Report on the Dutch User requirements for water quality monitoring

Modification history

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Table of Contents

Executive Summary

Background

Our society places a high demand on high quality fresh water for both drinking purposes, as well as in supplying industry and agriculture. However, the amount of pollutants in drinking and surface water, such as micro-plastics, medicine residues and (other) hormone disrupting substances, has increased in recent years. To combat this issue, policy makers in the Netherlands have the ambition to implement various measures that are necessary to guarantee water quality standards and achieve future-proof waters. In this strategy, the monitoring of water quality parameters plays an essential role. After all, without frequent and accurate measurements, it is not possible to address the related ecological issues or to evaluate the effect of implemented policy measures and regulation.

Traditional measurements, using local sampling and lab analyses, are mainly carried out on a local scale. These types of measurements are collected at national level. As such, this data contains all kinds of different data types, as well as measurements obtained with different objectives and techniques. New techniques, through methods of earth observation, have the potential to quickly evaluate large areas and have a relatively high temporal frequency. Satellite observations are, however, more difficult to interpret due to the coarse sensor (spectral and spatial) resolutions and the limited sensitivity of water parameters to light. As such, they are not yet used for monitoring the water quality at an operational scale.

Objective

Steering instrument development towards the development of better sensors will facilitate the implementation of earth observation methods for the monitoring of water quality. In order to achieve this direction, it is essential to map the specific user needs for water quality. The aim of this research is, therefore, to map the Dutch user requirements for information from products and services that use satellite data on the theme of water quality. Here, the added value and usability of (future) earth observation sensors and applications are investigated. For this purpose it is essential:

1. to get an overview of the user needs of the specific stakeholders (scientists / governments and other market parties)
2. to identify current (and future) methodologies
3. to evaluate the extent to which earth observation can play a role and offer added value for mapping water quality.

Methodology

In order to accomplish these objectives three major activities were performed in the project, namely:

- **Preliminary analysis**. The preliminary analysis focused on getting background information on the users, their applications, and finally which water quality parameters they mostly used (and could possibly be measured with remote sensing). To achieve this, the project performed a 1) meta-data analysis on the basis of peer-reviewed publications, 2) literature review of previous user-consultations, and 3) an in depth analysis of several overview-papers as well as water quality policies. This approach allowed the project to focus on currently relevant parameters and actual requirements from stakeholders.

- **User consultation.** In this activity, the project focused on acquiring direct feedback from the stakeholders. The results from the preliminary analysis revealed an importance to distinguish between 'target' and 'acceptable' spatial/temporal and accuracy requirements. These represent respectively the current local water quality state and the minimum water quality guideline standards. For this, an online-survey was created and distributed to the users. This distribution was performed through the first Dutch Remote Sensing in Ecology symposium, specifically organised in the framework of this project, and through participation in various national workshops. The results were then verified with the criteria found in literature. After the initial results of this user-consultation were obtained, several interviews with selected stakeholders were performed to identify additional, secondary requirements on the use of remotely sensed data.
- **Feasibility field study.** Parallel to the user consultation, a small field campaign was performed to study the feasibility of acquiring water quality parameters through hyperspectral/multispectral remote sensing. Here a machine learning approach was opted for (as opposed to using traditional modelling) to identify the signals present in remotely sensed observations. The choice for machine learning ensured that the results did not rely on specific assumptions present in the traditional model counterparts.

Results

Within our research we found that (both at national and international scale) different spatial and temporal resolutions are provided to indicate what is acceptable and required. Here target requirements are in accordance with the current daily practises of the users, while 'acceptable' requirements relate to the minimum criteria that would still be deemed useful.

Users reported target spatial resolutions of <1m for pH, CDOM, Chlorophyll, Phycocyanin, Salinity, Temperature , Turbidity and Vegetation Coverage**,** and target temporal frequencies of once per 1-7days. The users reported acceptable spatial resolutions from 10-100meters, which is lower than the target requirements for CDOM, Chlorophyll, Colour, DOC, Phycocyanin, Secchi Depth, TSM and Turbidity, and acceptable temporal frequencies of once per month for CDOM, color, DOC, Phycocyanin and Secchi Depth.

These requirements were afterwards evaluated against Sentinel-2 satellite platform specifications. It is shown that the Sentinel-2 constellation does provide high enough spatial and temporal resolutions to meet the 'acceptable' requirements but not the 'target' criteria. Furthermore, a feasibility study performed in this project showed that (on the hypothesis of a good atmospheric correction) there is enough information in Sentinel-2 observations to directly/indirectly assess for Dissolved Oxygen, Conductivity, Ph, Temperature, Chlorophyll and Turbidity.

Conclusions

The user requirements shown in this report are in accordance with results found in other national and international studies. Most notably, similar results were found despite the large difference between target and acceptable user-criteria. This is likely due to the international coordination efforts in homogenising water quality standards.

However, despite the potential of the Sentinel-2 constellation of satellites, there is presently only a 16,7% adoption of remotely sensed data in assessing water quality. This low adoption rate is attributed to the data not meeting several secondary requirements, specifically concerning 1) sensor/algorithm development, 2) service provisioning, 3) user capacity, 4) user community, and 5) constraints in the applications. Most worryingly, users fail to recognise that remote sensing will provide an additional tool to be used in parallel with the current measurements. Instead, there is a 'concern' in some organisations that using remote sensing might replace current expertise. These concerns need first to be addressed if the monitoring of water quality by means remote sensed data is to become a common practice to reinforce traditional methods of local sampling and laboratory analysis.

Nederlandse Samenvatting

Achtergrond

In onze maatschappij bestaat er een grote vraag naar water met een hoge kwaliteit voor zowel drinkwatervoorziening, als voor gebruik in de industrie en landbouw. Echter de hoeveelheden microplastics, medicijnresten en (andere) hormoon-verstorende stoffen zijn in het drink- en oppervlaktewater in de laatste jaren toegenomen (Wijbenga 2018). Op grond hiervan heeft Nederland de ambitie om diverse maatregelen te treffen die nodig zijn om de toekomstbestendigheid van de Nederlandse grote wateren te waarborgen. In deze toekomststrategie vervult het monitoren van diverse waterkwaliteitsparameters een essentiële rol. Zonder frequente en nauwkeurige metingen is het immers niet mogelijk om ecologische problematiek aan te kaarten en het effect van regelgeving te evalueren.

Traditionele metingen, gebruikmakend van lokale bemonstering en lab-analyses, worden voornamelijk uitgevoerd op lokale schaal. Gepaard met de relatief hoge kosten, worden in deze metingen ook relatief hoge nauwkeurigheden behaald. De resultaten van dergelijke metingen worden vervolgens op nationaal niveau bijeengebracht en bevatten dan allerlei verschillende type data, afkomstig van onderzoeken met verschillende doelstellingen, welk vervolgens weer gebruik hebben gemaakt van vele verschillende technieken. De omvang is beperkt doordat dergelijke metingen erg tijdrovend en kostbaar zijn (zowel het bemonsteren als het analyseren in het laboratorium). Nieuwe technieken die gebruikmaken van data afkomstig uit aardobservatie, daarentegen, kunnen snel grote gebieden bemeten en hebben een relatief hoge frequentie van metingen indien er gebruik wordt gemaakt van satellietdata. Aardobservaties zijn echter lastiger te interpreteren door de grove sensor (spectrale en ruimtelijke) resoluties en de beperkte lichtgevoeligheid van bepaalde waterkwaliteitsparameters. Om deze reden wordt er getracht instrumentontwikkeling beter te sturen zodat betere sensoren ontwikkeld kunnen worden om de huidige tekortkomingen overkomen. Voordat deze studie gedaan kan worden is het echter gewenst om de specifieke gebruikersbehoeften voor waterkwaliteitsmetingen in kaart te brengen.

Doel

Het doel van dit onderzoek betreft het in kaart brengen van de Nederlandse gebruikersbehoefte aan informatie uit producten en diensten die gebruik maken van satellietdata op het thema waterkwaliteit. Hierbij wordt de meerwaarde en bruikbaarheid van huidige en toekomstige aardobservatiesensoren en toepassingen onderzocht. Dit onderzoek bestaat dan ook uit het:

1. Ontwikkelen van een overzicht van de gebruikersbehoeften van de specifieke stakeholders (wetenschappers/ overheden en andere marktpartijen)

2. Inventariseren van huidige (en toekomstige) methodieken
3. Evalueren van de rol en meerwaarde van aardobservatie voor het in kaart brengen van de waterkwaliteit.

Methodologie

Om deze doelen te bereiken zijn er tijdens het project 3 specifieke activiteiten ontplooid:

- **Initiële analyse**. De initiële analyse is gericht op het verkrijgen van achtergrondinformatie over de gebruikers, hun toepassingen en uiteindelijk welke waterkwaliteitsparameters voor hun het meest van belang zijn. Hiervoor heeft het project: 1) meta-data-analyse uitgevoerd op wetenschappelijke publicaties; 2) literatuuronderzoek uitgevoerd op basis van eerdere gebruikersconsultaties; en 3) verschillende overzichtspapers en waterbeleidsdocumenten geanalyseerd. Middels deze aanpak kon we de hoofdzaak van het project beperken tot de relevante parameters en actuele vereisten van belanghebbenden in de huidige maatschappij.

- **Gebruikersbehoefteanalyse.** Deze activiteit concentreerde zich op directe feedback van de belanghebbenden. Uit de resultaten van de voorlopige analyse bleek dat er in het algemeen onderscheidt gemaakt wordt tussen twee type waterkwaliteitscriteria: 1) huidige lokale metingen (benoemd als de ‘gewenste’ vereisten); en 2) tot het minimum aan criteria dat nog nuttig zou zijn (benoemd als de ‘acceptabele’ vereisten). Om beide criteria goed in kaart te brengen is een online-enquête samengesteld die uitgedeeld is aan de gebruikers. Een belangrijk middel in de distributiestrategie was het eerste Nederlandse ‘Remote sensing in Ecology’ symposium (specifiek georganiseerd in het kader van dit project). Daarnaast leverde ook deelname aan verschillende nationale workshops een belangrijk bijdrage aan het doel om zo veel mogelijk relevante gebruikers te bereiken. Om de studie te onderzoeken op bias werden de resultaten van de gebruikersbehoefteanalyse vergeleken met de resultaten in de literatuur. Hierna zijn verschillende interviews met geselecteerde belanghebbenden uitgevoerd om aanvullende, secundaire vereisten voor het gebruik van remote sensing data te identificeren.

- **Haalbaarheids(veld)studie.** Parallel aan de gebruikersconsultatie is een kleine veldcampagne uitgevoerd om de haalbaarheid van Sentinel 2 observaties te onderzoeken. Om de signalen uit remote sensing-waarnemingen te identificeren is er, in plaats van inzet van traditionele modellen, voor een machine-learning benadering gekozen. Deze keuze zorgde ervoor dat de resultaten niet afhankelijk zouden zijn van de vele veronderstellingen die nodig zijn voor het uitvoeren van dergelijk onderzoek middels traditionele modellen.

Resultaten

Op basis van het onderzoek is er geconstateerd dat (zowel op nationaal als internationaal niveau) verschillende ruimtelijke en temporele resoluties worden aangegeven met betrekking tot acceptabele en ‘gewenste’ vereisten. Hier zijn de doelvereisten in overeenstemming met de huidige dagelijkse praktijken van de gebruikers, terwijl de 'acceptabele' vereisten betrekking hebben op de minimumcriteria - criteria die nog steeds als nuttig worden beschouwd.

Gebruikers rapporteerden ‘gewenste’ ruimtelijke resoluties van <1 m voor pH, CDOM, chlorofyl, phycocyanine, zoutgehalte, temperatuur, troebelheid en vegetatiedekking, en beoogde temporele frequenties van eenmaal per 1-7 dagen. De gebruikers rapporteerden ‘acceptabele’ ruimtelijke resoluties van 10-100 meter, (welke lager is dan de ‘gewenste’ criteria voor CDOM, chlorofyl, kleur, DOC, Phycocyanin, Secchi-diepte, TSM en troebelheid), en 'acceptabele' tijdelijke frequenties van eenmaal per maand voor CDOM, kleur, DOC , Phycocyanin en Secchi Depth.

Hierna werden deze vereisten geëvalueerd aan de hand van Sentinel-2 satellietplatformspecificaties. Er is aangetoond Sentinel-2 een voldoende hoog ruimtelijk en tijdelijke resolutie biedt om te voldoen aan de 'acceptabele' vereisten maar niet aan de 'gewenste' criteria. Verder heeft de haalbaarheidsstudie aangetoond dat (op de hypothese van een goede atmosferische correctie) er voldoende informatie is in Sentinel-2-waarnemingen om directe en indirecte bepalingen te kunnen doen betreft: opgeloste zuurstof, geleidbaarheid, pH, temperatuur, chlorofyl, en troebelheid .

Conclusies

De gebruikersvereisten in dit rapport zijn in overeenstemming met de resultaten in andere nationale en internationale studies. Vergelijkbare resultaten werden gevonden zelfs wanneer rekening werd gehouden met het grote verschil tussen doel- en acceptabele gebruikerscriteria. Een mogelijke verklaring hiervoor is dat een groot deel van deze 'acceptabele' vereisten worden bepaald in richtlijnen die ontwikkeld zijn in Europees en Internationaal verband.

Hoewel aan verschillende vereisten kan worden voldaan met behulp van de Sentinel-2-constellatie van satellieten, is er momenteel een zeer lage opname van 16,7% van remote sensing voor het uitvoeren van waterkwaliteitsbepalingen. Dit komt door verschillende secundaire criteria waaraan niet voldaan wordt ten opzichte van o.a.: 1) de ontwikkeling van sensoren / algoritmen, 2) de dienstverlening, 3) de kennis bij de eindgebruiker, 4) de gebruikersgemeenschap en 5) de beperkingen in de toepassingen. Het meest verontrustend is dat veel gebruikers de veronderstelling hebben dat remote sensing de traditionele methodiek zal vervangen - terwijl remote sensing de rol zou moeten hebben als een extra hulpmiddel. In sommige organisaties bestaat er dan ook de 'zorg' dat het gebruik van remote sensing de huidige expertise zal vervangen. Deze zorgen moeten eerst worden weggenomen voordat remote sensing een vaste plek krijgt in het monitoren en bepalen van de waterkwaliteit van de Nederlandse oppervlaktewateren.

Abbreviations

AI	Artificial Intelligence
BOD	Biochemical Oxygen Demand
CDOM	Colored Dissolved Organic Matters
CEOS	Committee on Earth Observation Satellites
CHL-a	Chlorophyll-a
CML	Institute of Environmental Sciences (Centrum voor Milieuwetenschappen)
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
EDA	Exploratory Data Analysis
EO	Earth Observation
ESA	European Space Agency
HAB	Harmful Algal Blooms
IOP	Inherent Optical Property
KRM	Marine Guidelines (Kaderrichtlijn Marien)
KRW	Water Guidelines (Kaderrichtlijn Water)
LEO	Low Earth Orbit
LMM	Minerals Policy Monitoring Programme (Landelijk Meetnet effecten Mestbeleid)
NAP	Non-Algal Particles
NeDL	Noise Equivelnt Downloading Radiance
NGO	Non-Governmental Organisation
NH3-N	Ammonia Nitrogen
NIOZ	Royal Netherlands Institute for Sea Research (Koninklijk Nederlands Instituut voor Onderzoek der Zee)
PCA	Principal Component Analysis
PO4	Ortho-Phosphate
PWN	Provincial Water Supply Company of North Holland (Provinciaal Waterleidingsbedrijf van Noord-Holland)
PZH	Province of South Holland (Provincie Zuid-Holland)
RF	Random Forrest (AI model)
RIVM	National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu
RWZI	Rioolwaterzuiveringsinstallatie
SDD	Secchi Disk Depth
SPM	Suspended Particulate Matter
SSS	Sea Surface Salinity
SVM	Support Vector Machines (AI model)
T	Temperature
TOC	Total Organic Carbon
TP	Total Phosphorus
TSM	Total Suspended Matters
TSS	Total Suspended Solids
TUR	Turbidity
UAV	Unmanned Aerial Vehicle

User – analysis

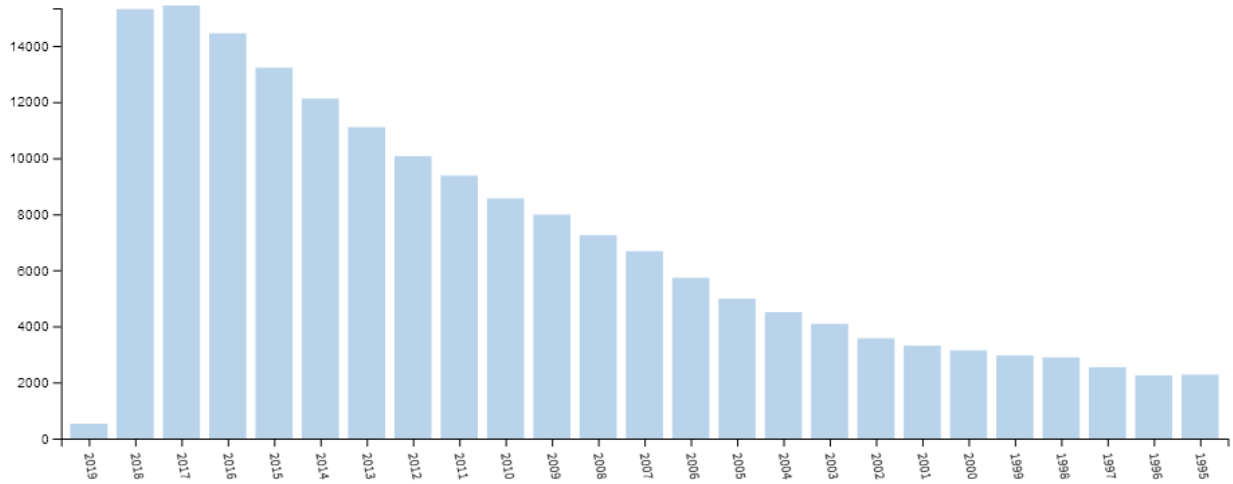
1. Stakeholder analysis
1.1 Literature review
1.2 National stakeholders overview
1.3 Selection of interviewed stakeholders

2 Water quality parameters selection
2.1 Water quality parameters overview for selected stakeholders
2.2 Spatial-temporal variability

1 Stakeholder analysis

1.1 Literature review

In order to get a full perspective on the water quality issue's, a preliminary literature study of web-of-science (http://wcs.webofknowledge.com) was performed. In total 182,264 scientific publications (papers/books) were found between 1945 until present when searching for 'water quality'. Of this number the majority is published after 2010, due to the increasing number of manuscripts. Please note that (during the time of this analysis in October 2018) the year 2018 is not finished yet some papers still need to be published/integrated into the database, the current number is lower than the papers in 2017.



This huge number of scientific articles provides us with enough data to perform a metadata analysis. However, considering we are only interested in present day activities, publications older than 5 years are omitted from further analysis. This still provides 70,493 number of publications, which is more than enough to perform a valid statistical analysis.

1.1.1 Dutch research overview

Additionally, the analysis also provides us with the possibility to provide the (region) origin of the manuscripts. Here the Dutch 'water quality' publications in the last 5 years takes up 2.2% of the full field, ranking as 17th water quality country (with all higher ranked countries having at least 2x the number of inhabitants). This therefore shows the Netherlands as a science driven country with high interest in 'water quality'.

Zooming further into the Netherlands also provides with a ranking on the published research, as is illustrated by Figure 1. It can be observed that most of the publications have been performed by universities (taking up the 8 spots of the top 10 spots); only Deltares on #6 (representing consultancy companies) and KWR Watercycle Research Institute on #7 (representing the dutch (drinking) water sector) are found in the top 10. Naturally, these institutes all collaborate with each other (as shown by Figure 2), which promotes the distribution of new techniques and models.

Figure 1: Dutch water quality published research ranking per institute.

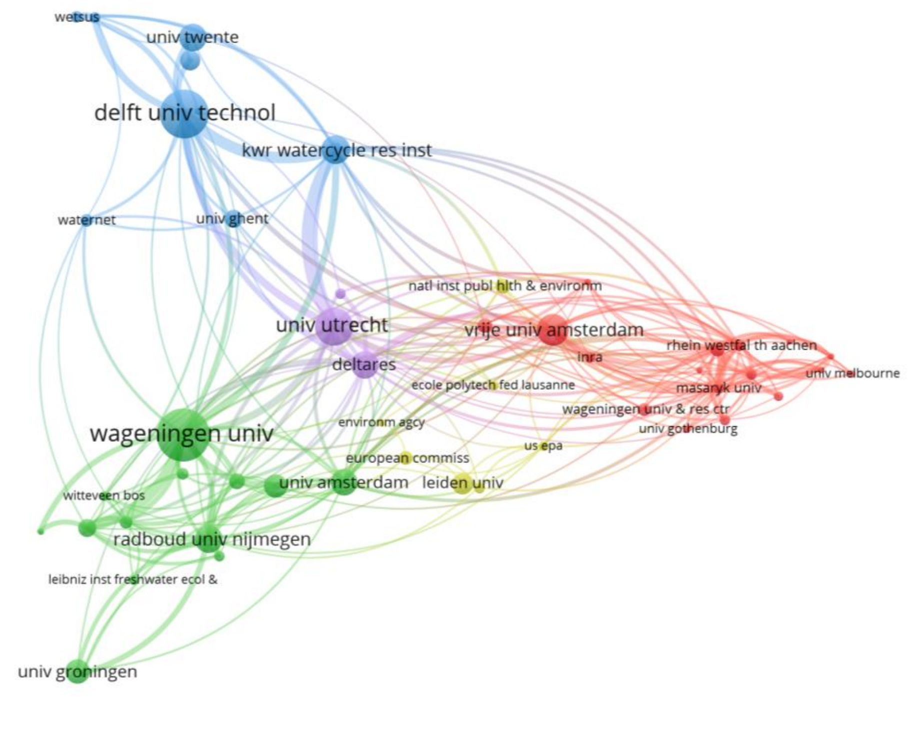


Figure 2: Connectivity between water quality research institutes

Please note this ranking in Figure 1 should not be seen as the ranking of most important water quality institutes in the Netherlands. This analysis used web-of-knowledge database which biases the analysis to published manuscripts. In particular, consultancy companies as well as governmental bodies do not focus on producing peer-reviewed papers, but on technical reports for their client's project. When selecting participants for the stakeholder analysis, this shortcoming needs to be addressed.

1.2 National stakeholders overview

As indicated in the introduction, there is a need to increase the water quality in the Netherlands in anticipation of the rise of pollutants in drinking and surface water, such as micro-plastics, medicine residues and (other) hormone disrupting substances. To this purpose, monitoring of water quality parameters plays an essential role. However, considering the large number of waterbody types that are present in the Netherlands (Dutch oceans, lakes, rivers, canals and ports), as well as the large number of applications for which this water is used (such as shipping, fishing, drinking and irrigation), it is not surprising that there is a large variety of stakeholders in the water quality sector, as was highlighted in the Roadmap "Waterkwaliteit Helderbeeld op Troebel Water" report by the University of Twente (Salama 2014). Instead therefore of focussing only on knowledge institutes (from Figure 1), this user consultation will adopt the stakeholder classification from Salama (2014), as shown below.

Stakeholders [1]	Interest in service	Public / Private
Water Boards	monitoring of **ecosystem** health, drinking water, recreational water	PU
Ports	port access in shallow waters	PU
Dredging sector	Erosion accretion of sediment / environmental impact (turbidity,…)	PR
Utility companies	**water and pollution monitoring**	PU/PR
Drinking Water Companies	chemical disasters/water quality/safety **management plans**	PR
Scientific community	understanding the **bio physical processes**,	PU
NGOs	Nature conservation	
Chemical producers	Pollutants discharges into surface water	PR
Aquaculture	Water quality (harmful algal blooms HAB)	PR
In-situ water quality sensor producers	Increase of market enhancement of sensors with **ICT and coupling to Geo-**ICT	PR
Geo-ICT industry	Geo-ICT to environmental monitoring	PR

1.3 Selection of interviewed stakeholders

Within the context of the project is was not feasible to perform interviews of this full sector. In that respect, the research focussed only on a subset of these, highlighted above. Instead (considering the background of the Institute of Environmental Sciences that executed this user consultation), the focus of this research was on investigating stakeholders with ecological affiliation. The group of end-users specifically targeted in this consultation are therefore provided below.

Participatory Stakeholders	Interest in service
Hoogheemraadschap Rijnland	Algal blooms, nutrients, dissolved oxygen,..
Dunea Drinking Water Company	Chemical disasters, harmfull algal blooms,
RIVM	Environmental monitoring
Leiden University	Ecological processes, nutrients, ecotoxicology
Water Insight	Sensor development and service provisioning

1.3.1 Hoogheemraadschap Rijnland

Hoogheemraadschap Rijnland is one of 12 Water Boards in the Netherlands. Rijnland specifically works in two provinces: North Holland and South Holland. The Rijnland area stretches from Wassenaar up to IJmuiden and from Gouda to and including part of Amsterdam, covering an area of 1,100 square kilometers and impacting 1.3 million people that live, work, travel and enjoy leisure activities. As such,

[1] Taken from the "Roadmap Waterkwaliteit Helderbeeld op Troebel Water" report by the University of Twente (Salama 2014).

Rijnland's key tasks include, among others, ensuring a good quality of open water so that it can be used for recreation, watering cattle and as a habitat for a large variety of plants and animals (water quality), as well as ensuring that polluted river, canal and lakebeds are cleaned in order to balance the water ecosystem so that the water provides opportunities for natural development in the countryside as well as in towns and cities (water management plus).

In order to ensure water quality, Rijnland processes waste water from homes and businesses. This waste water arrives at Rijnland's purifying plants via the sewage system. There the water is cleaned. This is done naturally with the aid of bacteria and oxygen. The clean water is then discharged into open water. Furthermore, Rijnland also devotes a lot of effort to preventing pollution in open water. Rijnland grants permits that impose strict conditions for discharging waste water. Rijnland checks for and investigates illegal discharges of waste water.

1.3.2 Dunea

Dunea produces and delivers drinking water up to 1,3 million clients in the western part of the South Holland. For this they protect the water uptake to these users, as well as manage the water uptake area in the dunes. In that aspect, they also receive up to 1 million tourists in the dunes between Monster and Katwijk on a yearly basis. Providing clean Drinking water as well as ensuring environmental services of the dunes form the basis of a good living habitat for humans in the Randstad. In that aspect, the dunes between Monster and Katwijk are of vital importance. To this purpose, Dunea ensures nature management in the dune area's of Solleveld, Meijendel and Berkheide. In order to meet the demand of drink water, Dunea imports purified riverwater from the 'Afgedamde Maas'.

These activities lead to Dunea having two specific affiliations with water quality: 1) to ensure the quality of the water from the Afgedamde Maas, as well as 2) ensuring the water quality of the surface area in the rivers and dunes.

1.3.3 RIVM

The National Institute for Public Health and the Environment (RIVM) works to prevent and control outbreaks of infectious diseases. RIVM promotes public health and consumer safety, and helps to protect the quality of the environment. As such, the main role of the RIVM is as a trusted advisor to government providing impartial advice on infectious diseases, vaccination, population screening, life style, nutrition, pharmaceuticals, environment, sustainability and safety.

Within this role, the RIVM is operationally monitoring the effects of agricultural fertilization onto the water quality on farms in the Netherlands (LMM, Minerals Policy Monitoring Programme). The LMM monitors the quality of water that leeches from the root zone (upper groundwater, drain water or soil water) and ditch water.

1.3.4 Leiden University

CML is an institute of the Faculty of Science of Leiden University. CML aspires to be the center of excellence for strategic and quantitative research and education on sustainable use and governance of natural resources and biodiversity. More specifically, within CML, the department of environmental biology aims to increase the scientific understanding of how current and emerging anthropogenic threats affect biodiversity and ecosystem services. Through this understanding they facilitate strategic management of natural resources by addressing urgent challenges in relation to involved mechanisms and their inter-linkages across scales. As such water quality is of high relevance.

Specifically, from the ecologist' point of view, there is knowledge required on what the issues are in the Dutch ditch water quality. These issues are mainly related to agricultural pressure on the landscape, such as fertilization of the agricultural fields, the use of pesticides on agricultural crops and soil subsidence. CML therefore performs research to acquire this knowledge, as well as share this with the world through for example the ‘pesticide atlas’ (http://www.bestrijdingsmiddelenatlas.nl/).

1.3.5 Water Insight

Water Insight is a water quality technology company founded in 2005. As such their mission is 1) To provide water quality information products and services based on their in-house developed sensors and satellite data processing, 2) Participate in European projects to benchmark the quality of their services, and 3) advocate the use of remote sensing techniques for water management. For this, Water Insight has developed its own “close sensing” portable water quality spectrometer, that is being widely used for in-situ measurements (for example by Water Boards) of ecologically relevant parameters, such as Chlorophyll-a, Suspended matter, Phycocyanin and Transparency. Furthermore, Water Insight also has extensive experience in providing remote sensing information to Dutch Governance. More specifically, In the period 2006 – 2012 Water Insight provided the Ministry of Infrastructure and Water Management (through its agency Rijkswaterstaat) with Harmful Algal Bloom bulletins for the Dutch part of the North Sea.

In this sense Water Insight provides a nice perspective of additional secondary requirements of stakeholders. In particular, they can provide comprehensive insights into questions asked by governmental institutes (such as Water Boards), as well as objective information regarding uptake of remote sensing services.

