European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Lake Water Quality Management in Germany

April 2021

Client:	ESA
Client Representative:	Alessandra Tassa
Date of Delivery:	May 2021
Version:	Draft
Author(s):	Geoff Sawyer (EARSC)
	Christopher Oligschläger (EARSC)
	Nikolay Khabarov (IIASA)
Reviewer	Alessandra Tassa (ESA)

Version	Date	Comment
1st Issue	May 2021	

or more information contact:

- **EARSC: info@earsc.org**
- **ESA: Alessandra.Tassa@esa.int**

Funded by the EU and ESA – ESA Contract Number: 4000119743/17/I-SBo.

The views expressed herein can in no way be taken to reflect the official opinion of the European Space Agency or the European Union.

Table of Contents

List of Figures

List of Tables

Setting the Scene

It was Maria's 14th birthday and her father had promised to take her with her brothers to the lake followed by a meal in town. Some of her friends would meet them at the lake and they would go on to eat together in Backnang.

She had asked to go to the Lake Ebnisee which was her favourite swimming spot and her father had suggested she use the local swimming portal to check on the local conditions. As she opened it and navigated to the information about Ebnisee her eye was caught by the word satellite. Maria was fascinated by all things to do with space and so she looked further.

She learned that the bathing water service is using data coming from Europe's Sentinel satellites to monitor the water quality in the bathing lakes and show if it becomes degraded. Happily, this does not happen often as the water management in Baden-Württemberg is of a very high quality. Nevertheless, Maria was happy to see that everything was blue at the Ebnisee meaning the swimming conditions were perfect.

Maria knew about the Sentinel satellites. She wanted to become an engineer like her father who worked for a company in Backnang which builds laser terminals for satellites. She had chosen to study maths and physics in her next school year to help her follow her dream. She already knew that each of the Sentinel satellites has a laser terminal on-board to allow it to send its data back to the ground via the European Data Relay Satellite (EDRS). This allowed Europe to collect data from all around the world.

Maria went to see her father to tell him about her discovery. Of course, he knew already! "*Our environmental agency, the LUBW in Karlsruhe, receives the information every few days but at least once per week from a small German company. This tells them if there is a build-up of particles in the water or if there is a risk of a Harmful Algal Bloom (HAB). These things are quite nasty when they happen turning the water a bright green and are best avoided. But they are perhaps even more dangerous just before they become visible as that is when if you swim and swallow any of the water it can make you quite ill."*

"Does the government not have rules to stop that happening," Maria asked?

"Of course, they do have laws which control the amount of fertiliser which farmers can use – as this is normally the cause of the problem, but that does not stop all the HAB's. The farmers are not allowed to use fertiliser close to any rivers or streams but even so, quite a lot gets into the lakes and builds up over the years in the sludge at the bottom. Under certain conditions, this gets released and triggers the HAB. If you are interested, I'll try to arrange for you to visit the LUBW, I know someone who works in their office near Friedrichshafen, she will be able to explain how they try to ensure that the law is met."

As they got into the car, Maria was still thinking about how important reducing pollution is for the planet. Not just for swimming but also to preserve the wildlife in and around the lake to make it attractive for all of us to enjoy the nature. She was a convinced environmentalist. But she also had another dream which she had not yet shared with her father. She had heard recently that ESA were looking for new astronauts. Now she is too young, but maybe in 10 years' time she could go into space and look down on this wonderful land from up there. Maybe she could even join a mission to Mars.

This story is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real, although the characters, the conversation and the situation are entirely fictional.

Executive Summary

Lakes are a key feature in our natural environment. Some are natural others are man-made, 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. Our case looks at the management of the water quality of lakes in Germany and how this is improved through the use of data coming from Sentinel and other satellites.

The focus of our attention is 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. But 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.

German legislation at the federal and regional level applies to maintaining the quality of water. The State Institute for the Environment Baden-Württemberg (LUBW) produces an annual report in which it provides details of the water quality in the lakes and rivers. Many of these laws link to European regulations such as the EU Water Framework Directive (WFD) and the Bathing Waters Directive (BWD) and require reporting at a European level through the European Environment Agency (EEA). For reporting purposes, the prescribed methods of measurement of the water quality do not explicitly include the use of satellite data.

But the responsibility of the LUBW and similar regional institutes does not stop with reporting. They are responsible as the competence centre for environmental protection and nature conservation for reporting on environmental issues of which the quality of the water in the lakes and rivers is a high priority.

Whilst the regional environment agencies report on the status, managing the water quality is the responsibility of the regional and local authorities. One of the key issues they face is the presence of chemicals in the water coming from farms. Controls on the level of fertiliser use are imposed by the Ministry for Agriculture in co-operation with the Ministry for the Environment. This leads to limits on the quantity of fertiliser that can be used and to buffer strips alongside each water body where the farmer may not apply any fertiliser.

Excess nitrogen and phosphorus in the water, coming from the run-off of fertilisers, can lead to Harmful Algal Blooms (HABs) which can be extremely dangerous to wildlife and indeed to humans. If an algal bloom occurs, unless remedial measures are taken, then fish and other wildlife may die, and people swimming in the water can become quite ill.

And this is where the satellite data comes in. Even if it cannot yet provide the type of measurements required by the controlling legislation, or meet the methodological needs, it can provide more extensive measurements both in terms of the number of lakes, variations within larger lakes and in the frequency of the measurements compared to very time consuming and logistically complicated in situ measurements. Hence the data coming from the satellites provides a much better overall picture of the water conditions. This allows a more precise understanding of the state of any particular lake or water body.

The local authorities are largely responsible for gathering the data required by the environment agencies. Resources are limited and are focused on the major lakes and rivers of the region. The region of Baden-Württemberg has around 260 lakes which are of a size of 10ha or more. Some of these are monitored on a constant basis by the LUBW and more (around 100 lakes) are monitored by the district authorities nominally once every 5 years through the detailing of a ground crew to take water samples. The other 150 lakes are not measured unless a problem emerges.

Several indicators are used to monitor the water bodies and to detect if problems are likely. These include the level of chlorophyll-a, the water temperature, the turbidity of the water and the presence of suspended organic matter. These can all be measured using satellite data and hence can enable more effective, more frequent and more widespread monitoring than is possible using in-situ monitoring only. Indeed, the satellite data can be complementary and indicate where deeper investigations should be made as part of the overall management process.

Data from both Sentinel-2 and Sentinel-3 is used by a German SME, EOMAP, to deliver a water quality service, which enables the LUBW and other stakeholders to access the environmental information for the water bodies in their region. This is starting to be used in a number of ways with a number of potential benefits for the region:

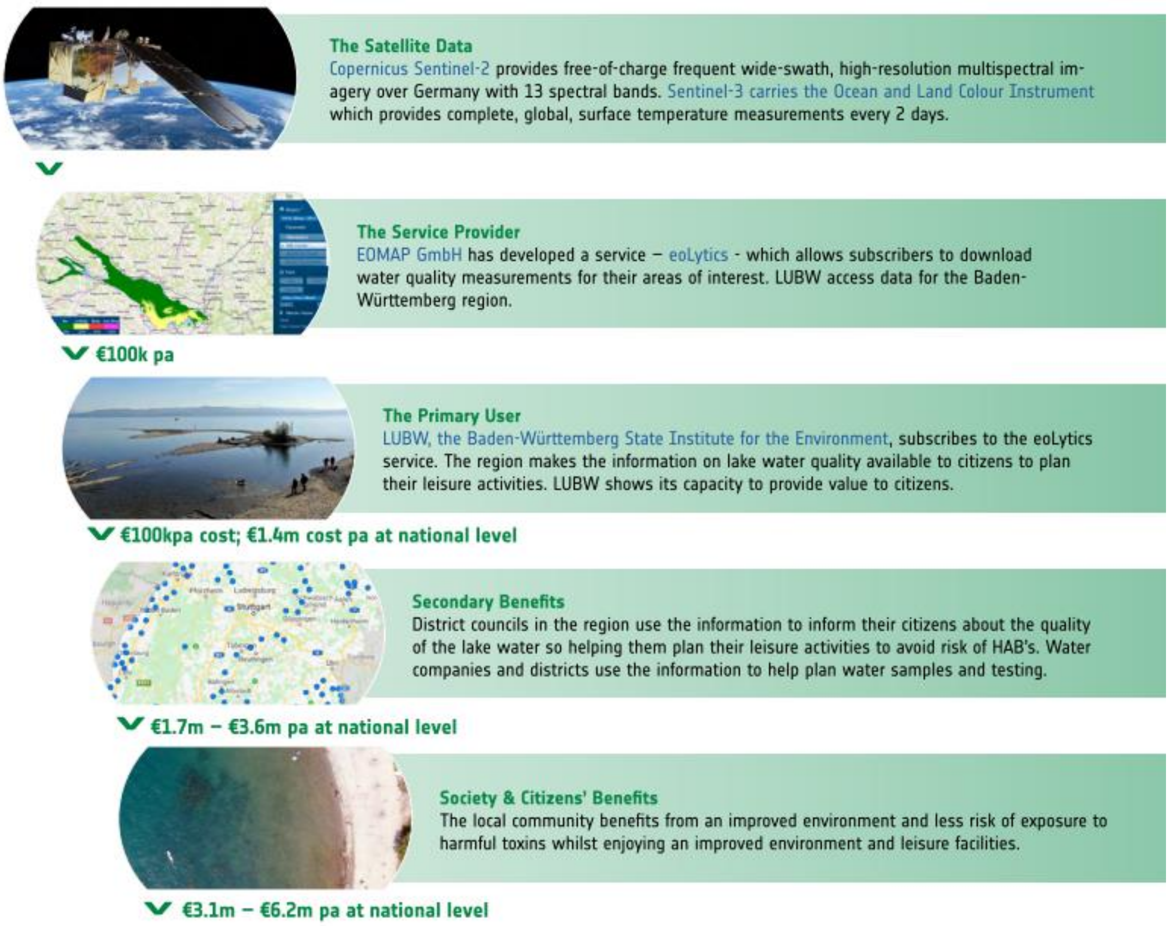
- To monitor the water quality of lakes and ponds in complement to in-situ measurements and to provide guidance on where in-situ measurements should be made.
- To implement measurements of small lakes and ponds which are too numerous to be realistically monitored using traditional, in-situ techniques.
- To identify when an algal bloom is likely or already taking place in order to firstly deploy ground measurements and ultimately to close the water to leisure use, so protecting citizens from harmful toxins.
- To monitor changes in water quality from year to year to inform policy makers and over the long-term trends in water quality to inform agriculture regulations on the use of fertiliser and other chemicals and environmental laws linked to biodiversity.
- To trigger a direct response in the case of a lake becoming too polluted, to protect fish-life. Response can be to modify the water flows and especially mixing of different layers, oxygenate the water, provide chemical treatment, or in an extreme to drain the lake and remove the polluted sediment.
- To inform water supply companies on the quality of the water entering their collection areas and hence to plan on the level of treatment necessary in water plants.
- To inform on the longer-term accretion of nitrates and phosphates and support more precise legislation and/or its implementation.

Various benefits can be induced through the decisions being taken linked to the processes described above.

- Citizens benefit through improved access to leisure facilities (swimming, fishing and sailing) and reduced risk of suffering from possible intoxication as a result of Harmful Algal Blooms.

- The environmental benefits and biodiversity are preserved by developing a better understanding of where water quality is degraded.
- Water companies can understand where suspended matter is becoming more severe and adapt their treatment accordingly.
- Regional environmental agencies are able to gather a wider picture of the quality of water bodies in their region.
- In economic terms, the benefits are estimated at €440k to €0.9m in Baden-Württemberg and between €4m and €7.8m if applied across the whole of Germany.

Overall, the capability to monitor water quality more effectively can lead to actions being taken to support a better quality of life for the citizens. Information derived from the satellites can potentially be made directly available to the citizens of Baden-Württemberg and other regions, so improving transparency and trust. Furthermore, it has the potential to improve environmental compliance in Germany through future regulatory changes.



1 Introduction & Scope

1.1 The Context of this study

The analysis of the case study *'Water Quality Management in Germany"* is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This 4-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 Germany, the quality of the water in lakes is controlled by regulations often at European level 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. But only a few lakes can be monitored with the resources available and in recent years, the environment agency in Baden-Württemberg has been using measurements using data from Sentinel 2 and 3 satellites to complement the official measurement samples. This allows more frequent measurements to be made, as well as for many more of the lakes and for problems to be identified earlier, so enabling more rapid corrective action.

Our case looks at the management of the water quality of lakes in Germany using the actions in Baden-Württemberg as a reference, and how overall decision making is improved through the use of data coming from the Sentinels and other satellites. A service from EOmap provides the State Institute for the Environment Baden-Württemberg (LUBW) measurements indicating the quality of the water every few days. This supports the institute in legal responsibility to protect the lakes and rivers of its region. This service can also be particularly useful for local citizens using the lakes and for water companies that draw water for local household supplies.

Hence, the satellite data is offering more extensive and much more frequent measurements of the water quality in the lakes and especially to indicate the presence of a Harmful Algal Bloom (HAB) which is dangerous for both swimmers and for wildlife including fish.

In the future, these data should also feed into new legislation recognising the added benefits which satellite data can bring to the maintenance of water quality in Germany.

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 first case that looks at water quality and also where the environment has such a strong impact on the characteristics of the case.

It is not the first case dealing with water. An earlier case looked at dealing with the response to flooding in Ireland[1], whilst another has looked at the issue of underground water abstraction[2]. However, neither were concerned with the quality of water but of its presence in excess (in Ireland) and the consequences of abstraction (in Spain).

In terms of the satellite data, Sentinel-2 has featured in many previous reports, especially linked to agriculture and farm management but it is the first case where Sentinel-3 appears. Further, the parameters being extracted from the Sentinel-2 images are very different from those used in crop monitoring. Hence this case is breaking new ground in both its application and its use of Sentinel data.

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. The full methodology which is used to analyse each case is described in detail in a dedicated report[3] which will be updated in line with findings of further cases as they are developed.

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

[1] Flood Management in Ireland, SeBS case December 2018;
[2] Aquifer Management in Spain, SeBS case, October 2020,
[3] SeBS Methodology, A practical guide for practioners, December 2020.

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, 20 case studies will be developed with reports to be published on each one. The study has started in March 2017 and will end in 2021.

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 Thomas Wolf who introduced us to a number of the experts we have consulted. We wish to thank the following persons for their time spent talking with us to develop the case.

- Dr Thomas Heege - EOMAP – founder and CEO EOMAP GmbH
- Dr Eva Haas - EOMAP)
- Dr Thomas Wolf - LUBW Baden-Württemberg State Institute for the Environment.
- Kristina Popp (LUBW) -
- Kathleen Rathenow - Regional Council Tübingen.
- Thomas Bechter-Wild - Office for Water and Soil Protection, Landratsamt Bodenseekreis
- Dr Karsten Rinke – Head of Lake Research at the Helmholtz Centre for Environmental Research
- Dr Martin Pusch – Research Group Leader Functional Ecology and Management of Rivers and Lake Shores - Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB).
- Stephane Isoard - Water and Marine – Head of Group, European Environment Agency.

Our time and availability to meet and discuss with experts were severely limited by the Covid pandemic and all interviews were conducted remotely. The personal meetings and visits during a field visit lend a great richness to our understanding of the cases and the stories behind them. We should like to have the opportunity to meet with the various water and environment experts cited in this report and to update with some personal perspectives. In the meantime, the story is still complete but maybe lacking in some details. We hope that you enjoy the read in any case.

Please contact us at info@earsc.org with any questions or observations.

2 Water Quality Management in Germany

2.1 Overview of Water Bodies

Water bodies and specifically lakes play a prominent role in everyday life in Germany. Most of Germany's natural lakes are located in Northern Germany, in the Alpine foothills and in the Alps, where they strongly determine the landscape's overall characteristics. In addition, there are numerous artificial lakes (open-cast mining lakes, dredging or excavation lakes in the course of clay, sand and gravel extraction, dams and lowland reservoirs). The natural lakes are distributed very unevenly in Germany and show great geomorphological and hydrological differences. They were mostly formed during the Ice Age and are therefore relatively young, i.e. less than 20,000 years old. The number of natural lakes in Germany is more than 12,000, of which about 750 are larger than 50 ha and are therefore also relevant for reporting and assessment according to the EU Water Framework Directive (WFD). Figure 2-1 gives an impression of the distribution of lakes throughout Germany. It shows only the natural lakes and how these are concentrated mainly within the northern/north-eastern Bundesländer of Brandenburg, Mecklenburg-Vorpommern and Schleswig-Holstein.

Verteilung der natürlichen Seen auf die Bundesländer (nach UBA Texte 36/03)

Bundesland	Seefläche			
	› 0,1 km^2	› 1 km2	› 10 km2	› 25 km2
Baden-Württemberg	10	4	1	1
Bayern*	67	23	4	3
Berlin	15	5	0	0
Brandenburg	700	100	4	0
Bremen	0	0	0	0
Hamburg	2	1	0	0
Hessen	7	0	0	0
Mecklenburg-Vorpommern	600	100	10**	4
Niedersachsen	5	5	2	1
Nordrhein-Westfalen	7	0	0	0
Rheinland-Pfalz	5	1	0	0
Saarland	0	0	0	0
Sachsen	0	0	0	0
Sachsen-Anhalt	8	4	0	0
Schleswig-Holstein	200	50	5	1
Thüringen	0	0	0	0
Summe	**1.626**	**293**	**26**	**10**

*natürliche und künstliche Seen, ** inklusive Schaalsee, der auf der Grenze zu Schleswig-Holstein liegt   Quelle: Umweltbundesamt

Figure 2-1 Distribution of natural lakes among the federal states in Germany © German Environment Agency

Similar to flowing waters, lakes are subject to influences and pressures from their surroundings. The composition of the biotic communities is determined by the environmental factors and, above all, by the degree of pollution. In particular, the increasing pressure of recreational use, but also nutrient inputs, is problematic for the sensitive lake ecosystems.[4]

In Baden-Württemberg, the south-western Bundesland, there are more than 4,500 standing waters with an area of more than 2000 sq. metres. The majority of these are small, natural lakes whose formation is closely linked to the last ice ages. Most of the natural small lakes are found in the Upper Swabian Alpine foothills and the Black Forest. In addition to these natural waters, Baden-Württemberg has reservoirs and a large number of man-made quarry ponds and other types of ponds. The quarry ponds, mainly located in the Upper Rhine Plain, date back to more recent times and are to a large extent currently used, i.e. gravelled out. The Upper Swabian ponds were used for milling and fish farming in earlier centuries and today are often hardly distinguishable from natural lakes. Due to the importance of lakes for drinking water supply, fishing, recreation and raw material extraction and their simultaneously high ecological value, areas of tension between use and sustainable development often arise.[5,6]

The most famous of the lakes in Baden-Württemberg is Lake Constance (see cover photo) being by far the biggest lake with an area of 536 km². Baden-Württemberg has 24 lakes with a size larger than 50ha, of which six are natural lakes, three are man-made dams or reservoirs and 15 are dredging lakes. Given their size, they fall under the EU WFD[7] and have to be monitored accordingly. On top of this, 260 lakes have a size of more than 10ha and around 1.300 smaller lakes with surfaces of more than 1ha.[8]

These lakes are used in various ways and play an important socio-economic and environmental role. Lakes and their shores not only offer several environmental benefits, but they affect our quality of life and support the economy. Lakes can mitigate the impact of floods and droughts by storing great amounts of water and releasing it during shortages. Lakes replenish groundwater, positively influence water quality of downstream watercourses, and maintain biodiversity and habitat of the area. When the ecological state of a lake is good it can provide major opportunities for recreation such as swimming, other water sports or fishing, tourism, and residential living. Both natural lakes, as well as dams and water reservoirs, can be a source of drinking water for a municipality. Lakes are a water supply for industry and an irrigation source for agriculture. To sum up, they are important ecosystems that can sustain a healthy balance of aquatic life, enjoyment and support our socio-economic needs in the long-term if used sustainably.[9]

Due to its area and economic importance, Lake Constance has a special need for monitoring. Lake Constance is surrounded by 3 countries - Germany, Switzerland and Austria have respectively the longest lengths of shoreline – which renders the management of this particular lake more complex

---

[4] Seen | Umweltbund https://www.umweltbundesamt.de/themen/wasser/seen#wissenswertesesamt
[5] https://www.LUBW.baden-wuerttemberg.de/wasser/seen-in-baden-wuerttemberg
[6] For a comprehensive list of lakes by name and location, go here: https://www.seen.de/seen-in-deutschland/baden-wuerttemberg/
[7] EU Water Framework Directive 2000/60/EC, EUR-Lex - 32000L0060 - EN - EUR-Lex (europa.eu)
[8] Satellite remote sensing of chlorophyll and sechi depth for monitoring lake water quality: Nathalie Karle, Thomas Wolf, Thomas Heege et al, Proceedings SPIE 2019
[9] https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/lakes/importance.html#:~:text=Proper%20lake%20function%20can%20ease,and%20habitat%20of%20the%20area

and also more important because of the shared interests. Due to its size and form, the lake is recognised as consisting of 3 separate water bodies – not linked to the three countries – which have different mixing properties. Specific reports are made annually by each administration concerning the water quality and its management.

2.2 The Relevance of Good Water Quality

As we have seen, lakes play a prominent role in our everyday life. Unsustainable and detrimental practices and over-use can affect the ecological conditions of these water bodies. Thus, lake water with a high quality is indispensable and a precondition to meet the aforementioned social, environmental and economic functions lakes can play in support of development and prosperity. In fact, and to underline this, safe access to clean (drinking) water and the sustainable management of water resources is recognised as the 6th goal of the UN Sustainable Development Goal recognising the significance of good water quality and its management also in the context of lakes[10].

However, many lakes suffer from various unsustainable practices. Rivers and streams absorb pollutants from the landscape which then concentrate in lakes and other standing waters. 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 applied by farmers to their fields, they can leach into streams and is transported downstream into lakes.

Pollution is generally classified by how it enters a lake – either point source (can be traced back to a specific source, location, and offender) or non-point source pollution (cannot be traced back to a specific source, location, and offender). Point source pollution is easier to manage compared to non-point source pollution as this pollution comes from many diffuse sources and often enters in small amounts but can become concentrated in lakes and other freshwater resources.[11]

One of the most pressing issues is the release of chemicals from pesticides 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 eutrophication and algae blooms that are harmful to aquatic and human life. Furthermore, extensive sourcing of water from lakes for irrigation purposes on nearby fields can affect the sustainability of the lake and in the worst-case scenario lead, to the drying-up of the lake.

Yet, it is not only unsustainable agricultural practices that can adversely affect the water quality of lakes. Industrial substances such as heavy metals including lead and mercury from construction activities or mining sites, waste water, logging and urban run-offs or sewage seepages can 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

[10] https://www.un.org/sustainabledevelopment/water-and-sanitation/

[11] https://www.lakescientist.com/pollution/#:~:text=How%20does%20pollution%20affect%20lakes%3F&text=Fertilizers%20and%20pesticides%20from%20agricultural,aquatic%20life%20and%20human%20health

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.[12] In the latter category, increasingly mercury deposition is a new problem whilst anthropogenic sources such as pesticides, fungicides and pharmaceutical constituents are also increasing.

Figure 2-2: Algal bloom off the Devils Table in Lake Constance (credit Dronestagr.am)

The legislators 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 on national and EU level. Several agencies and institutional actors such as environmental agencies, research institutes and contracted companies are involved in the process to maintain or improve water quality and monitor developments to take appropriate measures in a timely manner. These actions are the result of a long legislative process that started in the 1990s and led to the first version of the EU WFD in 2000, as well as other, water-related directives that aim to improve water quality. The next section looks more closely at the legislative framework that guides and gives the mandate to the involved stakeholders.

[12] Ibid.

