Water Quality Information for the Benefit of Society

Earth Observation of inland and coastal water quality: recent developments, priorities & public engagement

Loch Venachar, Scotland (photo credit Merrie Beth Neely)

Workshop Summary Report

29-31 August 2018, University of Stirling, Stirling, UK

a joint meeting co-organised by GEO AquaWatch & the NERC GloboLakes project

Water Quality Information for the Benefit of Society

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Executive Summary

A joint workshop between the United Kingdom's GloboLakes project and Group on Earth Observation (GEO) AquaWatch Initiative was held in Stirling, Scotland 29-31 August 2018. This workshop marked the culmination of the six-year GloboLakes project as well as featured the latest applications of Earth Observation (EO) to inland and near-shore coastal waters at local, regional and global scales and contributions to improved water management, climate studies, and achieving Sustainable Development Goals (SDGs). We engaged in community discussions of data and technology challenges, linkages between EO data providers and stakeholders, community-based water monitoring, and finally we identified the future GEO AquaWatch Initiative activities. The following is a brief summary of the workshop outcomes.

Needs of the community

Gaps and challenges highlighted by the community include:

- Standardization and accepted protocols for in situ data used for validation efforts. Increased availability of in situ data for algorithm development and atmospheric correction improvements
- Collaboration with existing national Water Quality (WQ) monitoring programs to assist with algorithm development and satellite validation and fill temporal gaps. Validation data needed for all optical water types and geographic regions.
- Barriers to users accessing available satellite products, lack of expertise to use and interpret imagery. Training materials should be offered in multiple languages
- Quality control of satellite products, transparency of how products were derived, algorithms, associated uncertainties
- Continued evolution of higher spatial resolution products using Sentinel-2 Multispectral Instrument (MSI) and Landsat, expanding the inventory of water bodies monitored
- Increased engagement with social and economic sciences for better understanding of informational needs
- Strengthen partnerships between the scientific community and end users to understand user requirements (temporal, spatial, parameters) and gain access to local data for validation
- Recommendations on new sensor designs, fulfilling requirements for inland waters, examining tradeoffs in temporal, spatial and radiometric resolutions
- Better marketing of existing products, garnering trust from the end users and further transition to operational tools.

Future Focus of AquaWatch

The workshop participants discussed and recommended changes to the current AquaWatch objectives and redefining the Water Quality Information Service (WQIS). With the advent of Analysis Ready Datasets (ARD) from multiple sources (e.g. Copernicus, United States Geological Survey (USGS)-Google Earth Engine, *Calimnos* from Globolakes Consortium, Open DataCube) AquaWatch should consider modifying AquaWatch's central goal of developing and delivering an EO-based global water quality system (i.e. new portal) to coordinating and integrating ARD-validated water quality EO systems. This "supportive" focus could include:

- Build knowledge hub, which would provide information and direction to water quality practitioner with all levels of expertise, i.e. from catalog of algorithms to readily available water quality products for area of interest. Understanding training needs (survey), developing educational materials and conducting capacity building programs, with an emphasis on developing countries. Topics include remote sensing theory, image processing, current software options and WQ data interpretation.
- Update existing data product inventory on the AquaWatch website (In situ, remote sensed, portal/static data sets), gap analysis and develop a database that is query-able. AquaWatch should provide the connection between project-based efforts and provide the transitional efforts to fully utilize these finding by technology transfer, outreach and end user training.
- Develop high profile demonstration projects that engage policy- and decision-makers, which would be useful in promoting EO as sustainable development tool and contribute the SDG program.
- Provide leadership and foster collaboration in the critical need for the validation of satellite products and activities surrounding that effort, including in situ water quality parameters and optical properties. Partner with related activities within the Committee on Earth Observation Satellites (CEOS) community.

Workshop Overview

Inland and near-shore coastal environments deliver multiple ecosystem services that benefit society, including food, water, energy, navigation and recreation resources that contribute to our economies, whilst also being crucial to regional and global-scale biogeochemical cycles. Freshwater availability is ranked among the greatest threat to global economy, and yet only a fraction of global inland water systems are routinely monitored for water quality.

The United Nations (UN) development agenda now fully recognizes the importance of managing water resources to reach the United Nation's SDGs and fosters collaboration across countries. Global Climate Observing System (GCOS) also recently deemed satellite-derived lake temperature, ice cover, and water-leaving reflectance as Essential Climate Variables (ECV). Data collection by EO satellites is expanding, and its suitability for observing inland and near-coastal water bodies makes remote sensing a valuable source of data on water quality and ecosystem condition at local and global scales. The workshop marked the culmination of the six-year GloboLakes project funded by the United Kingdom Natural Environmental Research Council (UK NERC) and featured the latest applications of EO to inland and near-shore coastal waters at local, regional and global scales and contributions to improved water management, climate studies, and achieving SDGs. We engaged in community discussions of data and technology challenges, linkages between EO data providers and stakeholders, community-based water monitoring, and finally we identified the future GEO AquaWatch Initiative activities. The workshop had presentations from many international projects and partnerships, providing unique opportunity to engage with the international water quality EO community, **with special emphasis on author/presenters and participants highlighting identified information gaps, and current unmet challenges and opportunities arising from their work and projects.**

Day 1 – GloboLakes

The first day was devoted to UK NERC-funded six-year GloboLakes Project with presentations of current status and future plans, (Hyperlinks to the presentations and posters are provided within the daily agendas below, and are archived on the GEO AquaWatch website).

Session 1: GloboLakes: The Development. Chair: Steve Greb, GEO AquaWatch

GEO AquaWatch Overview: Steve Greb, GEO AquaWatch
GloboLakes: The Overview: Andrew Tyler, University of Stirling
Optical Water Types and *LIMNADES*: Vagelis Spyrakos, University of Stirling
Algorithm Development at the Global Scale: Water Quality: Peter Hunter, University of Stirling
Lake Surface Water Temperature: Laura Carrera, University of Reading

Session 2: GloboLakes: Data Processing and Analysis. Chair: Carsten Brockmann, Brockmann Consult, GmbH

Near Real Time Data Processing and *Calimnos*: Stefan Simis, Plymouth Marine Laboratory
Estimating Drivers of Change: Mark Cutler, University of Dundee
Dealing with Data Uncertainty: Claire Miller, University of Glasgow
Clustering Lake Responses to Environmental Change: Mengyi Gong, University of Glasgow

Session 3: GloboLakes: Understanding Change. Chair: Andrew Tyler, University of Stirling

Status and Attribution of lake Water Quality: Laurence Carvalho, Centre for Ecology & Hydrology
Global forecast of the sensitivity of lake phytoplankton to environmental change: Ian Jones, Centre for Ecology & Hydrology
Global seasonality of lake phytoplankton: Ellie Mackay, Centre for Ecology & Hydrology
Predicting Lake Surface temperature dynamics: Stephen Maberly, Centre for Ecology & Hydrology