2 Water quality parameters selection

Based on the literature review an overview of the water quality parameters was created, as shown below. Within this overview, we also highlight water parameters that are not optically active and consequently cannot directly be estimated from remote sensing observations.

Table 1: The most commonly measured qualitative parameters of water by means of remote sensing [1] (in red not by remote sensing)

Water Quality Parameter	Abbreviation	Units	Optical Activity
Chlorophyll-a	CHL-a	mg/L	Active
Secchi Disk Depth	SDD	m	Active
Temperature	T	C	Active
Colored Dissolved Organic Matters	CDOM	mg/L	Active
Total Organic Carbon	TOC	mg/L	Active
Dissolved Organic Carbon	DOC	mg/L	Inactive
Total Suspended Matters	TSM	mg/L	Active
Turbidity	TUR	NTU	Active
Sea Surface Salinity	SSS	PSU	Active
Total Phosphorus	TP	mg/L	Inactive
Ortho-Phosphate	PO4	mg/L	Inactive
Chemical Oxygen Demand	COD	mg/L	Inactive
Biochemical Oxygen Demand	BOD	mg/L	Inactive
Electrical Conductivity	EC	s/cm	Active
Ammonia Nitrogen	NH3-N	mg/L	Inactive
Phycocyanin	PC	mg/L	Active
Aquatic vegetation	AV	-	Active
Micro-Plastics	MP	#/L	Inactive

2.1 Water quality parameters overview for selected stakeholders

In the following paragraphs an overview is provided for each of the selected water quality parameters.

2.1.1 Total suspended matter / Turbidity / Secchi Disk

The clarity and transparency[2] of water quality is defined by its turbidity and suspended solids. The Total suspended matter (TSM) also called total suspended solids (TSS) or suspended particulate matter (SPM) is the name given to the total mass of suspended particles as measured per volume of water including inorganic (minerals) and organic (detritus and phytoplankton) components[3]. TSM is an important parameter for water quality management, because it is related generally to primary production, sediment transport and, more specifically, water clarity/opacity, which is an indicator of water quality.

[2] Please note that the best-known operational estimation of water transparency is the Secchi Disk, created by Pietro Angelo Secchi SJ in 1865. The disc mounts on a line and lowers slowly down in the water until the pattern on the disk is no longer visible, with this depth called the Secchi Disk Depth. In this sense, Secchi Disk measurements cannot be performed from space. However, Secchi Disk Depth exhibits a direct inverse correlation with the amount of total suspended solids (TSS) present in the waterbodies.

2.1.2 Colored dissolved organic matter

Colored/Chromophoric dissolved organic matter (CDOM) is the fraction of dissolved organic matter (DOM) in natural waters that has an impact on optical radiation. CDOM plays a vital role in the biogeochemical cycle in aquatic ecosystems, in particular for freshwater lakes, saline lakes, rivers and streams, urban water bodies, and ice-covered lakes [6]. The sources of CDOM in aquatic ecosystems include among others microbial and phytoplankton. As such, it has been demonstrated that there exists a positively correlated relationship between the CDOM and dissolved organic carbon (DOC).

2.1.3 Chlorophyll-a pigment (of phytoplankton)

Phytoplanktons (tiny drifting plants) are major biological communities [7], which have vital roles in the aquatic food chain and are known as indicators of coastal and estuary conditions. It is necessary to be knowledgeable about changes in phytoplankton communities and their interactions with aquatic areas as this can reflect the physico-chemical quality of the aquatic area—phytoplanktons are able to respond significantly to variations in nutrient concentration, light, sediment load, and zooplankton grazing. As chlorophyll-a is the green pigment in most photosynthetic plants, measuring chlorophyll-a levels is a good reflection of the biomass of phytoplankton and trophic status in aquatic areas [7].

2.1.4 Cyanobacterial blooms / Phycocyanin

The detection of certain cyanobacteria is of great interest owing to the potentially great negative impacts these bloom-forming and sometimes toxic species have in coastal and inland waters, which may result in substantial economic losses [3]. Cyanobacterial blooms can lead to hypoxia and alter food-web dynamics, and may pose a substantial health risk for communities accessing affected water for drinking, irrigation and recreation if the blooms contains toxins [2].

2.1.5 Temperature

Changes in temperature can have a large effect on the quality of water, as well as the broader ecosystem. In general, water temperature changes can significantly destabilise ecosystems [1]. As such, water temperature has a strong economic impact. For example, the fishing and aquaculture industries are heavily dependent on water temperature measurements in their ecosystem management [11]. In addition, sea water temperature (in combination with sea water salinity) has a direct effect on the absorption and backscattering characteristics of water [12]. As such, this information is instrumental for accurately quantifying the other abiotic and biotic variables.

2.1.6 Aquatic vegetation phenology

Floating and submerged plants provide important structuring for freshwater ecosystems, influencing the physical and chemical environment and food web. Understanding the growth and distribution of aquatic vegetation is therefore useful in understanding subsequent ecosystem properties [2, 14].

2.1.7 Micro-plastics

The plastics released into the global environment have been increasing for decades [15]. The degradation process of plastics is very slow, and they can be broken down into tiny plastic particles under the long-term action of solar radiation or physical, chemical, or biological factors. In the marine environment, large plastic items break up into smaller pieces with dimensions as small as a few micrometers.

Micro-plastics can cause harm to wildlife through entanglement or ingestion and to habitats through smothering of the seabed. Indeed, ingestion posed greater potential risks for aquatic organisms. Many marine invertebrates, like bivalves, echinoderms, amphipods, and zooplankton are known to ingest micro-plastics. Internal and digestive enzyme system damage, even the reproduction, can be caused by the micro-plastic digestion.

2.2 Spatial-temporal variability

In order to frame to the spatio-temporal resolutions and uncertainty requirements a literature study was performed to provide an overview of reported variabilities. These are provided below

2.2.1 Total suspended matter / Turbidity / Secchi Disk

In optically complex water bodies, turbid levels have been defined [4] to range from clear (<3 g/m3) till very turbid (>200g/m3). These ranges were reported for large inland lakes [4]. For inland (optically dense) waterbodies, it was shown [2] that all freshwater systems in Europe can be suitably be monitored using resolution from 300m. In contrast, for Australia, this threshold is set to 30-60m, taken into account that this country has a much rougher geomorphology.

For the Wadden Sea, higher maximum values for SPM have been found up to 1225 g/m3, and even up to 4.000 g/m3 near the Dollard part of the Wadden Sea. These variations in the particulate matter are mainly caused by the spatial variability, as a seasonal variability of (only) 70 g/m3, was reported [5], as well as a tidal variability of (only) 14-88 g/m3. It was therefore reported that a resolution of 300m for this water body is sufficient.

2.2.2 Colored dissolved organic matter

The retrieval of a_{CDOM} has been the subject of more recent studies, as interest in optical measurements of the IOPs of natural waters is increasing [3]. Absorption by CDOM is one of the primary additive absorption IOPs, along with phytoplankton and water, and is therefore of great interest from a bio-optical perspective. The downside, however, is that the found absorption coefficients are performed at different wavelengths, thereby introducing spectral uncertainties on top of the possible spatio-temporal variations.

For optically complex waters, [4] a classification range was defined for low (<0.8 m^{-1}), medium (0.8-2 m^{-1}) and high (>2 m^{-1}) CDOM concentrations @400nm. The composition of DOM (CDOM) in such aquatic environments is highly heterogeneous. This is created by the various regional differences in sources. As such, the composition, properties and distribution of DOM/CDOM in riverine waters showed more uncertainties which are threatened by the changes of hydrology, geomorphology, land use/cover, soil types, and seasonality meteorology. This can only be solved if the resolution of the remote sensing instrument is at least three times higher than the width of the waterbody of interest.

For Wadden Sea, similar values are found, with a range from 0.5 - 2.5 m^{-1} @375 nm [5]. The variation here is mostly attributed to the spatial variation in this area, as the seasonal variability for individual in-situ measurements ranges from around 0.08-0.22 m^{-1} @375 nm [5]. It should be noted, however, that, in the shallow Wadden Sea sand beds were found to work as a sink for organic matter that can filter the entire water body of the Wadden Sea within 3–10 days [5]. This might be one of the reasons why maps of CDOM concentrations over the entire Wadden Sea area are sparse.

2.2.3 Chlorophyll-a pigment (of phytoplankton)

For inland waterbodies, no specific accuracy was found in the literature review. Instead, a classification was found representing low (oligotrophic, <3mg/m3), medium (mesotrophic, 3-10 mg/m3) to high (eutrophic, >10 mg/m3) chlorophyll-a conditions [4]. However, higher values have been found in different lakes. During a review of inland remote sensing capabilities, ranges for different lakes were reported [2] from 1.16 CHL to 57.8 to 93.8 mg/m3, for respectively Maggiore Lake, Trasimeno (with Cyano bacteria bloom of CPC 31.25 mg/m3) and Mantua (during a phytoplankton bloom). Even higher ranges were reported [8] from 1 till 350 mg/m3 under “algal scum” conditions. It was reported [4] that current NIR-Red algorithms are validated for up to 250 mg/m3 and suitable for a 10-100mg/m3 interval. Using the same approach as for TSM, a spatial resolution was defined based on the CORINE2006 land cover. This showed [2] that nearly all freshwater systems in Europe can be suitably be monitored using resolution from 300m.

For tidal water bodies, such as the Wadden Sea, similar values as inland waterbodies were found, ranging from 1 to 90 mg/m3 [5]. In contrast to the inland water bodies, variation here can both be attributed to location of the bloom [5] as well as the timing, with a strong seasonal component with variations ranging from 30-70 mg/m3.

Chlorophyll-a (together with several other biotic/abiotic parameters), is used for partitioning the ocean surface into different ecological functional classes [9]. Here, the specific classification methodology defines the spatio-temporal resolutions. For macroscale studies (>1000km), data is required to be available on a monthly frequency, while for mesoscale (10–1000 km) classifications, a temporal frequency of 3-5 days is required [9]. In the context of macroscale studies, global analysis form a special case. Global distribution analysis of Chlorophyll-a (Chl-a) showed that Chl-a–rich regions are located along the coasts and continental shelves, north of 45° North mostly because of a strong nutrient supply [10].

2.2.4 Cyanobacterial blooms / Phycocyanin

For inland lakes, a case study in Lake Mantua was performed[8]. This study showed that daily observations are required to adequately represent the high dynamic effects of the bloom. It was, however, indicated that this high observation frequency might have been caused by the patchiness of the bloom. If instead, a better resolution (then 300m) was used, this spatio-temporal variability might have been captured better, and would have led to lower temporal requirements. During this study, the highest CPC observation for which the bloom varied was from 31.25 mg/m3.

2.2.5 Temperature

For inland water bodies, the desired spatial resolutions are generally on the order of hundreds of meters, though some users require meter-scale resolution (for small streams). Temporal resolution requirements are generally on the scale of a day to a week [13, 14]. Previous studies have not indicated strong accuracy requirements, but these can be assumed to be on the 0.1-1 Kelvin scale [1], since the majority of previously indicated hydrological and ecological processes occur on these and larger scales.

For oceans, temperature (similar to chlorophyll-a) is used for ocean surface partitioning [9]. This therefore provides the same requirements, namely for macroscale studies (>1000km), data is required to be available on a monthly frequency, while for mesoscale (10–1000 km) classifications, a temporal frequency of 3-5 days is required [9].

2.2.6 Aquatic vegetation phenology

A case study of Lake Mantua showed that observing the phenology of various aquatic vegetation types could be retrieved at 30m resolution [2] at a 16day frequency. The classification that was used in this study relied heavily on a species map derived from the ground observations.

2.2.7 Micro-plastics

Here we consider the relatively new interest in micro-plastics for water quality purposes. In fact, only as of 2014 (Lusher et al.) ubiquitous micro-plastic pollution in the Northeast Atlantic Ocean was demonstrated [15] with an average plastic abundance of 2.46 particles/m3. In addition, in a recent study, Su et al. (2016) presented the pollution levels in Taihu Lake, indicating the high abundance ranged from 3.4 to 25.8 items L^{-1}. It is therefore not surprising, that few information was found on what specific spatio-temporal requirements are necessary. At present, most of the research focusses on determining the toxicity levels for different animals, before any efforts are made to perform large scale monitoring of this.

Primary Water quality requirements

3. Primary Water quality requirements
3.1 Approaching Primary requirements
3.2 Primary User requirements

4. Analysis of Primary requirements
4.1 Previously reported requirements
4.2 Policy driven requirements

5. Potential for remote sensing for these requirements
5.1 Adherence of Remote sensing platforms to current requirements
5.2 Sentinel-2 Feasibility Study results
5.3 Current usage of remote sensing data

3 Primary Water quality requirements

The approach of the analysis focused on

1. an online questionnaire distributed to several stakeholders. This questionnaire investigated specific objectives of the different stakeholders and the requirements that these participant currently set (and accept) on their measurements
2. An evaluation of these requirements against previously reported requirements, as well as spatial/temporal variability found in the different water bodies.

3.1 Approaching Primary requirements

The approach of this part of the user consultation, concerns primary requirements (such as observational resolution, frequency and accuracy). This analysis was performed on the basis of an online questionnaire distributed to different institutes belonging to the different stakeholder groups. This questionnaire investigated specific objectives of the different stakeholders and the requirements that these participant currently set (and accept) on their measurements.

In total over 50 institutes have been contacted to provide input to the questionnaire. In total 18 inputs have been provided. This is similar to the input/response for similar user consultations (such as the INFORM research). It should be noted that, while more inputs would have been beneficial, several participants specified that in fact their input represented an institutional point of view.

3.1.1 Participant's objectives

The first number of questions relate to the stakeholder in itself. These questions deal with the affiliation of the participant, as well as the work that these participants do in their institution. As can be observed from Figure 3 nine different types of affiliation were specified, with most participants working in universities (38.9%), followed by Public Administration (27.8%). Specifically, while there is a small bias towards Universities and Public Administration, we nicely find a large spread among the participants of water bodies of interest, see Figure 4. With only Lagoons, Ditches, Canals and Temporary pools having a lower percentage than 10%.

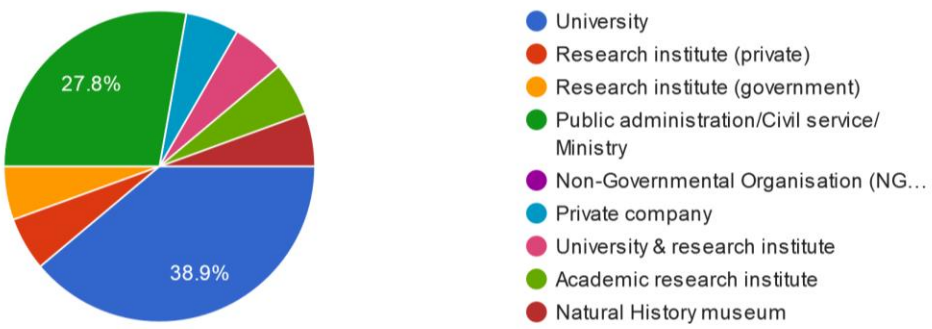


Figure 3: What type of organization do you work in

Considering the variety of institutes, it is not surprising to find a large variety of the participant's objectives, see Table 2. The objectives of each of these participants, range from 'knowledge driven' (61%, shown in blue) to 'policy' based (47%, shown in orange). This is in agreement with the ratio found for the different affiliations.

Table 2: Water quality measurement objectives

To what purpose do you use water quality measurements?
Gain insight in physical-chemical processes for reporting
Detection of blue algae; KRW goals; performance RWZI;
Relating biodiversity data to environmental driving factors
Research and consulting
To assess the effect of stressors on the abiotic environment
Evaluation of the manure act
Analyzing vegetation patterns.
Regulations
Research (retrieval of water quality from remote sensing; functioning of water bodies)
Salinity measurements of irrigation water is of high necessity to land practices
Meeting necessary river water quality to infiltrate into dune ponds and to meet biological and chemical requirements for the Water Guideline of these ponds including the effects of the water quality in the soil.
To relate environmental variables to the functional composition of macrofauna communities.
I am developing an instrument for the purpose of water quality measurements
To find human-induced alterations to the aquatic environment
To help parameterize remote sensing models
Quality assessments
To see trends. for measurements to improve water quality and ecology

3.1.2 Application area

Next to the objectives of the participants, the water body type as well as water quality parameter is of interest to this research, namely to provide a preliminary indication of what scales are of interest to the stakeholders. Similar to the variety of water bodies, the participants specified a large range of water quality parameters of interest, with none of the parameters in fact having a lower interest than 10%. The parameters of most interest to the participants are **chlorophyll-a**, floating vegetation, **turbidity** and **temperature** with respectively an agreement 75%, 62.5% and 2x 56.3. This is in accordance with the interests found in the preliminary literature analysis. It should be noted that the high percentage of floating vegetation most probably originates due to the high percentage of participants working on 'Lakes and Rivers' (of respectively 66.7% and 77.8%).

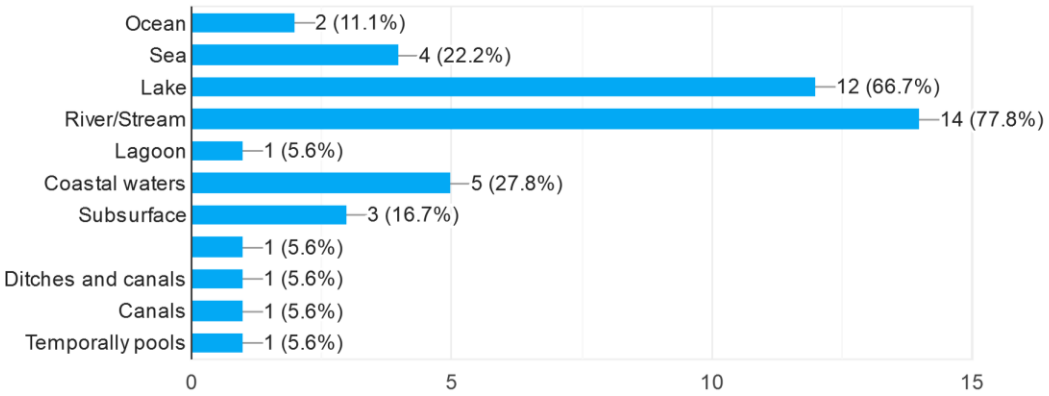


Figure 4: Which water body types do you study.

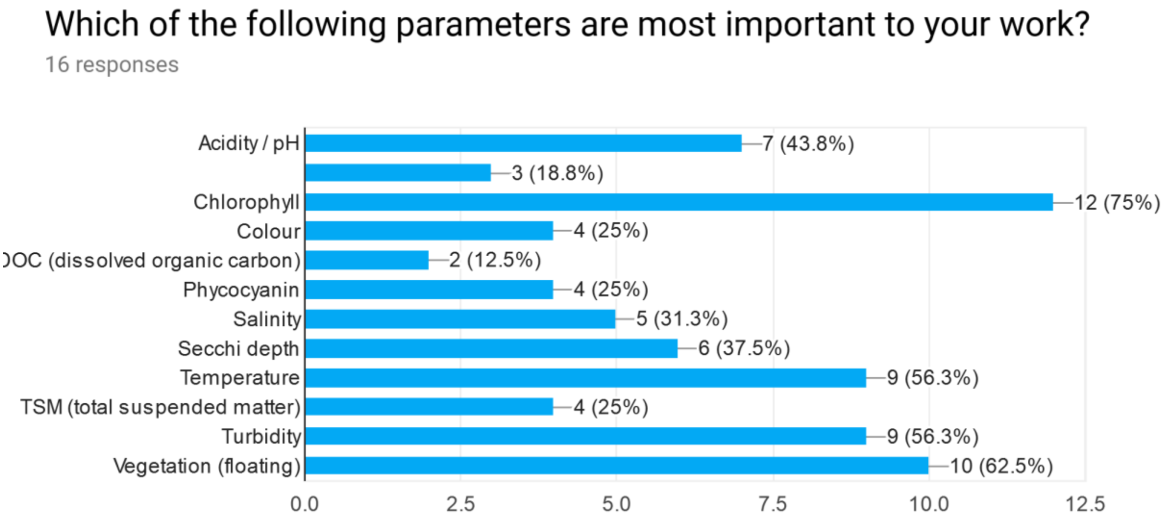


Figure 5:Which water quality parameter is of most interest to you.

3.2 Primary User requirements

Participants specified at this moment very high spatial and temporal resolutions are used in their water quality work, see Figure 6 and Figure 7.

- For **spatial resolutions**, the stakeholders report a current scale of **<1m** to be used for pH, CDOM, Chlorophyll-a, Phycocyanin, Salinity, Temperature , Turbidity and Vegetation Coverage. For ocean color, Secchi Depth and TSM, no specific spatial scale was preferred.
- For **temporal scales**, the stakeholders report, that for all water quality parameters an **observational frequency of once per 1-7 days** is mostly used. Only for pH, a lower temporal resolution, several times per year, is specified.

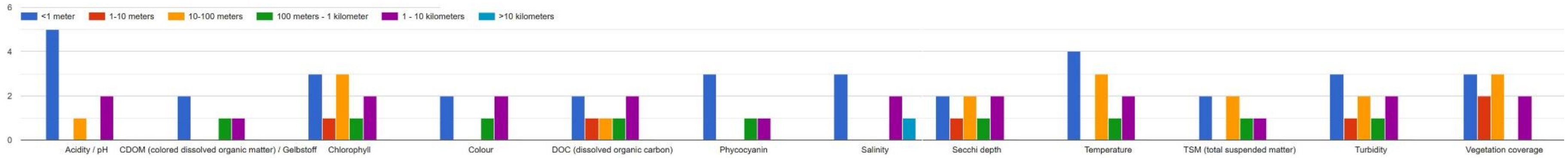


Figure 6: What is the Spatial Resolution that you currently use

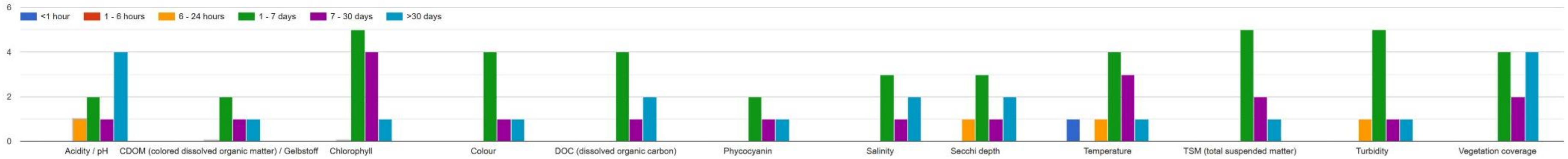


Figure 7: What is the current temporal resolution that you currently use

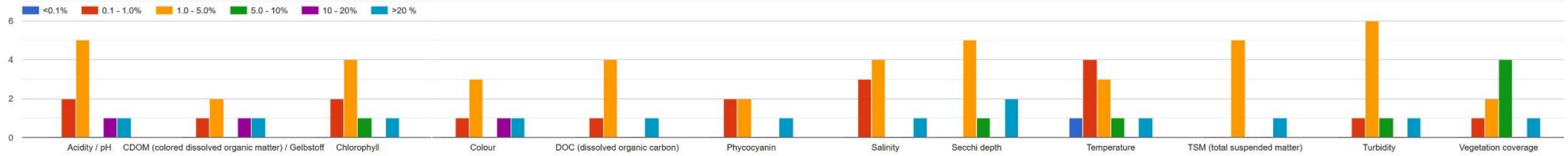


Figure 8: What is the uncertainty that you currently use

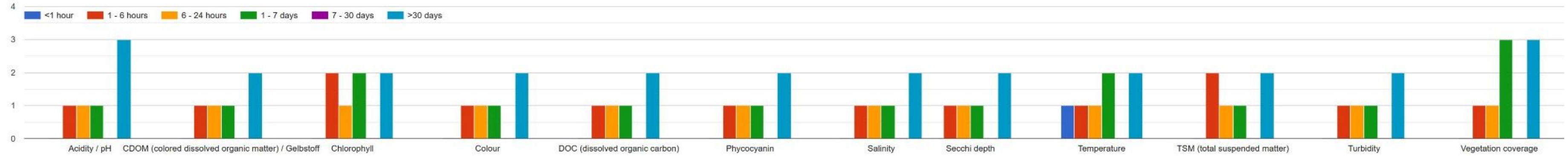


Figure 9: What is the minimum temporal resolution that you require

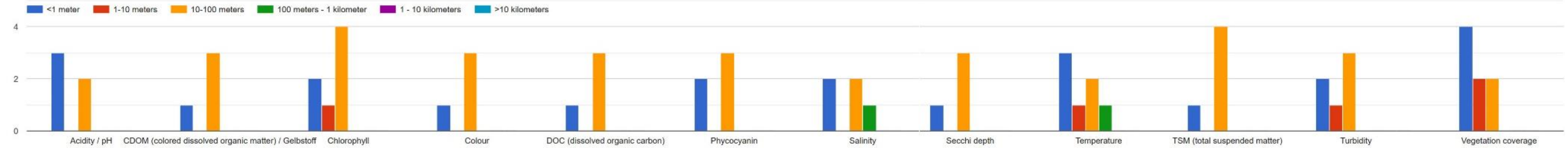


Figure 10: What is the minimum Spatial Resolution that you require

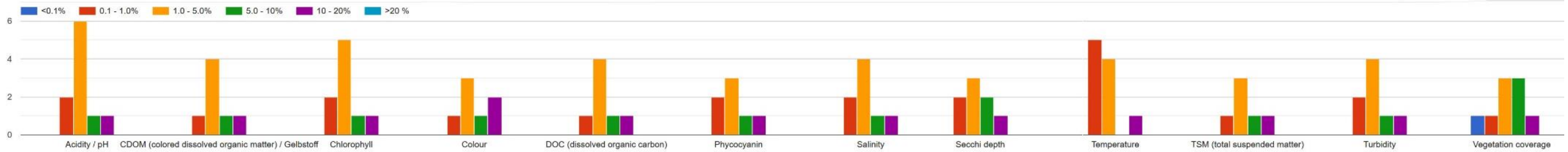


Figure 11: What is the minimum uncertainty you define.

These resolutions should be the target goal of any remote sensing to adhere to. Stakeholders did realize that these requirements in some case's might actually be too strict. They therefore also provided additional resolutions that would still be acceptable for their current water quality work, see Figure 9 and Figure 10. This data shows the following spatio-temporal considerations:

- Spatial resolutions that are still acceptable for the participant for almost all parameters is lower than their current usage. Specifically, a **10-100 meters** resolution is deemed acceptable for **CDOM, Chlorophyll-a, Color, DOC, Phycocyanin, Secchi Depth, TSM and Turbidity.** For water quality parameters pH, Salinity and Temperature, still the majority of participants require higher resolution (though the percentage of participants was smaller for each of these).
- Acceptable temporal resolutions for the different participants show for most water quality variables (**CDOM, color, DOC, Phycocyanin, Secchi Depth**) lower observational frequency (in the range of **once per month**) in respect to the currently used observational frequency. Only for Chlorophyll-a, temperature and TSM is this shift to lower temporal frequencies less clear (but still apparent). In addition to this, the temporal extent of the data is required (for all variables) to have a length of at least 1-12 months.

In terms of uncertainty, data is requested to have errors in the 1.0 till 5.0% range. This is irrespective of the current application, or a more lenient maximum criteria. Only for Phycocyanin and Temperature are lower uncertainties required (of 0.1-1%), while only for vegetation cover are higher uncertainties allowed (5.0-10%).

4 Analysis of Primary requirements

Several other researches apart from this one have investigated user requirements. These documented requirements can be split up into two sections: namely user-specified requirements, and policy driven requirements. Each of these will be discussed in the following sections.

4.1 Previously reported requirements

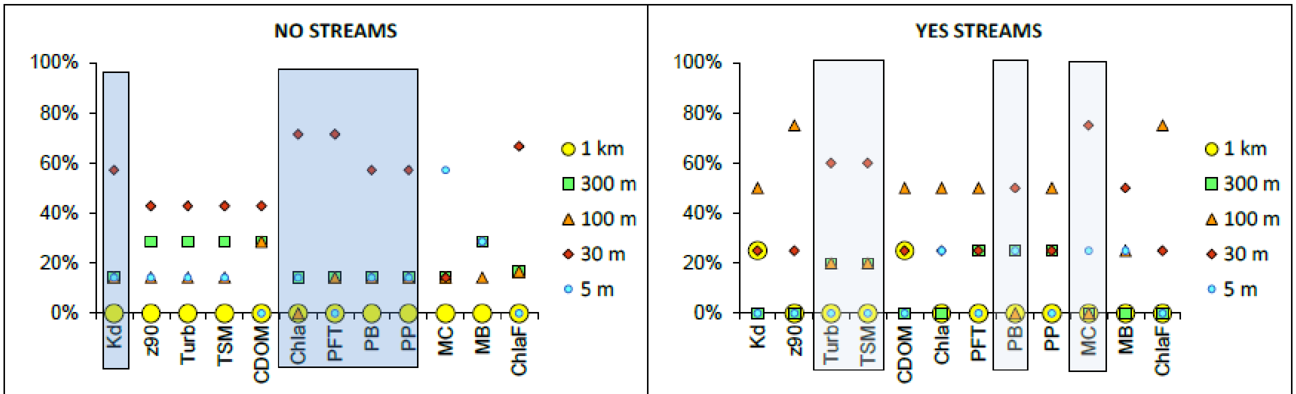
In general the findings provided above are in agreement with the observations made within international and national user consultation projects, such as INFORM, the CEOS feasibility study (by Water Insight and TNO), and the previous NSO downstream roadmap (written by the University of Twente). It should be noted that in contrast to this study, these projects considered a larger variety of aquatic ecosystems ranging from a ditch (with length scale of less than one meter), to oceans (with length scales of several km's). As such, there is a large diversity concerning coverage and geolocation requirements.