2.3 Regulatory Framework

2.3.1 EU Water Framework Directive

Only a few countries in the EU have national monitoring programmes for the assessment of the chemical and physical water quality of lakes. Most countries, however, undertake monitoring of lakes at regional or local scale, among them the German Federal States (Bundesländer) that monitor the environmental state of lakes in their respective geographical areas. Despite efforts of the co-ordinating group Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA) (see section 2.3.2), regional and local lake monitoring activities are generally not standardized at a national level, and the variables and sampling frequency vary. During the last 10-15 years, some countries have conducted national lake inventories and collected data and elaborated reports on the general environmental state of lakes based on locally gathered information. In the Nordic countries, in which there are many natural lakes, monitoring programmes cover a vast number of lakes. Finland, for instance, has been monitoring a wide range of lakes since the early 1960s. During the 1980s Norway and Sweden have conducted lake surveys to assess the extent of acidification and eutrophication. Some countries have a long tradition for monitoring large nationally important lakes – Austria has by way of example monitored Lake Constance and Neusiedler See since 1961 and 1972, respectively, and the Norwegian Lake Mjösa has been studied since 1971 while others, for example, the Netherlands and Portugal, do not have any specific lake monitoring programme, but include their lakes in river or inland water programmes.[13]

Adopted in 2000, the **EU WFD**[14] has given a push to European countries to **streamline** their monitoring activities and improve the ecology of their waters and the water quality of lakes. This has led to increased environmental awareness and increasing demands to counteract the accelerating pollution of European lakes described above.

There are a number of objectives in respect of which the quality of water is protected[15,16]. 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. 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.

The EU WFD has several links with other policies and policy objectives of the EU. Most of them are naturally mutually supporting but at times they may be contradictory. For example, the **Flood Protection Directive** allows measures that may conflict with the objectives of the EU WFD. Yet, on

---

[13] https://www.eea.europa.eu/publications/92-9167-001-4/page022.html

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

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

[16] "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

the whole, the water-related EU directives are mostly in line with the EU WFD in that they have the broad goal to improve the water quality of lakes.

The **EU Nitrates Directive** for instance 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.[17] Nitrates leaching into lakes through runoff into streams rivers or groundwater, are one of the main reasons that lakes develop eutrophication and suffer from an abundance of algae blooms[18]. Similarly, 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.[19] In a similar vein, the **EU Waste Water Directive** aims at tackling the root cause of lake water quality problems originating from urban waste water collection, treatment and discharge as well as the treatment and discharge of waste water from certain industrial sectors by protecting the environment from adverse effects thereof.[20] In a way, the EU WFD also links with the **EU Drinking Water Directive** in that achieving 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.[21]

The European Environment Agency (EEA) is required to prepare regular reports on the state of the environment in Europe based on the reports they receive from the EU Member States. However, as signalled earlier, not all MS report in the same way and data from one country is not always consistent with that from others – making the EEA task quite difficult. Reviews and amendments of the directives are designed to improve the reporting and indeed the efficacy of the directives for maintaining the healthy status of ecosystem. We'll consider this point later.

2.3.2 German Regulatory Framework on Lake Management

Water management in Germany is regulated through complex legislation, **linking the EU, federal and regional ("Länder") levels** and is strategically laid out within the German water protection policy.[22] The three most important long-term strategic goals are:

1. to maintain or restore **good ecological and chemical quality** of water bodies,
2. to ensure an **adequate supply** of drinking and process water, both in terms of quality and quantity, and

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

[18] Phosphorus as well is often an important key-substance with respect to eutrophication of lakes. Often the phosphorus level is taken as one (of several) indicators, whether a lake is eutrophic.

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

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

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

[22] https://www.bmu.de/en/topics/water-waste-soil/water-management/policy-goals-and-instruments/water-protection-policy-in-germany/

3. to **secure for the long term all other water uses** that serve the public interest (including leisure and recreation, shipping and energy production).[23]

To accomplish these policy goals, the implementation follows three important guiding principles, namely the '**precautionary principle**', the '**polluter pays principle, and full coverage of costs**'. The German water protection policy promotes **close cooperation** among all water users and stakeholders in the protection of the water bodies.

For their implementation, these policies have been translated into a number of legal instruments by the Bund (federal government) and Länder (regional government) which in turn have been impacted and shaped by EU legislation such as the EU Water Framework Directive, the EU Bathing Directive and others as explained above. This link to the EU WFD is visible in the first policy goal that seeks to achieve good ecological and chemical quality of all water bodies.

The most important legal instrument in the context of protecting water quality in Germany has been the Federal Water Act from 1957 and a revised version from 2010 that transposed the EU WFD and other water/marine related EU legislation such as the EU Floods Directive, the Marine Strategy Framework Directive as well as some water-related provisions of the Industrial Emissions Directive into German national law. On top of that, several key ordinances regarding the implementation of the federal water act exist in relation to wastewater, surface water and groundwater on the regional level. Water legislation published by the Länder (both acts and ordinances) can only supplement federal law since the German federal government has the main legislative competence in the area of water protection.

In summary, the protection of the water quality of lakes and their management is highly complex, requires a great deal of coordination between the involved stakeholders and needs to take into consideration a seemingly "web" of pieces of interlinked legislation. Moreover, Länder can deviate from federal provisions, except for substance-specific, installation-specific and EU regulations. Deviations are, however, relatively few and, if at all, put in place stricter regulations. Many Länder have passed supplementary provisions.

As will be shown in the next chapter, the **implementation** of federal and Länder legislation is exclusively the responsibility of the Länder and will be explained here using the example of Baden-Württemberg. The federal level has no supervisory competence in this regard. In most of the Länder, water management follows the typical three-level administrative structure.[24]

To respond to current challenges and design up-to-date water policies in Germany and in cooperation amongst the Bundesländer and with the industry, a **National Water Dialogue** was initiated in 2018. New and pressing challenges such as the impact of climate change, demographic developments, land use changes, technological innovations and changing consumer behaviour have led to increasing water demand over the past decades that necessitate changes and adaptations to the current water management regime in Germany. Led and conducted by the Federal Environment

[23] Ibid.
[24] https://www.bmu.de/en/topics/water-waste-soil/water-management/policy-goals-and-instruments/water-protection-policy-in-germany/

Ministry and the Federal Environment Agency, in this two-year dialogue process, experts from science, industry, practice, administration and interest groups have identified the main future challenges, guidelines and objectives to speed up the transformation of current water management practices. Options for action and fields of action for the future development of German water management and the management of water and water bodies were discussed and elaborated.[25]

A crucial institutional body is the **Water Coordination Group LAWA** (Bund/Länder-Arbeitsgemeinschaft Wasser), a working group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry. Set up in 1956, it aims at discussing questions arising in the areas of water management and water legislation (related to water supply, inland water, water polluting substances, etc.), formulating solutions and putting forward recommendations for their implementation – increasingly also in supranational and international contexts. Taking into account the growing number of legislative documents regarding water management stemming from the EU level, LAWA is increasingly engaging also with EU bodies. The results coming from this work form the basis for the implementation of a standardised water management system within the Federal States. The formulated policies, management plans and measures however allow for some freedom by considering the specific regional characteristics.[26]

2.3.3 Lake Management in Baden-Württemberg

As the Länder are responsible for the effective implementation of the Water Protection policy in Germany, the supreme authority for the execution of water management policy in Baden-Württemberg is the Ministry of the Environment, Climate Protection and the Energy Sector[27]. The Ministry is in charge of giving guidance and overarching administrative procedures, supervising the practical implementation such as local inspections and taking samples of water management via four more locally located intermediate authorities so called “Mittelbehörden” (These are called regional councils/governmental districts or “Regierungspräsidien” in Baden-Württemberg). These regional councils (“Regierungspräsidien”) take over regional water management planning and monitoring, implement procedures under water management law that are of special significance such as water quality monitoring of some bigger lakes and the execution of administrative procedures. One such authority is the Regional Council Tübingen[28] and we will look at its operations in more detail in chapter 4.

[25] https://www.bmu.de/wasserdialog/
[26] https://www.lawa.de/English-About-LAWA.html
[27] https://um.baden-wuerttemberg.de/en/topics/sustainable-river-basin-management/water-framework-directive/
[28] https://rp.baden-wuerttemberg.de/rpt/Seiten/default.aspx

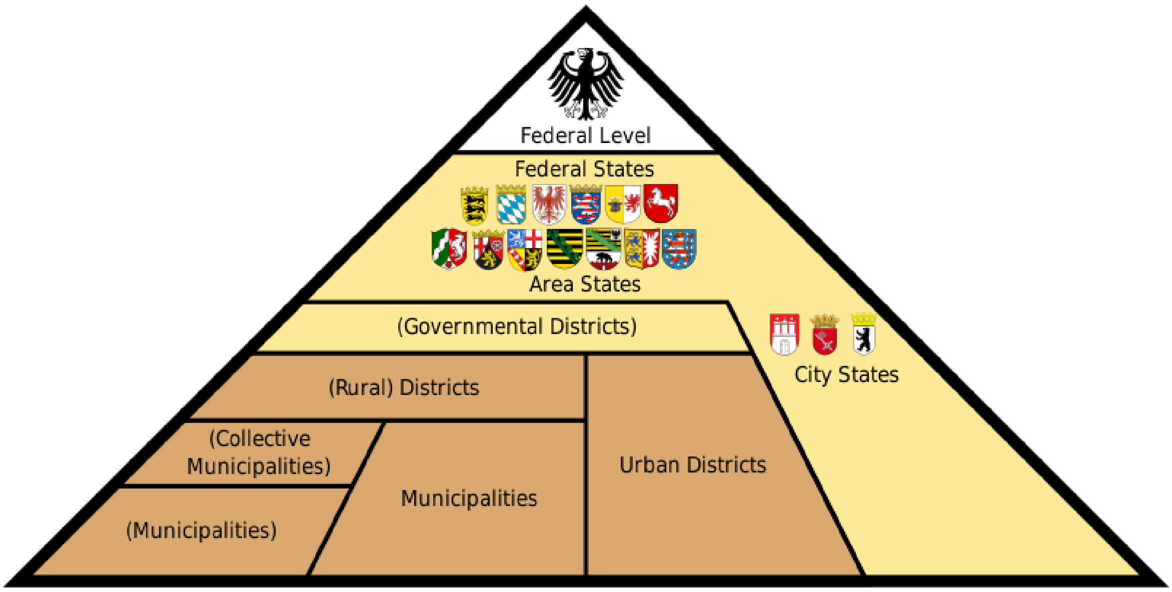


Figure 2-3 Administrative structure in Germany © Wikipedia

The lower water authorities in the counties such as for instance Bodenseekreis and other non-county municipalities are responsible for the procedures under the water management law including the practical aspects of the monitoring of all other (smaller) water bodies and surface waters in their geographic area that do not fall under the remit of the regional councils (that are usually responsible for the bigger water bodies). Often, the water monitoring is outsourced to contractors both by the intermediate and lower water authority offices.

2.4 Measuring Water Quality

Limnology is the science of studying the inland aquatic systems. These systems, e.g., rivers, natural, and man-made lakes, are very complex and can be described by a multitude of variables relevant to their biological functioning, chemical processes, and physical characteristics.

Figure 2-4: The four Regional Council areas in Baden-Württemberg © Heimat u. Welt

The key parameters that are routinely measured in-situ for the purposes of a lake monitoring, and which are relevant to this particular case study of satellite data use are: 1) chlorophyll-a concentration and 2) the Secchi disk depth. Here we provide a basic discussion on some related in-situ measurement techniques and the meaning of those indicators with respect to the harmful algae bloom (HAB), which is the focus of this case. Not all algae generate toxins and the HABs in water are caused by a high concentration of cyanobacteria, which is also called blue-green algae.

- **Chlorophyll-a (Chl-a)** is a green pigment found in algae and plants, and so 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. Chlorophyll is accordingly used to describe the trophic status of a water body. There are several methods for determining the Chl-a content in a water sample, while the most accurate one is the high-performance liquid chromatography (HPLC) analysis, which requires special equipment in a laboratory. The HPLC method is accepted for official monitoring purposes according to the European Union Water Framework Directive.

- **Secchi disk depth (SDD)** is one of the indicators measuring the turbidity of water linked to the concentration of inorganic and organic particles suspended in the water. The SDD is measured visually by using a black and white disk of about 20-30 cm diameter connected to a rope and immersed into the water on a shady side of a ship to avoid reflections from the water surface. The SDD is the water depth at which the disk becomes invisible to the observer, i.e., when the black and white areas of the disk become visually indistinguishable from each other.

The values of Chl-a and SDD are usually correlated, meaning that the higher is the concentration of Chl-a, the smaller is the SDD (and vice versa for Phytoplankton dominated waters). These values can indicate high concentration of algae, i.e., forthcoming or ongoing algal bloom, with all its potential negative consequences to the lake ecosystem that are caused by e.g. toxins produced by a specific group of algae, the Cyanobacteria. These toxins may cause various health problems for the exposed to the contaminated water wildlife, home animals, and humans, e.g., skin irritation, gastro-intestinal disorder, or even neurodegenerative deceases. Such harmful algae blooms formed by Cyanobacteria (HAB's) can be detected by satellite, separated from the broader pigment group with Chlorophyll-a as an additional indicator.

Figure 2-5: Algae on the lakeshore.

One of the key characteristics of all lakes, with a strong influence on the formation of HAB's, is their mixing properties i.e. how colder water from lower layers in the lake mixes with the warmer waters above. The mixing brings nutrients from the bottom layers towards the warmer surface water which may lead to the formation of harmful algal blooms. Smaller lakes may mix several times per year whilst larger ones may exhibit different mixing properties in different parts of the lake. The mixing depends on the depth, the weather conditions and the flow of rivers entering the lake. Climate change, which is affecting several of these parameters is changing the way lakes mix and hence how HAB's may form.

A high concentration of algae can also lead to oxygen depletion in the lower layers of the lake water. Whilst this process is not generating toxins, the lack of oxygen has consequences for fish and water plants.

In addition to the Chl-a and SDD, other parameters are of interest for assessing the ecological status of a water body and indeed responding to the reporting needs of legislation. The authorities may look at further parameters[29] including:

1. **Biological quality components**
    - Fish
    - Macrozoobenthos (invertebrates living at the bottom of the water body)
    - Macrophytes and phytobenthos (higher aquatic plants and regrowing algae, here limited to diatoms)
    - Phytoplankton (algae floating in the water)

2. **Hydromorphological quality components**
    - Embankments such as walls, ramparts
    - Harbour facilities, buoys, navigation marks, jetties, slipways
    - Vegetation – natural or cultivated.
    - Connection with the hinterland
    - Substrate – the nature of the lake or river bed

3. **Physical-chemical quality components**
    - Water temperature
    - Oxygen concentration
    - Electrical conductivity, acid-binding capacity and pH-value
    - Nutrients as total and ortho-phosphate, nitrite, nitrate and ammonium
    - Anions and cations (potassium, sodium, magnesium, calcium, silicon, chloride, hydrogen carbonate, sulphate)
    - Chlorophyll a, depth of vision (turbidity)
    - Dissolved organic carbon (DOC) and hydrogen sulphide.

[29] Dokumentation zur Bewertung der Seen (baden-wuerttemberg.de)

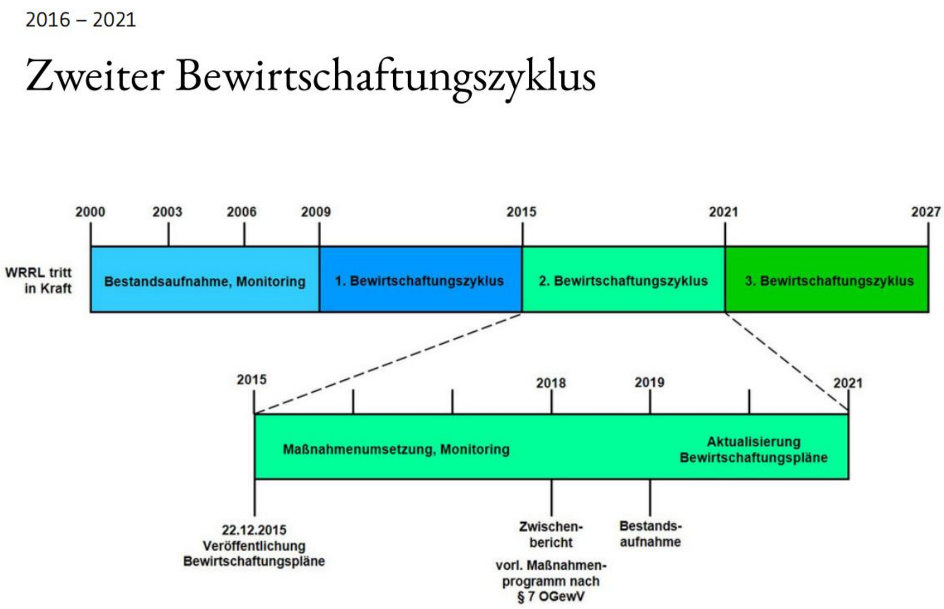


Figure 2-6 Second Water Management Cycle 2015-2021 for Baden-Württemberg

As the Länder are the responsible authorities for the implementation of the Federal Water Act and the EU WFD, they have set up dedicated, locally adapted, implementation action plans to achieve the objectives of the policies and ultimately a good ecological and chemical state of the lake. Baden-Württemberg is currently implementing its "2nd Water Management Cycle" plan for the period 2015-2021. The plan includes practical steps towards achieving a good state of the water bodies in Baden-Württemberg and the monitoring of progress.[30]

The most important fields of the action plan focus on:

- reducing hydromorphological i.e. structural deficits in rivers and streams, including the improvement of passability (pervasiveness) and minimum water
- reduction of point and diffuse nutrient inputs into surface waters
- reduction of material pollution, especially by ubiquitous substances e.g. plastics and other pollutants
- further reduction of nitrate inputs to groundwater

Within each water management cycle action plan, a comprehensive set of measures has been designed to meet the challenge of reaching a good ecological and chemical state of the water bodies in BW. As an example, to reduce diffuse nutrient input, BW introduced so-called *riparian zones* or *strips* of a width of 5m bounding the surface waters including lakes where it is illegal to use and store fertilisers and plant protection chemicals as these could easily enter the water bodies through natural erosion and run-off processes.

[30] Umsetzung der EG-Wasserrahmenrichtlinie in Baden-Württemberg: Zwischenbericht 2018 (baden-wuerttemberg.de)

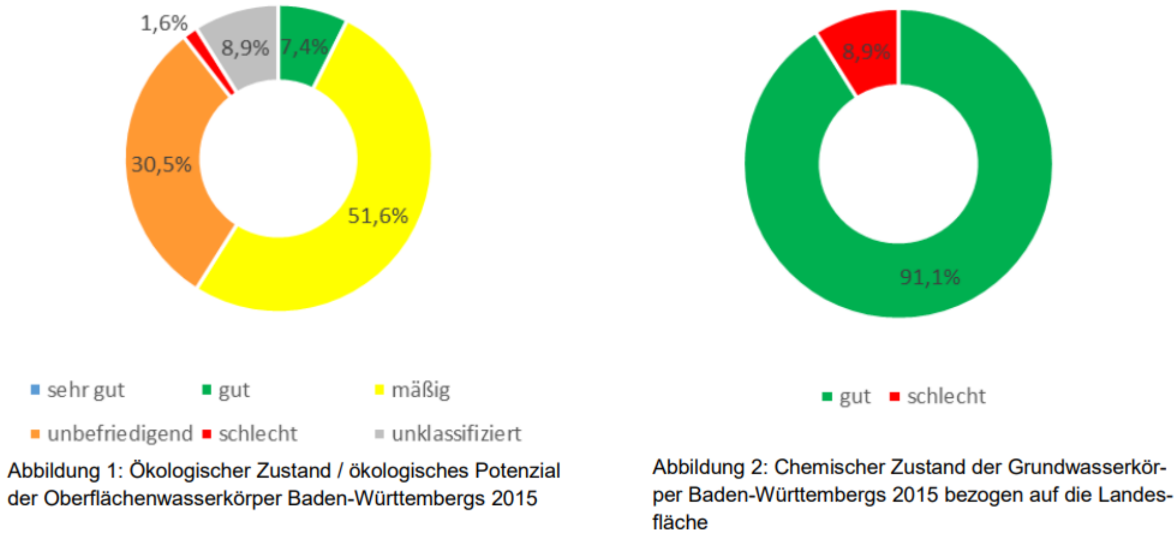


Figure 2-7 The Ecological and Chemical Status of Surface Waters in Baden Württemberg

While the ecological status of surface waters (graphic on the left) was mixed (clockwise: good (7.4%), moderate, unsatisfactory, bad, unclassified) in a 2015 interim report, the chemical status (right) was overall reported as good (91.1%). It should be noted though that due to the one-out-all-out principle described in the EU WFD and transposed national legislation, the condition of several surface waters had to be classified as bad although in several cases only one parameter out of several did not meet the desired target value.[31]

While the estimates of the ecological status in Figure 2-7 call for improvement, according to the European Environment Agency's European bathing water quality assessment report published in 2020, Germany is one of the top-ranked countries in Europe in terms of bathing water quality (Figure 2-8).

[31] 2015 Interim Report

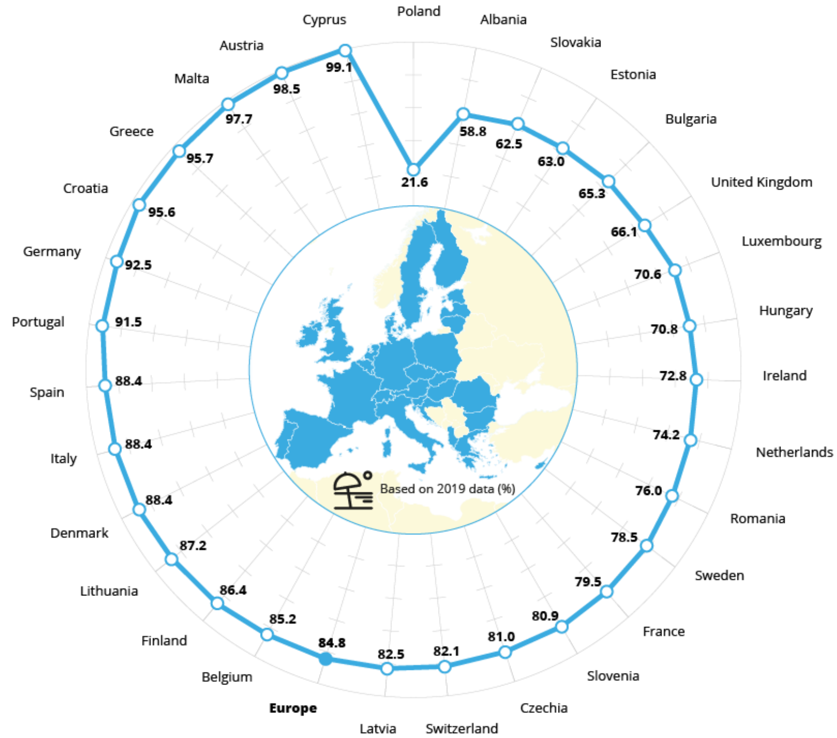


Figure 2-8 Proportion of bathing waters with excellent quality in European countries in 2019. (Source: https://ec.europa.eu/environment/water/water-bathing/index_en.html)

The 3rd water management cycle is currently being designed by a variety of stakeholders for the period 2022-2027 as it is expected that the extent of the current programmes and measures will not suffice to reach both a good ecological and chemical status of the water bodies in Baden Württemberg.

2.5 Ecosystem Services and the RESI Index

The utilisation and benefit of various elements of the environment including water surfaces may be represented **by the ecological functions** that a specific landscape provides to society. These ecological functions or **ecosystem services** can only be partially measured directly and therefore are captured through the use of indicator variables. The **level of available ecosystem services** can be assessed against the fulfilment of objectives plus, interactions between the different uses can also be taken into account. These evaluations of individual ecosystem services can be considered within the specific landscape of water bodies and summarised in indices. Such an approach, specifically targeting river landscapes and their ecosystem services, has been developed within the RESI project[32] to generate the **River Ecosystem Service Index concept**. The concept applies to the overall evaluation of the capacity of the natural resources in riverine landscapes. In several ways, the concept can be applied to the ecosystem services of water bodies such as lakes in Baden

[32] RESI Project

Württemberg as well. Below, we provide a short overview of the RESI concept in connection to the various ecosystem services benefits it entails.

The RESI index enables the development of sustainable and integrative management approaches, as it seeks the economic-ecological optimisation of land and water use. On the one hand, this helps to avoid considerable social costs and, on the other hand, allows economically interesting and sustainable use options to be identified in river corridors. The RESI index can thus facilitate the implementation of relevant societal objectives by (environmental) administrations and responsible and sustainable business concepts by private companies. On top of this, the RESI concept can justify investments into environmental ecosystems by demonstrating effectively and in a holistic and comprehensive way that benefits are delivered for society at large through these investments. This is also the reason why the RESI index is a useful approach to understanding and conceptualising the value and benefit of good water quality in lakes in that the index can facilitate the analysis of the environmental benefits by pointing towards the appropriate indicator variables.

