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Development and Classroom Implementation of an Environmental Data Creation and Sharing Tool

DANIEL S. BROGAN

WALTER M. MCDONALD

VINOD K. LOHANI

RANDEL L. DYMOND
Virginia Tech
Blacksburg, VA

AND

AARON J. BRADNER
NEON, Inc.
Oak Ridge, TN

ABSTRACT

Education is essential for solving the complex water-related challenges facing society. The Learning Enhanced Watershed Assessment System (LEWAS) and the Online Watershed Learning System (OWLS) provide data creation and data sharing infrastructures, respectively, that combine to form an environmental learning tool. This system collects, integrates and stores real-time, high-frequency environmental monitoring data and imagery from a small urbanized watershed and makes it available to users at anytime from anywhere they have internet access. This paper discusses both the developmental and maintenance challenges associated with the LEWAS and the design details of the OWLS. A pilot test of the OWLS was implemented in a senior level hydrology course as a part of an NSF funded project. Results indicate that 80% of students (n = 30) valued the anywhere, anytime access to the data and 97% of students believed that access to the OWLS helped them to learn hydrologic concepts. A similar pilot test implemented in a community college freshman engineering course as part of the same project indicates that students (n=27) who used the OWLS felt that the OWLS assignment was valuable and relevant to their coursework even when their academic performance was underwhelming (40% correct on multiple choice questions). Future plans to expand the scope of the LEWAS-OWLS to cover environmental data from other geographical regions are discussed.

Key words: Real-Time Monitoring Operational Challenges, Water Sustainability Education, Online Learning Systems

INTRODUCTION

A recent report on *Challenges and Opportunities in Hydrologic Sciences* by the National Academy of Sciences states that the solution to the complex water-related challenges facing society today begins with education (National Research Council, 2012). Foundational to Science Technology Engineering and Math (STEM) education about the hydrologic cycle are the data that represent physical and chemical processes of water. The breadth and depth of environmental data is increasing due to contemporary sensing and computing technologies that can remotely measure environmental data in real-time and at high-frequencies. As these types of technologies become more integrated into modern society, it is critical that we harness this technology to educate people about water sustainability issues.

In this paper, we describe a data creation and sharing infrastructure that facilitates the flow of data from measurement instruments to end users via the Learning Enhanced Watershed Assessment System (LEWAS), which utilizes recent technological advances to improve water sustainability education. In the context of this paper, we define water sustainability education as education that addresses water availability, quality or reuse, water health impacts, or the relationship of water to a changing climate. The LEWAS is a real-time, high-frequency environmental monitoring lab at Virginia Tech that employs environmental sensing instruments to collect flow, water quality, and weather parameters. In this paper, high frequency sampling refers to a temporal rate of measurement collection on the order of once every few seconds to once every few minutes and real-time monitoring refers to the availability of measurement data within a few seconds. This real-time, high-frequency data from the LEWAS has been used in engineering courses at Virginia Western Community College (VWCC) in Roanoke, VA, USA and multiple departments at Virginia Tech (VT) in Blacksburg, VA, USA including Engineering Education (EngE), Civil and Environmental Engineering (CEE), Geosciences (GEOS), Crop and Soil Environmental Sciences (CSES) and Computer Science (CS), reaching over 10,000 students since 2009 (Delgoshaei, 2012; Dymond et al., 2013; Delgoshaei and Lohani, 2014; McDonald et al., 2014b; McDonald et al., 2015a; Basu et al., 2015). In 2015, it has also been demonstrated in a first year engineering course at KLE Technological University in Hubli, Karnataka, India, an upper undergraduate level civil engineering course at the University of Queensland in St. Lucia, QLD, Australia, an upper undergraduate level water resources management course at Central State University in Wilberforce, OH, USA, a C2GEN online course, and an engineering course at Floyd County High School in Floyd, VA, USA.

The user interface for the LEWAS is the Online Watershed Learning System (OWLS), where users can access historic and live data, examine case studies, and virtually explore the watershed (http://www.lewas.centers.vt.edu/dataviewer/). The OWLS allows teachers, students, researchers and the public to access the LEWAS remotely from anywhere at any time. The OWLS does this by using HTML5 to deliver live data regardless of the hardware (i.e., desktop, laptop, tablet, smartphone, etc.) or software (i.e., Windows, iOS, Android, etc.) being used. Pilot studies presented in this paper, that integrate the OWLS into a senior-level hydrology course at VT and a freshman level introduction to engineering course at VWCC, sought to improve student understanding of important watershed concepts.

The development of the interdisciplinary LEWAS-OWLS system has required integrating knowledge from a wide variety of disciplines including hydrology, environmental science, renewable energy, embedded system and database programming, and learning interface design. This development was made possible through the combined strength of a multidisciplinary LEWAS team including faculty, graduate students and undergraduate students with backgrounds in engineering education, civil and environmental engineering, electrical engineering, computer engineering, computer science, environmental science, biology, chemistry and chemical engineering.

This paper presents the data creation and sharing infrastructure of the combined LEWAS-OWLS system. We discuss the data creation infrastructure known as the LEWAS and several of the challenges encountered in the development and operation of this system. Subsequently, we review the development of the data sharing infrastructure, the OWLS, including important components and case studies that demonstrate the educational value of the system. Finally, we present the results of pilot studies of the OWLS in a senior-level hydrology course and a freshmen engineering course and discuss future work for expanding the LEWAS and the OWLS into other educational institutions and classrooms.