The results found in these other investigations overlap well with the spatial, temporal and accuracy requirements. For a full analysis on these reports, we have summarized these in Appendices B to D. Specific findings are provided in the paragraphs below.

4.1.1 Spatial resolutions

Figure 12 shows the spatial resolution preferences for each EO derived product for both 'stationary' water types and 'flowing' water type bodies.

It can be observed that end-users working on streams and rivers choose in general lower spatial resolutions than the end-users not working on these waterbodies. When aggregating the results for the different parameters (Figure 13), this is highlighted more clearly (with the streams-working end-users mostly requesting resolutions in the range of 100m, in contrast to the other group requesting 30m resolutions).



-	Kd	Light Attenuation (m^{-1})	-	PFT	Phytoplankton functional types
-	z90	Euphotic depth (m)	-	PB	Phytoplankton bloom occurrence
-	Turb	Turbidity (NTU)	-	PP	Phytoplankton primary production
-	TSM	Total suspended matter (g/m^3)	-	MC	Macrophyte cover
-	CDOM	Colored Dissolved Organic Matter (m^{-1})	-	MB	Macrophyte biomass (mg/m^3)
-	Chla	Chlorophyll-a concentration (mg/m^3)	-	ChlaF	Sun induced Chlorophyll-a fluorescence

Figure 12: Scatter plots showing the spatial resolution preferences for each single EO derived parameter. End-users are divided in working or not on streams and rivers (first row).

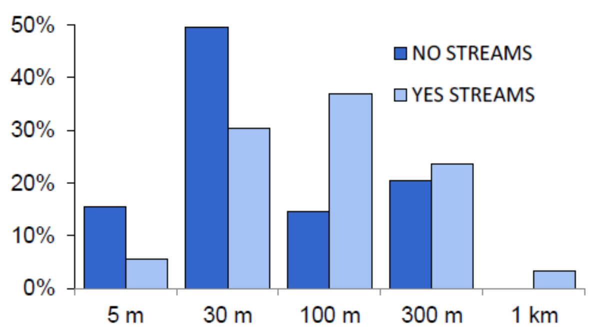


Figure 13: Bar chart showing the spatial resolution preferred by the end-users subdivided in two *groups (working or not on streams and rivers).*

In general, all inland, wetland, estuarine, deltaic, agonal, coastal and coral reef waters with water depths less than 30 m and larger than ~0.002 ha, require spatial resolutions of **~33 m (threshold) to ~17 m (goal).** These maps should not only provide high resolution but should be properly georeferenced and geometric corrections with the baseline requirement of respectively 0.2 and 0.4 pixels or less in along and across track directions.

4.1.2 Temporal resolution

With regard to the observational frequency, similar requirements were documented (as shown in Figure 15) in the previous reports. Specifically, for almost all parameters, observations were required at **weekly** time intervals in non-flowing waters and monthly intervals in streaming water bodies. Only for the characterization of **chlorophyll-a and phytoplankton** blooms was the temporal requirement higher (for stationary waters), namely the request of **daily observations**.

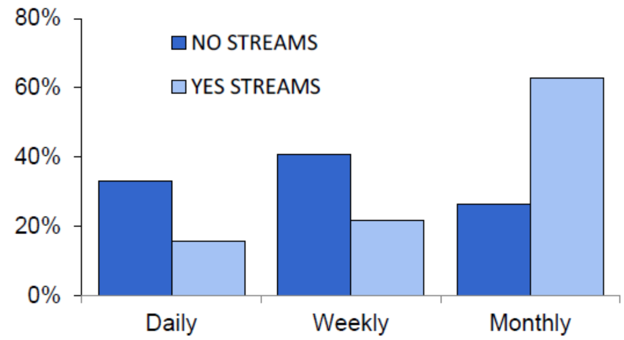
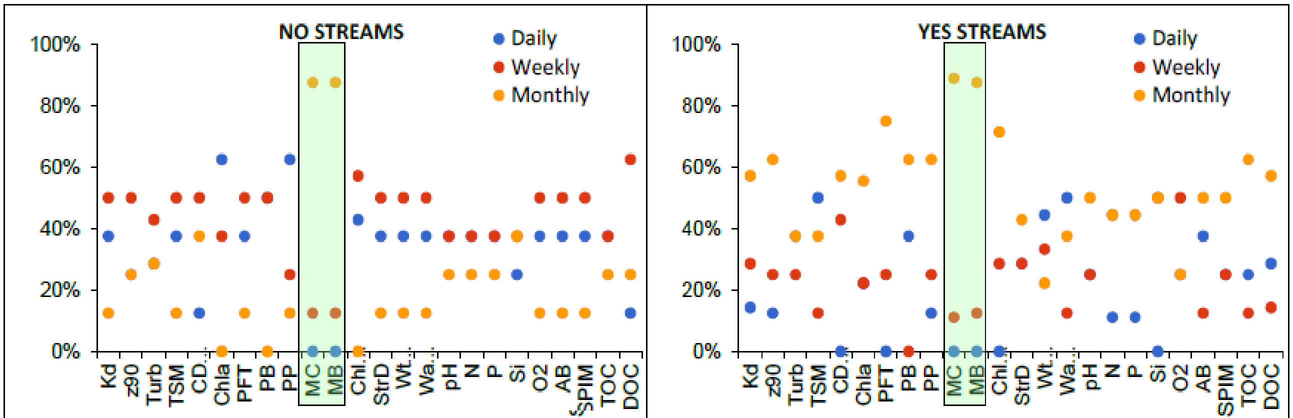


Figure 14: Bar chart showing the temporal resolution preferred by the end-users subdivided in two groups (working or not on streams and rivers).

More specifically, it was reported that the needed temporal resolution depends on processes that change:

1. **Within hours** such as algal blooms, flood events with associated influxes of high nutrient, high colored dissolved organic matter and suspended sediment loads into reservoirs, estuaries or coastal seas or with tidal or wind driven events.
2. Within days such as pollution events, dredging effects
3. Within weeks such as coral bleaching events, and finally
4. seasonally to yearly to longer term such as successions of phytoplankton functional types or emergence, florescence and decay of macrophytes.



Kd	Light Attenuation (m^{-1})	StrD	Stratification depth (m)
z90	Euphotic depth (m)	Wtemp	Water temperature (°C)
Turb	Turbidity (NTU)	Waves	Surface roughness (waves)
TSM	Total suspended matter (g/m^3)	pH	pH
CDOM	Colored Dissolved Organic Matter (m^{-1})	N	N (Total, NH4, NO3) (mg/L)
Chla	Chlorophyll-a concentration (mg/m^3)	P	P (Total, PO4) (mg/L)
PFT	Phytoplankton functional types	Si	Si (mg/L)
PB	Phytoplankton bloom occurrence	O2	O2 (mg/L)
PP	Phytoplankton primary production	AB	Algal biomass (mg/m3)
MC	Macrophyte cover	SPIM	Particulate Inorganic Matter (g/m^3)
MB	Macrophyte biomass (mg/m^3)	TIC	Total Inorganic Carbon (mg/L)
ChlaF	Sun induced Chlorophyll-a fluorescence	DOC	DOC (mg/L)

Figure 15: Scatter plots showing the preferences about the temporal frequencies for each single EO and biogeochemical modeling derived parameter. End-users are divided in working or not on streams and rivers (first row).

It was highlighted that, despite the differences that can be summarized at global level, it is interesting to notice that for those parameters describing macrophytes (cover and biomass) all end-users agree in selecting the monthly temporal frequency as the best solution. This preference is obviously imposed by the seasonality that characterizes the growing and development of green vegetation. By aggregating the temporal requirements (Figure 14), stakeholders dealing with streams require lower temporal resolutions (monthly) than stakeholders dealing with other waterbodies (weekly).

4.1.3 Radiometric and spectral requirements

In contrast to this research, in the previous projects no specific accuracy claim was specified, due to a focus on remote sensing techniques instead of ground truth observations. Instead, these projects focused on providing requirements how well remote sensing data should be radiometrically calibrated and atmospherically corrected. More than 90% of the optical signal received at a Low Earth Orbiting (LEO) satellite observing a waterbody will be the result of atmospheric interaction. In the infrared region of the spectrum, this percentage is even higher. This low amount of radiation reflected by the water body (~10%), originates because little light is reflected due to low concentration of light scattering particles (TSM) or high concentration of light absorbing matter (CDOM or NAP with high organic matter contents). Absorbing water types can have remote sensing reflectance (Rrs) maxima below 0.005 sr-1 and Rrs minima in the order of 10-4 sr-1, and 10% concentration changes of chlorophyll-a can affect Rrs as little as 10-6 sr-1 and even below, which seems impossible to resolve by current spaceborne instrument at a fine spatial resolution.

The current study has evaluated the dynamic range of radiometric values to be measured across the desired wavelength range and concluded:

- Maximum radiances over dark water bodies: 100 mW m-2 sr-1 nm-1 in the blue and 20 mW m-2 sr-1 nm-1 in the red,
- Radiometric sensitivity NeDL: in the range 0.005 mW m-2 sr-1 nm-1 (optimal) and 0.010 mW m-2 sr-1 nm-1
- Radiance range for monitoring extremely turbid waters, bleached corals, and shallow waters with bright sand: 400 mW m-2 sr-1 nm-1 in the blue and 200 mW m-2 sr-1 nm-1 in the red.

4.2 Policy driven requirements

Monitoring water quality of Dutch oceans, lakes, rivers, canals and ports is an essential step towards a sustainable management of aquatic ecosystems. For this, several traditional methods are used to provide information on the water quality. These methods can be divided into two segments:

- Chemical information is used for: reporting to governmental agencies and politics, monitoring water quality standards, rating of chemical land ecological potential of the main water system, enforcement of Water permits, and warning of drinking water companies and agricultural practices.
- Ecological information is used for reviewing water quality standards, exploration, for management of nature and water quality legislation, and drafting policies.

In order to enable governance of these water bodies, several policies have been specifically developed providing requirements for these segments, namely: the Kaderrichtlijn Water (KRW) en de Kaderrichtlijn Marien (KRM), de zwemwaterrichtlijn. For more information, we have highlighted these in Appendix E. In general, the policies report similar spatial and spectral resolutions for the measurement, as the minimum acceptable requirements. This is in principle understandable, as these user requirements should be fully in line with Dutch and European legislation. This also provides a better understanding why the 'acceptable' resolutions and 'target resolution' vary between themselves with 1 and 2 order differences. This also provides possibly a reason, why the requirements found in this report have not increased over the last couple of years in respect to the requirements found in the literature analysis and previous user consultations.

5 Potential for remote sensing for these requirements

In order to investigate whether remote sensing is capable of achieving these requirements, we analyzed these against the specifications of different (currently operational and planned) remote sensing instruments. Furthermore we have performed a preliminary feasibility analysis using machine learning techniques to investigate the possibility of estimating some parameters irrespective of the applied algorithm.

5.1 Adherence of Remote sensing platforms to current requirements

As highlighted, stakeholders reported (both at national and international level) different spatial resolutions as acceptable and required. While currently all parameters are measured at the submeter level (due to local sampling), stakeholders do except lower resolutions for some parameters. Specifically, for **CDOM, Chlorophyll-a, Color, DOC, Phycocyanin, Secchi Depth, TSM and Turbidity,** the stakeholders highlight that spatial resolutions would be useful from **10-100 meters.** Only for pH, Salinity and Temperature do the requirements remain at the <1m resolution.

Similar to the spatial requirements, stakeholders reported (both at national and international level) different temporal resolutions as acceptable and required. While currently parameters (**CDOM, Chlorophyll-a, Color, DOC, Phycocyanin, PH, Secchi Depth, Salinity Temperature, TSM and Turbidity**) are measured at a weekly interval, and **Chlorophyll-a and Phycocyanin** at **daily resolution**, stakeholders do except lower temporal resolutions for some parameters. Specifically, for **CDOM, Color, DOC, Phycocyanin, Secchi Depth**, the requirements lower to a **monthly resolution**. In addition to this, the temporal extent of the data is required (for all variables) to have a length of at least 1-12 months.

In principle these requirements then could be addressed using the Sentinel-2 constellation of satellites, that provide ~20m resolution at weekly intervals (for the Netherlands). In addition to these spatio-temporal resolutions, the specific spectral and radiometric requirements are set for these observations to be useful for retrieving the water quality variables. While it was not the focus of this research to investigate these radiometric and spectral requirements, previous projects report the necessity of multispectral (~26 bands) observations between 380nm and 730nm, or even better hyperspectral measurement of the same region with 5-8 nm spectral resolution. For this purpose we performed a feasibility analysis on locally measured hyperspectral acquisitions. Within the analysis, the sensitivity of Sentinel-2 to these water quality analysis was then analysed by degrading the hyperspectral information to the Sentinel-2 observations.

5.2 Sentinel-2 Feasibility study results

As specified, we performed a small feasibility study (see Appendix H) to understand whether particular variables can be retrieved from 'hyperspectral' remote sensing observations. This study provided insights of which spectral bands better can predict the presence/quantity of each water quality parameter and enable an understanding of the potential application of satellite remote sensing using high-end hyperspectral sensors.

5.2.1 Water quality acquisitions

Water samples have been collected over the Markermeer and Afgedamde Maas at the same time as the spectral reflectance is measured with a RS-3500 spectrometer. From the water samples, the following chemical and physical parameters could be retrieved on site, or in the lab. Below is given an overview of which variables were considered:

Table 3: Measured Water quality variables

	Variable	Units
Chemical	Chlorophyll[2]	µg/L
	Dissolved Oxygen[1]	mg/L
	Conductivity[1]	µS/cm
	pH[1]	-
	Phosphates[5]	mg/L
	Nitrates[5]	mg/L
Physical	Turbidity[2]	NTU
	Water colour[6]	Forel-Ule scale
	Water Temperature[1]	ºC

5.2.2 Analysis approach

There are a host of algorithms and models that can estimate water quality parameters from hyperspectral observations. Within this feasibility study, however, the objective was not on validating these algorithms, but instead provide a general understanding whether particular variables leave a signal in the remote sensing observation large enough for retrieval purposes. For this reason, we have chosen to use machine learning concepts to create a simple artificial intelligence model (trained on some of the data), and apply this model on an independent set of observations for testing. In particular then, machine learning methods such as Random Forest or Support Vector Machines will be trained and tested using the spectral data as covariates and the various water parameters as the dependent variables.

5.2.3 Results

The first results focused on whether there is actually a cross-dependency between the different variables. This is to 1) determine whether an empirical relationship between these exist that can potentially be used for one variable as a proxy of another variable and 2) that the neural networks are not overtrained. An overview of these correlations can be seen below.

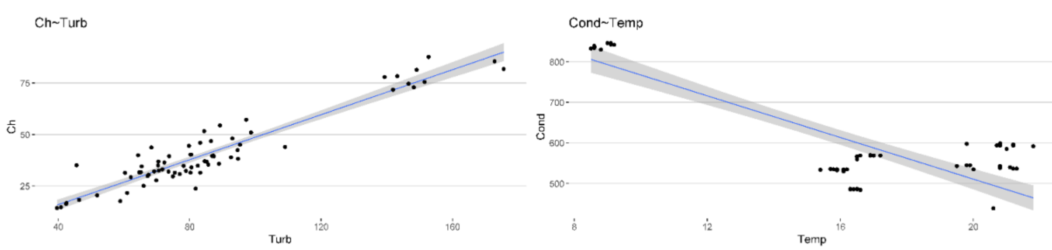
Some high correlations between parameters were found: Dissolved oxygen is highly correlated with pH and Temperature; Conductivity was found to be correlated with Temperature and Chlorophyll-a was found to be correlated with Turbidity. Some cases are expected, for example, chlorophyll-a and turbidity are often found to be correlated in research. Still, in some cases these R^2 appear to be inflated if we take look at the X, Y plot of the graphic. It’s possible that with more field data, the observed R^2 would become more meaningful.

Table 4: cross correlations between individual measured water quality parameters

	R^2	p-val	Intercept	p-val	slope	p-val
DO~Cond	0,505	***	5,786	***	0,005	***
DO~Ph	0,811	***	-34,149	***	5,318	***
DO~Temp	0,776	***	12,149	***	-0,198	***

DO~Ch	0,455	***	7,501	***	0,039	***
DO~Turb	0,475	***	7,129	***	0,023	***
Cond~Ph	0,253	***	-2637,379	***	401,586	***
Cond~Temp	0,714	***	1024,102	***	-25,658	***
Cond~Ch	0,235	***	473,489	***	3,764	***
Cond~Turb	0,310	***	413,785	***	2,495	***
Ph~Temp	0,420	***	8,512	***	-0,025	***
Ph~Ch	0,436	***	7,867	***	0,006	***
Ph~Turb	0,370	***	7,837	***	0,003	***
Temp~Ch	0,263	***	20,822	***	-0,131	***
Temp~Turb	0,357	***	23,014	***	-0,088	***
Ch~Turb	0,892	***	-5,819	**	0,546	***

(*** means p-val ≤ 0.0001)



By looking at both these example graphs we can see how R^2 can be misleading. While on the left side it is clearly visible that there is a relationship between Chlorophyll-a and Turbidity, on the right side, the reported R^2 of 0.7 can be misleading. Still, potentially collecting more field data could result in more confidence in the reported R^2.

After this initial investigation, we investigated whether there exists a correlation between the hyperspectral observations with any of the field measurements. In particular we were interested to see whether any spectral band has higher sensitivities than others. In principle then this is a simple evaluation of the variation of the R^2 value between each spectral band and the measured value.

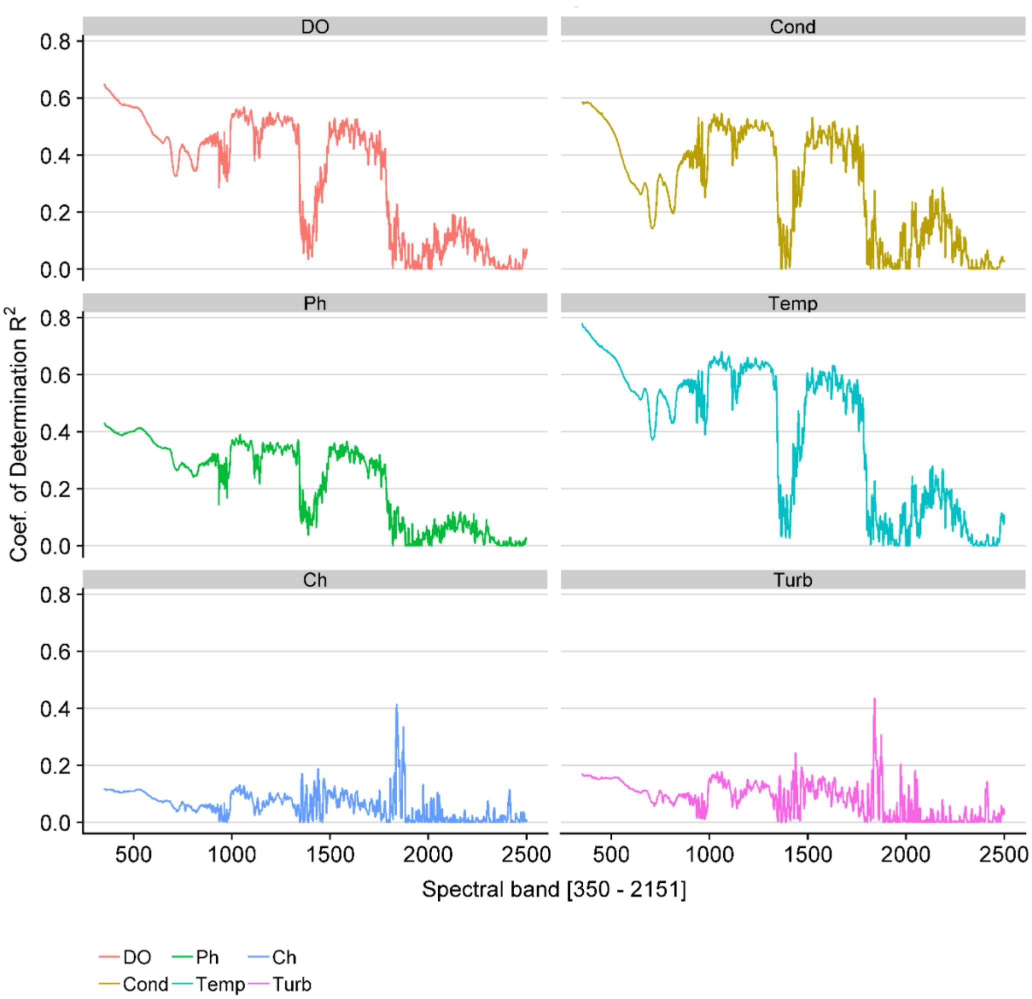


Figure 16: Spectral correlation of different water quality parameters per band

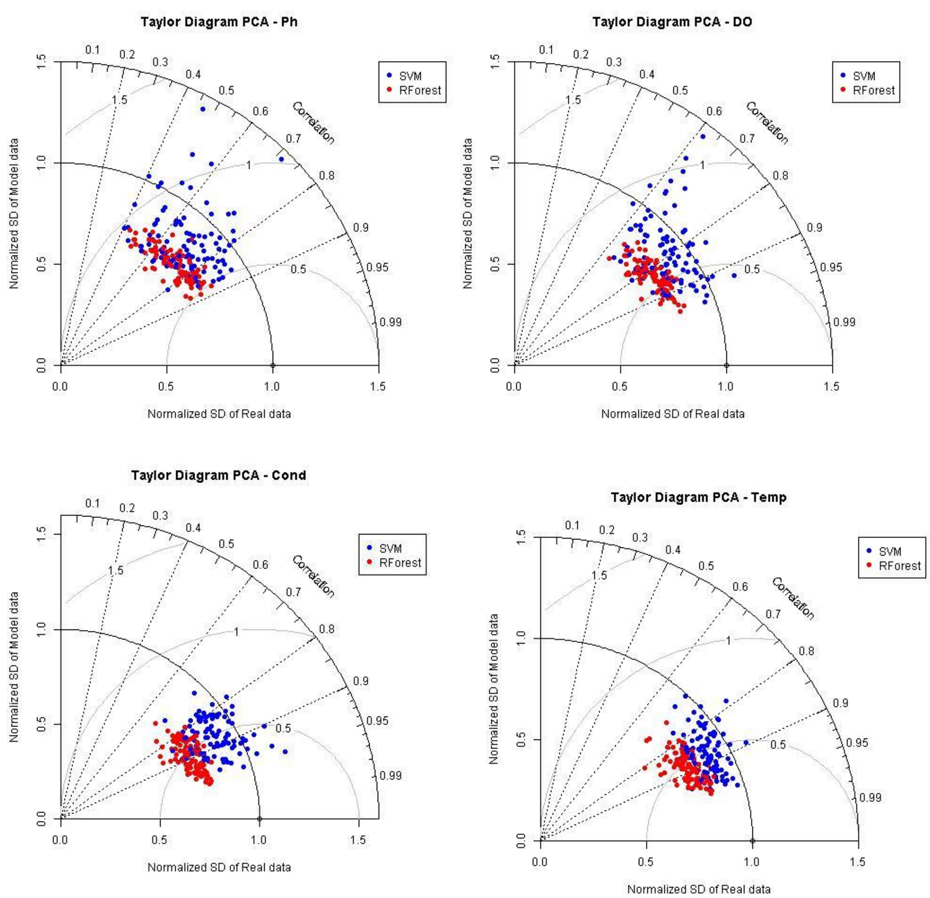
These results show that there is no specific band with very high possibility of predicting any of the field data parameters. Only for temperature, the bands with lowest wavelength seem to be very correlated with temperature. This is of course understandable, as thermal radiation is emitted in the range of 2500 to 12000 nm). On the other hand, there is significant evidence of correlated response between the spectral responses for the different parameters as these seem to follow similar patterns. It is important to consider that the Chlorophyll-a and Turbidity were obtained using the AquaFluor while Dissolved Oxygen, Condudctivity, pH and Temperature were all obtained using the Hach meter.

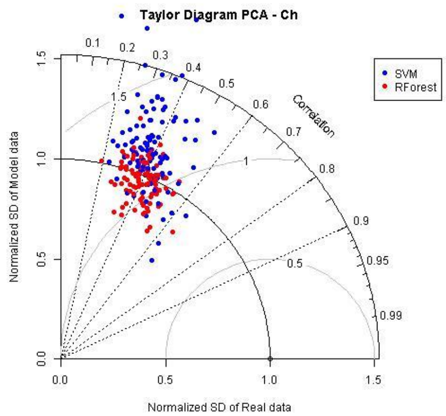
There are clear patterns that carry over from the measuring device but the value of R^2 is quite different for most cases. These exploratory results imply that any further algorithm to be applied to the spectral bands should address this autocorrelation between the signals. One option is to reduce the spectral responses to their most significant components of variation using a PCA technique.

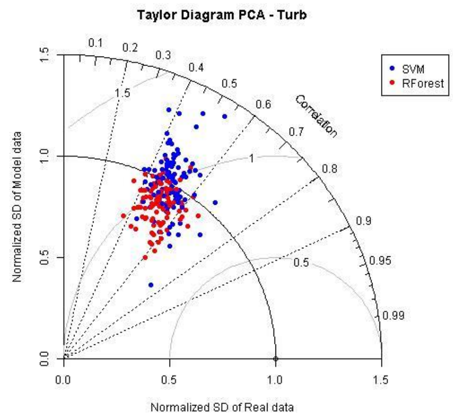
Finally we performed the machine learning to create two AI models, Support Vector Machines (SVM) and Random Forest (RF). Due to the overall low number of samples we evaluated the accuracy by repeating each model 100 times. For each run, 60% of the data was randomly sampled for training and 40% left for validation. We then accessed the average of the correlation coefficient, sum of squared errors and mean squared error between the real data and the predicted data for each model run. Another alternative to look into the model output is to see the variation of each iteration. For that, the Taylor Diagrams are shown below.

These diagrams show the dispersion of the R^2 for 100 iterations and give an insight into how much impact each sample run can have on the final model. An ideal model would have a R^2 of 1 and a coinciding SD between the Real and predicted data. Although some of the models performed better, none was perfect.

Finally we converted the measured hyperspectral measurements to their Sentinel-2 equivalent bands and performed the analysis again. The table below shows the average result of 100 independent runs of the SVM and RF for this dataset.







Here we find good correlation values between the measurements and the AI predictions. However, it should be noted that while R^2 gives an indication of the agreement between the model and the real data, it does not give a good indication of how close they are between them**. In that sense, the machine learning approach does provide an indication that there is a definitive signal in the simulated Sentinel-2 bands observations to the different water quality parameters**, but that due to uncertainties in the training (probably caused by the low number of observations), a bias occurs.

		R^2	Sum of squared errors	Mean squared error
Dissolved Oxygen	SVM	0,87	4,21	0,16
	RF	0,89	3,35	0,13
Conductivity	SVM	0,89	64943,00	2497,80
	RF	0,83	89872,00	3456,60
Ph	SVM	0,77	0,20	0,01
	RF	0,86	0,13	0,00
Temperature	SVM	0,93	43,57	1,68
	RF	0,90	59,62	2,29
Chlorophyll-a	SVM	0,71	2940,00	113,09
	RF	0,71	2783,00	107,04
Turbidity	SVM	0,67	9281,00	357,00
	RF	0,69	8676,00	333,70

5.3 Current usage of remote sensing data

As indicated, for particular variables, we could find a definite signal in Sentinel-2 bands, although specific uncertainty remains. This result is further strengthened by several other studies that have used Sentinel-

2 for water quality retrieval. As such it is interesting to investigate how many of the stakeholders are already investigating the potential of such observations.

Within the online survey, the participants were asked on their current use of remote sensing for water quality.

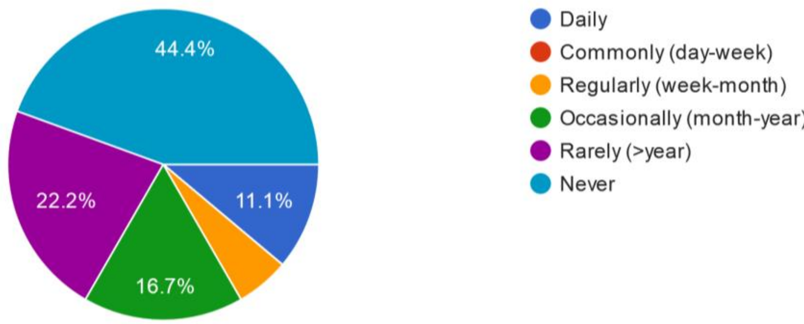


Figure 17: How often do you use remote sensing data for water quality

Of the participants that employ remote sensing in general (not specific for water quality purposes) 16.7% use it on daily basis, 5.6% on a commonly basis, 22% on an occasional basis, and 27.8% rarely. These numbers decrease when considering remote sensing of water quality, as shown in Figure 17, to respectively 11.1%, 5.6%, 16.7%, and 22,2%. As such, the percentage of people not using remote sensing for water quality purposes is 44.4%. In contrast, it was found that only 16.6% of the participants was fully unaware of remote sensing applications in water quality, and 11.1% only mildly aware. As such, there is a huge potential within the participants on increasing the remote sensing use.