2.6 Informed decisions, coordinated actions, and effective interventions.

2.6.1 What Decisions?

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 and, in particular, in Baden-Württemberg. Informed decisions can however only be taken if all relevant sources of information are effectively used. Thus, having the best possible situational awareness – i.e. where and when water quality is deteriorating – is crucial for the regional councils and their local district offices to make informed decisions, effectively execute their mandate and avoid negative unintended effects. Should the lakes' water quality be deteriorating to such an extent, knowledge on the "where and when" would enable the regional councils and their subordinate district offices to coordinate actions, for instance, through treatments[33], the closing of lakes or putting in place specific mitigation measures to restore water quality.

The monitoring of the lakes in BW is addressing these issues and aims:

- To monitor the water quality of lakes and ponds in complement to in-situ measurements and to provide guidance on where in-situ measurements should be made.
- To implement measurements of small lakes and ponds which are too numerous to be realistically monitored using traditional, in-situ techniques.

[33] Suppression of Bloom-forming, colonial cyanobacteria by phosphate precipitation: A 30 years case study in Lake Barlebar (Germany), Ronicke et al, Ecological Engineering, Volume 162, April 2021.

- To identify when an algal bloom is likely or already taking place in order to firstly deploy ground measurements and ultimately to close the water to leisure use, so protecting citizens from harmful toxins.
- To monitor changes in water quality from year to year to inform policy makers and over the long-term trends in water quality to inform agriculture regulations on the use of fertiliser and other chemicals and environmental laws linked to biodiversity.
- To trigger a direct response in the case of a lake becoming too oxygen-poor, to protect fish-life. Algal blooms are causing oxygen depletion as a result of the decomposition of organic materials. Response can be to modify the water flows and especially mixing of different layers, oxygenate the water, provide chemical treatment, or in an extreme to drain the lake and remove the polluted sediment.
- To inform water supply companies on the quality of the water entering their collection areas and hence to plan on the level of treatment necessary in water plants.
- To inform on the longer-term accretion of nitrates and phosphates and support more precise legislation and/or its implementation.

The decisions as to what measures have to be taken to restore or preserve water quality are taken by the regional council or by the local district offices. For the bigger lakes, it is usually the regional council that is in charge. For the smaller lakes, it is the local district office that decides whether to take a measure. In their decision-making process, they are supported by the Baden-Württemberg State Institute for the Environment[34] (LUBW) and in particular, their Institute for Lake Research[35] (ISF) that advises and helps regional councils and local district offices in the monitoring of lakes and their water quality with their scientific expertise. Naturally, the scope of the measures depends on the severity of the lake's water quality status in question and is compared against the necessary minimum standards as laid down in the EU Water Framework Directive as well as in the EU Bathing Waters Directive called "environmental quality standards" (EQS) for the substances in surface waters.[36]

If water quality is below standard requirements, there are several steps the authorities can take to alleviate the situation depending on type of lake and its use. In the short-term, lake closures can help in avoiding direct risks to human health. Depending on the size of the lakes, in the worst case, they can also be drained and be filled up again after a longer period of time with fresh water. This is only possible in very small ponds though. Warnings are issued of course where there is a danger and risk. In the long-term, decisions to improve water quality are taken on a higher more strategic, political level in the form of revised legislation that seeks for instance to bring about structural change and tackle the root causes of pollution. That type of change may aim at the prevention of nitrates or phosphates leaching into the lakes or the prohibition of the use of certain substances in industrial activities nearby the lake if such substances could enter groundwater or lakes and

[34] https://www.LUBW.baden-wuerttemberg.de/startseite
[35] https://www.LUBW.baden-wuerttemberg.de/wasser/institut-fuer-seenforschung
[36] https://ec.europa.eu/environment/water/water-dangersub/pri_substances.htm

concentrate in lakes. Often, long-term decisions are taken on the federal level involving the Federal Environmental Agency and federal government and are coordinated through the LAWA given natural regional or local specificities.

Besides lakes used for leisure activities which are the primary focus of this study, decisions related to reservoirs and lakes used for water supply may differ in that water companies have different needs and operate on a for-profit basis. In this respect, some water cleaning plants have started to install active carbon filters to remove traces of substances ie pharmaceutical residues. These filters are expensive and are only used where a significant problem has been identified.

2.6.2 What Data?

To fulfil their mandate, the 4 regional councils in Baden-Württemberg (Tübingen, Freiburg, Karlsruhe and Stuttgart) and their subordinate water-related district offices, are monitoring the lakes' water quality within their geographic mandate according to a water management plan. In order to perform the required monitoring, the district offices take around 6 samples for each lake through the monitoring period (typically June to September) from a total of around 20 lakes per year on a rotating basis, meaning that the majority of lakes are only investigated every 4-5 years. These in-situ measurements and samples are tested for:

- Chlorophyll-a
- Temperature
- Secchi depth
- Cyanobacteria
- Turbidity
- Eutrophic state
- Organic absorption

The geographical location of the points at which the measurements are carried out are chosen depending on their significance or reflecting the overall dynamics of the lake in question. Usually, two samples per 100 ha are carried out, although one sample per 100ha is considered acceptable, too.

From these local (point) measurements, the authorities can extrapolate to the other parts of the lake. The bigger lakes like Lake Constance are split in several "water bodies" where samples are taken from each part – in the case of Lake Constance, there are 3 such parts.

2.6.3 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 EU WFD and EU Bathing Directive. They however only provide information about the status of the water quality in that precise location of the in-situ measurement and 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 faced by the authorities; for instance, health-damaging algae bloom from eutrophication can appear and disappear in very short periods of time and this stay undetected by the responsible authorities. Thus, 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 the lakes requires putting in place the right measures and prioritise accordingly in-situ measurements; these measurements can inform on the quality parameters of the aforementioned priority substances and their evolution. Achieving this with traditional in-situ measurement techniques would be extremely difficult and costly, and practically impossible. In-situ measurements are costly and often outsourced to contracted companies as internal resources are not sufficient. The data obtained via in-situ measurements has a limited spatial coverage and only a maximum o20 to 25 lakes can be monitored in-situ per year under current resource constraints. As opposed to that, satellite data could fill these gaps and provide several measurements per year depending on cloud cover on every reasonably sized lake.
- **Ensuring continuous monitoring**: Maintaining an accurate picture of the evolution of the water quality in the lakes throughout Baden-Württemberg would require continued and widespread use of in-situ measurements and thus is particularly resource-intensive. At the moment for instance, the Regional Council Tübingen outsources measurements to a company that is paid 3.5k per year for each lake being measured. Some 20 to 25 lakes are measured each year in a rolling programme over 5 years which covers 100 lakes across the region. While in-situ measurements can give exact current data, the historical records are usually quite sparse. Filling this gap can be partially achieved with historical archived satellite data.
- **Facilitating common understanding**: Communicating on the evolution of the 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 point measurements.

All these limitations can – to a large extent – be addressed by the use of satellite data. Therefore, a few years ago, the Institute of Lake Research (ISF) started a research project in collaboration with EOMAP[37], a German Earth observation company, to support the ISF in their advising role and consultant work towards the Regional Councils and subordinate district offices in Baden-Württemberg by monitoring lake water quality through Earth observation.

Freely available data from spatially reasonable high-resolution satellites (e.g. Sentinel-2: 10m) open up new possibilities for monitoring the water quality of a larger number of small lakes (i.e. all lakes except Lake Constance). Besides, it is possible to obtain better information on spatial inhomogeneities of Chl-a distributions (patchiness) in large lakes such as Lake Constance. 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. Furthermore, EO data can be used to achieve better temporal resolution i.e. more frequent measurements. This is a

[37] https://www.eomap.com/

great advantage, especially in case of sudden changes in lake ecology such as upcoming harmful algal blooms which especially appear locally under extreme spatio-temporal heterogeneities. In this way, existing in-situ monitoring programs and evaluation methods can be usefully supplemented with satellite measurements.[38]

We will look into the use of satellite data and the specific application provided by EOMAP in more detail 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 delivered (chapter 5).

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

3 The Use of Sentinel Satellite Data

3.1 How can Satellites help with Lake Monitoring?

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

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 principles by which the reflectance measurements are made are shown in Figure 3-1 taken from the NASA Applied Remote Sensing Training programme (ARSET)[39]. Other sensors detect the direct radiation from the water surface which allows the water surface temperature and salinity to be measured.

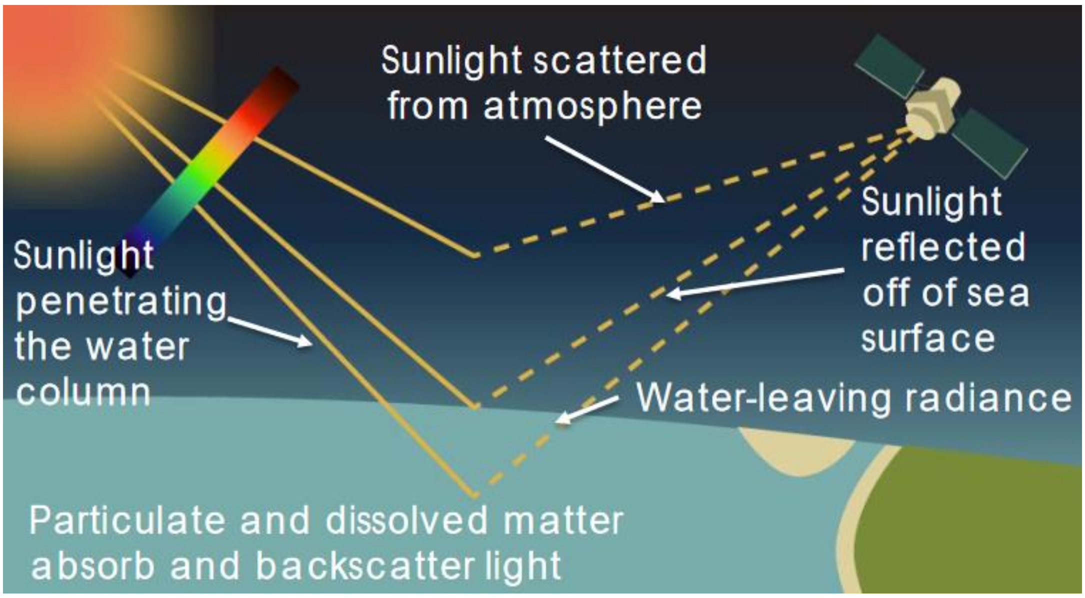


Figure 3-1: Principles of satellite-based water quality measurement

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

---

[39] Satellite Observations of Water Quality for Sustainable Development Goal 6.

- **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 measures but provides an indicator of the presence of these pigments.

The suitability of the measurements for the purpose of monitoring water quality depends on a number of factors including the observation angle of the sensor, the spatial resolution of the sensor compared to the lake size and the meteorological conditions, particularly the absence of cloud and a good light quality. The use of multiple sensors to increase the number of observations is important and using Landsat 8, Sentinel-2 and Sentinel-3 enables measurements to be made at weekly intervals extending down to even daily measurements under good conditions (for example in dry, cloud-free regions). Measurements can be made from early spring to late autumn as, outside of this period, the light angles are too low for effective measurements to be made.

A number of satellites with optical sensors are used to monitor the water bodies. Sentinel-2, Landsat 7 and Landsat 8 provide imagery every few days with a spatial resolution of 10m to 30m which is suitable for monitoring smaller lakes. Imagery from Sentinel-3 and MODIS can provide daily imaging but at a spatial resolution of 300m to 500m which is useful for large lakes – such as Lake Constance in our area of interest (see Figure **3-2**). Sentinel-3 is particularly useful given its large number (21) of measurement channels that are tuned to measure water characteristics.

The ability to gather better information on spatial inhomogeneities of Chl-a in large lakes such as Lake Constance is particularly important and which is extremely difficult to achieve by virtue of in-situ measurements.

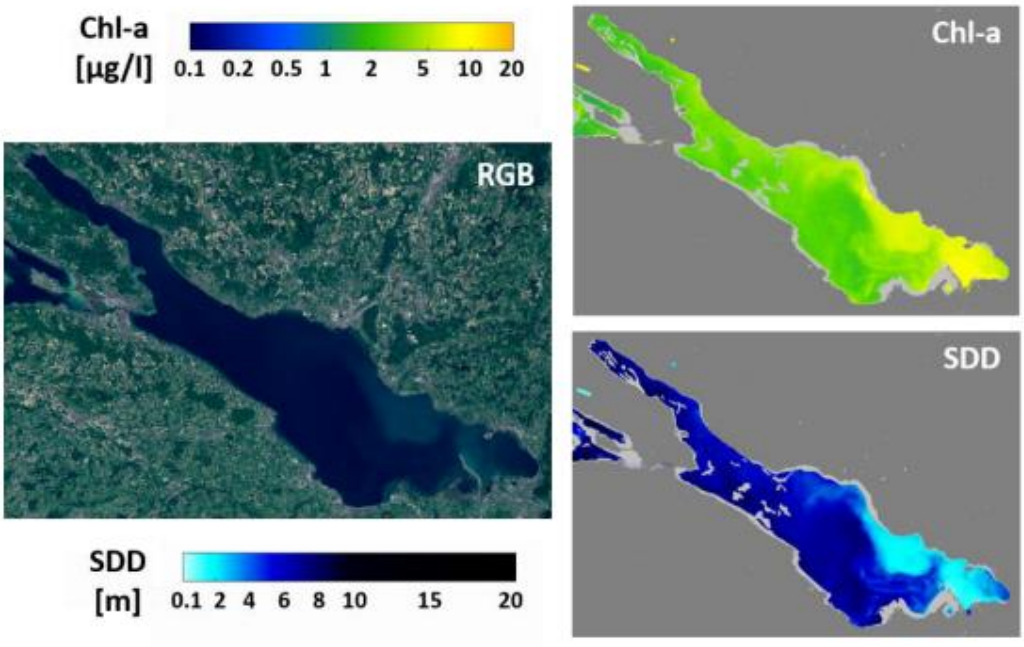


Figure 3-2: Sentinel-2 data for Lake Constance on May 17th 2017. RGB image left and Chlorophyll-a top right and Sechi depth bottom right.

For smaller lakes, the size of the measurement footprint, ie the pixel, is too large but a compromise can be reached. The satellite with the most sensitivity to the environmental parameters due to its large number of measurement bands is Sentinel-3 but its 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 by clouds which prevent the satellites from taking their pictures.

The great advantage of satellite imagery is its wide geographical coverage that allows for monitoring many more lakes than could practically be achieved with traditional methods. Satellite data can provide information to help make the decisions described in chapter 2.6 - but not for all lakes and not all the time.

- Not all the time as whilst satellite observations are available every few days some of the images are obscured by clouds. Fortunately, using several satellites, images of the lakes can be obtained regularly enough to detect problems in time to respond.
- Not for all lakes as, for smaller lakes, the satellite spatial resolution on the ground means that just a few measurement pixels cover a lake and those around the edge are corrupted by containing a mixture of water and land in the signal.

For all lakes greater than about 10ha in size (of which there are about 260 in Baden-Württemberg), the measurements made are quite reliable and accurate. For lakes down to a minimum surface area of 1ha, they 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 data analysis process.

3.2 Copernicus and the Sentinels

Imagery used to support the monitoring of lakes in Germany is coming from optical satellites carrying sensors with multiple imaging bands (ie observing different parts of the light spectrum). These include the Sentinel-2 and Sentinel-3 satellites which are part of the EU Copernicus programme[40] and Landsat 8 which is a US satellite.

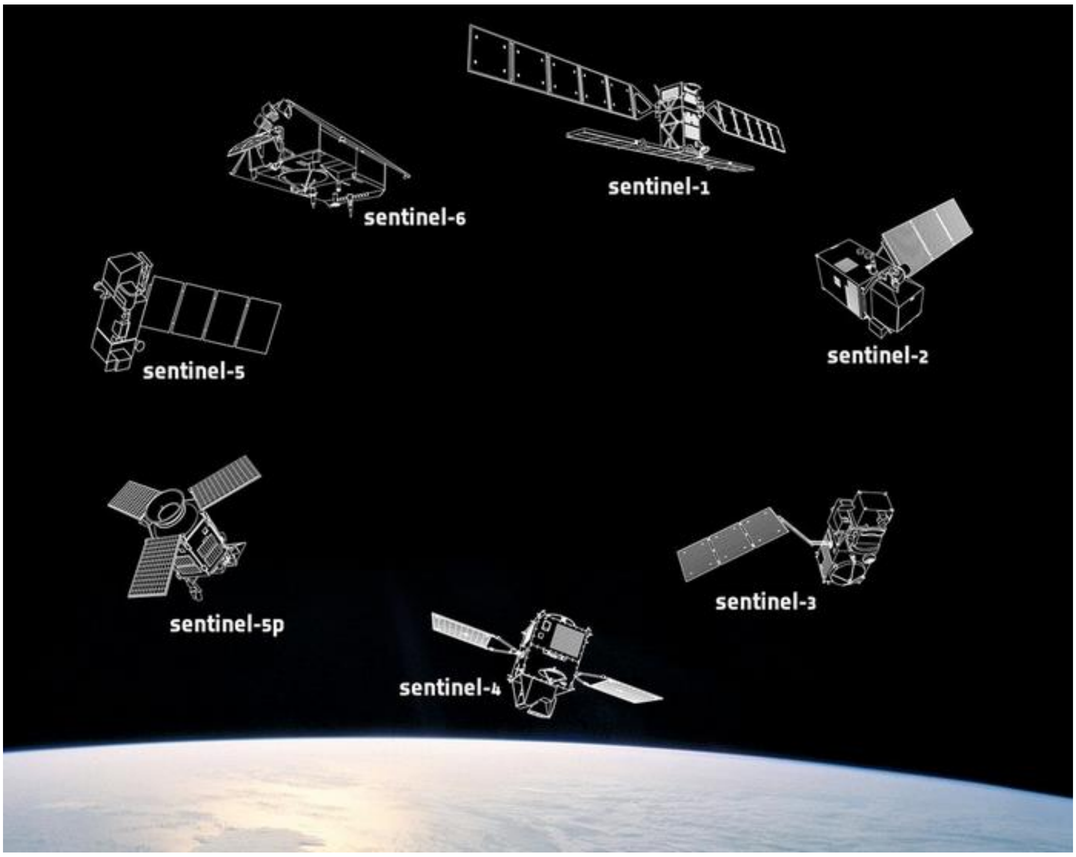


Figure 3-3: Current Sentinel satellites

Copernicus is an EU flagship programme[41] 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

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

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

EU and operated by ESA and Eumetsat and currently comprising six types of satellites, see Figure 3-3.

Our case is defined by Sentinel-2[42] and Sentinel-3 satellites (see the info boxes).

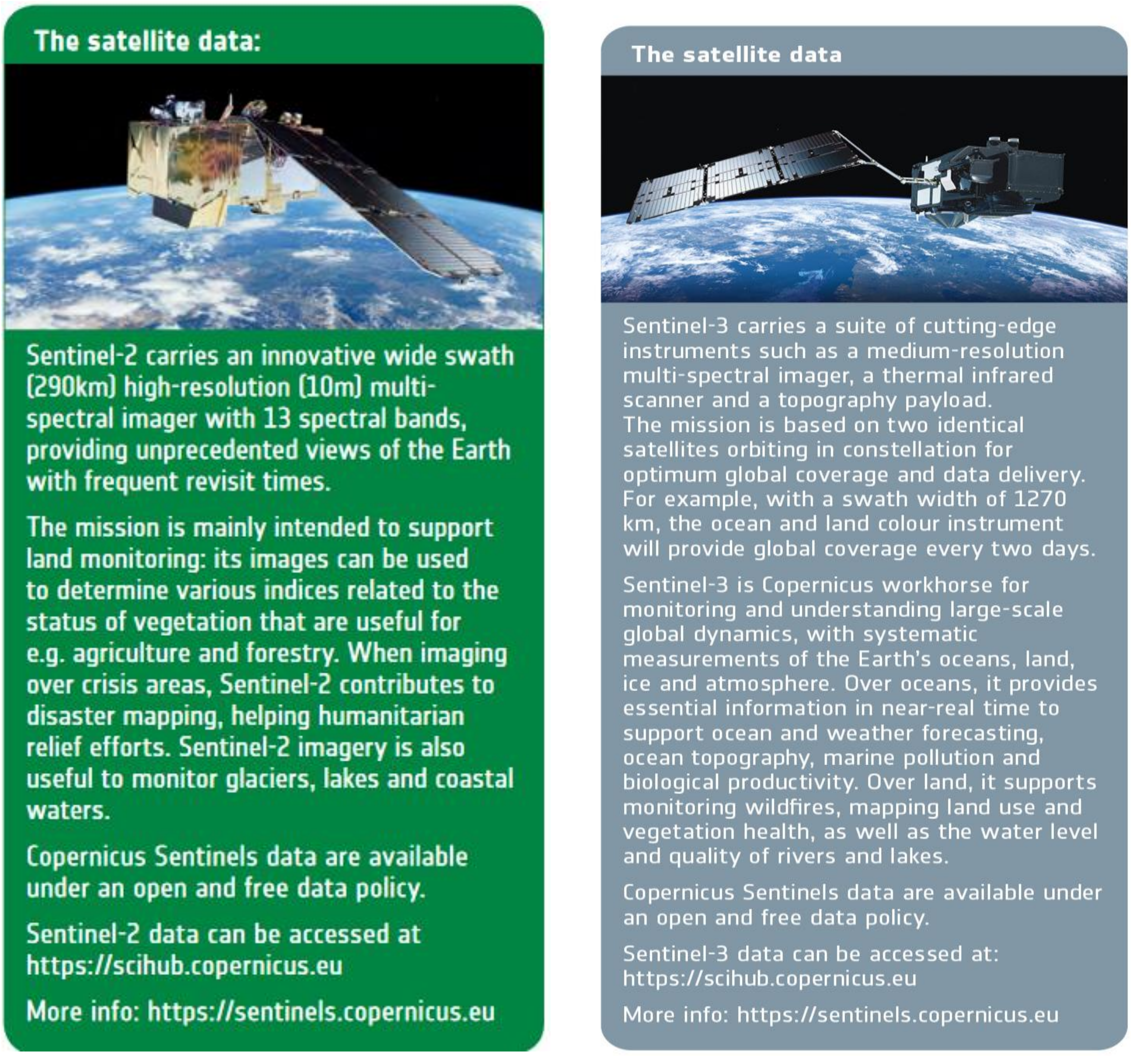


Figure 3-4: Sentinel-2 and Sentinel-3 Satellites

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.

[42] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2

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.

3.3 The Water Quality Service

A water quality service has been developed by a German SME, EOMAP, which combines these different data sources and further ones such as Landsat 8 so enabling the various stakeholders to access environmental information concerning the water bodies in their region.

The inland water quality service provides subscribers with regular updates on the water quality in their area of interest. The parameters discussed above are available along with other information including meta data on the scene(s).

Two tools are available for users; eoLytics which is the satellite data processing engine for water quality assessments and the eoApp web application which provides an easy online-access to the products.

EoLytics provides subscribers with the tools to run their own water quality analyses which is the approach taken by the LUBW. The user defines the points or regions which are of interest as well as the satellite data which they wish to use. Once set up as a project, the system will automatically run when new satellite data is available so yielding regular updates.

EoLytics is based upon an algorithm (MIP – Multiple Inversion and Processing) that was developed by DLR and the University of Munich from 1996 and has been continued since 2006 by EOMAP. The MIP algorithms have been subject to extensive validations within international research projects and commercial applications for a wide variety of lakes, reservoirs and rivers worldwide[43].

The eoApp gives access to detailed water quality information. The web application allows users to browse interactively and access satellite-derived water quality measures generated using the MIP.

A free demo version of the eoApp is provided with the World Water Quality Portal (WWQP) giving access to a global set of water quality parameters at 90m resolution for all inland water bodies and coastal areas. Time series products at 30m resolution can also be accessed for selected regions in each continent and several additional locations.

Reports from the eoApp can be extracted ie history over 1 year of a specific water body. The parameters available through the WWQP are:

[43] The SDG6 reporting portal; part of the Hydrology TEP.June 2020.

Chlorophyll-a: Chlorophyll-a is an essential pigment included in phytoplankton cells and therefore a measure of phytoplankton concentration. The displayed Chlorophyll-a (Chl-a) is calculated from total scattering and total organic absorption of water constituents. Unit is [µg/l]

Figure 3-5: Chlorophyll-a concentrations across Lake Constance (from WWQP)

HAB Indicator: Harmful Algae Blooms (HAB) indicator shows possible areas affected by harmful algae blooms formed by cyanobacteria containing phycocyanin.