REVIEW OF THE LITERATURE

Water sustainability education

Educating students about important water sustainability issues is a critical component of solving our most pressing hydrologic issues (National Academy of Engineering, 2004). Covitt, Gunckel and Anderson (2009) determined that water literacy is not sufficiently taught to students in grades 3–12, and recommended that, "Instruction should first address the structure and movement of water and other substances in individual systems, and then it should gradually move toward building connections among these systems to help students develop deep, meaningful understanding." Because the sustainability of water resources is one of the major engineering challenges facing society in this century (National Academy of Engineering, 2012) and because humans play major roles (for both good and bad) in water management (National Research Council, 2012), it is imperative that every level of student is exposed to this challenge.

Two major themes emerge from prior studies that have investigated water sustainability education for students ranging from third grade through undergraduate seniors (Armstrong and Bennett, 2005; Iqbal, 2013; Habib et al., 2012; Fisman, 2005; Bodzin, 2008; Hotaling et al., 2012; Overholt and MacKenzie, 2005; Kamarainen et al., 2013; Brogan et al., 2014). One theme is the desire to provide students with more authentic learning experiences by exposing them, either physically or virtually, to the physical environments where the theory they are taught becomes practice. The other theme is the utilization of technological advances to integrate this exposure into the students' learning experiences. Taking advantage of these new technologies to advance hydrologic education is a critical component of solving our most pressing water issues (National Research Council, 2012).

Key to water sustainability education are the monitoring efforts that provide scientific data for understanding complex hydro-atmospheric behaviors. Recent advances in computing and sensing technologies have enabled the development of continuous remote monitoring systems that can measure various parameters in real-time (Glasgow et al., 2004; Parra et al., 2005; Henjum et al., 2010) and at high frequencies (Kirchner et al., 2004; Zennaro et al., 2009; Henjum et al., 2010). Such monitoring stations are capable of providing measurements of parameters such as stream or river flow rate and stage, local weather conditions, and various water quality measures. These measurements can provide invaluable insights into hydrologic processes, the health of a watershed and the impacts of various events. Providing such insights and environmental data to students through hands-on or virtual field experiences has enormous potential for enhancing student learning.

There have been recent efforts in education to bring environmental monitoring into the classroom. In New York State, teachers have used sensors that monitor water quality to enrich STEM education in classrooms, reaching over 1,700 middle and high school students (Hotaling et al., 2012). Researchers at the University of Northern Iowa have used outdoor groundwater monitoring wells to give undergraduate students hands-on sampling experience to improve student understanding of hydrologic concepts (Iqbal, 2007). The Basic Observation Buoy (BOB) is a student designed monitoring device at the University of North Carolina – Wilmington that collects aquatic and atmospheric parameters in real time for education and research purposes (Adams et al., 2012). All of these cases have recognized the value that hands-on environmental sensing has for educating students about real-time data, data collection methods, water quality, and hydrologic concepts.

An advantage of environmental monitoring systems that use in-situ sensing instruments is the ability to collect, store, and transmit data in real-time, which can be used to create an environmental virtual or remote lab, such as the OWLS, where students can explore the local environment, case studies, and live data. Virtual labs are software that mimic the real environment whereas remote labs are labs where experiments are conducted remotely across the internet (Ma and Nickerson, 2006; Balamuralithara and Woods, 2009; Henke, Ostendorff, Wuttke, and Simon, 2013). Virtual labs have been shown to be effective in improving student understanding of important engineering concepts (Baher, 1998; Koretsky et al., 2011; Kolloffel et al., 2013). For example, researchers at UCLA found that students had positive perceived learning gains when using the Interactive Site Investigation Software (ISIS) to perform virtual field work such as constructing wells, collecting groundwater samples, submitting samples for laboratory testing, and executing hydraulic transport experiments (Harmon et al., 2002). Applications of remote labs in engineering education have also been shown to improve student understanding of engineering concepts (Gurocak, 2001; Alexander and Smelser, 2003) and are comparable to hands-on labs (Ogot et al., 2003; Nedic et al., 2003; Corter et al., 2004). For example, researchers at Rutgers University found that there was no difference in educational outcomes between students who participated in a remote lab versus an in-person lab (Ogot et al., 2003). Beyond measuring students' learning, students' perceptions of their learning (Araújo and Cardoso, 2009) and students' motivation to learn (Fabregas et al., 2011; Delgoshaei and Lohani, 2014) have been used to measure the effectiveness of remote labs. The OWLS uses components of both virtual labs (students can virtually explore a simulated environment through geographic representations of the physical world) and remote labs (students can choose which parameters they want to measure) to give users a unique educational experience. This combination of virtual and remote labs classifies the OWLS as a hybrid online lab (Henke et al., 2013).