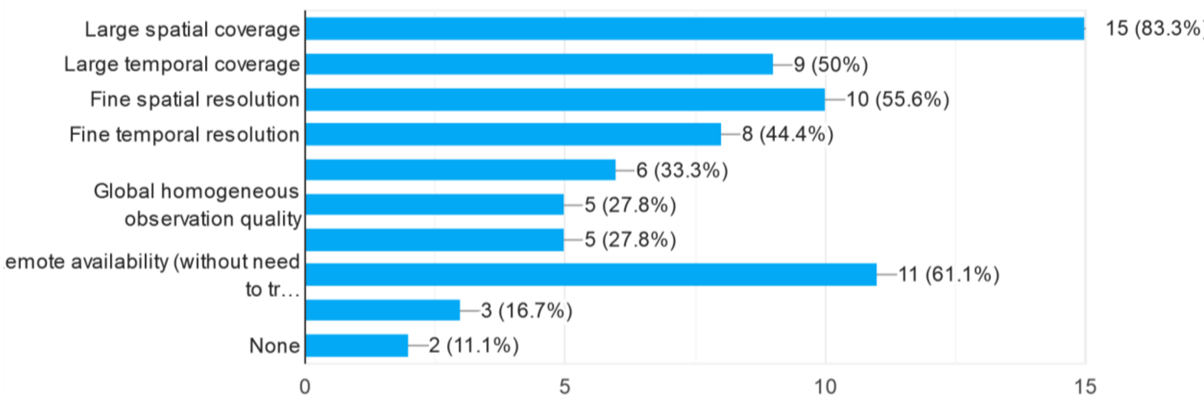


Figure 18: What are the benefits of remote sensing data for water quality.

This was further observed, when the participants specified their viewpoints on the advantages of using remote sensing for water quality, see Figure 18. Here, the participants agreed on "spatial coverage" (83.3%) with fine resolutions (55.6%), online measurements (61.1%) and large temporal coverage (50%). All other advantages showed lower agreement that 50%, such as remote sensing having a 'fine temporal resolution' (44.4%). This most probably originates from the fact that the need for high resolution was in the past only available for particular satellites with low temporal coverage. Although Sentinel-2 does provide high temporal and spatial coverage, this satellite has only been launched recently, and consequently not all people have gained experience with this data.

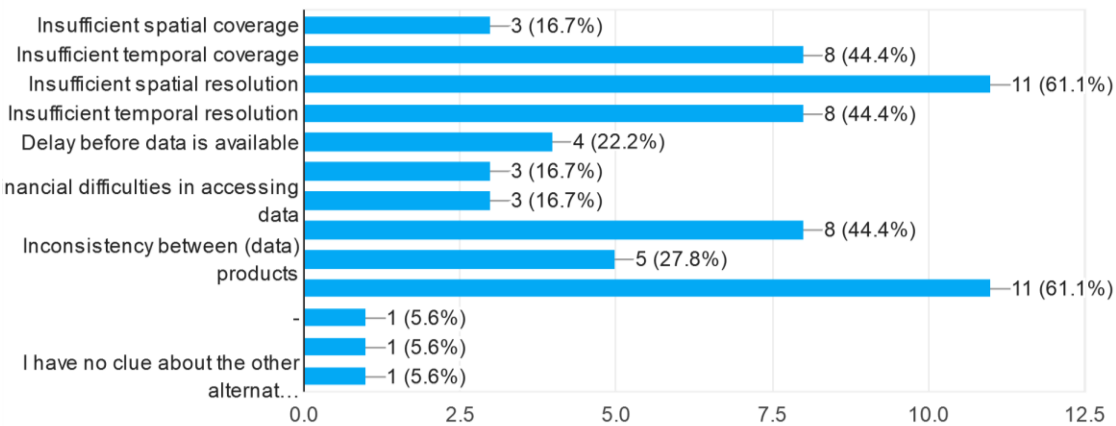


Figure 19: Which problems are currently facing remote sensing data for water quality

This is further exemplified in the disadvantages of remote sensing viewed by the participants, see Figure 19. Where insufficient spatial resolution (61.1%), together with insufficient temporal coverage (44.4%) and temporal resolution (44.4%) are highlighted.

Secondary requirements

6. Secondary requirements constraining adapting of remote sensing
6.1 Approaching secondary requirements
6.2 Secondary User requirements

6 Secondary requirements constraining adapting of remote sensing

In 2014[3] it was specified that monitoring of the water quality is performed at the policy and user-desired levels, water quality in many places in the Netherlands do not yet meet the requirements which policies like KRW state. In terms of chemical water quality, there are concerns about crop protection agents, micro-plastics, metals and medicine residues in surface water, while for biotic water quality blue-algae blooms, duck beds and flab are still abundant.

Clean water is a core task of water management, but the commitment (of the regional water managers) to provide good water quality often lags behind to other themes, such as flood and drought risk management. The methods for determining the state and trend are standardized within the Netherlands. However, it is clear that the monitoring information is insufficient to 1) determine the cause of a problem or 2) what the effects of specific policies are on the water quality and consequently the ecology.

In this context, a lot of progress has been made (with regards to remote sensing data), by the onset of the Copernicus programme, and the launch of the Sentinel-2 satellite. As specified in the previous section, it is recognised by the stakeholders that there is a huge potential for remote sensing. The reason why there is little capitalization on this potential has been investigated with several stakeholders during detailed interviews.

6.1 Approaching secondary requirements

This particular part of the research focussed on two specific activities for the results. The first Remote Sensing in Ecology workshop (RSiE, see Appendix G) was held. Here a specific parallel discussion was organized on user requirements in ecological monitoring. Secondly, a session within the MESOCOSM workshop on water quality was planned. An analysis is given below on the cancellation. Finally, several interviews were held (see the appendices for the individual summaries of these). In total 5 dedicated interviews were performed. The total variability of users contact through these interviews and through the workshop ranged from knowledge institutes (University of Twente, Wageningen University, Leiden University , Radboud University, TU Delft, Water Boards and water organisations (NIOZ, Rijkswaterstaat), consulting companies (iH20, Arcadis, Viridian Raven, Metabolic), and water quality information services (Water Insight), and governmental entities (Provincie Noord-Holland).

6.2 Secondary User requirements

A summary of all the interviews is provided in the Appendices. In the following paragraphs, these results of the user consultation is summarized in different paragraphs, namely on:

- Sensor/algorithm development
- Service provisioning
- User capacity
- User community
- Application

6.2.1 Sensor/Algorithm Development

There exists a disconnect between end-users and information providers.

[3] Based on the "Roadmap Waterkwaliteit Helderbeeld op Troebel Water" report by the University of Twente (Salama 2014), the "Inventarisatie Kennisbehoefte Waterkwaliteit rapport van de kerngroep Waterkwaliteit van de STOWA" report by the STOWA, and "MONOCLE report on analysis of the requirements for MONOCLE sensors including projection of cost savings and stakeholder feedback" report by MONOCLE.

Water Insight has developed a new WISP-10 water quality instrument. As indicated by them, the instrument is fully developed on the basis of the knowledge of Water Insight with regard to the user requirements as known to them. However, they agree that some user requirements might not be met fully. It was highlighted by them that a more comprehensive user requirements analysis (such as performed in this project) might alleviate this problem.

Inconsistencies between in-situ observations

In general terms, the reliability of the instruments and knowledge is difficult to estimate. One reason for this can be seen in the fact that water quality data are usually not collected with a water system analysis in mind. It has been suggested that a good monitoring strategy that solves this problem can lead to cost reduction in time. In addition, more attention should be paid to a joint monitoring strategy for water (constituents) flows. While in general, the data is collected in a standardized way, this does not mean that the quality of the data is always transparent or that it is clear with what kind of data one has to deal with. Not only availability of data is important for water system analysis, but also insight into the extent to which the data are suitable for the purpose is important.

End-users do not often purchase remote sensing instruments. Furthermore, most institutes are limited financially when ordering new instruments. As such, this leads to less uptake of in-situ measurements over different water quality stakeholders. As such there is a large variability in operational sensors. Each of these sensors (within their processing chain) relies on specific assumptions. However, compatibility between these assumptions is not guaranteed. Different in-situ measurements therefore might provide inconsistent results.

Shortcomings of current validation campaigns

Each remote sensing observation needs to be validated. Current validation campaigns (due to a limited number of sensors) focus on comparing remote sensing observations with traditional singular point measurements. Furthermore, these measurements are not collocated in time. Instead in-situ measurements are not performed during the overpass of the satellite. Not only does this create extra uncertainties in the comparison, this approach also fails to validate the ‘unique selling point’ of remote sensing, namely the gridded data.

Attribution of errors in validation of remote sensing information

Considering the inconsistencies in the in-situ measurements, and the shortcomings of validation campaigns, it is not clear what actual truth is. This limitation is further enhanced as there are multiple remote sensing models that each provide different results. While each of these algorithms is specifically made (on empirical basis) for particular applications, this is often not taken into account. As such, at present uncertainties found these validation activities are only assigned to remote sensing information, without taking into account the uncertainty of the in-situ measurements, and the representativeness of remote sensing data/algorithm. In principle such issues can be circumvented if the uncertainty of the different instruments is well known, and inter-calibration exercises are organized regularly.

Intercalibration of Operational services

At this moment, no merging takes place between in-situ measurements and remote sensing. While remote sensing might provide good data, uncertainties will always be present in the observation (due to lacking atmospheric correction, and a low representiveness of the observation). Within proper validation activities, this has been highlighted. At no point, however, is there research ongoing to merge in-situ data with remote sensing observations, to get the best of both worlds: good absolute data and well spatially mapped.

Focusing on user criteria

End-users show little interest in raw remote sensing data. Instead they are interested in final information products. Due to the operational nature of their missions, there is little time available to spend on investigating different water quality information parameters than they are currently using. Furthermore, the variability of the data formats used (in terms of file formats, data projection and data structure) provides an extra threshold to integrate remote sensing in their operational chain. As such this particular project is of vital importance to show the potential of remote sensing applications.

6.2.2 Remote sensing services

Traditional methodologies cannot handle remote sensing data.

Traditional methodologies and Existing frameworks are focused towards point measurements. Gridded remote sensing water quality maps can therefore not be used in an operational approach. Advancing these frameworks requires detailed knowledge, not only on water quality dynamics, but also remote sensing techniques.

Relatively low capacity in end-users

There is a large understanding within the end-users of the potential of remote sensing. However, there is a general lack of knowledge on the methodology to extract this information. End-users do not show an interest in developing this capacity and are only interested in final (information) products.

Cost Effective monitoring

Professional users (e.g. researchers and monitoring agencies) will pay particular attention to sensor performance in terms of measurement accuracy. While sensor cost versus functionality will in most cases ultimately determine the choice of sensor, the price bracket for sensors in this category is one or two orders of magnitude higher than for other users. The same principle generally applies to operational (deployment and maintenance) cost. On the other end of the user spectrum are individuals and organizations seeking to maximize spatial cover at the lowest sensor acquisition, deployment and maintenance cost.

6.2.3 User capacity

Too little known what remote sensing does

There is an uncertainty within institutes regarding remote sensing, caused by few people within the organization who at present have experience in using remote sensing for water quality measurements. This uncertainty leads to erroneous opinions being formed, such as, for example, that drone monitoring of dikes would lead to a reduction of dike -monitoring- jobs. As such, no critical mass has been established to convince the executive board to invest in remote sensing. Furthermore, this mass might shrink even further, as a high percentage of current remote sensing users might retire in the next 10 years.

There is a strong need in increasing the capacity of water managers on remote sensing applications. However, only three research institutes in the Netherlands provide scientific research on remote sensing of water quality. In addition, from these institutes only the University Twente provides accredited academic courses on the subject matter of hydrologic optics.

In general most stakeholders have a low experience in remote sensing

Part of the uncertainty originates from lack of experience with remote sensing. In specific organisations (such as Dunea and RIVM) the advantage of remote sensing had already been proven (in the case of air quality). This success showed the advantages of remote sensing, but also showed the limitations (and the need for experts on the ground). As such, within these institutes there is a high push towards remote sensing to advance their monitoring capabilities. In institutes where such initial researches have not been performed yet, the user uncertainty is much higher.

Uptake of remote sensing should be pushed within the organizational structure

Only within the institutes where remote sensing is actively pushed, and time resources are allocated, have satellite observations been implemented. This push can in part be attributed to the success of remote sensing in previous (other) researches. However, in many cases (of Dunea and RIVM), there is a policy driving the need for remote sensing monitoring.

There exist a large variety in the used language of different stakeholders

Another part of the uncertainty originates from the difference in the used language between different end-users. This originates from the background of the different stakeholders. While sensor/algorithm developers use very technical language (such as radiative transfer modelling, adjacency effects, absorption lines..) this is in contrast to water institutes, that focus on applicability. Due to this difference in language, such services are not sold in a convincing manner.

There is a lack of transparency concerning the services

Most remote sensing services are given without proper documentation concerning the validation exercises and the limitations of the product. This is caused by the remote sensing information provisioning companies feeling the need to adhere (and sell) to the high expectations of the end-user.

Metadata information is not provided

Detailed information must be reported on how the data has been collected (in terms of location, frequency, parameter, processing method). At present, however, this is not performed in a satisfactory manner, in particular for availability and disclosure of such data. More specifically, for carrying out water system research this metadata information, including the preparation of water and substance balances, is often inadequate.

6.2.4 User Community

Variability of applications

Water quality is a very broad field. The field of water quality is extensive, spanning from global ocean water bodies, to small ditches. Within each of these water bodies there exist a large variety of primary processes. Water quality research can therefore not be seen as a well-connected community, but instead should be seen as more independent groups of smaller communities each focusing on individual water body.

There was a volunteer initiative called “Light and Water” that has faded away. A small financial support of such an initiative would have kept it running. The community should foster the efforts in promoting earth observation application to water quality through public meetings and joint courses. The community should also work together to promote the Netherlands to host one of the most important conferences in the subject area: Ocean Optics. But researchers of the Dutch community must also compete with each other. The funding for application of remote sensing of water quality is limited in scope.

Diversity of knowledge providers

As such, there is a wide variety of algorithms in existence each focused towards individual parameters. This large variety of applications leads to a large variety of knowledge providers. These knowledge providers do not necessarily communicate with each other. Naturally, within each subfield (focused on individual waterbodies), there are very strong connections. This is, however, not true for institutes working on separate water bodies. For an outsider (such as a Water Board) this then leads to an image of a sparsely distributed 'water quality' community. This creates an additional threshold for end-users to start working on remote sensing water quality.

Tension within water stakeholders

There is a tension within the water quality community regarding the application of information monitoring for applying policies. From the ecologist's point of view, it is clear that ditch water quality is most affected by agriculture. In this sense, these stakeholders do not feel the need for improved monitoring capabilities. Instead, they demand action to be taken, on the use of pesticides on agricultural crops and soil subsidence, by Water Boards. However, this is not a task for the Water Boards, but instead for the Ministry of Agriculture, Nature and Food Quality. Their primary objective is to ensure good prospects for the Dutch farming, horticulture and fishing sectors, not towards increasing the water quality of these ditches. As a result of the split in responsibility, progress in monitoring has not been meaningful in the last decades. So although there are a lot of problems in our common freshwater field that justify much better monitoring, the immediate need is lacking as a result of situation described above.

6.2.5 Application.

Most of the participants are only interested in end-products. Any constraint in data provisioning and tool development there restricts uptake of remote sensing in water quality. For example, stakeholders reported that remote sensing should increase the consistency between different data products (61.1%) as well as improving the data availability (44.4%).This originates from a general dissatisfaction with currently available data and tools.

Data provisioning

The majority of participants indicated a high interest in final products, such as Level 5 products (68.8%) and Level 4 products (62.5%), This stands in contrast to the lower percentage (56.3%) of participants interested in lower product levels (L1, L2 polarimetric and L3). While the majority of participants originated from university affiliations, it can be concluded that most are not interested in algorithm development, but actually in studying the interaction between ecology and water quality.

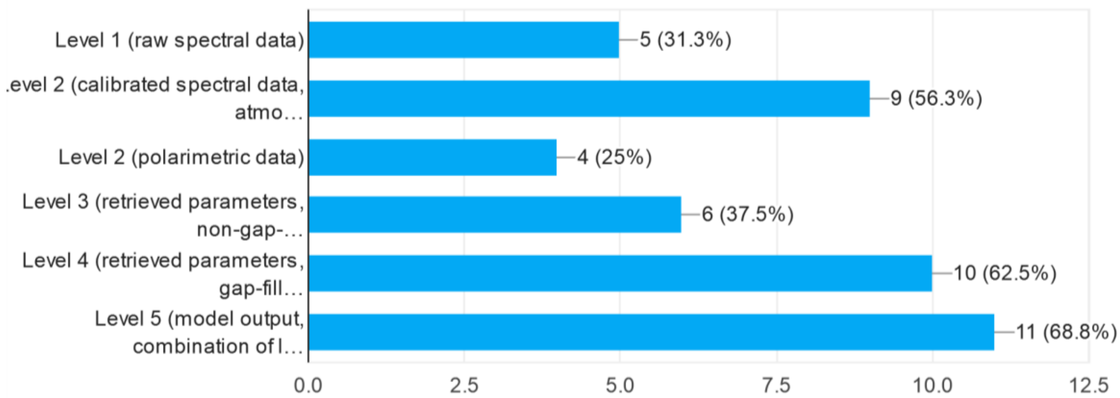


Figure 20: Which type of data products would you be interested in?

Tool development

In comparison with water quantity research, it appears that the hydrologists are the most (> 60%) satisfied with their models and tools (Figure 21), followed by water quality employees (~ 55%) and with the ecologists least satisfied (<40 %).

That the hydrologists are most satisfied with their instruments is probably the result of years of development, which did not go without discussion. In contrast, models for water quality and ecology are still relatively new, unknown or not yet fully developed.

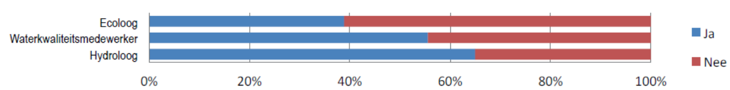


Figure 21: Stakeholder satisfaction on Remote sensing Tools

Discussion and Conclusions

7. Limitations on analysis

8. Conclusions

7 Limitations on analysis

Within this research, we have applied a metadata analysis of published literature, as well as a user consultation with different stakeholders. Each of these approaches provide limitations that could potentially bias the results. Therefore we highlight these in the following paragraphs.

7.1 User consultation

Within the research we have tried to be as open as possible with regard to the selection of stakeholders, as well as the choice for the different participants in the online survey and the interviews. However, as indicated due to the background of the CML institute that executed this research, there might be a bias in the results towards more ecological applications. Considering that both water quality researcher and hydrologists indicate a higher satisfaction with regard to the (remote sensing) data and tools, we believe that this bias is actually meaningful in representing an otherwise overlooked part of the Dutch water quality sector.

7.2 Metadata Analysis

As indicated, we have applied a metadata analysis based on web-of-knowledge published literature. There are, however, limitations to a the web-of-knowledge analysis.

- First, the results are dependent on the terms being used, particularly if a low number of results are found. In a specific research field the nomenclature can vary, leading to mixed results. Only when the majority of the field uses the same terminology (leading to large enough results), can analysis be performed. Considering the large amount of manuscripts found (>70K), there is limited effect of this for the 'water quality' query. In contrast, when searching for the combination of 'water quality' and 'earth observation' only 169 results were found. This number increased when considering also the synonymous terms of 'remote sensing' and 'satellite'.
- Secondly, the analysis only focusses on published results, such as peer-reviewed articles proceedings papers and book (chapters), see Figure 22. This analysis therefore omits technical reports, governmental documents, patents, or unpublished works in general. As such, a significant part of information is missing from the analysis.

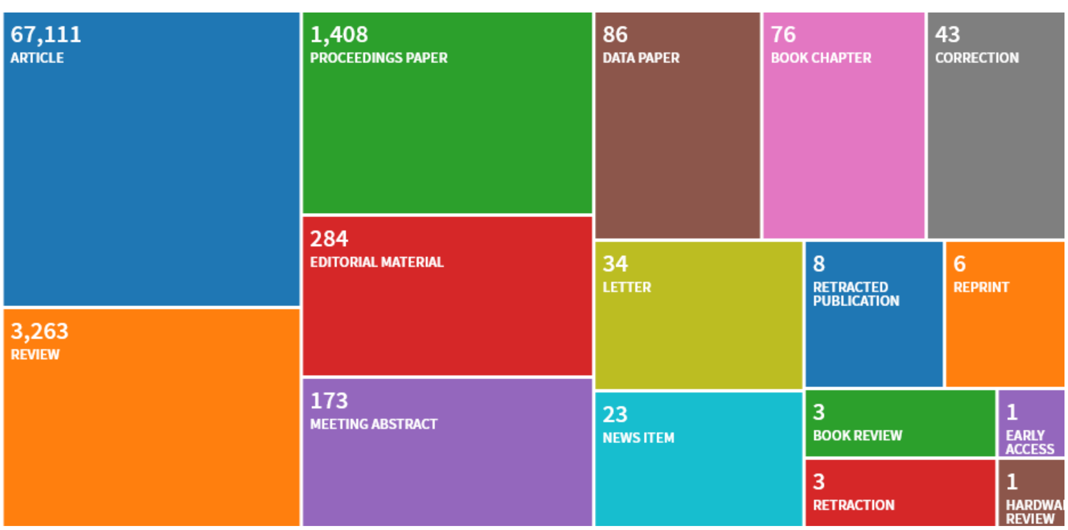


Figure 22: Water quality publication types

As such, the qualitative results of this metadata analysis can only be considered indicative. However, considering the large number of manuscripts found, these qualitative findings still have merit.

In addition to this limitation, most research on water quality has been performed on large waterbodies and oceans. This is because (prior to Sentinel-2), no remote sensing sensor with the appropriate spectral bands was available at high resolution. In that perspective, retrieving accurate information on spatial characterization is very labour intensive. This has had a direct impact on the literature review presented here, as few studies have been performed on feasibilities towards other water bodies [16]. In fact, for coastal and inland waters, processes such as nearshore tidal currents, resuspension events, and point source delivery of nutrients, suspended sediments and CDOM, as well as highly dynamic surface algal bloom events can create variability on much smaller spatial scales than for most open ocean waters for well mixed conditions. This is further exemplified by some cyanobacteria that are able to regulate their buoyancy, that require spatial resolution higher than 30 m [16].

Furthermore, spatial variability in many cases was only reported in consideration to particular remote sensing instruments. The alternative to this approach would be to use a detailed landcover map to characterize the water bodies. For inland (optically dense) waterbodies, it was shown [2] that, using the CORINE2006 land cover map, nearly all freshwater systems in Europe can be suitably monitored using resolutions from 300m. In contrast, for Australia, this threshold is set to 30-60m, taken into account that this country has a much rougher geomorphology. However, CORINE itself only has a 30m resolution. As such, the landcover map does not include ditches or small rivers. As such, the resolutions found in the literature are biased towards waterbodies that show up in the CORINE landcover map.

The final limitation to this literature review stems from the fact that, due to the spatial resolution limitations and consequently focus on larger lakes, it is also biased towards optically deep waters. As such, only few research focusses on optically shallow water bodies. Furthermore, due to bottom properties (bottom substrate and depth) often varying independently from water column properties, algorithms developed for optically deep waters are not applicable for such environments [16].

8 Conclusions

Water quality research and applications demand high requirements on the monitoring activities. Within our research we found that (both at national and international scale) different spatial and temporal resolutions are provided to indicate what is acceptable and required. Concerning the spatial resolution, the target of our stakeholders indicate a <1m resolution for all parameters due to their current operational method of local sampling. However, with respect to remote sensing, for **CDOM, Chlorophyll-a, Colour, DOC, Phycocyanin, Secchi Depth, TSM and Turbidity,** the stakeholders highlight that spatial resolutions would be useful from **10-100 meters.** Only for pH, Salinity and Temperature do the requirements remain at the <1m resolution.

Similar to the spatial requirements, stakeholders reported (both at national and international level) different temporal resolutions as acceptable and required. While currently parameters (**CDOM, Chlorophyll-a, Colour, DOC, Phycocyanin, PH, Secchi Depth, Salinity, Temperature, TSM and Turbidity**) are measured at a weekly interval, and **Chlorophyll-a and Phycocyanin** at **daily resolution,** stakeholders do except lower temporal resolutions for some parameters. Specifically, for **CDOM, Colour, DOC, Phycocyanin, Secchi Depth**, the frequency requirements lower to a **monthly resolution**. In addition to this, the temporal extent of the data is required (for all variables) to have a length of at least 1-12 months.

While in principle these requirements could be addressed using the Sentinel-2 constellation of satellites, we also discovered a very low uptake of remote sensing observations, namely around 16,7%. Naturally some delay in uptake can be assumed as Sentinel-2 has only become operational since 23 June 2015 which causes a delay in the development of appropriate algorithms/services for this. However, we found that the low uptake is also caused by several additional secondary requirements, concerning 1) Sensor/algorithm development, 2) Service provisioning, 3) User capacity, 4) User community, and 4) constraints in the applications. These therefore need to be addressed as well in order to have better uptake of remote sensing in water quality research.

9 References

1. Gholizadeh, M.H., A.M. Melesse, and L. Reddi. *A Comprehensive Review on Water Quality Parameters Estimation Using Remote Sensing Techniques*. in *Sensors*. 2016.
2. Hestir, E.L., et al., *Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission.* Remote Sensing of Environment, 2015. **167**: p. 181-195.
3. *A current review of empirical procedures of remote sensing in inland and near-coastal transitional waters AU - Matthews, Mark William.* International Journal of Remote Sensing, 2011. **32**(21): p. 6855-6899.
4. Odermatt, D., et al., *Review of constituent retrieval in optically deep and complex waters from satellite imagery.* Remote Sensing of Environment, 2012. **118**: p. 116-126.
5. Hommersom, A., et al., *A review on substances and processes relevant for optical remote sensing of extremely turbid marine areas, with a focus on the Wadden Sea.* Helgoland Marine Research, 2010. **64**(2): p. 75-92.
6. Song, K., et al., *A systematic examination of the relationship between CDOM and DOC for various inland waters across China.* Hydrol. Earth Syst. Sci. Discuss., 2016. **2016**: p. 1-35.
7. Tavakoly Sany, S.B., et al., *A review of strategies to monitor water and sediment quality for a sustainability assessment of marine environment.* Environmental Science and Pollution Research, 2014. **21**(2): p. 813-833.
8. Palmer, S.C.J., T. Kutser, and P.D. Hunter, *Remote sensing of inland waters: Challenges, progress and future directions.* Remote Sensing of Environment, 2015. **157**: p. 1-8.
9. Krug, L.A., et al., *Ocean surface partitioning strategies using ocean colour remote Sensing: A review.* Progress in Oceanography, 2017. **155**: p. 41-53.
10. Blondeau-Patissier, D., et al., *A review of ocean color remote sensing methods and statistical techniques for the detection, mapping and analysis of phytoplankton blooms in coastal and open oceans.* Progress in Oceanography, 2014. **123**: p. 123-144.
11. Jackson, F.L., et al., *A spatio-temporal statistical model of maximum daily river temperatures to inform the management of Scotland's Atlantic salmon rivers under climate change.* Science of The Total Environment, 2018. **612**: p. 1543-1558.
12. Werdell, P.J., et al., *An overview of approaches and challenges for retrieving marine inherent optical properties from ocean color remote sensing.* Progress in oceanography, 2018. **160**: p. 186-212.
13. Salama, M.S., *Roadmap: Water Quality*. 2014, University of Twente: Enschede.
14. Van Der Zande, D., et al., *INFORM REPORT ON RECOMMENDATIONS FOR INLAND WATER QUALITY MONITORING FOR FUTURE SATELLITE MISSIONS*. 2016.
15. Yu, Y., et al., *Advancement and Challenges of Micro-plastic Pollution in the Aquatic Environment: a Review.* Water, Air, & Soil Pollution, 2018. **229**(5): p. 140.
16. Mouw, C.B., et al., *Aquatic color radiometry remote sensing of coastal and inland waters: Challenges and recommendations for future satellite missions.* Remote Sensing of Environment, 2015. **160**: p. 15-30.

Appendices

10 Appendix A: Initiatives taken into account for global framing

10.1 CEOS

CEOS was established in September, 1984 in response to a recommendation from a Panel of Experts on Remote Sensing from Space and set up under the aegis of the G7 Economic Summit of Industrial Nations Working Group on Growth, Technology, and Employment. This Panel recognized the multidisciplinary nature of space-based Earth observations and the value of coordinating international Earth observation efforts to benefit society.

Accordingly, the original function of CEOS was to coordinate and harmonize Earth observations to make it easier for the user community to access and use data. CEOS initially focused on interoperability, common data formats, the inter-calibration of instruments, and common validation and inter-comparison of products

10.2 INFORM

The 4-years EU FP7-SPACE INFORM project started on 1 January 2014 with the goal to develop novel and improved user-driven products for inland water quality monitoring. The INFORM project focused on the development of algorithms for new innovative products such as stratification, yellow matter and phytoplankton functional types. To achieve proper embedding in the community, the INFORM project strongly interacted with its end users and was able to 1) create awareness on the different products and 2) awareness on their applicability for inland water monitoring.

