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Using Remote Sensing to Empower the Public to Address Water Pollution

September 14-16, 2016 ~ Wingspread Conference Center, Racine, WI

Meeting Summary

Overview

On September 14-16, 2016 approximately 30 experts from academia, federal and state agencies, nongovernmental organizations (NGOs), private companies, and foundation representatives, convened for the workshop, *Using Remote Sensing to Empower the Public to Address Water Pollution*. The purpose of the workshop was to generate ideas about how researchers, technology companies, government agencies, and funders can collaborate to rapidly advance the use of remote sensing to address pollution in U.S. inland surface waters – both still and flowing waters of rivers, lakes, reservoirs and estuaries. The broader goal was to lay groundwork for a longer-term effort aimed at empowering conservation NGOs to make better use of remote sensing data to achieve water resource protection objectives. The specific workshop objectives were stated as follows:

- Understand the capabilities and limitations of remote sensing technology and related methods for generating actionable information about water pollution in U.S. inland surface waters;
- Learn about the capabilities and limitations of existing remote sensing derived products for monitoring water pollution and its sources;
- Identify product capabilities and interface features that would be most useful for informing the conservation activities of NGO end-users;
- Generate ideas about how NGO field staff can support the development of actionable remotely sensed water quality data;
- Identify opportunities for funders to accelerate the development and deployment of user-friendly remote sensing derived monitoring products relevant to water quality; and
- Generate ideas about potential partnerships and activities to raise awareness about remote sensing technology and make available products more accessible to target NGO end-users.

Since the workshop was focused on learning and idea generation and involved a novel diversity of participants compared to previous related dialogues, the scope of the discussions was framed broadly to allow for consideration of how an array of available remote sensing technologies could help support the work of diverse NGOs focused on water quality in inland water bodies.

In terms of water pollution challenges, the workshop focused primarily on those that may be discernible using remote sensing including chlorophyll-a to detect algal blooms, turbidity, and temperature and associated land-based sources and sinks. Key working definitions put forth for framing the meeting included:

- **Inland waters**: rivers, lakes, reservoirs and estuaries;
- **Land-based sources**: non-point and point sources of water pollution including runoff from rural/agricultural and residential/urban areas (non-point sources); as well as discharges from wastewater plants and municipal separate storm sewer systems (point sources);
- **Land-based sinks**: natural or engineered vegetated areas that take up pollutants and prevent them from entering water bodies;
- **Earth observation**: the gathering of information about Earth's physical, chemical and biological systems using tools such as remote sensing technologies; and
- **Remote sensing**: measuring the earth's surface without coming into contact with it through sensing and recording reflected or emitted energy; encompasses satellites as well as boat, jetty, buoy or other platform-based measurements of reflected or emitted energy in the visible, infrared or thermal regions.

These working definitions and other important framing concepts and background information were presented in a paper shared with participants in advance of the workshop. The background paper was prepared specifically for the group to help establish a common understanding of the topical scope of the workshop and key parameters for the discussions. In addition, the paper also provided an overview of the state-of-the-art with respect to the use of remote sensing technology for monitoring water quality and tracking land-based sources and sinks of water pollution.

The workshop began with a series of brief lightning talks to build upon the background paper content in setting the stage for the workshop discussions. The first set of talks reviewed the state of remote sensing technology, data and methods for generating actionable information about water quality problems and conveying it to lay users. The second set of talks described existing data-driven water quality monitoring projects and remote sensing derived products for monitoring pollution in inland water bodies and tracking related land-based sources. The central portion of the workshop was comprised of facilitated plenary and breakout discussions that explored remote sensing data collection, processing and validation; product development and design; and how to deploy and raise awareness about the different potential uses of remote sensing for addressing water pollution. The discussions also covered how in situ monitoring relates to remote sensing and opportunities for the two approaches to support and reinforce each other. Toward the conclusion of the workshop, the group spent time brainstorming and sharing ideas about ways to accelerate the deployment and uptake of remote sensing derived products.

The workshop background paper and other advance materials, as well as the final workshop agenda and participant list, and lightning talk presentations, can be found online at: https://drive.google.com/open?id=0B6o0Sf-dad5FbWxnX2RfVm9UbkU.

The summary that follows captures key themes and highlights from the workshop discussions, and catalogues a range of ideas about opportunities to advance the development and deployment of remote sensing derived products and other advanced technologies for monitoring water quality, tracking land-based sources of pollution, and measuring the ecological impact of watershed conservation and pollution mitigation actions.