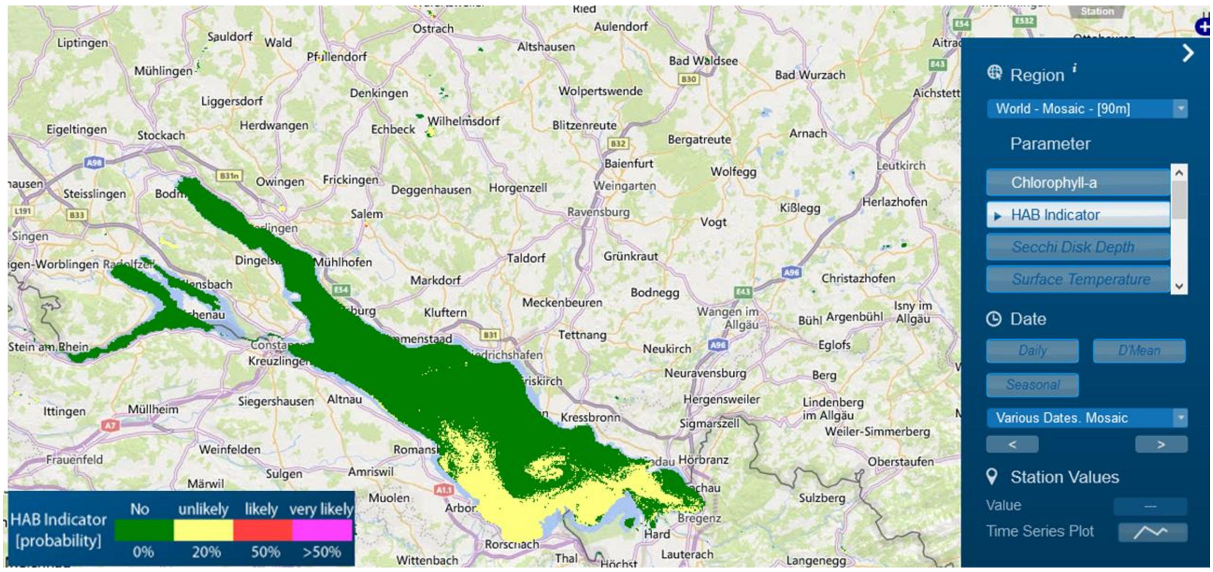


Figure 3-6: HAB risk across Lake Constance (from WWQP)

Secchi Disk depth: Secchi Disc Depth or visibility in (m) is a measure of transparency in the water column. The EOMAP SDD product is calculated from the attenuation coefficient Kd after Lee et al[44] and applied using Sentinel-2 and Sentinel-3 data.

Surface Temperature: Surface Water Temperature in degree Celsius is calculated from thermal infrared channels recorded by optical satellites – Landsat 8. It measures the top skin temperature of the water body.

Total Absorption: Total Absorption is retrieved from the absorption of light by particulate and dissolved organic and inorganic matter. The relative contribution of inorganic absorptions varies for changing specific inherent optical properties (SIOPs), which are monitored within the retrieval algorithms. The total absorption product includes the absorption of organic and inorganic components in 1/m at 440nm.

Total Suspended Matter: Total Suspended Matter or Total Suspended Solids (TSS) is essentially related to the total scattering of organic and inorganic particles in the water column and is therefore linearly related to turbidity at low to moderate values. High concentrations of particles affect for example the light penetration, influences habitat quality for fishes or other aquatic life and can provide attachment possibilities for pollutants such as bacteria or heavy metals. The measurement unit of Total Suspended Matter is mg/l or g/m³. The linear relation between turbidity and suspended matter/solids in low to moderate concentrations is in most cases regional constant but can vary with particle size distribution. A regional calibration may further assure the accuracy for high concentrations.

Trophic State: Trophic State Index provides a classification of biological productivity following the proposed scale from Carlson (1977)[45], calculated from the Chlorophyll-a concentrations. The Trophic State Index ranges from 0 to 100, while values of below 40 indicate an oligotrophic state, values above 70 represent a hypereutrophic state.

Turbidity: measures the degree to which light is being backscattered by particles in the water. Tracking changes in turbidity is useful when monitoring sediment plumes from dredging and dumping activities. The measurement unit is Earth Observation Turbidity Unit (ETU) and directly related to backscattering of particles, very similar in magnitude to Nephelometric and Formazine Turbidity Units (NTU and FTU). It is linearly related to Total Suspended Matter (TSM) at low to moderate turbidity values.

[44] A semi-analytical scheme to estimate Secchi-disk depth from Landsat-8 measurements. Lee et al, Remote Sensing of the Environment, vol 177, May 2016.

[45] A Trophic State Index for Lakes. Carlson, Limnology and Oceanography 22. March 1977

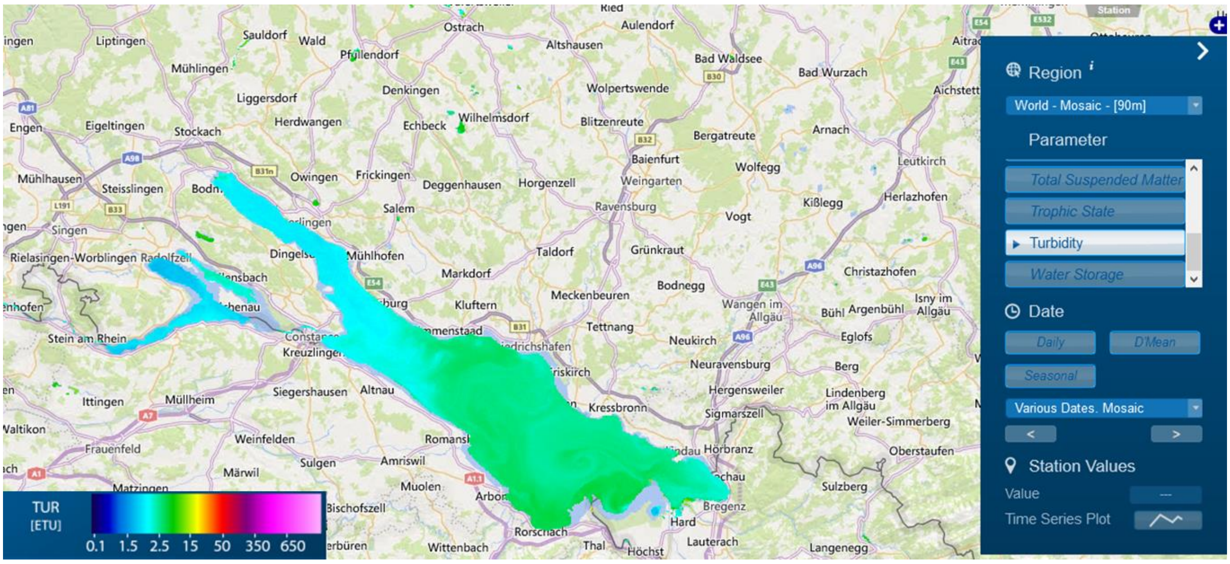


Figure 3-7: Turbidity levels for Lake Constance (from WWQP)

<u>Water Storage:</u> Water storage variation is obtained thanks to the combination of Water Area Extent (WAE) of a reservoir and its Water Surface Elevation (WSE). WAE is computed by segmented optical or Synthetic Aperture Radar (SAR) satellite imageries between land and water pixels. WSE is derived from satellite altimetry mission tracks crossing the reservoir and bias corrected between missions. These two features are then aggregated monthly to calculate monthly water storage variation of this reservoir.

In addition to the visual representations shown in the above figures, the WWQP will provide specific measurement values for the days when measurements were possible. This is illustrated in Figure 3-8 and Figure 3-9. Here a snapshot of lakes across northern Germany for the Mecklenburg Lake Plateau is shown and then for the selected point, the individual measurements are shown superimposed.

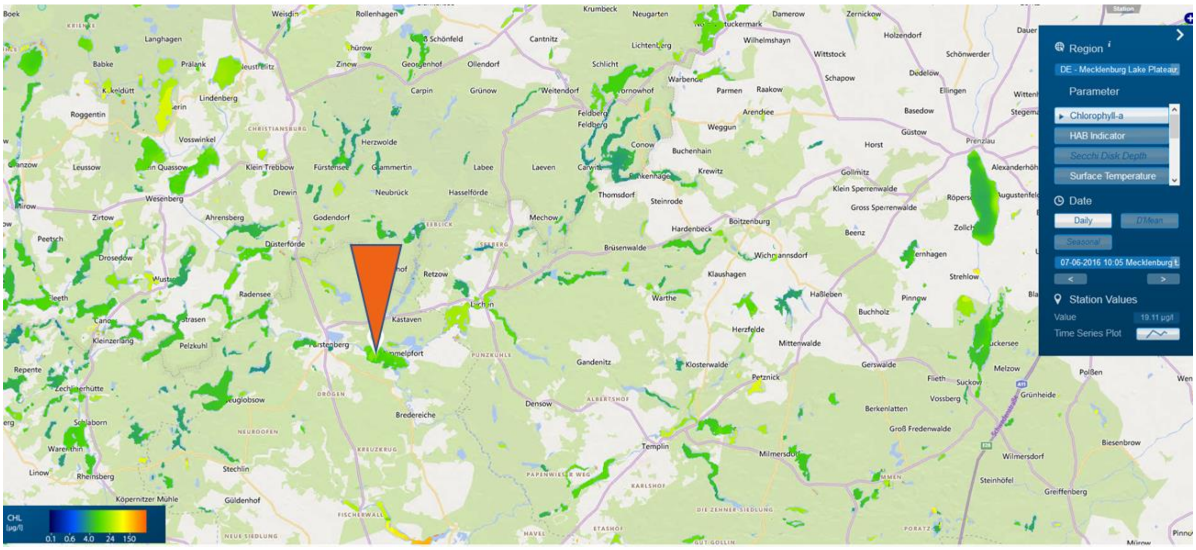


Figure 3-8: Chlorophyll-a levels in lakes across Northern Germany

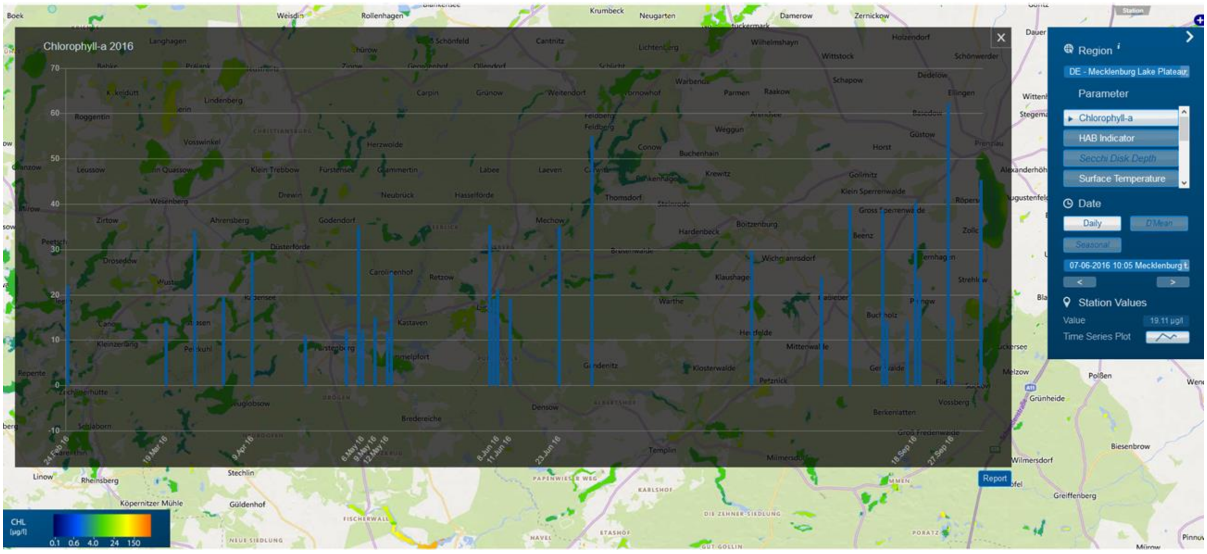


Figure 3-9: History of measurements for selected point (marked by the orange arrow) in the previous image.

A second example is shown in Figures 3-10 and 3-11. This time, for the same area in Northern Germany, the surface temperature is shown; graphically in Figure 3-10 and then as a history time plot in Figure 3-11.

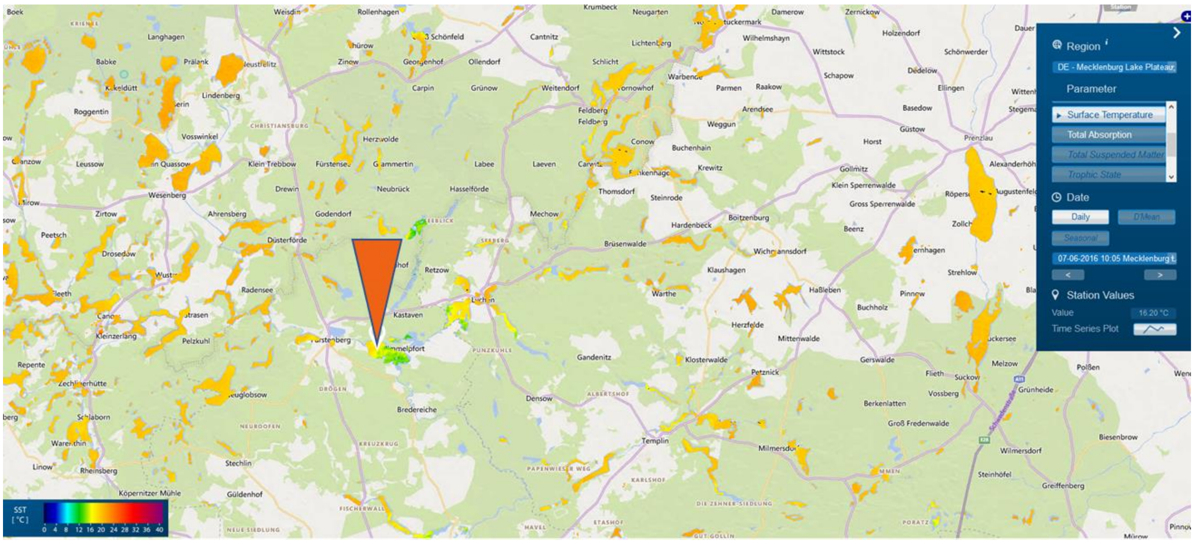


Figure 3-10: Lake surface temperature shown for Lakes across Northern Germany

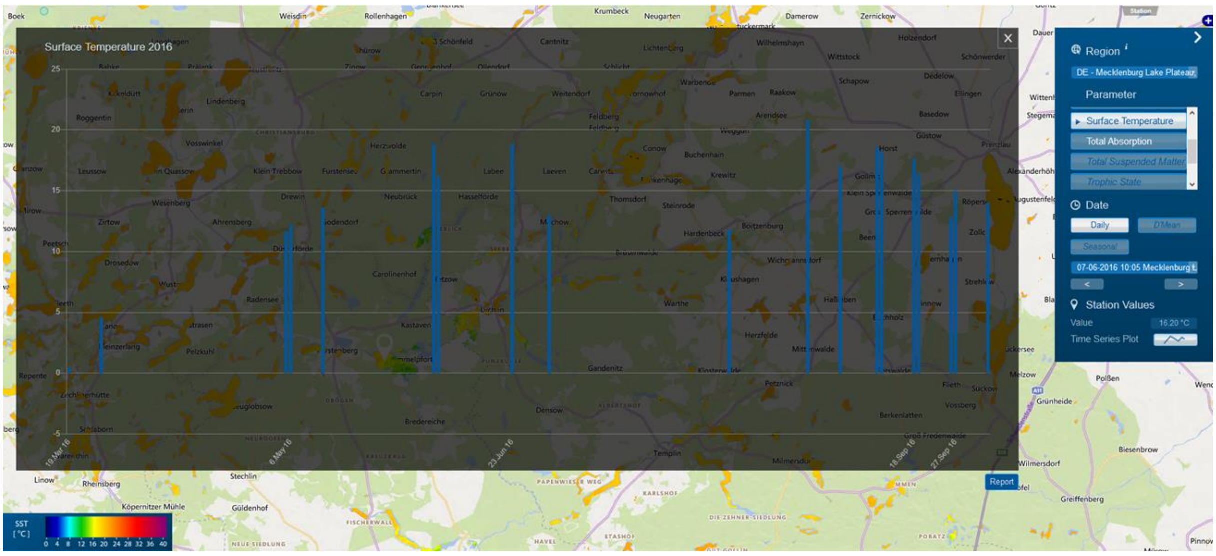


Figure 3-11: History of lake surface temperatures for the selected point in the previous image.

3.4 The Future Evolution of the Service

The water quality service is continuously being improved in terms of product accuracy, spatio-temporal resolution, user-friendly access mechanisms as well as the level of integration into client-specific environments. There are several drivers for this:

a) To serve a greatly anticipated client base, the service is being scaled up with increased processing capacity as well as cloud storage. The user configuration is being improved to make it easier for clients to determine their region of interest and to set up processing chains for their required products.

b) To establish a new on-line service which will meet the needs of the Copernicus Emergency Services which seeks to offer a water quality product to the portfolio. This will be available on-demand with a global reach and should offer a rapid response.
c) To prepare a technical response according to the needs of a European wide water quality service being planned within the European Copernicus programme.
d) Improving the technical offering through better resolution (look at smaller lakes) and to ensure a reliable service of high quality.
e) Improvements of the robustness of the service and the ability to take advantage of new data sources concerning new public and commercial satellites and sensors. This requires enhancement of algorithms used to process the data and provide the service.
f) A desire to introduce standards to the products offered as a means to ensure the quality and to differentiate from other suppliers.

Using cloud-based Software-as-as-Service (SaaS) concepts as provided with the eoLytics platform, users are increasingly self-enabled to use the platform with underlying satellite data as flexible measurements device.

4 Understanding the Value Chain

4.1 Description of the Value-Chain

The core value chain is shown in Figure 4-1. In the first tier, EOMAP - the service provider - is supplying access to their eoLytics service which enables their users to generate maps and time-series data of the critical parameters indicating water quality.

The Baden-Württemberg environmental agency (LUBW) - the primary user – is using the information generated by eoLytics to conduct research, track dynamics, support decision making and compile reports on the water quality of lakes in their region, so fulfilling their mission.

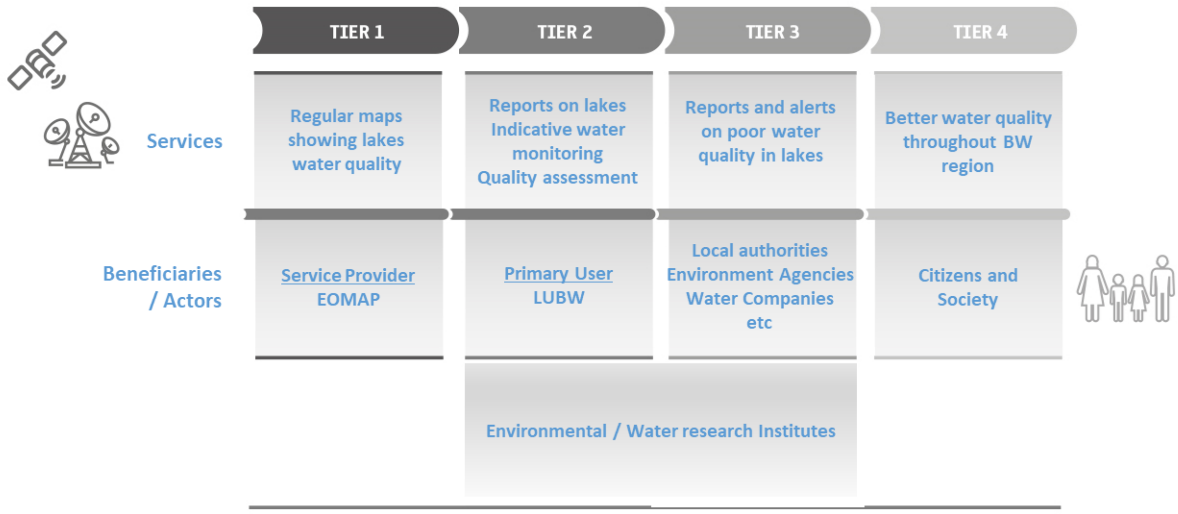


Figure 4-1: Core value chain for Lake Monitoring in Germany.

In tier 3, many users are benefiting from the water quality information which the LUBW is recording. These include other environmental agencies and particularly the federal agency responsible for national reporting, local authorities and water companies. There are also many users of the water resources which we group together under tier 4 i.e. citizens and society.

Outside the core value chain, there are also many interests in other ministries i.e. agriculture which are monitoring the impact of other activities i.e. farming and the use of nitrates with policy implications, and research institutes that are monitoring the impact of lakes and the quality of the water on the environment and the overall ecosystem.

4.2 The Actors

4.2.1 Tier 1: Service Provider – EOMAP

EOMAP is a small, privately-owned German company founded by Thomas Heege in 2006. Headquartered in Seefeld just outside Munich, EOMAP has grown to employ more than 20 persons in 2021 (actual status: 20 Germany + 4 abroad).

The main focus of EOMAPs services is on optical remote sensing of marine and freshwater aquatic environments. This includes bathymetric surveying (see SeBS short case on dredging in the Maldives), shoreline mapping as well as water quality monitoring addressed in this report.

The EOMAP water quality service has a strong research pedigree arising from the German space agency (DLR) – see EOMAP history. Several research papers testify to the service's history and to validation of the products which are offered.

EOMAP software processors for monitoring water quality have been installed in satellite ground stations in Europe, Australia, and Asia to ensure fast and efficient access to a wide range of current and future satellite sensors. Facilities are also installed in large cloud infrastructures, as well as in data hubs in Germany, Malaysia, Singapore and India. These measures ensure that the EOMAP Workflow System (EWS), delivers continuous 24-hour production of data every day of the year.

EOMAP is working with the CreoDIAS for access to Sentinel data, largely Sentinel-2 and Sentinel-3, whilst e.g. Landsat data used is accessed through Amazon cloud services.

EOMAP's production chains have been established to deliver standardised, qualitatively and quantitatively inter-comparable, i.e. sensor-independent, products for a full range of temporal and spatial resolutions. All products come with metadata conforming to the standards of the Open Geospatial Consortium (OGC) and the European INSPIRE directive.

In 2015, LUBW initiated an internal research project to understand how satellite data could help their work. This established the relationship with EOMAP which now provides reports every 3 months for 20 lakes which are defined by LUBW. As well as the reports, LUBW licenses the EOMAP eoApp for data visualization and the eoLytics cloud-based software, which is accessible via browser to run on their own satellite data processing with the satellite data accessed through EOMAP links with CreoDIAS and Amazon web services.

The EOMAP Story

EOMAP was started in 2006 by Thomas Heege, the current owner and driving force behind the company. At the time, Thomas had been working for 10 years as a research scientist with the German Space Agency (DLR) developing a system to perform aquatic data processing. With the agreement of the agency, and supported by a department dealing with technology transfer, Thomas left with an agreement that he could exploit the aquatic data processing system under a license against which he would pay royalties.

Within 2 months, EOMAP won their first commercial contract with an oil company to provide EO derived mapping for an oil-pipeline project which allowed Thomas to recruit the first additional employee. A research grant was won a few months later, and another recruitment followed meaning that EOMAP reached the size of 3 people within 6 months of starting and before the end of 2006.

Further commercial contracts with oil and offshore companies followed, building on relations developed with the DLR and most of them outside of Europe including several in Australia. This encouraged EOMAP to seek further international business and discussions started with partners operating in Asia and USA.

Still, the market readiness required time to be evolve and major financial investments to develop successful international affiliates. In 2013, EOMAP launched the EOMAP office in Singapore, which quickly evolved to support the continent, it's maritime industry and agencies. Offices and country representatives for US, Brazil and Indonesia followed recently in 2020 and 2021, providing as well in-house and cloud-based software for clients based on the EOMAP technologies.

This provoked a change to the business model as various customers preferred to license the software for internal use. As a result, EOMAP still operates today with this dual approach to its customers offering software licences and/or services running on EOMAP defined platforms. This is the case for the customer in our case study, the LUBW which accesses services as well as running licences software on their own machines.