Prior studies suggest that students learn more about the environment they are studying if they have the opportunity to connect classroom learning to experiences in that physical environment (Cantor, 1997). Furthermore, studies in water sustainability suggest that these experiences can be a combination of physical visits and virtual visits (Armstrong and Bennett, 2005; Iqbal, 2013; Habib et al., 2012; Bodzin, 2008; Hotaling et al., 2012; Kamarainen et al., 2013). Situated learning is an appropriate theoretical framework for studying water sustainability education because student learning is altered by modifying the learning environment. Situated learning argues that knowledge is "distributed among people and their environments" (Greeno et al., 1996, p.17) and can be separated into two primary components. The first is the distribution of knowledge across people, e.g. communities of practice (Lave and Wegner, 1991), and the second is the dependence of knowledge on the learning environment (Scribner, 1997). These components form the sociocultural and sociocognitive traditions of situated learning, respectively (Johri et al., 2013). The OWLS utilizes the framework of sociocognitive situated learning by virtually situating users at the LEWAS field site.

Technological advances have increased our ability to integrate remotely sensed environmental data into the learning environment (Glasgow et al., 2004; Orduña et al., 2011). Remote labs provide this access by utilizing advances in digital technology (Grober et al., 2007; Delgoshaei and Lohani, 2014; Cochrane and Bateman, 2010; Boulos, Warren, Gong, and Yue, 2010; Mao, Wu, and Cao, 2012; Xu and Zhu, 2011), which is especially powerful when it is interactive (Crawford, 2002). Multimedia reaches users via multiple types of content, e.g. text, imagery, video and audio. Many types of interactive multimedia are used in learning systems, such as open-ended learning environments, tutorials and serious games (Alessi and Trollip, 2000). However, according to Johri, Olds and O'Connor, "The role of technological tools, particularly digital tools, is extremely under-theorized in engineering education and a perspective of mediation can prove useful to develop a deeper understanding of technology use and design." (Johri et al., 2013, p.53) Mediation deals with the ways that physical objects and data representations alter the learning environment (Johri et al., 2013). Graphs and images are types of data representations that engineers often use to help them understand systems. According to Newstetter and Svinicki (2013, p.39), "Effective learning environments support the learner in developing an ability to integrate the external environment structures and internal knowledge in problem solving." The OWLS, which has been designed in alignment with this goal, is an open-ended guided cyberlearning environment that includes several multimedia components in its interface including graphs, imagery and geospatial visualizations. This is discussed in more detail later in the paper.

The LEWAS field site

The Learning Enhanced Watershed Assessment System (LEWAS) was initiated in 2008 as part of an engineering education research project at Virginia Tech (Delgoshaei, 2012; Delgoshaei and Lohani, 2014) that was supported by the National Science Foundation. The development of the LEWAS is described in detail in Delgoshaei (2012), McDonald et al. (2014a), Delgoshaei and Lohani (2014), and McDonald et al. (2015c). The LEWAS field site (37.2282 deg N, 80.4270 deg W) is located on the Virginia Tech campus in the town of Blacksburg, VA. It monitors the Webb Branch sub-watershed (2.78 km^2) within the Stroubles Creek Watershed. Just downstream from the field site, the Webb Branch drains into the Upper Duck Pond on the Virginia Tech campus. The first 8 km of Stroubles Creek below the Upper and Lower Duck Ponds has been classified as benthically impaired (i.e., the body of water does not adequately support aquatic organisms) in all Virginia Department of Environmental Quality (VDEQ) reports from 1996 to the present (VDEQ, 2006; VDEQ 2012).

The LEWAS has three primary environmental instruments and four supporting instruments that collect data from the field site, as illustrated in the physical layout of the lab in Figure 1. The first primary instrument is a SonTek Argonaut-SW Acoustic Doppler Current Profiler (ADCP) (flow meter) that measures stage and velocity every 1 minute in a natural cross section of the stream. The second is a Hach Hydrolab MS-5 Sonde that measures pH, dissolved oxygen, oxygen reduction potential, turbidity, specific conductance, and temperature in 3 minute intervals. The third is a Vaisala WXT520 weather transmitter that measures precipitation data instantaneously, wind every 5 seconds, and temperature, pressure and humidity every 1 minute. Supporting precipitation

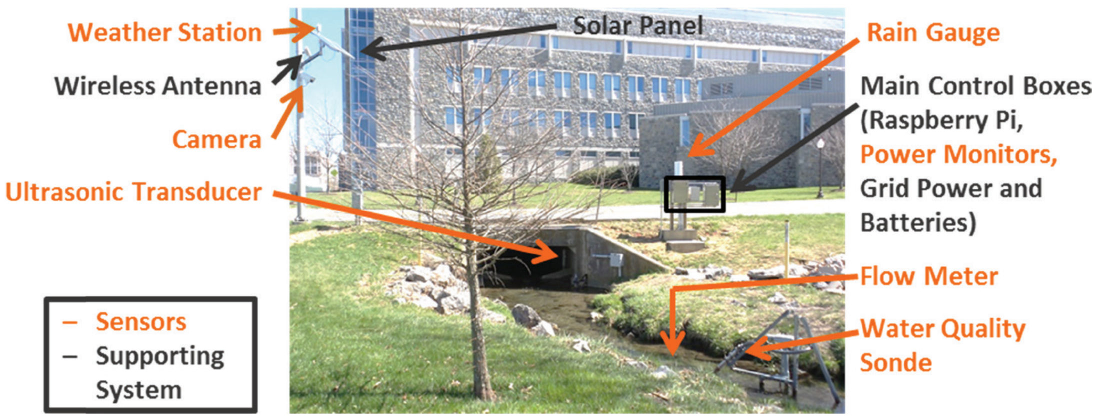

Figure 1. The LEWAS Field Site.

data is provided by a Weathertronics Tipping Bucket rain gage that is installed on top of the main control box. A Global Water WL705-02 ultrasonic level transducer is installed behind a weir upstream of the site to provide secondary flow measurements. Secondary rainfall and flow measurements provide data verification used to maintain data quality. A StarDot Technologies netcam-XL network camera is installed on a light pole at the site to record real-time pictures and video of the stream conditions.