Key Themes & Highlights

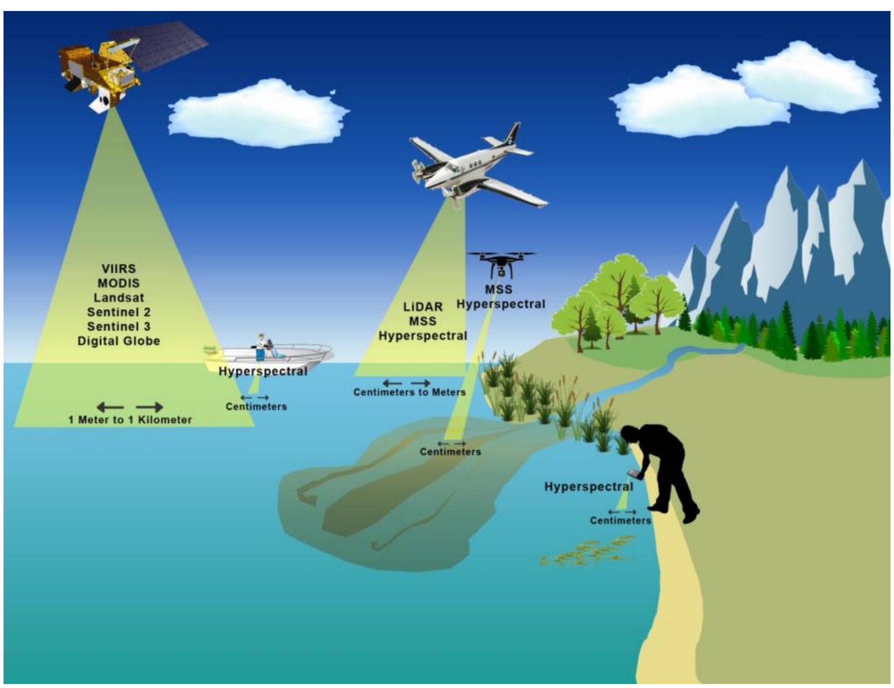
The workshop discussions revealed several key themes about the state-of-the-art regarding the use of remote sensing for addressing water pollution and how to increase the use of the technology among prospective NGO users. An important overarching theme flows from the fact that raw remote sensing data must be translated or converted into actionable information in order to inform decision making and practice on the ground. Much of the workshop discussions revolved around the challenges and opportunities associated with obtaining or collecting data, processing and packaging it, and making it available to and useful for target users. Several organizations represented at the workshop are collecting, analyzing, and packaging remote sensing data for a variety of water resource protection purposes, including U.S. EPA, Michigan Tech Research Institute, Chesapeake Conservancy, Freshwater Trust, and SkyTruth. Overall, it is clear that remote sensing is emerging as a powerful component of a suite of advanced water quality monitoring technologies that collectively hold the promise to transform how NGOs and the public "gather intelligence" about water quality, identify and respond to pollution problems in water bodies, and implement and evaluate action to mitigate land-based sources of pollution. The balance of this section summarizes additional key themes and highlights from the workshop discussions.

Diversity of Remote Sensing Technologies

Satellites are currently the primary source of remote sensing imagery, and many datasets are publicly available from missions such as Landsat. Satellites collect data at a range of spatial and temporal frequencies and all existing (and currently planned) missions are designed primarily for land and ocean applications. Since there has not yet been a satellite launched for the specific purpose of gathering remote sensing data on water quality in inland freshwaters, the usefulness of today's publicly available datasets for water quality monitoring is limited. The resolution of existing public datasets is generally 30 meters or higher and the satellites carry multispectral sensors, which do not capture blue-green infrared bands. As a result, the most accessible currently available remote sensing data can be used to monitor larger water bodies for traditional water quality parameters such as temperature, turbidity, algae/chlorophyll-a, and harmful algal blooms. However, the resolution is currently not adequate to monitor the vast majority of rivers and streams so that remains a significant challenge. Nevertheless, the data that are publicly available can be used in conjunction with remotely sensed land use data (i.e., tree cover, cover crop cover, stream buffers, etc.) to help plan, implement and monitor watershed protection and restoration efforts around large freshwater lakes and reservoirs, for example. Remote sensing data can also be used with soil type, hydrology, and other data layers to inform GIS-based planning and remediation.

While there are limitations on the range of water bodies for which remote sensing is currently a useful monitoring tool, satellite technology is evolving rapidly with the advent of new "nano" satellites. Nanosatellites are much smaller in size, less costly to deploy, and can be launched in "constellations" such that they are able to cover vast geographic areas with high frequency. These newer satellites generate high resolution data (3 to 5 meters) and can also host hyperspectral sensors which cover a much wider range of the visible and infrared spectrum and may yield more detailed information about a broader set of water quality parameters. There are several existing private satellite companies, some which have deployed nanosatellites, that possess higher resolution data (1 meter or less) and increased spectral band imagery that could be useful for water quality applications, but the commercial images are costly to obtain. There may be opportunities for NGOs to forge partnerships with such companies to enable access to relevant imagery at more affordable cost.

Aerial sensor systems mounted on airplanes and unmanned aerial vehicles (UAVs) or drones, as well as platform-based systems are also considered remote sensing technologies and can currently be used to cover smaller lakes, rivers and streams. In addition, handheld hyperspectral / multispectral sensor devices are now available such as that described here. Currently, there are few sources of publicly available data that are generated using non-satellite remote sensing technologies and obtaining or using such systems is cost-prohibitive for most NGOs. See the workshop background paper on Google Drive for more in-depth information about the capabilities and limitations of available remote sensing technologies.



Graphic credit: Michigan Tech Research Institute

Diversity of Target Users

There is potential for remote sensing to help a broad range of potential NGO users achieve their water resource protection or restoration objectives. However, the diversity of NGOs working on water pollution issues – from national organizations with significant technical and financial resources, to regional organizations with moderate technical expertise and modest budgets, to local watershed organizations with limited technical expertise and substantial fiscal constraints – presents a significant challenge. Some are focused on monitoring water quality in the water column, others are interested in watershed dynamics, and others are focused specifically on implementing projects on land that help improve water quality. Some are focused on nutrient runoff, eutrophication and harmful algal blooms in lakes, reservoirs, and estuaries. The latter currently are the use cases most fully developed for the application of existing remote sensing products derived from publicly available satellite data.