Session 4: GloboLakes: Wrap Up. Chairs: Andrew Tyler & Steve Greb

Day 1 Summary of GloboLakes Findings, Identified Information Gaps, and Current Unmet Challenges and Opportunities Arising From Their Work and Projects

A. GloboLakes Overarching Themes and Outcomes:

Our planet's surface waters are a fundamental resource encompassing a broad range of ecosystems that are core to our water, food and energy security in addition to biodiversity and global biogeochemical cycling. Despite this, these same waters are impacted by multiple conflicting demands, the effects of which are compounded further by the pressures and drivers of environmental change. In recognition of the very limited data available on the status and change in the quality of our inland waters globally, the UK NERC-funded six-year GloboLakes research programme was developed to investigate the state of lakes and their response to climatic and other environmental drivers of change. This was achieved through the realization of a near-real time satellite-based observatory (Sentinel-3) and archive data processing (MEdium Resolution Imaging Spectrometer (MERIS))) to produce a >10-year time-series of observed ecological parameters and lake temperature for more than 1000 lakes globally.

The series of presentations provided an overview of the approach adopted by the GloboLakes team to deliver a global observation platform exploiting European Space Agency(ESA) EnviSat MERIS and Sentinel 3 Ocean and Land Colour Instrument (OLCI) data. GloboLakes galvenised the global inland water community into providing data to the project for over 1500 lakes globally for calibration and validation activities. These data have been used to develop the community owned database *LIMNADES* which is being developed for the EO water quality community. GloboLakes contributed in excess of 650 data points to this data sets from a diverse range of inland and coastal waters. Data from over 4000 in situ radiometric stations from 250 lakes globally were used to statistically define thirteen optical water types (OWTs). These data provided the framework to test and retune published algorithms for optical water quality constituent retrieval (chlorophyll a, phycocyanin, colour dissolved organic matter and total suspended matter). The best performing algorithm for each OWT were then tuned dramatically improving product accuracy. GloboLakes also reviewed and identified the best performing atmospheric correction for water constituent retrieval across the different OWTs. The presentations also described the challenges and solutions in the development of a Lake surface water temperature was also included in the array of variables mapped global observation platform.

The *Calimnos* processing chain was developed as a collaboration between Brockmann Consult, the Plymouth Marine Laboratory and the University of Stirling. *Calimnos* uses the best-available algorithms, dynamically assigned to optical water types at the pixel level for each image and each lake, and tuned to remove systematic errors in atmospheric correction. Effective validation of *Calimnos* outputs necessitated the need to take into account the uncertainties on in situ data as well as the satellite products. Demonstrations were provided of the need to account for these uncertainties in match-up data in addition to combining in-situ and satellite date from different temporal and spatial scales.

The drivers of environmental change were also assessed for the 1000 catchments associated with each lake. A global dataset of sensitivity factors (lake properties) and climatic and terrestrial spatio- temporal variables provide the basis to apportion the key drivers of observed change alongside a statistical analysis of understanding how clusters of lakes changing coherently or incoherently within the global data set. This analysis has also included modelling of lake vulnerability based on 'human pressure risk' and 'lake sensitivity'.

Preliminary results of the local and global examples of the data outputs were presented, including the global eutrophic status of lakes and how these are changing over recent years. The data are now being used to assess the differential sensitivity of lakes to catchment and climate change drivers. The data are also being use to drive models of lake responses to future climate change scenarios including resulting changes in temperature and chlorophyll a.

B. Summary of GloboLakes Information Gaps:

In situ data continues to be needed for the development of the OWT system and its adoption to other sensors including Sentinel 2. Understanding how the OWT system work with different sensors and the deterioration in sensor performance also needs to be explored. Validation data are biased towards OWTs with moderate to high Chl-a; more focus needed on low biomass waters to improve algorithm performance as identify system vulnerable to change.

Discussions over Glengoyne Distillery whisky-tasting at the beautiful Venechar Lochside restaurant with breaktaking views! (photo credit Merrie Beth Neely)

C. Summary of GloboLakes Current Unmet Challenges:

Data Quality remains a challenge and there is a need going forward to try and standardise in situ data entry to ensure comparability and quality of data around the world for cal/val activities. Some European programmes developing Research Infrastructures (e.g. DANUBIUS-RI) are addressing these issues. Simple solutions must include the deployment of in-situ sensors for validation purposes and programmes such as H2020 Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries (MONOCLE) are exploring a range of sensors to fill the temporal, spatial and technology capability gaps, including the opportunities that cheaper low-cost sensors deployed through citizen science networks present.

Whilst GloboLakes has pulled together the largest community available data set, this still remains limited for OWT validation. Assessing the uncertainty for all lakes remains problematic. This problem is overcome a little by focusing on lake clusters/groups with similar OWTs. However, there is more data for northern hemisphere lakes and there are significant data poor regions of the world where additional in situ data are needed, especially if capability is to be of value to developing countries and respond to the national reporting needs of the SDGs.

D. Summary of GloboLakes Current Unmet Opportunities:

Having developed the *Calimnos* system to understand how lakes are changing in response to environmental change drivers, we have also developed a global monitoring system that can facilitate better management of water and sanitation as well as promote environmental stewardship at the community, industry and governance levels. This presents an important opportunity and focus for capacity building activities to help deliver on the monitoring and reporting requirements of SDG 6.

Day 2- Water Quality Community Forum

The second day of the workshop provided an opportunity for other members of the AquaWatch community to showcase their current work.

Session 5: Partner Projects & Developments Lightning Talks Moderator: Ghada El Serafy, Deltares

NERC Knowledge Exchange: EO in Industry and Regulation - Claire Neil/Andrew Tyler, University of Stirling
H2020 EOMORES – Steef Peters, Water Insight
Copernicus Global Land – Kerstin Stelzer, Brockmann Consult, GmbH
H2020 MONOCLE – Stefan Simis, Plymouth Marine Laboratory
H2020 CoastObs – Steef Peters, Water Insight
H2020 Coastal Water Data Cube – Carsten Brockmann, Brockmann Consult, GmbH
H2020 DANUBIUS-PP – Andrew Tyler, University of Stirling
H2020 Co-ReSyF – Eirini Politi, University of Dundee

Session 6: H2O2O Community Discussion. Facilitator: Arnold Dekker, SAT-DEK

Presenter Panel Discussion and Q&A, challenges/opportunities.