10.3 STOWA-water quality committee

In 2014 a committee on water quality was formed by the STOWA. This committee works on the development of new methods and instruments dedicated to questions relating to water quality. Starting in the year 2000, when the KRW was started up, a lot has been achieved. Water quality has been improved and several measures have been taken to further improve this. In particular, excess use of fertilizers and pesticides has been significantly been reduced, causing less demand on water filtration systems. In addition, several actions are taken to improve the water system infrastructure towards a more sustainable environment for plants and animals.

10.4 University of Twente, Faculty of ITC

In support of the Netherlands policy in development cooperation, the Water Cycle and Climate department at the Faculty of GeoInformation Sciences and Earth Observation (ITC) of the University of Twente, is actively engaged in research and education in applications of earth observation technologies to monitor water availability and food security in terms of water quantity and quality, and water disasters in terms of floods, droughts and water pollutions, particularly in developing countries where an in-situ monitoring network is often missing.

10.5 Water Insight

Water Insight was founded in 2005 by Steef Peters and Marnix Laanen, to bridge the gap between satellite monitoring and in-situ sampling. As such their mission is

- To provide water quality information products and services based on their in-house developed sensors and satellite data processing
- Participate in European projects to benchmark the quality of their services
- The advocate the use of remote sensing techniques for water management.

For this, Water Insight has developed its own "close sensing" portable water quality spectrometer (the WISP-3), that is being widely used for in-situ measurements (by Water Boards) in either an operational capacity or calibration/validation activities. Furthermore, Water Insight also has extensive experience in providing remote sensing information to Dutch governance. More specifically, In the period 2006 – 2012 Water Insight provided the Ministry of Infrastructure and Water Management (through its agency Rijkswaterstaat) with Harmful Algal Bloom bulletins for the Dutch part of the North Sea.

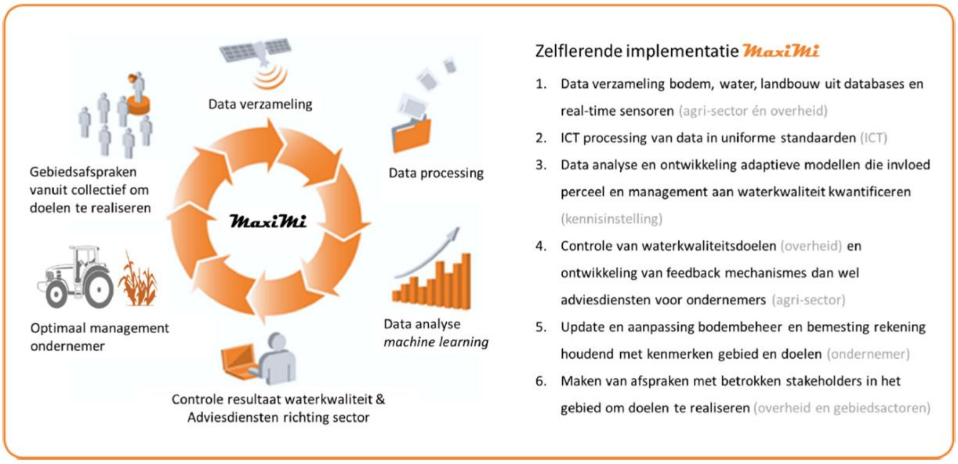
10.6 MONOCLE

MONOCLE develops essential research and technology to lower the cost of acquisition, maintenance, and regular deployment of *in-situ* sensors related to optical water quality. The MONOCLE sensor system includes handheld devices, smartphone applications, and piloted and autonomous drones, as well as automated observation systems for e.g. buoys and shipborne operation. The sensors are networked to establish interactive links between operational Earth Observation (EO) and essential environmental monitoring in inland and transitional water bodies, which are particularly vulnerable to environmental change.

10.7 MaxiMi

As indicated by results of the interviews (most notably of CML, Leiden University), there is a split in responsibility between the monitoring of water quality and the regulation of policies. As such, progress in monitoring has not been meaningful in the last decades. So although there are a lot of problems in our common freshwater that justify much better monitoring, the immediate need is lacking as a result of the situation described above. One solution to this might be focus on result effective oriented approaches, as proposed within the MaxiMi project.

Towards the end of 2017, the ministry of Economic Affairs organized a hackathon to produce smart solutions for the manure problem in the Netherlands. The winning team came up with an innovative concept that utilizes the innovative powers of entrepreneurs by means of smart, area directed management of manure and minerals. The concept is named MaxiMi, short for 'Maximal environmental performance by Minimal (government) effort'. MaxiMi has the ambition to renew the present input directed manure policy by means of a result oriented approach, in which the quality of water (both in the soil and on its surface) directs agricultural management. This means a shift from Compliance to Environmental Performance and at the same time a shift from public to private direction (control and maintenance) with possibilities for horizontal supervision by authorities. The approach uses sensors and a data based (and self-learning) machine learning system, which couples parcel properties, soil management and fertilization (read: measures) to water quality in the area. In this way, MaxiMi offers a fact based action perspective to the entrepreneur and stimulates sustainable management. Besides the data will be available for advisory services directed at effective management decisions. In this way the innovation power of the agricultural sector will be deployed to integrate agricultural enterprise objectives with water quality objectives for the area.



Figuur 3.1 *Conceptuele omschrijving van de onderdelen van het concept MaxiMi.*

11 Appendix B: Global user requirements

Based on the "Report on End-User Consultation for global water quality purposes"

Within the H2020 INFORM project, a user consultation on water quality was organized. For this, an online questionnaire was created to investigate the main end-user requirements about the products provided by the INFORM Project. QUESTIONNAIRE #1 has been submitted to more than 50 additional end-users, receiving 20 new answers. These results were then analysed per stakeholder group, by dividing them into groups, such as a division in 'university affiliated' or 'local agency affiliated'. Within this report, we focus on the division between stakeholders 'investigating streams and rivers' or 'investigating non-stream related water bodies', as it more presents the difference in waterbodies.

11.1 Preferred parameters

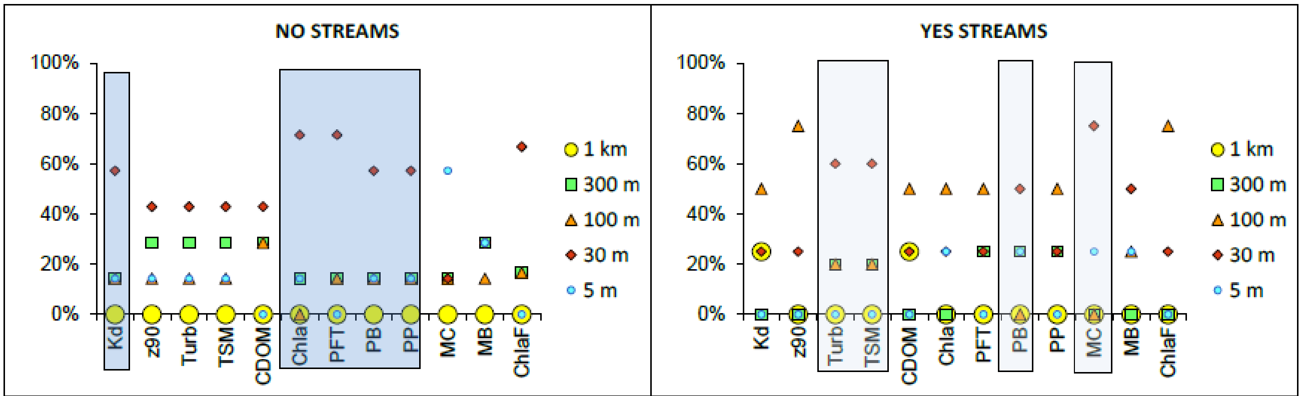
Stakeholders were asked to provide their preference on two lists of parameters (EO oriented, and biogeochemical modelling oriented) in order to collect their preferences about them. The results of this is shown in Table 5. Here it is observed that end-users not working on streams and rivers consider all the parameters as useful (V+M±50%). In particular, the parameters describing the phytoplankton (its presence and ecological functions) are greatly important for them, together with parameters more generally describing the quality of water (i.e. light attenuation and euphotic depth). In contrast to these findings, the group of end-users with competences also on streams and rivers expressed less importance in general, with the exclusion of total suspended matter concentration and macrophyte cover parameters, which collected the 89% and 78% of preferences respectively.

Table 5: Table showing the parameter preferences of the end-users working (light blue) or not (dark blue) on streams and rivers. V+M = Very + Most useful

EO products	V+M	Modeling products	V+M
Light Attenuation (Kd) (m-1)	100%	Stratification depth (m)	88%
	38%		25%
Euphotic depth (m)	88%	Water temperature (°C)	88%
	33%		56%
Turbidity (NTU)	63%	Surface roughness (waves)	38%
	56%		44%
Total suspended matter (g/m3)	75%	pH	75%
	89%		22%
Colored Dissolved Organic Matter (m-1)	63%	N (Total, NH4, NO3) (mg/L)	100%
	38%		78%
Chlorophyll-a concentration (mg/m3)	100%	P (Total, PO4) (mg/L)	100%
	78%		78%
Phytoplankton functional types	100%	Si (mg/L)	63%
	56%		22%
Phytoplankton bloom occurrence	100%	O2(mg/L)	100%
	56%		56%
Phytoplankton primary production	100%	Algal biomass (mg/m3)	100%
	25%		67%
Macrophyte cover	50%	Particulate Inorganic Matter (g/m3)	100%
	78%		63%
Macrophyte biomass (mg/m3)	50%	Total Inorganic Carbon (mg/L)	88%
	38%		56%
Sun induced Chlorophyll-a fluorescence	63%	DOC (mg/L)	88%
	25%		50%

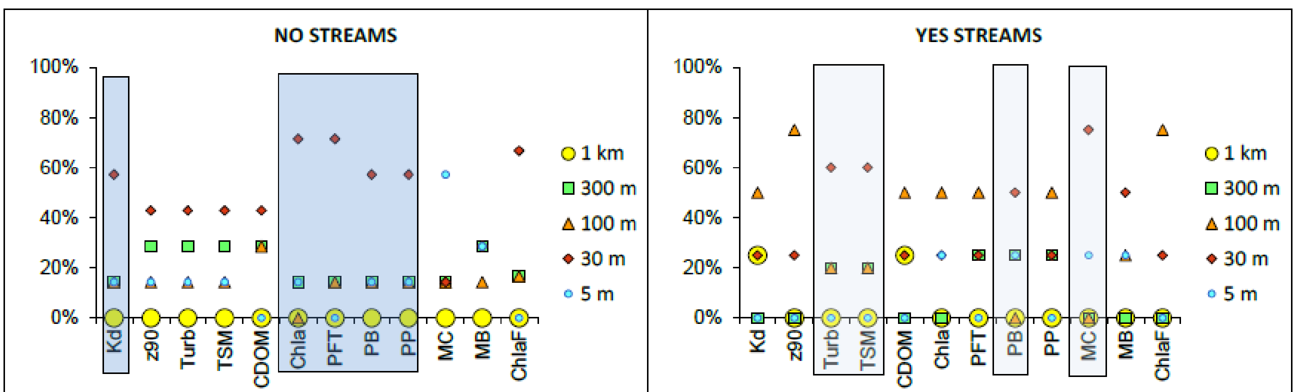
11.2 Spatial resolution

For the same parameters as in Table 5, the end-users were consulted on the preferred spatial resolutions.



Kd	Light Attenuation (m^{-1})	PFT	Phytoplankton functional types
z90	Euphotic depth (m)	PB	Phytoplankton bloom occurrence
Turb	Turbidity (NTU)	PP	Phytoplankton primary production
TSM	Total suspended matter (g/m^3)	MC	Macrophyte cover
CDOM	Colored Dissolved Organic Matter (m^{-1})	MB	Macrophyte biomass (mg/m^3)
Chla	Chlorophyll-a concentration (mg/m^3)	ChlaF	Sun induced Chlorophyll-a fluorescence

Figure 23 shows the spatial resolution preferences for each EO derived product for the three categories of end-users.



Kd	Light Attenuation (m^{-1})	PFT	Phytoplankton functional types
z90	Euphotic depth (m)	PB	Phytoplankton bloom occurrence
Turb	Turbidity (NTU)	PP	Phytoplankton primary production
TSM	Total suspended matter (g/m^3)	MC	Macrophyte cover
CDOM	Colored Dissolved Organic Matter (m^{-1})	MB	Macrophyte biomass (mg/m^3)
Chla	Chlorophyll-a concentration (mg/m^3)	ChlaF	Sun induced Chlorophyll-a fluorescence

Figure 23: Scatter plots showing the spatial resolution preferences for each single EO derived parameter. End-users are divided in working or not on streams and rivers (first row).

It can be observed that end-users working on streams and rivers choose in general lower spatial resolutions than the end-users not working on these waterbodies. When aggregating the results for the different parameters, this is highlighted more clearly (with the streams-working end-users mostly requesting resolutions in the range of 100m, in contrast to the other group requesting 30m resolutions).

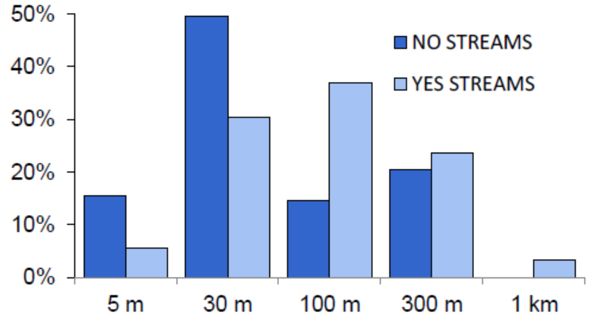
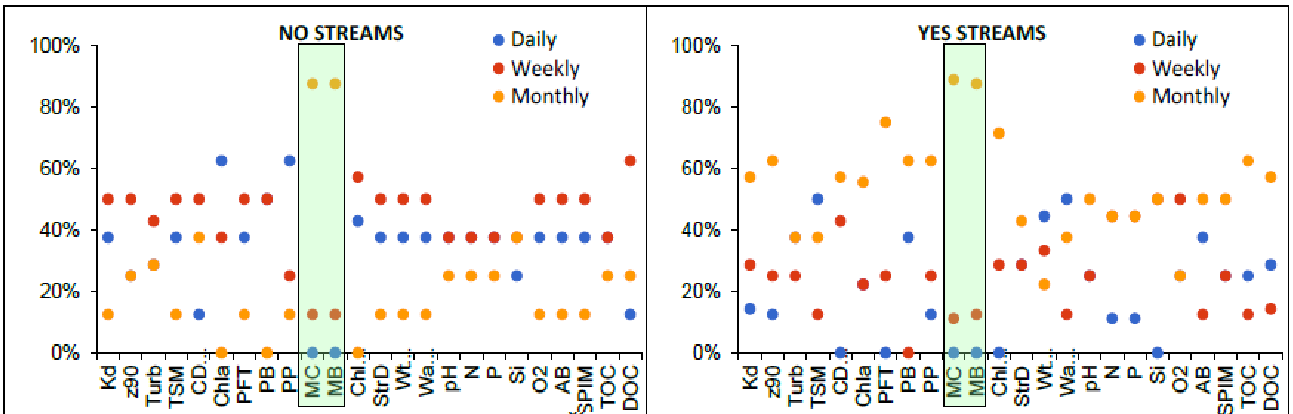


Figure 24: Bar chart showing the spatial resolution preferred by the end-users subdivided in two *groups (working or not on streams and rivers).*

11.3 Temporal resolution

Similar to the spatial resolution, temporal resolution was investigated, as show in Figure 25.



-	Kd	Light Attenuation (m^{-1})	-	StrD	Stratification depth (m)
-	z90	Euphotic depth (m)	-	Wtemp	Water temperature (°C)
-	Turb	Turbidity (NTU)	-	Waves	Surface roughness (waves)
-	TSM	Total suspended matter (g/m^3)	-	pH	pH
-	CDOM	Colored Dissolved Organic Matter (m^{-1})	-	N	N (Total, NH4, NO3) (mg/L)
-	Chla	Chlorophyll-a concentration (mg/m^3)	-	P	P (Total, PO4) (mg/L)
-	PFT	Phytoplankton functional types	-	Si	Si (mg/L)
-	PB	Phytoplankton bloom occurrence	-	O2	O2 (mg/L)
-	PP	Phytoplankton primary production	-	AB	Algal biomass (mg/m3)
-	MC	Macrophyte cover	-	SPIM	Particulate Inorganic Matter (g/m^3)
-	MB	Macrophyte biomass (mg/m^3)	-	TIC	Total Inorganic Carbon (mg/L)
-	ChlaF	Sun induced Chlorophyll-a fluorescence	-	DOC	DOC (mg/L)

Figure 25: Scatter plots showing the preferences about the temporal frequencies for each single EOand biogeochemical modeling derived parameter. End-users are divided in working or not on streams and rivers (first row).

It was highlighted that despite the differences that can be summarized at global level, it is interesting to notice that for those parameters describing macrophytes (cover and biomass) all end-users agree in selecting the monthly temporal frequency as the best solution. This preference is obviously imposed by the seasonality that characterize the growing and development of green vegetation. By aggregating the temporal requirements (Figure 26), stakeholders dealing with streams require lower temporal resolutions (monthly) than stakeholders dealing with other waterbodies (weekly).

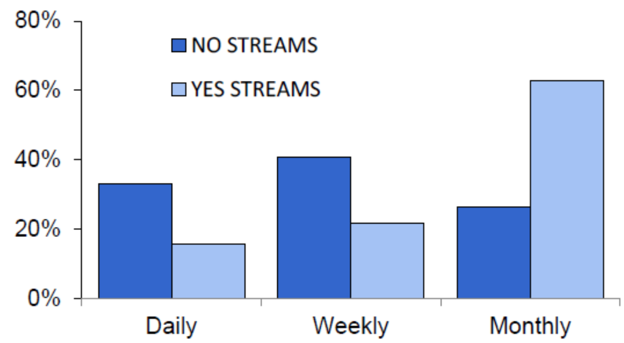


Figure 26: Bar chart showing the temporal resolution preferred by the end-users subdivided in two *groups (working or not on streams and rivers).*

11.4 Accuracy

Unfortunately, no questions were posed in relationship to the specifically required accuracy of information products. Within their kick-off requirements summary two important aspects of this are mentioned.

- ACCURACY: products need to be accurate or at least with associated information about the quality of pixel values (e.g. flags). Furthermore, products have to be retrieved using robust algorithms (with reference to literature or algorithm theoretical baseline document), which can be adapted to extreme water conditions too (e.g. high water turbidity).
- CONSISTENCY: end-users require consistency between products derived from different sensors; this is important for archiving data and for allowing comparisons of data coming from different sources in different times. A good atmospheric correction (with reference to literature or algorithm theoretical baseline document) is a prerequisite for consistent products.

However, it is not clear on what basis these statements are made.

12 Appendix C: Transforming Global to Dutch user requirements

Based on the "Report on End-User Consultation for global water quality purposes, the CEOS report on "Feasibility Study for an Aquatic Ecosystem Earth Observing System, March 2018", as well as the reports " Feasibility Study for an Imaging Spectrometer for Water Quality" from TNO, as well as "CEOS Feasibility study for a (non-oceanic) aquatic ecosystem Earth observing sensor: Conclusions for the Dutch situation" from Water Insight.

In parallel to the INFORM project, CEOS commissioned a study (Feasibility Study for an Aquatic Ecosystem Earth Observing System, March 2018) to provide information on the science and technology to evaluate space remote sensing of regions of non-oceanic shallow (benthic) coastal waters , wetlands and lakes where in general there are biological ecosystems consisting of plant, algae and various grasses and, where there is water, that the depth is such that the bottom surface forms part of the reflected signal received by the remote sensing platform.

12.1 Requirements

Initially this work had a more limited scope to focus on inland waters only. However, this inland water focus was considered as being of too limited scope as there has never been a dedicated published study to assess the requirements for an aquatic ecosystem imaging spectrometer or multispectral sensor excluding ocean requirements). Because there are global pressures (e.g., growing human exploitation of coastal and inland resources and changing climate), we need to study effects on global scales. A global observation system is thus an appropriate and invaluable tool to assess the impact at all spatial and temporal scales. As such, the research first condensed a global literature study with a focus on quantitative research including end user requirements (as well as the sensor specifications required to be able to detect and assess aquatic ecosystem variables). This resulted in the definition of several scenarios representing different (optical) deep water bodies that could be investigated (using radiative transfer models), as illustrated in Table 6. In each scenario, the range of different variables for different water bodies is provided, which form the baseline requirements for retrieval of these variables by satellites sensors.

Table 6: Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical(min-max).

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	low TSM	high TSM	low aCDOM	high aCDOM	low CHL	high CHL
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	2 Finnish l.
TSM [g m-3]	**1**	**5**	1(0.2-10)	5(1-10)	1(0.2-20)	10(5-15)
aCDOM [m-1]	0.5(0.2-2)	2.5(1-5)	**0.2**	**2.5**	0.1(0.04-2)	2.5(1.5-4)
CHL [mg m-3]	2(0.5-15)	5(1-20)	1(0.2-5)	5(1-20)	**1**	**40**
SCDOM [nm-1]	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)

12.2 Water Insight analysis of CEOS feasibility study

In consideration with the specified requirements in Table 6, an analysis was performed on the representativeness to Dutch scenario's. Parameter ranges are quite large in Dutch waters and cover most of the ranges mentioned in the CEOS report (with Chl-a: 0.1 – 500, SPM: 0.1 – 500 and CDOM 0.005-10). More specifically, the several scenarios simulated within the CEOS study, were designated to the most representative individual Dutch waterbody.

Standard scenarios

- X- : Clear deep lakes and water storage basins (e.g. BiesBos)
- X+: Clear lakes and coastal waters (e.g. Oosterscheldt)
- Y-: Most Dutch lakes
- Y+: Humid lakes (vennen) and e.g. Eems Dollart
- C-: Clear deep lakes outside blooming season
- C+: Most lakes except during bloom peaks

Extreme scenarios

- X-- : Drinking water storage basins
- X++: Markermeer, Waddenzee, Westerscheldt
- Y--: Drinking water storage basins, deep clear lakes
- Y++: Industrial water, water sewage spills, Ijsselmeer, Eems Dollart
- C--: Not really present in the Netherlands except in North Sea, far outward stations
- C++: Small ponds, channels and ponds in urbanised areas

12.3 TNO summary

In addition to the Water Insight analysis, a follow-up study was performed by TNO on mission specifications that fulfill these found requirements, specifically for mapping of macrophytes, macro-algae, seagrasses, coral reefs and shallow water bathymetry in inland, estuarine, deltaic and near coastal waters.

The study performed, however, focusses on the technical capabilities required of the satellite, instead of collating the requirements of the end-users. In this manner, the requirements are not specific to particular water quality applications. Instead, a general approach was adopted to provide sensor requirements in terms of:

- Spatial resolution: as a water body cannot be measured if the pixels are too large
- Spectral resolution: as aquatic ecosystems variables need to be identified through their spectral signature (including spectral absorption and spectral backscattering in the water column or spectral reflectance of floating or submerged macrophytes, of the substratum and its cover); atmospheric and air-water interface effects removal require specific spectral bands too
- Radiometric resolution: Coastal and inland water and adjacent terrestrial targets cover a large radiance range, with many dark to bright surfaces of interest. Such an environment requires a sensor that can make radiometric measurements that cover this range while accurately resolving variation in dark targets.
- Temporal resolution: Once priorities 1 through to 3 are adequately addressed of course temporal resolution becomes the most important factor as it will determine how often suitable images of aquatic ecosystem areas will be revisited.

12.4 Spatial Resolution

The study has considered all types of aquatic ecosystems to be investigated that range from less than one meter to km’s. As such, there is a large diversity concerning coverage and geolocation requirements. In general, all inland, wetland, estuarine, deltaic, agonal, coastal and coral reef waters with water depths less than ~30 m and larger than ~0.002 ha, require spatial resolutions of ~33 m (threshold) to ~17 m (goal). These maps should not only provide high resolution but should be properly georeferenced and geometric corrections with the baseline requirement of respectively 0.2 and 0.4 pixels or less in along and across track directions.

12.5 Radiometric and spectral requirements

More than 90% of the optical signal received at a Low Earth Orbiting (LEO) satellite observing a waterbody will be the result of atmospheric interaction. In the Infrared region of the spectrum, this percentage is even higher. This low amount of radiation reflected by the water body (~10%), originates because little light is reflected due to low concentration of light scattering particles (TSM) or high concentration of light absorbing matter (CDOM or NAP with high organic matter contents). Absorbing water types can have remote sensing reflectance (Rrs) maxima below 0.005 sr-1 and Rrs minima in the order of 10-4 sr-1, and 10% concentration changes of chlorophyll-a can affect Rrs as little as 10-6 sr-1 and even below, which seems impossible to resolve by current spaceborne instrument at a fine spatial resolution.

The study has evaluated the dynamic range of radiometric values to be measured across the desired wavelength range and concluded:

- Maximum radiances over dark water bodies: 100 mW m-2 sr-1 nm-1 in the blue and 20 mW m-2 sr-1 nm-1 in the red,
- Radiometric sensitivity NeDL: in the range 0.005 mW m-2 sr-1 nm-1 (optimal) and 0.010 mW m-2 sr-1 nm-1
- Radiance range for monitoring extremely turbid waters, bleached corals, and shallow waters with bright sand: 400 mW m-2 sr-1 nm-1 in the blue and 200 mW m-2 sr-1 nm-1 in the red.

12.6 Temporal resolution

The temporal resolution needs to be as high as possible as aquatic ecosystem variables can change:

1) Within hours such as algal blooms, flood events with associated influxes of high nutrient, high coloured dissolved organic matter and suspended sediment loads into reservoirs, estuaries or coastal seas or with tidal or wind driven events.
2) Within days such as pollution events, dredging effects etc,
3) Within weeks such as coral bleaching events, and finally
4) seasonally to yearly to longer term such as successions of phytoplankton functional types or emergence, florescence and decay of macrophytes.

12.7 Dutch Secondary Requirements

In addition, several secondary requirements were proposed to help with integrating remote sensing in operational practices:

1) Invest in a (small) network of in-situ continuous reflectance measurements to calibrate atmospheric correction models to the Dutch situation.
2) Invest in developing and deploying (automated) specific inherent optical properties (SIOP) collection methods / instruments to better characterize the variability in Dutch inland and coastal waters.
3) Invest in continuous registration of water reflectance and supporting data such as fluorescence, ab-sorption and (back)scattering.
4) Set up (at selected sites) AERONET-OC stations and participate actively in the global network.
5) Participate actively in upgrading the quality of in-situ measurements to fiducial quality.

6) Participate actively in Cal/Val activities to make sure that national water quality ranges are well represented.

12.8 Feasibility

The type of instrumentation needed for these missions are:

- Aquatic: Broadband 380nm -730nm hyperspectral (5-8 nm bands) or multispectral (26 bands)
- Atmospheric: Either specific wavebands or dedicated instrument
- Polarisation: Dedicated instrument for on-orbit TOA information

All three areas are well covered in The Netherlands with recent instrument developments:

1. Hyperscout for multispectral measurements
2. Spectrolite atmospheric chemistry
3. SPEX family for polarisation measurements

Nevertheless, no one of these instruments would directly meet the needs described in the report, requiring much higher spatial, radiometric performance (Hyperscout), and /or spatial resolution (Spectrolite, SPEX). Based on past, current and planned missions the NASA JPL HyspIRI mission (http://database.eohandbook.com/database/missionsummary.aspx?missionID=644) comes close to the overall summary requirements in meeting most threshold requirements, but not the more desired goal parameters (e.g. spatial resolution).

13 Appendix D: Additional Dutch requirements on water quality

Based on the "Roadmap Waterkwaliteit Helderbeeld op Troebel Water" report by the University of Twente (Salama 2014)[4].

Several stakeholders regarding institutional and commercial applications and services are active in the Netherlands. While some of these are obliged to adhere to the requirements specified in the policies, some of these have additional requirements.

Stakeholders	Interest in service	Public / Private
Water Boards	monitoring of ecosystem health, drinking water, recreational water	PU
Ports	port access in shallow waters	PU
Dredging sector	Erosion accretion of sediment / environmental impact (turbidity,…)	PR
Utility companies	water and pollution monitoring	PU/PR
Drinking Water Companies	chemical disasters/water quality/safety management plans	PR
Scientific community	understanding the bio physical processes,	PU
NGOs	Nature conservation	
Chemical producers	Pollutants discharges into surface water	PR
Aquaculture	Water quality (harmful algal blooms HAB) and -currents	PR
In-situ water quality sensor producers	Increase of market enhancement of sensors with ICT and coupling to Geo-ICT	PR
Geo-ICT industry (informatics, communication technology)	wider scope of Geo-ICT to environmental monitoring	PR

13.1 Previous user requirements analysis

Users require timely and accurate data at regular intervals over sustained periods for their particular region that adequately resolve the processes, phenomena and characteristics of interest for regional and local water quality monitoring and management. In the previous user requirements analysis, the desirable spatial and temporal resolution of specific variables are highlighted, see the table below. However, these variables are only limited to those that could be retrieved from EO and were foreseen to be available in the near future.

