US EPA perspective on integrating Earth System Science with Water Quality Research and Management

Blake A. Schaeffer and Darryl J. Keith

This is one of three responses formally provided by the EPA to the National Research Council in response to the Request for Information concerning the 2017-2027 NRC Decadal Survey in Earth Science and Applications from Space.

Question 1

Good water quality is necessary to support drinking water supplies, aquatic life, as well as recreation in and on the water. It is important to have scientific understanding of environmental processes to inform water quality management decisions to protect biological, physical, and chemical water quality characteristics. We highlight the need to consider inland water bodies, defined as lakes and reservoirs, and estuaries as a new and important aspect of Earth System Science (ESS). Traditionally, inland water and estuary sciences are categorized under ocean or land science. However, there is increased demand from state, federal, and non-governmental organizations (NGOs) for the ability to monitor water quality by re-purposing ocean color and land imaging satellites. Therefore, we recommend an emphasis be placed on water quality for inland and estuarine waters. The next decade of ESS should be equally weighted with inland and estuary water quality applied research, applications and operations. Global consistency and continuity of future satellite missions is required because of the spatial, spectral, and temporal disconnect between sensors. The key science challenge that can be addressed is the ability to link anthropogenic stressors to their environmental responses. ESS can help detect and quantify harmful algal blooms (Lunetta et al., 2015), invasive species (GLRI, GLWQA, 2014), water clarity in optically shallow waters (Barnes et al., 2013), estuarine acidification (EPA, 2015a), effluent detection, pathogen indicators (EPA, 2012a), and climate temperature changes (EPA, 2015b). ESS also complements monitoring and assessments (Schaeffer, 2015; Keith et al., 2014), such as oil spill thickness and extent (ICCOPR, 2015), fate and transport of nutrients and co-pollutants (Schaeffer et al. 2012; Schaeffer et al, 2013a), and benthic habitat monitoring (Barnes et al. 2014), ESS can also assist in developing quantitative water quality expectations that can lead to pollution reduction (EPA, 2012b). Robust models are necessary for management, but current models cannot resolve events because of limitations on knowing when and where these events occur. Operationally, a challenge is improving the capacity of current and future missions to routinely provide quality measurements that support federal and state agencies tasked with water quality management. ESS provides information on dynamic and ephemeral events over extensive spatial and temporal scales.

Section a

There are future missions planned that may address some current sensor limitations such as GEO-CAPE and Sentinel-3, and with continued repurposing of satellites such as Sentinel-2A, 2B; and Landsat 8/9. Additional investments are needed for Landsat-10 and beyond, which include spectral wavebands and signal-to-noise ratios required for deriving water quality. PACE and GEO-CAPE should include the highest spatial resolution possible to resolve the maximum number of water bodies and spatial gradients when imaging within the continental US. The PACE science definition team suggested resolutions at 250-500m for lakes and estuaries (PACE SDT, 2012). However, as of the 2015 IOCS Meeting, PACE may only provide 1km resolution globally, which reduces applicability for inland waters. Recent studies suggest 100-200m ground sample distance requirements are needed to resolve spatial gradients (Tzortziou et al., 2011). Spatial resolution still remains a major hurdle for inland waters, where sensors with a 300m pixel resolution provide data for <4% of US lakes and reservoirs. Conversely, Landsat resolution (30m) may resolve 30% of these waters.

Future ocean color and land missions should no longer be categorized as just land or ocean missions, but integrated equally with inland and estuary water quality research and applications.

Question 2

Ocean color satellites have been equipped with sensors optimized for collecting data over the global ocean (McClain, 2009), but not over inland or estuarine waters. Due to the coarse spatial resolution, water quality science and applications also depend on terrestrial sensors, such as Landsat (Mouw et al., 2015). Progress has been demonstrated in deriving data from inland and estuarine waters using MODIS, MERIS, HICO, and Landsat. All of these sensors have provided access to inland and estuarine waters (Keith, 2014; Keith et al., 2014). Landsat 8 may be useful due to its radiometric resolution and calibration accuracy (Vanhellemont and Ruddick, 2014; Franz et al., 2015). We expect that with Sentinel 2A and the forthcoming Sentinel 2B, temporal resolutions will improve, approaching those associated with ocean color missions (Hestir et al., 2015; Mouw et al., 2015). In-water algorithms, atmospheric corrections, and land adjacency effects will require mature approaches over the coming decade. Calibration and validation exercises are typically not inclusive of inland and estuarine waters, but should be integrated into future missions (Palmer et al., 2015). The next decade is an opportune time to begin addressing technology modifications required for these water systems such as sensor sensitivity, dynamic range, and appropriate spatial, temporal and spectral resolution (Mouw et al., 2015). The lack of current and planned missions focused on the scales of variability encountered within inland and estuarine waters suggests new missions should be planned to meet these new requirements. Overall, greater spectral and spatial resolution with frequent resampling is required for applications and operations.