Session 7: Agency & International Program Lightning Talks. Moderator: Emily Smail, University of Maryland

UNESCO World Water Quality Portal – Thomas Heege, EOMAP GmbH & Co.KG
Water-related SDGs – Bilqis Hoque, Environment and Population Research Centre and Andrew Tyler, University of Stirling/Douglas Cripe, Group on Earth Observations (GEO) Secretariat/Merrie Beth Neely, GEO AquaWatch
GEMS Water and SDGs – Deborah Chapman, GEMS/Water
US CyAN project – Blake Schaeffer, US Environmental Protection Agency
US CoastWatch – Emily Smail, University of Maryland
CEOS EO for Aquatic Ecosystems Study – Arnold Dekker, SAT-DEK
Trophic state assessment of global inland waters using a MODIS-derived Forel-Ule index. - Shenglei Wang, RADI Chinese Academy of Sciences
Relevance of thermal forcing for optical remote sensing of stratified lakes - Daniel Odermatt, Odermatt and Brockmann
Spatial and Temporal Perspectives on Multiple Stressor Impacts Spanning Inland to Coastal Ecosystems - John Schalles, Creighton University

Session 8: Community Discussion. Facilitator: Blake Schaeffer, US Environmental Protection Agency

Posters:

Global Lake and Water Products Within the Copernicus Land Service**:** Kerstin Stelzer, Brockmann Consult, GmbH

Data Cube Service for Copernicus – a novel EO data interaction capability: Carsten Brockmann, Brockmann Consult, GmbH

Integrating Satellite Data Into Multi-disciplinary Coast Research: Eirini Politi, University of Dundee

Sustainable Development Goal Indicator for Ambient Water Quality: Deborah Chapman, GEMS/Water

Design Considerations for Aquatic Ecosystem Earth Observing System: Does This Cover Your Requirements?: Arnold Dekker, SAT-DEK

The Dynamic Littoral Fringe: John Schalles, Creighton University

Day 2 Summary of European Union (EU) and Horizon 2020 Findings, Identified Information Gaps, and Current Unmet Challenges and Opportunities Arising From Their Work and Projects.

A. Summary of EU/Horizon 2020 Information Gaps or Barriers:

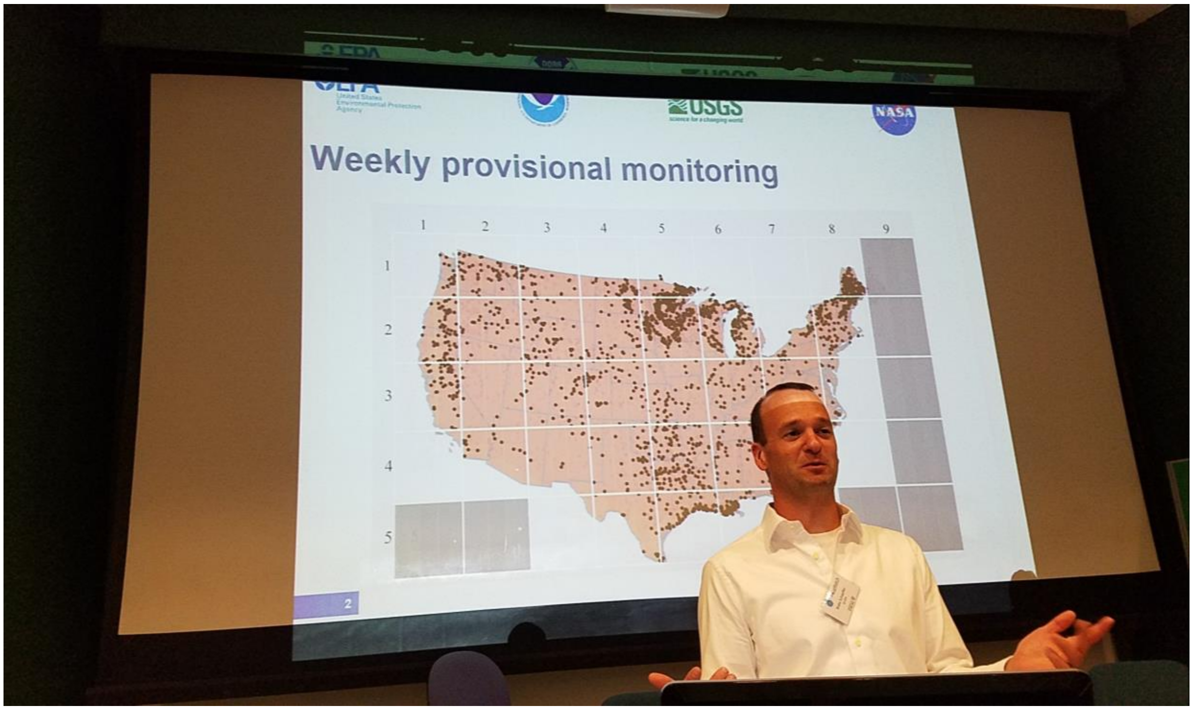
Copernicus Inland Water Service identified one gap which the WQ Community could attempt to close through future work: available *in situ* data for algorithm calibration and product validation (OLCI + MSI). The Data Cube Service for Copernicus Project (DCS4COP) presented a few barriers to users accessing the available information, mainly that it requires expert knowledge, both in internet technology and thematic know-how. Their program has found it difficult to access data from major data providers including: ESA, European Organisation for Meteorological Satellites (EUMETSAT), nat. Collab.GS, Copernicus Marine Environment Monitoring Service (CMEMS), Copernicus Land Monitoring Service (CLMS), Copernicus Climate Change Service (C3S), Data Integration and Analysis System (DIAS - Japan), AWS, GC/GEE. It was also difficult to manage what data and information they acquired. There was a general concern that this might lead to unknown product quality and further difficulties in disseminating results by DCS4COP. H2020 funding is supporting the development of a new pan-European infrastructure on River-Sea systems called DANUBIUS-RI. With an overarching mission to make river-sea systems work, this interdisciplinary research infrastrcuture includes an Observation Node which exploits EO capability to characterise the river sea continuum and will include standardised in situ instrumention for fedicial reference measurements across catchments, estauraies and deltas to validate satellite based products across these optically complex environments. DANUBIUS_RI is on the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap and is working towards a the full legal status of a European Research Infrastructure Consortium (ERIC) enabling better understanding of drivers of change across boundaries of large transboundary catchments and between river-sea systems across Europe, facilitating more effective catchment management and associated societal and economic growth.

B. Summary of EU/Horizon 2020 Current Unmet Challenges:

With respect to unmet challenges to the water quality community, Copernicus Inland Water Service felt transfer of scientifically sound results into operational services needed to be stressed to product providers. Specifically, applying atmospheric correction among the wide range of different water types found across the globe. Also, further efforts to reducing artefacts that arise in merged products (time and space). Finally, the signal to noise ratio of Sentinel-2 MSI data and consistency of sensors are two areas needing improvement.