Variable	Frequency	Spatial resolution	users
Suspended sediments	Weekly 10-50 m inland lakes	50-300 m estuaries 300-1000 m coast	Dredging company/ Water Boards
HAB/ algae	1-3 days	10-50 m inland lakes	Drinking water companies, Water Boards

[4] Please Note that while the publication of this report was from 2014, it was (up to this study) the most recent analysis on water quality requirements performed for the NSO. While several of the recommendations have been fulfilled (for example by the launch of Sentinel-2), several others remain relevant.

Temperature	Weekly	50-300 m estuaries 300-1000 m coast 10-50 m inland lakes	Fisheries/aquaculture companies
Salinity	Monthly	50-300 m estuaries 300-1000 m coast 10-50 m inland lakes	Drinking water companies, Water Boards

As such, several application have been developed to address this need for water quality information.

Application	Reasons	TRL	MRL	User	Area /scale
Support to dredging activities	Quantification of suspended sediment/plume of the dredging	4	3	Port Rotterdam/ dredging companies	Coastal areas/estuaries ~300m
Coastal engineering	Quantification of suspended sediment for coastal protection and geomorphology	4	3	Coast protection/ Rijkswaterstaat	Coastal areas/estuaries ~300m
Dynamics of the ocean	Height, temperature and salinity to aid general circulation models and whether predictions	9	6	Coast protection/ Rijkswaterstaat	Open ocean ~100km
Fishers	Improving and managing the fish catch	6	5	Fisheries/ Rijkswaterstaat	Open ocean
Aqua culture	Best location / health monitoring	2	2	Fisheries/ Rijkswaterstaat	Coastal areas ~300m
Turbid Water quality	Environmental monitoring and recreation	3	2	Rijkswaterstaat/ Water Boards/Recreation	Coasts, estuaries and lakes <300m
Monitoring of algae bloom	Drinking water and treatment	1	1	Drinking water companies/ Rijkswaterstaat	<5m
	algae aquaculture for medical industry: to produce proteins and other medical substances	2	1	Medical industry	<5 m
	protect desalinization plants	1	2	Drinking water	Coasts <300 m
	Primary production, biology, gas exchange and climatic change	9	6	Rijkswaterstaat/ Fisheries	Open ocean 4-9 km
Harmful algae detection	Protection of ocean	5	4	Rijkswaterstaat/ fisheries	Open ocean and coastal areas, large lakes 4-9 km
	Protection of coastal area, lakes and recreation and early warning for fishers. This service requires a specific spectral band that is only available in MERIS	4	3	Rijkswaterstaat/ Fisheries and aquaculture industry	Estuaries, coastal areas, lakes 10-300 m

Salinity in fresh water reservoirs	Drinking and irrigation water quality monitoring	1	1	Drinking water and agriculture	Fresh water <20 m

14 Appendix E: Dutch Policy driven water quality requirements

Based on the "Beschrijving van de Rijkswaterstaat meetnetten voor natuur en waterkwaliteit " report by Rijkswaterstaat (RWS) and the "Inventarisatie Kennisbehoefte Waterkwaliteit rapport van de kerngroep Waterkwaliteit van de STOWA" report by the STOWA.

Monitoring water quality of Dutch oceans, lakes, rivers, canals and ports is an essential step towards a sustainable management of aquatic ecosystems. For this, several traditional methods are used to provide information on the water quality. These methods can be divided into two segments:

- Chemical information is used for: reporting to governmental agencies and politics, monitoring water quality standards, rating of chemical land ecological potential of the main water system, enforcement of Water permits, and warning of drinking water companies and agricultural practices.
- Ecological information is used for reviewing water quality standards, exploration, for management of nature and water quality legislation, and drafting policies.

In order to provide specific requirements for each of these segments, several policies have been developed, namely: the Kaderrichtlijn Water (KRW) (Water Guideline), the Kaderrichtlijn Marien (KRM) (Marine Guideline), and the Zwemwaterrichtlijn (Swimming Water Guideline).

14.1 KRW

The KRW aims to ensure good chemical and ecological water quality in Dutch waters. For this, ecological and chemical data is gathered, as well as information on oxygen and salinity content, as well as temperature. This guideline is applicable to all Dutch waters (except the North Sea at distances further than 1 km from the shore), and focusses on two information needs: ecological and chemical.

14.1.1 Ecological Requirements

Phytoplankton

For the KRW (as for the KRM), similar requirements have been defined for measuring phytoplankton, see Table 7. For most of the measurement locations in the chemical measurement network, phytoplankton is measured using chlorofyll-a. In February 2018 a new strategy has been defined to allow (apart from abundance) species identification by means of 'vinger aan de pols' of the effects of eutrophication. For these locations, the original requirement on sampling for phaeocystis has been cancelled.

For chlorophyll-a a threshold level of 100um/l is defined (averaged per summer for eutrophication sensitive stagnant water bodies (see https://rvszoeksysteem.rivm.nl/stof/detail/448). For both Phaeocystis-bloom species distribution (for every waterbody), no target values are reported in the KRW. Instead, three passing scores (Very good, Good, Poor) are defined (in addition to Very Poor) based on relative distributions in relationship to an 'undisturbed state', see Table 8. This, however, does provide quantifiable levels of quality.

Table 7: Phytoplankton requirements according to the KRW and KRM

Area	Sampling points	Frequency	Parameters	Method
All water bodies	North Sea: 18;	Seven per yearly to monthly	Chlorophyll-a, Phaeocystis bloom, species composition	Water samples, lab analysis
	Diverse: 1-3			

Table 8:Hydromorphological water quality requirements

Very Good	Good	Poor
Species composition and abundance of phytoplankton concur with undisturbed state. The average biomass resembles type-specific chemical conditions. The bloom of plankton agrees in frequency and intensity to normal physical-chemical conditions	Species composition and abundance of phytoplankton show slight deviations from an undisturbed state. The average biomass shows slight deviations from type-specific chemical conditions. The bloom of plankton shows slight increases in frequency and intensity to normal physical-chemical conditions	Species composition and abundance of phytoplankton show medium deviations from an undisturbed state. The average biomass shows medium deviations from type-specific chemical conditions. The bloom of plankton shows medium increases in frequency and intensity to normal physical-chemical conditions

Table 9: Water plants requirements according to KWR

Area	Sampling Points	Frequency	Parameters	Method
IJssselmeer, Markermeer and Randmeren	160 in area covering grid	Three-yearly	Total coverage per species	On sight and with 1-3 local sampling (harkworpen)
Lakes	Dozens per water body	Three-yearly	Coverage of growth form and species composition	5 local sampling
Ijsselmeer				1-3 local sampling
Rivers	Dozens per water body for a shore length of 100 m	Three-yearly		On sight
Canals	Dozens per water body for 100 m	Six-yearly		

Water plants

In both the KRW and the KRM, specific information regarding growing water plants (including sedge and water cane) are required. The KRW, however, has different standards than the Natura 2000 requirements (that are used for the KRM). The KRW requires information regarding, see Table 9, species composition and relative coverage area of the specific species.

In terms of accuracy, no target values for quantifying the water quality on basis of water plants composition and abundance exist. Instead, similar to the Phaeocystis, three passing scores (Very good, Good, Poor) are defined (in addition to Very Poor) based on relative distributions in relationship to an 'undisturbed state'.

Phytobenthos

The KRW requires for both freshwater and coastal areas information regarding the species composition and abundance, see Table 10. Specifically the requirements designate the bloom of unwanted species that have a negative influence on humans

Table 10: Phytobenthos requirements according to the KRW

Area	Sampling Points	Frequency	Parameters	Method
18 Water bodies	1 per water body	yearly	Species composition and relative abundance	Water samples, lab analysis

In terms of accuracy, no target values for quantifying the water quality on the basis of Phytobenthos composition and abundance exist. Instead, similar to the Phaeocystis, three passing scores (Very good, Good, Poor) are defined (in addition to Very Poor) based on relative distributions in relationship to an 'undisturbed state'.

14.1.2 Abiotic requirements

There are several abiotic parameters defined to quantify the water quality. These can be divided into suspended sediment (SPM), and chemical parameters. These chemical parameters can be divided into non-synthetic parameters, such as temperature, phosphor and nitrate, and synthetic parameters (created in industry), of which the KWR specifies a list of specific interest, see Table 11. Considering that detecting these synthetic substances in water requires in itself chemical analysis in the lab, there is great uncertainty if remote sensing could play a role here. As such, these will not be discussed further. In contrast, non-synthetic chemical parameters, such as water temperature, nitrate and phosphor, and chloride (salt), can be detected by remote sensing. In fact, water temperature has been measured for a long time with thermal remote sensing techniques. In addition, a dedicated remote sensing instrument (SMOS) was designed to measure the ocean salinity using microwave radition. For both phosphor and nitrate, no satellites have been constructed, though proof-of-concept studies have been performed. (Wang et al., 2018).

In the KRW, through the Drinkwaterrichtlijn (Drinking Water Guideline, 80/778/EEG), it is defined that the water temperature for most rivers is required to remain below daily threshold of 25 degrees, and for specific northern streams set to 18 degrees for the restriction of drinking water uptake. Furthermore, the KRW specifies that water put into the rivers is allowed to increase the river water temperature to a maximum of 3ºC, to the restriction releasing cooling water from electricity plants. The threshold level for sodium chloride is defined to be 20000 ug/l (https://rvszoeksysteem.rivm.nl/stof/detail/989) for fresh water bodies, while for nitrate two threshold levels are defined of 50 mg/l and 5.6 mg/l, for respectively surface/groundwater intended for drinking water production, and groundwater as a target value.

<table>
<tr><th>Parameter</th><th>Type Water</th><th>Frequency</th><th>Method</th><th>Spatial Coverage</th><th>Critical Values</th></tr>
<tr><td>Suspended sediment (SPM)</td><td>all</td><td>2/year</td><td>gravimetric</td><td rowspan="2">One site per water way.Two per large water body(North Sea, Wadden Sea and IJselmeer)</td><td>mg/l</td></tr>
<tr><td>Primary chemical parameters*</td><td>all</td><td>12/year</td><td></td><td>-</td></tr>
</table>

Table 11 Lijst van Prioritaire stoffen op het gebied van Waterbeleid

Nummer	CAS-nummer (1)	EU-nummer (2)	Naam van de prioritaire stof (3)	Aangewezen als prioritaire gevaarlijke stof
(1)	15972-60-8	240-110-8	Alachloor	
(2)	120-12-7	204-371-1	Antraceen	X
(3)	1912-24-9	217-617-8	Atrazine	
(4)	71-43-2	200-753-7	Benzeen	
(5)	niet van toepassing	niet van toepassing	Gebromeerde difenylethers	X (4)
(6)	7440-43-9	231-152-8	Cadmium en cadmiumverbindingen	X
(7)	85535-84-8	287-476-5	Chlooralkanen, C_{10-13}	X
(8)	470-90-6	207-432-0	Chloorfenvinfos	
(9)	2921-88-2	220-864-4	Chloorpyrifos (chloorpyrifosethyl)	
(10)	107-06-2	203-458-1	1,2-dichloorethaan	
(11)	75-09-2	200-838-9	Dichloormethaan	
(12)	117-81-7	204-211-0	Di(2-ethylhexyl)ftalaat (DEHP)-	X
(13)	330-54-1	206-354-4	Diuron	
(14)	115-29-7	204-079-4	Endosulfan	X
(15)	206-44-0	205-912-4	Fluoranteen	
(16)	118-74-1	204-273-9	Hexachloorbenzeen	X
(17)	87-68-3	201-765-5	Hexachloorbutadieen	X
(18)	608-73-1	210-168-9	Hexachloorcyclohexaan	X
(19)	34123-59-6	251-835-4	Isoproturon	
(20)	7439-92-1	231-100-4	Lood en loodverbindingen	
(21)	7439-97-6	231-106-7	Kwik en kwikverbindingen	X
(22)	91-20-3	202-049-5	Naftaleen	
(23)	7440-02-0	231-111-4	Nikkel en nikkelverbindingen	
(24)	niet van toepassing	niet van toepassing	Nonylfenolen	X (5)
(25)	niet van toepassing	niet van toepassing	Octylfenolen (6)	
(26)	608-93-5	210-172-0	Pentachloorbenzeen	X
(27)	87-86-5	201-778-6	Pentachloorfenol	
(28)	niet van toepassing	niet van toepassing	Polycyclische aromatische koolwaterstoffen (PAK) (7)	X
(29)	122-34-9	204-535-2	Simazine	
(30)	niet van toepassing	niet van toepassing	Tributyltinverbindingen	X (8)
(31)	12002-48-1	234-413-4	Trichloorbenzenen	
(32)	67-66-3	200-663-8	Trichloormethaan (chloroform)	
(33)	1582-09-8	216-428-8	Trifluraline	X
(34)	115-32-2	204-082-0	Dicofol	X
(35)	1763-23-1	217-179-8	Perfluoroctaansulfonzuur en zijn derivaten (PFOS)	X
(36)	124495-18-7	niet van toepassing	Quinoxyfen	X
(37)	niet van toepassing	niet van toepassing	Dioxinen en dioxineachtige verbindingen	X (9)
(38)	74070-46-5	277-704-1	Aclonifen	
(39)	42576-02-3	255-894-7	Bifenox	
(40)	28159-98-0	248-872-3	Cybutryne	
(41)	52315-07-8	257-842-9	Cypermethrin (10)	
(42)	62-73-7	200-547-7	Dichloorvos	
(43)	niet van toepassing	niet van toepassing	Hexabroomcyclododecaan (HBCDD)	X (11)
(44)	76-44-8/ 1024-57-3	200-962-3/ 213-831-0	Heptachloor en heptachloorepoxide	X
(45)	886-50-0	212-950-5	Terbutryn	

14.2 Kaderrichtlijn Marien (KRM)

The purpose of the KRM is to ensure a good ecological status in the North Sea. For this, the KRM demands information on stress factors as well as indicators on the ecosystem functioning.

14.2.1 Requirements for stresses

As indicated earlier, the KRM uses the same requirements as the KRW for the monitoring of Phytoplankton, see Table 7.

14.2.2 Requirements for ecosystem indicators

Similar to the stress factors, there is a significant overlap between KRW and KRM requirements. As such, these requirements have already been mentioned. The most notable difference found, was in regard to the water plants. As mentioned earlier, there are significant similarities between the KRW and the KRM regarding the monitoring of the water plants. However, the KRM has adopted N2000 standards for sampling and species determination, see Table 12.

Table 12: Water plants requirements according to the KRM

Area	Sampling Points	Frequency	Parameters	Method
IJssselmeer, Markermeer and Randmeren	N2000: ~10000 in area covering grid	Three-yearly	Total coverage per species	On sight and with 1-3 local sampling (harkworpen)
Lakes	Dozens per water body	Three-yearly	Coverage of growth form and species composition	5 local sampling
Ijsselmeer				1-3 local sampling
Rivers	Dozens per water body for a shore-length of 100 m	Three-yearly		On sight
Canals	Dozens per water body for 100 m	Six-yearly		

14.3 Zwemwaterrichtlijn

This guideline defines the legislation for the monitoring and controlling of swimming water locations (of which there are approximately 700 in the Netherlands). The guideline requires the monitoring of the bacteria: intestinal enterococci (IE) en Escherichia Coli (E. coli). In high risk area's (covering about 10% of the total area) the RWS also monitors for blue algae.

Table 13: Bacteria en blue-algal requirements according to swimming water guideline

Area	Parameters	Sampling Points	Period	Frequency	Method
Normal swimming water	enterococcen en E.coli	1 per water body	1 May-1 Oct	Monthly	Water samples, lab analysis
High risk area'as				Weekly-two weekly	
	Blue-algae conc.	3 per water body			

Table 14: Norm according to Richtlijn 76/160/EEG

Waterbody	Parameter		quality		
		Unit	excellent	Good	Acceptable
Fresh water	Intestinale enterokokken	(kve/100 ml)	200 (*)	400 (*)	330 (**)
	Escherichia coli	(kve/100 ml)	500 (*)	1 000 (*)	900 (**)
Coastal and Transitional	Intestinale enterokokken	(kve/100 ml)	100 (*)	200 (*)	185 (**)
	Escherichia coli	(kve/100 ml)	250 (*)	500 (*)	500 (**)

(*) 95-percentile, (**)90-percentile

15 Appendix F: Summaries of interviews

15.1 CML

Participant: Olivier Burggraaff (Astronomy, Leiden University, MONOCLE), Maarten Schrama (Leiden University) and Joris Timmermans (Institute for Environmental Sciences, Leiden University)

CML is an institute of the Faculty of Science of Leiden University. Our institute aspires to be the center of excellence for strategic and quantitative research and education on sustainable use and governance of natural resources and biodiversity. More specifically, within CML, the department of environmental biology aims to increase the scientific understanding of how current and emerging anthropogenic threats affect biodiversity and ecosystem services. Through this understanding they facilitate strategic management of natural resources by addressing urgent challenges in relation to involved mechanisms and their inter-linkages across scales. As such water quality is of high relevance.

15.1.1 Organisation of workshop on water quality policies in mesocosms

Within the scheduled activities for the NSO project the organization of a water quality workshop within the MESOCOSM workshop was planned. However, this particular workshop was cancelled due to lack of response from potential participants. Specifically, they highlighted that while (advancing of) water quality monitoring is important, there are particular issues that prohibit the uptake of such information into operational applications as explained below.

From the ecologist's point of view, there is knowledge what the issues are in the Dutch ditch water quality. These issues are mainly related to agricultural pressure on the landscape, such as fertilization of the agricultural fields, the use of pesticides on agricultural crops and soil subsidence. The main hurdle to solve these issues, is not being able to measure more accurately these water quality parameters, but in fact in policy on improving these agricultural applications. However, there is tension between ecological monitoring and agricultural practitioners. The water quality in Dutch ditches is the primary responsibility of the Water Boards, which implies that Water Boards do not have the capacity to enforce legislation on the agricultural sectors. On the other hand, the land is the primary responsibility of the Ministry of Agriculture, Nature and Food Quality as well as the farmers themselves.

However, the primary objective of the Ministry of Agriculture, Nature and Food Quality is not towards increasing the water quality of these ditches. Instead, the Ministry aims to ensure good prospects for the Dutch farming, horticulture and fishing sectors, which are renowned worldwide for producing high-quality food that is safe and affordable. Moreover, it aims to consolidate the agriculture sector's leading international position, strengthen the link between nature and agriculture, and improve farmers' economic situation. In this capacity, the Ministry focusses on preventing depletion of soil, freshwater supplies and raw materials, halt the decline in biodiversity and fulfil our commitments to the Paris climate agreement.

As a result for the split in responsibility, progress in monitoring has not been meaningful in the last decades. So although there are a lot of problems in our common freshwater that justify much better monitoring, the immediate need is lacking as a result of situation described above.

15.1.2 Interfacing with stakeholders

CML group is also contributing to the H2020 MONOCLE research project focused on exploiting water quality measurements with citizen science-ship for Coastal waters, Lakes and Estuaries. As such the consortium aims not only to create water quality services (usefull to stakeholders such as the Water Board and drinking companies), but include citizens to help measure (with remote sensing techniques) the water.

As such, specific information regarding the lack of uptake from Water Boards can be specified. It was observed that (during the Stowa symposium on water quality, October 2018), there were high reservations regarding the applications of remote sensing. At some point in the discussion (concerning dike monitoring by drones) it was mentioned that this would in fact lead to a reduction of jobs on dike monitoring. This is in contrast how remote sensing services work. While remote sensing might reduce some of the load of these managers, at no such time should remote sensing replace those persons. In fact, without dedicated people on the ground, remote sensing services cannot be validated, or information extracted. In this sense, the relative new field of remote sensing is found scary by traditional water managers for the wrong reasons. It is therefore of vital importance to show the advantages of remote sensing and make the threshold for application lower.

In this regard, some of the findings within the MONOCLE project are of high relevance. Here they also use novel techniques (smartphones) first developed for atmospheric composition measurements (in the iSPEX-project) that are now being deployed for water quality measurements. Here, however, much less fear has been observed in the introduction of this due to its citizen-science nature . This is caused by two aspects, 1) the success of the application within iSPEX, provides a positive balance to potential negative feelings towards such novel techniques and 2) the language that is used to explain the techniques.

15.1.3 Experience with water quality community

Here, due to the focus on citizen-science the used language (intended for laymen) is much easier to understand than the technological terminology used by remote sensing experts and remote sensing consultants. Furthermore, the clear objective (towards Coastal waters, Lakes and Estuaries) makes the message simpler to understand, considering that this is only a small part of the full variety of waterbodies in the Netherlands. Water quality research cannot be seen as a well-connected community, but instead should be seen as more idendepent groups of smaller communities each focusing on an individual water body. As such, there is a wide variety of algorithms in existence each focused towards individual parameters. In addition to the complexity of the subject, the diversity of different applications might provide too large of a threshold to pass over.

15.2 Water Insight

Participant: Steef Peters (Water Insight), Catherine Poser(Water Insight), Marnix Laanen(Water Insight), Joris Timmermans (Leiden University)

Water Insight was founded in 2005 by Steef Peters and Marnix Laanen, to bridge the gap between satellite monitoring and in-situ sampling. As such their mission is

- To provide water quality information products and services based their inhouse developed sensors and satellite data processing
- Participate in European projects to benchmark the quality of their services
- The advocate the use of remote sensing techniques for water management.

For this, Water Insight has developed its own “close sensing” portable water quality spectrometer (the WISP-3). That is being widely used for in-situ measurements (by Water Boards) in either an operational capacity or calibration/validation activities. Furthermore, Water Insight also has extensive experience in providing remote sensing information to dutch governance. More specifically, In the period 2006 – 2012 Water Insight provided the Ministry of Infrastructure and Water Management (through its agency Rijkswaterstaat) with Harmful Algal Bloom bulletins for the Dutch part of the North Sea.

In this sense Water Insight provides a nice perspective of additional secondary requirements of stakeholders. In particular, they can provide comprehensive and insights to questions asked by governmental organisations (such as Water Boards), as well as objective information regarding (positive/negative) uptake of remote sensing services.

15.2.1 In-situ measurements

Water Insight has developed specific sensors for water quality, such as the WISP-3 and the to-be-launched WISP-10. The development of these sensors was not top-down steered in any capacity due to absence of dedicated funding tenders. As such, the instruments are fully developed on the basis of the knowledge of Water Insight with regard to the user requirements as known to them. As such, there is a risk that some particular user requirements are not fully met in this capacity. As developing new sensors is a costly capacity, this might lead to stagnation of adaptability. The generation of specific project tenders, taking into account a more comprehensive user requirements analysis (such as performed in this project) might contribute to this.

While confident in their sensor solutions, Water Insight recognizes that other instruments exist that for particular research are better suited. Considering that institutes not often purchase new instruments, this could lead to less uptake of in-situ measurements over different water quality stakeholders, and might have big impacts. In principle, such issues can be circumvented if the uncertainty of the different instruments is well known, and inter-calibration excersises (such as Water Insight is contributing to in a European Capacity) are organized regularly. However, in Dutch capacity, such intercalibration campaigns are not performed.

15.2.2 Satellite services

In terms of the uptake of satellite data, Water Insight's perspective is that this is lower than the uptake of in-situ measurements. In particular, they specify that uptake in other (developing) countries is in fact much higher than in the Netherlands. The cause of this is the existence of an existing frameworks in (water) institutes, such as the Water Boards, focused towards point measurements. Gridded remote sensing water quality maps can therefore not be used in an operational approach. It is their experience that actual usage of remote sensing services depends heavily on particular individuals within these organisations, and that further uptake of these services is limited due to lack of knowledge. In this sense, capacity building activities focused towards operational management with remote sensing observations could be very helpful.

Water Insight, however, does specify that there is a large understanding within their clientele of the potential of remote sensing. In particular they observe that when the success of a singular remote sensing service has been shown for one stakeholder, this community can rapidly increase. Though naturally, these services need to adhere first to primary requirements (concerning spatio-temporal resolutions and accuracies). Furthermore, they indicate that (due to the lack of knowledge) such users are not interested in 'water parameters' as they are interested in information products (such as plume phenology and morphology). It is Water Insight's experience that using terminology defined within research methods (such as radiative transfer modelling), only scares end-users away. As such using appropriate language is vital.

Finally, uptake of satellite services is limited due to erroneous opinions regarding such services. In calibration/validation campaigns for such services, only few in-situ observations are used. Considering the large spatial variation that can occur, this in fact can lead to biases in the validation. Furthermore, in-situ measurements are not often performed during overpasses of the satellite sensor. As such, errors further increase due to temporal variations. All of these uncertainties are then attributed to the satellite service, without considering the errors within the in-situ measurements. Therefore, not only is the biggest potential (namely spatial coverage) not properly examined (due to the low number of sampling points), it is often wrongly concluded that services relying on remote sensing have too high uncertainties (in regard to the 'perfect' in-situ observations). Furthermore, no services actually combine both point and satellite observations for operational management to get the best of both worlds.

15.3 Hoogheemraadschap Rijnland

Participant: Bart Schaub, (Rijnland), Brunschot, Chiel (Rijnland), Ernst Brous (Rijnland) & Joris Timmermans (Leiden University)

Hoogheemraadschap Rijnland is one of 12 Water Boards in the Netherlands. Rijnland specifically works in two provinces: North Holland and South Holland. The Rijnland area stretches from Wassenaar up to IJmuiden and from Gouda to and including part of Amsterdam, covering an area of 1,100 square kilometres and impacting 1.3 million people that live, work, travel and enjoy leisure activities. As such, Rijnland's key tasks include, among others, ensuring a good quality of open water so that it can be used for recreation, watering cattle and as a habitat for a large variety of plants and animals (water quality), as well as ensuring that polluted river, canal and lakebeds are cleaned in order to balance the water ecosystem so that the water provides opportunities for natural development in the countryside as well as in towns and cities (water management plus).

In order to ensure water quality, Rijnland processes waste water from homes and businesses. This waste water arrives at Rijnland's purifying plants via the sewage system. There the water is cleaned. This is done naturally with the aid of bacteria and oxygen. The clean water is then discharged into open water. Furthermore, Rijnland also devotes a lot of effort to preventing pollution in open water. Rijnland grants permits that impose strict conditions for discharging waste water. Rijnland checks for and investigates illegal discharges of waste water.

15.3.1 Current practices

Rijnland at this moment does not use remote sensing for operational monitoring of the water quality, instead they rely on tried and tested traditional in-situ measurements. The analysis of these samples are carried out by a dedicated laboratory, AquonTO scrutinize for the presence of heavy metals, salt, oxygen, phosphates and nitrogen. The quality and composition of plant and animal life in the water is consideration as well.

15.3.2 Restrictions on using remote sensing

This lack of remote sensing applications and the non-acceptance of remote sensing as an additional information source is due to several issues. This includes primary (spatio-temporal and accuracy requirements specified in the first document), as well as secondary requirements, provided below:

- There is a lot of uncertainty regarding remote sensing, caused by few people within the organization who at present have experience in using remote sensing for water quality measurements. As such, no critical mass has been established to convince the executive board of Rijnland to invest in remote sensing. This in principle is therefore a circular spiral that cannot be broken from within the Water Board itself. While there is an interest in remote sensing techniques (such as drones), only when the full potential is highlighted was this convincing enough to movement within Rijnland.
- Remote sensing data is considered expensive. While there now are new satellites available (such as the Sentinels) that are freely available, various other commercial satellite observations are expensive. Considering that there is no specific funding within Rijnland to explore these data

sources, a huge potential is left untouched. Furthermore, the large amount of remote sensing data now available provides a need for storage spaces, of which currently there is no funding available.

- The complexity of retrieving information from remote sensing data. The Water Board does not house radiative transfer experts, due to the fact that Rijnland is only interested in particular information products that can directly be used, not on actual processing of the data. In contrast, most remote sensing consulting companies (that have been established by former scientists) present advances in their services by focusing on the advances of technical specifications of their algorithms. Due to this difference in language, such services are not provided in a convincing manner.
- Applicability of currently available water information products. The Water Board does not show an interest in raw remote sensing data. Instead they are interested in final information products. Due to the operational nature of their missions, there is little time available to spend on investigating different water quality information parameters than they are currently using. Considering the top-down approach (not user-driven) that has been used in the past in remote sensing water quality services, most of these information products could not directly be implemented into the operational chain. Furthermore, the variability of the data formats used (in terms of file formats, data projection and data structure) provides an extra threshold to integrate remote sensing in their operational chain. As such this particular project is (according to Rijnland) of vital importance to show the potential of remote sensing applications.
- There is a lack of transparency concerning the services. Most remote sensing services are given without proper documentation concerning the validation exercises and the limitations of the product. This is caused by the consulting companies feeling the need to adhere to the high expectations of the Water Board. Of course (due to the operational nature of the Water Boards), these expectations are based on high requirements. However, at no such point is the potential of remote sensing, namely the spatial coverage, explored.

15.3.3 Possible Solutions

There are several solutions to the above limitations:

- Have a large pilot, with multiple remote sensing service providers showing the capabilities of their applications. Furthermore, integrating remote sensing with traditional techniques can greatly help. This way, biases that might occur in remote sensing products can be circumvented, and the information characteristics directly are of use for Rijnland. Such a pilot, however, only shows the potential of remote sensing at one singular point in time; thereby omitting any progress after the pilot.
- Include in proposal tenders for water quality research, a requirement that remote sensing techniques should be explored as a possible alternative. Such an inclusion would only be possible if instructed from overseeing governmental bodies.
- While demonstrating the results of such pilots could greatly help the acceptance of remote sensing as a usefull tool, a basic level of understanding needs to be created. As such, capacity-building activities (using the results of the pilots) is instrumental.
- To fully explore the possibilities of remote sensing techniques, all appropriate data should be made available. In this view, the remote sensing data portal of the NSO could contribute in this manner, by purchasing the expensive data of commercial satellites, and providing the opportunity for consulting companies to develop specific water quality applications for the Water Boards. After the pilot phase, the consulting companies can then set up business models to ensure continuous revenue.

