Article

High-frequency lake data benefit society through broader engagement with stakeholders: a synthesis of GLEON data use survey and member experiences

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Abstract

The Global Lake Ecological Observatory Network (GLEON) has a tremendous opportunity to facilitate greater public understanding of lakes and enable evidence-based decision making for freshwater ecosystems with high frequency data. To investigate this potential as well as the scope of outreach activities currently underway, we surveyed the 46 GLEON sites active as of 2013 about the uses of the high-frequency lake data (HFD). Of the 26 who responded, 69% engaged in or were aware of the use of GLEON HFD beyond academics. To highlight some of the outreach activities conducted in collaboration with GLEON scientists, we elaborate on 3 categories of data use: (1) engaging with citizens, (2) educating students and teachers, and (3) aiding in decision making. When synthesized with a discussion of examples of broader engagement activities across the network from the perspective of participants, the results suggest GLEON's network science approach enables the diffusion of ideas and tools for conducting effective outreach. Results also point to opportunities for GLEON to build on existing experience to encourage greater engagement of member scientists in lake conservation, restoration, and management. In light of the growing challenges in managing water quality and quantity, our findings will help determine best practices and provide guidance to scientists on how to engage a broader range of stakeholders in lake research and management.

Key words: citizen science, lake management, participatory research, science communication, science outreach

Introduction

The grassroots Global Lake Ecological Observatory Network (GLEON) is collectively recording millions of data points per year from lakes around the world (Porter et al. 2012). Data are gathered with on-lake automated buoys equipped with a wide range of sensors capable of high-frequency ($\geq$1 h^{-1}) measurements of lake and meteorological parameters. These lake observatories are designed and maintained from the bottom-up with the resources of member sites and linked through GLEON's cyberinfrastructure, meetings, and other activities (Hanson et al.

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2016, Rose et al. 2016). By networking globally distributed sites collecting high-frequency lake data, GLEON enables discoveries about lakes and reservoirs at spatial and temporal scales not previously possible (Hanson 2008, Rose et al. 2016). In addition to global-scale research, lake observatories and high-frequency data (HFD) create novel opportunities for engaging with lake stakeholders. In this article, we highlight the diverse use of HFD for outreach and education across GLEON. At many lakes, recreational users benefit from the real-time observatory data (e.g., 1821 Designs 2009). At some sites, lake observatories are at the center of participatory research and education programs (e.g., McGowan et al. 2014) while at others, HFD are used with models to make predictions that support decision making about water supplies (e.g., Hamilton and McBride 2008, Li et al. 2013). Outreach and citizen science efforts are necessary to improve the public's understanding of both science and socioecological systems as well as build capacity for sound environmental management (Covitt et al. 2009, Shirk et al. 2012, Peters et al. 2015). This broad support is needed to address the complex threats to lakes and other ecosystems.

Lakes and other inland waters are among the most degraded types of ecosystems on Earth (Millennium Ecosystem Assessment 2005). Declining water quality and loss of habitat and biodiversity threaten the life-sustaining ecosystem services provided by freshwater ecosystems, such as drinking and irrigation water, food resources, and pollution mitigation (Millennium Ecosystem Assessment 2005). Major threats such as nutrient pollution, invasive species, fishing pressures, and escalating water withdrawals are exacerbated by the effects of climate change (Carpenter et al. 2011). Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease lake water quality in many ways, including increases in sediment, nutrient, and other pollutant loads (Georgakakos et al. 2014). Climate change creates even greater challenges for those tasked with managing and restoring already degraded lake environments. For example, warming combined with a high influx of nutrients is linked to the growing problem of toxic cyanobacterial blooms (Cai et al. 2012, Carey et al. 2012a, Rigosi et al. 2014).