As a result of these moves, EOMAP has grown faster since 2017 onwards. Thomas still remains at the head of the company which has grown entirely organically, and Thomas still holds 100% of the equity.

Today, EOMAP prides itself on its flexibility to respond to customers' needs and the strong attention given to customer service. The company advances under tight control, but consideration is being given to seeking external finance of a strategic nature to move it onto a more aggressive growth path. Water quality services would be at the heart of that push in line with the findings of this case study.

4.2.2 Tier 2: Primary User – State Institute for the Environment, Baden-Württemberg

The LUBW (Landesanstalt für Umwelt Baden-Württemberg) is the State Institute for the Environment (in) Baden-Württemberg and has the overall mission to "manage, protect and preserve the natural environment" of Baden-Württemberg. According to its website:

> *LUBW is the competence centre of the State of Baden-Württemberg in matters of environmental protection and nature conservation, technical occupational health and safety, radiation protection and product safety. As an independent state institution, it advises politicians and administrators in Baden Württemberg on a wide range of technical issues, such as climate change and adaptation, wind power and species protection, or flood and low-water forecasting, to name just a few. To fulfil these diverse tasks, it collects data with extensive state-wide measurement networks and mapping. These data provide a solid basis for assessing the development of environmental quality in Baden-Württemberg."*

The LUBW has 550 employees from the natural sciences, engineering and technology as well as laboratories and administration who work to find joint solutions for the increasingly complex environmental problems.

LUBW describe their role under three tasks:

- To observe through operating measurement networks for air, water, soil and radioactivity nationwide. Mapping of fauna and flora provides information about the state of nature and the landscape.
- To analyse by evaluating the measurement results across disciplines and across regions including the development of IT processes that provide an overview of the data obtained.
- To advise the state government and the environmental and nature conservation administration in Baden-Württemberg. LUBW prepares regularly environmental status reports for Baden-Württemberg.

The LUBW has its headquarters in Karlsruhe and its centre for lake research (ISF) is located on Lake Constance. Dr Thomas Wolf, from this centre, along with Thomas Heege (EOmap), Björn Baschek (BfG) and Christian Schweitzer (UBA) has been pioneering the use of satellite-derived water quality products for lake monitoring in the region and supporting its introduction throughout Germany. One of the main platforms for this is the water coordination group – LAWA - which brings together representatives from each of the environmental institutes of the 16 German regions to exchange on common interests and best practices. This helped launch a state project in 2019 under the digitalisation agenda of Baden-Württemberg which is helping to developing IT tools which can integrate the data from EO based measurements with the in-situ measurements.

The work of the institute includes reporting against the German legislation which in some cases enshrines European regulations. The legal framework in BW brings 6 specific pieces of legislation to the management of water resources which are directly linked to the water framework directive:

- The Water Framework directive is Europe-wide and provides the legal basis in Germany implemented by the federal agency.
- Directive 2008/105 / EC on environmental quality standards in the field of water policy which limits the presence of specific chemicals in the water.
- The Water Resources Act defines responsibilities in Germany for management of water bodies.
- The Surface Waters Ordinance brings a number of EU directives and regulations into German law.
- The Groundwater Ordinance covers measures to control pollution of water supplies.
- The Baden-Württemberg Waters Act covers specific measures for the region.

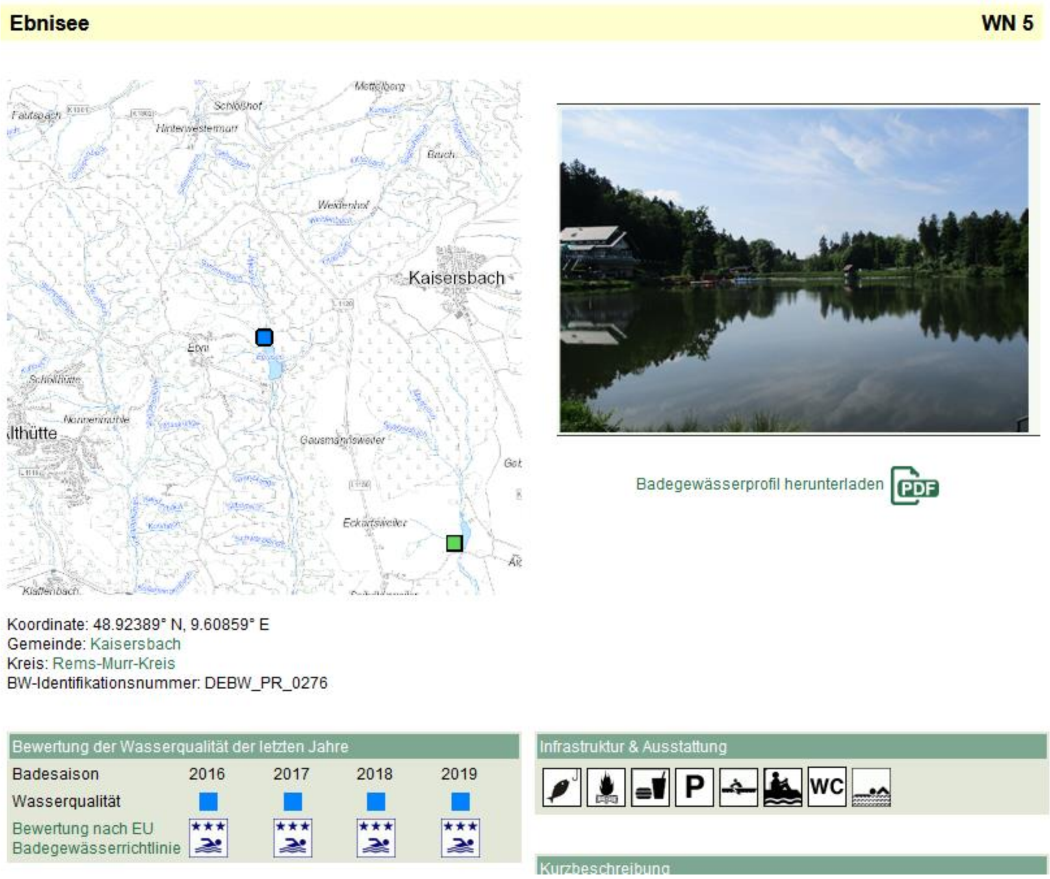


Figure 4-2: Bathing water information from the LUBW bathing sites portal.

In addition, the Bathing Waters directive and the Nitrates Directive are directly applicable. The LUBW provides information to the public on the quality of the bathing waters at all the declared bathing sites in the region. This shows the facilities, the quality of the water and information on the local conditions ie temperatures, weather conditions, in the season between mid-May and end September. An example of the information for Lake Ebnisee is shown in Figure **4**-**2**.

LUBW routinely monitors around 10 lakes every year (not always the same ones) out of a total of 25 in total. These are supplemented by 20-30 lakes measured each year by the district councils.

These change each year on a 5-year cycle meaning that overall, more than 100 lakes are regularly monitored at least once every 5 years. Formally, all lakes of size more than 50 ha, must be measured every 5 to 6 years under reporting requirements against the WFD.

Work is on-going to evaluate how many of the 260 lakes of >10ha can be reliably measured using Sentinel data. Not all will be possible as there will be lakes - also within this size class of 10ha - which might have some problems - due to e.g. low observability due to meteorological conditions (e.g. often dust / fog in the Mountains of the Schwarzwald / Black forest), very shallow lakes and sometimes maybe also lakes with very high concentrations of CDOM Coloured Dissolved Organic Matter /"yellow substances". In these cases the data of EO-based lake monitoring may be less robust. LUBW are advancing cautiously to avoid confusion and over promising on performance.

In addition, measurements will be taken, mostly by the district councils, if there are thought to be water quality issues in a lake.

However, it is most important to note that the work is not just about reporting and this is an extremely important observation in the context of this case as it also relates to the use of satellite data and the way that this has been introduced into the institutes work – see highlight box.

Water Management Department of Rheinland Pfalz.

Another region in Germany has also been using the EOMAP water quality services served through the eoApp platform and we decided to include them in the case as a second example of a user. Rheinland Pfalz State Office for the Environment (LfU) is a subordinate authority to the Ministry for the Environment, Energy, Food and Forests of Rhineland-Palatinate. The region is situated in western Germany with borders to Belgium, France and Luxembourg.

Under the motto "Measure, evaluate, advise", the state office with its around 275 employees, provides the basis for informing citizens as well as decision makers on topics such as nature conservation and landscape management, waste and soil protection through measurements and professional advice, water management and flood protection, occupational safety and pollution control. The LfU is headquartered in the state capital Mainz with offices on the banks of the Rhine in Mainz (Rhine investigation station), in Worms (Rhine quality station) and on the Moselle near Fankel (water investigation station).

The LfU has started to use eoLytics in 2019 to monitor water bodies in their region in a similar way to LUBW. This process will be discussed in chapter 5 when we look at the benefits.

Introducing EO-based water quality measurements into LUBW

The first tentative steps to use satellite data to support water quality monitoring in Baden-Württemberg, were made in 2000-2002. Discussions were held with the DLR to establish a trial project, but which faltered after the DLR placed the focus of their work on radar. Nevertheless, work did continue and Thomas Heege from EOMAP, who was working at the DLR at this time, was instrumental in this research.

At this time, in the early noughties, the GMES initiative was starting where DLR, as one of the major European space agencies was a key player. A co-ordination group, the national GMES user forum, was set up in Germany which organised a major, national meeting every 18 months (roughly). This brought together up to 500 researchers, administrators, and industrialists under the patronage of 3 Federal Ministries for R&D, Industry, and the Environment; later extended to include the Federal Ministries for Transport and Digital Infrastructure, Home Affairs, and Agriculture. This included a group dedicated to the use of satellite data to monitor inland waters. LUBW (Thomas Wolf) joined this group in 2014.

At this time the barriers to introduce the service in the institute were high.

- The technical performance was limited due to the limited satellite data,
- LUBW had no internal remote sensing expertise of lake monitoring so were relying on EOMAP,
- There was no formal requirement for the data since it did not correspond to formal reporting needs.

Finally, a research project (WASMON-CT) was set up in 2016 by LUBW working with the Bundesanstalt für Gewässerkunde (BfG). The project was funded by the Federal Ministry for Transport and Digital Infrastructure (BMVI) to explore the use of the satellite-derived data on water quality in rivers (BfG) and in lakes (LUBW). The project was supported by the DLR and data was provided by EOMAP.

Despite the positive results, once the project ended, no budget had been foreseen for the work to continue. Convincing others was a long process involving deep scientific discussion followed on the merits and difficulties of using satellite data and how to combine the results with in-situ measurements to take advantage of both methods.

But awareness of the complementary nature of the two technologies was growing, and which was helped by the region (Baden-Württemberg) instigating an unrelated project (SAMOSEE-BW) to extend the use of digital technology throughout the administration. The project manager in charge of this became interested in the lake monitoring project and supported its introduction in the digitalisation project.

This in turn gave support to a follow-up research activity which demonstrated that water quality could be measured with a good precision for many of the lakes in the region with an area >10ha. It was helped also by some of the Federal ministries recognising that EO data was being used in some other countries and that helped convinced them that the lake monitoring service could be more widely used.

Today, the benefits of the service are recognised even if no formal evaluation has been made, and the institute is committed to continuing its use. For the first time, in 2021, the institute will compile a more systematic approach for more lakes, using remote sensing water quality data to be included in the annual report. The LUBW success has encouraged Rheinland-Pfalz to follow a similar approach, and, through the LAWA, a project is starting to standardise the methodologies used for lake water quality measurement across Germany.

Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA)

We have mentioned the LAWA a few times already. The LAWA is the German Working Group on water issues of the Federal States and the Federal Government represented by the Federal Environment Ministry.

The Working Group on water issues (LAWA) was set up in 1956 as an amalgamation of the ministries of the States of the Federal Republic of Germany responsible for water management and water legislation.

The aims of the Working Group of the Federal States on water issues are to discuss in detail questions arising in the areas of water management and water legislation, to formulate solutions and to put forward recommendations for their implementation. In addition, topical questions in the national, supranational and international sphere are also adopted, discussed on a broad basis and the findings submitted to the relevant organisations.

4.2.3 Tier 3: Secondary Beneficiaries

Tier 3 (refer to Figure 4-1) concerns the users of the information on lake water quality. This includes the federal environment agency to which LUBW supplies its annual reports and the immediate users of those reports, other environmental agencies, local authorities in the region, and water companies. The more extensive list of users of the lakes will be considered in tier 4.

Federal Environmental Agency (UBA)

As Germany's main environmental protection agency, the Federal Environmental Agency (UBA)'s task is to ensure that German citizens have a healthy environment with clean air and water, free of pollutants to the greatest extent possible. The agency is concerned with a broad spectrum of issues, including waste avoidance, climate protection, and pesticide approvals.

The mission of the UBA is to detect environmental risks and threats as early as possible, to assess them and find viable solutions to address them in a timely manner. In support, UBA conducts research in their own labs and with scientific institutions such as Helmholtz and IGB (see 4.2.5), in Germany and abroad.

The work of the UBA centres around gathering data concerning the state of the environment, investigating the relevant interrelationships and making projections – and then, based on these findings, providing federal bodies such as the Ministry of the Environment with policy advice. Information is also made freely available to the general public. The UBA also implements environmental law and makes sure that it is applied in areas such as CO2 trading and approval processes for chemicals, pharmaceutical drugs and pesticides.

The mission of UBA in relation to water resources was recently emphasised by Federal Environment Minister Svenja Schulze on the occasion of the conclusion of the **National Water Dialogue**:

> *"Fortunately, our country is still a long way from a water emergency. I want this to remain so in times of climate change, which is why Germany needs a* ***national water strategy****. One important element is the establishment of principles for prioritising water use, in other words a water hierarchy. Equally major challenges are the pollution of water bodies, maintaining the functionality of water ecosystems and securing services of general interest. The National Water Dialogue has analysed the current and foreseeable challenges more thoroughly than ever before. The results are a good basis for the first national water strategy, which we in the Federal Environment Ministry will develop starting today."*

The UBA has set out a strategy for management of lakes and the quality of water.

The UBA gathers the information supplied by the regional institutes which is then used to compile a national level report. Since the focus is on meeting EU directives where satellite data is not mandated to be used, these reports are constructed based on in-situ measurements. However, the ability to monitor the water quality in many of the smaller water bodies opens the possibility to bring an expansion of this mandate.

Even so, the wider measurement of water quality is used to develop a better understanding of the impact of agricultural practices and the links with legislation such as the EU Nitrates Directive. The environmental institutes are seeking to monitor the efficacy of the measures preventing farmers from using chemicals within 5m of defined water courses.

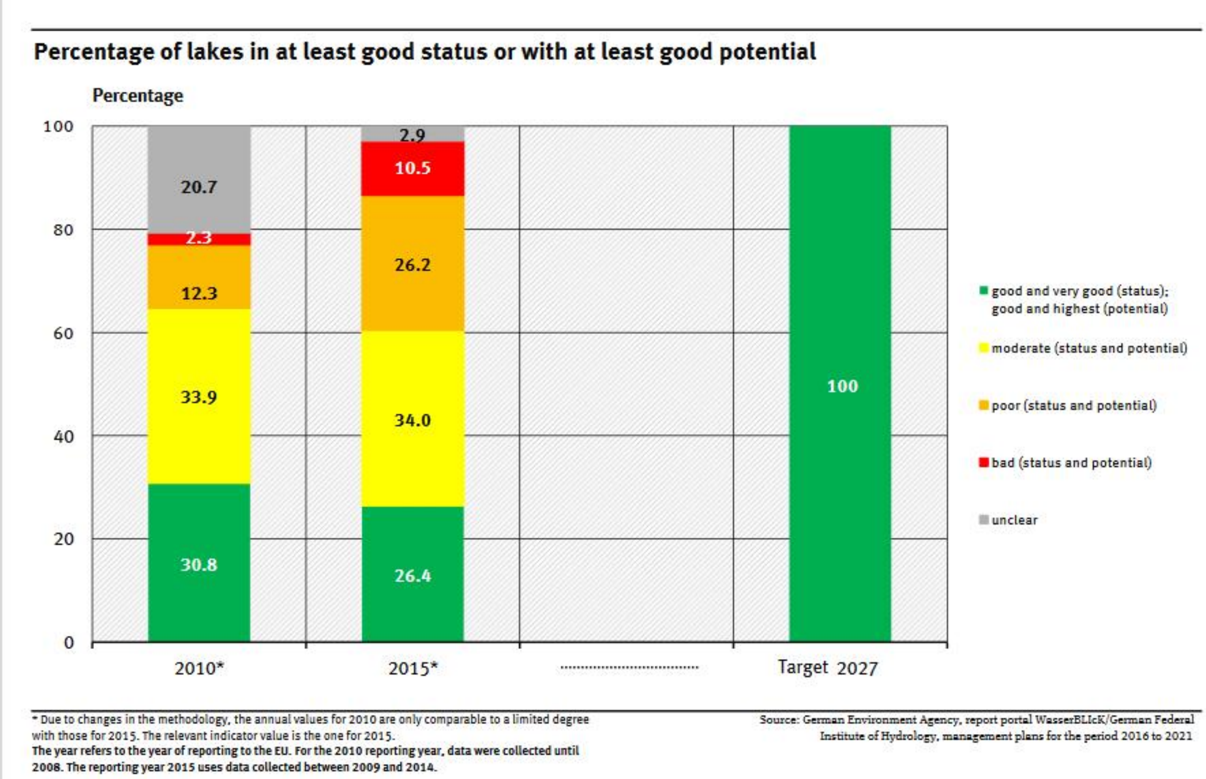


Figure 4-3: Ratings of German lakes water quality Source UBA[46].

Local Authorities

Within the 16 federal states, Bundesländer, districts execute the relevant legislation and monitor compliance. They also gather much of the data being used in the reporting chain up to the Federal Ministries and eventually relating to compliance at EU level also. Within Baden-Württemberg, there are 4 administrative districts and we discussed the water quality management practice with the district office of **Tübingen** which lies in the centre of the region and extends to the southern border represented by Lake Constance (the Bodensee).

Tübingen district authority

Tübingen is one of the 4 administrative districts in the region of Baden-Württemberg. It covers most of the shore of Lake Constance as well as the start of the Danube river valley. It is divided into 9 local districts including the Bodensee.

The district authority monitors and reports on the lakes within its area and the information is supplied to LUBW. Typically, measurements are made on 20-25 lakes each year out of 100 lakes which are monitored on a 5-year cycle. Responsibility for taking measurements is shared between

46 https://www.umweltbundesamt.de/en/indicator-ecological-status-of-lakes#at-a-glance

the administrative district office and the local office. The measurements are outsourced to a local company.

Tübingen district interest regarding the quality of the lake water is linked to leisure activities and farming. The latter primarily concerns the farmers use of chemicals that may run off into the lakes and the guard strips which are imposed along water courses. The data gathered by the districts help understand the efficacy of the limits imposed on the use of chemicals. Leisure activities are of interest to the local community and provide revenues for the district by attracting visitors from outside **Tübingen** district.

Local district office / Landratsamt Bodenseekreis

Landratsamt Bodenseekreis is one of the local district offices within the **Tübingen** region which are responsible for the implementation of legislation. In this respect, they manage the quality of the water in the district. Two areas of responsibility stand out:

- monitoring planning decisions for appropriate application of environmental assessments. Will there be a future impact on water quality and has the impact been adequately assessed? (including giving authorisations e.g. for future buildings after environmental impact assessment)
- The quality of the water in lakes, ponds and especially streams and rivers; is there a health risk? Can water be safely abstracted?

Mostly, the local district office is receiving information from the administrative office and taking decisions based on the water quality; for example, whether to open or close lakes for public use in the case of HABs flowering or whether to allow or limit water abstraction for irrigation.

Water Companies

Baden-Württemberg is a water-rich state, with a water supply capacity of around 49 billion m³ per year. In 2010, the public drinking water supply withdrew 618 million m³, around 1% of the supply. However, there are differences in the availability and quality of drinking water in smaller areas. There are very water-rich areas along the state borders of Baden-Württemberg, at Lake Constance, in the Iller and Danube valleys and in the Upper Rhine Graben. These are contrasted by water-poor areas in the central and north-eastern parts of the state, such as the central Neckar region, the high plateau of the Swabian Alb and individual regions in the Black Forest.

Water abstraction by the public water supply has declined continuously in the state since 1991. 1991 was a dry year in which a particularly large amount of water was extracted. Although the number of inhabitants connected to the public water supply increased by about 770 000 people between 1991 and 2010, water extraction decreased by 107 million m³. These savings were achieved mainly through new technologies and a change in consumption behaviour. In addition, renovation work has reduced pipe losses and the waterworks' own consumption by 29 million m³ over the last 19 years.

With water extraction continuing to decline, there were a **total of 1,334 public water suppliers based in Baden-Württemberg in 2010**. About two thirds of these companies also extracted water themselves. The total volume of water abstracted was just under 652 million m³ of groundwater, spring water and surface water, of which just under 34 million m³ was abstracted on Bavarian territory. This means that in 2010 about 6 million m³ less water was extracted than in 2007. This is almost half the capacity of the Kleine Kinzig drinking water reservoir in the Black Forest.

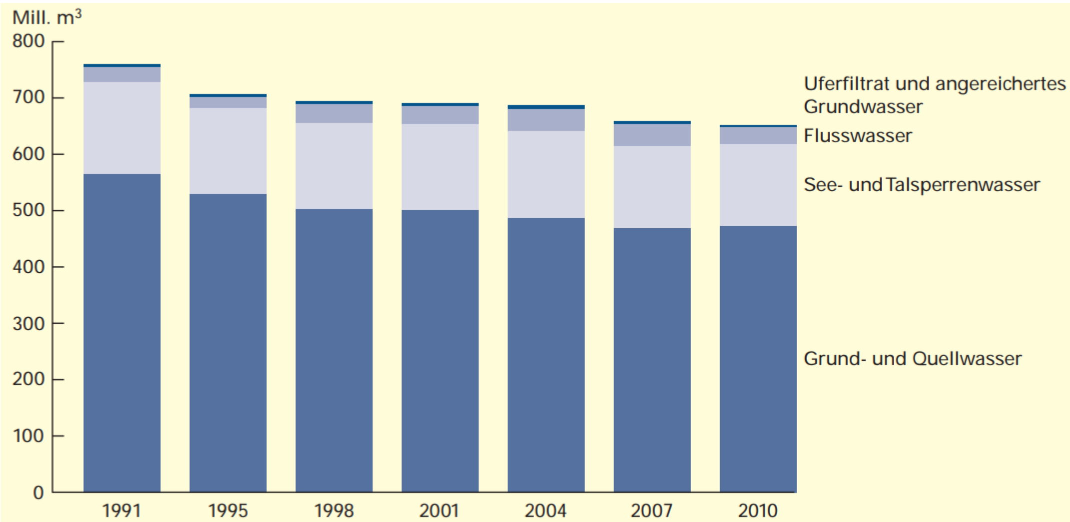


Figure 4-4: Public water supply in BW since 1991 ©Land Statistical Office BW

In Baden-Württemberg, **groundwater (Grundwasser) is mainly extracted for drinking water supply**. Since 1975, the share of groundwater has always been above 50 %. The state water supply and the water supply of north-east Baden-Württemberg also primarily extract groundwater and spring water. **In second place is the extraction of water from Lake Constance**. The first plants of the Lake Constance water supply were put into operation as early as 1958. Since 1998, the **share of extraction of lake and reservoir (See- und Talsperrenwasser) water has overtaken the extraction of spring water (Quellwasser)**. The Kleine Kinzig in the Black Forest is the only drinking water dam in the region. The drinking water obtained from rivers (Flusswasser) for supply in the state comes entirely from the Danube.

