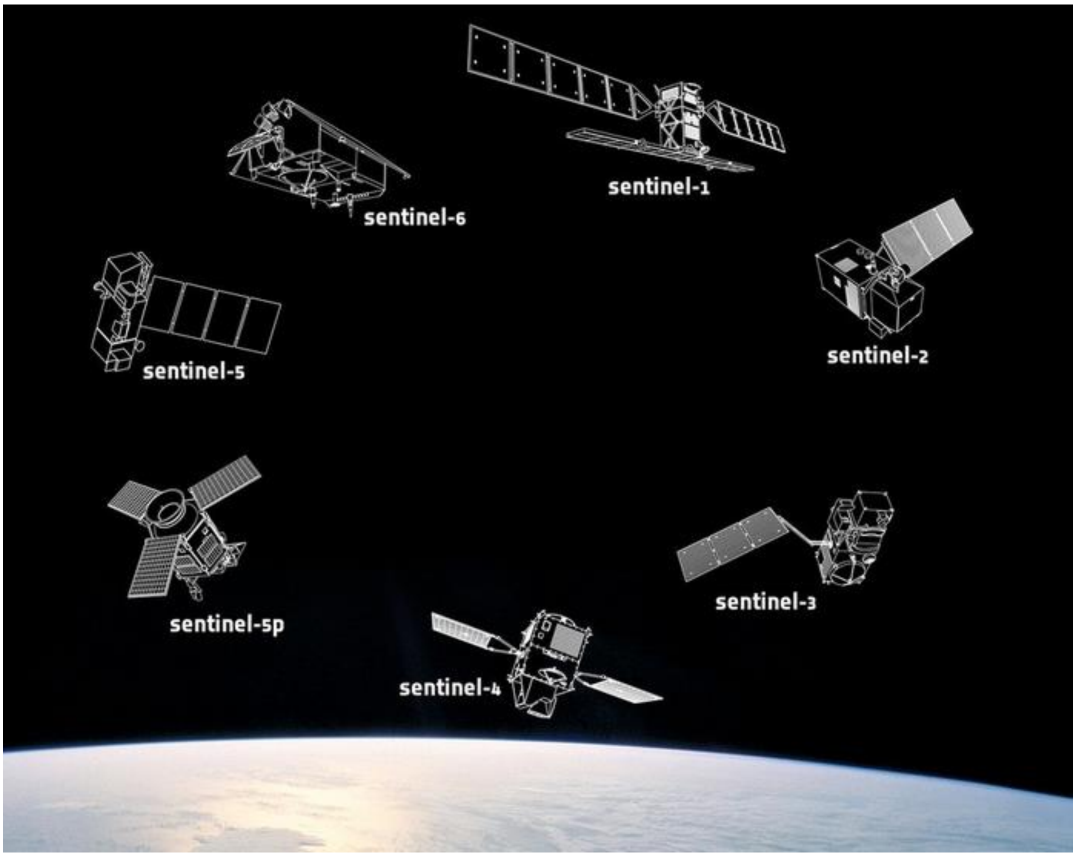


Figure 3-7 Current Sentinel satellites

Copernicus is an EU flagship programme[63] 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 **Error! Reference source not found.**7 above.

Our case is defined by Sentinel-2[64] and Sentinel-3 satellites (see the info boxes).

62 https://www.copernicus.eu/en
63 https://www.copernicus.eu/en
64 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2

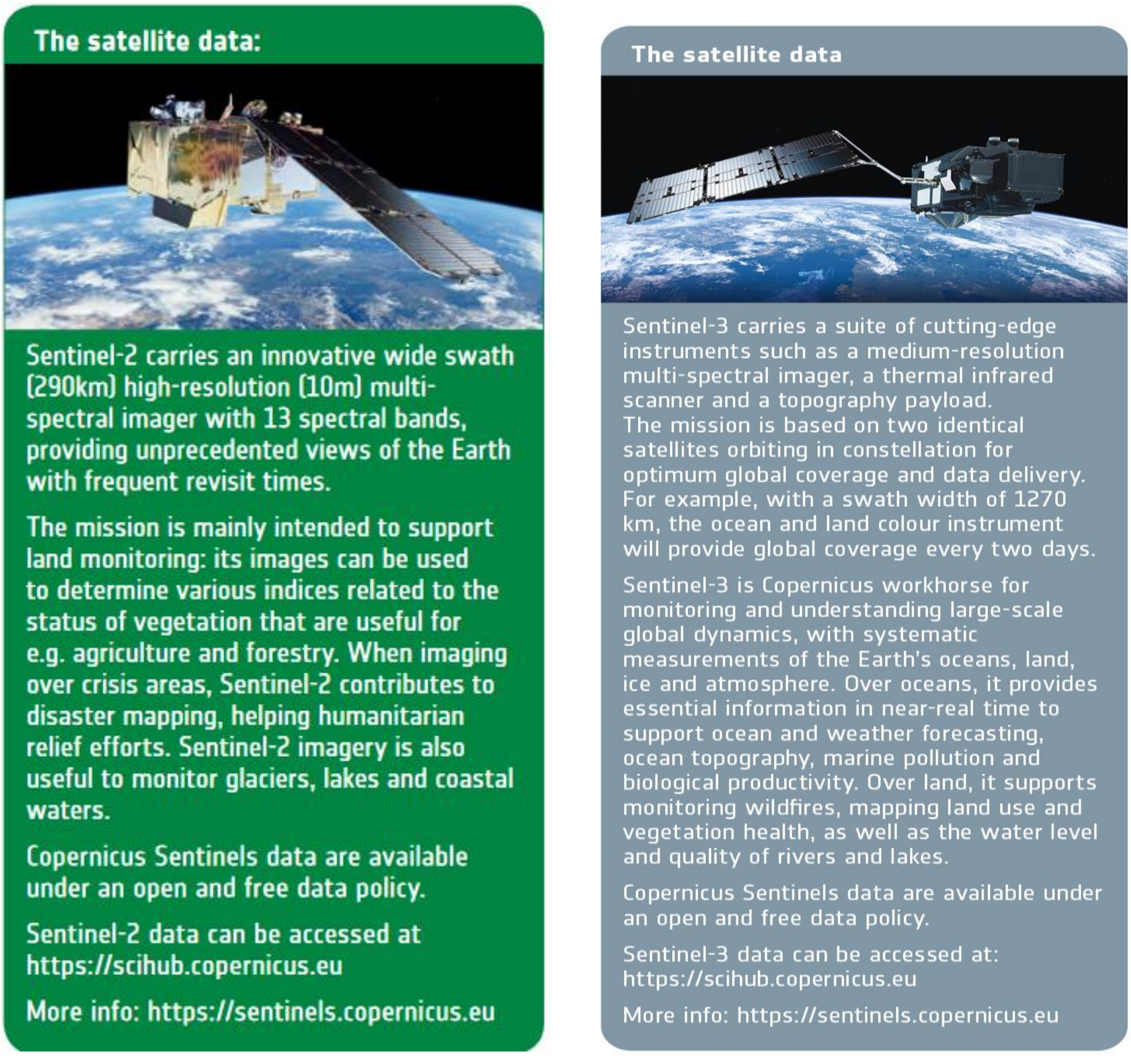


Figure 3-8 Sentinel-2 and Sentinel-3 Satellites

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: The main objective of the Sentinel-3 mission 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, ENVISAT and SPOT 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. Hence it can be used only for the larger lakes. On the other hand, Sentinel-2 can measure down to 10m 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 2 to 3 days. These intervals are made even longer during cloudy weathers as clouds make pictures worthless. To take the example of Finland, observations are obtained at medium resolution (300m-1km) daily and more precisely (10-60m) approximately every two to three days.

3.3 SYKE Services

SYKE is an EU pioneer in developing water monitoring services based on satellite data. As seen in previous sections, Sentinel/EO data are very valuable in monitoring water quality but there were no such available services SYKE could use. Noting this market need, SYKE benefitted from EU and national funding (from the Ministry of Environment) to develop and launch its own open EO services in 2018 entitled **TARKKA**. It also created **STATUS**, an interface and a dedicated database which provides all sorts of computed statistics aimed at experts and public authorities.

The open interface TARKKA uses mainly Sentinel-series instrument[65] observations coupled with machine learning processes to provide information on water quality and water temperature together with visual satellite true colour imagery.[66] Various natural phenomena and changes in the environment can be illustrated with the help of true-colour images (see examples in figures 3-9 and 3-10 below).[67]

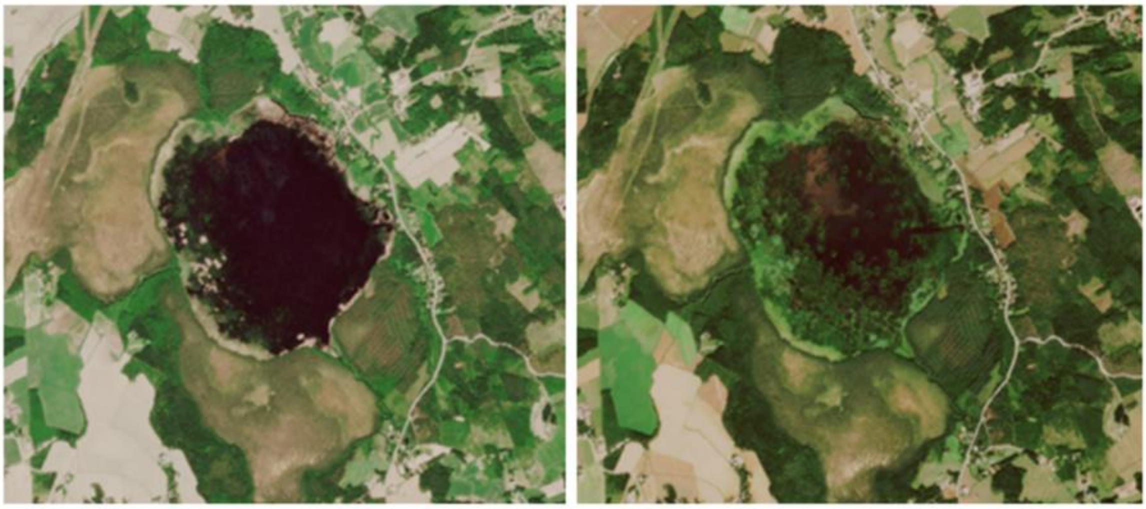
65 Satellite products are based on several NASA, NOAA and EU Copernicus program satellite instruments. Currently Sentinel-2 (ESA), Sentinel-3 (ESA), Landsat-8 (NASA)and TERRA MODIS (NASA) satellites are utilized for monitoring (source: https://www.syke.fi/en-US/Open_information/Satellite_observations).

66 True color images are the so-called RGB images and are produced by composing the red, green, and blue wavelength observations of satellite optical instruments (source: https://syke.atlassian.net/wiki/spaces/sykeEO/pages/583241586/Tosiv+rikuvat).

67 https://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/EO_FP_CUP_Water
https://syke.atlassian.net/wiki/spaces/sykeEO/pages/583241586/Tosiv+rikuvat

Figure 3-9 True colour images can be used to visually monitor the algae situation in lakes, especially those with an annual algal abundance.[68]

TARKKA provides EO-based information for the national daily monitoring and reporting purposes as well as material of interest for the general public. Information is updated on daily basis and is used for various purposes including environmental monitoring and informing the public on changes or events in water quality. With regards to true-colour images, the phenomena to be observed in the summer are for example cyanobacterial blooms, macrophyte growth (see image below), water turbidity variations and dredging areas. In addition, the service offers excellent observations of the icy months of winter and the melting season during the springtime.



[68] source: EO-wiki by SYKE https://syke.atlassian.net/wiki/spaces/sykeEO/pages/583241586/Tosiv+rikuvat and https://syke.fiTARKKA/en

Figure 3-10 Lake Ridasjärvi and annual macrophyte growth. Left in late May and right in July *macrophytes in August, year 2018 '*

Figure 3-11 Illustrating the above picture macrophytes from underwater (picture by Ilkka Lastumäki)

SYKE has also developed **STATUS** (see figure 4-3 below) which is an expert interface for the environmental authorities responsible for monitoring over 2200 water bodies in Finland (87% of the total area) and open Baltic Sea areas. STATUS is based on a database that provides periodically aggregated statistics, time series and histograms of the distribution of Earth Observation and station sampling. In the framework of this project, TARKKA is currently being further developed with functionalities that best suit users' purposes. More specifically, another version of STATUS is going to be very soon implemented on TARKKA aimed at the general public.