Addressing threats to lake ecosystems requires management interventions in lakes and their surrounding watersheds (Schindler 2006, Hudnell 2010). Best management practice calls for the use of science as a basis for managing lakes and reservoirs for recreation, climate change resiliency, sustainable drinking water supplies, and other societal uses (Choi et al. 2005, Gutriche et al. 2005, Holmes and Clark 2008). The scientific information needed to support sound decision making is not necessarily available to managers and policy makers, however, and this impairs our ability to address complex environmental problems (McNie 2007, McKinley et al. 2012). By capturing lake dynamics unresolved by comparatively low-frequency manual sampling (weekly–seasonal), HFD improves our understanding of lake ecosystems, especially in the face of unprecedented global change. The mere collection of data is not enough, however; strong linkages between scientists and decision makers are needed to narrow the science–policy gap (McNie 2007, McKinley et al. 2012). As we show with examples from the GLEON network, conceptual and numerical models can be important tools for making scientific data more salient to decision makers.

Building the capacity for sound environmental decision making within the general public is also important (Covitt et al. 2009, Shirk et al. 2012). The International Lake Environment Committee (2005) found involving citizens and other stakeholders in identifying and resolving critical lake problems was key to successful lake management and restoration. Citizen science and other participatory research programs serve to augment scientific datasets, improve scientific literacy among participants, and build capacity for decision making, in some cases by directly addressing questions of public interest (Bonney et al. 2009, Shirk et al. 2012). Advanced technologies and large datasets provide new opportunities to engage a broader audience and further understanding of the scientific process (Bonney et al. 2009, Newman et al. 2012). At several GLEON sites, lake observatories serve to galvanize support from stakeholders in a wide range of participatory research efforts (discussed later).

GLEON members are engaged in a broad range of outreach activities. As with the lake observatories themselves, outreach emerges largely from local needs and resources (Hanson et al. 2016). In this article, we consider the ways GLEON HFD are used to engage with lake stakeholders. We present results from a brief survey of GLEON sites regarding the use of lake HFD. We then highlight the ways in which HFD and a team science approach are used to engage a wide range of lake stakeholders, including recreational users, students, teachers, citizen scientists, and decision makers. Finally, we discuss opportunities to enhance the practice of outreach and participatory research across GLEON. Such outreach efforts are important for fulfilling GLEON's vision of "placing critical lake information at the fingertips of researchers, managers, and the general public" and developing "international community of scientists, educators, policy makers, and citizens invested in the future of fresh waters" (http://www.gleon.org/about/vision-and-mission).

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GLEON data use survey methods

The primary contacts of GLEON sites active as of December 2013 were surveyed regarding the use of lake buoy data (Caruso et al. 2013). A Request to Participate and a SurveyMonkey hyperlink were distributed in an email from the GLEON Program Coordinator. Follow-up emails were sent approximately 4 and 6 weeks after the initial survey request. Survey participants were asked about the current and projected academic and nonacademic uses of their site's GLEON buoy data (Caruso et al. 2013). They were also asked about the utility of the buoy data for achieving research goals and making management decisions for the lake. The questionnaire was reviewed by several GLEON members at the GLEON 15 meeting in Argentina, 2013, and revised based on their feedback. With only 9 questions, the questionnaire was kept concise for ease of response (De Leeuw et al. 2008). Likert-scale ratings questions were used to get quick answers about the utility of buoy data. Skip-logic was used to automatically pass questions not relevant to respondents based on previous responses; any question could be manually skipped, and respondents were given the option to identify their site at the end of the survey. Additional literature and internet research was conducted to follow-up on information about sites and programs provided in survey responses. GLEON members involved in some of the outreach initiatives identified in the survey contributed additional information through participant observation. We discuss survey results in the context of relevant literature, websites, and participant insights.

Survey results and discussion

We received 26 responses from 46 sites for a response rate of 57%. All but 6 respondents opted to identify their site in their returned survey. Mirroring the distribution of GLEON sites, most responses were from sites in North America and Europe, with one response each from China, New Zealand, and Argentina (Fig. 1). Most respondents identified themselves as Researchers/Scientists (62%) and/or Professors (31%) with expertise in limnology, microbial/plankton ecology, aquatic ecology, carbon cycling, ecotoxicology, biogeochemistry, GIS and remote sensing, hydrology, and lake monitoring/long-term ecological research. The remaining respondents identified themselves as Executive Director and Information Manager.