Ensuring the supply of safe drinking water, even during hot spells, is a core task of public services. In Baden-Württemberg, this is guaranteed by a historically evolved system of three levels of water supply. This includes local water supply (mainly drinking water via individual wells), group water supply (mainly rainwater collected in cisterns as drinking water) and long-distance water supply that still exists today. This last level refers to public water supply, where the place of water extraction is far away from the actual supply area. There are **four large long-distance water supply companies** in Baden-Württemberg:

- Bodensee-Wasserversorgung (BWV)
- Landeswasserversorgung (LW)
- Wasserversorgung Nordostwürttemberg (NOW)
- Wasserversorgung Kleine Kinzig (WKK).[47]

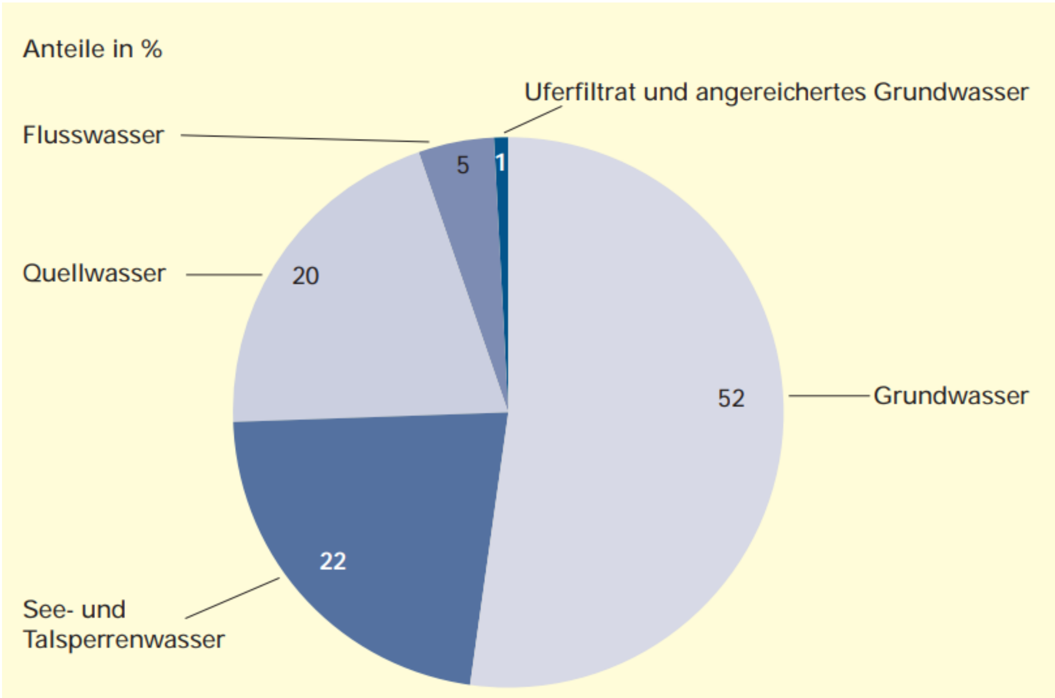


Figure 4-5 Share of Water Supply (22% on lakes and reservoirs) ©Land Statistical Office BW

During industrialisation, the population and economy in the Stuttgart area grew rapidly. The drinking water supply could no longer be covered by the local water resources. This led to the founding of the state water supply company in 1912, which supplied the Stuttgart area with water from the Donauried. Due to the economic boom and the rising population figures after the Second World War, supply difficulties arose again. The idea developed that Lake Constance could permanently solve the water supply problems in the southwest. In 1954, the Lake Constance Water Supply Company was founded and supplies water to 4-5 million residents of southern Baden-Württemberg. In 1953, Wasserversorgung Nordostwürttemberg was formed to supply the areas of north-east Württemberg. The Zweckverband Kleine Kinzig supplies the inhabitants with water from the Kleine Kinzig dam in the Black Forest, which was put into operation in 1984.

[47] https://www.statistik-bw.de/Service/Veroeff/Monatshefte/PDF/Beitrag12_05_09.pdf

4.2.4 Tier 4: Citizens and Society

In tier 4 (see Figure 4-1), we include all the recreational users of water bodies i.e. for swimming, sailing, fishing, and for other activities in the area surrounding the water bodies ie hunters, farmers, foresters, etc. Poor water quality may affect the natural habitat and wildlife, potentially killing fish and other fauna and reducing biodiversity.

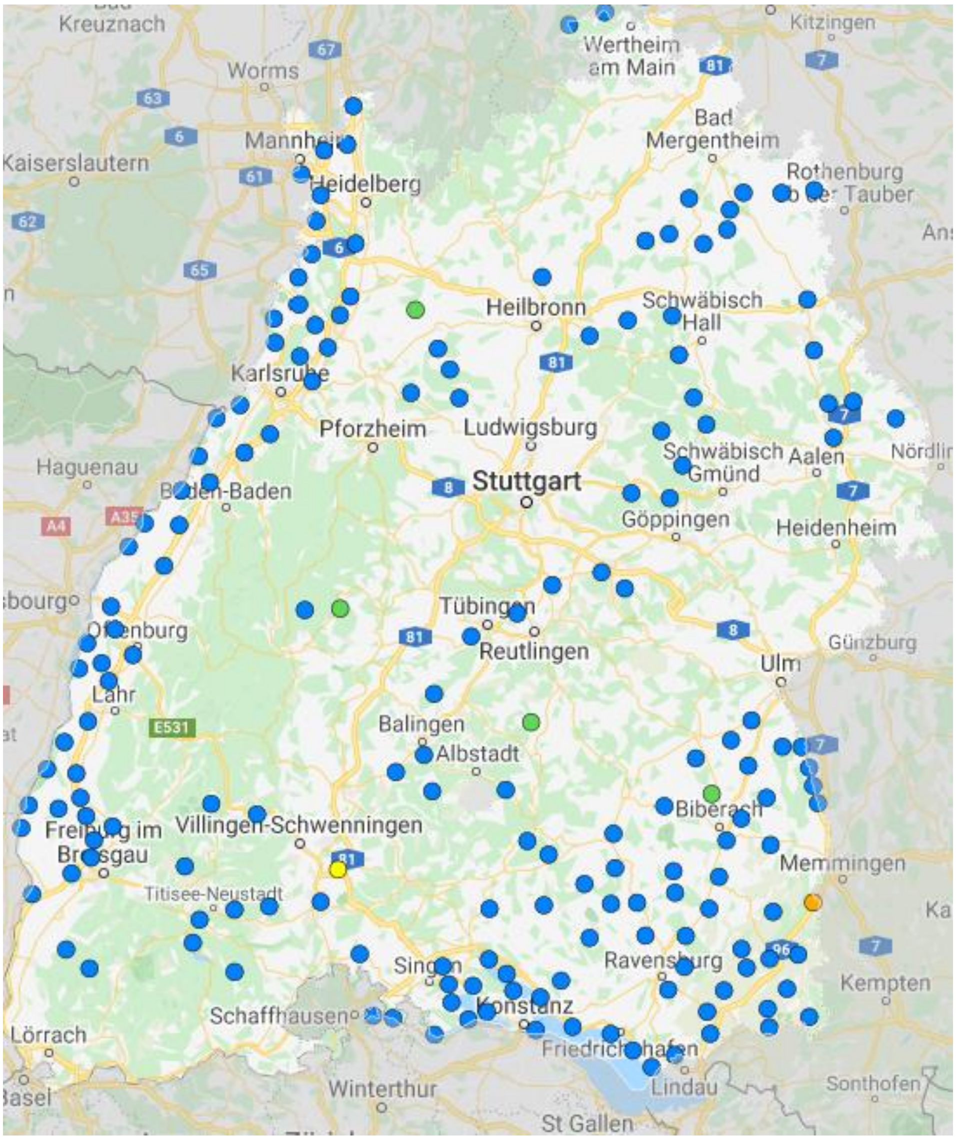


Figure 4-6: Quality of bathing waters in Baden-Württemberg in 2019, (blue is excellent, green is good, yellow is acceptable, and orange is not tested).

Swimming is a very popular pastime and a holiday activity. Maintaining high quality bathing water and avoiding the closure of bathing locations is a key goal for the region. The EU Bathing Water

Directive, described in chapter 2.3, sets out the regulatory framework to ensure swimmers enjoy pure waters.

Both Baden-Württemberg (via the LUBW Bathing water map) and Rheinland-Pfalz (via the district bathing waters map) maintain a portal to guide bathers. An extract for Baden-Württemberg is shown in Figure 4-6 showing the status at each of the recognised swimming locations on rivers and lakes in the region. Further detail may be envisioned on the actual water quality situation for each defined bathing location so enabling citizens to decide on where they should go and more particularly on which locations should be avoided in the case of problems.

Fishing is another popular pastime and tourist activity. Many of the lakes are stocked with fish and many are maintained by fishing clubs. The great danger for the fish is a build-up of HABs potentially causing a high build-up of toxins, a lack of oxygen or death. Build-up of nutrients in the sediment of the lakes may be released by bottom to top circulation of water which is why this must be monitored. If a lake becomes too polluted, it will be necessary to either oxygenate the water, which is quite expensive or in the worst case, to drain the lake and extract the bottom sludge. Oxygenation is only used where the influx of nutrients is limited, otherwise, there is a strong risk that the process will not succeed.

Sailing is yet another very popular pastime and tourist attraction. Lake Constance is the main sailing lake in the region with strict controls on qualified skippers. As shown on the front cover of this report, yachts abound on the waters and the lake becomes very crowded in summer and at weekends. Water quality is less of an issue for sailors except if there are actual HAB's present when the water is unpleasant to be near. Fortunately, HAB's on Lake Constance are rare events although, in the last few years, a number of small, blue-algae blooms have been observed.

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[48]. This 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. Baden-Württemberg is contributing its share to Natura 2000 and has declared 11.6 % of its area of the state as habitats directive sites and 10.9 % as birds' directive sites. In its management plans, the presence of 53 types of habitats, 61 protected species as well as 39 breeding birds species are being recorded and the conservation and development objectives are defined[49].

4.2.5 Other Beneficiaries

Other beneficiaries include other ministries which are taking decisions based upon the water quality reports, for example, the ministry for agriculture, and research bodies that are doing work linked to water quality. Two research institutes stand out for their activities linked to water quality and

[48] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
[49] Nature Conservation (in Baden Wurttenberg)

how they impact, or may impact in the future, on the regulatory environment and implementation of legislation. They are also significant beneficiaries of the satellite-based monitoring of water quality.

The Helmholtz Centre for Environmental Research - UFZ was established in 1991 and has more than 1,100 employees in Leipzig, Halle/S. and Magdeburg. They study the complex interactions between humans and the environment in cultivated and damaged landscapes. Scientists develop concepts and processes to help secure the natural foundations of human life for future generations.

The Department concerned with Lake research comes under the "water resources and environment" research unit along with several other departments concerned with water quality. The goal is to help *develop strategies for sustainable water management that can be implemented in selected regions around the world*.

The work of the department focuses on *reservoirs that are heavily managed due to anthropogenic use. The management of reservoirs is characterised by the conflicts surrounding their use, such as the provision of fresh drinking water or flood protection. Important issues such as the connection between the water volume and the management of the water quality or minimising the ecological effects of the reservoir on downstream rivers remain unresolved.*

The availability of wide-scale and regular measurements of lake properties enables research into the policy aspect s of lake management and the impacts on the local ecosystem.

IGB/RESI

River Ecosystem Services Index (RESI) – described in chapter 2.4 - is not a single institute but is the result of a collaborative research project funded under the BMBF program "Regional Water Resources Management for Sustainable Protection of Waters in Germany (ReWaM)". The goal of RESI is to assess, evaluate and visualize ecosystem services provided by rivers and their floodplains. The interactions of various ecosystem services are analysed in order to identify cross-sectoral optimized management options and synergies, for example between water management, recreation and nature conservation.

The project RESI is led by the **Leipzig Institute of Freshwater Ecology and Inland Fisheries (IGB)** and involves a team of 16 research institutes and SME's. IGB is Germany's largest research centre for freshwaters and one of the leading institutes in the world. Rheinland Pfalz State Office for the Environment (LfU) is a partner in the RESI project.

LUBW is not a direct partner of RESI but had their own, similar project SEEZEICHEN, which dealt with ground water – lake – interactions and different kinds of matter fluxes into lakes (river plumes), and which is associated to RESI through the ReWaM-Project-Cluster which is a partner.

5 Assessing the Benefits

5.1 Overview

In this section, we consider the actors in each of the tiers and analyse the benefits which they obtain through the use of the Sentinel data. The 6 dimensions are used as the framework for analysis and the benefits are presented for each of the dimensions. However, before we dive into the discussion for each of the tiers it is instructive to make some high-level observations:

1. **Timing.**

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 as the measurements become recognised in legislative measures. None of the relevant legislations discussed earlier, currently recognise the use of satellite data as a measurement tool for reporting. The use is not banned but is not encouraged as are direct measurements. Some countries, as is the case in Baden-Württemberg, 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, which it surely will 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 coming in 2018. 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 will be introduced by the EEA in 2021/2022. It remains for the Environmental Ministries to recognise its use for monitoring and reporting purposes.

However, the Bathing Waters Directive, which is reported on every year, is being reviewed in 2021, as this report is being written. This could provide a first vehicle to introduce satellite measurements and the European service will be relevant to meet reporting needs.

2. Attribution:

In most of the previous cases which have been analysed, we face the issue of attribution ie where there is shown to be an economic benefit, how much of this is due to the use of the data from Sentinel satellites? In the case of lake monitoring in Germany, the eoLytics service is based mostly on data from Sentinel-2 or Sentinel-3 with some contribution coming from Landsat. We can safely attribute 100% of the benefits to satellite data and shall take 80% of this as being due to the use of the data coming from the Sentinels.

3. Extrapolation

In order to extrapolate from the region of Baden-Württemberg to the whole of Germany, we can use a number of parameters –possibilities include:

- **Number of lakes**. Figure 2-1 shows the number of natural lakes of a given size in each of the German regions. Taking lakes greater than 10ha in area, there are 10 in Baden-Württemberg compared to 1626 in the whole of Germany. This gives an extrapolation ratio of 160. Note that since the number of water bodies is much higher than this and the service cost is not significantly increased by the number of lakes, this parameter will not be used.
- **Population**. The population of Baden-Württemberg is just over 11m people compared to 84m for the whole of Germany. This gives an extrapolation ratio of 8.
- **Land Area**; the surface area of Baden-Württemberg is 35,000km2 compared to 357,000km2 for the whole of Germany, a ratio of 10.
- **GDP**; the GDP of Baden-Württemberg is around €520b compared to €3t for the whole of Germany; a ratio of 6.
- **Number of Regions**. There are 16 German regions. But the size varies, as do the number of lakes in each, so this would be too simplistic used on its own.

Which one(s) to use depends a great deal on how the benefits are manifest. Intuitively, the number of lakes could be considered most relevant and this is certainly the case if we consider environmental benefits. Nevertheless, many of the benefits are societal in nature linked to the tier 4, and in this case, either the population ratio or GDP ratio would seem the most appropriate to use. As this is more conservative than using the ratios of the number of lakes, we shall use these ratios in our analysis, where each is most appropriate.

4. Winners and losers:

This is not really a case with winners and losers. Other cases have recognised that where economic gains are made through cost savings, this may imply loss of jobs. However, the factors present in this case all lead to indicators which are more to do with improved conditions, better health and time savings for individuals.

5. 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 water, maintaining a rich flora and fauna (which may or may not be a question linked to biodiversity), or in the quality of life and culture.

Many attempts are being made to tackle this issue and we shall discuss some in chapter 5.2.3 and 5.2.4.

IPBES – [the intergovernmental science-policy platform on Biodiversity and ecosystem services](#) - acknowledges that different types of values need to be promoted in decision-making. While the intrinsic values of 'nature' are recognized as important for decision-making, IPBES also acknowledges that decision-making relies to a great extent on the instrumental values of [Natures Contribution to People](#) (NCP). In addition, NCP can embody symbolic relationships with natural entities to the extent that such relationships are inextricably linked to people's sense of identity and spirituality, to a meaningful life and to 'doing the right thing'. In this case, NCP are associated with relational values, that is values that do not directly emanate from nature but are derivative of our relationships with it and our responsibilities towards it.

With all that said, the next section presents a systematic analysis of the economic value ("adding a price tag") and other types of benefits arising from the use of Sentinel data in each Tier.

5.2 Benefits along the Value-Chain

5.2.1 Tier 1: Service Provider – EOMAP

EOMAP, as we have seen, has built its business around water – namely freshwater and coastal services. The company started before the days of Copernicus and so has built business on the use of Landsat rather than on Sentinels. These have come later but do contribute today to EOMAP's continued success.

The water quality service using Sentinel data has undoubtedly contributed to EOMAP's growth in recent years. Employment has grown from 10 to 20 in the period since Sentinel-2 was launched and some of this – we shall assume half – can be attributed to Sentinel use.

As we prepare this report in 2021, this success will be challenged as the EEA has been contracted by the EC to establish a European-wide service with overlapping features to that in use in Germany. This is both an opportunity and a threat for EOMAP. An opportunity to succeed in the tender and to directly establish a service at the European level. This could be achieved in partnership with a few other companies, but all will need to provide an identical service to make comparisons across Europe. It is also a threat since the German environmental agencies might expect that a Europe-wide service in the future could serve their requirements instead of the customized services from companies such as EOMAP. Centralization of environmental data services challenge companies like EOMAP

Not all will be lost as the European service will be limited in the parameters and possibly (TBC) in the frequency of updates of the measurements. As in other similar moves (ie the European Ground Motion Service), the existence of a service coming for free (under the Copernicus free and open data policy) triggers interest in the results and leads to additional business to complement the free service with a commercial one.

In our analysis, where EOMAP is supplying regional authorities in Germany, the revenue achieved by EOMAP will directly appear as a cost for the authorities. Hence this will cancel out as we examine and add up the benefits along the value chain. Where EOMAP can lever the service is in other markets outside Germany. Even if the Sentinel data is free, the service offered by EOMAP builds upon this and creates the opportunity for export business.

We do not have any direct figures for the service since these are considered confidential by EOMAP. Nevertheless, if we make a basic assumption that each customer will pay €50k-€100k per annum for a similar service to that taken by LUBW and Rheinland Pfalz, this implies €1m additional revenue is possible in Germany from the 14 other Länder. Whilst this revenue could be expected to grow as services are improved, competitive pressures will certainly constrain the ability to raise prices and it is likely that the revenue will stay roughly stable as performance is improved. The impact of the European service will also need to be accounted for.

Markets overseas are also accessible by EOMAP, not limited to Australia, Indonesia or the USA where their subsidiaries are active. EOMAP has provided the service to UNESCO and some other international bodies, demonstrating the interest. If the total market in Germany can be considered at around €1.5m per annum, other countries could be expected to pay a proportional amount based on a mixture of population size and number of lakes or their area. We shall not calculate or present any figures but simply note the significant market potential open for EOMAP.

In terms of the service, EOMAP founder Thomas Heege was at the heart of the innovation which led to the system being developed by DLR and then licenced to EOMAP. Innovation has continued including the introduction of Sentinel data, the establishment of on-line platforms for accessing and processing different forms of satellite data, and the creation of on-line portals to give access to pre-processed results. Hence the user-requirements driven innovation component is strong with a certain part of this attributable to Sentinel data.

5.2.2 Tier 2: Primary User – Regional Environmental Agencies

The use of the eoLytics water quality service by the regional environmental agencies LUBW and LfU has been an extension of their activities rather than directly attached to their core tasks. It enables each to monitor many more lakes / water bodies than would be possible using traditional in-situ measurements and to monitor the larger ones better. How can this generate benefits to the agencies?

Reporting against the requirements of the EU WFD, and the equivalent measures recognised under German law, the agencies are not yet able to use the satellite-derived data to meet this need as the directive favours the taking of in-situ samples and analyses. Only 15 of the several hundred lakes in Baden-Württemberg are implicated by the directive. Testing is outsourced and generally costs around €3.5k per lake tested. A total cost for this activity would be around €50k per annum.

This would be roughly the same situation in Rheinland Pfalz and hence we take the same figures as for Baden-Württemberg.

Similarly, testing against the Bathing Waters Directive also requires dedicated in-situ samples and measurements to be taken. The health authorities monitor the hygienic quality (= microbiological quality) of the bathing water. The results of these examinations (germ counts) are communicated to the relevant state environmental institute, among others, which makes the hygiene data available to all interested parties at the bathers' website (see chapter 4.2.2) and reports it to the EU via the Federal Environment Agency at the end of a season.

Before each bathing season, the Ministry for the Environment, Energy, Food and Forests determines and publishes the list of official bathing waters for each region. In 2013 the number of registered bathing lakes in Rheinland Pfalz was 69 whilst in Baden-Württemberg, there are over 300 registered bathing sites. The bathing season spans the period from May 15th to August 31st of each year.

Monitoring of the waters takes place through inspections, sampling and analysis of the samples obtained. Samples are taken at the places where the water is most used by bathers (defined bathing zones, monitoring points). We understand that around 20 lakes are tested each year in a rotation of 5 years meaning 100 lakes in total are tested once every 5 years. When problems are identified, then tests will be made of waters that are considered at risk.

Bathing water quality is generally good as can be seen from the ranking of European countries made by the European Commission (EC), see Figure 2-8. The EC rated only 8 bathing waters in Germany 'poor' for the 2019 season according to the criteria of the EU Bathing Water Directive[50] out of a total of 2291 sites throughout Germany. 105 sites were closed either temporarily or entirely, 53 of which because of problems with cyanobacteria (blue-green algae). The reasons for longer-term closures were usually remediation measures or a lack of operator; 27 sites were closed temporarily due to poor hygienic quality of water, which in most cases was the result of storms and torrential rains causing effluent to be washed into bathing waters.

The value of the eoLytics data to the regional authority then lies more in providing the state authorities with the information based on which they can monitor the quality of the water rather than to meet specific reporting or regulatory needs. LUBW has started to use the term “indicative lake monitoring” to distinguish the measurements from these directly meeting reporting needs. This allows them to improve the service they provide to citizens by helping them to avoid health-risk by swimming in lakes where harmful toxins are present. The eoLytics data allows far more water bodies to be monitored than is necessary to meet the needs of either the EU WFD or the EU Bathing Waters Directive and/or their German equivalents or would be practical using in-situ samples. The benefits, therefore, accrue more to society at large than directly to the regional authorities or their agencies.

---

[50] https://www.umweltbundesamt.de/en/press/pressinformation/clean-bathing-waters-but-the-fun-has-its-limits

Nevertheless, the regional authorities are investing in the use of the eoLytics service and therefore must perceive that the value to the region outweighs the cost of the service. We can only assign some of that benefit to the tier 2 stakeholders if these perceived benefits would justify a higher cost than that paid for the eoLytics service. Since this cost would then be deducted from the economic benefits later, it is probably safe to set this aside at this stage and to concentrate on the wider societal benefits for which ultimately, the regional government (and also at federal level) is responsible.

This is a really important result, showing that there may be a "negative economic benefit" (ie cost with no offsetting savings) that is accepted by the institute or those providing its budget, but which is deemed to be valuable as a service to its citizens. In other words, there is no direct economic benefit to the public agency, but there is a significant social benefit. The agency does however benefit from non-economic benefits such as a better reputation or improved trust through transparency as well as increasing its knowledge which may produce further benefits in due course. Overall, it improves their capability to be recognised as a true competence centre.

The satellite data also provides the possibility for long-term monitoring of the situation and the introduction of remedial actions where possible. Therefore, over the longer-term, there will be an impact on the environment within and surrounding the lakes and a positive effect on biodiversity.

In addition to this positive social benefit, can there be other direct benefits for the agency? Possibly, by reducing costs of running the service in the future. 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. There may also be a reputational benefit to the agency if it is perceived by the local population to be offering a useful service.

In Baden-Württemberg, there are 265 lakes which are of sufficient size to register and we are told that, for the Tübingen district, each in-situ measurement costs €3,5k, hence it would cost nearly €1m (927k) to test all lakes. This places a notional upper value on the potential economic benefit but we cannot be sure that, should this be the cost, the measurements would take place. With this uncertainty, we shall not include any figure for this hypothetical situation even though there is certainly some economic benefit to be found.

Can the measurements generate additional value? This could be the case for stakeholders further along the value chain which is where we shall now focus our attention.

5.2.3 Tier 3: Secondary Beneficiaries

We have considered that the satellite-derived data is helping the regional environmental institutes to do a **better** job **of monitoring the quality of water bodies in their region.** Whilst this does not help their role of reporting against regulatory requirements it does enable them to do a better job of environmental protection and water protection, to serve their citizens. Yet it is an additional cost for them, borne by the state authorities, which yields marginal or zero direct economic benefits to the agencies carrying out the tasks. Are their stakeholders, which are using data generated by the agencies, able to benefit directly?

Federal Environment Agency (UBA)

In many ways, the federal environment agency is in the same position as the regional bodies. Their direct task requires in-situ measurements to take place to which the satellite data cannot contribute, but the satellite data is useful in extending monitoring beyond that required for reporting purposes. There may be a value to the agency in the future but there is no direct benefit today.