To better understand how TARKKA is presented, below is a screenshot of its landing page. This brings up recent highlights from satellite observations and tweets related to TARKKA imagery. During the summer holiday period, tweets and re-tweets are often related to cyanobacteria blooms. TARKKA also combines time series of EO and station sampling observations of turbidity, temperature and chl-a.

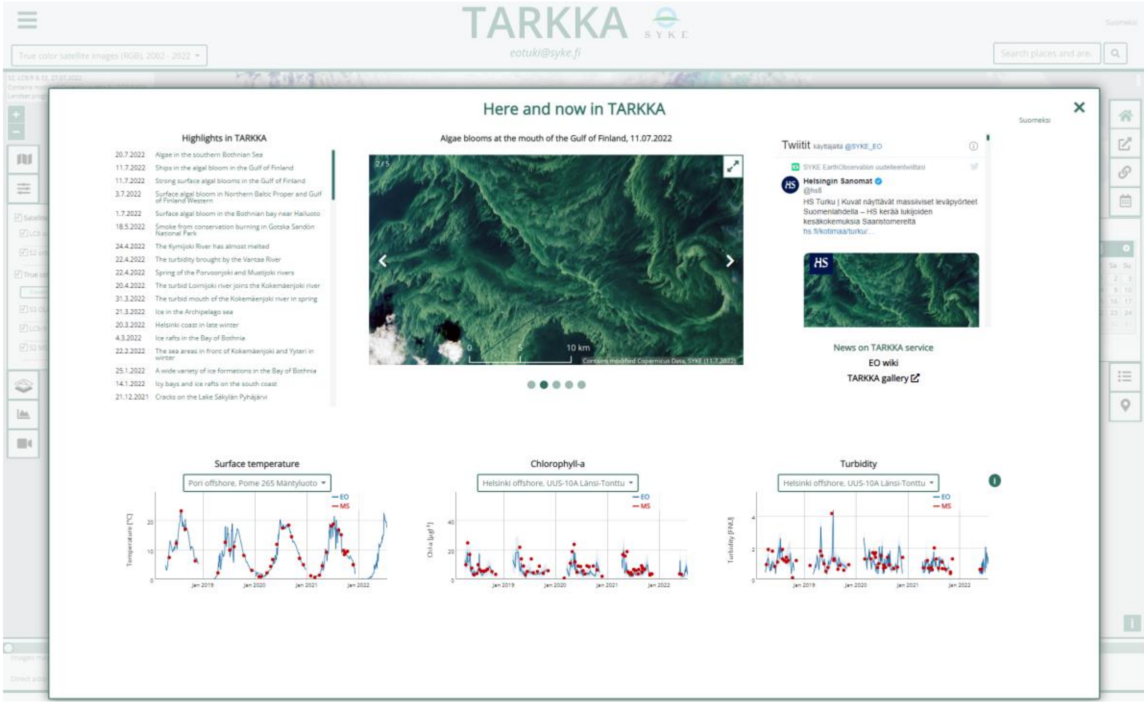


Figure 3-12 Frontpage of the next version of TARKKA captured on 27th of August 2022.

Additionally, the TARKKA+ version under development combines EO under various themes linked to users' interests, like algae blooms, turbidity, dredging and time series of satellite observations and station sampling observations per station site and water body. These are combined with complementary GIS material, like water body divisions as in this example.

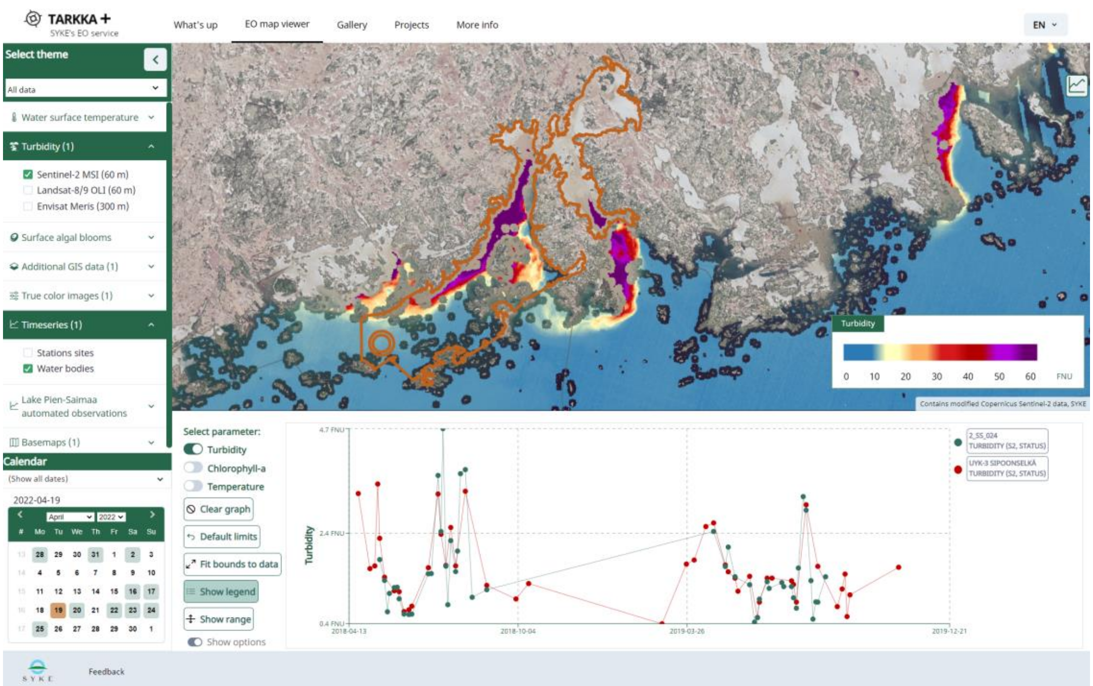


Figure 3-13 shows TARKKA+

By the means of local news and its website, SYKE also shares useful information for the general public on water quality, especially regarding Cyanobacteria and other algae observations. This information is extremely useful for leisure and fishing activities in lakes. For example, below are a map, a graph and a local news article shared by SYKE providing cyanobacterial observations for last summer (2021).

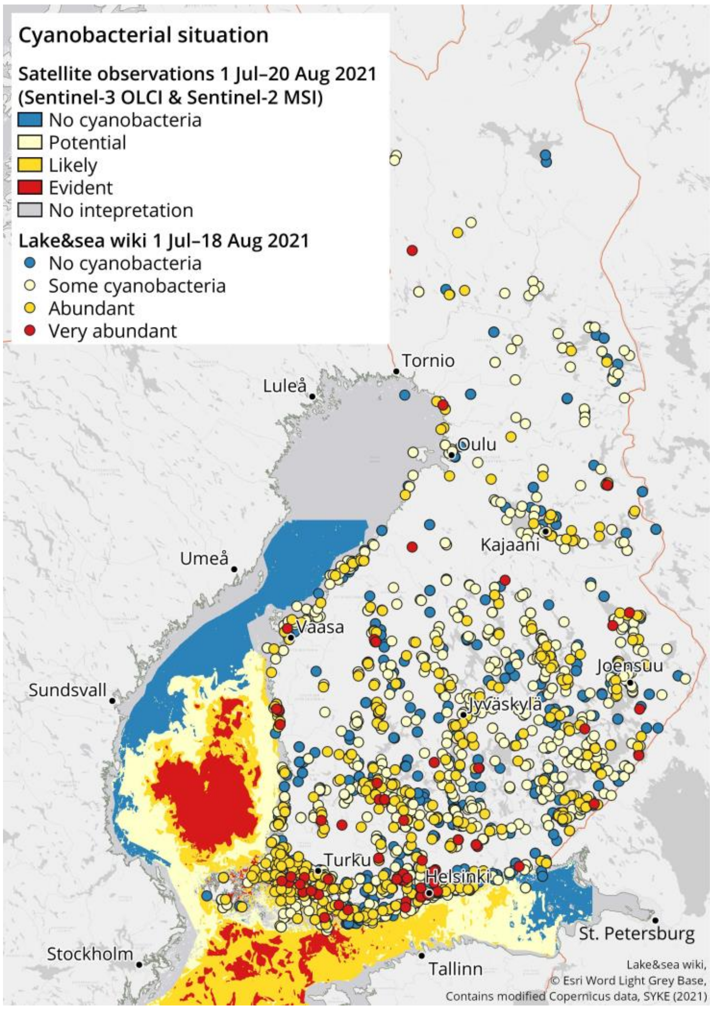


Figure 3-14 Cyanobacterial situation during summer 2021 in Finland[69]

[69] Source: https://www.syke.fi/en-US/Current/Algal_reviews/Summary_of_algal_bloom_monitoring_JuneAu(61391)

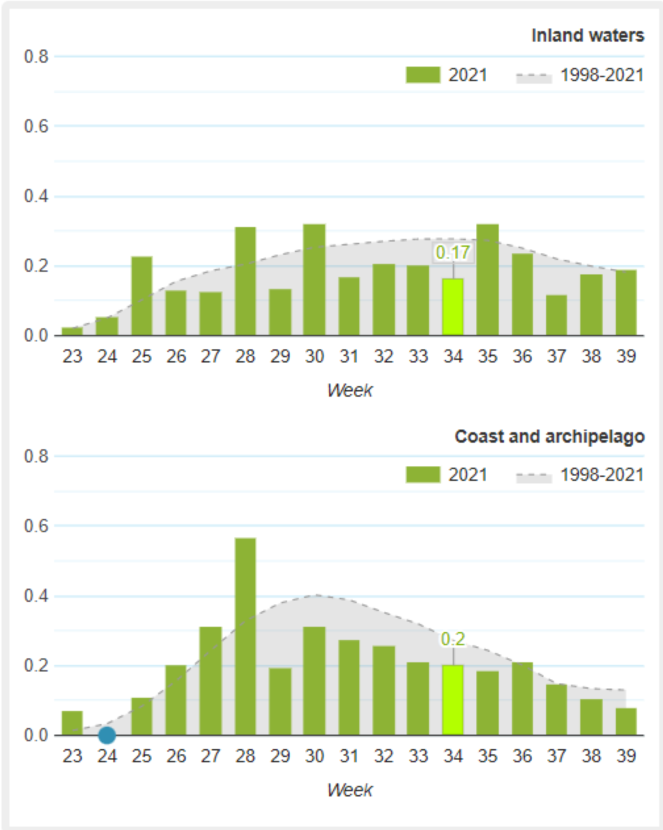


Figure 3-15 Algae barometer during Summer 2021 in Finland[70]

Figure 3-7 Local Finnish News spreading information about HAB and river outflow bringing turbid and humic materials in coastal waters (source: SYKE).

70 Source : https://www.syke.fi/en-US/Current/Algal_reviews/Summary_of_algal_bloom_monitoring_JuneAu(61391))

The most recent evolution of the service which is being continuously updated is a TARKKA gallery page showing evolution of cloudless observations over selected lakes annually, starting from the ice melt to autumn. This service is very useful to show evolutions such as melting ice, floods or HAB evolution. At present, it operates on 40 lakes areas (and 10 coastal regions) and new areas of interests are being updated according to the wishes by regional centres and SYKE centres for Freshwater and Marine research. Below is an example of TARKKA-gallery observations covering lake Enäjärvi in the southern Finland in 2022 where cyanobacteria is a severe annual problem. The observations start before the ice melt and capture the most relevant high-resolution observations over this small-sized lake. On the 19th of April, the lake is covered by ice. Ice cover melts gradually and the lake is completely ice-free by the beginning of May. Cyanobacteria blooms appear typically around mid-Summer. In 2022, first observation of cyanobacteria was captured on 24th of June.