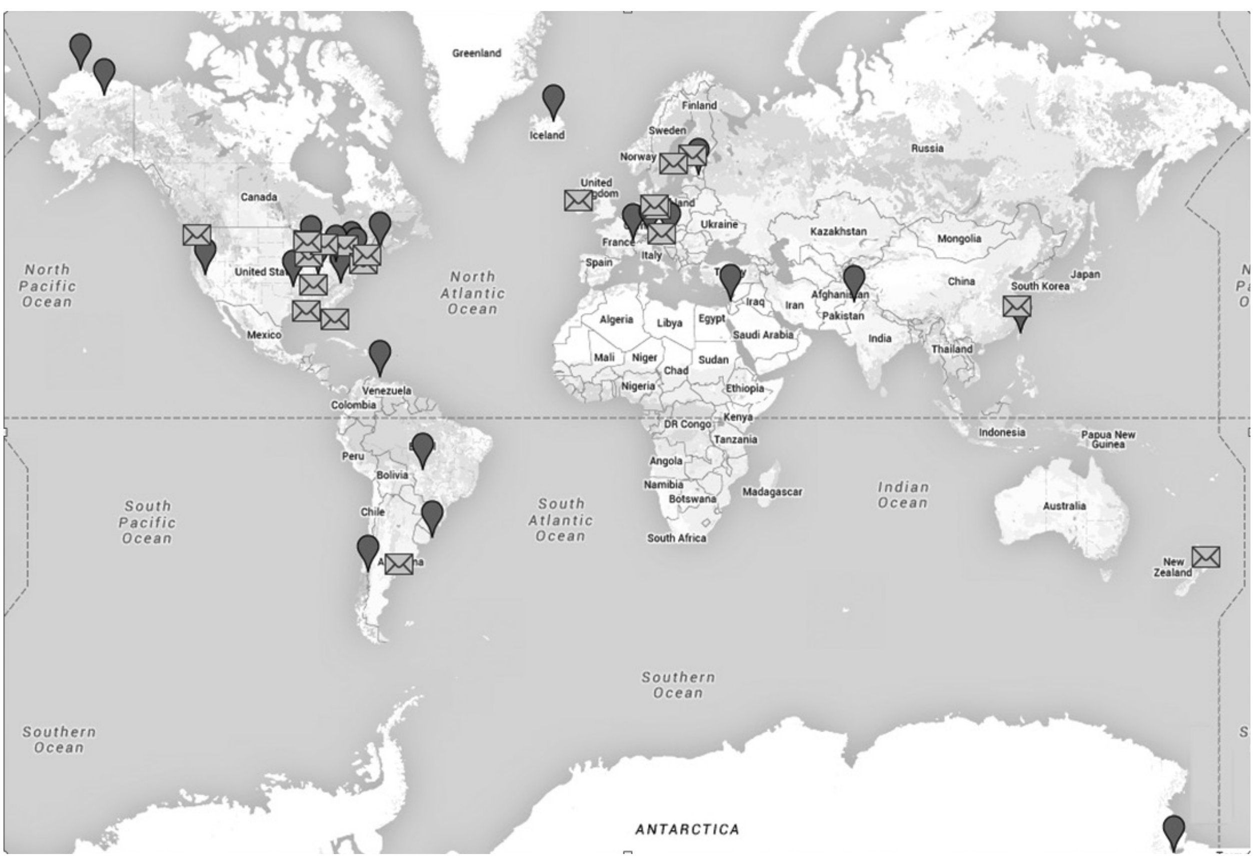

Fig. 1. Locations of the 46 GLEON sites at time of survey. Envelopes indicate sites that opted to identify themselves in their survey response (20 of 26 responses). Balloons indicate remaining GLEON sites and include 6 anonymous survey responses.