The MONOCLE project suggested making hyperspectral cameras more affordable could increase the use on drones. A drawback to using remote sensing of water color is identifying what is happening below the water surface. Remote sensing of water colour observes the surface layer and 90% of the signal is reflected within the 'first optical depth'. This causes two problems in data interpretation: the water column not always mixed over this depth and photochemistry is more complex near-surface. Another issue is applying the best light attenuation coefficient. Vertical attenuation is scarcely measured in situ. Access to optically deep water is required as well as specialized equipment. One work around for this has been the development of low-cost buoys which may double as indicators of stratification. Finally, the biggest question MONOCLE faced was "Who compensates site operators?" They suggest a new paradigm on data licensing and sharing is needed. Perhaps move towards providing hybrid EO, offering both remote sensing products and in situ observation services.

DCS4COP's research challenges were related to assuring quality data layers (products). For this program this task requires a large effort. Automation of more quality tests need to be developed. Qualified reference data and consensus-driven community-wide protocols need to be arbitrated. DANUBIUS, referring to their data for Large River Sea Systems requires evaluation of the preconditioned natural forces of change acting on river-seas systems to assess the ability to absorb man-induced perturbations and extreme events for effective management and the avoidance of tipping points. The challenges for Coastal Waters Research Synergy Framework (CoReSyf) were: Maintaining community engagement, data and methods quality control and assurance, platform sustainability, maintenance and running costs, providing a user helpdesk, and reiterated that a major obstacle for advanced users was the need for programming skills.



GEO AquaWatch Management Team Member Blake Schaeffer (USEPA) presenting the CyAN project. (Photo credit Merrie Beth Neely).

C. Summary of EU/Horizon 2020 Current Unmet Opportunities:

With respect to evolutions for programs to consider or take advantage, Copernicus Inland Water Service identified three Evolutions. The first would be Product evolution: especially 1.) 100m spatial resolution based on MSI products 2) Trophic State Index - > Chlorophyll conc. under discussion and 3) Integration of OLCI-B, SLSTR-B (Sea and Land Surface Temperature Radiometer). Another area to evolve is algorithm improvement. Copernicus Inland Water wishes to generate turbidity directly from reflectance & improve parameter retrieval for clear water types. They also wish to provide an Atmospheric correction for Sentinel-2 MSI and OLCI, and provide pixel classification: shoreline pixels, ice, cloud, cloud shadow, etc. Evolving on the longer term, they suggest global products of resolvable water bodies instead of selected (and isolated) lakes.

The MONOCLE program identified several opportunities. The program was focused on developing sensors, deployment and data processing solutions while supporting collaboration with site operators (to improve network compatibility), sensor manufacturers (to improve data interface development) and with citizen science initiatives (to host testbeds for new sensors). MONOCLE also recommends improved data accessibility through connected sensors supports anomaly detection, response times, sensor auditing, live visualization, and supports satellite observation: everyone wins but only some profit.

DCS4COP suggested opportunities could be found in setting priorities for data cube software, such as:

- On-the-fly production
- Python & xarray
- Performance, costs
- Processing as a services versus software as a service
- Costs for flexibility (which internet technology infrastructures to support, storage models, etc.)

And in using the fair economic model:

- Cost efficient for user (IBU), low financial risk
- Revenues for service providers, low financial risk
- Sustainability is key to become accepted

DANUBIUS-RI suggested an opportunity lies in identifying holistic approaches to characterize, understand and manage effectively the conflicting demands (with high socio-economic values). Problems in standardizing and synchronizing existing national sampling campaigns can be overcome by the deployment of complimentary sensors to assist with satellite validation and deliver temporal gap filling data. CoReSyf's identified opportunities were: increasing community interaction, enabling easier EO data access, promoting multi-source data for (synergistic) research applications, encouraging and enabling faster and larger dataset processing, investing smaller resource effort than in conventional data processing, and ensuring data are open access and open source.

Day 2 Summary of EU and Horizon 2020 Projects Morning Panel Discussion :Horizon 2020 Consortia and GEO AquaWatch– How can they help the community and suggestions?

Is there demand for GEO AquaWatch to create (yet) another portal or database or service?

There is a need for interoperability in portals/databases/services. Global users are sometimes missing data portals and vice versa, local and regional user groups all over world e.g. developing countries (e.g Bilqis (Bangladesh) and Fajar (Indonesia)) need much additional information on their areas. We must include livelihoods of users as an important aspect or driver of the products and the education of the users. Engage social and economic sciences as well as traditional sciences now when the SDGs are being emphasized so much.

GEO AquaWatch should be the link or connection between other projects, give specific users technology transfer and products to use with some outreach and training, etc. GEO AquaWatch helps customize the data product connection for, and with, the user community. It is key to have operational products. Need good outreach program offering training materials in multiple languages, educational pages are missing from most programs, technology transfer and hands on training are missing too.

GEO AquaWatch should do technology transfer workshops, so users can customize the data they use and their data portal themselves and do it for themselves. End-users can ask for products to be developed for their area, provide user requirements to develop that product, to help provide in situ data for product validation and money for work.

All workshop presenters were touting ‘operational service’ and ‘consortia’. How much of these are the same products and processes vs how much are they different. GEO AquaWatch has an excel spreadsheet of datasets and products – expand this to include near real-time or real-time and producing operational services. Include the temporal-spatial resolution of the products. GEO AquaWatch should help separate research and development/discovery vs operational products, global products, capacity building. Would identify duplication and gaps.

There is also a clear role for GEO AquaWatch: many project-based initiatives only provide Research and Development type, pre-operational, operational products for a selection of lakes and other water bodies often based on technical feasibility or ease rather than end-user requirements. Synergies are needed between projects: a clear role for GEO AquaWatch.

Although important globally and regionally GEO AquaWatch is not doing much in area of littoral zones (supratidal, intertidal and subtidal) and submerged aquatic vegetation. There is a need though: is GEO AquaWatch the right organization to do this? Possibly GEO could help more to coordinate among other GEO groups (example GEO AquaWatch, GEO Wetlands, GEOGLOWS) to get better at tackling these related topical issues from freshwater to estuaries to coasts. GEO AquaWatch could go to the EU or Horizon Europe to request reorganization of the proposal process to solve above issues

Use programs such as GCOS with ECV, GEOGLOWS with Essential Water Variables (EWV), SDG’s to determine operational products required globally.

EU sees Copernicus as operational, very little involvement in local data validation that users want to verify whether Copernicus projects are suitable for use in their area (GEO AquaWatch might advocate/lobby on behalf of this to enable local groups to participate in data validation, especially if they share data).

GEO AquaWatch can help by identifying and amplifying the voice of ephemeral projects – offering data protection and increasing lifespan of a product.

The EU focused Freshwater Information Platform is an excellent example of combining freshwater data-how to make this global? What is relationship with GEMS, with the Water Quality Assessment Service? With Water Quality Information Service (WQIS), etc.

Some disagreement on the proposal to get end-users to adapt an *in sit*u program to be more aligned with EO WQ product validation, or deploy complimentary sensor systems.