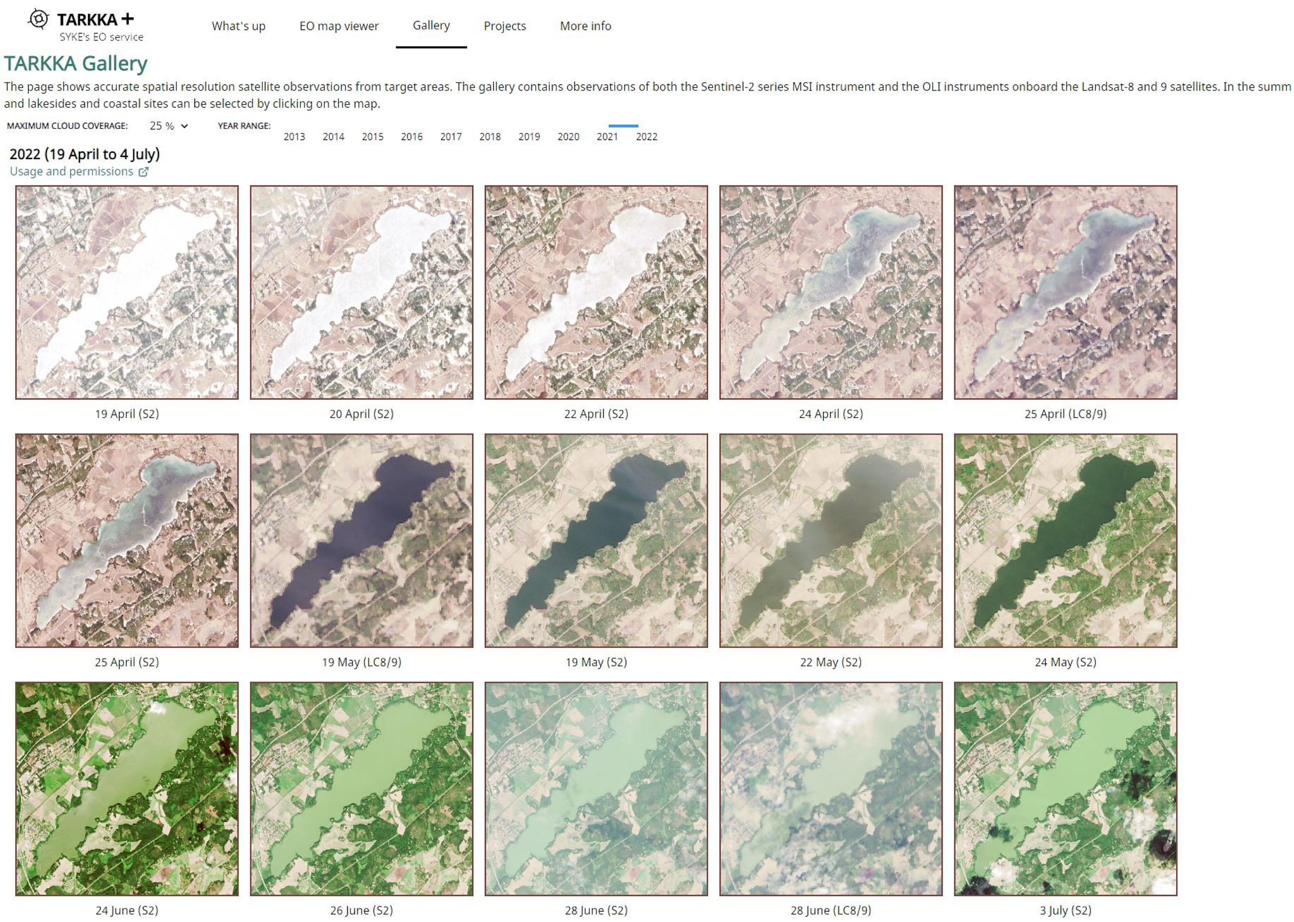


Figure 3-8 TARKKA-gallery observations of lake Enäjärvi[71]

[71] Source: https://testbed.ymparisto.fi/eo-tarkka/gallery/

3.3.1 Future Evolution of the Service

TARKKA services are being developed further and their visual appearance and functionalities are being updated according to users' definitions while the number of users is exponentially increasing (see Figure 5-2 below).

Short term evolutions are related to services improvements such as using AI methods for detecting interesting phenomena (hot spots), like turbidity river blooms during springtime. SYKE will also in the coming year implement more AI methods for cyanobacteria bloom detection and other phenomena requiring special attention. As Earth observations provide huge amounts of observations over large lakes, it is worthwhile developing automated functionalities that alert about interesting or unusual observations. Another goal is to offer barometer information that provide indications on changes over the lakes, like comparisons of cyanobacteria situations between the annual summer periods. Trends analysis related to changes in brownification, algae blooms and turbidity levels will be of importance in the future. All of these have linkages to anticipated effects caused by climate change (i.e. more rains in the wintertime will induce more nutrients, suspended sediments and CDOM (chromophoric dissolved organic matter)[72] from the drainage basin to the lakes, rivers and coastal waters).

In the longer term, the plans for the Copernicus program evolution are to improve the instruments in terms of observation accuracy and capabilities. Currently, observations are obtained for the territory of Finland at medium resolution (300m-1km) daily and more precisely (10-60m) approximately every two to three days. Additional and more accurate data are increasingly obtained from commercial actors as part of Copernicus contributing missions, which produce, among other things, observations of very accurate terrain resolution (0.5 - <3 m). These data are however less frequently ingested in relevant products (e.g. for Copernicus Land Monitoring Service), such as once every two years.

With the forthcoming Copernicus Sentinel Next Generation series, the regional accuracy of the observations will improve to around 5 m, which will open up new opportunities for the development of regular monitoring, especially of small-scale natural sites which will prove very useful for the specific features of Finnish nature, such as dark water areas.[73]

[72] Colored dissolved organic matter (CDOM) is the optically measurable component of dissolved organic matter in water.
[73] Source: Future use of EO in Finland (provided by SYKE)

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 (both from an environmental and an economic point of view) 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

The core value chain is shown in Figure 4-1. In the first tier, **SYKE - the service provider -** is supplying access to their TARKKA service which enables their users to generate maps and time-series data of the critical parameters indicating water quality. Although SYKE is the service provider with its EO service (TARKKA), it has other roles to play in the value chain as it collaborates with Ministries and Regional Centres to monitor water quality in Finland.

The **Centres for Economic Development, Transport and the Environment** (ELY Centres) - the primary user – are using the information generated by TARKKA to conduct research, track dynamics, support decision making and compile reports on the water quality of lakes in their region, so fulfilling their mission.

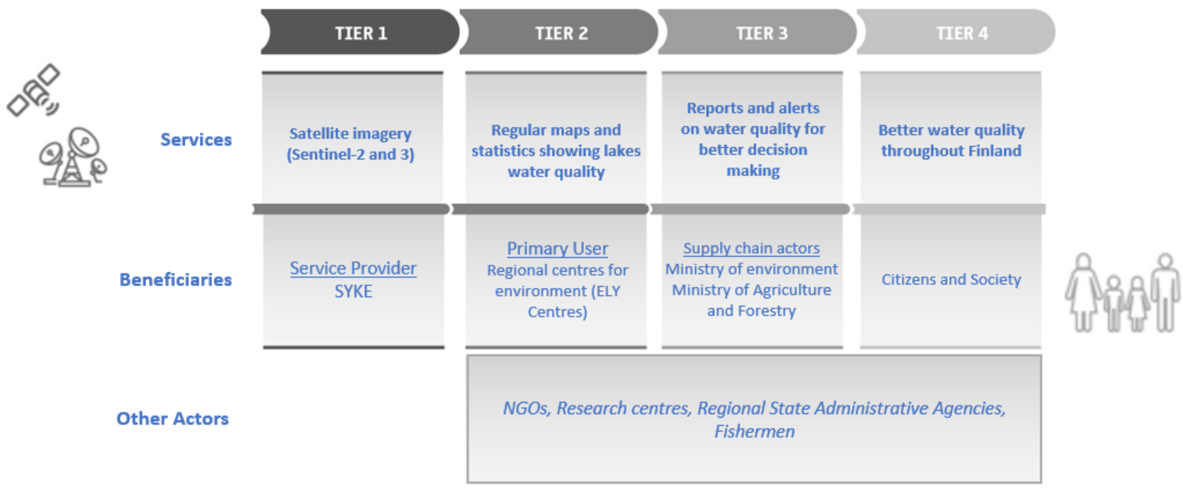


Figure 4-1 The value chain for lake monitoring in Finland

In tier 3, **the Ministry of environment and Ministry of agriculture and forestry** use information generated by TARKKA and the regional centres to provide guidelines and make decisions regarding water quality.

These decisions, empowered by the information provided through TARKKA, enable a host of benefits for **citizens and society** at large, occupying tier 4 of the value chain.

Outside the core value chain, there are also many interests in NGOs (e.g. NGO involved in biodiversity preservation), research institutes (e.g. monitoring the impact of lakes and the quality of the water on the environment and the overall ecosystem) and fishers who have access to healthy fish and information on where to go fishing.

4.2 The Actors

4.2.1 Tier 1: Service Provider – SYKE

The Finnish Environment Institute (SYKE) was formed in 1995 and is a multidisciplinary research and expert institute under the Ministry of the Environment. SYKE has four office and research facilities in Helsinki, Oulu, Jyväskylä and Joensuu. SYKE newly formed strategy sets its vision to a sustainability transformation. SYKE supports the building of a sustainable society with research, knowledge, and services, also at an international level. SYKE describes its role in 5 main objectives towards sustainability transformation:

1. Enhancing climate change mitigation and adaptation
2. Advancing the transition to a sustainable circular economy and bioeconomy
3. Supporting urban areas on their way to becoming forerunners of sustainability
4. Promoting well-being through nature-based solutions and preventing biodiversity loss
5. **Developing new approaches for reaching a good state of the seas and inland waters and achieving sustainable use of water resources**[74]

In other words, their most important task is to solve society's most burning questions that have an impact on the environment. In this aim, SYKE produces valuable data on the state of the environment in Finland. It also assesses future trends and develops solutions to promote sustainable development. SYKE compiles, processes and publicises a wide range of studies and data, while meeting Finland's reporting obligations under European Union environmental legislation (such as the Water Framework Directive) and other international agreements.

SYKE comprises about 700 competent experts and researchers who work in close and stimulating co-operation with Finnish and international partners.[75]

[74] https://www.syke.fi/en-US/Current/SYKEs_vision_is_Sustainability_Transform(61826)
[75] https://www.syke.fi/en-US/SYKE_Info

Figure 4-2 SYKE research vessel, Aranda, making water sampling during cyanobacteria period (Source: SYKE, Sirpa Lehtinen)

SYKE is currently represented by seven centres: Freshwater, Marine research, Biodiversity, Consumption and production, Environmental policy, Data and information, and Laboratory centres. The main tasks of these centres are research, development and production of various services. For maintenance and support functions at SYKE, there are the Administrative services, the Communications unit and the General Director's staff. International Expert Services provides a wide range of expertise for client organisations outside Finland.

The centre of interest for this analysis is the **Freshwater Centre**. It supports water protection and water resources management by collecting information, by doing multidisciplinary research, and by developing assessment tools and sustainable solutions. After 2022, SYKE's organization will be updated and there will be a division of current centres to new units that combine the expertise of present centres responsible for marine and freshwater research and monitoring. The new strategy for SYKE highlights the development of new approaches for reaching a good state of the seas and inland waters and achieving sustainable use of water resources as one of its impacting objectives.[76] SYKEs ways of operating rely on the principles of open data and open science. Furthermore, SYKE focuses on being a forerunner in developing and applying new research methods and opportunities presented by digitalisation.[77]

SYKE has, since 2000, developed environmental monitoring approaches based on satellite observations, especially with regard to water quality, land cover and its use, snow and lake ice cover, and more recently also habitats. The collected data is compiled for both daily and longer-term statistics for the purposes of reporting (e.g. EU Water Framework Directive, HELCOM status assessment, HOLAS, Holistic Assessment of the Ecosystem Health of the Baltic Sea), monitoring and research.[78]

As SYKE needed specific services linked to Earth Observation to better monitor Finnish waters, it launched its own open EO services in 2018 called **TARKKA**. As mentioned in chapter 3, this uses mainly Sentinel-series instrument observations coupled with machine learning processes to provide information on water quality and water temperature together with visual satellite true colour imagery. SYKE was the first research institute in Finland to open up its data banks to the public. SYKE's wide metadata service meets the requirements of the Academy of Finland, enabling their data to be widely shared and used.[79] In their need of monitoring water, SYKE Freshwater centre and Marine centre are actively using TARKKA services.

SYKE also provides the **STATUS service.** As seen in section 3.3, STATUS is an expert interface provided within TARKKA. It provides periodically aggregated statistics, time series and histograms of the distribution of Earth Observation and station sampling. An example about lake Lappajärvi is provided in figure 4-3 below. The green area shows the pixels that are accounted in accumulating statistics. Shallow areas and areas nearby islands are excluded. Corresponding lake statistics in STATUS interface for the summer period of 2018. Station observations are shown as grey dots in the time series, cyan colour represents daily statistics (median, surrounded with P25 to P75 from the lake area).

[76] https://www.syke.fi/en-US/Current/SYKEs_vision_is_Sustainability_Transform(61826)
[77] Ibid
[78] https://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/EO_FP_CUP_Water https://syke.atlassian.net/wiki/spaces/sykeEO/pages/583241586/Tosiv+rikuvat
[79] https://issuu.com/suomenymparistokeskus/docs/syke_2016_current-issues_en_v190520#:~:text=SYKE%20was%20the%20first%20research%20institute%20in%20Finland,our%20data%20to%20be%20widely%20shared%20and%20utilised.