As evidenced by the 166 peer reviewed publications that acknowledge GLEON to date (www.gleon.org), GLEON scientists are using HFD to make new discoveries about lakes (e.g., Klug et al. 2012, Read et al. 2012, Sharma et al. 2015). As expected, most survey respondents (96%) indicated HFD are used for preparing peer reviewed publications. Buoy data were also widely used for student research (85%) and grant applications (73%). Other HFD uses volunteered by respondents included long-term monitoring (8%) and algal bloom forecasting (4%). All researchers found the buoy data to be moderately useful (12%), useful (46%), or very useful (42%) in meeting their research goals. One site, Lake Sammamish/Lake Washington, Washington, USA, reported no academic use of the buoy data. This site is operated by the King County government as part of their Major Lakes Monitoring Program. Lake data from this site are shared with the public in real-time (https://green.kingcounty.gov/lake-buoy/default.aspx) and used first and foremost by the county government to promote environmental stewardship and recreational activities (King County 2014).

An encouraging 69% of respondents reported awareness of one or more use(s) of GLEON HFD beyond traditional research and academics (Fig. 2). As with the design of lake observatories themselves, science outreach activities vary across the network because they emerge from local circumstances. Yet GLEON scientists face common challenges in utilizing HFD for outreach, including but not limited to data visualization and interpretation for citizens and decision makers (discussed below). In the following sections, we show commonalities among the outreach initiatives that stem from GLEON observatories as well as evidence that lessons learned at individual sites are shared through the network and adapted to meet local needs. We also discuss ways GLEON HFD are used to engage with (1) the public, including recreational users and citizen scientists; (2) students and educators in surrounding communities; and (3) decision makers tasked with managing water quality and other attributes of lake ecosystems.

Using GLEON HFD to engage with the public

Nearly half of the survey respondents were aware of recreational uses of lake buoy data (Fig. 2). For example, at Lake Mendota, Wisconsin, USA, fishermen and members of a local sailing club use a mobile phone application (app) created by a web development studio, 1821 Design, to get information on water temperature at a range of depths as well as wind speed and direction (1821 Design 2009). The app pulls data from the Lake Mendota buoy, a long-standing GLEON site maintained by the University of Wisconsin-Madison. Simply providing the data in real-time makes them valuable recreational users of that lake and potentially other lakes in the region. For example, the Muskoka Rowing Club in Ontario, Canada, regularly uses real-time water temperature data from Harp Lake, some 50 km away, as a proxy for water temperatures on its own rowing venue to help ensure the safety of its members on the water. As shown by a global-scale analysis that included data from 291 lakes, many of them GLEON sites, surface water temperatures in particular are regionally coherent (Sharma et al. 2015). Regional coherence in lake response extends the geographic reach and utility of real-time lake data beyond the instrumented lake, especially when these spatial patterns are recognized by lake users.

Readily accessible GLEON buoy data are also utilized by outreach and advocacy organizations (also called boundary organizations; Driscoll et al. 2011). For example, the Vanajavesi Centre in Finland is a regional initiative to improve the status of lakes and rivers in the Lake Vanajavesi watershed (Vanajavesikeskus 2015). This advocacy organization links