Nevertheless, in its role as guardian of the environment in Germany, the use of the measurements coming from satellite data is generating value for society and this reflects on the agency. As for the regions, we shall not ascribe any economic value to the measurements but consider those in relation to society at large.

In the future, this is likely to change as regulations become updated to reflect the availability of Sentinel data. Recently, the EU has updated the Common Agriculture Policy (CAP) regulation taking into account that data from Copernicus can support the policy implementation. Consideration is being given to updating other regulations in the same way; for example, the Directorate General CLIMA is considering introducing satellite data into the reporting requirements for monitoring Greenhouse gases (GHG)[51] including carbon levels and carbon flux.

The availability of more data from more lakes enables the federal environment agency to have better information on which to base new policy decisions. These may relate to the sources of pollution through the release of nitrates from farming, or the impacts of HABs on local wildlife and biodiversity.

Local Authorities:

The local authorities have a direct operational responsibility in relation to the public access and use of water bodies in their region. How are they benefiting from access to improved measurements on the lakes in their district?

For regulatory aspects and reporting, the situation is no different than for the agencies. However, the districts having access to satellite-derived measurements are able to respond more quickly to poor water quality conditions and especially to erupting HABs which are the key risk to health. Without this data, local districts are reliant on reporting from citizens that a HAB is occurring. This has two problems, firstly the delay between the report and action being taken, but of greater

[51] Analysis and Proposals for enhancing Monitoring, Reporting and Verification of Greenhouse Gases from Land Use, Land Use Change and Forestry in the EU. EC-Joint Research Centre, 2014.

concern is that the water may already be dangerous for several days before the HAB becomes visible. The use of satellite data reduces this risk.

The detection of a potential or actual bloom is followed by in-situ testing which confirms the danger or not and determines action if confirmed. Without satellite data either many more planned in-situ tests would need to be carried out, or the delay between an event being reported by a lake user, which would also trigger a test, would become more significant. In addition, there is a utility loss where a suspected bloom causes precautionary lake closure, but which subsequently proves to be unnecessary.

The benefits arising from this process can be a reduction in in-situ tests by the authority, as it is able to concentrate on detected outbreaks which are more likely to be real, and to the local citizens through less health risk in the period between a HAB emerging and a closure of the lake. This applies to all users of the lake facilities.

Let us make a very simple assumption that each district can make a saving of 10 to 20 in-situ tests each year, across all the lakes in the district, through the use of satellite data. We have been quoted €3.5k as the cost of in-situ testing but this seems rather high, and we suspect that it is for testing of one site over the course of a year – so maybe 10 tests. This would suggest a figure of circa €300 for a single test.

We can put this number into perspective by taking a different approach. The test requires a technician to travel to the lake, to extract a water sample, and to return this to a laboratory for the test itself. If we take an average travel time of 4 hours, an average person cost of €50 per hour and €100 for laboratory costs, we arrive at the same cost for a test. On this basis, it seems a reasonable assumption that the cost per lake test is around €300 and we shall assume a maximum of €500.

Using the €300 per test figure implies a saving of €3k per year for each local district authority. In Baden-Württemberg, there are 4 districts and hence this is an implied saving of around €12k per annum across the region. At the national level, the saving is 16 times €12k ie €200k per annum.

Making the same calculation based on an average test cost of €500 and a saving of 20 tests per year gives €10k saving per district, €40k saving for Baden-Württemberg and €640k across the whole of Germany. This will represent an upper limit.

We should also note that the use of the satellite data may increase the number of in-situ tests and hence increase the costs as a result of detecting outbreaks that may otherwise not be reported. If this were to be the case, we can safely assume that the societal benefit would be considered higher through reducing the health risk to the lake users, and hence the overall benefit will be at least as large as has been calculated.

Water Companies

Water companies supplying drinking water also have access to the information on testing coming from the local authorities. This partnership helps reduce the health risk to the local community. Water companies are in any case testing waters regularly and often in order to understand if water quality is becoming degraded. If this is the case, the cost of treating the water increases and hence the companies have an interest to understand if a problem is arising and to treat it more rapidly.

We do understand that water companies are using the water quality measurements coming from eoLytics and hence there must be some value there. Regrettably, we have not been able to discuss this directly and we must fall back on assumptions made for Germany compared to the UK where we studied the benefits of using satellite imagery to monitor peatlands in Scotland and SW England[52] (population 800,000). The annual water treatment cost was around €20m of which 90% was for recycling and 10% or €2m was on the treatment of non-recycled water – where the suspended organic matter needs to be processed. If we take a pro-rata cost based on population, we arrive at a total cost for BW (population 11m) of some €260m in total and €26m for the treatment of "new" water.

In the UK case, water treatment savings were estimated to be €1m p.a which would scale to around €13m in Baden-Württemberg (based on population ratios). However, the UK water catchment area was one where 50% of the new supply contained high organic matter and the companies intervened at the source[53] to prevent the organic matter entering their water supply. In Baden-Württemberg, much of the water used as a source for domestic consumption comes from underground supplies and the rest is largely drawn from Lake Constance which serves to supply about 1/3rd of the population in the region, hence the situation is very different. Lake Constance is monitored on a continuous basis and organic matter entering the lake or resulting from biological mixing processes, will quickly become widely dispersed. The benefit of satellite data providing early warning in the region will therefore be much less than was the case in the UK.

We understand from interviews that 15% of drinking water in Germany comes from rivers or lakes which is consistent with the situation in Baden-Württemberg. We shall assume that between 10% and 20% of the catchment areas are liable to depositing sediments in the water sources. Hence the percentage exposed to the risk is between 1.5% and 3% in Baden-Württemberg compared to the equivalent situation in the UK.

Drawing on the UK figures scaled up by population and down by exposure, leads to a potential saving in the region of €200k to €400k where the satellite data can provide an early warning of high levels of suspended matter.

Extrapolating to the whole of Germany based on population would lead to an overall benefit of 7.8 times that of Baden-Württemberg ie €1.5m to €3m. This is likely to be an underestimate since other regions in Germany take more water from surface sources that are exposed to sediment in peatland areas.

[52] Peatlands Management in the UK. SeBS short case.
[53] Note: the intervention involved restoration of the peatlands to avoid the cause of the problem, not to lean the water as a result of it.

5.2.4 Tier 4: Citizens and Society

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 term for this entering wider use is the **value of ecosystem services**. This is reflected in actions being taken in Germany and elsewhere in RESI and other initiatives. Indeed, the quality (and quantity of good quality) water is getting increased attention in most countries around the world.

Overall, we see two key benefits to citizens from having access to lakes with better water quality.

- Amenity value from safer leisure activities on the lakes
- A better environment, offering cleaner water and greater biodiversity.

How to value these two benefits?

Putting a Price on Leisure?

Local citizens enjoy using the lakes for many leisure activities. Swimming, fishing, sailing, diving, canoeing are all very popular pastimes. Improving the quality of the water makes all these activities more pleasurable and reduces time when the lakes may be closed due to HAB. Giving access to better information on the water quality means that users can be warned of any problems and make better plans for their leisure time. For example, by choosing to visit an alternative lake or bathing site if their first choice is compromised.

What is the value of this information to the users? Benefits to them can be:

- Saving time by avoiding visits to water bodies that have been closed due to a HAB.
- Avoidance of ill health due to bathing in poor quality water

How to assess each of these benefits for the population of lake users?

Swimming: A previous study[54] has looked at the value of satellite-based monitoring of water bodies in the US. At the heart, the authors study a HAB outbreak on Lake Utah in 2017 for which they calculate that a benefit of around $370k (€300k) was made through using Landsat data to warn lake users (bathers) of the risk. By closing the lake 7 days earlier than would have been the case without the early warning, 30 bathers (out of 8000) avoided a severe illness and 400 in total were spared any illness.

We saw earlier that, in 2019, 53 bathing sites were closed due to HABs across the whole of Germany. Depending on the popularity of the site, large numbers of potential bathers will have been spared exposure to the HABs. We do not have figures for the number of bathers so let us make an assumption that 500 to 1000 bathers will have been spared at each site. Scaling from the US figures leads us to conclude that around 2,500 people would not be ill and around 200 would be

[54] 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.

spared a severe illness. The overall benefit across the whole of Germany is therefore between €1m and €2m. We shall assume that 1 event happens in Baden-Württemberg such that the regional benefits in this respect are €20k to €40k.

But health issues are not the only factor which we are considering. In this case up to 5000 and most probably more bathers are dissuaded from travelling to the lake which has been flagged as dangerous to health. If each bather saves a net 1 hour of their time on which we can place a value of €20, this means a net benefit of between €60k and €100k. This is additional to the health savings calculated above.

Fishing: There are around 150,000 anglers in Baden-Württemberg according to Robert Arlinghaus[55] each of whom spends around €1000 each year on their passion[56] generating an economic benefit of around €1600[55] or €240m for the whole of Baden-Württemberg. Across the whole of Germany, the figures are 3.5m anglers, spending €3b and generating 52,000 jobs. Each pays a licence fee of around €20 per annum (the annual fee is €30 but multi-year licences reduce the average spent) hence generating a revenue for Baden-Württemberg of €3m and across Germany €70m (assuming the same fees).

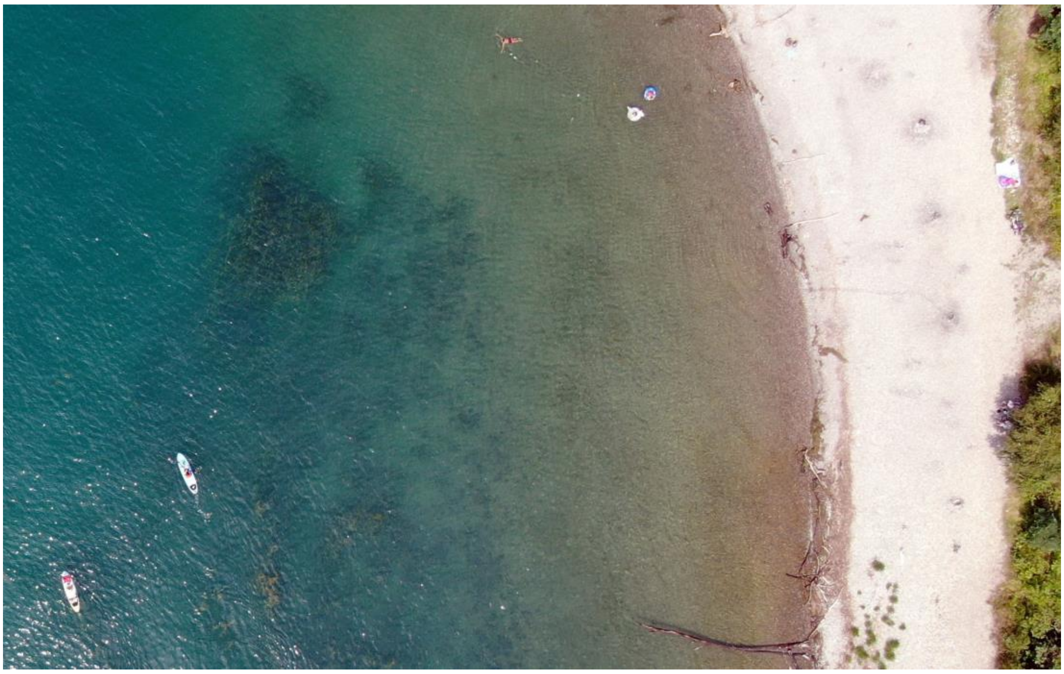


Figure 5-1: Enjoying the waters on the shore of Lake Constance (credit Thomas Wolf)

If the lake water quality degrades, not only does angling become less pleasurable but there is a real risk that fish die rendering the lake sterile. In this case, oxygenation of the water is the first recourse but if the situation is severe, the lake may be drained and the mud from the bottom removed to

[55] Arlinghaus, Robert: Recreational Fishing in Germany. Institut für Gewässerökologie und Binnenfischerei (IGB) im Forschungsverbund Berlin e.V.“

[56] In Germany, three and a half million active anglers spend over 3 billion euros a year on their passion, creating 52,000 jobs. Across Europe, approximately 25 to 30 million anglers represent an economic factor of around 25 billion euros.

get rid of the stocked nitrates. In either case, the lake may be out of use for several months whilst the remedial measures are taken.

If a lake is closed due to a HAB, then the anglers will go elsewhere, but clearly, there is a value to them and the state of keeping the water bodies open and keeping the environment attractive. Many anglers will also prefer river fishing to lakes. The annual fees give us a measure of how much the state is prepared to spend on keeping an attractive environment for the anglers. Not all of it will support maintaining water quality in lakes but a substantial proportion of it can be assumed to do so. Let us assume that between 10% and 20% would be a fair proportion to represent the spending on monitoring the lakes on a persistent basis without access to satellite data. This leads us to the counterfactual economic benefit coming from fishing of €300k to €600k for Baden-Württemberg and €2.1m to €4.2m across the whole of Germany.

Another study from 2006 relating to Queensland in Australia[57] found that anglers were prepared to pay on average $32 (€20) for a 20% improvement in catches. In Baden-Württemberg this would equate to €3m per annum. Based on our earlier assessment of €300k to €600k this would relate to a willingness to pay of €2 to €3 suggesting that our figures are highly conservative – or that German anglers would be willing to pay less than Australian ones for a good catch!

Sailing: for convenience, we shall consider sailing to include canoeing, kayaking and rowing even if each is significantly different. This category of lake user is less directly affected than the anglers or the bathers and the consequences are more limited. We shall not include any figures for an economic benefit from the sailors but noting that there clearly is an interest for the region to maintain a high level of water quality to keep attracting visitors to its lakes.

Putting a Price on Nature?

It is widely recognised that for the global economy to develop further, it must be sustainable which has not been the case in the past. 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[58], just published in February 2021. Commissioned by the UK government, this report looks at the economics of Biodiversity saying:

---

[57] The Economic and Social Impact of Water Quality Improvement. Khorshed Alam & John Rolfe, Australian Journal of Regional Studies, 2006.

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

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 science 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 is made clear in a recent 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?

In an analysis published in 1997[59], a research group estimated that the global mean value of the natural resources' contribution to human welfare is $33t which is roughly double the global gross national product (GNP) of $18t at that time. This was updated in 2014[60] with the same conclusion that ecosystem services contribute around twice as much to human wellbeing as GDP. It also re-enforces the view that estimates in monetary units are useful to show the relative magnitude of ecosystem services. In 2011, the value was estimated to be around $125t per annum.

This earlier work, and much more besides, led to the establishment in 2012 of the IPBES (International Platform on Biodiversity and Ecosystem Services) under the umbrella of the (UN Environment Programme (UNEP). It grew out of a move towards Natural Capital Accounting and a study into the Economics of Ecosystems and Biodiversity (TEEB) published in 2010. The TEEB was launched by Germany and the EC as a major international initiative to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation.

IPBES has also introduced the concept of Nature's Contribution to People (NCP) which leads to new ways of approaching the valuation of ecosystem services. The IPBES approach is described in a paper[61] as:

Nature is perceived and valued in starkly different and often conflicting ways. This paper presents the rationale for the inclusive valuation of nature's contributions to people (NCP)

---

59 The value of the world's ecosystem services and natural capital, Costanza et al, Nature May 1997.

60 Changes in the Value of Ecosystem Services, Costanza et al, Global Environmental Change, 26. May 2014.

61 Valuing nature's contributions to people: the IPBES approach. Science Direct, 2017.

in decision making, as well as broad methodological steps for doing so. While developed within the context of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), this approach is more widely applicable to initiatives at the knowledge–policy interface, which requires a pluralistic approach to recognizing the diversity of values.

Figure 5-2 illustrates the framework for looking at NCP with a progression from purely natural values through to human and societal values which links nicely with the approach we follow in SeBS. The grading in the colours of Figure 5-2 indicates that both instrumental and relational values can be ascribed to the value of NCP. For an explanation of the "instrumental" and "relational" values, please refer to Section 5.1.

Clean water is a priority for all of us. The Convention on Biodiversity established in 1993 under the UN umbrella, has recognised the importance of water which makes a pillar of its work[62]. In the assessment leading to the Global Biodiversity Outlook (GB04)[62], it is recognised that links between the water sector and biodiversity feed both ways. Five themes are developed:

- Urban water management to protect biodiversity in water catchment areas.
- Agricultural Water Management to reduce pollution and especially nitrates feeding into water bodies by introducing buffer strips along water bodies and controlling chemical use.
- Water management for dams and hydropower where controlling vegetation growth leads to longer life for the infrastructure.
- Disaster Risk reduction where management of water ecosystems can reduce drought and limit run-off causing floods.

Note that water quality is also one of the sustainable development goals and that monitoring using EO data becomes a feasible and very effective means of monitoring in Africa and many remote regions around the world.

[62] Water and Biodiversity, A summary of the findings of GBO4, and implications for actions on water; Secretariat of the Convention on Biodiversity, 2015.

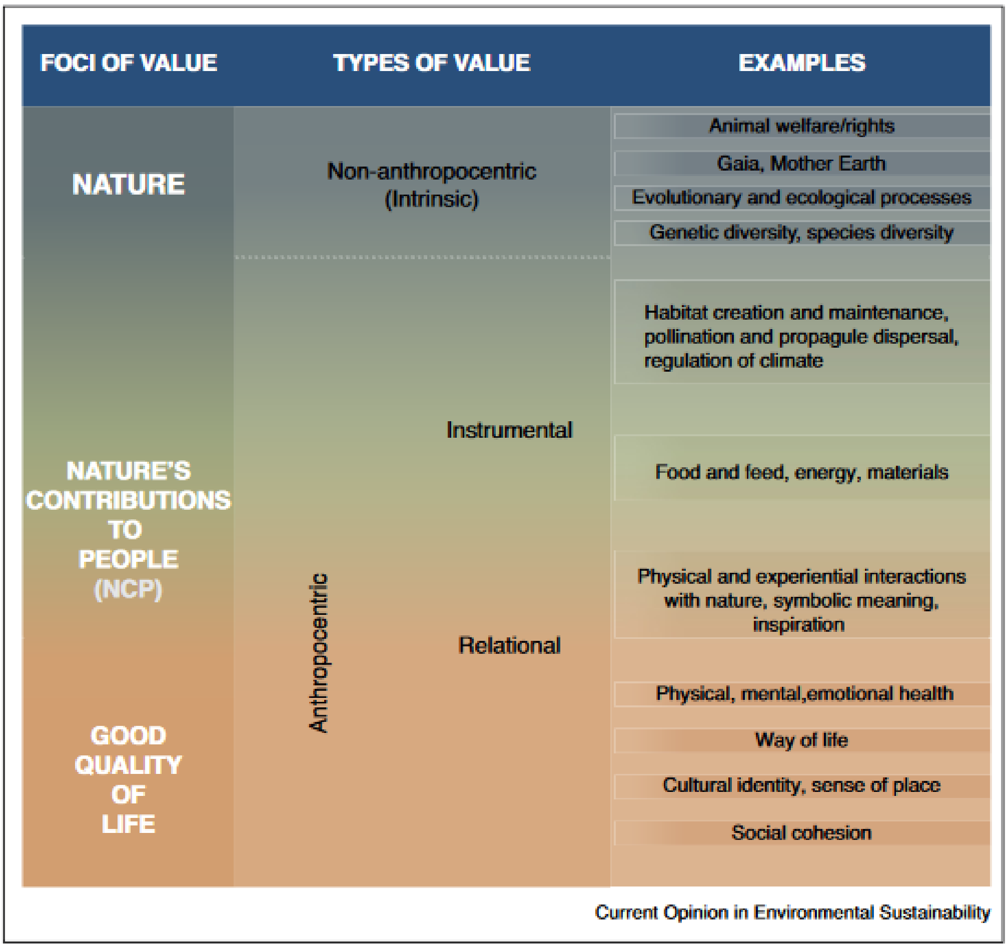


Figure 5-2: Diverse values related to nature, Nature's Contributions to People (NCP) and a good quality of life[59].

Drinking water supply where it is more cost-effective to improve the catchment area as a means to reduce water treatment than introducing artificial water treatment measures.

More recently, as this case analysis was ongoing, the Dasgupta review of "The Economics of Biodiversity"[58] has been published. This has the goal to consider whether the current path of economic development is sustainable. Rather than measuring economic performance through GDP which is a flow of value from one year to the next, Dasgupta is looking at assets or stocks of value both in man-made infrastructure but also in nature and whether the stocks can sustain a certain standard of living.

An economy could record a high rate of growth of GDP by depreciating its assets, but one would not know that from national statistics[63]. Below we show that in recent decades eroding natural assets has been exactly the means the world economy has

[63] The United Nations' Human Development Index (UNDP, 1990) suffers from the same weakness.

deployed for enjoying what is routinely celebrated as 'economic growth' and that sustainable economic growth requires a different measure than GDP.

This work is moving towards systematic approaches to placing values on ecosystem services. Taking the 1997 report cited earlier, 17 different ecosystem services are identified with a value of $33t. Of these, lakes and rivers are estimated to contribute $1.7t or 5% of the total.

The GDP of Baden-Württemberg today is around €500b. If the ecosystem services are valued at double the GDP it implies these are worth €1t and hence the natural contribution of lakes and rivers are valued at €20b. This is all rather simplistic but at least provides us with a number to work with. What would be the contribution of Sentinel data to maintaining this value? If it were 0.01%, the benefit would be around €2m.

The figures calculated in 1997 take account of the various ways in which the ecosystem services contribute to the economy including leisure activity, tourism etc. As a result, we shall not accumulate this benefit together with those from the leisure activities. However, it serves to act as a reference point and validate the overall total.

Tier 4 benefits	Baden-Württemberg		Germany	
	Min	Max	Min	Max
Bathers	€20k	€40k	€1m	€2m
Anglers	€300k	€600k	€2.1m	€4.2m
Sailors		0		0
Total	€320k	€640k	€3.1m	€6.2m

Table 5-1: Tier 4 benefits deriving from Improved Water quality monitoring relating to leisure use of the water bodies.

As a means to cross-check the numbers shown in Table 5-1, could we also consider, as a thought experiment, a willingness to pay (WTP) method to assess these values? Given that we have no possibility to do direct research and hence must resort to a thought experiment, we are somewhat reluctant to use the WTP tool to assess the economic benefits and use it generally as a tool of last resort. Nevertheless, it can provide a useful crosscheck on figures derived by other means as we have done above in the case of the anglers.

Taking the population of Baden-Württemberg as 11m people and using the figures above suggests each person paying between 3 and 6cents each year to have the benefit of a better environment for leisure activities in the region. Even if we assume that this is limited to 20% of the population being that proportion which regularly goes swimming, fishing or sailing, this become 15c to 30cents.

Figure 5-3: Dogs in the water are also vulnerable to HABs. (credit Thomas Wolf)

Maybe we are wrong, but we would estimate a figure closer to €10 for what citizens would pay each year to know that they have a high quality of water in their region. The majority of this would be spent on corrective measures and only a small proportion of this would be attributed to the benefits of monitoring through the use of satellite data, but again, working backwards, if the population would pay upwards of €110m for the improved amenity (ie €10 each from 11m persons), the figure shown in Table **5-1** would suggest that between 0.3% to 0.6% would be attributed to the information arising from the use of satellite data. Hence, we conclude that the economic benefits attributed to the use of satellite data are realistic and probably rather modest. Noting also that they are significantly less than the potential cost of monitoring through other means (see section 5.2.2).

5.2.5 Other Beneficiaries

The other beneficiaries identified in the value chain and in Section 4 are linked to research institutes that are working on water, freshwater bodies and ecosystem services. We highlight the **Leipniz Institute of Freshwater Ecology and Inland Fisheries (IGB)** and the **Helmholtz Centre for Environmental Research.**

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 – as is the case in RESI.

5.3 Summary of Benefits

In this chapter, we draw together the different benefits to the stakeholders identified along the value chain, grouping them by the six dimensions of the value-chain analysis framework.

5.3.1 Economic

The summary of the total economic benefits is shown in Table 5-2 below.

Tier	Total Case benefits	Baden-Württemberg		Germany	
		Min	Max	Min	Max
1	Service Provider (EOMAP)	€100k		€1.4m	
2	Primary User (LUBW)	(€100k)		(€1.4m)	
3	Federal Environment Agency (UAB)	-	-	-	-
	Local Authorities	€12k	€40k	€200k	€640k
	Water Companies	€200k	€400k	€1.5m	€3m
4	Citizens and Society	€320k	€640k	€3.1m	€6.2m
	Total	€550k	€1100k	€5m	€9.8m
	Attribution to Sentinels (80%)				
	Total	€440k	€880k	€4m	€7.8m

Table 5-2: Summary of total economic benefits for Baden-Württemberg and scaled for Germany.