In New South Wales Australia they have adapted *in situ* measurements as there are only guidelines and on strict legal set methods. In US there is resistance due to legal requirements defining how to measure WQ. In Europe Water Framework Directive is prepared to adopt EO based methods. Also in the EU Sea Surface Temperature, altimetry, etc. is being micro-funded by European Commission. GEO AquaWatch can investigate Fiducial Reference Measurements approach. Another approach is to add a layer of sensors (to existing Water Quality Managers *in situ* data efforts) to take the samples the EO community needs for validation – this is what DANUBIUS is doing. To make matters more complicated data collected for regulatory purposes is not necessarily suitable for SDG or EO validation.

In conclusion : in countries where adapting in situ WQ methods to be more suitable for EO product validation is possible this should be advocated strongly; that will help getting countries hampered by current legislation to change methods down the track.

Other ideas: We require annual or biannual GEO AquaWatch meetings as this area of EO is in flux and rapid developments are occurring.

Day 2 Agency & International Program - Summary of Findings, Identified Information Gaps, and Current Unmet Challenges and Opportunities Arising From Their Work and Projects.

A. Overarching Themes and Outcomes

Many successful projects were described in these presentations. A number of programs are underway or in development looking for water quality measurements specifically to advance country's reporting efforts on SDGs. GEMS/Water currently collects five parameters for inland waters: Dissolved Oxygen (DO), Nitrogen, Phosphorus, salinity or Total Dissolved Solids, and acidification. UN Environment is in search of a demonstration of high-profile global products that can be used to measure change over time as an assessment. They are looking at Chl-*a* but also perhaps total suspended solids for the project and are keen to advance efforts by March 2019.

The WQ Community has developed portals capable of ingesting the in situ data and making it available to remote sensing experts to validate their global data products – there is no need to reinvent new services and we should continue to use and invest in what we have to make them better and more useful. However, concerns over whether those data are being discovered and used, their metadata provenance and trustworthiness, and simple questions such as: Where are they being stored? Are they free and open source?

B. Summary of Agency & International Program Information Gaps

Various projects reiterated the validation of data and finding ways to ensure customers are using the best product that is fit-for-their-purpose as areas of information gaps. Can we increase the available data to provide product validation in more locations?

A useful demonstration project in a developing country is lacking – we have examples of use in developed countries but a meaningful example in Bangladesh could have much more impact in increasing the use of EO by decision-makers. Is there a coordinated or centralized capability to ensure users are trained in EO use and to understand the useful limits of different satellite data products?

It might be useful for GEO AquaWatch to bring input from their *ad hoc* panels of Subject Matter Experts to bear on more topics affecting the Water Quality Community. This knowledge can be useful and since scientific generalists at various global policy agencies and NGOs are often the ones compiling broadly crafted policy documents, this might be a targeted use of SME input. Better coordination with GEO AquaWatch would enable available SMEs to get early access to drafts to avoid a poor quality or error-filled policy and planning document is made public and possibly acted upon.

Many EO data service providers want the *in situ* data and want to know the provenance or methodology used for collection (metadata) and for water quality practitioners to use best practices for the collection of in situ data – not always available and not always possible. Another concern was who is providing data and will they be asked to tweak their data collection methods to suit the satellite remote sensing community – this is highly discouraged as monitoring programs are even more restricted on funding and are generally collecting data for some existing mandate, making it an improbable imposition to just ask water quality data practitioners to collect more data in new locations and using different procedures. Many agencies are especially interested in nutrients, especially silica and microbiological data (related to harmful algal blooms and human health) – but they are not always available, tempo-spatially patchy, or the metadata is insufficient to deem the data reliable.

We can be missing what is happening on a smaller and more local scale both temporally and spatially. Satellites don't show always this. In some cases remote sensing products don't help resolve the issues due to sensor resolution limitations or gaps in satellite coverage (example dramatic losses in *Spartina* aboveground biomass in southeaster US saltmarshes). The issue of sensor design and requirements is ripe with CEOS and among various space agencies planning missions and hardware for launch. Should there be a mix of spectral and spatial resolution standards in sensors or all meet some minimum requirements? There are a lot of terrestrial, ocean and atmospheric sensors, but none specifically for where ~60% of global population lives and ~$60 Trillion US Dollars of GDP is produced. What sensor resolution is the best for a global mapping mission? It may depend on the environmental question to be answered, but somewhere between 30m and 1.6m. What temporal resolution needed for the various users and their desired fit-for-purpose products? It may be hours for flooding, weather forecasting, turbidity plumes, and algal blooms, and on the scale of weeks for coral bleaching, infestations and disease, etc. We must critically examine these tradeoffs in resolution: Higher spatial resolution = lower radiometric resolution = less depth penetration. Spatial and spectral resolution are the core needs of sensors in development – 17-33m and ~26 bands in the 380-780nm wavelength range for retrieving the aquatic ecosystem variables ~15 spectral bands between 360-380nm and 780-1400nm for removing atmospheric and air-water interface effects.

C. Summary of Agency & International Program Current Unmet Challenges

Accessibility and discoverability of the available data products and in situ data for validation remains a challenge to the service providers. Data providers should follow the tenets of the European "GO (Global Open) FAIR" which is a 'bottom up' initiative that aims at making fragmented and unlinked (research) data Findable, Accessible, Interoperable and thus Reusable (FAIR). The needs of the user groups are often not fully met with the available data products – the feedback loop to inform service providers are not fully implemented. Even if they were implemented, there are costs associated with meeting specific user needs or refinement of a data product for a specific purpose. If a data product does reach a user audience, can they easily use it and for the right purpose (within its limitations). A challenge is determining if products are reaching users with available training and ensuring understanding of those product limitations for wise use?

We know we aren't reaching developing countries with our existing remote sensing products and tools and we also aren't getting meaningful in situ water quality monitoring validation data from them. We also know decision-makers aren't using EO in making their decisions – there are some great high profile pilot project opportunities in Bangladesh that would engage the policy and decision-makers – they just need implemented.

GEMS/Water identified many challenges to achieving their mission and building SDG 6.3.2 capacity in developing countries. Challenges include the lack of technical and institutional capacity in many countries to monitor water quality, manage the data and report results. This leads to large observational gaps in the available data. There is also a lack of knowledge and appreciation amongst policy makers about the importance of ambient water quality data in validation of global satellite data products. While there are some requirements for the data countries are reporting, they lack knowledge and a clear understanding of the end user data and information requirements. There is also a lack of observational/monitoring requirements for targeted in situ water quality data collection. Regarding interoperability, there is a lack of international standards for the exchange of available water quality data. The best solution would integrate various approaches, combining traditional and novel data sources (remote sensing, in situ sensors, citizen science, models).