State, federal, and NGOs have begun to actively request available satellite data to address scientific questions and applications with regard to water quality management. Recent advances in cloud-based infrastructure allows for coordinated data sharing with centralized, open access, publically available data (Mouw et al., 2015). Water quality managers have, and continue, to overcome barriers (Schaeffer et al., 2013b) in adopting new methods that leverage satellite data. For example, EPA recently accepted the use of ESS derived water quality products in developing numeric nutrient criteria (Schaeffer et al, 2012; Schaeffer et al, 2013a).

Section b

Space-based observations are one of the many tools available to state, federal, and NGO entities for addressing water quality questions. Satellites provide information and answers to questions at improved spatial and temporal scales. *In situ* monitoring along with evolving sensor technologies can provide insights at resolutions that complement ESS. Discrete sampling and moorings *do not provide complete spatial and temporal coverage and* have limited ability to quantify the full range in variability that can impact human health and the environment. However, discrete samples and moored instruments can fill ESS gaps during periods of cloud cover, or in areas not currently resolvable, and provide validation data. Citizen science is emerging as a data source into the next decade. Crowd sourced internet tools such as interactive maps (Meier, 2012) can be used to identify locations of concern within communities that weren't possible a few years ago. ESS can address or inform communities on water quality changes that impact societal uses. Technologies, such as open source Arduino microcontrollers, will allow for development of low costs sensors (Leeuw et al., 2013) that can be combined and integrated with ESS to derive now-cast and forecast models at watershed scales. Mobile technology allows complex satellite data files to be simplified and made accessible to communities for informational outreach. ESS data products will also assist with targeted deployment of existing federal, state, tribal, and municipal monitoring and research efforts (Mattas-Curry et al, 2015). Mobile technology also show promise for citizen science such as Citclops, HydroColor, Secchi, and EPA Cyanoscope apps.

Question 3

Feasibility of incorporating ESS into water quality monitoring has been demonstrated and operational applications are expanding. Many state, federal, and NGO entities conduct field-based activities with limited resources to provide information. ESS is a potential solution to overcome limited geographic extent and temporal coverage. When coupled with field-based observations, ESS data provide a more comprehensive understanding and establish the capability to monitor, assess and forecast changes in ecological condition. Information is needed to assess baseline conditions and to understand trends for management. Inland and estuarine waters present a challenge because of the complex hydrologic connections and spatial separation, variable ecological drivers, and anthropogenic stressors. ESS allows for an integrated and system level approach that may will be beneficial as extreme events increase (IPCC, 2012).

Section c

Water quality is connected to economic success, human health, social well-being, and drinking water security. Citizens are familiar with weather reports for daily decisions. ESS for water quality could provide information, achieving similar levels of familiarity in the coming decade, influencing decisions on where to take vacations, purchase homes, or best times for fishing, diving, or swimming. Finally state, federal, NGOs, tribes, and local municipalities will be better informed for protecting water supplies and the public.

Section d

Inland and estuary water quality science could facilitate integration (NRC, 2014) of freshwater, ocean, atmospheric, and land sciences to solve problems in order to protect humans and the environment. Participation by ocean color, landscape and aquatic ecology, public health, economics, computational and hydrologic modeling science communities is anticipated. Government agencies, such as CDC, NIEHS, USACE and EPA, can integrate application sciences with research from NASA, USGS, and NOAA. Benefits would extend to state agencies, health and environmental departments, non-profits such as World Resources Institute and Nature Conservancy, in addition to the World Bank, World Health Organization, and United Nations.

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