Power for the entire system is provided by a hybrid system including two solar panels installed on the light pole near the site and grid power. The solar power is regulated to 24 V and charges two 12 V deep-cycle lead acid batteries connected in series that are located in their own box. Grid power was recently added to the LEWAS as a backup source to improve the reliability of the power supply so that no instruments lose power during extended overcast periods. Two WattsVIEW DC-1000 power monitors are installed in the main control box to monitor the power generation, storage, and consumption.

All of the data from the instruments are collected and processed using a Raspberry Pi system, which is low cost, open source, programming language flexible, and has a small power demand. Details of how custom programs have been developed for each proprietary instrument to create an integrated data collection system can be found in Delgoshaei (2012), Rai et al. (2013) and Basu et al. (2015). The data from each instrument is collected and stored in a local database on the Raspberry Pi and then sent via a wireless link to a server hosting the common database where it can be accessed by end users (Purviance et al., 2014; Basu et al., 2015). More information about the LEWAS can be found in the following brief video introduction: https://www.youtube.com/watch?v=5nMnb6ujz80.

As part of the development process, the LEWAS undergoes frequent modifications and upgrades. Regular updates of this process are posted on our Twitter account (https://twitter.com/LEWASLab). Many additional photos of the lab can be found on our website (http://www.lewas.centers.vt.edu/) and in the OWLS (photo archive: http://www.lewas.centers.vt.edu/dataviewer/photo_index.html and camera archive: http://lewaspedia.enge.vt.edu:8080/videos/stroubles1/).

Data creation infrastructure

The LEWAS' data flow from measurement devices to end users is illustrated in Figure 2. The LEWAS contains the data creation infrastructure of the combined LEWAS-OWLS system and is represented by the first three blocks of the data flow diagram. The first block represents the flow, water quality, and weather instrumentation that is deployed continuously in the field. The second block represents the local processing system that collects data from each instrument and temporarily stores the data. The third block, and last component of the data creation infrastructure, represents the server where the data is stored. The final block represents the data sharing infrastructure of the OWLS which displays historic and live data obtained from the database.

The LEWAS-OWLS is a complex system that requires an implementation and operation team with a diverse skillset. This team currently consists of two faculty members, four doctoral students, two masters' students and five bachelors' students with backgrounds in engineering education, electrical and computer engineering, civil and environmental engineering, computer science, biological systems engineering and biology. Traditionally, the lab formed into two teams with an "electrical" team focused on electrical hardware and programming and a "civil" team focused on instrument calibration and deployment and data collection. However, as the lab has grown, small groups of students have been dedicated to specific roles related to each block in Figure 2.

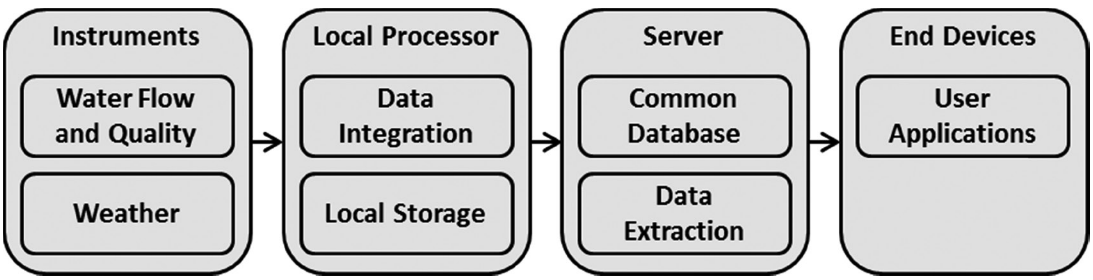

Figure 2. LEWAS data flow.

LEWAS developmental and operational challenges

The LEWAS team has encountered numerous unforeseen development and maintenance challenges over the course of the lab's history. While we have resolved many of the problems, others require constant evaluation. Some of these challenges relate to the specific physical environment in which the LEWAS operates. These include sediment transport through the field site, stream bank erosion near the field site, natural and man-made debris gathering on and around the instruments, and algal growth on the instruments (McDonald et al., 2014a).

Data quality assurance

The large amount of real-time, high-frequency data generated by the LEWAS would be of little value if the quality of the data were poor. In order to maintain a high level of quality of the data, a three pronged approach is used, i.e., site maintenance, instrument calibration and duplicate measurement systems as discussed in the LEWAS field site description. Site maintenance, including the removal of transported sediment, debris, and algal growth is performed on a weekly basis (Raamanathan, 2014).