- Finally, expectation values concerning remote sensing data need to be kept in check. On the one hand this is a task for the Water Boards itself, while on the other hand, remote sensing service providers also need to realise that their services not necessarily need to be based solely on remote sensing data. Instead, combining remote sensing observations with local data could in fact lead to the best of both worlds, with accurate absolute values obtained through the in-situ observations, while providing a spatial coverage through the (bias-corrected) remote sensing data.

15.4 Dunea Water company

Participants: Harry van der Haagen (Dunea), Joris Timmermans (Leiden University)

Dunea produces and supplies reliable drinking water to approximately 1.3 million customers in the western part of South Holland. Every year we receive 1 million visitors in the dunes between Monster and Katwijk. We manage this beautiful nature reserve while also protecting drinking water extraction. The dunes between Monster and Katwijk are crucial in the purification and production process. We have been doing this for over 140 years. Clean drinking water, peace and space in the Randstad form the basis for a good life.

For this reason, Dunea performs the full water management in the dune areas Solleveld, Meijendel and Berkheide. To be able to meet drinking water demand, water is supplied from outside. Dunea has used several different sources of water for this, for Berkheide pre-purified river water (since 1990), for Meijendel and Solleveld pre-purified river water (since respectively 1955 and 1983) from the Afgedamde Maas.

15.4.1 Activities

These activities ensure that Dunea has interest for water quality: they are required 1) to ensure the quality of the absorbed water from the Ingedamde Maas, and 2), to ensure the water quality of the surface water in the river and in the dunes. These interests are further explained below, with possible risk factors highlighted

- The water from the Ingedamde Maas is regularly measured to keep the quality high before the water is taken up. For this, measurements are performed of both biotic and abiotic quality properties.
    - Biotic properties. The water toxin levels are regularly checked through the use of Daphnia's. This information is used operationally wise (in conjunction with reports from other governmental bodies) to make decisions to continue/stop the intake of water. One measure to increase the water quality in this step includes the filtering of the water with micro sieves to prevent mussel growth (on the walls of the transport pipes).
    - Abiotic properties. The temperature, pH and a few dozen substances of the water in the Andelse Maas are currently being measured in accordance with the IB agreement with PZH. Flocculation is one measure used to filter suspended matter, phosphates and many other substances from the water. This water purification stops in the winter, due to the absence of biological activity during this period. One possible disturbance in the future on this are the plans for potential areas to extract energy from the water in the transport pipes. An accumulation of these activities can lead to a negative influence on the water temperature in the infiltration ponds and therefore on biology.

- Dunea, together with water companies Waternet and PWN, has a joint laboratory (The Water Laboratory), that conducts research into water quality in the supply, in the dunes and in the distribution system. In this perspective, Dunea has decided to comply with the Kader Richtlijn Water (KRW) in terms of monitoring requirements. However, the KRW stipulates that any measures to comply with these guidelines fall on the Water Boards (specifically the Hollands Noorderkwartier, Rijnland and Delfland). However, this creates inconsistencies.
    - Similar to Dunea, the Water Boards have outsourced their water quality analysis to a single company, Aquon. However, this is not the same laboratory as the Dunea (that uses the Water-Laboratorium). As no agreement is made which protocol is used, this might cause inconsistencies in the final water quality values.
    - In addition, a specific sampling strategy has been chosen for the entire consortium. For the Dunea area, this means sampling 3 locations. However, it is doubtful whether these 3 locations are in fact representative of the total area, or even sampled water body.

Finally, there are issues regarding data sharing. At present there is not an official data sharing policy agreed between the different companies. Instead, this is done on an ad-hoc approach. Furthermore, the dissemination is hampered by uncertainties in the meta-data. For example, in the past conversion tables were lost, leading to data prior to 1980 become useless. In addition, no inter-calibration activities have been organised. Due to differences in modeling software, this means inconsistencies in monitoring and control (!) of adjacent areas.

15.4.2 Potential of Earth Observation

Dunea indicates that remote sensing techniques could provide a solution in several areas, namely:

- Continuous observations
- Observations irrespective of sensor networks, protocols and personal aspects
- Large Area covering observations.

15.4.3 Earth Observation applications

Although Dunea recognises a considerable potential in remote sensing, the operational application of satellite images has not yet been used. This is due to a number of aspects

- There is not enough data. For example, at this moment aerial photos with 10x10cm resolution with a false-color spectrum are currently being used. This is in contrast to the state-of-the art satellite remote sensing platforms, with only have 50x50cm resolution (while also missing infrared bands).
- Only False-Color data is currently used. With this, only a number of parameters can be measured. Although much research is being done into newer data types and models these are not being applied for dune-specific problems.
- There is a lack of knowledge with regard to earth observation. The number of people qualified to work with earth observation in Dunea is low. In addition, there are a large proportion of these qualified people who will retire within 10 years. As such, there is therefore a great need for the training of new "earth observation" experts.

- There are differences (in methodologies/protocols) between different institutions. This causes an inherent slowness in the system. After all, a change (in methodology) of 1 institute does not have a major impact on the collaboration between all stakeholders. In this regard, an inter-calibration campaign would already be very useful.

15.5 RIVM

Participant: Arno Hooijboer (RIVM), Joris Timmermans (Leiden University)

The National Institute for Public Health and the Environment (RIVM) works to prevent and control outbreaks of infectious diseases, promotes public health and consumer safety, and helps to protect the quality of the environment. As such, the main role of the RIVM is as a trusted advisor to government providing impartial advice on infectious diseases, vaccination, population screening, life style, nutrition, pharmaceuticals, environment, sustainability and safety.

Within this role, the RIVM is operationally monitoring the effects of agricultural fertilization onto the water quality on farms in the Netherlands (LMM, Minerals Policy Monitoring Programme). The LMM monitors the quality of water that leeches from the root zone (upper groundwater, drain water or soil water) and ditch water. At present this is being performed based on a national network of in-situ samplings. Afterwards these samplings are analysed within TNO. The current operational application has been deemed well suited to the current policy issues. However, there is a growing focus towards estimate water quality at higher accuracies. In the 6^{th} Nitrate Action Programme there is a focus on regional customization, which is on a smaller scale than provided within the current LMM. Also there is a wish for an effect driven policy. In particular, better effectiveness (accomplished by higher accuracy) is deemed to be achieved by having better representability of observations to the actual reality and a measurement harmonization at temporal scale. At present only 16 sampling points are within the measurement network. As such, the spatial variability of water quality within the ditches can be argued.

15.5.1 Institutional view towards remote sensing

The RIVM has a long history on the application of remote sensing, mostly for air quality. Therefore, although there are still several open questions remaining the potential of water quality within RIVM, the institute has a high positive attitude towards the application of remote sensing. In fact, within the RIVM, the board has decided to dedicate a significant time resource on the investigation of new innovative technology for the monitoring of water quality. The WaterSNIP project also aims to investigate application of remote sensing observations for monitoring the water quality, specifically nitrates and phosphor concentrations.

This project tackles the two individual topics from the LMM where water quality sensors might play a significant role: surface water (ditches) and leeching from the root zone (the upper ground water). From these two challenges RIVM expects to use remote sensing for the monitoring of the upper groundwater. For the monitoring of ditch water RIVM expect that automatic real time water sampling with sensors play the major role.

15.5.2 Surface Water.

The surface water that is being targeted in the WaterSNIP project concerns the ditches between agricultural plots. Considering the length scales of such ditches (~1m width), at present remote sensing cannot contribute to the strict requirements necessary for monitoring the water quality in the surface water bodies in question. Considering this, it is speculated that more advances can be achieved by increasing the number of in-situ measurements in the ditches. It is hypothesized that due to the flow within the ditches, a single measurement within the ditch will provide sufficient information on the agricultural fertilization. However, considering the total number of ditches in the Netherlands, full coverage is not achievable. In this sense, (future) remote sensing products (available at high resolution) integrated with the in-situ measurement network could provide such a full coverage. In such an information system, additional sensor measurements (such as provided by precision agricultural practises) could be integrated. Although such synergistic merging of remote sensing and local information flows is not being considered within WaterSNIP, there are some initiatives, concerning data harmonization, that could lead to such incorporation at a large stage.

15.5.3 Ground Water.

At present, most information on ground water quality is extracted from boreholes. This, however, does not provide a good understanding of the spatial variability. As such, within the WaterSNIP project, remote sensing is considered to provide this. As ground water cannot be observed directly from remote sensing, this approach focusses on monitoring the indirect effects of water quality of the vegetation. As both nitrogen and phosphor can induce stresses in vegetation growth. However, in such an application, other effects also need to be incorporated, such as salinity stress as well as drought stress.

15.5.4 Capacity Building

While within RIVM there is substantial knowledge regarding air quality remote sensing this is not available for water quality. Furthermore, it was specified that there is also no appropriate information regarding the different knowledge providers (universities/service providers). Naturally this originates due to the fact that WaterSnip only recently was started (2018). However, better insight to this might be helped if the community was not so sparsely distributed and there was better information regarding possible capacity building on this topic. The RIVM has specified that the most important aspect here is collaboration and joint participation in order to homogeneously gain knowledge.

15.5.5 Data sharing and Privacy

The RIVM strives towards an open-data policy, as adherence to the governmental policy on this. However, concerning the water quality measurements, this data is not openly shared. This is because the measurements are being performed on the farm sites under the agreement of privacy protection. It can be debated if water quality information should in fact be considered as privacy-sensitive information. However, RIVM relies on the approval of the farmers to perform their measurements, and hence is bound by their wishes.

In terms of remote sensing, however, such arrangement does not necessarily have to be created. As such, data sharing could be performed in a much more open manner, similar to the Basis Registratie Plots (BRP). However, before any specific decision is made, a more open discussion should be held. In particular, as with the advances of satellite remote sensing (resolutions), these data become more invasive to the human privacy. In this sense, new legislation should be considered (which would also be applicable for drones).

16 Appendix G: Remote sensing in Ecology symposium parallel sessions

In addition to the presentations of 'Remote Sensing in Ecology' experts, the 1st RSiE symposium also provided a platform for user consultation in the form of 3 parallel discussions. These three parallel discussions focus on the three layers of stakeholders of Ecology applications, namely researchers, the industry and government.

1. Integrating remote sensing with policy design
2. Bundling remote sensing and ecology efforts
3. Ecological user requirements on remote sensing

In the following paragraphs, the current issues/limitations (indicated by the participants) are provided, as well as possible opportunities to meet those challenges.

16.1 Integrating remote sensing with policy design

Policy making still depends on traditional research approaches of measuring in the field instead of looking at novel (large scale) approaches of collecting data, such as remote sensing. This complicates researching the different questions. Traditional samplings are in certain cases not objective. In such a scenario in-situ observations may conflict with one another; for example: hunters and ornithologists report differently on bird populations. Here, remote sensing can provide additional, and sometimes more detailed, data that can help with policy making. However, there are several problems in utilizing the potential of remote sensing data for policy design:

1. Low number of people having the appropriate knowledge: Dutch institutions should be brought up to speed on this so they can use this data.
2. The Netherlands has a tremendous ground data network. The added benefit of using remote sensing in the Netherlands is therefore lower than, for example, in developing countries where data density is lower. In that perspective the Netherlands is not a good proof of concept for the rest of the world because it is too well measured and we mostly benefit from additional improvements in spatial resolution. Our knowledge, however, could be exported to other regions.
3. Researchers and Policy makers use different communication routes. Scientific publications will, in general, not be read by policy makers, and consequently are not the way to promote integration of remote sensing data into governance.
4. End-users feel that they have not been included into the design of remote sensing programs.
5. User requirements are unclear! This is a result of a standoff between policy makers and researchers. On the one hand, policy makers do not know what is possible, while on the other hand researchers do not know what is required. In the end, the user just wants a map, while he does not need to know where it came from. They do, however, need to know what uncertainties are associated with the data.
6. There is a misplaced opinion on what the role of remote sensing should be. Remote sensing has in the past been advertised to solve all problems, thereby indirectly claiming to fully replace the traditional methods of performing research. This causes people to be hesitant on using these novel techniques, as they are unsure on whether or not they can adapt to these novel approaches.
7. Also, data is not always easy to find. While data of the Netherlands is abundant (PDOK, the National Georegister, Satellite Data Portal), it is not always easily accessible for users. Many data, like area photographs of the coast, are only accessible after asking the responsible government agency to provide a link.

16.1.1 Opportunities

Within the parallel discussion for 'integrating remote sensing with policy design' for each of these seven issues/challenges possible solutions were also discussed. These opportunities are given below.

1. In particular, the abundance of free public data should be emphasized to show the huge potential and build interest in remote sensing observations.
2. Many models are tested in small scale specific test locations and are never applied to larger scale. Since multiyear data has become available we are able to train and test models in larger areas. <u>We should try to go from small scale *in-situ* data to national scale.</u>
3. There is a middle ground between research testing and researches being taken up for application. We need to bridge that phase. Scientific publications are not the only way for which research to be made public. For instance, more effort could be provided to host small symposia that bring scientific progress to the industry and policy makers.
4. We should adapt a philosophy that integrates user consultation. For example, NASA Smart Mission involved the user community from the start. They had early adopters with synthetic data, so they could start straight away. This method accelerates applications. When data was missing the response was very fast.
5. *The issue (of missing user requirements) was discussed in more detail in the last parallel session. Therefore the opportunities on user requirements will be reported in the respective paragraph on this session.*
6. It needs to be made clear that satellite remote sensing is only a piece of the puzzle. In addition, people might be more susceptible to embedding remote sensing if the steps are smaller. For instance, when flying UAVs in conjunction to traditional sampling schemes, the initial change is less overwhelming. As an added reason, UAVs provide spatial resolutions that are currently simply unachievable by existing satellite sensors.
7. It would be helpful for users if a national remote sensing data website was developed.

16.2 Bundling remote sensing and ecology efforts

In order to facilitate a more coherent approach of integrating remote sensing in ecological researche, more intensive collaboration between universities, industry and government institutes is required. However, these efforts face the problems that remote sensing is still in its infancy. Therefore, knowledge of this field is not as far spread compared to other fields. Specifically:

1. Sharing knowledge between remote sensing experts themselves and ecologists: knowledge of remote sensing projects executed by one university is not always shared to other universities (apart from when the research is completed). This is not beneficial for the advancement of advancing remote sensing itself, or advancing research that uses remote sensing. In addition, most ecologists are not very interested in how remote sensing works, but are more interested in the end product. This leads to a decreased involvement of ecologists in remote sensing symposiums/workshops.

2. Sharing knowledge between remote sensing experts and government/industry. General public (including industry) has little understanding of "remote sensing" research at university level.

16.2.1 Opportunities

In order to better forward the integration of remote sensing in ecology, the following opportunities arise:

1. Sharing knowledge between remote sensing experts themselves and ecologists:

a. More symposia with a variety of research presentations, similar to the 1st RSiE. This has worked well in many fields. If such a symposium is cohosted by the Ministry or organised by ESA or another industrial leader, it has the potential to attract bigger audiences and involve more organisations. The overall objective of these symposia, however, should be kept small in order to create real impact.

b. Universities need to facilitate the requirement of high end researchers/developers working with remote sensing. For this a remote sensing program at masters level should be created. At present only few faculties/universities, such as ITC (University of Twente), have such a program. Furthermore, the ITC program focusses on students from, and case studies in, developing countries. In addition, at this moment (in most universities), there is not enough support for the implementation of nationally-oriented programs. A short term solution would be to have a centralized program until there is enough to be spread out across individual universities.

c. Connect data between people. Research data needs to be shared more freely between researchers, industry and policy makers. The first requirement here, however, is to have such data 1) be cross calibrated, 2) contain metadata (such as uncertainties and proper documentation), and 3) be processed with similar (consistent) process chains.

2. Sharing knowledge between remote sensing experts and governance/industry:

   a. Similar to having more workshops focussed on small specific goals, it would be beneficial to have symposia that involve more end-users, e.g. from companies, small and large. This may promote the use of remote sensing in the private sector.

   b. Sharing knowledge between remote sensing experts, governments and industry should be facilitated better. Examples of such efforts are working email lists and new groups that communicate needs or availability of student positions, information, etc. It should be noted that while efforts in general focus on the 'community' to create the discussions, it still requires a single organising body to act as moderator. This is required to keep the network "manageable" by keeping goals tight and clear.

   c. Create transparency between users and developers knowing what kind of data would be beneficial.

   d. Ministry: connect with users, like through data "hackathons" – ways to create value of remote sensing data into the private sector.

16.3 Ecological user requirements on remote sensing

As mentioned earlier, user requirements are often unclear! In principle this is caused by the lack of communication between policy makers and researchers. However, as found earlier, knowledge sharing between remote sensing experts and governance/industry is limited. There are two main reasons for this:

1. In principle user requirements (such as spatio-temporal resolutions, uncertainty levels and metadata availability) are application dependent. Furthermore within a single ecological application, such as monitoring ecosystem functioning, a large variety of spatio-temporal scales and uncertainty levels, have been identified in order to investigate (human-ecological, environmental-ecological) interactions across scales. However, reporting of such requirements has not been performed on a regular basis.

2. In addition, reporting on application requirements is complicated because, remote sensing in ecology does not (!) focus on individual data products, but instead uses a myriad of different products together. Furthermore, applications, such as ecosystem functioning and ecosystem diversity loss/patterns/stability, are benefitting from using combinations of remote sensing products. The large variety of datatypes does put severe constraints on which data is in fact useful. Only when data products meet the user requirements, advances in ecological studies can be accomplished. However, up to this moment, applications have simply used products on basis of their availability (in the eyes of the end user) instead of their suitability (in the form of user requirements) to the required study.

16.3.1 Opportunities

At present 'Remote Sensing (in Ecology)' stakeholders might have a misplaced mindset: applications depend too much on particular products, instead of products depending on specific applications. The first thing is to try to change the mindset: "first understand users on their information need", not "data need".

1. For this, first user requirements should be clear to the end users. Often even to the end users, it is not clear what requirements are necessary. Instead, end users provide nonrealistic wishes of future requirements, without considering current (and future) limitations. After end users have agreed upon a set of (application dependent) requirements, these requirements need to be provided to the scientists/industry. Most readily this could be performed during user consultations that can be held together with the workshops and collaborator's networks.
2. In addition, more clear (metadata) information should be provided on remote sensing products. Specifically, information on the scales of interest, format, and actual end user of the data. One possible solution is to consider maturity ratings (which have been defined for analyzing the maturity/applicability of Essential Climate Variables (ECV's)). In such a maturity rating, objective ratings can be highlighted on:
   - Data provisioning,
   - FAIRness (Findability, Accessibility, Interoperability , and Reusability) of the data,
   - Availability of metadata (such as dependency of bands, resolution),
   - Validation of the data,
   - Publication of the data (e.g. open-access, technical reports),
   - Computing solutions (such as cloud computing).

17 Appendix H: Exploratory study on Remote Sensing of Water quality.

17.1 Objectives

The objective of this task is to collect both field spectral data as well as water samples to evaluate the usability of spectroscopy to measure water quality parameters. Water samples will be collected at the same time as the spectral reflectance is measured with a RS-3500 spectrometer. Posteriorly, machine learning methods such as Random Forest or Support Vector Machines will be trained and tested using the spectral data as covariates and the various water parameters as the dependent variables.

This will provide insights of which spectral bands can better predict the presence/quantity of each water quality parameter and enable an understanding of the potential application of remote sensing using high-end hyperspectral sensors.

17.2 Research questions

- Can we predict water quality parameters through field spectroscopy?
- Can this field approach be used to parametrize machine learning models to predict water quality by using Remote Sensing?

17.3 Methodology

17.3.1 Data/materials collected

- Chemical
    - Chlorophyll(µg/L)
    - Dissolved Oxygen(mg/L)
    - Conductivity(µS/cm)
    - pH[1]
    - Phosphates(mg/L)
    - Nitrates(mg/L)
- Physical
    - Turbidity(NTU)
    - Water colour(Forel-Ule scale)
    - Water Temperature(ºC)
- Other
    - Spectral reflectance of the objects of interest(%)
    - Scene pictures (360º and Normal)
    - Geographic position

17.3.2 Field Equipment

- Portable HQ 40d electronic multi-parameter meter (HACH)+ probe
- AquaFluor Handheld Fluorometer/Turbidmeter
- RS-3500 Field Spectrometer
    - Spectral calibration pane
- 360º capable camera and a normal camera
- Water sample collection materials
    - Plastic pipettes and cuvettes,
    - 15ml plastic test tubes
    - Distilled water bottle

- Thermal bag
- Netlake citizen science water colour sheet[6]
- GNSS capable mobile[7]

17.3.3 Study sites

Markermeer

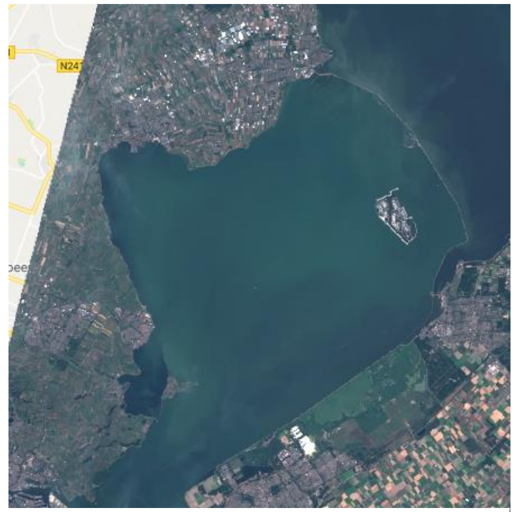


Figure 27 - Google earth engine clip of Markermeer

The Markermeer is a triangular shaped lake in Noord-Holland of about 700 km2 with a depth of 2 to 4 m. It has been used as a freshwater reservoir and as protection against flooding. Although it was not its original plan, it has become a location with significant ecological recreational importance.

Afgedamde Maas

This tributary of the Waal river connects the town of Woudrichem and Heusden. The company Dunea has a water quality monitoring station in this tributary river.

Figure 28 - Google earth engine clip of Afgedamde Maas

Location	Codename	Date Visited	dLatitude	dLongitude	Field samples	Phosphate samples	Nitrates samples
Afgedamde Maas	Woudrichem_1	18-09-18	51,810750000	5,011466667	10	1	1
	Woudrichem_2	18-09-18	51,782700000	5,061650000	10	1	1
	Woudrichem_3	18-09-18	51,785050000	5,116950000	10	1	1
	Woudrichem_4	28-09-18	51,773716670	5,136916667	10	1	1
	Woudrichem_5	28-09-18	51,741383330	5,185850000	10	1	1
Markermeer	Markermeer_1	01-11-18	51,467283330	5,331316667	10	1	1
	Markermeer_2	01-11-18	52,519716670	5,436400000	10	1	1

17.3.4 Sampling Protocol - overview

1. Opportunistic sampling approach
2. Plots were considered as 10x10m areas where spectral profiles of water and nearby bodies were collected
    a. Geographic position
    b. 360º image of the location
    c. Photograph of the sampling area
3. For each Water body with a plot
    a. 10 spectral samples were collected
        i. The probe was aimed in the direction of the target object at approximately 1m distance.
    b. On the same location where each spectral sample was collected the following water quality parameters were also collected:
        i. Chlorophyll;
        ii. Dissolved Oxygen
        iii. Conductivity
        iv. pH
        v. Turbidity
        vi. Water temperature
    c. 2 water samples were collected for lab analysis and the following parameters were posteriorly quantified in the lab:
        i. Phosphates
        ii. Nitrates
    d. Water colour was estimated using the Netlake citizen science water colour sheet protocol
4. For other objects within the plot:
    a. Vegetation: 5 spectral samples were collected
    b. Other objects (roads, land, dirt, etc): 1 spectral sample

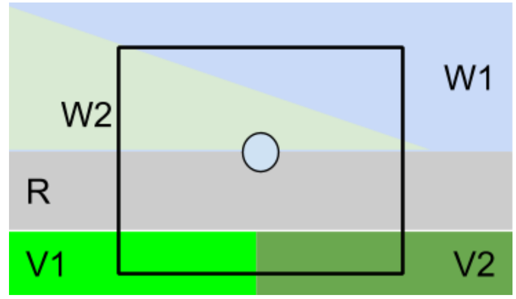


Figure 3 – Visual exemple of sampling plot; W – Water; R – Road; V – Vegetation; Numbers represent different types.

17.3.5 Operation

1. The first operator collected the spectral samples in succession in intervals of approximately 2m from each other.
2. At this step, each operator collected samples either using (HACH) meter or the AquaFluor individually.
    a. The Hach meter requires the use of probes which are simply positioned in the water to obtain the measurements.
    b. The AquaFluor requires the collection of a water sample to be measured inside the equipment
    c. Both devices were used in the same locations where each spectral sample was taken
3. Once this step was finalized, 2 sets of 15ml water samples were collected and stored in the thermal bag
4. Water colour was estimated for the entire plot (or different water body) using the protocol described in Netlake project: https://nioo.knaw.nl/sites/default/files/downloads/Protocol%204b%20Water%20Colour%20manually.pdf

5. Pictures of the locations were taken using both cameras
6. GNSS coordinates were recorded

Figure 4 - Preparing the location; white buckets used to mark the spots for sampling; Locations like the one on the right were avoided due to the difficulty in safely operation the spectrometer on them.

17.3.6 Machine Learning Methods

Also, before reporting the results, it's important to summarize the following parameters for each of the machine learning models:

Support Vector Machine:

- R package: e1071
- Kernel: Radial
    - Tuning approach: Grid search
    - Grid limits:
        - Gamma – 0.1 to 0.9 by 0.1 steps
        - Cost – 1 to 106 by 11 steps
    - Each model was run on the best solution of the grid search
- Type: eps-regression

Random Forest:

- R Package: randomForest
- Default settings
    - Number of trees: 500
- No tree pruning

17.4 Hyperspectral Exploratory data analysis

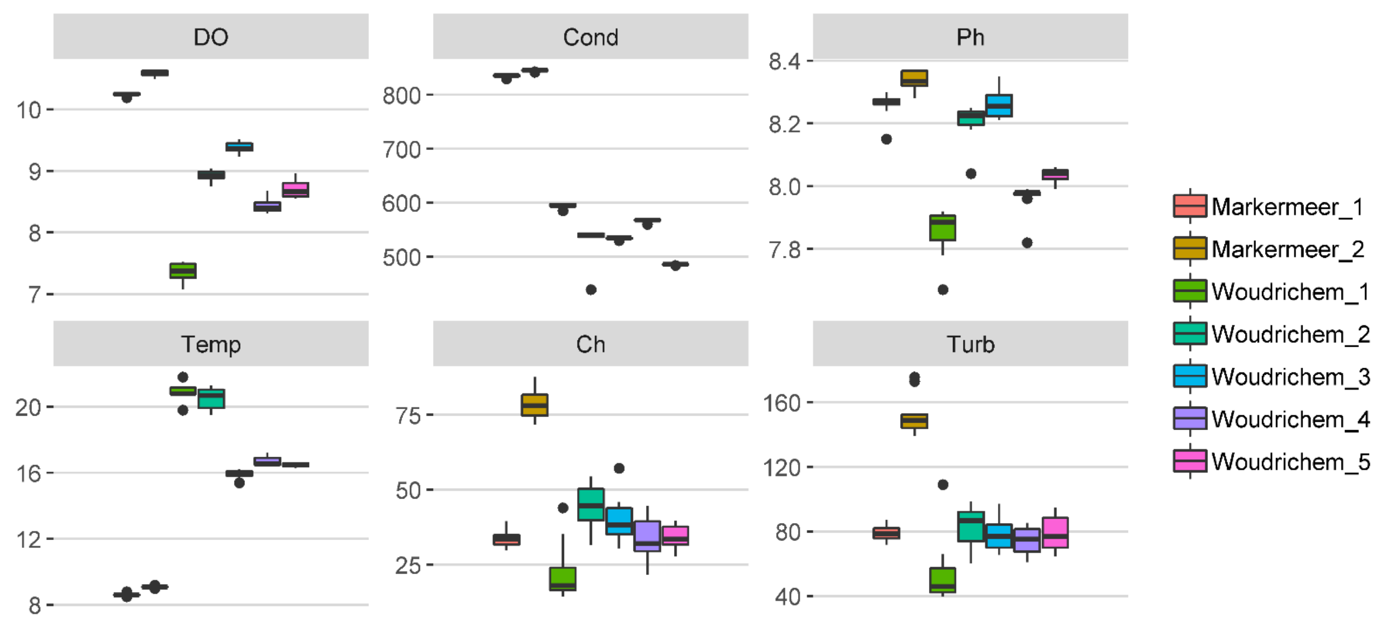
The first step of every EDA exercise is to investigate the differences on the available data. An initial data exploration revealed very low variation on the parameter of water colour. Since we experienced very low variation of water colour during our fieldwork, we consider that it is not sensible to analyse this data. On the other hand, since only 7 locations were sampled for water nutrients, we consider that it is also incorrect to do any analysis that aims to correlate nutrients with spectroscopy. Since we only have one sample of each water nutrient parameter per plot, it is not meaningful to make a per plot comparison of these as well.