D. Summary of Agency & International Program Current Unmet Opportunities:

A little bit of effort towards promoting and use of EO could fill a lot of needs in developing countries, and high profile demonstration projects that engage policy- and decision-makers would be useful in promoting EO as sustainable development tool. These are opportunities GEO AquaWatch and others should take advantage of. Promoting other technology tools for EO are opportunities for the water quality practitioners and vendors to exploit, including the use of drones for sampling and remote sensing in local areas, or where available satellite products fail to meet the resolution needed to assess change for some in water ecosystems. This may be a market driver for sensor technology developers and space agencies as well.

The UN Environment's World Water Quality Portal is operational, but static. Opportunities abound for innovation and encouraging the practical use of EO analytics. Examples include: awareness, capacity building, marketing, e.g. global flagship showcases. These offer opportunities to 1.) Exchange/access to public financed data: e.g. GEO's System of Systems (GEOSS), World Water Quality Portal, etc. and 2.) Alignment to meet demand by: providing reliable, cost-efficient and quality assured products and services; pushing for further innovation that is market driven rather than institutional driven; and pushing international standards for global comparability, requirements, Quality Control, etc.

Summary of Afternoon Plenary Panel Discussion

Following the afternoon presentations by agency and international programs, a presenter panel addressed questions from workshop participants and focused on the current and future challenges and opportunities. This session was led by Blake Schaeffer, US EPA.

Consensus expressed among the workshop participants included:

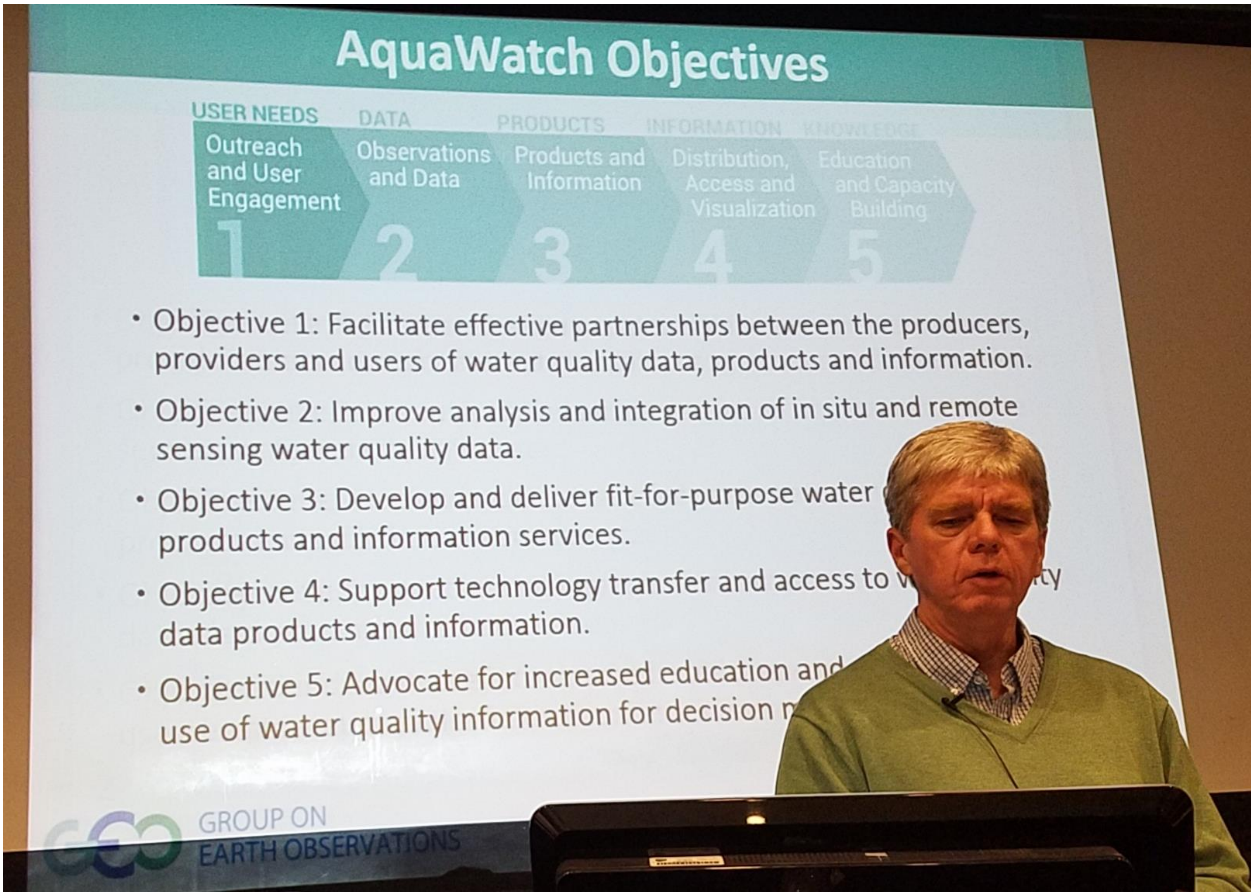
For those agencies that now have web-based products available, uptake of these products has generally been slow. A number of factors are likely contributing to this fact, including institutional resistance to utilize these products. The GEO AquaWatch community needs to do a better job of marketing these products and continue to garner trust from the end user community. Social media and associated publicity can/has helped this issue.

GEMS Water, which maintains a key global water quality database and portal, has a keen interest in merging satellite generated water quality data with their in situ database. One pilot project carried out over the past few years, termed SPONGE, has demonstrated the feasibility of inclusion of satellite data products and proposed data processing chains suitable for unsupervised automated processing. These efforts could help fill gaps anticipated in the reporting of SDG simple indicators. Parallel with this effort is the need for expertise to assist in the interpretation of the data products and how the data was produced. GEO AquaWatch could play a technical advisory role. Other examples of successful regional demands of current and future satellite products, namely US and Australia. The bigger issue is finding a ”legacy” institution which can provide information continuity and a sustainable portal, which will help end user confidence and increased use.

It was also pointed out that satellite remote sensing cannot fulfill all the monitoring needs and newer approaches such as drones and citizen science networks, including revisiting Forel-Ule color scale comparative methods can be useful to measure local eutrophic conditions.

One targeted end user group should be women in developing countries, who are generally responsible for securing water on a daily basis. It was suggested that efforts to reach this group could be done through engagement with economists and social scientists in finding the best ways to perform outreach or in crafting outreach campaigns

A common concern of the discussion group was the critical importance of high-quality validation data and what role can GEO AquaWatch play to support this need. Validation data is not equally distributed across the globe though some regions such as Europe are well covered. One step would be to document these geographic gaps. A lot of water quality data from citizen groups and non-governmental organizations (NGOs) go undiscovered and aren’t found in global data sets. We should collaborate on validation, crowdsource, etc. best effort but also fit for purpose to the extent we can provide that information. Validation will ensure confidence from the end user community. “Accuracy breeds trust”. Just as important is reporting of errors about estimated values. Optical data archives such as *LIMNADES* should be supported in the future along with proposed future collaboration with the CEOS Working Group on Calibration & Validation (WGCV).