Calibration is critical for maintaining a quality data flow in all three primary instruments. In the location where the ADCP unit collects flow measurements, forward flow is not uniform throughout the stream cross-section and point measurements of forward flow in vertical segments across the cross-section are made by hand using a SonTek Flow Tracker at various stage levels in order to develop and calibrate an index-velocity rating (Welch et al., 2011; Rogers, 2012; McDonald et al., 2014a). The weather transmitter requires its temperature, humidity, and air pressure module to be replaced every two years for accuracy. Other features of the weather transmitter, such as wind speed and direction, do not require replacement unless severe physical trauma occurs to the weather transmitter. The Sonde, upon recommendation from the manufacturer, should be calibrated every two weeks. However, we performed tests at 1, 2, 3 and 4 week intervals and determined that there is negligible drift after three weeks but not after four weeks. These results indicated that calibrating every three weeks instead of every two weeks cuts lab calibration resource use by 50%.

DATA SHARING INFRASTRUCTURE

The data sharing infrastructure, known as the OWLS (www.lewas.centers.vt.edu/dataviewer/), is an environmental exploration tool that gives users access to historical and live LEWAS data and imagery, case studies, and virtual tours of the LEWAS watershed. This section describes the development of OWLS, key features of the data sharing infrastructure, example case studies that demonstrate the value of OWLS in education, and a summary of the results from pilot implementations of the OWLS into a senior-level hydrology course at VT and freshmen-level engineering course at VWCC.

Development of the OWLS

The OWLS is designed to take advantage of the strengths of the increasing integration of internet-based technology into global society. Given the increasing diversity of hardware (desktop, laptop, tablet, smartphone, etc.) and software (Windows, Linux, iOS, Android, etc.) platforms being used (Orduña et al., 2011) and the goal of reaching the broadest possible audience, we undertook the OWLS development with the goal of interactively delivering integrated live and/or historical environmental monitoring data (atmospheric, hydrologic, geographical, visual, etc.) to end users regardless of the hardware and software platforms used (Figure 3). Such a design has two primary strengths. The first is access to live and historical data at any time from anywhere the end user has internet access (Rochadel et al., 2013; Waterson, Landay, Berkeley and Matthews, 2002). The second is the integration of visual and graphical environmental data that virtually situates the end user at the LEWAS site and provides interactive means of mediating aspects of the physical environment within the OWLS environment (Lowe, Murray, Lindsay and Liu, 2009; Cochrane and Bateman, 2010).

The OWLS was developed using the storyboarding process (Golombisky and Hagen, 2010) (including the development of a process book and a design document) as a guided open-ended cyberlearning environment (Alessi and Trollip, 2000). This design process, which was completed by the lead author as a semester project in the course Interactive Learning Media Development taught

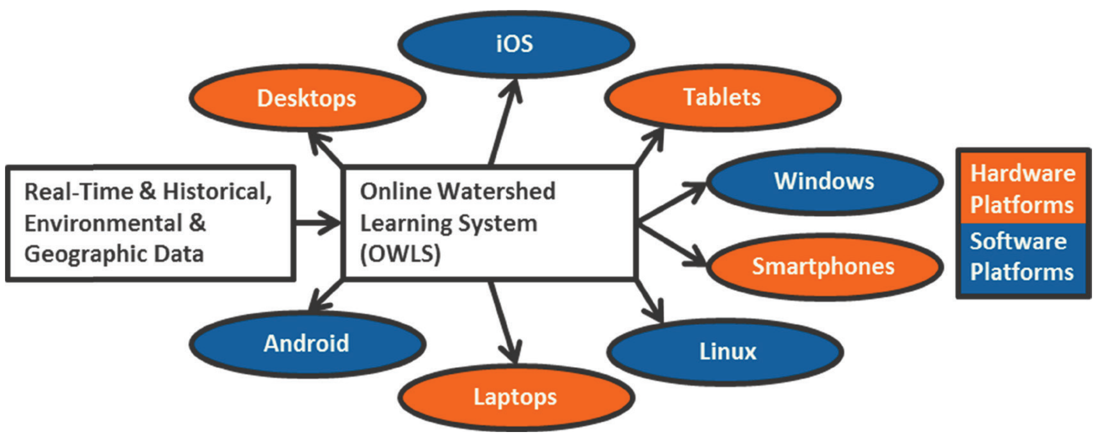

Figure 3. The OWLS reaches users across many platforms (Basu et al., 2015, Figure 4).