Many groups focus on pollution issues in rivers and smaller tributaries and streams, which are more difficult to monitor using current publicly available satellite remote sensing data. However, land uses that impact such waters, including impervious surfaces, can be monitored using public satellite datasets. There is also an array of agriculture focused NGOs that could use remote sensing technology to track and address land use, farming and conservation practices that impact water quality. For these groups, satellite remote sensing currently works best for monitoring land use that impacts water quality and tracking land-based pollution sources and sinks, rather than directly measuring water quality. In the near-term, UAVs and other remote sensors offer viable alternatives, but are more expensive to deploy. Over the longer term, the ability to monitor inland water quality – in large surface waters and smaller rivers and streams – will be greatly improved as new high-resolution hyperspectral data becomes available via new government-led missions or arrangements with commercial satellite companies.

Remote Sensing as Component of Layered Water Quality Monitoring

Compared to in situ monitoring, remote sensing offers the ability to more easily and frequently monitor inland surface waters and track trends over time, particularly in large or inaccessible water bodies. Remote sensing data must be calibrated and validated using in situ water quality monitoring data and there for, there is a great need to use the full suite of emerging and conventional water quality monitoring technologies in complementary ways. For example, the Cyanobacteria Assessment Network (CyAn) project seeks to use remote sensing data to monitor and provide early warning of chlorophyll-a and harmful cyanobacteria blooms in surface freshwaters using ocean satellites. Such an early warning system could trigger in situ sampling in "hot spots" and/or the deployment of higher resolution sensors on aircraft or UAVs to verify the satellite data. In addition, remote sensing can be used to identify potential pollution sources on land and inform immediate mitigation actions as well as the design of long-term mitigation and restoration projects. A potential new frontier in this vein is the ability to link harmful algal bloom indicators in the water column to land-based sources. Incorporating remote sensing data into this type of layered approach to monitoring and response could help NGOs and other users more efficiently and effectively deploy limited human and financial resources to meet water quality objectives.

Co-Design of Products

Funders, universities, and technology companies want to invest in and build products that people will use. With so many potential use cases among the NGO community, it is important that product developers identify and engage target end-users early and often in the research and development process. Designing remote sensing derived products in consultation with target users allows developers to understand the water quality parameters of concern, what resolution data is necessary, as well as preferences regarding information format and interface design. A recent water resources solicitation from the NASA Earth Sciences Division, Applied Sciences Program reflects the importance of co-design, as it stipulated that proposed projects "should clearly demonstrate how the proposed effort would enhance current decision-making processes employed by water managers and their stakeholders."

This type of co-design, fit-for-purpose approach helps ensure uptake and can enable scaling across similar use cases because developers will be better equipped to articulate to funders and others, for whom their product is intended and how it will help target end-users achieve their water quality objectives. In addition, the ability to provide a specific set of requirements could enable the use of competitions or "hackathons" aimed at rapidly producing new advanced water quality monitoring products that fit certain use cases or that can be easily customized to different use cases and users of varying technical capacity.

Integration and Accessibility of U.S. Water Quality Data

Realizing the vision of a layered, multi-faceted water quality "intelligence gathering" apparatus for U.S. inland waters will require greater integration among conventional and emerging data sources. It was suggested that there is a need for one or more central, national-level platforms that can accept and integrate different types of data and make it available for the creation of actionable water quality information. Such platforms should be able to accommodate in situ data collected by existing state and federal monitoring systems, different types of remotely sensed geospatial data, as well as data gathered by citizen scientists using traditional and advanced in situ monitoring tools. Ideally data could be shared and accessed in real-time or near real-time. To achieve this, there would need to be broadly-accepted citizen science data collection protocols that meet or align with federal standards. Such quality assurance and control could be built into computer or mobile device applications. Existing cloud-based platforms could be used to receive, store and process data collected from various sources. Such a central data storage and access platform could enable the development of data visualization products and web-based portals to deliver useful, actionable water quality information to end users. Access to these types of products could help NGOs across the nation incorporate compelling, science-based information into their work, regardless of the tactics they use to achieve their particular water quality objectives.

Education, Awareness, and Capacity Building

The use of remote sensing to address water pollution is a nascent movement in the water quality arena. While a significant amount of research and a number of watershed-specific pilot projects are ongoing, there is a general lack of awareness among NGOs, regulatory agencies, and policy makers regarding the potential applications of remote sensing for monitoring water quality and linking pollution problems with land-based sources. In recent years, the level of information sharing among academics, government scientists, technology developers, and other technical experts working on remote sensing of inland freshwaters has been on the rise. The challenge at hand is to strengthen connectivity and collaboration within the technical community geared toward raising awareness among target users regarding the state-of-the-art of remote sensing for water quality, existing research and investment needs, available products, and future possibilities. Partners such as the AmericaView consortium, GEO AquaWatch, U.S. EPA, the NASA Applied Remote Sensing Training Program and other federal agencies, private companies such as Esri and Google, and national-scale NGO networks could collaborate to develop and disseminate educational resources and curriculum to prospective users and decision makers. Interested parties may also be able to work together to influence policy makers responsible for approving federal investments in satellites to ensure that future missions include technology specifically designed to generate geospatial data suited for inland water quality monitoring. Potential pathways for doing so include providing input to the National Academies of Sciences 2017-2027 Decadal Survey for Earth Science and Applications from Space, or discussing needs with key members of Congress and their staffs.