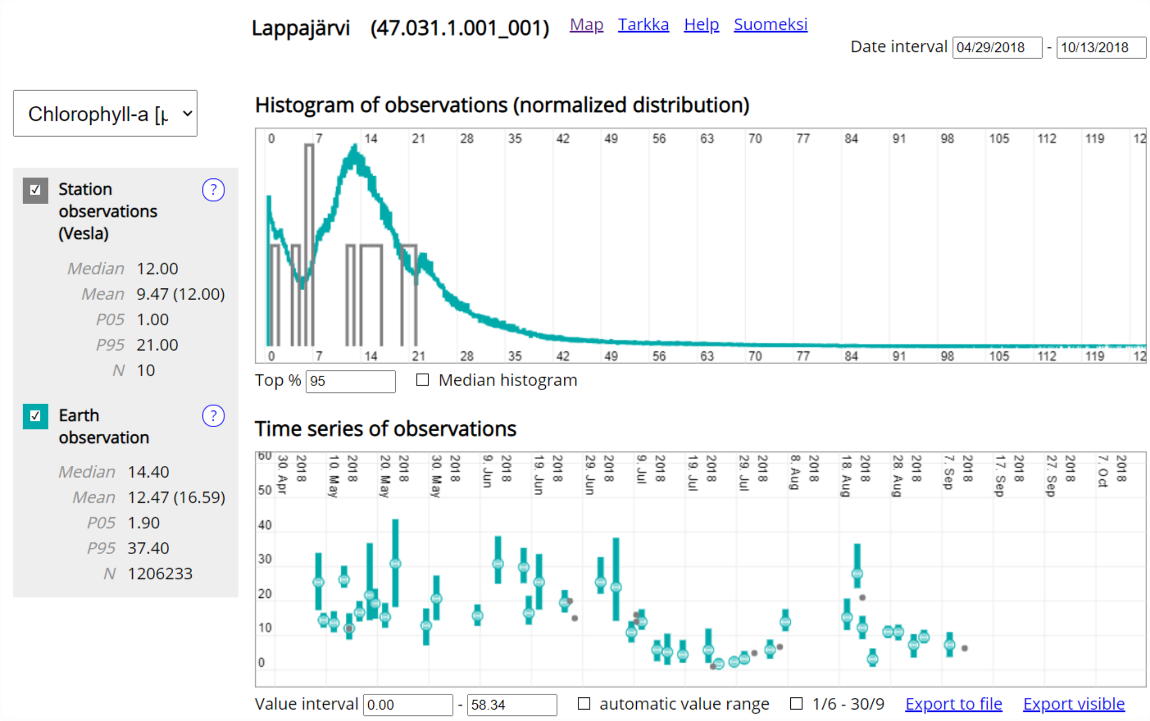


Figure 4-3 Histogram of observations on lake Lappajärvi provided by STATUS (source: SYKE)

4.2.2 Tier 2: Primary User – regional Centres for Economic Development, Transport and the Environment.

There are 15 Centres for Economic Development, Transport and the Environment in Finland (ELY Centres). Together with the six Regional State Administrative Agencies they operate as the country's regional state administrative authorities. The ELY Centres are local offices of the Finnish government placed in each of the regions of Finland.

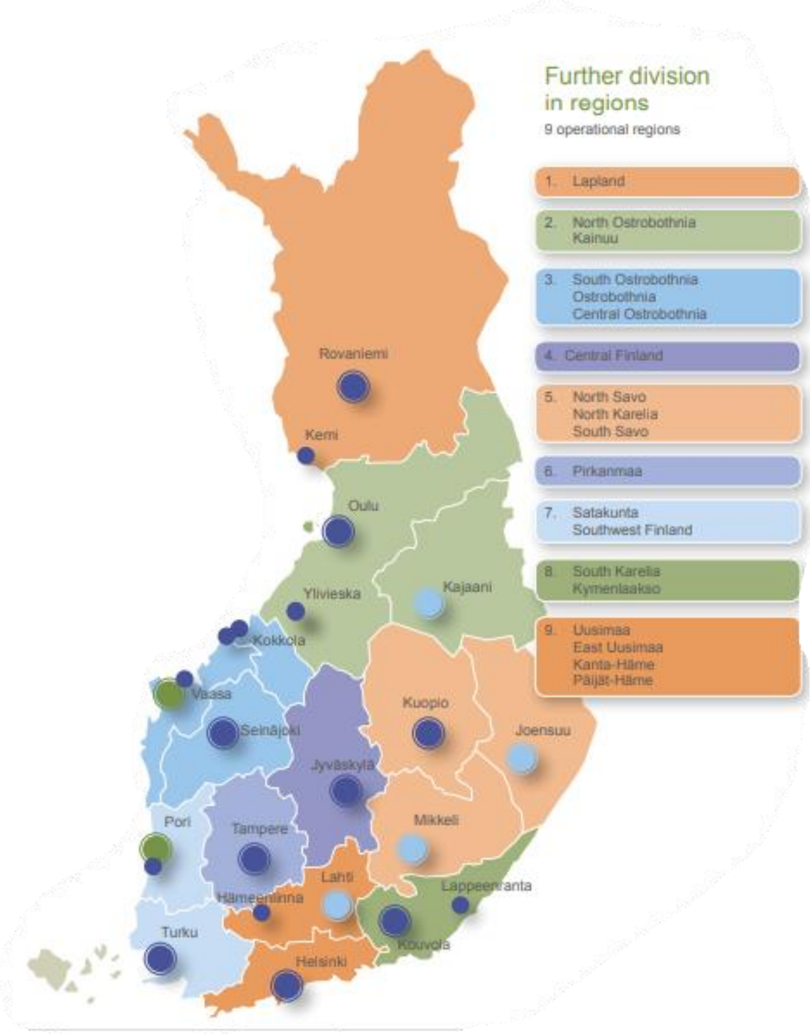


Figure 4-4 Areas of ELY centres on the map 2021[80]

These centres are tasked with promoting regional competitiveness, well-being and sustainable development as well as limiting climate change impacts. They are distinct from Regional State Administrative Agencies, which cover multiple regions and are tasked with law enforcement and related duties instead.

ELY Centres have three areas of responsibility:

- Environment and natural resources
- Business and industry, labour force, competence and cultural activities
- Transport and infrastructure

80 source: https://www.ely-keskus.fi/documents/10191/183923/ELY_esite_englanti.pdf/04d8e5ff-e21b-43d6-be1b-237c47e88087

Depending on the subjects to be treated, these centres work under the supervision of different ministries. For environmental matters and water resource use and management, they work under the supervision of the Ministries of Environment and of Agriculture and Forestry.[81]

ELY Centres are responsible for the planning of river basin management in their respective River Basin Districts (RBD - see figure 4-5 below). They have additionally set up joint working groups on protection and state of water bodies with representatives of the main national and local authorities, organisations, landowners and businesses.[82] In this map, the red borders define the division of ELY responsibility areas related to environmental tasks.

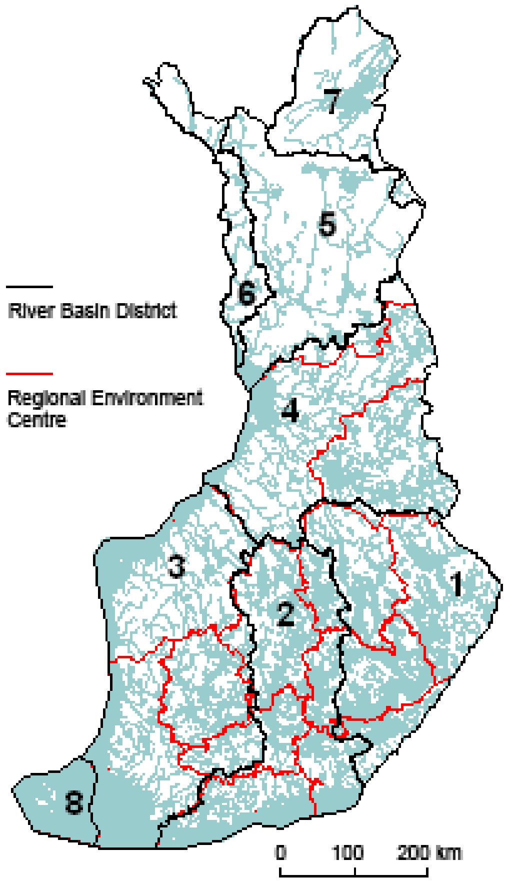


Figure 4-5 River Basin Districts[83]

In their role of water management, they take responsibility for regional implementation and tasks of the central government on environment and national resources, support SYKE in the monitoring

[81] https://www.ymparisto.fi/en-US/Finlands_environmental_administration(24294)
[82] https://www.ymparisto.fi/en-US/Waters/Protection_of_waters/Planning_and_cooperation_in_river_basin_districts/River_basin_districts
[83] source: https://www.ymparisto.fi/en-US/Waters/Protection_of_waters/Planning_and_cooperation_in_river_basin_districts/River_basin_districts

of water status, supervise adherence to the water permits granted by the Regional State Administrative Agencies, promote flood protection and prevention, supervise dam safety and support the development of water services and sewerage and supervision of water supply.

ELY Centres use **STATUS** and **TARKKA** services to assess lakes' quality (almost daily monitoring) and take decisions. As TARKKA and STATUS services are rather young, these Centres still need to adapt their monitoring processes to EO services. In this regard, some of these centres are more active than others.

Application of EO in different districts varies. The most present issues they are dealing with are **algal bloom**. When algal bloom occurs in a lake, it is often detected in-situ and it is confirmed by TARKKA. The added value of TARKKA services is to complement in-situ observation by providing a full picture of lakes and going back in time to analyse the evolution of the algal bloom. TARKKA images also help ELY Centres (together with SYKE) to communicate to the general public (through local newspaper or website), it then helps citizens to avoid going to infested lakes for recreational activities. In order to prevent algal bloom in lakes, ELY centres and other authorities also take initiatives (use of gypsum, structure liming and fibre sludge) to limit the use of nutrients in nearby agriculture areas. However, as this practice is rather new, results from these initiatives are not yet significantly observed. Nutrients are indeed still widely used in agriculture and remain for years in the soil layers. Additionally, ELY centres manage ecological restoration of watercourses as it is an important way to improve the status and habitats of lakes, rivers and small waters degraded by human actions.

ELY centres also 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). ELY centres provide EO images/pieces of evidence when litigations occur in these domains. It happened during dredging activities where citizens were impacted in their recreational activities by sediments in nearby rivers. It also happened when **restoration of natural habitats** in and around water bodies created floods in the nearby fields. For example, restoration of shallow areas in lake Puurijärvi (see figure below) improved the area for birds' habitats (building new water paths enabled the development of bird habitats in the dried areas). The effects of this restoration work have been monitored using TARKKA as some concerns from local farmers (increased flooding due to restoration in the fields, during the springtime) were raised.

Figure 4-6 A case of restoration area in lake Puurijärvi where regional ELY centre is actively utilising TARKKA service to follow their restoration work and its effects.

Another interesting activity performed by ELY centres is **winter flooding risk assessment**. In fact, a rainy autumn can cause a heavy discharge in rivers in November. When this discharge is associated with a rapid drop in temperature, it creates fragile ice on top of the rivers. When this ice is pushed by strong flows, it creates ice damming downstream which in turn creates important floods. Thanks to TARKKA services, it is much easier to observe and predict this phenomenon because, in many cases, there are no roads leading to places where this thin ice is created. During these periods, ELY centres are meeting experts very regularly to prevent or reduce flooding by regulating related lakes inflows and outflows.

Figure 4-7 Observation from the flooding of the river Kokemäenjoki on 10th of January 2022.

Additional activities of ELY centres linked to EO are the control of **water temperature** – e.g. a nuclear power plant on the coastal area is increasing water temperature which affects biodiversity (see figure below).