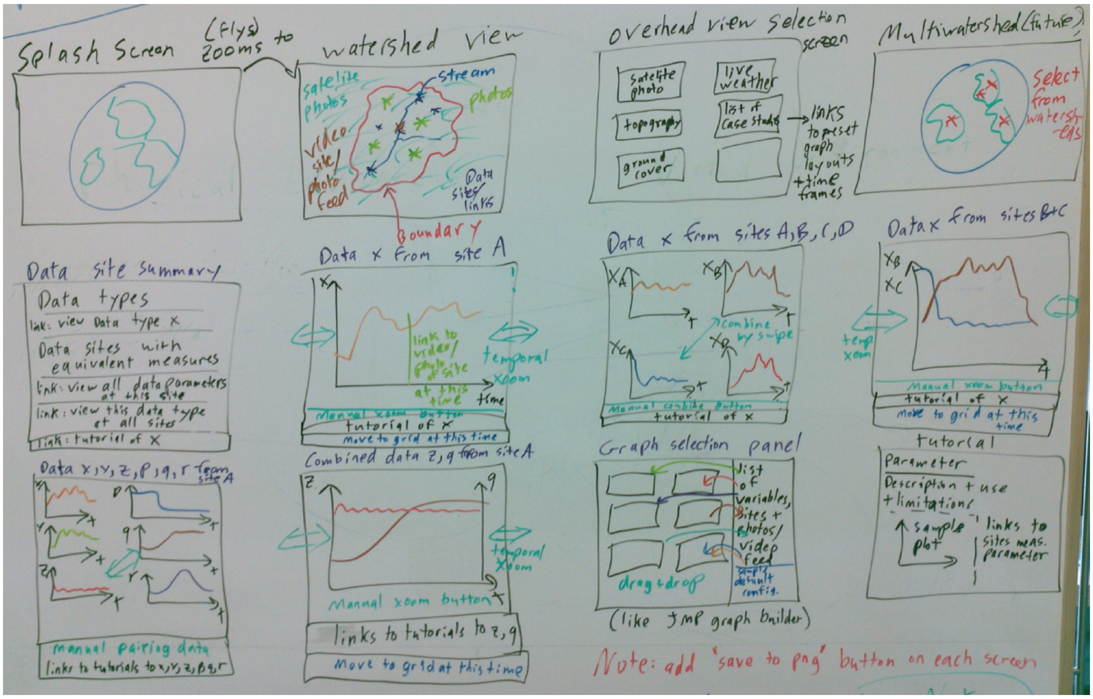

Figure 4. Stage three of the OWLS storyboarding process – hand sketches of the user interface.

by two faculty from the department of Instructional Design and Technology at VT, included multiple revisions that progressed through the following steps: 1) sticky notes and data flow brainstorming, 2) images of potential content, 3) hand sketches of the user interface (Figure 4), 4) digital mockups of the user interface, 5) proposed user navigation through the digital interface, and 6) an interactive prototype with working navigation links. A team of other designers from the course reviewed each version in order to integrate multiple perspectives into the final design, and a team of experts offered feedback at the end of the course on the interactive prototype. Using these multiple design revisions allowed for careful consideration of the user experience.

The HTML5-driven web interface used for the implementation of the OWLS achieves platform independence by working across modern web browsers. On the other hand, plugin-driven systems running on Java or Flash are less widely supported (Mougharbel et al., 2006; Chen et al., 2010; Maiti and Tripathy, 2012) and "relying on a plug-in will exhaustively decrease the number of supported users" because many mobile devices do not support common plug-ins (Orduña et al., 2011, p. 313). In addition to HTML5, the OWLS uses two other languages that are also widely supported across platforms, i.e., CSS and JavaScript for accessing the LEWAS database.

Key features of the OWLS

There are several key features of the OWLS interface that can be reached from the Home Screen or Site Map (Figures 5 and 6). These include key components of the system, a LEWAS introduction, a summary of the Webb Branch watershed, and virtual placements in the local geographic setting via the Overhead View and Doppler Radar view, in the field site via interactive graphs and imagery and in watershed events via case studies. Since the OWLS is a guided, open-ended cyberlearning environment, a user is able to navigate through the interface, but is limited to the guided structure defined by the Site Map. The OWLS is an adaptable system that can be used with other watersheds or generalized to other remote measurement systems. The Site Map, as illustrated in Figure 6, is already generalized for these adaptations. As development continues, the OWLS interface undergoes regular modification from one version to the next. The screenshots shown in this section represent beta version 3.1 as of January 2016.

Geographic setting

The Overhead View places the user in the local geographic setting using a Google Maps plugin (Figure 7). In this initial implementation, the geographic features include Webb Branch of Stroubles Creek, the Upper Duck Pond, the LEWAS field site, and the watershed delineated by the LEWAS team. The plugin allows the features to be shown over a local street map or satellite imagery. Future

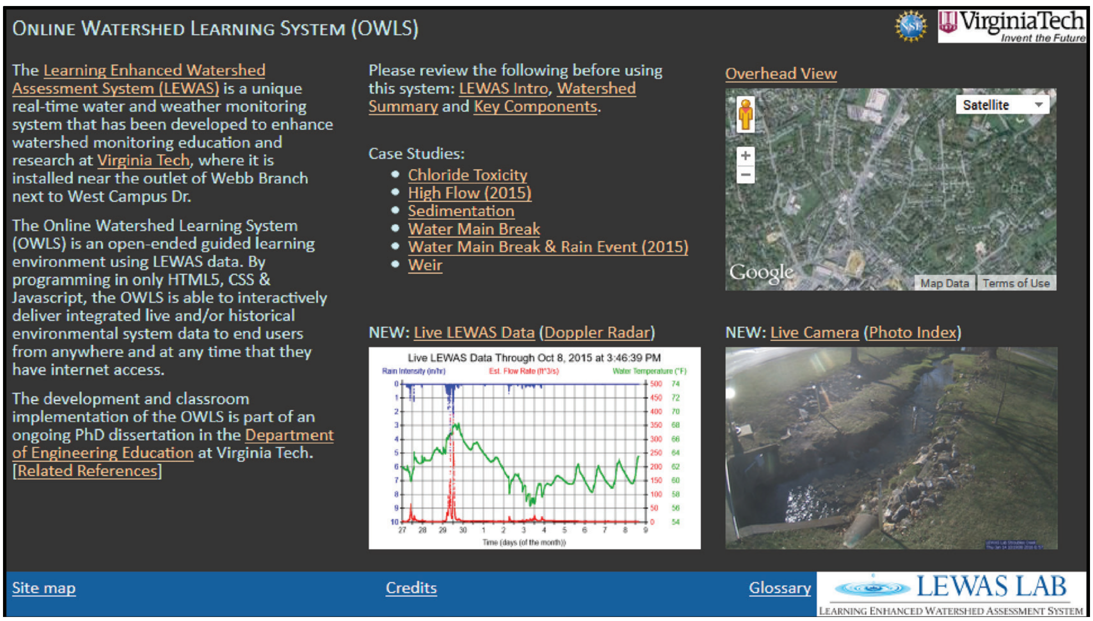

Figure 5. OWLS Home Screen (http://www.lewas.centers.vt.edu/dataviewer/index.html).