Opportunities to Accelerate Development and Deployment

On Day 3 of the workshop, participants engaged in a brainstorming exercise designed to generate specific ideas about how to accelerate the development and deployment of remote sensing derived products that could bolster the efforts of NGOs focused on water quality improvement. To stimulate thinking, the exercise was framed around funding opportunities (near-term, mid-range, and long-term); opportunities to influence policy or investments; and partnerships. For purposes of the workshop, "funders" was defined broadly to include philanthropic foundations, government agencies, corporate foundations and direct-giving programs, impact investors and venture capitalists. For funding opportunities, participants were encouraged to include cost estimates, potential funders, and key players in their suggestions. The group produced a broad range of ideas falling into the following categories:

- Project Ideas and Funding Opportunities
    - Demonstrate and Scale-Up Successful Approaches
    - Catalyze Development of Products and Tools
    - Create Information Hubs
    - Establish Funding, Technical Assistance, and Networking Mechanisms for NGOs
    - Coordinate Educational and Training Curriculum

    - Focus on Algae and Harmful Algal Blooms
    - Develop and Test Agriculture-Focused Applications
    - Fund Major Advanced Water Quality Monitoring Projects and Initiatives
    - Build and Launch New Satellites
- Opportunities for Influence
- Potential Partnerships

The document attached to the end of this meeting summary provides a detailed "menu of opportunities" structured around these categories. Though it is included here as an attachment to this workshop summary, it may also be used as a standalone document.

Generally, the project ideas and funding opportunities focus on improving or scaling up existing tools or projects; developing new tools; information sharing, education, and awareness; and supporting new projects and initiatives. Key opportunities for influencing policy or investments include advocating for the deployment of higher spatial resolution, government-operated satellites and integrating the use of remote sensing into the program design and monitoring operations of federal conservation programs. There are also a wide range of potential partnerships that could move the field forward, from pilot projects involving multiple sectors; to NGO consortiums; to opportunities to shape federal projects, collaborate with universities on research and product development, or establish relationships with corporations using remote sensing.

Conclusion

Remote sensing technology has the potential to transform how a wide range of NGOs and others approach and tackle water pollution challenges, but its use is a nascent movement in the water quality monitoring and protection arena. While much is possible today with available technology and existing tools, there is substantial work to be done to enhance the resolution and accessibility of the data, accelerate the development of useful, affordable products, and educate target users about the potential of remote sensing and how to use available products in their work. Advancing the deployment and uptake of remote sensing and other advanced water quality monitoring technologies will require ongoing collaboration among diverse groups of experts and stakeholders like the one convened for this workshop, as well as the active interest and commitment of a broad range of funders.

Using Remote Sensing to Address Water Pollution: Menu of Opportunities

Project Ideas, Funding Opportunities, Opportunities for Influence, and Potential Partnerships

November 2016

Overview

This document presents a menu of opportunities identified during a brainstorming session at the September 14-16, 2016 workshop, "Using Remote Sensing to Empower the Public to Address Water Pollution." Workshop participants did not analyze or prioritize the results of the brainstorm session. This compilation reflects Meridian Institute's post-workshop effort to synthesize and condense the large number of ideas and opportunities that were shared at the workshop. As such, the list has been streamlined and structured to facilitate the ability of interested readers to digest the myriad ideas shared at the September 2016 workshop. The content is organized into the following categories:

- Project Ideas and Funding Opportunities
    - A. Demonstrate and Scale-Up Successful Approaches
    - B. Catalyze Development of Products and Tools
    - C. Create Information Hubs
    - D. Establish Funding, Technical Assistance, and Networking Mechanisms for NGOs
    - E. Coordinate Educational and Training Curriculum
    - F. Focus on Algae and Harmful Algal Blooms
    - G. Develop and Test Agriculture-Focused Applications
    - H. Fund Major Advanced Water Quality Monitoring Projects and Initiatives
    - I. Build and Launch New Satellites
- Opportunities for Influence
- Potential Partnerships

For additional materials from the September 2016 workshop, please visit: https://drive.google.com/open?id=0B6o0Sf-dad5FbWxnX2RfVm9UbkU.

Please contact Brad Spangler at Meridian Institute (bspangler@merid.org) for additional details or to request contact information regarding particular opportunities.

Project Ideas and Funding Opportunities

A. Demonstrate and Scale-Up Successful Approaches

1) Identify successful regional water quality monitoring, protection or restoration projects that use remote sensing data, and replicate use of methodology and tools in other regions to test and document extent of applicability across different landscapes.
    a. Example 1: Replicate the Chesapeake Conservancy Precision Conservation approach in other watersheds/regions such as Maumee River (Lake Erie) watershed or Delaware River Basin
        i. Contact: Jeff Allenby, Chesapeake Conservancy
    b. Example 2: Replicate MinnesotaView product in other state – Map and Monitor Land and Water Resources with Landsat 8 and Sentinel 2 data (water clarity, chlorophyll, colored dissolved organic matter and suspended solids); web delivery system will distribute remote sensing derived maps, statistics, and analyses. Results will be used by state and local agencies to assist in management and policy decisions on land and water resources.
    c. Other stateview projects from AmericaView consortium.
        i. Contact: Terri Benko, AmericaView
    d. Potential funders: NASA Applied Sciences Program, NASA Glenn Research Center, USGS, foundations
2) Conduct demonstration projects and/or scale up use of products using remote sensing data to map, monitoring and assessing or modeling landscape change that impacts surface water quality; 3 potential areas of focus include:
    a. Agricultural soil erosion and loss
    b. Post-wildfire erosion and sediment loading (USGS offers an operational Landsat-derived product showing burn severity)
    c. Wetland mapping (using Landsat and Synthetic Aperture Radar; existing methodology and basic products available for Great Lakes Region)
    d. Potential funders: USFS, US EPA, NASA Applied Science Program, local or regional environmental agencies
    e. Contact: Nancy French, Michigan Tech Research Institute