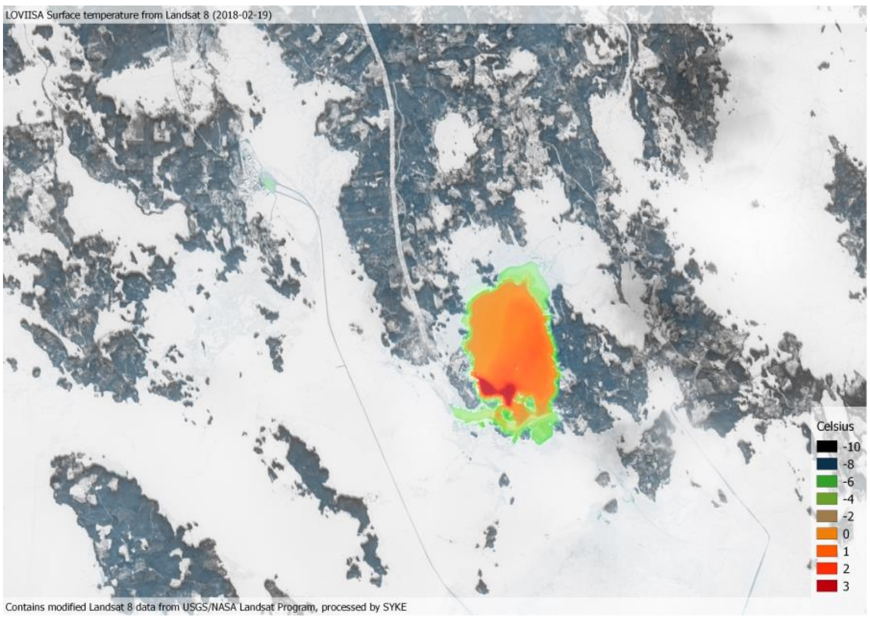


Figure 4-8 TARKKA observation of higher water temperature nearby a nuclear power plant

ELY centres also monitor **water quality and turbidity during springtime**, when snow, ice and frost melts; the changes in water turbidity are intensive and ELY centres follow these changes via TARKKA (see figure below).

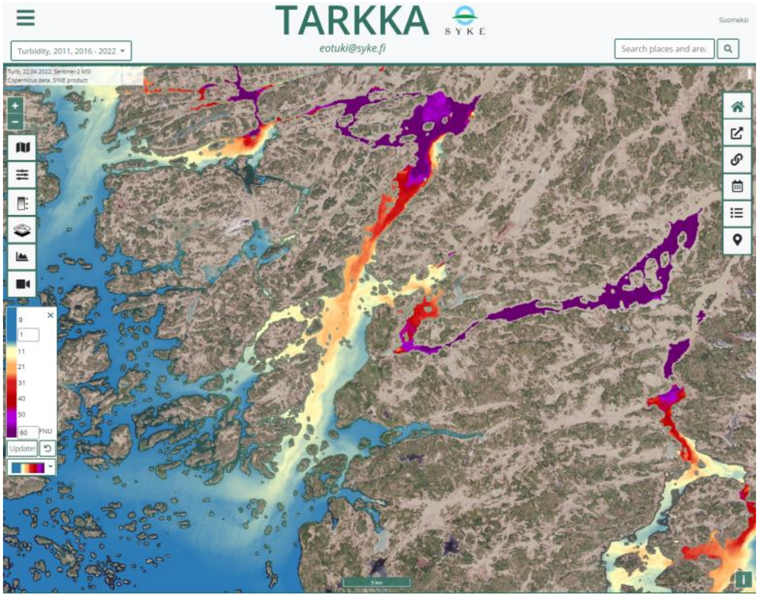


Figure 4-9 Turbidity in coastal estuaries and water paths as estimated using Sentinel-2 data, 22nd of April, 2022

Another activity of ELY centres is to monitor **drinking water areas**. Below is an image from TARKKA of an artificial lake in the coastal area (the area is restricted from the sea). This water is used as drinking water for the nearby city of Uusikaupunki and is monitored by regional centres (together with SYKE) thanks to the use of TARKKA.

Figure 4-10 Monitoring of a drinking water artificial lake with TARKKA (Source: SYKE).

A last activity of ELY centres is the monitoring of **wastewater in the sea** – e.g. a leak of waste water was confirmed thanks to satellite observation.

4.2.3 Tier 3: Ministries of Environment and of Agriculture and Forestry

The above cited regional centres mainly report to the Ministries of Environment and of Agriculture and Forestry regarding topics related to water quality. These ministries take decisions and adapt legislation based upon the relevant water quality reports.

The **Ministry of the Environment** formulates the Finnish Government's environmental and housing policies. These policies cover issues such as environmental protection, land use, nature conservation, construction and housing. This Ministry is also responsible for strategic planning and management in its administrative area, the drafting of new legislation, and international co-operation on environmental issues.

Thanks to the data and research provided by regional centres, the Ministry of environment (in collaboration with SYKE) makes an assessment of the ecological status of lakes every six years as requested by the EU Water Framework Directive (last report was made in 2019 for the period 2012-2017). This information on waters also provides a valuable support on where action is needed to achieve to improve or maintain the ecological status.

Under the programme to enhance the effectiveness of water protection launched in 2019, significant efforts are made to boost the protection of the Baltic Sea and inland waters. The measures include the use of gypsum, structure liming and fibre sludge to reduce nutrient emissions from agriculture to waters, promoting water restoration projects, and reducing the emissions of harmful substances to waters close to cities and built-up areas.[84]

The **Ministry of Agriculture and Forestry** secures domestic food production and sustainable use of renewable natural resources and creates the preconditions for economic activities and well-being derived from these. The Ministry's administrative branch comprises agriculture and horticulture, rural development, forestry, veterinary service, control of foodstuffs of animal origin, fisheries, game and reindeer husbandry, use of water resources, land surveying and spatial information.[85]

4.2.4 Tier 4: Citizens and Society

In tier 4, we include all the recreational users of water bodies 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. Additionally, citizens can be warned of water quality directly through the

[84] https://www.environment.fi/en-US/Waters/Assessment_of_the_status_of_Finlands_wat(51377)#:~:text=Ministry%20of%20the%20Environment%20and%20Finnish%20Environment%20Institute%3A,condition.%20Eutrophication%20is%20still%20the%20most%20significant%20problem.

[85] https://www.valtiolle.fi/en-US/Employers_and_employees/Ministry_of_Agriculture_and_Forestry

TARKKA website but also through newspapers (which use TARKKA products/bulletins). During the years 2020-2022, about 50 articles in press/media were using SYKE or TARKKA as a source.

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.

Figure 4-11 Enjoying a swim in lake Päijänne[86]

Fishing is another very popular pastime activity, especially ice fishing. Thanks to the use of TARKKA, fishers get a much better idea on where the ice is not too thin or fragile to walk and dig a hole (see figure 4-13 below). They also share TARKKA information on dedicated communities on social media. Fisher guides also use TARKKA to bring their clients to the right place on the lake. 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.

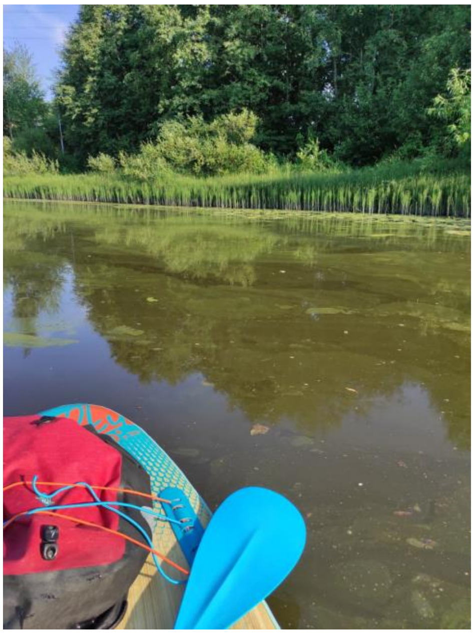
Figure 4-12 Ice-fishing on a lake of the Tampere region[87]

[86] Source: https://wildswimmingfinland.fi/

[87] Source: https://www.zanderland.fi/winterfishing/

Figure 4-13 A TARKKA image illustrating ice-cover over a lake[88]

Kayaking and canoeing are yet another very popular pastime and tourist attraction. Water quality is less of an issue for these activities except when actual Algae Bloom present make the water unpleasant to be nearby.



[88] Source: https://wwwi4.ymparisto.fi/i4/eng/tarkka/index.html?type=RGB&date=2021-04-03&datespan=1&name=SEASONCHANGE&lang=en&zoom=12&lat=61.02396&lon=22.27718&op=0

Figure 4-14 River Vantaanjoki in summer 2021 during cyanobacteria bloom period. Along with kayaking and canoeing, Sup-boarding is popular in the rivers, lakes and coastal waters (Photo by Jenni Attila).

Enjoying the summer near a lake is the characteristic feature of the Finnish culture, perhaps even unique in its scale, is the large number of summer cottages, mostly located at the shores of or close to inland waters. Their total amount is around 509800.[89] Altogether around 41 % of Finns have free-time accommodation regularly to be used. As summer cottages are made occasionally available for relatives and friends, it has been estimated that two thirds of Finns have access to this form of free-time housing, being a basis in particular for many water related activities (together with all the above activities, it doesn't come as a surprise that Finland was voted the happiest country in the world for the fifth straight year at the annual World Happiness Report[90] (!)).

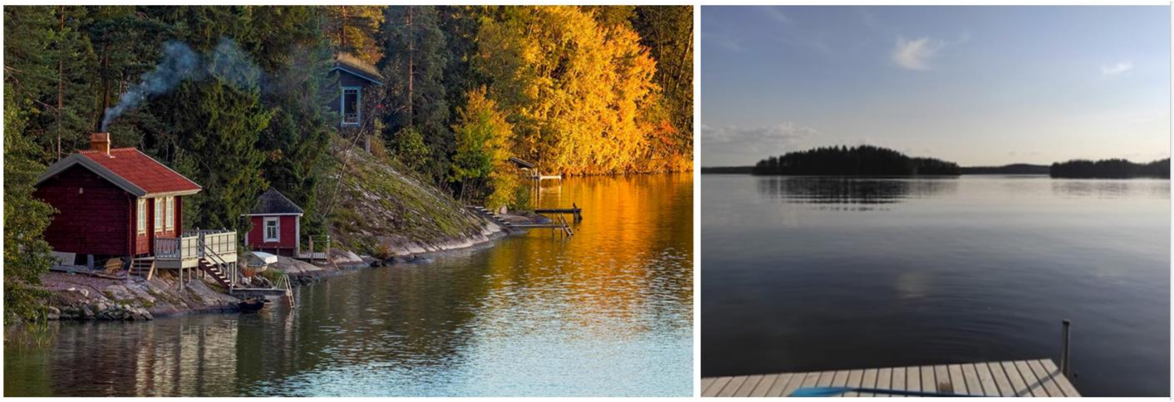


Figure 4-15 Picture on the left: summer cottages with the usual sauna cabin[91]; picture on the right: a view on Finnish lake in an area with many summer cottages in the Southern Finland, lake Pyhäjärvi in Hauho.

Natural Habitats. Lakes and rivers are natural habitats supporting a diversity of wildlife. Their preservation is important and also covered by several EU directives but principally the habitats directive.[92] 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. Lake Saimaa is also the home for the **Saimaa ringed seal** (see figure 4-16 below) affected by water quality. This species can only be found at Lake Saimaa – being one of two species of freshwater seal in the world. It has survived near extinction and with the help of locals and persistent protection work it now has more than doubled its population in recent years.

[89] https://vesistosaatio.fi/en/finnish-fresh-waters/#:~:text=The%20status%20of%20Finnish%20fresh%20waters%20has%20improved,of%20inland%20waters%20in%20Finland%20is%20fairly%20good
[90] https://eu.usatoday.com/story/news/world/2022/03/21/finland-us-happiest-country/7114106001/
[91] https://featuringfinland.com/finland-summer-cottage-cabin/
[92] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

Figure 4-16 Saimaa ringed seal[93]

4.2.5 Other Beneficiaries

Outside the core value chain, there are also many interests in NGOs such as the Finnish Freshwater Foundation which aims to improve the state of Finnish fresh waters.[94] Their mission includes safeguarding the cultural heritage and saving clean waters for the future generations. They operate closely with the environmental administration, NGO's, private bodies and the public to share knowledge and best practices about water ecosystems and their management.

Additional beneficiaries are research institutes (e.g. monitoring the impact of lakes and the quality of the water on the environment and the overall ecosystem), regional state administrative agencies who deliver permits, water companies sourcing part of their water in lakes and commercial fishermen who need to know where to go fishing and benefit from catching healthy fishes.

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.

