Key Challenges for Inland Water Ecosystems

1. What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?

Inland sources of fresh water are critical for life on our planet. Even though 50% of the world's population lives within 3 km of inland rivers and lakes, over 1.1 billion people currently do not have access to clean water (WHO, 2006). Water crises are the greatest risk facing the world today according to the World Economic Forum (WEF, 2015). Over 80% of the world's population currently faces high level water risk (Vorosmarty et al., 2010). Half of the world's 500 major rivers and half the world's lakes are classified as seriously degraded or over-depleted (UNEP, 2006). The decline in the quality of water resources is causing the extinction of freshwater species and a severe loss of biodiversity. Therefore, the most pressing question for inland water ecosystems that can be addressed with remote sensing is ***"how is freshwater quality and quantity changing in response to increasing stress from population growth and climate change?"*** Specifically, the following ecosystem stressors and societal challenges can be addressed with remote sensing capability:

1) Eutrophication, Harmful Algal Blooms and Water Clarity

Eutrophication caused by excessive nutrient loading from anthropogenic sources can lead to excessive algal growth and toxic cyanobacterial blooms. Factors including nitrogen, temperature, and possibly conductivity all contribute to this excessive growth (Paerl et al., 2014; Rigosi et al. 2014) resulting in low oxygen, loss of biodiversity, loss of fisheries, decreased light penetration causing the loss of submergent vegetation, and aesthetic and odor issues that impact drinking water, commerce and tourism. Though known to be widespread across all continents, the extent and intensity of these blooms is uncertain. Hence, we pose two key research questions:

- What are the trophic states of global inland waters and how are they changing?
- Where are toxic algal blooms occurring, and what is the frequency of occurrence?

2) Watershed Alterations and Impacts

Inland waters are strongly influenced by land use, which can affect the timing and location of inflows and water quality. Changes in runoff, particularly due to urbanization and associated impervious surfaces, can increase flash flooding, extend periods of low flows, and alter channel morphology. The increased intensity of the runoff events can increase erosional power and entrain more soil particulate with greater particle size. The resulting water quality impacts include greater siltation in receiving waters negatively impacting fisheries and benthic organisms. Silt-laden water supply intakes incur greater cost to process and clean. Nutrients, metals, and organic pollutants are also transported in association with the particulates. It is therefore necessary to know and address:

- How do inland waters respond to changes in their watersheds?

- What is the rate of siltation in our waterways and reservoirs and what are the biological consequences?
- What role do particulates play in the transport and deposition of nutrients, metals and organic pollutants in the aquatic ecosystem?

3) Climate Change Impacts

Aquatic ecosystems are particularly vulnerable to climate change. Changes to the hydrologic cycle such as storm magnitude and frequency, extreme events, ratio of snow/rain, and water stress all affect inland waters. Variations in meteorological conditions cause changes in water temperature, evaporation, lake level, ice cover, hydrobiogeochemical regimes, and entire lake ecosystems. Of particular concern are the impacts of changes in water temperature, which may result in changes in species composition, abundance, and productivity. Temperature changes impact lake area (through evaporation), stratification, thermal structure and subsequent fisheries habitat, water chemistry such as $CaCO_3$ and O_2 solubility, mercury methylation rates, carbon cycling such as CO_2 flux out of the surface water, and bioaccumulation in sediments. It is therefore important to address:

- How will future climate change impact the quantity and quality of inland waters?
- What role do inland waters play in the global carbon cycle and how is that changing?
- How do thermal budgets of lakes vary in response to climate change and what are the resulting biogeochemical responses?

4) Biodiversity and Invasive Species

Aquatic ecosystems are sensitive to species shifts caused by changes in their physical and biogeochemical characteristics. These shifts can result in the loss of native species and introduction of invasive species. Invasive species can harm native ecosystems and the commercial, agricultural, or recreational activities that depend on them. The costs to control and eradicate invasive species in the U.S. alone amount to more than $120 billion annually (Pimentel, 2005). Remote sensing has been utilized to document impacts from invasive species, including Great Lakes water clarity due to invasive dreissenids (Limburg et al., 2010), distinguish between native and non-native aquatic plant species (Santos, 2012), and support bioenergetic modeling for invasive species (Anderson et al., 2015). It is therefore urgent and important to know:

- How have invasive species altered inland water bodies and what are the long-term consequences?
- What are the future invasive species and biodiversity threats for inland waters?

2. Why are these challenge/questions timely to address now especially with respect to readiness?

We are experiencing an unprecedented, rapidly changing environment, where inland water quantity and quality are being impacted. We have very limited long-term data, and for only a few of the 117 million lakes in the world. Many global lakes are in places where regular in-situ sampling is not possible (remote high latitude lakes or large lakes in East Africa, for example). In addition, our management and modeling approaches are ready for a stronger spatial

component and we need these data to validate models and to improve our understanding of how aquatic systems develop spatially (e.g. algal blooms) so we can develop more effective management strategies.