B. Catalyze Development of New Products and Tools

Products

1) Fund development and scaling up of handheld hyperspectral sensors and related best practices.
    a. Estimated Cost: $100K - $2M
    b. Potential funders: foundations
2) Fund development of turbidity monitoring product for the Americas.
    a. Estimated Cost: $100K - $2M
    b. Potential funders: foundations
3) Develop a tri-coder smartphone application.
    a. Estimated Cost: $250K – 500K
    b. Potential funders: foundations, federal government
    c. Players: sensor technologists, could-based data processors
4) Build a tool that makes it easier to validate land cover models; upload your model and validation points; preserve the validation points for evaluating future land cover models
    a. Contact: Tyler Erickson, Google Earth Engine
5) Build a national remote sensing platform for inland and coastal water quality; cover Chlorophyll A, turbidity, colored dissolved organics; provide real-time, historical data, and projections; link to land use change, watershed models to help identify sources [of pollution]
    a. Estimated Cost: $500K - $1M
    b. Potential funders: foundations, government
    c. Key players: EPA, NOAA, NASA, universities, technology developer, World Resources Institute (tool development, user engagement)
    d. Contact: Sara Walker, World Resources Institute
6) Develop integrated data hub that can accommodate satellite remote sensing, drones, in-situ, and citizen science data on a core set of water quality indicators (pigment, temperature, clarity, c-l index)

Design Events

7) Organize a hackathon to develop handheld hyperspectral sensors coupled with mobile collection apps for water pollution.
    a. Estimated Cost: $50K
    b. Potential funders: foundations, industry, government agencies
    c. Players: techies, government, NGOs
8) Organize regional prizes and hackathons to engage local watershed groups in developing apps and integrating remotely sensed data into their work; could include technical training and support for watershed groups.

9) Issue a design challenge in partnership with a technology company and farmer organization to develop and pilot a nitrate sensor which costs one-tenth of current sensors.
    a. Estimated Cost: $1M – $3M
    b. Funders: foundations and corporations
    c. Players: Technology companies, farmer organizations, environmental NGOs
10) Convene a co-design or hackathon type of forum that brings together technology experts and watershed organizations to determine what additional funding would be needed to support implementation. Apply those funds to pilot/case studies and share/disseminate the case studies when they're completed.
    a. Players: Engage a group of watershed organizations (possibly through River Network) with an interest in how remote sensing can help to monitor, plan and improve their watersheds.
11) Create an "x-prize" type challenge to advance development of low-cost water quality monitoring tools
    a. Estimated Cost: $1M
    b. Potential funders: EPA, technology developers

C. Create Information Hubs

1) Create an online clearinghouse of tools and resources to share information about advanced water quality monitoring technologies available to watershed organizations; offer case studies and webinars to introduce tools; catalogue user needs and disseminate back to technology developers
    a. Estimated Cost: $100K
    b. Potential funder: private foundations
2) Create comprehensive inventory of existing Federal databases, geospatial analytical platforms and data portals
3) Conduct landscape analysis of current efforts to monitor water quality using remote sensing; document the following: what parameters, where, by whom; methods used to generate actionable information; success factors, lessons learned; best practices for communicating resulting information; opportunities for scaling up/replication
    a. Estimated Cost: $100K – 200K
    b. Potential funders: private foundations
4) Fund development of AquaWatch website as an information, data and education portal for remote sensing of water quality
    a. Potential funders: private foundations, Google, Amazon, Microsoft
    b. Contact: Emily Smail, AquaWatch / Group on Earth Observations

D. Establish Funding, Technical Assistance, and Networking Mechanisms for NGOs

Funding

1) Create a Technical Assistance Grant Program that makes a pool of funding available to NGOs/local organizations to contract technical experts to help work on specific water quality protection problems; stipulate that projects aim to create models that can be replicated by other groups.
2) Create a pool of funds that nonprofits, academics, researchers with interesting data/reports can access to create visualization and communications resources to better convey research and monitoring results to target audiences.
3) Establish federal/private/NGO remote sensing fellowships to stimulate information exchange, bolster training, and foster partnerships.
    a. Estimated Cost: $50K – 200K per person/year; potentially in-kind?
    b. Potential funders: foundations and government agencies
4) Major donors give a set amount to the Esri non-profit program to lower the cost for entry for qualifying 501c3 environmental organizations to participate in the program with the specific goal of recruiting water pollution action NGOs into the program.
    a. Estimated Cost: $100 for an individual subscriber; $10K for small organization; $50K; $1M buys in 100 small organizations
    b. Potential funders: Pisces Foundation, McKnight Foundation, Walton Family Foundation, AAWA
    c. Key players: Esri, agencies, funders

Technical Assistance

5) Create a hub of technical assistance support that works to provide modeling and remote sensing expertise to local restoration implementation organizations; offering a concentrated source of technical functions would allow more rapid advancement than many groups working redundantly toward the same ends, or not utilizing remote sensing data because of an inability to transform it into useful information.