93 Source: https://www.visitsaimaa.fi/en/saimaa-ringed-seal/

94 https://vesistosaatio.fi/en/about-us/

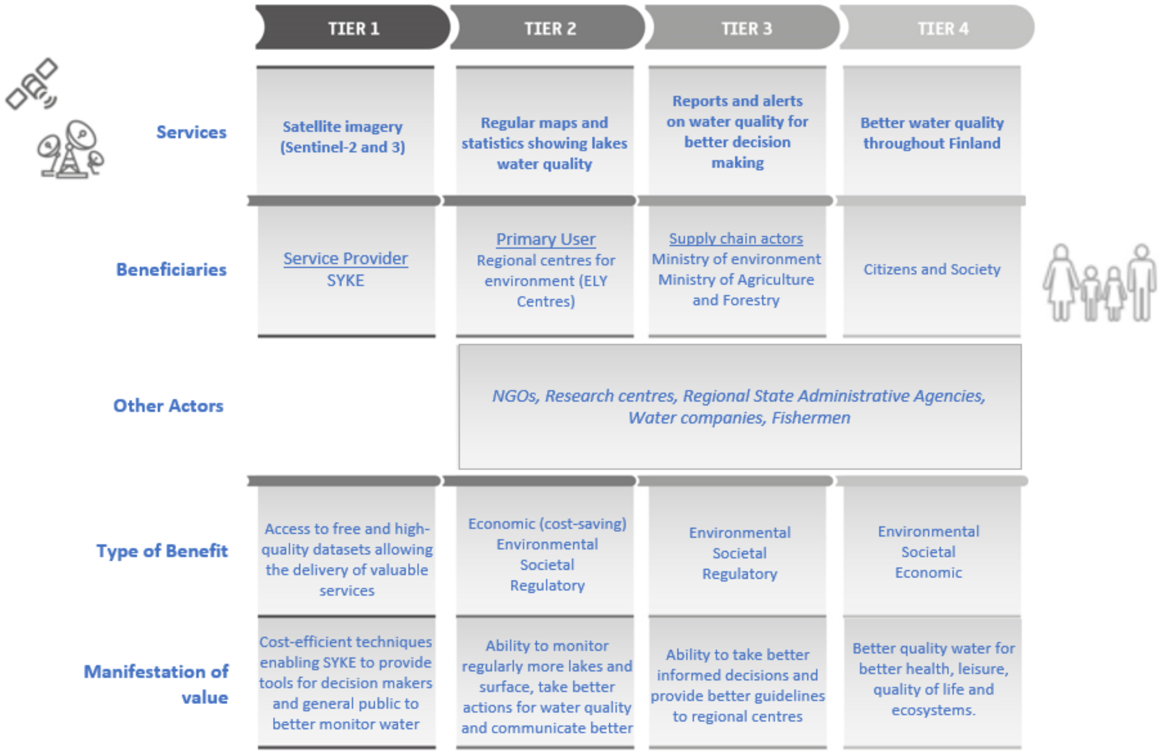


Figure 5-1 Benefits along the value chain

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. 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. 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 in the second half of this decade, 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.95 It remains for the Environmental Ministries to recognise its use for monitoring and reporting purposes. However, the Bathing Waters Directive, which is reported on a yearly basis, is being reviewed. This could provide a first vehicle to introduce satellite measurements and the European service will be relevant to meet reporting needs.

- Adapting to EO measurements and changing practices need important resources and take time. Some ELY centres still have to adapt their processes to EO while others are more advanced and already very actively using EO and TARKKA. 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.

- While more lakes can be monitored more regularly thanks to EO, actions for better quality water also need to be taken afterward. When these actions are taken, it also takes time to observe the results. For example, authorities in Finland promote the use of Gypsum, pulp mill fibre, and structural lime to limit the nutrients in agriculture and limit eutrophication. These soil improving agents have been studied in 2019–2021; the studies have received funding from the Ministry of the Environment's Water Protection Programme. The research results have been compiled in a practical guide end of 2021, from which farmers can select the most suitable soil improving agent for each parcel. As this practice is rather new, long-term results from these initiatives are not yet observed on a large scale. Nutrients are indeed still widely used in agriculture whereas is stays for years into soil layers and in the sediment.[96]

2. Attribution to sentinel data

95 Source: SeBS case on water quality in Germany.

96 https://www.ymparisto.fi/en-US/Waters/Soil_improving_agents_reduce_water_pollu(62072)

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 Finland, the SYKE service is based mostly on 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 – SYKE

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

1) Quantifying the economic added value associated with the number of workers employed by SYKE and whose employment can be directly tied to the utilisation of Sentinel data. In this regard, TARKKA development currently provides work for two persons full time (as an updated version is under development). This represents approximately **200k€ of salary per year**. Additionally, the maintenance and quality control of the material involves 6 persons part-time, representing around **60-70k€ per year**. This includes checking the quality of the maps referring to algal bloom, turbidity and sea surface temperature as well as checking the quality of automated statistics in the STATUS database.[97]
2) Additional funding received by the development of TARKKA-material in Research & Development projects (e.g. Horizon 2020, HEU, ESA and other national R&D fundings). As an example, external funding available for 2022 is about 405k€ (without overheads) and it is about 82% of the total funding (~494k€, without overheads) for water quality related projects and budget funding.[98]

97 The indicated costs are rough estimates from SYKE
98 Source: SYKE

Additionally, the fact that SYKE's primary input data source is free means they consistently save large amounts of costs.[99] SYKE would simply not be able to pay for such huge amounts of rich data if they had to procure commercial VHR data and would probably not have built TARKKA otherwise.

Beyond the economic aspects, it is important to note that SYKE contributes greatly to the 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, a process further supported through SYKE's participation in R&I projects.

Furthermore, by having access to such rich data, SYKE and other researchers can improve their **research** on environmental issues which in turn supports SYKE's **environmental mission**. For example, TARKKA services provided great help to generate the following studies published in high quality journals:

- *The evolution of cyanobacteria bloom observation in the Baltic Sea* (Haraguchi et al., 2021)
- *Observation chlorophyll a data in assessment of water status via MERIS with implications for the use of OLCI sensors* (Attila et al., 2018)
- *A novel cyanobacterial surface accumulation indicator for the Balti Sea. A novel earth observation based ecological indicator for cyanobacterial blooms* (Anttila et al. 2018)
- *Optical model for the Baltic Sea with an explicit CDOM state variable: a case study with Model ERGOM* (Neumann et al., 2021)
- *Satellite-assisted monitoring of water quality to support the implementation of the Water Framework Directive* (Papathanasopoulou et al., 2019)
- *Partition of Marine Environment Dynamics According to Remote Sensing Reflectance and Relations of Dynamics to Physical Factors* (Suominen et al, 2021)
- *A Synthesis of Marine Monitoring Methods With the Potential to Enhance the Status Assessment of the Baltic Sea* (Mack et al, 2020)
- *The evolution of cyanobacteria bloom observation in the Baltic Sea* (Haraguchi et al, 2021)
- Utilizing high-frequency, Earth Observations and empirical data for water quality monitoring and modelling, (Ukonmaanaho L. et al, 2022, in preparation, soon to be sent to evaluation to Environmental monitoring and assessment)
- Modeling the drivers of eutrophication in Finland with a machine learning approach, submitted to Ecosphere (Heikonen, 2022). *To be published.*

Ultimately, the increased usage of SYKE services (see Figure 5-2 below) from the general public, public authorities and research centres provides more **visibility** to SYKE activities. It in turns impacts positively the general public awareness on lake quality and **environment** (a benefit reflected in Tier 4). It also leads to other non-economic benefits such as a better reputation or improved trust through transparency. Furthermore, with this innovation, SYKE is increasing its knowledge which

[99] Although the use of SentinelHub service requires some annual costs.

may produce further benefits in due course. Overall, it improves SYKE's capability to be recognised as a true centre of excellence.

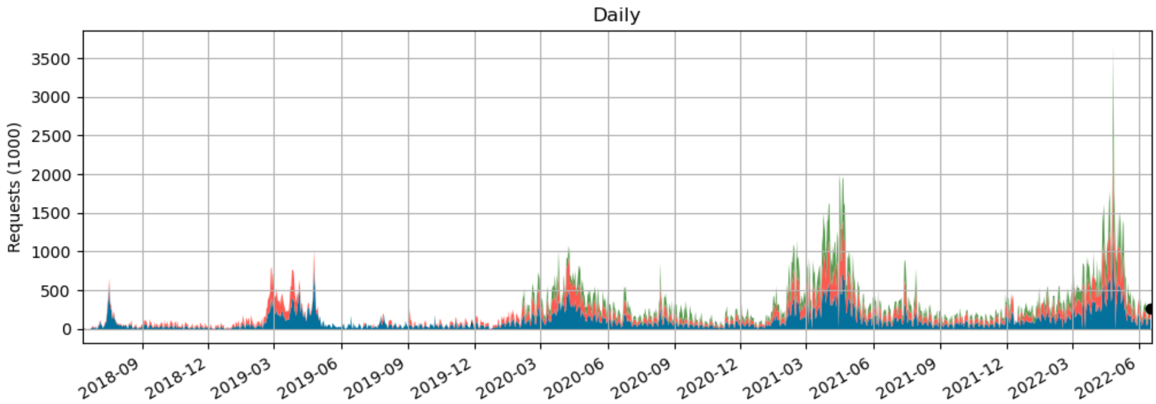


Figure 5-2 Daily usage volume of true-colour images in TARKKA service represented as count of requests to Sentinel-Hub API. (Source: SYKE)

5.2.2 Tier 2: Primary User – regional Centres for Economic Development, Transport and the Environment.

The primary user of SYKE's service, the Regional Centres for Economic Development, Transport and the Environment, experience several types of benefits. First of all, these regional centres obtain a host of free data and observations which are very useful for their water monitoring process. TARKKA data offers environmental status assessment (e.g. a-chlorophyl and turbidity) which covers the entire territory with almost real-time observations. It also enables the monitoring of many more water bodies than would be possible using traditional in-situ measurements, as well as better monitoring of the larger lakes (thanks to full and regular coverage). TARKKA also provides the ability to analyse past status of water quality.

This availability of free data from earth observation allows important cost savings as it would cost tens of millions to monitor most water surface of the Finnish territory otherwise. To compute the associated cost savings, we first evaluate the average cost for one lake to be monitored and then estimate the number of lakes to be monitored.

To evaluate the **cost of one lake to be monitored** we use two different sources

1. When testing is outsourced, it generally costs around €1250 (i.e. 500*2,5) per lake per year. This estimate is computed by counting €500 per lake sampling visit (regarding the physical-chemical parameters) while there is a need to have two to three visits (sometimes four) per year during ice-free period.[100] This value is rather important compared to the values below. It shows that we are quite conservative when estimating the costs below.

[100] This value is sourced from SYKE. It is a rough estimate as it was complicated for the experts to evaluate how much annual visits cost on average per year as various costs are combined together in monitoring costs and the visiting times per year are not the same for all lakes.

2. Currently in Finland, in-situ monitoring is applied to about 4640 water bodies which have to be monitored against requirements of the EU WFD. The current budget to monitor water quality is about €4 million/year (including lakes, rivers, ground, and coastal waters and all variables).[101] Out of this, the total costs for lakes is about €2,7 million (for 4640 lakes under directive reporting). **It comes out to an average annual cost per lake per year of 582€ (i.e. €2,7m/4640)**.

To evaluate the number of lakes to be monitored on top of the WFD requirements, we start with the 57,000 lakes[102] with the size of one hectare or larger in Finland (the other lakes are currently too small, shallow or narrow for satellite observation) from which we subtract the 4640 lakes monitored under the WFD.[103] It comes out with 52,360 lakes. However, as not all lakes need to be monitored to improve their quality (e.g. some lakes are too far from any polluting source or population), we can estimate the number of additional lakes (on top of the lakes monitored by the WFD) to benefit with more information via satellites between 10,000 and 30,000.

From these hypotheses, we estimate potential in-situ monitoring costs (in general in Finland, not within WFD obligations) as the following (using only the conservative 582€ per lake):

1. Maximum cost of €17,46 million (30k lakes*€ 582)
2. Mid-range cost of €11,64 million (20k lakes*€ 582)
3. Minimum cost of €5,82 million (10K lakes*€ 582)

We therefore estimate that satellite data generates useful additional data for a broader knowledg e base over a larger set of lakes with a cost value of approximately €5,82 million to €17,46 million. In other words, **satellite data allows preventing increases in costs of €5,82 million to €17,46 million** which would be required if in-situ monitoring would be expanded to cover a larger number of lakes that are not currently monitored under the WFD.

When making these estimates, we also made the hypothesis of an offset between advantages and disadvantages of in-situ vs satellite monitoring. The first one offers more precise observations on wide range of variables while the second one offers observation more regularly on a larger spectrum. At present, EO offers information on turbidity, chl-a, water colour, CDOM and temperature. These parameters can be linked to other variables in the future. EO offers a much larger number of observations with high spatial and temporal confidence.