GEO AquaWatch Director Steve Greb Reviewing the Initiative's objectives before the Water Quality Information Service discussion and annual work plan breakouts. (photo credit: Merrie Beth Neely)

Discussions over Glengoyne Distillery whisky-tasting at the beautiful Venechar Lochside restaurant with breaktaking views! (photo credit Merrie Beth Neely)

Day 3 - GEO AquaWatch Planning

This day was a working session to engage the Steering Committee and Community in review, discussion and planning activities for the coming year. The day was split into two parts. The first session focused on building GEO AquaWatch's flagship WQIS and discuss an action plan to fund and complete work packages 3-7. The second session identified new issues/activities and further discussed the action plan to fund and address both the WQIS and new activities. The final session, chaired by the entire Steering Committee, assigned tasks for the GEO AquaWatch Annual Workplan.

Session 8: GEO AquaWatch Setting the Scene for Day 3.
Co-chairs: Steve Greb & Arnold Dekker

Recap **challenges and opportunities** from the previous 2 days. How can the community activities presented over the past two days help GEO AquaWatch reach its goals? How can GEO AquaWatch help the community reach their goals?

Session 9: WQIS Plenary Group Discussion.

Review of Work Packages 3-7. Engage in a detailed group discussion of the **WQIS** and embracing assessment role of the various information services produced by others. (Facilitators: Ghada El Serafy and Carsten Brockmann)

Session 10: Working Group Breakouts. Co-Chairs Leigh Fletcher, Steering Committee, and Steve Groom, Plymouth Marine Laboratory. NOTE – for efficiency instead of five breakouts we split only into two of them – 1&5 (user engagement & outreach, and capacity building) and then 2,3, and 4 (data, products, and visualization)

Questions to be answered:
How can GEO AquaWatch address the identified action & knowledge gaps?
What new issues can/should GEO AquaWatch address in next 12-18 months and how do we do it?

Session 11: Annual Work Plan & Assignments Plenary. Chairs: Entire Steering Committee

Steering Committee Feedback and Plenary Discussion: How will identified knowledge/action gaps shape GEO AquaWatch Annual Workplan? Build a Framework to implement agreed upon tasks, schedule next 12-18 months, and assign people to tasks.

Summary of Previous Day Recap and GEO Secretariat Update:

This session started off with some introductory remarks from the representative of the GEO Secretariat's office. He presented an update and challenges to the AquaWatch community. GEO has recently come under new leadership and is being led by Gilberto Camara, from Brazil's National Institute for Space Research (INPE). The new secretariat director would like to stress the focus and role of GEO being a supplier of data and information and all initiative follow the GEO centralized model of becoming a knowledge hub by connecting the large number of disparate data sources coming from the project-based efforts around the globe. He also emphasized the importance of providing services and capacity building efforts in developing countries. The theme of the 2019 ministerial summit is *demonstrate the power of EO* and it might be an opportune time to showcase some of the GEO Aquawatch efforts. Being held in Australia, maybe GEO AquaWatch membership could appeal to the hosts for support. As far as what GEO Secretariat (GEOSEC) can offer our Initiative, they have convening power i.e. administer large teleconferencing and venue to hold centralized meetings in Geneva. They provide a "neutral platform", which can be advantageous for international collaboration, a trusted international broker of data, especially in-situ, and help foster relationships between the private (commercial) and public sectors.

Summary of Water Quality Information Service Plenary:

A. AquaWatch Engagement

There was a discussion of GEO AquaWatch's daily operational efforts, where we advertise GEO AquaWatch meetings, community activities and accomplishments and how we can elevate our visibility. Outlets suggested include International Ocean Color Coordinating Group (IOCCG), websites, GEO blogpost at 6 weeks and 12 weeks, email messages, SumItUp, National Lakes Assessment for Managers, Remote Sensing and photogrammetry organizations, European Funding, Horizon and Innovation magazine, Scientific American, Environmental Science & Technology, Marine Technology Society

To keep the community engaged, we should have meetings at least every 12-18 months, 2 years is too long. We should have consistent regularly scheduled telecons in between with the community, every 6 months have a community-focused meeting. Other ways to connect are through informal gatherings and town halls at upcoming professional meetings. One venue suggested for the next meeting was the International Ocean Color Science in Buson, South Korea is in May 2019. Ocean Optics and ESA - Living Planet meeting are other opportunities to engage. We should start to plan for the 2019 GEO Plenary in Australia in November 2019.

B. GEO AquaWatch Goal and Objective Review

There was an open community discussion on the AquaWatch current objectives and whether they need revising given recent and quickly evolving science and technology advancements. Recent years has seen a rapid increase in developing products and portals and we may want to reconsider our role in the community, specifically whether we should be developing our own WQIS. What can GEO AquaWatch realistically do and what are the best use of our limited resources. It is not evident what is coming out of GEO AquaWatch, reports by collaborators have been enabled GEO AquaWatch and should be published on the website to show GEO measurable value in supporting GEO AquaWatch. We should link to global commitments in our objectives to motivate the government sector to both fund and participate, define what purpose(s) data can be used, choose indicators that tell us what water is good for what uses, It is the difference between advocacy versus promotion – tell them WHY they should go to our GEO AquaWatch website, this helps build trust and more effective partnerships. Objectives should emphasize assessment, outreach and training in addition to a couple of suggested projects. This will help document why and how this can improve GEO AquaWatch connection and value to the community. One project suggestion would be to define the level 1, 2, and 3 SDG indicators and suggest a low-cost optical water quality product for each – "level 1 product recommendation" – this is what most developing countries seek, gives them a place to start, there is a market for this.

With respect to GEO AquaWatch Objective 3 [Develop and deliver fit-for-purpose water quality products and information services] suggested language should include pointing towards assessment and the importance for validation and quality of data. This may include ensuring quality data for *in situ* measurements as well as satellite-derived data. GEO AquaWatch could play a role in setting standards for quality of data, current quality of data and advising end users as to what the data can and cannot be used for applications. Additional novel areas for GEO AquaWatch to focus: consider other data sets like catchment data, link to other projects which have that information, suggest new indicators to use, suggest new monitoring systems to countries or regions or municipalities. GEMS/Water can be useful here because of SDGs, they must have metadata and need lakes and microbiology data of open water bodies. GEO AquaWatch and GEMS/Water can mutually benefit from collaboration because GEMS/Water has the database and GEO AquaWatch can improve their products or fill gaps.