Networking

6) Fund a national (or regional) network on remote sensing for inland water quality. Share experiences; share and collaborate on funding opportunities; collectively advance technology and application of remote sensing
    a. Cost: ~$100K per year
    b. Funders: foundations, government
    c. Key players: remote sensing project managers, convenor

7) Fund a web-based water quality social network where groups can share project information, funding opportunities, register datasets, products, outreach efforts, restoration and conservation projects, etc. and allow for connections across fields.
8) Convene a remote sensing workshop for water NGOs; designed to keep exchange information about ongoing projects and state of science around remote sensing and advanced water quality monitoring; more workshops that are open the water community; foster networking among NGOs interested in using remote sensing.
9) NGOs work with universities to improve research extension and outreach; funders provide support for communication and networking between researchers and practitioners

E. Coordinate Educational and Training Curriculum

1) Fund outreach and education projects about remote sensing functionality.
2) Fund projects to identify and create instructional materials about best practices for data collection.
3) Identify existing watershed academies (EPA, Waterkeeper, USGS) and add content on remote sensing for water quality improvement; potential partners include EPA, USGS.
4) Develop online training/MOOC/manual on “What LIDAR can do for you”.
   a. Estimated Cost: $75K
   b. Potential partners: Chesapeake Conservancy, River Network

F. Focus on Algae and Harmful Algal Blooms

1) Scale the US-focused CyAN project to make global predictions
   a. Funders: USAID, SERVIR
   b. Key players: EPA, NOAA, NASA, Google Earth Engine, GEO AquaWatch
2) Fund a harmful algal bloom (HAB) reduction and intervention pilot program, soup to nuts in one large lake (e.g., Western Lake Erie).
   a. Use existing datasets to create best estimate of current conditions – MTRI/EPA; $150K for 3 staff
   b. Model/prioritize best places to intervene – Chesapeake Conservancy, Freshwater Trust; $100K for 2 staff
   c. Implement intervention by changing management practices – local groups, state agencies; $300K for 2 staff plus payments
   d. Contact: Gary Kohlhepp, Michigan DEQ
3) Develop a Global Algae Watch web portal
   a. Use modeling developed by EPA (and affiliated researchers) to monitor and predict algae blooms around the globe.
   b. Key players:

i. EPA: model development, choice and engagement with state stakeholders
ii. SkyTruth: implement algorithms in Earth Engine and develop IT infrastructure; potentially incorporate other imagery.
iii. Google: provide technical support, Earth Engine
iv. Vizzuality: make it beautiful.
v. World Resources Institute: application and policy engagement.
vi. Swim Guide: on-the-ground use, engagement and verification

c. Estimated Cost range: very cheap (build simple website with EPA data) to >$5M
d. Contact: David Kroodsma, SkyTruth

G. Develop and Test Agriculture-Focused Applications

1) Targeting conservation through Soil and Water Conservation Districts; provide remote sensing information to local soil and water conservation districts; enable watershed planning; targeting; capacity building; centralized functions
    a. Estimated Cost: $10M (scalable)
2) National or regional platform remote sensing platform to monitor implementation and environmental impact of agricultural best management practices (e.g., buffers, wetlands, cover crops, nutrient management, pasture fencing)
    a. Estimated Cost: $500K to $1M
    b. Funders: foundations, USDA
    c. Key players: university remote sensing experts, agricultural community (conservation districts), tool developers
3) Develop remote sensing derived products for soil loss detection and conservation practice targeting; highlight accelerated soil loss associated with extreme rainfall events
4) Develop remote sensing tools for agriculture-related applications, for example:
    a. Tracking soil moisture, with potential application to Western Lake Erie basin to determine drainage patterns
    b. Identifying application of manure to frozen ground
    c. Identify areas to apply "precision conservation" techniques
    d. Potential funders: foundations, Great Lakes funders
5) Collaborate with Field to Market to track as many farmer practices as possible with remote sensing and facilitate farmer use of the Field Point Calculator.
6) Remote sensing for landscape mapping – remote sensing of agricultural soil erosion:
    a. Support RUSLE and WEPP soil erosion modeling
    b. Multispectral sensors (Landsat)
    c. Synthetic Aperture Radar (SAR) (Sentinel 1 a/b)
    d. Image fusion

  e. Estimated Cost: ~$500K for development; additional for translation to users
  f. Potential funder: USDA ARF Program
  g. Key players: university (for development), USDA, farmers, NHFF
7) Facilitate more farmer and farm group acceptance of remote sensing by providing agronomically useful data to farmers.
8) Remote sensing tools/products to track continuous living cover, cropping systems, status of buffer strips, etc.
9) In a key Nutrient Reduction Strategy State (IA or IL), use remote sensing to ground truth and track progress and adaptively manage progress toward goals.
10) Fund research to remote measure inorganic fertilizer rate; and organic fertilizer rate and form
    a. Funders: government agencies
    b. Players: NASA, satellite companies, sensor companies
11) Crowdsource the identification and monitoring of harmful agricultural practices such as CAFOs or spreading cattle manure on snow (questionable feasibility).
12) Conduct pilot beta tests on use of low-cost monitors (once developed) in nutrient trading (non-point source).
    a. Estimated Cost: $500,000
    b. Key players: EPA, state agencies, farmers, technologies developers, wastewater utilities