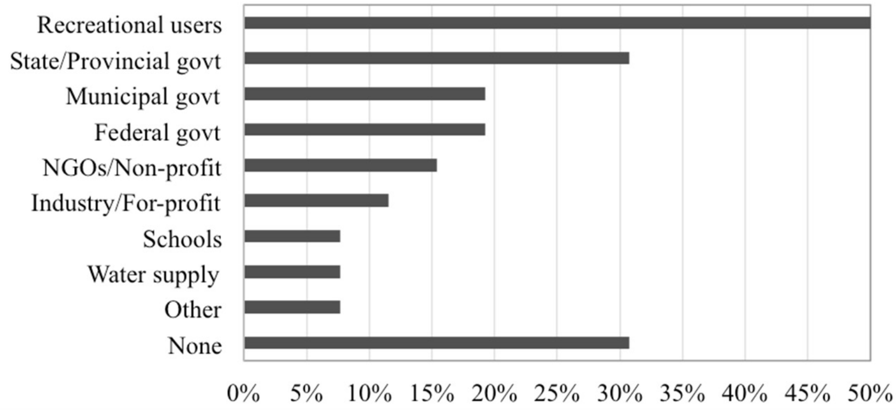

Fig. 2. Nonacademic data uses reported by survey respondents. Participants were given the option to check off more than one data use and write in other uses.

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directly to the Lake Vanajavesi buoy data provided by the University of Helsinki's Lammi Biological Station (http://www.helsinki.fi/lammi/tutkimus/research.html). Similarly, the Harp Lake Association in Ontario, Canada, links to real-time data from the anthropomorphized buoy THELMA (The Harp Environmental Lake Monitoring Ark) maintained by the Dorset Environmental Science Centre (DESC). DESC uses dygraphs 1.1.0 to display data so they can be easily manipulated by users with simple points, clicks, and drags (http://desc.ca/data/thelma). A presentation about the utility of dygraphs for real-time HFD display given at GLEON 13 in the US, 2011, has led other sites to adopt this software solution for interactively displaying data from their sites (e.g., http://www.toddrexmiller.com/?q=node/34, http://www.lehigh.edu/~brh0/pocono_mon/index.html). This is an example of the diffusion of an outreach solution through the network. Although dygraphs is a ready-made solution that works well for users familiar with lake and/or time-series data, this type of data visualization may not be accessible to the broadest audience of lake stakeholders, as shown by our next example.

The GLEON buoy on Lake Sunapee, New Hampshire, USA, was designed, built, and is maintained by the Lake Sunapee Protective Association (LSPA), a century-old nonprofit education and outreach organization supported primarily through membership (www.lakesunapee.org). During a series of cyber-infrastructure co-development meetings with scientists and LSPA affiliates, it became clear that data displays commonly used to communicate high-frequency lake data among scientists were neither clear nor compelling to nonscientists involved in the project (Benson et al. 2008, Carey et al. 2012b; Weathers, Chiu, and Richardson unpublished). The issues of data visualization for a broad audience were central to an NSF Cyber-Infrastructure Team project, and a collaborative process ultimately led to the development of a Lake Sunapee dashboard display (http://www.lakesunapee.org/templates/gleon_new.html; Weathers, Chiu, and Richardson unpublished). The dashboard, for example, shows dissolved oxygen concentration in terms of what is needed for fish to survive rather than color maps of concentration in milligrams per liter (mg L^{-1}) used by scientists (Carey et al. 2012b). As with dygraphs, there is evidence that the lessons learned at Lake Sunapee have influenced lake data use and displays at other sites (e.g., http://web.colby.edu/lakes/).

Other elements of successful outreach diffuse through the network. With perspective from the LSPA–researcher partnership shared through GLEON, scientists from Fairfield University partnered with the nonprofit Friends of the Lake (FOTL) to co-design a high-frequency monitoring program for Lake Lillinonah, Connecticut, USA. Lillinonah, a hydroelectric impoundment, has a problem with large floating woody debris and the hazard it poses to boating and waterskiing activities. Members of FOTL recognized that high water level exacerbates the debris problem by floating shoreline debris onto the main body of the lake, and they suggested including a water level sensor during lake observatory design. The resulting data are displayed as a colored warning system on the FOTL website to inform lake users of potentially hazardous conditions (http://www.friendsofthelake.org). Water level is not a routine measurement across GLEON sites, but its inclusion on the Lake Lillinonah buoy makes the HFD more salient to local users. Partnerships with local stakeholders can help identify data needs and uses that might not be obvious to researchers driven by basic research questions. In fact, partnerships with stakeholder groups can drive research on questions motivated by public interest. For example, the continued collaboration on Lake Lillinonah has led Fairfield students to investigate temperature and oxygen conditions that may stress fish. Such collaborations are important for reconciling the supply and demand for scientific information (McNie 2007).