C. Future of the Water Quality Information Service

The development of a single product (turbidity, under work package 3) is the next step in the WQIS progression but it will take more resources than a best effort activity and this activity has slowed. Emerging use of data cubes may be a relatively expedient way to demonstrate for example how water quality-related algorithms work, but there are still issues, particularly with atmospheric correction. The UNESCO presents a nice Water Quality Portal that might be a good model moving forward towards an operational effort. Some issues with the current portal is it is not open source and limited validation, hence some erroneous values. GEOSEC wants to see demonstration of how EO is benefitting society (not just talk or pictures), and how technology is expanded on, and it must be open source. Being open use is key and should not prevent commerciality, as long as not exclusive. If methods aren't open and peer-reviewed they are not defensible and GEO AquaWatch can 'endorse' a product. There was some concern about what products (and from who) get put into the WQIS portal and development of policies. It was also pointed out some users don't want to be handed data products to use but want to be given the tools to do it themselves (such as the USGS – National Aeronautics and Space Administration (NASA) – Australia remote sensing reflectance, 'analysis-ready' data), while others just want to the product not the tool. Another question posed was WQIS considered a top down or bottom up approach? Can be both. Offer a global sentinel network identifying high quality products (top down), emphasize data validated products (bottom up).

It was suggested that GEO AquaWatch should focus more on supportive efforts instead of the WQIS. Maybe we should focus on the gaps in delivery, including data interpretation and trends. GEO AquaWatch can identify gaps and work on them, and facilitate interactions, build an information exchange network, which also helps build capacity. Interpretation of data is a problem for managers, support technology transfer and access to water quality data products, information and interpretation is a barrier in developing countries. This could be an objective of Working Group 5, including a summary of water quality efforts in development, information on what products are available and fit for purpose information.

Fun at the Cèilidh. (photo credit Merrie Beth Neely)

Summary of GEO AquaWatch Annual Work Plan Breakouts and Recommendations for GEO AquaWatch 2018-19 Annual Workplan Tasks

Breakout formation and charge: Two breakout groups were formed, the first (Breakout group 1) termed "Capacity Building, Outreach and Education", comprised of GEO AquaWatch standing working groups 1 and 5 the second (Breakout group 2) termed "Data Products and Information; and Distribution, Access, and Visualization Data" comprised of GEO AquaWatch's standing working groups 2-4.

Each breakout group was convened to create lists of tasks/projects, prioritize them, assign names to accomplish tasks on best effort, and suggest funding sources to submit proposals to for dedicated funded efforts. We wanted to identify gaps in knowledge or function; describe and 'qualify' existing information systems (assessment, quality, flags, etc.); use of data cubes (analysis-ready data); perform analysis, quality control and assessment of remote sensing and *in situ* data.

Steve Groom lead the Data breakout, Merrie Beth Neely was rapporteur. Leigh Fletcher led the Outreach/Education breakout, and Emily Smail was rapporteur.

Results of Breakout Group 1- Capacity Building, Outreach and Education

Overview – 4 phased tasks leading to a demonstration project

1.) **Training/Best Practices**
   - Phase I: Develop decision tree (**Arnold**)
     - World Bank report flow chart as starting place

     Timeline: Now – October 31st, 2019

   - Phase II: Survey of training needs and existing capacity **(Merrie Beth, Andrew, Bilqis, Social Scientist)**
     - Guidelines for materials for training/capacity building (**Steve Greb**)
     - Analysis of survey results **(Erin U. aka Blake's post-doc)**

     Timeline: Now – December 2018

   - Phase III: Compilation/vetting of existing training **(Merrie Beth with potential support from UMD grad student and Hayley (?), Nima (?)**
     - Guidelines for GEO AquaWatch advertised trainings
     - Compilation of existing trainings; gap identification surveys (e.g. JRC, literature reviews)
       - NASA Applied Remote Sensing Training (ARSET) program for training, IOCCG, EUMETSAT, Copernicus
       - Collaborative trainings between GEO AquaWatch and EUMETSAT, Copernicus, etc.?
       - Massive open online course links
       - Remote sensing toolkit at the University of Queensland (introductory level)
       - GEMS/Water training materials/workshops

     Timeline: Now – September 1, 2019

   - Phase IV: Review/vetting of trainings (peer-review, led by Emma Tebbs)
     - Guidelines for principles for training

     Timeline: Start by September 2019 (on going)

2.) Demonstration Project

- Demonstration project (potentially Bangladesh)

Timeline: September 2019 – September 2020

Results of the Breakout Group 2- Observations and Data; Data Products and Information; and Distribution, Access, and Visualization

Overview – 4 parallel tasks with timelines and a possible 5th task using ensemble approach to bring applicable efforts together

1.) Inventories:
1 month: working groups and GEO AquaWatch Secretariat, Working Group (WG) members update the existing data product inventory on GEO AquaWatch website and turn it into a database that is query-able.

This will include operational status and have a column indicating if:

- *In Situ* (Peter)
- Remote Sensing Service (EVERYONE)
- Portal/static data set – Steve Groom and WG4

4 weeks after: Then perform a gap analysis of each of the three items

3-6 months: gap analysis use cases to seek funding for a $20M project !!!

Longer-term: brochure development, flashy to grab attention and present to the funders and decision-makers to build capacity

2.) Community of Best Practices:
Library of Algorithms - Steef and Ghada and WG3, develop a review paper on this library of algorithms that is peer reviewed, needs 6 months for this

The outcome can be posted on GEO AquaWatch website. Like GLEON collaboration site– this will be collaborative.

3.) Best Practices:
Peter and Mortimer will produce a document on optical standards for optical properties – inventory of protocols too. This will point to other standards if they exist.

- GEO AquaWatch Secretariat will facilitate communication to working groups and other network connections.

- This list will map standards, metadata, etc. and will notionally be like an Fiducial Reference Model but not exclusive – can list different levels and a gold standard.
- Action – GEO AquaWatch Secretariat needs emails of outsiders to contact and point to Peter and Mortimer as who to respond to
- Timeframe is 6 months.

4.) Citizen Science:

All 3 citizen science efforts need to find a parameter that is useful and makes it relevant to the citizen scientist or community!

- Laurence Carvalho has smart phone app – doing a paper – 6 months
- John Schalles has information on drones – also a paper – 6 months
- Caitlin Riddick will list low cost sensors in development – also a paper – 6 months

5.) **Ensemble approach:** still working on this…….better idea in 6 months' time.

Want to use the various algorithm inventories and a comparison of outputs of the processing services for e.g. lakes in Africa, or where there is in situ data – both can occur in parallel on ~6 months schedule.

Then notionally use ensemble approach to explain differences in the outcomes and may recommend products for decision-makers to use based on quality and uncertainties of each.

Additional General Tasks applicable to all activities. 1) Validation activities, since a critical need was identified for validation data sets. This might build off the inventory and gap analysis that work group 2 is tackling. 2) Work with the CEOS Working Group on Calibration & Validation (WGCV).