Beside avoiding huge amounts of monitoring costs, regional centres also experience regulatory benefit as satellite-based observations offer additional proof of adherence to the relevant provisions under the EU WFD. These benefits could increase in the future, when EO measurements

[101] Approximation made by Petri Liljaniemi, Ministerial Adviser (Department of the Natural Environment, Water resources and marine protection). It corresponds to 16,5 people hired (5,5 in SYKE and 11 in ELY centres) + € 2,2m spent on organising monitoring (material, outsourced services, …).

[102] https://www.stat.fi/tup/suoluk/suoluk_alue_en.html

[103] Although we note that the 4640 lakes that are already monitored under the WFD benefit from extra monitoring with Earth Observation, we make the hypothesis in this study, for the sake of simplicity, that they get sufficient monitoring with in-situ monitoring.

will enter into regulatory frameworks. Whilst satellite-derived measurements are not admitted for monitoring compliance with the two aforementioned directives, this may change in the future – indeed should change – even if it cannot replace entirely the in-situ measurements. Papathanasopoulou, E., Simis, S. et al. (2019), in their study (co-authored with SYKE) supporting satellite-based monitoring in the framework of the WFD, provide interesting recommendations and views on the implementation and evolution of the costs. The authors make the following analysis:

> *"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. There is, therefore, likely to be an added cost of including satellite products into statutory reporting. However, this cost is likely to be small compared to the existing investment in the Copernicus programme of satellites and services, designed to support activities such as these. Direct cost savings may nevertheless be expected when satellite data help deliver better prioritisation and more efficient catchment management and, in some cases, a more strategic design of in situ sampling programmes. Moreover, and although not explicitly relevant to WFD monitoring requirements, more frequent and wider coverage of algal bloom monitoring using satellite products could have spin-off social and economic benefits by providing early warning of and reducing risks and mitigation costs to the public, water utilities and recreational sectors."*

Ultimately, as stated in chapter 4, TARKKA services provide useful evidence in other activities led by regional centres. These activities are supervising adherence to the water permits granted by the Regional State Administrative Agencies, promoting flood protection and prevention, supporting the water services and sewage, supervising water supply and monitoring drinking water quality, providing evidence during litigations (e.g. when dredging affect quality of life of citizens or when lake ecosystems restoration affect the nearby agriculture fields). All this would further contribute to the total economic benefit for ELY centres but the precise estimation goes beyond the scope of this study.

5.2.3 Tier 3: Ministries of Environment and of Agriculture and Forestry

Ministries of Environment and of Agriculture and Forestry obtain strong regulatory benefits as they have access to better information - more comprehensive reports and data from SYKE and the regional centres - 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, or the impacts of HABs on local wildlife and biodiversity. This comprehensive information may also help the ministry to evaluate the impact of other policies on water quality.

For example, the Finnish Government decided to allocate EUR 69 million in funding to enhance water protection in 2019–2023. The programme to enhance water protection brings together the relevant actors, ensures funding for the measures and creates continuity to water protection. The programme funds the most effective measures to improve the status of waters, strengthens cooperation between the different actors and introduces new practices and methods.[104] Studies and reports supported by satellite-derived products are of great help in choosing the most effective measures to be supported by this funding.

The Ministry of Environment also benefits from additional long-term regulatory benefits as continuous observation of water quality helps in establishing correlation between water status and polluting industries (see figure 2-3 above). It in turns allows ministries to be better informed to take policy decisions.

Furthermore, thanks to the use of TARKKA, 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 TARKKA images offer straightforward interpretations.

Good water quality has an influence on tourism which in turn impacts national revenues. Thanks to its beautiful lakes and landscapes, Finland attracts international tourism. More specifically about 6.8 million foreign tourists in 2018 visited Finland. It represents a great income for the country of about 4,6 billion euros (accounting for numbers of 2017) or 2,6% of the Finnish GDP, providing approximately 140.200 jobs.[105]

Last but not least, Finland, 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

Reading 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**. Indeed, quality (and quantity of good quality) water is getting increased attention in most countries around the world. In this regard, table 5-1 below presents ecosystem services offered by fresh water in Finland in 2012.

[104] https://ym.fi/en/water-protection-programme
[105] https://en.wikipedia.org/wiki/Tourism_in_Finland

Freshwater ecosystem services			
Provisioning	**Regulating**	**Cultural**	**Supporting**
Food	Macro-climate regulation (!)	Recreation	Nutrient cycling
Clean water (!)	Micro-climate regulation	Aesthetic value (!)	Soil formation (!)
Energy	Air quality regulation	Cultural heritage (!)	Food web dynamics (!)
Transportation	Water flow regulation	Science and education (!)	Habitat (!)
Biochemical resources (!)	Water purification	Inspirational value (!)	Primary production
Ornamental resources (!)	Invasion resistance (!)		Photosynthesis
Construction	Disease regulation (!)		Water cycling (!)
Genetic resources (!)	Seed dispersal and pollination (!)		
	Erosion regulation (!)		
	Natural hazard regulation		

Table 5-1 ecosystem services of fresh water in Finland in 2012[106]

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.

In Finland, good quality freshwater benefits to

1. **1,5 million recreational fishers catching 22 million kg of fishes per year**[107]

One way to quantify this market is to estimate the price of all this fish if it was to be sold. If we consider that the price of a fresh trout in Finland is about €7,9/kg[108], this market would represent 173 million euros (which makes sense as it represents a share of 21% of the ecosystem services computed below).

This value provides an estimate of the recreational fishing market in fresh water in Finland. To go one step further, the benefits brought by TARKKA 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 300 public beaches by lakes and rivers and other swimmers in fresh water**

A previous study[109] 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

106 Source: https://helda.helsinki.fi/handle/10138/39076

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

108 https://www.finlandprices.com/food-drinks-prices-finland/

109 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.

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 Finland are currently provided by in-situ observation and citizen observations, TARKKA services in Finland allow to confirm such danger. Warnings are then shared on SYKE weekly publications and in local newspaper so that citizens are aware of the HAB.

In Finland, last summer, the nationwide algal monitoring in lakes included about 290 sites, of which cyanobacteria were observed on 136 sites. Minor cyanobacterial blooms were found at 108 sites, abundant blooms at 23 sites and very abundant blooms at only 5 sites.[110]

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 but we can make the assumption that between 500 and 1000 bathers will have been spared at each site. Scaling from the US figures leads us to conclude that 700 to 1400 people would not be ill and from 52 to 104 would be spared a severe illness. The overall benefit of the warning across Finland is therefore estimated between 525k and 1050k.

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

Estimating sentinel added value in this warning process would be hazardous because sentinels are not yet providing the warning for most cases in Finland but the above numbers provide a good idea of future possibilities of sentinels added value.

3. 95 000 kayakers and canoers[111]

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.

4. People enjoying their summer cottages (Finland is counting around 509,800 summer cottages)[112]

A study made by Hakkanen et al. (2022) shows interesting facts about cottages in Finland. Among these they show that buyers primarily pay attention to the cleanliness of nature and especially the body of water surrounding their cottage; in fact, there is greater demand for waterfront cottages. Knowing that, there is no doubt that cottage (as well as other real estate) prices are definitely

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110 https://www.syke.fi/en-US/Current/Algal_reviews/Summary_of_algal_bloom_monitoring_JuneAu(61391)

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

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

correlated to good water quality and that improved ability to monitor water quality (and thus intervene to fix it) should have a small positive impact on real estate value. To provide an idea of the cottage prices, a basic cottage of 37m2 with one room can cost only 65K whereas a cottage with two rooms of 57m2 costs 205k.[113]

Putting a Price on Nature?

It is now widely acknowledged that the global economy must be sustainable to further develop. Inputs in the form of raw materials and energy have added to the pace of development whilst being depleted. The consequences of development have led to increased pollution of our planet. Unless controlled, both these effects lead to an unsustainable future.

In order to understand what level of resource use, 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 is to be found in the Dasgupta review[114], 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 work still to do 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?

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113 https://realting.com/property-for-sale/finland/cottages

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

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.

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 €. Bringing that to Finnish population (5,5 million inhabitant, who all live close to a lake), we can estimate lakes cultural services at 821 million€.

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. 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. 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 TARKKA products are rather recent, it would be too soon to estimate 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. To estimate benefits linked to TARKKA services, it would be interesting to take two facts into account: (1) water bodies quality that have been improved thanks to TARKKA and (2) other water bodies that should have been deteriorated with time but have been stable (or less deteriorated) thanks to TARKKA. To make such analysis, two comparisons need to be done: (1) before and after the introduction of TARKKA services - 5 years difference or more should be ideal to be able to observe results of actions - and (2) a comparison with similar countries to Finland (e.g. neighbouring countries) who did not introduce such kind of EO services to monitor water bodies (to account for the counterfactual, i.e. the natural evolution of water quality when only in-situ monitoring services are used). Additionally, watercourse restoration would be interesting cases to study to provide additional evidence for such model.

We still, as a start, make some rough estimate as the below table provides the only currently available data. To do so we look at the evolution of inland bathing water quality in Finland since the introduction of TARKKA in 2018 (see table 5-1 below). From this table we compare year 2017 (one year before the launch of TARKKA) and year 2020 (two years – which is rather low - after the introduction of TARKKA). Between those years, the percentage of good and excellent quality water has improved from 95,9% to 97,4%. However, this positive evolution of 1,5 percentage points can be explained by many other factors not immediately linked to remote sensing (especially some measurement distortions which led unclassified lakes to be moved in the good or excellent state category). One must also note that the "poor" status also increased by 0.5% (which also may come from unclassified lake bias). All in all, we are not yet in a position to confidently exhibit the direct impact of TARKKA to improved water quality. Nevertheless, we make the rough estimation that

TARKKA allowed the evolution of good and excellent quality water of 0 to 1 percentage points with an average of 0.5 percentage points. We believe that this value will progressively increase in the following years because, as stated above, it is yet too soon to observe tangible impacts of TARKKA services on ecosystem services. Going back to the value of 821 million euros of lakes cultural service and advancing the hypothesis that 0.5% of this value is brough by TARKKA services, it leads us 4,1 million€ of ecosystem services for leisure activities brough by TARKKA. As stated at the beginning of this chapter, we compute 80% of this value to estimate sentinels' benefits among other EO providers. **It comes out to a value of 3,28 million euros/year (minimum is 0 and maximum is 6,56 million euros) of ecosystem services benefits brought by sentinels on lakes quality**.

		Total number of bathing waters	Excellent		Good		Sufficient		Poor		Not classified	
			Count	%	Count	%	Count	%	Count	%	Count	%
Coastal	2017	77	53	68.8%	11	14.3%	4	5.2%	2	2.6%	7	9.1%
	2018	76	50	65.8%	12	15.8%	6	7.9%	0	0.0%	8	10.5%
	2019	77	49	63.6%	12	15.6%	7	9.1%	1	1.3%	8	10.4%
	2020	78	56	71.8%	14	17.9%	4	5.1%	2	2.6%	2	2.6%
Inland	2017	222	203	91.4%	10	4.5%	1	0.5%	0	0.0%	8	3.6%
	2018	225	205	91.1%	8	3.6%	1	0.4%	1	0.4%	10	4.4%
	2019	224	211	94.2%	4	1.8%	1	0.4%	1	0.4%	7	3.1%
	2020	225	213	94.7%	6	2.7%	1	0.4%	2	0.9%	3	1.3%
Total	**2017**	**299**	**256**	**85.6%**	**21**	**7.0%**	**5**	**1.7%**	**2**	**0.7%**	**15**	**5.0%**
	2018	**301**	**255**	**84.7%**	**20**	**6.6%**	**7**	**2.3%**	**1**	**0.3%**	**18**	**6.0%**
	2019	**301**	**260**	**86.4%**	**16**	**5.3%**	**8**	**2.7%**	**2**	**0.7%**	**15**	**5.0%**
	2020	**303**	**269**	**88.8%**	**20**	**6.6%**	**5**	**1.7%**	**4**	**1.3%**	**5**	**1.7%**

Table 5-2 evolution of bathing water quality in Finland[115]

In addition to the above estimations, we have seen in chapter 4 that the open platform TARKKA brings direct (or indirect through social media communities, websites and local news) valuable information to ice fishers who would like to estimate the ice thickness (not too thin for not falling through the ice and not too thick for not digging too much through the ice layer) and to swimmers who need to assess quality of water before going a lake.

The estimation of TARKKA number of regular users[116] was about 40k in 2021, although some of them are not bather or fishers (e.g. they can be researchers) we estimate that it offsets the network

[115] Source: https://www.eea.europa.eu/publications/bathing-water-quality-in-2021/european-bathing-water-quality-in-2021/#fn1

[116] The term "users" in Google Analytics focuses on the number of people who visit the website. A person that visits the website is given a unique identifier to help track if a user comes back to the website or not. A user will only be

effect brought by social media for example. If each fisher and bather saves a net 1 hour (by finding the information on TARKKA instead of other channels) of their time on which we can place a value of €20, this means a net benefit of about €800K.