Using HFD for science education

Capacity for sound decision making can also be built through water science education (Covitt et al. 2009). More than half the respondents reported using buoy data in the undergraduate classroom (Fig. 2). Examples include instructors using local buoy data to illustrate seasonal changes in lakes and using GLEON network-developed tools (Read et al. 2016) to update classic limnological laboratory exercises, such as the Wetzel and Likens "tank" lab (Wetzel and Likens 1991). In addition, GLEON members are involved in collaborative efforts to develop teaching modules using large datasets, including GLEON buoy data. These modules are designed to improve quantitative skills and reasoning, develop scientific discourse and argumentation, and increase student engagement in science (Carey et al. 2015; projecteddie.org).

Two survey respondents reported use of buoy data for education programs with primary and secondary school (pre-university) students and teachers, one at Lake Feeagh, Ireland, and the other at La Salada, Argentina. Here we describe the initiative on La Salada, where a GLEON buoy was installed on September 2011, making it the first lake in Argentina with continuous HFD collection. Regional drought results in water withdrawals from La Salada that in turn have led to biodiversity loss and reductions in fishing (Ferelli 2012, Diovisalvi et al. 2015). The research effort on La Salada aims to quantify changes, develop a management plan for the lake, and create local awareness of the lake and its ecosystem. The project on La

Salada is part of the Sensing the Americas Freshwater Ecosystem Risk (SAFER) to Climate Change project. Devised during GLEON 14, 2012, and funded by the Inter-American Institute for Global Change Research, SAFER is using nodes across the Americas in a continental-scale risk assessment of freshwater resources. SAFER sites explicitly engage citizens in the local watersheds to develop risk assessments (Harmon et al. unpublished) and culturally sensitive, place-based management and water quality mitigation strategies. Guided by SAFER, researchers from the Instituto Argentino de Oceanografía (IADO) prioritized the participation of the local community in the La Salada study to enhance the knowledge and protect the ecosystem. Based on this on-going interaction among primary and secondary school teachers, students, and researchers, the students now check the buoy, use sensing equipment, and take water samples. Since the program began, the students have shared their enthusiasm with their parents, who in turn, approach researchers with questions of their own about lake water quality and the potential impacts of the lake on the health of their children. This technology and data-centered education initiative is creating a sense of responsibility for the lake. Encouraged by the collaborations between scientists and lake associations demonstrated at recent GLEON meetings, an effort is underway to start a lake association around La Salada, with guidance from the LSPA. Although participatory research is uncommon in Argentina, students and citizens around La Salada have been participating enthusiastically in this citizen science project. IADO researchers are now seeking to replicate this program at other lakes in the Buenos Aires Province.

Using HFD to support decision making

GLEON buoy data are also being used to support decision making at various levels of government (Fig. 2). One way this happens is by making buoy data easily accessible for download. For example, data from Louisiana Universities Marine Consortium (LUMCON)'s Lake Pontchartrain observatory (http://weather.lumcon.edu/) were cited in a report—Biological and Recreational Monitoring of the Impacts of the 2008 Bonnet Carré Spillway Opening, St Charles Parish, Louisiana (GEC 2009)—prepared by Gulf Engineers and Consultants for United States Army Corps of Engineers, New Orleans District. This is an example of buoy data being used to support levee district management in the watersheds of the rivers that flow into Lake Pontchartrain.