Several points should be recalled:

- The supplier (EOMAP) is expected to see an increase in revenue through sales to other regions in Germany and through export sales (not included). This is a cost to the primary users and so cancels out in the overall calculation.
- The net benefit to EOMAP is a placeholder and does not represent real contract values that are confidential.
- The economic benefits to LUBW and other environmental institutes are "negative" as there is the cost of buying the service, but benefits are not economic in nature as can often be the case for public agencies ie they represent a public payment for a societal good.
- Benefits in tier 3 are from cost savings.
- The main benefits in tier 4 are calculated on a conservative basis and are most likely an underestimate.
- Benefits in Tier 4 come from increased amenity use, better health and better access to nature.
- There is also an employment benefit where EOMAP has increased their numbers by 5 persons attributed to the expansion of this service.

We classify the contribution to economic benefits as 2 stars.

- Increased revenue (tier 1)
- Cost savings from in-situ testing and less chemicals for water treatment (tier 3)
- Citizens saving time, better health, access to leisure amenities as well as nature (tier 4)

5.3.2 Environmental

Many of the key benefits are environmental in nature although they may not be felt fully for some years due to regulatory issues and also because of the temporal scale associated with the lake water quality dynamics. Indeed, the environmental benefits go hand-in-hand with those regulations. Nevertheless, increasing water quality has a large impact on the preservation of wildlife and biodiversity.

The concept of ecosystem services is relevant and as explored earlier, the value placed upon these ecosystem services – which we have partly used in calculating economic benefits.

The environmental benefits derived from the use of satellite data and primarily that coming from the Sentinels' to observe and monitor water quality are:

- Track the possible consequences of and ultimately support reduction of pollution through fertiliser run-off.
- Earlier detection of environmental issues notably HABs.
- Preservation of nature and biodiversity.

We classify the contribution to environmental benefits as 5 stars.

- Reduced pollution (less fertiliser run-off)
- Maintaining natural habitats and biodiversity (tier 4)
- Earlier detection of environmental threats – HAB's. (tier 3 & 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 to monitor water quality in Germany but also elsewhere. This is discussed in more detail in chapter 6.2 where we address the extrapolation of the service.

Today, the service is becoming recognised by LUBW and other, regional environmental institutes as a very cost-effective way to improve their ability to monitor the quality of the water under their responsibility. The data help:

- the LUBW to improve its ability to carry out its own institutional monitoring tasks in accordance with its legal statutes and regional and national laws.
- the ministry to evaluate the impact of other policies on water quality and to design better controls in the future.
- the ministry to improve regulations on the water sector (including use of fertilisers, water abstraction etc…)

The further advantage that could be derived, from better and streamlined reporting to e.g. the federal level and the EU levels, however, does not currently materialize because of the lack of recognition of the use of EO data in the current regulations. That this may change is subject to much debate and a new European-wide water quality monitoring service is to be introduced by the EEA under the umbrella of the Copernicus services later in 2021.

We classify the contribution to the regulatory benefits as 4 stars but with strong potential to become 5.

- Improving regulations on the water sector (use of fertiliser, chemicals, water)
- Improving controls and reporting on water quality
- Improving understanding of regulatory impacts leading to further improvements in policy design.

5.3.4 Entrepreneurship & Innovation

The level of innovation in this case is high. In addition to the development of the new product and service for eolytics and the move to cloud technology and hosting by EOMAP, the move is also significant for LUBW and the other regional environmental agencies.

Firstly, for EOMAP, the basis for the service is 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 clients. A strong innovative element has been present throughout this process.

EOMAP has increased the size of the business and in the last few years has grown from 10 to 20 employees of which 5 additional are attributed to the eoLytics line of business. That EOMAP is able to supply customers as LUBW in their home market, has been important to help them to develop new business with customers outside of Germany.

Secondly, for LUBW, the introduction of new processes into a public agency is never easy (see the highlight box in chapter 4.2.3. When we first came across this case, the LUBW representatives preferred to wait until their full annual process had been tested with reports based upon the use of the satellite data. During this time, the German government launched an initiative[64] to introduce more digitalisation into their operations and LUBW led a project to bring the water quality information (with other geomatics) into greater use in the regional agencies.

Hence, the water quality software and IT infrastructure are essential tools supporting innovation inside the German regional agencies responsible for the environment.

On balance, we classify the contribution to social benefits as 4 stars on our qualitative scale.

- Innovation driver within the supplier and the primary user as well as extended network (Tier 1&2)
- Changing "operational practices within the German environment agencies. (Tier 3)

[64] Digitalisierungsstrategie des Landes Baden-Württemberg (federal state initiative) https://www.baden-wuerttemberg.de/fileadmin/redaktion/dateien/PDF/Digitalisierungsstrategie-BW.pdf

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 and on lakes and rivers can be supported by new, large-scale data derived from the satellite measurements. The RESI project is taking on board this data and similar research projects exist in many other countries.

A strong determinant of the scientific benefit 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 the ecosystem 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), 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 5 stars.

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

5.3.6 Societal

The benefits to citizens and to society are possibly the most consequent ones deriving from this case – and naturally, there is also a strong overlap with the environmental benefits. Indeed, it highlights the circular nature that a case which has strong environmental benefits, must also have societal and regulatory benefits. On the one hand, because those are being increasingly recognized by the public and on the other hand because the impact of activities on the environment is usually subject to legislation.

We noted earlier the concept of “Nature’s Contribution to People”, which seems to be a significant concept here. The improvement in the quality of lakes and rivers is a pleasure shared by many whether it is for swimming, fishing or sailing 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. Indeed, 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.

In addition, the health risk reduction due to a timely detection of the HAB development potential is an important societal benefit. It is contributing to a higher quality of life through creating a more secure environment for leisure activities.

The more frequent and wider monitoring of lakes throughout Baden-Württemberg and Germany enables potential users of those lakes to be informed when there are any problems with the water quality. Data collected is entered into a portal and the publicly available information improves people’s trust in their local authority.

> *With the help of the Rhineland-Palatinate bathing water atlas, planning a trip to the water is easy, because you can call up the current measurement data of all lakes registered as bathing water in Rhineland-Palatinate during the bathing season from May 15 to August 31, and also all year round for some lakes You can also find out about the size, depth and opening times, or see whether you can find a place to lie in the shade and whether you can take your surfboard with you.*

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.

From a more practical standpoint, the public portal also allows users to check on the water situation before travelling to the lake concerned.

We classify the contribution to social benefits as 5 stars.

- Improved access to amenities linked to water bodies (swimming, fishing, sailing, etc
- Fewer health issues induced by poor water quality
- Better quality of life.

6 Key Findings and Final Thoughts

6.1 Key Findings

The benefits from using Sentinel-2 and Sentinel-3 data to provide measurements of lake water quality in Baden-Württemberg is quite striking. The system provides quite 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 by other means.

Whilst the data being collected does not (yet) contribute to regulatory reporting, this is because of the way in which the regulations have been framed to only authorise the collection of lake water samples for laboratory analysis. Yet the satellite data provides so much more that it would seem likely that the regulations will be amended to recognise this additional value.

Satellite data cannot replace the in-situ sampling, but equally, there is no other method available today to provide wide-scale measurements of the water quality across a whole region or country. The impact of this is reflected in the fact that the regions are devoting budget to buying the service even if it is not contributing to their core reporting mission.

One of the most striking aspects of this case is the really strong contribution to value that is being generated right across the full range of dimensions, see Figure 6-1. 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.

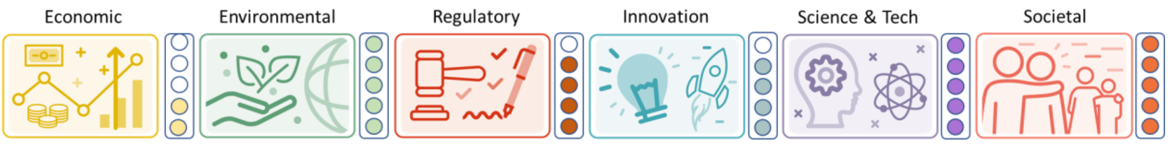


Figure 6-1: Delivering value across the full range of dimensions.

The economic benefits have been calculated based on a realistic scenario today. They are based largely on bathers and fishermen having access to cleaner water and saving time and expense linked to poor water quality. The size of this may grow in the future as there is more awareness as well as access to more detailed information. Conversely, more awareness and better control over chemicals use by farmers could lead to a reduction in the incidence of HABs. How would we value that? The benefit is felt through the reduction or absence of poor water quality and the counterfactual would not be the same as other measures would have been taken.

We shall not dwell further on this except to note that in some circumstances, the evidence obtained through the satellite data can lead to decisions being taken regarding remedial measures which then in turn reduce the benefit of having the satellite-derived information. Given the social benefits, this would be a positive situation should it arise.

The value chain presented at the opening of chapter 4, can be updated to show the types of benefit which are arising at each tier and how the value is being manifest. This developed value chain is shown in Figure 6-2.

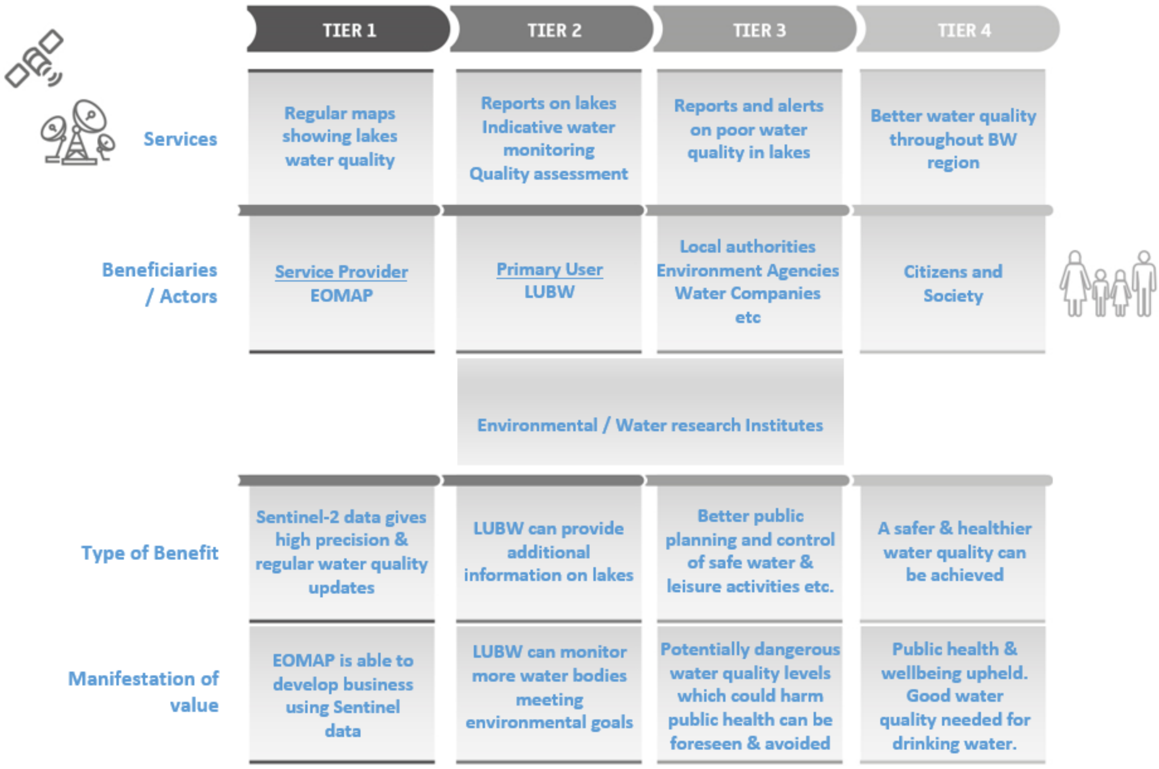


Figure 6-2: Developed Value chain for water quality measurements.

6.2 The Impact of Sentinel Data

The Sentinel data is the primary source of data 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 considered to be due to Sentinel data.

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

6.3 Widening the Perspective

Geographic Extension

The case has centred on the German Lander of Baden-Württemberg and has also been extended to the whole of Germany taking into account different scaling factors.

The issue of water quality touches every country and the capability to measure the water quality is demonstrated by eoLytics around the world. EOMAP has provided a dedicated portal for water quality to UNESCO and through their own portal, can provide the data on any water body in the world above around 10ha in size. Hence the service has a global application.

Irrespective of whether EOMAP supplies the service, measurement of water quality has a global applicability.

The benefits depend to a large extent on the local regulatory conditions. Throughout Europe, the water framework directive and the bathing waters directive apply and will require reporting. However, since the service is not eligible to serve these needs today, the benefit depends on wider social and environmental factors outside of the regulations.

Increased Market Penetration

There is strong potential to increase the uptake of the service within Germany and elsewhere. The LUBW has been one of the pioneers, along with Rheinland-Pfalz, Sachsen, Niedersachsen, Mecklenburg Vormpommern, leading efforts to extend the use of the service to all the regions in Germany. Hence the use by the regional environmental agencies and the districts which they serve. Beyond this, other users of water bodies may also benefit. We have discussed the water companies where the uptake as of today is rather low. Other public bodies are also interested in the quality of water and of knowing when this becomes degraded. Many of these link to the regional environmental agencies but others public and private organisations can also benefit from the data.

Would it be considered as a public data and hence open data? This would be a question of contractual and licensing arrangements if the public body is buying the service.

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.

This is a market strongly driven by regulation and as we have noted, current regulations do not formally recognise the use of satellite data for official reporting on the quality of water. Yet many more water bodies can be monitored at a reasonable cost. It seems that the regulations could be changed in order to take advantage of the benefits which satellite monitoring can bring.

This applies to a number of regulations as has been discussed, but mostly to the EU WFD and the EU Bathing Waters Directive where water bodies <u>must</u> be monitored. EO derived data can detect the presence of algal blooms as well as the onset of conditions where they can occur even if they cannot detect all the problems that in-situ testing can. Further, the EO measurements can be performed cost-effectively and over a wide area which would otherwise not be possible. They can also be used as a trigger for in-situ measurements so increasing the efficiency of the overall measurement process.

Notwithstanding, there are issues with this. The WFD requires MS to report every 6 years. The last report was published in 2018 and the next one is due in 2024. Data for the reports is collected at different times (years) and is not entirely consistent between one MS and the next. The use of satellite data can provide consistency over a wide area and so help overcome some of these difficulties. But the review and impact assessment carried out after the last report has not recommended this change. The WFD will not be reviewed again until after the next report (after 2024) meaning that the next opportunity for the use of satellite data within the reporting mechanism will not occur until towards the end of the decade.

In the meantime, the BWD requires reporting every year and, in March 2021, a review of the legislation has just started. This provides the possible means to introduce the use of satellite monitoring to improve overall monitoring of lakes used officially for bathing.

As a prelude to this possibility, data for lake monitoring is to be generated under the Copernicus Land Monitoring Service operated by the EEA. A European wide water quality service is planned to be introduced starting in 2022.

Improved Technological Maturity

Several improvements to the technology are possible leading to improved information services. These range from increased frequency of observations (to look at the lakes more often) and improved spatial resolution on the ground (to look at smaller lakes and in more detail) to more powerful computing capability (to make information available faster) and more cloud storage (to reduce production costs).

6.4 Final Thoughts

This case has shown the potential for greater use of Sentinel data to provide measurements of water quality in inland waters. The service is offered by a number of companies and indeed some laboratories and the use of the information appears to be in its infancy. Support for the service by the Environment Agency of Baden-Württemberg LUBW has encouraged other regions to look at its use and should expand the service in Germany. A European service will extend this across the whole of the EU which will also enable the introduction of more precise regulations including the use of satellite-derived measurements.

The case shows benefits are obtained over the full range of dimensions and is the broadest base of any that we have so far analysed. It could be interesting to revisit this in a few years time after the Europe-wide service becomes established and to assess the changes which that will have triggered.

The 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.

Annex 1: References and Sources

The list below covers only the main sources used extensively throughout the study. The reader can find more references in the form of footnotes or hyperlinks throughout the report.

1. The Global Assessment Report on Biodiversity and Ecosystem Services. IPBES 2019
2. The Economics of Biodiversity. Dasgupta Report Abridged version, February 2021.
3. The Value of the World's Ecosystem Services and Natural Capital. Constanza et al, Nature 1997.

3a. Dasgupta Report – Headline Messages

3b. Dasgupta Report – Full report.

4. Valuing Nature's Contribution to People; The IPBES Approach. Science Direct, 2017
5. 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. Valuables consortium; AGU Geohealth, June 2020
6. Economic and Social Impact Assessment of Water Quality Improvement; Khorshed Alam, John Rolfe & Peter Donaghy, Australasian Journal of Regional Studies 2006.
7. Satellite remote sensing of chlorophyll and sechi depth for monitoring lake water quality: Nathalie Karle, Thomas Wolf, Thomas Heege et al, Proceedings SPIE 2019
8. Analysis and Proposals for enhancing Monitoring, Reporting and Verification of Greenhouse Gases from Land Use, Land Use Change and Forestry in the EU. EC-Joint Research Centre, 2014.

Annex 2: List of Acronyms and Abbreviations

BfG	Bundesanstalt für Gewässerkunde; Federal Institute for Hydrology
BWD	EU Bathing Waters Directive
CAP	EU Common Agriculture Policy
EC	European Commission
EEA	European Environment Agency
EU	European Union
HAB	Harmful Algal Bloom
IPBES	International Science-Policy Platform for Biodiversity and Ecosystem Services
LAWA	Bund/Länder-Arbeitsgemeinschaft Wasser (Water Co-ordination Group)
LfU	Rheinland Pfalz State Office for the Environment
LUBW	Landesanstalt für Umwelt Baden-Württemberg State Institute for the Environment Baden Wurttenberg
NCP	Nature’s Contribution to People
RESI	River Ecosystem Services Index
SDD	Secchi Disk Depth
TEEB	The Economics of Ecosystems and Biodiversity
UBA	Federal Environment Agency
UNEP	United Nations Environment Programme
WFD	EO Water Framework Directive

Annex 3: 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[65], 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 65. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

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

65 SeBS Methodology; June 2017.

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.

<table>
<tr><th>Rank</th><th>Benefit status</th><th>Criteria</th></tr>
<tr><td>0</td><td>Null</td><td>The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.</td></tr>
<tr><td>1</td><td>Latent</td><td>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.</td></tr>
<tr><td>2</td><td rowspan="4">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:</td><td>Low</td></tr>
<tr><td>3</td><td>Moderate</td></tr>
<tr><td>4</td><td>High</td></tr>
<tr><td>5</td><td>Exceptional</td></tr>
</table>

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 section 5.3.6, and a full list of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs (AV)	Alternative means to gather data
	Increased Revenues (IR)	Increased production/sales
	Reduced Inputs (RI)	Less time spent or material saved
	Improved Efficiency (IE)	Better use of resources
Environmental	Reduced pollution (RP)	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources (RR)	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health (IPH)	Less toxicological risk
	Common Understanding (CU)	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency (ITT)	Improved preparedness / response
	Strategic Value (SV)	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 4: Winners… and losers?

The creation and subsequent usage of Sentinel data down the value chain has a significant economic impact. Quite prominently, product and process innovation based on the availability and subsequent application of the data, lead to positive effects where new products and services emerge and existing processes can be run more effectively and efficiently. Conversely of course, there are also consequences on some of the previous beneficiaries. For instance, revenues might be shifted and jobs displaced and sometimes even destroyed, creating technological unemployment. In the current study, for example, some workforce might have been lost in reducing the site inspections while savings from farmers certainly translates into loss of revenues for the agro-chemical industry.

> As we have shown in our study 'Winter navigation in the Baltics' as the captains on the icebreakers in the Baltics could suddenly rely on Sentinel based ice charts providing a fully synoptic picture of the ice, the helicopter pilots they traditionally relied upon, became abundant.[66] Similarly, in our study 'Forest Management in Sweden' the Swedish Forest Agency could reduce the number of forest inspectors, as Sentinel data allowed for a reduction of in situ inspections.[67]

How technological progress and innovation are related to employment has been an area of fierce debate for centuries. From fairly recent studies appear that product innovation spark new economic activities, creating new sectors, more jobs, whereas process innovation[68] is more job destroying, although market mechanisms can sometimes largely compensate for the direct job losses, mitigating the ultimate impact on demand for labour. Such price and income compensations can derive from a decrease in wages, leading to an increase in demand for labour or the effects of new investments (enabled by accumulated savings) creating new jobs elsewhere. Obviously, the speed and impact of such effects are highly dependent on the flexibility of markets, the level of competition, demand elasticity, the extent of substitutability between capital and labour and, of course, possible institutional rigidity.[69]

> A German study on the co-evolution of R&D expenditures, patents, and employment in four manufacturing sectors concluded that patents and employment are positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics)

but not in the other two more traditional sectors (chemicals and transport equipment).[70] Similarly, a study using a panel database covering 677 European manufacturing and service firms over 19 years (1990–2008) detected a positive and significant employment impact of R&D expenditures only in services and high-tech manufacturing but not in the more traditional manufacturing sectors.[71] Another study found a small but significant positive link between a firm's gross investment in innovation and its employment based on longitudinal data set of 575 Italian manufacturing firms over 1992–1997.[72]

Clearly, this tells us that the ultimate 'net' impact of innovation – both at product and process level - brought about by the availability of new technology, such as Sentinel data, will be closely related to the market and institutional settings in which they become effective. However, on the whole the conclusion seems justified that the 'negative' effects, in the form of possible loss of employment, is largely outweighed by the positive economic effects throughout the value chain.

Accordingly, in this study – and likewise for the past and future ones - we will concentrate on the positive effects brought about by the availability of the Sentinel data throughout the value chain. That there are also (temporary) 'negative' impacts is a given, but the net effect at macro level will always be positive.

Annex 5: About the Authors

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.

Christopher Oligschläger, M.A in International Politics

Christopher is an analyst with EARSC. He holds a Bachelor degree in European Studies from Maastricht University and a Double Master's degree in Governance and International Politics from Aston University, UK and Otto-Friedrich-University Bamberg. He gained first work experience (2017) at the Institute for European Politics in Berlin and the OSCE's Conflict Prevention Centre in Vienna before focusing on European space policy and concrete space applications through earth observation. christopher.oligschlaeger@earsc.org.

Other Contributors to the Study:

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

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.

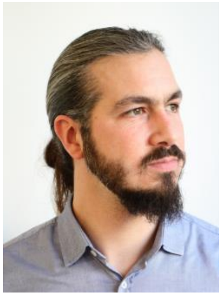
Geoff Sawyer, BSc (Electronics), MBA

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.

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). In the past 10 years, 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), universities and private companies.

lef@earsc.org and lefteris@evenflowconsulting.eu



Dimitrios Papadakis, M.Sc. Research Methods

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.

dimitri.papadakis@earsc.org and dimitri@evenflowconsulting.eu

EARSC European Association of Remote Sensing Companies THE GREEN LAND IIASA

Marc de Vries, BSc EC, LLM

Marc has professional degrees in both law and economics (Utrecht 1991). He has been active in the field of Open Data re-use for more than 18 years, both at the national and European levels. Through his company The Green Land he serves clients in the public and private sectors in the Netherlands and beyond (EC institutions in particular). He is a frequent speaker and moderator on Open Data conferences and events. Also he has published various books and articles on PSI, highlighting the legal, economic and policy perspectives. marc@thegreenland.eu.

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

Christopher Oligschläger,

Christopher is an analyst with EARSC. He holds a Bachelor degree in European Studies from Maastricht University and a Double Master's degree in Governance and International Politics from Aston University, UK and Otto-Friedrich-University Bamberg. He gained first work experience (2017) at the Institute for European Politics in Berlin and the OSCE's Conflict Prevention Centre in Vienna before focusing on European space policy and concrete space applications through earth observation. christopher.oligschlaeger@earsc.org.

Dáire Boyle, BEng (Electrical Engineering), MSc Business & Economics

Dáire is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). Dáire worked as an engineer for a large upstream oil & gas company in Aberdeen, Scotland for 4 years before moving to Belgium to complete a Masters in International Business Economics & Management. Daire has extensive root cause analysis and statistical analysis skills developed through both his professional and academic career. He currently acts as exploitation manager for the H2020 CYBELE project. daire@evenflowconsulting.eu