17.4.1 Are there any significant differences between each sampling plot?

Since we can't confirm that all the data collected in the field follows a parametric distribution (e.g. normal distribution) we need to use a non-parametric test. The Kruskal-Wallis test offers an alternative to perform this assessment. It is important to denote that the null hypothesis is that the medians of all groups are equal, while the alternative is that at least one median of one group is different.

Variable	Pval	H0:
DO	1,79E-12	Rejected
Cond	2,28E-12	Rejected
Ph	1,30E-11	Rejected
Temp	2,76E-12	Rejected
Ch	8,38E-08	Rejected
Turb	1,09E-06	Rejected

Since the Pval is lower than 0.05, we can reject that the medians of the different groups are equal. This test does not tell us which samples are different, a follow up test must be done to evaluate this. The Dunn Test pairwise comparisons using the Bonferroni method for p-value adjustment is chosen for this report. A more obvious way to confirm and explore these differences is by visualizing the boxplots in function of each sampling location.



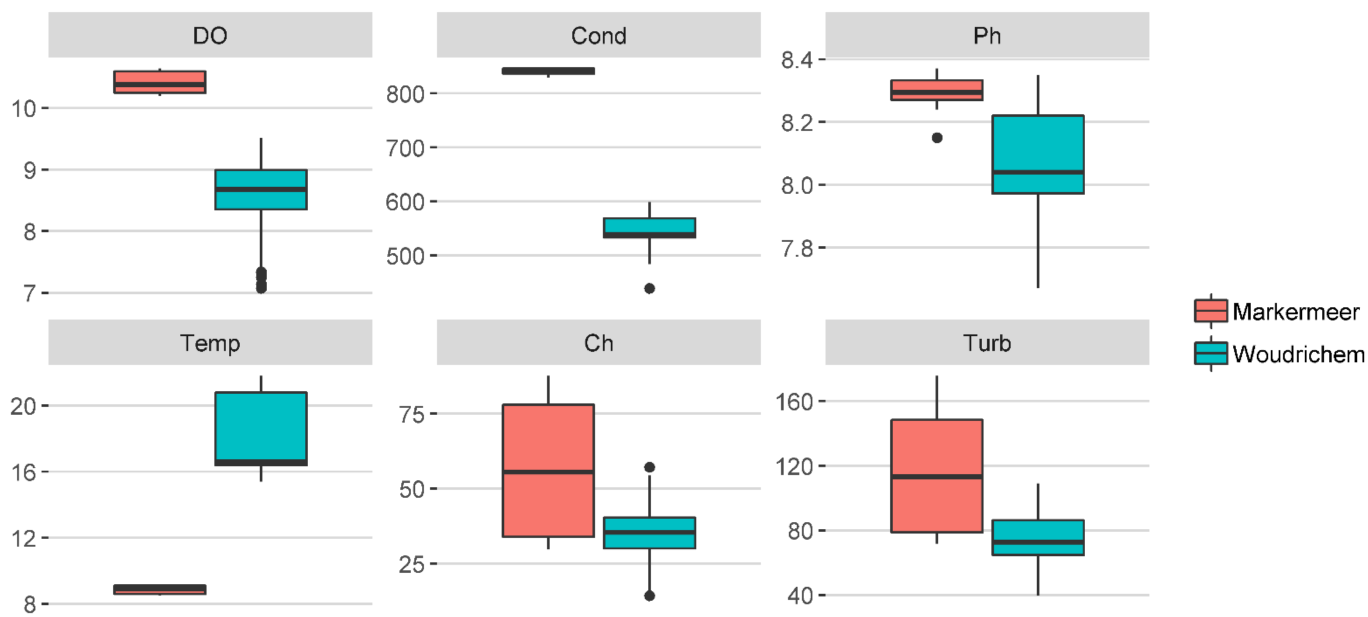
Each location was given a different number. Observing this box-plot the variation between each site is easily identifiable for most cases. **<u>The analysis of our data collected in the field enables us to conclude that there are indeed differences between each sampling plot for most cases/most parameters.</u>**

17.4.2 Are there any significant differences between the two different locations?

This exercise is in everything like the previous but focusing on the two locations: Markeemeer and Woudrichem.

Variable	Pval	H0:
DO	7,97E-11	Rejected
Cond	2,28E-11	Rejected
Ph	1,30E-08	Rejected
Temp	2,76E-11	Rejected
Ch	6,45E-03	Rejected
Turb	1,01E-04	Rejected

Since the Pval was lower than 0,05 for all cases, it is possible to reject the null hypothesis for all cases. The Dunn Test now allows us to investigate the differences between each variable..



Contrary to the previous analysis, in this case it is possible to add the summary of the Dunn Test output here. The following table shows that for all cases, **<u>there was significant difference between both locations and variables measured</u>**.

	Markermeer - Woudrichem
Variable	P- adjusted
Dissolved Oxygen	7,972E-11
Conductivity	7,603E-11
Ph	2,060E-08
Temperature	7,192E-11
Ch	6,456E-03
Turbidity	1,014E-04

17.4.3 Are any of the field collected parameters correlated with each other?

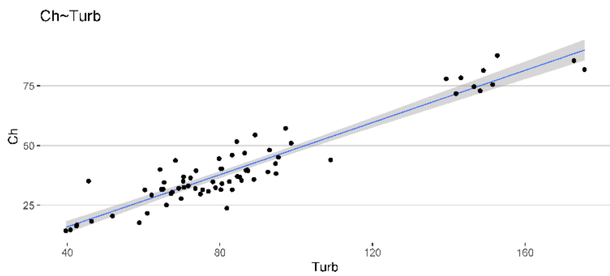
Determining an empirical relationship between these parameters can potentially enable the use of one variable as a proxy of another variable. It's also important to always determine the potential correlations between variables before any further modelling that uses this data.

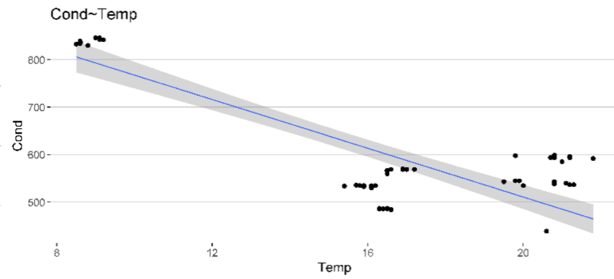
An overview of these correlations can be seen in the following table:

	R^2	p-val	Intercept	p-val	slope	p-val
DO~Cond	0,505	***	5,786	***	0,005	***
DO~Ph	0,811	***	-34,149	***	5,318	***
DO~Temp	0,776	***	12,149	***	-0,198	***
DO~Ch	0,455	***	7,501	***	0,039	***
DO~Turb	0,475	***	7,129	***	0,023	***
Cond~Ph	0,253	***	-2637,379	***	401,586	***
Cond~Temp	0,714	***	1024,102	***	-25,658	***
Cond~Ch	0,235	***	473,489	***	3,764	***
Cond~Turb	0,310	***	413,785	***	2,495	***
Ph~Temp	0,420	***	8,512	***	-0,025	***
Ph~Ch	0,436	***	7,867	***	0,006	***
Ph~Turb	0,370	***	7,837	***	0,003	***
Temp~Ch	0,263	***	20,822	***	-0,131	***
Temp~Turb	0,357	***	23,014	***	-0,088	***
Ch~Turb	0,892	***	-5,819	**	0,546	***

(*** means p-val ≤ 0.0001)

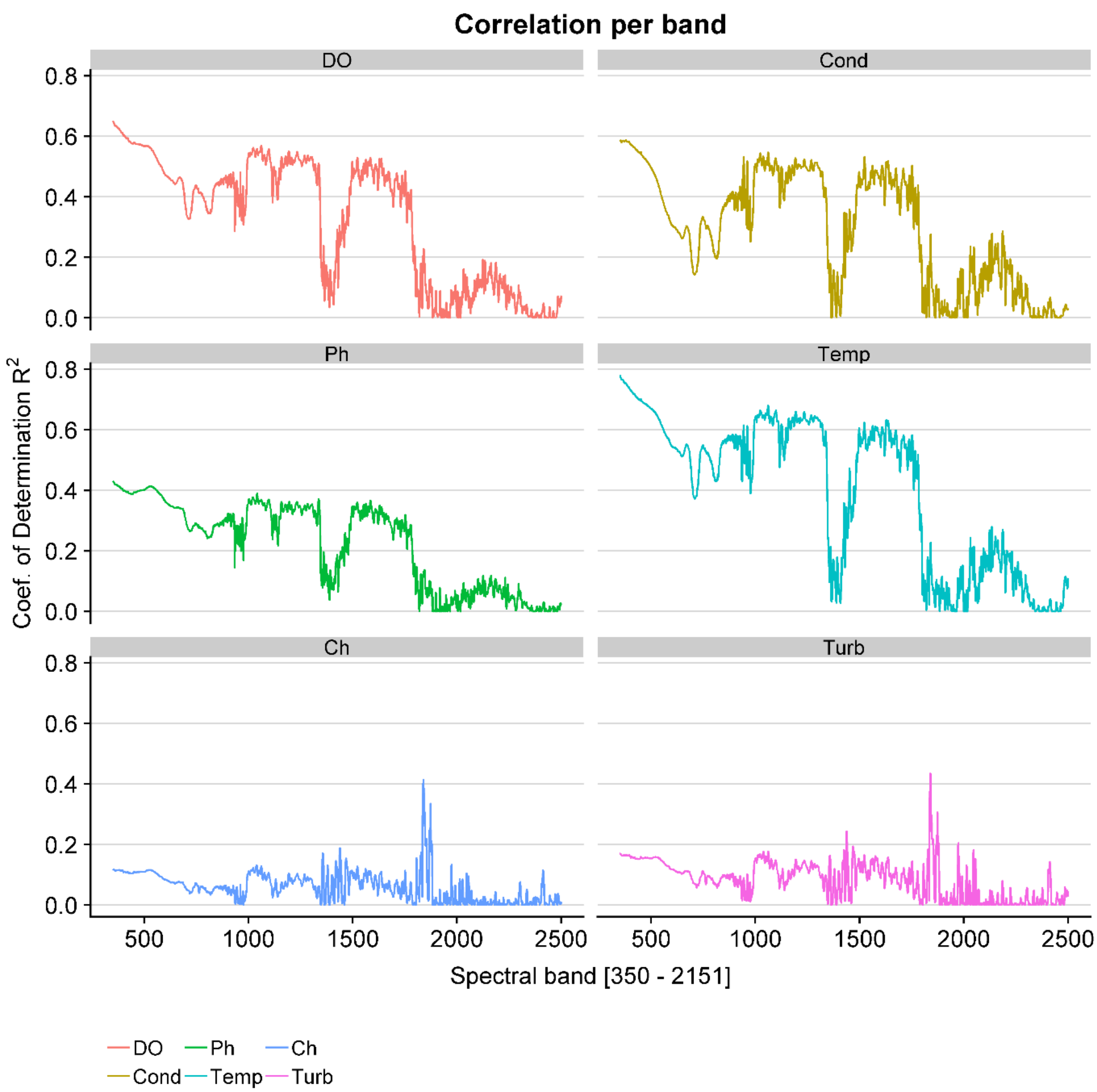
Some high correlations between parameters were found: Dissolved oxygen is highly correlated with pH and Temperature; Conductivity was found to be correlated with Temperature and Chlorophyll-a was found to be correlated with Turbidity. Some cases are expected, for example, chlorophyll-a and turbidity are often found to be correlated in research. Still, in some cases these R^2 appear to be inflated if we take look at the X, Y plot of the graphic. It's possible that with more field data, the observed R^2 would become more meaningful.





By looking at both these example graphs we can see how R^2 can be misleading. While on the left side it is clearly visible that there is a relationship between Chlorophyll-a and Turbidity, on the right side, the reported R^2 of 0.7 can be misleading. Still, potentially collecting more field data could result in more confidence in the reported R^2.

This is the first part where we assess if there is any relationship between the parameters we measured in the field and the spectral properties of the water we collected at the same time. This is a simple evaluation of the variation of the R^2 value between each spectral band and the measured value. It can provide an insight if there is any particular band or set of bands that are of interest.



These results show that there is no specific band with very high possibility of predicting any of the field data parameters. Only for temperature, where the bands with lowest wavelength seem to be very correlated with temperature.

On the other hand, there is significant evidence of correlated response between the spectral responses of the different parameters as these seem to follow similar patterns. It is important to consider that the Ch and Turb were obtained using the AquaFluor while DO, Cond, pH and Temp were all obtained using the Hach meter.

There are clear patterns that carry over from the measuring device but the value of R^2 is quite different for most cases. These exploratory results imply that any further algorithm to be applied to the spectral bands should address this autocorrelation between the signals. One option is to reduce the spectral responses to their most significant components of variation using a PCA technique.

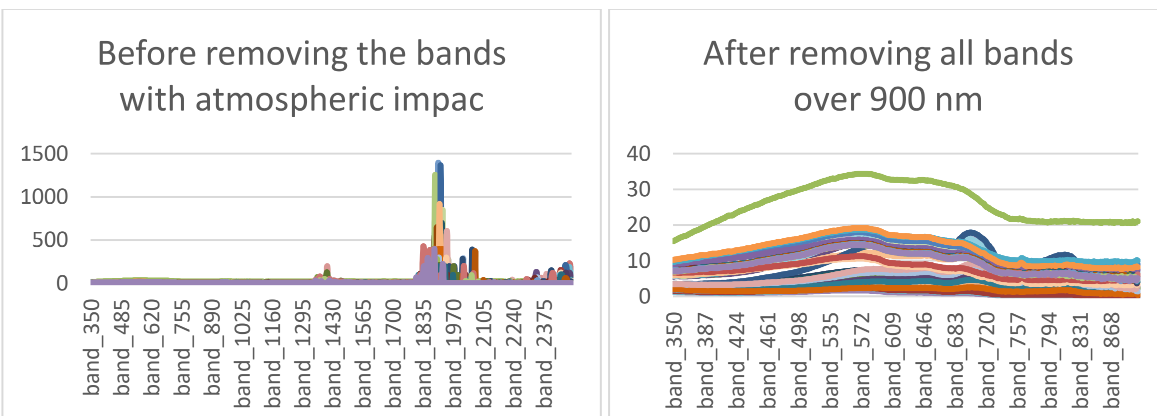
17.4.4 Predicting Water quality parameters through Machine Learning

In this step we evaluated the possibility of predicting the parameters using machine learning techniques. We opted to do this step using two specific algorithms due to their robustness and common usage in the field of Remote Sensing: Support Vector Machines (SVM) and Random Forest (RF).

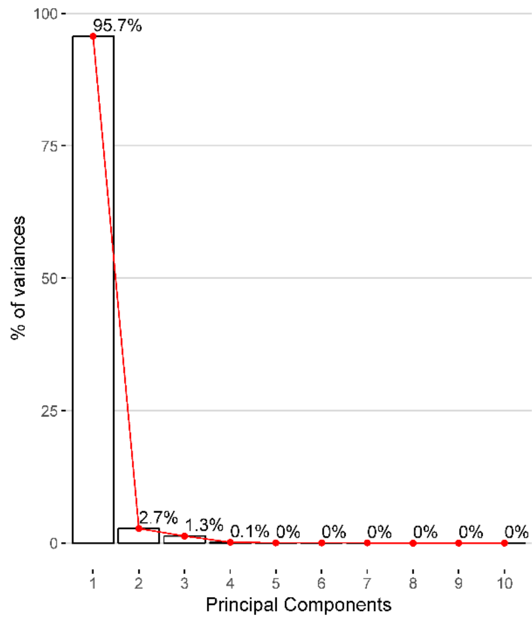
Due to the overall low number of samples we evaluated the accuracy by repeating each model 100 times. For each run, 60% of the data was randomly sampled for training and 40% left for validation. We then accessed the average of the correlation coefficient, sum of squared errors and mean squared error between the real data and the predicted data for each model run. To further access the models, we also produced Taylor diagrams that allow us to visualize the spread of our predictions.

We implemented these algorithms in two different datasets: 1. To reduce the autocorrelation impact on the explanatory variables, we reduced their dimensionality through a PCA. 2. By converting the bands to the equivalent bands in the Sentinel-2 satellite. This allows us to test the usability of calibrating models based on the field data to create predictions using the satellite data.

The PCA band reduction was done only on the bands between [350, 900] to remove the impacts of the atmosphere. The figure below shows the impact of the atmospheric windows (or not) on the data. Specific bands collected 0% reflectance and therefore, the solution was undetermined. These bands need to be removed before applying the PCA or they will have the most impact in the data variance.



The first step is to show how many components of the PCA were selected and why.



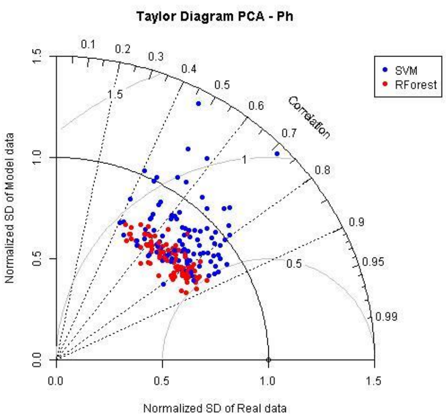
A total of 70 components were defined while only the first 10 are plotted above. The first 4 components have over 99% of the overall cumulative proportion of the variance. These were the 4 components used to train the SVM and RF models.

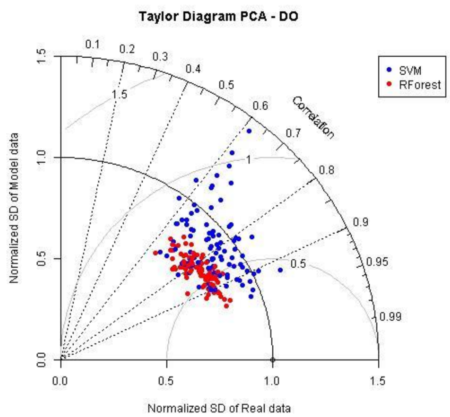
The average correlation between validation - model per run are reported in the following table:

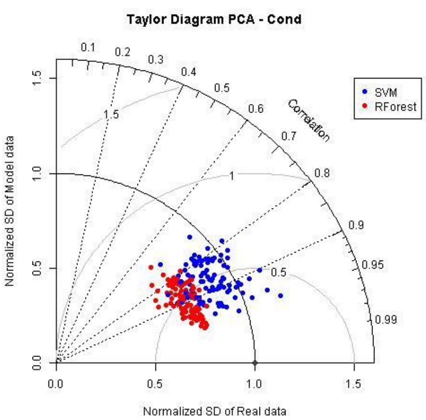
		R^2	Sum of squared errors	Mean squared error
Dissolved Oxygen	SVM	0,79	7,28	0,28
	RF	0,87	4,74	0,18
Conductivity	SVM	0,84	91407,00	3515,70
	RF	0,87	87264,00	3356,30
Ph	SVM	0,74	0,25	0,01
	RF	0,82	0,17	0,01
Temperature	SVM	0,86	86,84	3,34
	RF	0,88	88,74	3,41
Chlorophyll-a	SVM	0,71	2778,00	3,34
	RF	0,69	3077,00	118,33
Turbidity	SVM	0,72	8157,00	313,70
	RF	0,68	9633,00	370,50

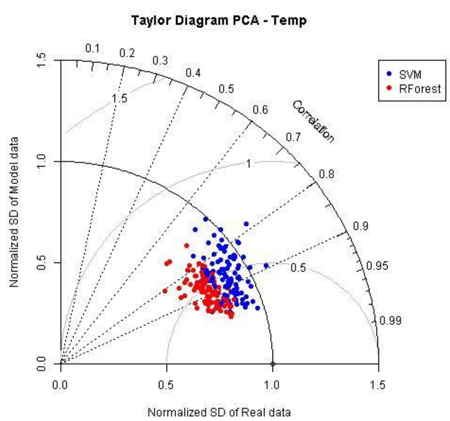
The higher the R^2 the better the correlation between the predicted values and real data. R^2 does not give an indication if the actual predicted values are in the same dimension as the real data. For that, we should investigate the SSE and MSE that give an indication of how close our predictions were to the real data. The lower these are, the better. In most cases the models are below par except for the Ph, DO and temperature. This is likely a consequence of the lack of field data which would allow more robust models to be developed.

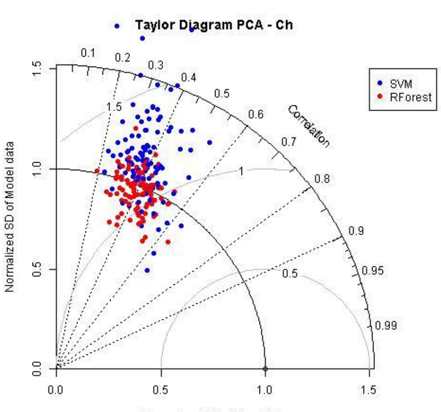
Another alternative to look into the model output is to see the variation of each iteration. For that, the following Taylor Diagrams are shown:

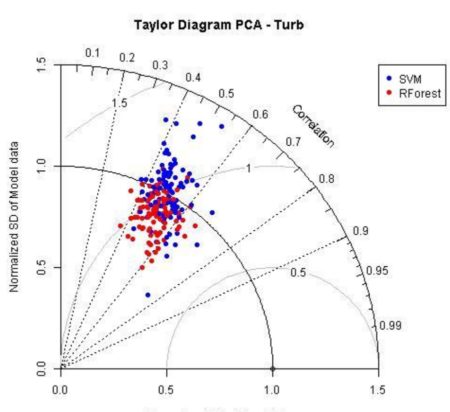












These diagrams show the dispersion of the R^2 from 100 iterations and give an insight into how much impact each sample run can have on the final model. An ideal model would have a R^2 of 1 and a coinciding SD between the Real and predicted data. Although some of the models performed better, none was perfect.

17.5 Sentinel-2 exploratory analysis

For the next step, we converted the spectral responses of the spectrometer to the equivalent bands of the Sentinel. The following information is provided by ESA regarding the Sentinel-2 bands:

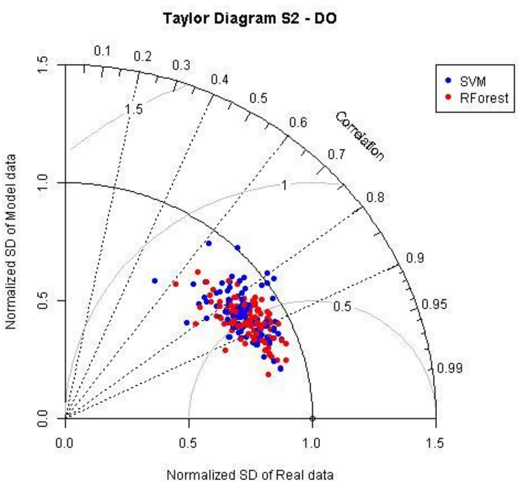
Sentinel-2 bands	Central wavelength (nm)	Bandwidth (nm)	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
Band 1 Coastal aerosol	442,7	21	442,2	21	60
Band 2 Blue	492,4	66	492,1	66	10
Band 3 Green	559,8	36	559	36	10
Band 4 Red	664,6	31	664,9	31	10
Band 5 Vegetation red	704,1	15	703,8	16	20
Band 6 Vegetation red	740,5	15	739,1	15	20
Band 7 Vegetation red	782,8	20	779,7	20	20
Band 8 NIR	832,8	106	832,9	106	10
Band 8A Narrow NIR	864,7	21	864	22	20
Band 9 Water vapour	945,1	20	943,2	21	60
Band 10 SWIR – Cirrus	1373,5	31	1376,9	30	60
Band 11 SWIR	1613,7	91	1610,4	94	20
Band 12 SWIR	2202,4	175	2185,7	185	20

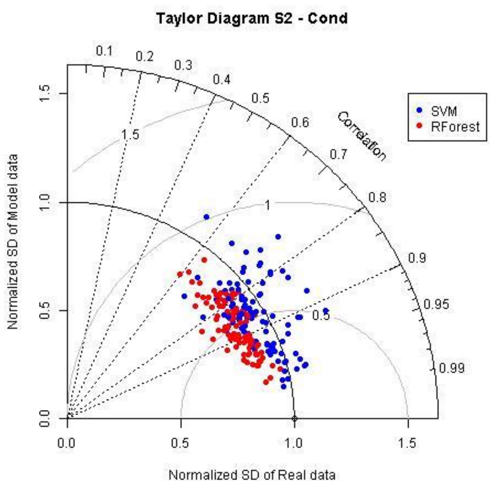
This information was considered for creating substitute bands from our spectrometer data. We considered the lowest and the highest spectral value (central wavelength + ½ bandwidth) between the two satellites A/B and averaged the value of our readings on the spectrometer. Only the bands critically unaffected by the atmosphere were used: Bands 1 to 8A from the previous table. The following table shows the average result of 100 independent runs of the SVM and RF for this dataset.

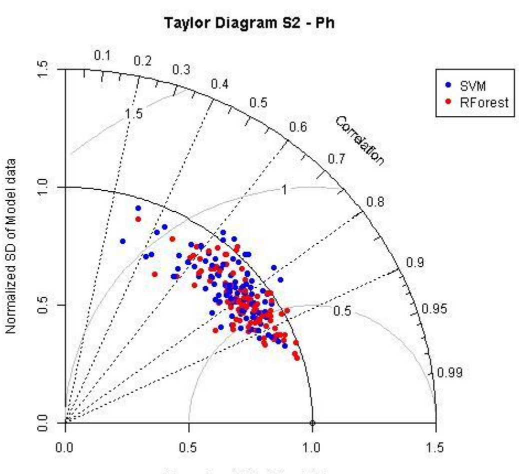
		R^2	Sum of squared errors	Mean squared error
Dissolved Oxygen	SVM	0,87	4,21	0,16
	RF	0,89	3,35	0,13
Conductivity	SVM	0,89	64943,00	2497,80
	RF	0,83	89872,00	3456,60
Ph	SVM	0,77	0,20	0,01
	RF	0,86	0,13	0,00

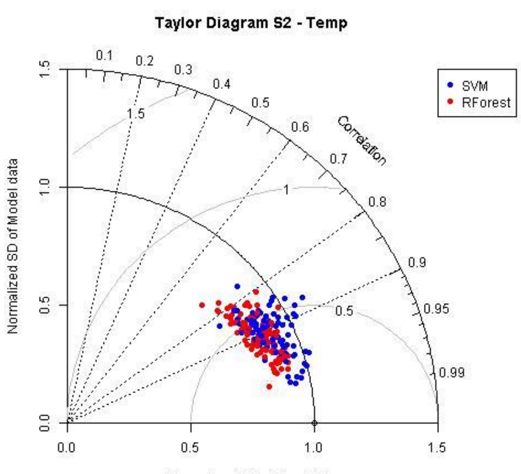
Temperature	SVM	0,93	43,57	1,68
	RF	0,90	59,62	2,29
Chlorophyll-a	SVM	0,71	2940,00	113,09
	RF	0,71	2783,00	107,04
Turbidity	SVM	0,67	9281,00	357,00
	RF	0,69	8676,00	333,70

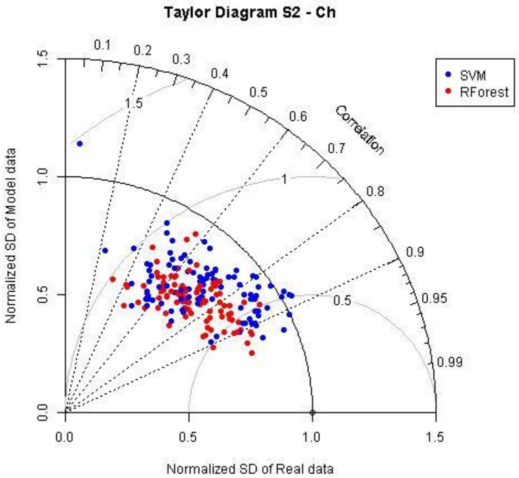
The same conclusions from this table can be drawn. R^2 gives an indication of the agreement between the model and the real data but does not give a good indication of how close they are between them. pH was the only parameter where there was a good agreement and correlation between the predicted and real data.

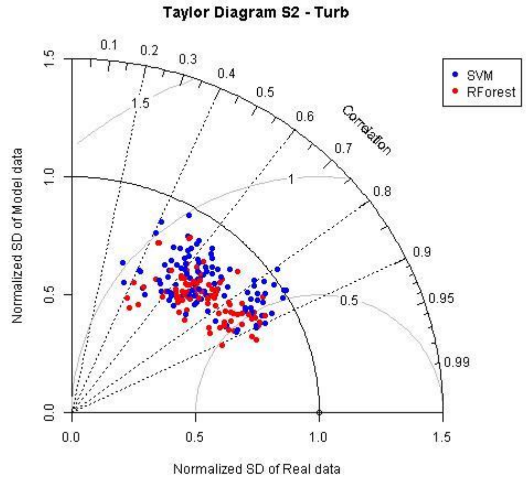












The Taylor diagrams offer more insights into the dispersion of our solutions. These show that there is some agreement between both machine learning methods and that the more consistent method is the one predicting temperature. Ultimately, with more field data to train a better model, this approach would allow us to predict water quality through Remote Sensing by training a model based on field spectroscopy.