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, water companies and commercial Fishers.

The transparency provided by the Sentinel-powered service allows NGOs 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. Drinking water in Finland is produced from different raw waters as follows: 42% from groundwater, 39% of surface water (lake, river or coastal water) and 19% of artificial groundwater.[117] Lake Päijänne, the second largest Finnish lake (1,118 square kilometres) serves as the source of drinking water for millions of people in the country. For the algae bloom period during the summer of 2022 TARKKA gallery is used to monitor the water inlet of drinking water in lake Päijänne.

TARKKA also provides valuable data on water status to potentially 340 commercial fishermen inland (compared to 2200 in sea) who produce 4,5 million kg of commercial fishery catch. These fishers also benefit from high quality water which has an important impact on fishes' health and number.

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 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 A2.

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

Table 5-3 Benefits Assessment by Category

counted once within your selected date range in Google Analytics (source: https://netvantagemarketing.com/google-analytics-sessions-vs-users-vs-new-users/)

117 https://thl.fi/en/web/environmental-health/water/drinking-water

5.3.1 Economic

The economic benefits are shown in the table below.

Tier	Benefits identified		Annual economic value stemming from the use of Sentinel-enabled services (in €)	
		Min	Mid-range	Max
Tier 1 (SYKE)	Cost savings for avoided satellite data acquisition and avoided in-situ monitoring costs	**N/A**	**N/A**	**N/A**
Tier 2 (ELY Centres)	Cost savings for avoided in-situ monitoring costs	**€5,82 m**	**€11,64 m**	**€17,46 m**
Tier 3 (Ministries)	N/A	**N/A**	**N/A**	**N/A**
Tier 4 (Citizens and Society)	Cultural ecosystem services Time saved by using TARKKA	**0** **€0,8m**	**€3,28 m** **€0,8m**	**€6,56 m** **€0,8m**
TOTAL		**€6,62 m**	**€15,72 m**	**€24,82 m**

Table 5-4 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. For example, in tier 4 our analysis suggested that the benefits of HAB warning across Finland could reach €1,05m. The use of TARKKA's service certainly helps in assessing the state of a lake and providing the warning, but to assign a percentage of this figure to the use of a Sentinel-powered service would require several assumptions and ultimately would be quite an uncertain figure. 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 classify the contribution to economic benefits as 4 stars, mainly coming from monitoring cost savings.

- Cost savings from avoided satellite data acquisition (tier 1)
- Cost savings from avoided in-situ monitoring (tier 2)
- Cultural ecosystem services from good quality water (tier 4)

5.3.2 Environmental

As discussed in the previous sections, the Sentinel-enabled TARKKA service supports the monitoring of water quality in Finland, giving rise to significant environmental 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.
- 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 TARKKA 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.

- Reduce pollution (less fertilizer run-off)
- Maintenance of natural habitats and ecosystems (tier 4)
- Supporting tool in the detection of environmental threats (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 Finland but also elsewhere. In that regard, the TARKKA service is becoming recognised by SYKE and ELY Centres as an effective way to improve their ability to monitor the quality of water under their legal responsibility. The data helps:

- ELY centres (together with SYKE) to improve their ability to carry out their own institutional monitoring tasks in accordance with their legal statutes and regional and national laws.
- ELY centres to support Regional State Administrative Agencies in dredging and industrial permits and when litigation occurs in these domains.
- ELY centres to provide evidence during litigation with farmers when lake ecosystems restoration may affect the nearby agriculture fields.
- ELY centres 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 (especially in the WFD).

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

5.3.4 Entrepreneurship & Innovation

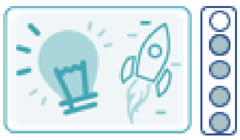
The level of innovation in this case is high. In addition to the development of the new product combining artificial intelligence and remote sensing for SYKE, this dimension is also present at a user level for SYKE, ELY Centres and the other environmental agencies.

Firstly, for SYKE, TARKKA 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 ELY Centres, 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 the Finnish regional agencies responsible for the environment.

When looking at the interaction between SYKE, ELY Centres, 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 4 stars on our qualitative scale.



- 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.

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.

On a more practical side, the public portal also allows users to check on the water situation before travelling to the lake concerned. It brings direct (or indirect through social media communities, websites and local news) valuable information to ice fishers who would like to estimate the ice thickness and to swimmers who need to assess quality of water before going a lake.

Obtaining wide-scale data on the quality of the water in lakes and rivers is really only possible through the use of satellite imagery. The data is less precise 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 TARKKA services will evolve and its effects on water quality (with an effect on the use of lakes for leisure) 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 (SYKE)	Revenue linked to **EU and national fundings**	Economic	
	Cost-savings from the use of free satellite data	Economic	
	Creation of **innovative services**	Entrepreneurship and innovation	

	Perform **better research**	Science	
	Support own **environmental mission**	Environmental	
Tier 2 (ELY Centres)	**Cost savings** for avoided in-situ monitoring costs	Economic	**€ 5.82-17.46 million**
	Support to **other activities** (permits, floods monitoring, etc.)	Economic	
	Additional **proof of adherence** to the relevant provisions under EU and national regulation	Regulatory	
	Support own **environmental mission**	Environmental	
Tier 3 (Ministries)	Better information for **better decision-making**	Regulatory	
	Common understanding	Societal	
Tier 4 (Citizens and Society)	**Ecosystem** services	Economic	**0 - €6,56 million**
	Time saved by using EO services	Economic	**€0,8 million**
	Better health and quality of life	Societal	
	Maintenance of **natural habitats and ecosystems**	Environmental	
TOTALS			**€ 6,62 – 24,82 million**

Table 5-5 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 Finland are striking. This technology provides detailed measurements of several parameters linked to the water quality over a large geographical area. Its use 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 are starting to devote higher budgets for Sentinel-enabled services even if it is not contributing to their core reporting mission – simply because its not explicitly foreseen in the relevant regulation.

Such services are especially relevant in a country like Finland where the enormous amount of water bodies, many of them situated in very remote areas, would put significant strain on the relevant authorities in terms of logistics and costs if they were to use only in-situ monitoring methods. This would inevitably reflect on a poorer quality water and hence quality of life of citizens and other economic variables. Additionally, TARKKA services do not only serve water quality, but also the monitoring of a wide range of events such as watercourse restorations and its impact on nearby fields, litigations over some dredging events, winter floods prevention, fishing opportunities, etc.

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. Of course, with hindsight, it is clear that this would be the case as the link between the environmental and regulatory dimensions is so close.

Additionally, the economic benefits have been calculated based on a realistic scenario today. They are based largely on regional centres saving monitoring costs as well as citizens having access to cleaner water and saving time and expense linked to poor water quality. The size of economic benefits should grow in the future.

Another important fact about this case is that the benefits will grow in the future. This exemplary use of satellite data in Finland is at a relatively early stage and its positive impact on the environment, economic variables, society, innovation and science are going to grow significantly in the next five to ten years. Such growth should be induced by regulation adaptation to satellite data (the use of EO data as reporting method in the current 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 measurements of water quality. Some data coming from Landsat 8 is also used to increase the frequency 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 Finland (and in a previous study in Germany), this issue is very relevant for every country and the respective solutions have global applicability.

TARKKA services are mainly provided on the Finnish territory (to a less extend also on neighbouring countries territories, figure 6-1 below shows TARKKA users[118] per country) and are adapted to

[118] The term "users" in Google Analytics focuses on the number of people who visit the website. A person that visits the website is given a unique identifier to help track if a user comes back to the website or not. A user will only be counted once within your selected date range in Google Analytics (source: https://netvantagemarketing.com/google-analytics-sessions-vs-users-vs-new-users/)

Finnish water specificities (which vary a lot from one country to another). These specific services developed by the Finnish Institute for the Environment are therefore mainly limited to Finland.

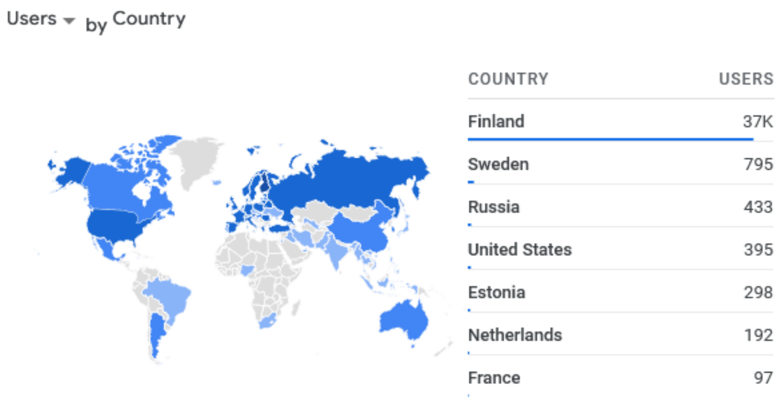


Figure 6-1 number of users (during the last 12 months, July 2021 to June 2022) of TARKKA services per country.

Nevertheless, it would be extremely valuable for other countries to be inspired by TARKKA success story and to develop their own services. 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 8 other countries (Denmark, Belgium, Germany, France, Sweden, Estonia, Norway and the Netherlands), we can state that such service is already developed in Germany (using EOMAP private services), Belgium is using Sentinel-2 for temporal and special monitoring of Chl-a, Sweden has a project on its way (Brockmann Geomatics has developed for a lot of lakes specific services for their customers, mostly public sector) and Estonia (via Tartu observatory) is very experienced in lakes water quality R&D. Additionally, R&D projects exist in Denmark, Norway France and the Netherlands 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. This has the potential to expand the market and the use of the products into other user segments not addressed so far.[119]

Increased Market Penetration

There is strong potential to increase the uptake of TARKKA and STATUS services within Finland as it is an open data/public service. ELY centres are still adapting to these services and will increasingly rely on it. Beyond this, other users of water bodies may also benefit from such service. Additionally, citizens (mainly fishers and swimmers) are increasingly using TARKKA and are sharing their findings

[119] Source: SeBS case on water quality in Germany

on social media on where to go swimming or fishing. This fact is more detailed in chapter 5 and observed in figure 5-2 which shows an important increase of the usage during the last 4 years (to reach 40K users – amongst which 37K are in Finland - in the last year). Many other public bodies are also interested in the quality of water and of knowing when this becomes degraded. Water companies could also potentially use TARKKA services (as in the case of Germany). In addition, already some of the local members of the “the water restoration network” (regional water protection association; their goal is to improve the water quality in lakes and rivers) follow their lakes/coastal areas of interest through TARKKA.[120]

Improved Technological Maturity

TARKKA services are being developed further and their visual appearance and functionalities are being updated according to users’ requirements while the number of users is continuously increasing.

Short term evolutions are related to services improvements such as the use of AI methods for detecting interesting phenomena (hot spots) and turbidity river blooms during springtime. 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 TARKKA.

[120] https://www.ymparisto.fi/en-US/Finnish_water_restoration_and_management_network

6.4 Final Thoughts

A comparison with the SeBS case in Germany is instructive. When looking at the big picture, the overall benefits are in the same ranges of value in both cases and benefits in all dimensions are rather important. Nevertheless, the two differences stated in section 1.3 lead to some variations in terms of benefits.

1. The greater economic benefits in this case (€6,8 m to €18,8 m compared to €4 m to €7.8 m in Germany) are mainly attributed to the geographical features of Finland having many more lakes than Germany. Cost savings from lake monitoring with in-situ techniques are therefore higher.
2. Additional benefits are taken into account in Germany as the service provider is a commercial company (EOMAP) for which an economic added value is attributed from selling its product.
3. In Finland, satellite observation derived services developed by SYKE are publicly available as they are open-source services. In Germany, this service is not publicly available. This fact allows Finnish citizens (and other institutes) to gain benefits as they can themselves have access to water monitoring data. This inevitably reflects positively on most dimensions studied in this case.

Additionally, it is essential to highlight that Sentinel-derived services have been providing, in both case, a rich source of information generating significant economic and environmental sustainability impact. Also in both cases this is expected to 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, in both 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 Finnish case also links 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.

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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[121], 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 121. 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.

[121] 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)

INNOVATION-ENTREPRENEURSHIP	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.
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

Lauriane Dewulf, PhD in Economics

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 Mamais, MSc in Theoretical Physics

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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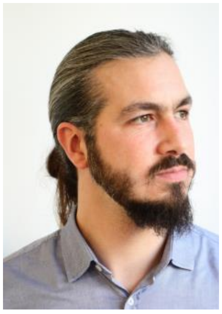
The SeBS Study Team

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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