H. Fund Major Advanced Water Quality Monitoring Projects and Initiatives

1) Fund AquaWatch to develop a regional prototype project that includes local grassroots citizen science data collection; national, state, and academic data collection; and data visualization to produce actionable information products and activate outreach efforts to engage mitigation experts.
    a. Potential regions: Mississippi River, Great Lakes, Atlanta area
    b. Estimated Cost range: $1M - $10M
    c. Potential funders: foundations, government agencies
    d. Key players: AquaWatch, local and regional NGOs, foundations
    e. Contact: Emily Smail, GEO AquaWatch
2) Assess and develop mechanisms to improve cataloguing and communication of in situ data to align with and enhance remote sensing data
    a. In situ monitoring campaigns are currently designed for drawing conclusions without remote sensing data
    b. Attempt to modify/improve in situ metadata to make these data more useful for remote sensing needs.
    c. Partners: USGS, EPA, remote sensing consortium, NASA

3) Illustrate/compare how we monitor now (cost, scope, gaps) versus how we could do it using remote sensing and other tools (e.g., "The Power of Remote Sensing for Water Quality Monitoring: Visualized")
    a. Target Audience: funders, agencies
    b. Goal: demonstrate modern data visualization/storytelling to raise awareness of possibilities
    c. Estimated Cost: $200K mostly for synthesis
4) Need a pilot to demonstrate the current and future capabilities to monitor through layered data collection, including use of the following technologies: target (rivers); in-water (buoys); bridge-mounted hyperspectral imaging; quadcopter-mounted hyperspectral imaging; NASA U2 hyperspectral imaging; DigitalGlobe multi-spectral imaging (WV3, WV1; GeoEye); data and handling (store and share)
    a. Correlated data can then be compared and assessed for their individual and integrated/fused value to assess the "State of Water"
    b. Estimated Cost: $300K (need to price out sensors)
5) Algorithm development; formulize target water bodies; Need to able to translate the collected data along with other products, terrain, weather, surface characteristics to provide an answer
    a. Estimated Cost: $200K
6) Major donors fund a Blue Infrastructure Initiative.
    a. Similar to Esri Green Infrastructure Initiative that assembles water infrastructure and water quality information to provide context and connectedness to water an green infrastructure improvement projects. Create website for data ad tools to standardize approach to building GI and pollution control
    b. Estimated Cost: up to $1M
    c. Players: Esri, universities
    d. Funders: major foundations
    e. Contact: Terry Martin, Esri
7) Funders sponsor a remote sensing in water pollution development meet-up series to demonstrate approach and applications and foster community of practice (based on Esri meet-ups)
    a. Estimated Cost: $50K each
    b. Funders: Esri agencies
    c. Key players: Esri, NGOs, government agencies
    d. Contact: Terry Martin, Esri
8) Major donors fund a coalition of organizations united against water pollution using imagery and remote sensing in GIS. Umbrella coalition funds software, training, development and implementation as well as a Geo Hub for remote sensing data. – Terry Martin

   a. App discovery and groups for sharing
   b. Coalition funds a remote sensing for water pollution conference held annually at Esri headquarters (similar to the oceans conference)
   c. Estimated Cost range: plus/minus $1M
   d. Potential funders: Gates Foundation, Clinton Foundation, Esri, Walton Family Foundation, Pisces
   e. Key players: Esri, agencies, funders

9) Major donors fund an annual conference at Esri headquarters, "Public Empowerment to Use Remote Sensing in GIS to Stop Water Pollution" – Esri creates space for NGOs at the user conference and a user group – Terry Martin
   a. Estimated Cost range: $50K – 500K
   b. Potential funders: major and intermediate foundations, private water services companies (e.g., American Water)
   c. Key players: Esri, utilities, funders, government agencies, NGOs
10) Major donors fund Esri and Chesapeake Conservancy to develop a standard approach to water pollution projects including data requirements, GeoHub, tools, workflows and grant assistance – a template for point and non-point source, tools, sample websites, demonstration project presentations at Esri conference and conference paper track. – Terry Martin
   a. Estimated Cost: $500K
   b. Potential funders: government contract, large foundation
   c. Players: Esri, Chesapeake Conservancy, EPA
11) Major donor funds a Climate Change Infrastructure GeoHub with data, applications, community to provide context and connectivity for climate, green infrastructure, blue infrastructure, pollution projects globally – Terry Martin
   a. Estimated Cost: $1M plus
   b. Funders: Gates Foundation, Walton Family Foundation, Intel
   c. Key players: water, climate, government, water NGOs
12) Complete time series water quality satellite maps for Great Lakes
   a. Estimated Cost: $500K
   b. Funders: NASA, NOAA, EPA
   c. Key players: universities, NOAA
13) Need an analysis of remote sensing technology alternatives; government-funded longitudinal study of requirements, platforms, sensors, algorithms, and existing infrastructure systems.
14) Survey of land use change along <u>all rivers</u> in the U.S. since 2000; use NAIP and Google Earth Engine to identify land use change along all rivers in the US
15) Mapping lake trophic status and aquatic vegetation in each state on a recurring interval.
   a. Estimated Cost: Uncertain

  b. Potential funder: Federal government, perhaps with state contributions
  c. Key players: EPA, USGS, NOAA, NASA, states, tribes, NALMS

16) Investigate how drought is changing our watersheds
  a. Collect normalized difference vegetation indices (NDVI) around all streams in the West; translate NDVI to stream dewatering using citizen science; use photo and location services to locate streams
  b. Create temporal map to track impact of drought over time
  c. Estimated Cost: $200K

17) Long-Term Goal: Understand the water pollution status of every water body in America (daily, weekly, annually).
  a. Combine research and technology to monitor from satellites and make the information available to the public and software engineers.
  b. Make it easy for people with drones to immediately upload imagery and get back pollution parameters (feed into global database of pollution information).
  c. Make it easy for anyone to manually measure water quality and share data with the world.
  d. All elements feed into an app that lets stewards of watersheds/rivers/lakes know more about their spaces without the app.