At some GLEON sites, scientists use HFD from buoys with models to predict future lake conditions that support management decision making. We present 2 examples. The first uses lake buoy data for short-term forecasts of harmful algal blooms that threaten drinking water supplies in China, and the second uses buoy data in models to predict impacts of land use and climate change on water quality in New Zealand lakes. Taihu is the third largest lake in China and the drinking water source for 6 million people, including the cities of Wuxi, Suzhou, and part of Shanghai. This formerly mesotrophic, shallow lake (mean depth 2 m) has become hypereutrophic from industrial, agricultural, and municipal discharges (Jin and Hu 2003, Qin et al. 2007). Harmful algal blooms are a persistent problem, with an extreme event in 2007 leaving 2 million people dependent on bottled water for a week (Qin et al. 2010). In response to this water quality crisis, GLEON scientists from the Nanjing Institute of Geography and Limnology (NIGLAS) use HFD from lake observatories, manually collected biological samples, and weather predictions to model and forecast blooms in Taihu (Qin et al. 2007, Li et al. 2013). Forecast reports are distributed semiweekly to 17 officials across the municipal, provincial, and national offices of water resource management and pollution prevention. The goal of these forecast reports is to help water suppliers decide how to manage water intakes in the short term. They also serve to raise awareness of Taihu's algae bloom problem at higher levels of government (Caruso 2014).

At the Rotorua lakes in New Zealand, GLEON scientists are actively engaged in on-going lake management (Hamilton and McBride 2008). High nutrient loads, particularly nitrogen from dairy production, are problematic. HFD are used to demonstrate hypolimnetic oxygen depletion and examine the role of heat waves in exacerbating water quality problems. The data provide a gauge of lake "health" over time (Hamilton and McBride 2008). GLEON and other scientists also use models to predict the long-term effects of land use and climate change on water quality in the Rotorua lakes. Robust predictions are needed to support policy change and address reluctance from those impacted by potential management actions (Hamilton and McBride 2008).

Across the globe, GLEON HFD are used in novel ways to engage stakeholders, broaden participation in research, enhance understanding of lakes and water quality changes, and improve local and regional decision making. The practice of outreach and citizen engagement varies considerably from site to site, stemming from the grassroots nature of GLEON and the differences in opportunities and needs for outreach and engagement across lake sites. It is not unusual for GLEON scientists to partner with existing lake stakeholder groups or to engage with managers to face major eutrophication problems, for example. At some sites, particularly remote sites, outreach connections may be less clear or less urgent and therefore slow to develop (nearly a third of the survey respondents were unaware of HFD uses beyond research and academics).

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While providing some insights, the survey we conducted was limited in scope. Only the primary site contacts were surveyed (<10% of GLEON membership). Typically, several members are affiliated with a given site, and many members have no affiliation to a particular site; therefore, some outreach activities involving GLEON scientists and HFD were not captured or described here. Additional research is needed to characterize the outreach-related activities of the complete GLEON membership (discussed later). The survey also narrowly focused on HFD from individual sites and did not capture cross-site initiatives, meetings, and the role of other network activities in encouraging outreach. Two regional initiatives that prominently feature decision support and capacity building (essentially outreach), have emerged from GLEON: SAFER and NETLAKE (Networking Lake Observatories in Europe). Both initiatives are based on applied science questions and have explicit objectives related to decision support and water stewardship. NETLAKE is funded by a European Cooperation in Science and Technology (COST) Action (ES1201). Two of the principal aims of the 4-year project are to provide an overview of the use of HFD for lake and reservoir management and to develop a set of case studies on the use of HFD in decision making in the water sector for use by lake managers, scientists, and citizens across Europe (http://www.dkit.ie/netlake). Focusing on developing case studies, the COST Action brought together researchers (many of them members of GLEON) and water managers from 16 countries at an initial meeting in Amersfoort, Netherlands, in October 2014. Three topics were selected for case studies and are now underway: cyanobacterial blooms, potential formation of disinfection by-products from dissolved organic carbon, and the effects of extreme mixing events on lakes and reservoirs. In addition to the traditional academic outputs, the COST Action tailors the outputs of these case studies for the management sector to ensure that relevant information becomes embedded in that community, for example by use of policy briefs and through web-based dissemination.