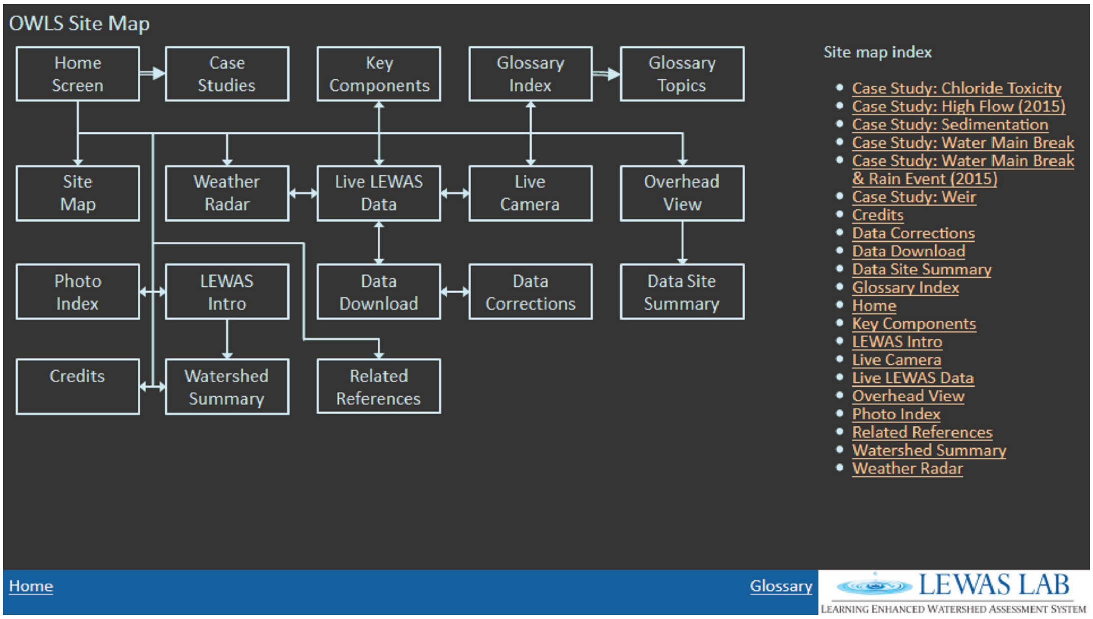

Figure 6. OWLS Site Map (http://www.lewas.centers.vt.edu/dataviewer/site_map.html).

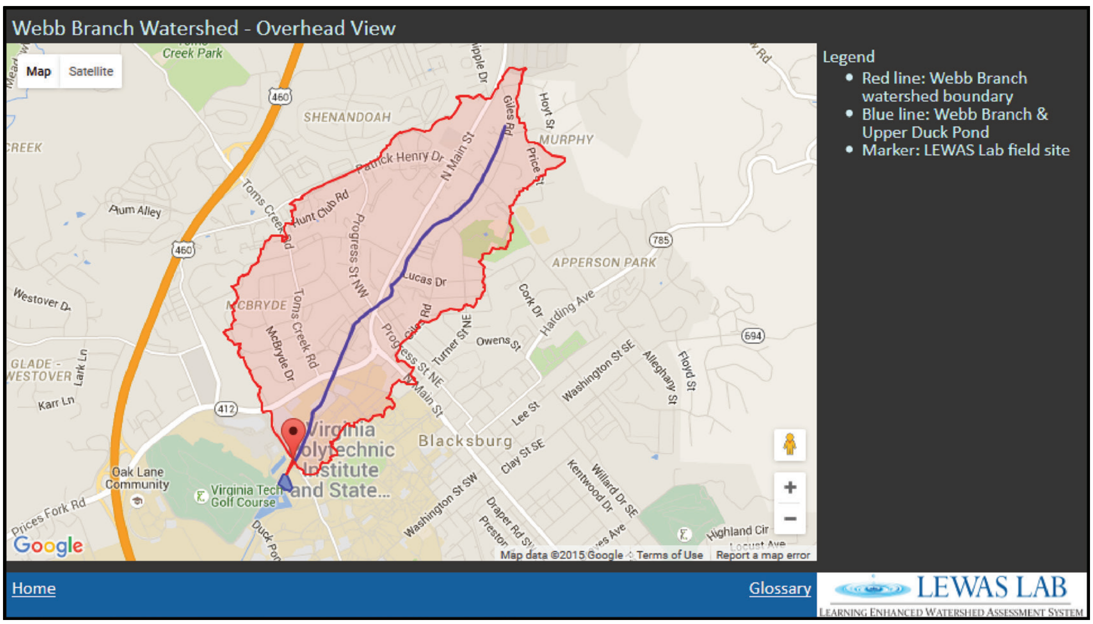

Figure 7. OWLS Overhead View (http://www.lewas.centers.vt.edu/dataviewer/overhead.html).

versions will include maps of land use, topography, slopes, stormwater inlets and pipes, and other important features. The current version integrates the Blacksburg, VA Doppler weather radar from the National Weather Service to add spatial precipitation information. Users are able to explore the watershed using their keyboard, mouse or touchscreen and can get further information about the instrumentation at the site by clicking on the LEWAS field site marker.