I. Build and Launch New Satellites

1) Build and launch a constellation of 200 hyperspectral satellites; will require significant communications infrastructure, data processing, data storage, data distribution, data exploitation. Constellation it necessary to attain an agnostic, global solution to satellite remote sensing of water quality in inland surface waters. Large number of sensors is critical to support timing/coverage requirements. Cloud-based data processing infrastructure will be required.
  a. Estimated Cost: $1B or more

2) Build an inland water satellite with less than 5m resolution, a daily time-step, and bands for chlorophyll A, cyanobacteria, temperature, and turbidity.
  a. Estimated Cost: $1M plus
  b. Funders: federal agencies, NASA

Opportunities for Influence

1) Push high spatial resolution (5 -10m) for new generation optical satellites, as well as for hyperspectral so that blue-green bands are included.
2) Target infrastructure funds to data collection and management. What is the financing model for states and municipalities to invest in data?

3) AmericaView – lead principal investigator from each stateview visits Congress every winter/spring to share their remote sensing work and the impact in their states.
4) If a network is funded with project managers to share experiences and advance the science and application, the group can work collectively to influence policy makers, funders, and investments in necessary technologies.
5) Aim to inform solicitations issued by the NASA Applied Sciences Program related to water quality.
6) Advocate for utilizing remote sensing to monitor NRCS conservation programs in the Farm Bill, expected in 2018.
7) Integrate remote sensing data into program design and evaluation for all Farm Bill cost share and conservation programs.

Potential Partnerships

A. Multi-Sector

1) Work with existing organizations to identify remote sensing monitoring needs. Examples include: National Water Quality Monitoring Council; Great Lakes Beach Managers; River Network; Association of Clean Water Administrators (ACWA); State/regional monitoring councils.
2) The Freshwater Trust, Google Earth Engine, Chesapeake Conservancy partner with SkyTruth to assess changes in riparian corridors – how much development, degradation or improvement has occurred over time?
3) Esri and Chesapeake Conservancy to develop baseline Green/Blue Infrastructure requirements for watershed restoration.
    a. Players: industry, NGOs, local to federal government agencies
    b. Funders: foundations, technology companies
    c. Estimated Cost: $1M
4) Develop a baseline Green Infrastructure and Blue Infrastructure dataset (HSI, MSI, imagery and vector data)
    a. Potential funders: foundations
5) Global Lake Ecological Observatory Network (GLEON), Globolakes, federal agencies, academics, etc. – partner on lake and reservoir water quality assessment.
6) Companies and institutions with visual information (e.g., satellite imagery) share data with grassroots monitoring organizations so those groups can make better decisions about when and where to sample (improve return on investment).
7) Forge partnerships between information producers and outreach groups

a. Potential funders: foundations
b. Key players: federal, state agencies, NGOs and science experts

8) Partners to support Water Lens Pilot (NGRECC, Riverside Research, AmericaView, NASA, MTRI, Esri)
9) Connect with state and federal agencies and NGOs with a stake in citizen science monitoring.

B. NGOs

1) National Ecological Observatory Network (NEON Inc.); continental-scale observation system for examining ecological change over time; has identified field sites, data standards, field-to-sky sampling; includes regular acquisitions of airborne LIDAR and hyperspectral imaging.
2) Conservation GIS Consortium: bring together leading NGO partners to take on larger/national scale projects that would be too big for one organization to take on themselves; knowledge and best practice transfer; skills and expertise sharing. Contact: Jeff Allenby, Chesapeake Conservancy

C. Federal Agency

1) National Water Quality Monitoring Council; meet and confer regularly, but remote sensing is not a priority topic to date.
2) National Science Foundation (NSF) is interested in broader impacts; partner with universities and NGOs to implement science for broader impacts and outreach. Contact: Erin Hestir, NC State.
3) Natural Resources Conservation Service (NRCS) - examine whether remote sensing can improve models of soil erosion and nutrient export from farm fields.
4) CyAN project team is open to collaboration and linking with other efforts. Contact: Blake Schaeffer, EPA.

D. Academia

1) AmericaView as partner to disseminate data products and systems to multiple states quickly.
2) Technology advancement ideas for implementation by NGOs – university (MTRI) develop technologies (MTRI); university extension services help disseminate to NGOs; NGOs help disseminate to other NGOs (Lake Ontario Waterkeeper, SwimGuide).
3) Work with social scientists at universities to better communicate information learned [about remote sensing and water quality] to appropriate audiences (decision makers, public, NGOs, etc.)

E. Corporate

1) Planet (satellite company in San Francisco that will be providing daily and global 5m imagery) and SkyTruth and anyone with a good idea.
2) Coca Cola – large-scale consortium that works on practices to reduce impact of corn production on water quality.
3) Form a partnership between Esri and AmericaView to host data in the Ecological Atlas or the Living Atlas.
4) IBM is very interested in "aquahacking" – not only finding solutions to water problems with technology but also funding implementation of startup businesses