By collecting HFD in many different lakes across the Americas, the SAFER project leverages HFD to help develop effective management and mitigation strategies that are place-based and culturally appropriate (Harmon et al. unpublished). The gradients in economies and development that exist among participating countries, ranging from Chile and Argentina in the south to the US and Canada in the north, are large and diverse, but like GLEON, the acquisition of lake sensor data is the commonality that links all sites. These data provide the necessary background for modeling the effects of climate change (Bohn et al. 2015) as well as a means of engaging the communities that depend on these water resources and the ecosystem services they provide (see earlier La Salada example). Both NETLAKE and SAFER are likely to yield new outreach approaches that will be shared through the network.

Growing cross-site interest in cultivating connections with stakeholders and exploring the uses of GLEON HFD and research for resource management applications is further signaled by the formation of the Reservoir and Lake Management Working Group (RLM-WG), one of several GLEON working groups that serve as operational units within GLEON, as described in Weathers et al. (2013). The RLM-WG was initiated by members at GLEON 13, 2012, and has quickly grown to more than 30 active participants. At the GLEON 15 meeting in Quebec, 2014, the RLM-WG initiated several research and outreach projects on lake management-related topics, including a survey of the complete GLEON membership to better understand management challenges at GLEON-affiliated lakes. A recent meeting of GLEON members from northeastern North America (NE GLEON) with a majority of participants from GLEON sites with strong ties to citizen groups (e.g., FOTL, Friends of Acadia, LSPA, etc.) identified best practices for lake outreach as a common need and priority goal. Assessments of outreach efforts across the network in achieving science communication goals, with special attention to how HFD are used, could improve our understanding of how cultural and ecological factors influence effective science communication and enable robust recommendations for outreach in different scenarios.

Further research is needed to develop a comprehensive understanding of the practice of outreach that specifically uses HFD across GLEON and identify opportunities to enhance it. The GLEON data-use survey provided each primary site contact an opportunity to report on the use of HFD from their site for research, education, and outreach. From this, we highlighted some novel ways GLEON HFD are used for education and outreach across the network. This brief survey did not, however, fully capture the outreach conducted by GLEON members or the effect of the network on outreach practice across GLEON. Anecdotal evidence suggests the network enables the spread of tools and approaches to addressing a wide range of common outreach challenges. For instance, all sites grapple with the challenges of visualizing HFD for diverse audiences. Many sites have a need to integrate sensor HFD with low frequency data collected over longer timeframes to support decision making. At some sites, citizen groups provide the natural history context and motivation for research (McGowan et al. 2014, Hanson et al. 2016). Further survey research is needed to fully characterize the range of education, participatory research, and decision support activities that involve GLEON HFD and members. Additional research could also help determine common challenges to identify and meet outreach needs and improve understanding of the role of the network in promoting outreach and participatory research.

Conclusion

HFD are at the center of GLEON. The early years of GLEON were focused on sensor technology and data management (Kratz et al. 2006, Benson et al. 2008, Hanson 2008). Research productivity increased as the network grew (Porter et al. 2009, 2012, Weathers et al. 2013), and tools were developed for analyzing GLEON HFD (e.g., Read et al. 2011, Woolway et al. 2015, Winslow et al. 2016). Globally networked HFD enable new scientific discoveries about lakes (Rose et al. 2016); they also provide novel opportunities for outreach. Based on the survey results and examples presented here, we conclude there is tremendous potential across GLEON to further evolve an outreach and engagement component. Although outreach activities are largely dependent on local needs and resources, the network provides an opportunity to share experiences and solutions to common challenges. Recent activity suggests a growing collective interest among GLEON members in the practice of outreach. GLEON scientists are embracing GLEON's mission (Weathers et al. 2013, GLEON 2015) and responding to the growing challenges of managing freshwater ecosystems in the face of global change (Carpenter et al. 2011, Paerl et al. 2011) and the greater demand for scientists to engage effectively with decision makers and the public at large (McNie 2007, McKinley et al. 2012, Boezeman et al. 2013).

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