Presently a few satellite sensors can provide limited information on water quality, such as water temperature, transparency, loading of suspended sediments, phytoplankton (bloom) index, distribution of submerged vegetation, etc. In particular, the newly launched Landsat-8 with the added blue band provides new capabilities to observe phytoplankton in medium-size lakes (>100 x 100 m^2) and the planned PACE sensor will have hyperspectral capability, which could provide the ability to improve discrimination of colored dissolved organic matter, non-algal particles and provide more detailed information on phytoplankton community in the large lakes (> 1000 x 1000 m^2). Further, geostationary capability planned through GEO-CAPE will significantly improve the resolution of time varying processes. Although there are still uncertainties in the derived products from satellite measurements and some of these can be quite large, the advancement of sensor technologies and retrieving algorithms should lead to substantial improvements in the quality of these data products in the coming decades.

In addition, there are various airborne missions underway or planned for the observation and monitoring of lake waters, with general measurements of hyperspectral sensors, which would also significantly improve our capabilities in monitoring lake waters from a remote platform. All these advancements will result in unprecedented data sources to achieve improved management of inland water bodies.

3. Why are space-based observations fundamental to addressing these challenges/questions?

Proper water management relies on accurate information on water quality conditions. Given the global extent of these critical water issues and the inability of traditional approaches to address our informational needs, space-borne Earth Observations approaches are a promising way forward. This is in particularly true and demanding for the many lakes that are in remote locations where regular in-situ sampling is not possible. Space-based observations are unique in that they can provide synoptic observations of multiple lakes across different continents, and therefore provide a more accurate understanding of the response of different lake ecosystems under the changing climate. In addition, traditional monitoring frameworks are becoming increasingly expensive at the same time agency budgets are declining and water quality issues become more numerous and pervasive. Though many areas of the world face similar water quality issues, they are viewed as inherently local and do not receive national or international attention. Critical space-based observations needed are temperature and color at high spatial- (better than 100m) and temporal -resolutions (at least every 4 days). The color measurements should have high spectral resolution (5nm sampling from 0.4-1.0 um). These will help innumerable local water monitoring and management efforts, while also furthering our scientific knowledge of how these critical ecosystems function.

References:

Anderson K.R., et al. 2015. Suitability of Lake Erie for bigheaded carps based on bioenergetic models and remote sensing. Journal of Great Lakes Research. Volume 41, Issue 2, June 2015, Pages 358–366.

FAO. 2012. AQUASTAT, FAO's global information system on water and agriculture. http://www.fao.org/nr/aquastat

Limburg, K.E., V.A. Luzadis, M. Ramsey, K.L. Schulz, and C.M. Mayer. 2010. The good, the bad, and the algae: perceiving ecosystem services and disservices generated by zebra and quagga mussels. Journal of Great Lakes Research 36:86-92.

Paerl, H. W. et al. 2014.; Algal blooms: Noteworthy nitrogen. Science. Volume: 346 Issue: 6206 Pages: 175-175.

Pimentel, D., R. Zuniga, and D. Morrison. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. 52 (2005) 273-288.

Rigosi, A., et al. 2014. The interaction between climate warming and eutrophication to promote cyanobacteria is dependent on trophic state and varies among taxa. LIMNOLOGY AND OCEANOGRAPHY Volume: 59, Issue: 1, Pages: 99-114

Santos, M.J., E.L. Hestir, S. Khanna, S.L. Ustin 2012. Image spectroscopy and stable isotopes elucidate functional dissimilarity between native and nonnative plant species in the aquatic environment. New Phytol. 2012 Feb; 193(3):683-95.

Tranvik, L.J., et al. 2009. Lakes and impoundments as regulators of carbon cycling and climate *Limnol. Oceanogr. 54(6, part 2), 2298–2314*

UNEP GEMS/Water Programme. 2006. Water quality for ecosystem and human health. UNEP GEMS/Water, Burlington, Ontario.

Vorosmarty, C. et al. 2010. Global Threats to human water security and river biodiversity. Nature 467, 555–561.

WEF. 2015. Global Risks 2015, 10th Edition. Published by the World Economic Forum, Geneva, CH. http://www3.weforum.org/docs/WEF_Global_Risks_2015_Report15.pdf

WHO. 2006. Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. WHO Press, World Health Organization. Geneva, CH. ISBN 978 92 4 156325 3

Authors:

Steven Greb, co-chair	Wisconsin Department of Natural Resources
Simon Hook, co-chair	Jet Propulsion Laboratory, California Institute of Technology
Jay Austin	University of Minnesota, Duluth
Paul DiGiacomo	NOAA/NESDIS
Erin Hestir	North Carolina State University
ZhongPing Lee	University of Massachusetts - Boston
John Lenters	Limnotech, Ann Arbor, MI
John Melack	University of California- Santa Barbara
Colleen Mouw	Michigan Tech University
Catherine O'Reilly	Illinois State University
Blake Schaeffer	US Environmental Protection Agency

Geoffrey Schladow	University of California- Davis
John Schott	Rochester Institute of Technology
Larry Smith	University of California at Los Angeles
Richard Stumpf	US National Oceanic and Atmospheric Administration
Menghua Wang	NOAA/NESDIS/STAR