Interactive data graphs

The LEWAS Live Data view places the user at the LEWAS field site using interactive graphs and time-stamped imagery (Figure 8). In this view, the user is able to plot any three of thirteen environmental parameters measured by the LEWAS in either SI or common US units. The y-axes auto scale to match the selected data, and the x-axis can be scaled to 1, 3, 6, or 12 days. Although the current version displays data through the present, future versions will include the capability to display data ending at other times. This will allow historical events to be investigated. Figure 8 reveals the impacts of rain events on the flow rate and turbidity in the stream on March 13 and 14, 2015. It also shows the

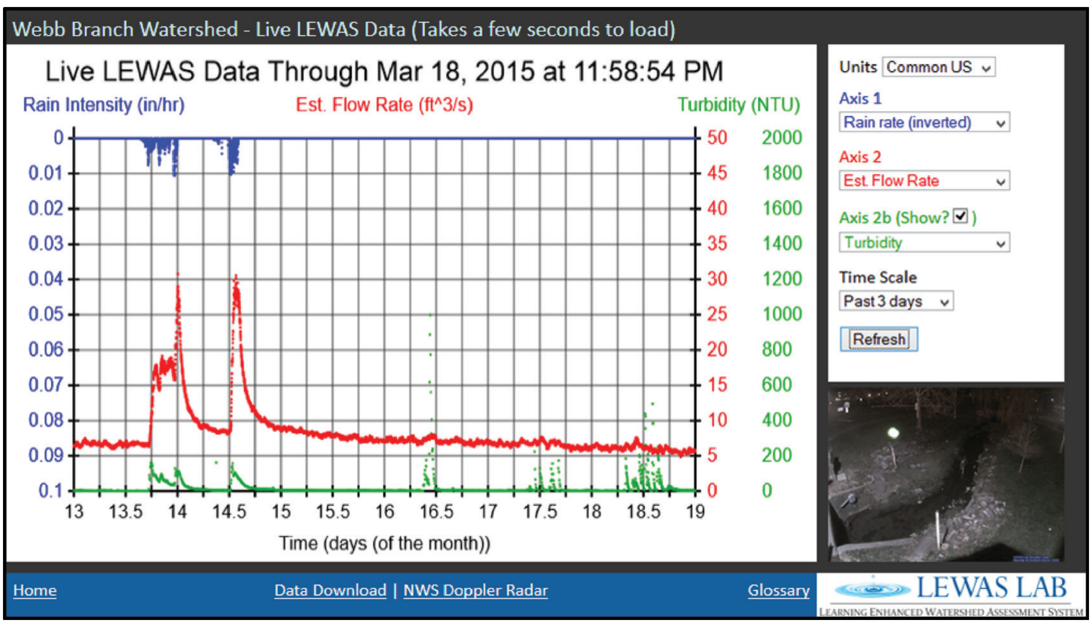

Figure 8. OWLS interactive LEWAS Live Data view showing impacts of rain events on March 13 and 14, 2015 and impacts of accumulated water pumped off of a construction site during business hours on March 16-18, 2015. (http://www.lewas.centers.vt.edu/dataviewer/single_graph.html).

turbidity impacts of a local construction site pumping accumulated water into the stream during business hours on March 16-18, 2015. These impacts would likely have been missed if not for high frequency monitoring. In addition to the interactive graph, time-stamped visual imagery provides users with a visual representation of the field site at the time of the data they are viewing. The camera provides continuous visual data of the field site alongside the real-time parameters. The live camera feed can be viewed at http://www.lewas.centers.vt.edu/dataviewer/camera.html, and the camera archive can be viewed at http://lewaspedia.enge.vt.edu:8080/videos/stroubles1/. At the heart of the LEWAS Live Data view is an HTML5 canvas object that acts as a blank canvas that is drawn on using JavaScript to draw lines, text and data (Zhu, 2012; Grady, 2010). While the OWLS is a visualization tool and does not have the computational power needed for user-defined analysis that would be possible using computational software, users are able to save the graphed data locally for further analysis using the Data Download page (http://www.lewas.centers.vt.edu/dataviewer/rawData.html).

Case studies

Another component of the OWLS is the educational case studies that have been developed using LEWAS data. We define case studies as exemplary events captured by the LEWAS instruments that demonstrate important principles and further understanding of complex environmental systems. Some of the case studies describe events in the watershed that have been captured by the LEWAS instruments over the years and serve to educate users about the local watershed. We have observed several types of events in the Webb Branch watershed during the past two years including high-volume summer thunderstorms, winter storms with salt wash, and a water main break. Other case studies are designed to educate users about the operation of the LEWAS including volume measurement using a weir and, in the future, renewable energy use in the LEWAS.

A water main break case study and a winter storm salt runoff case study emphasize the strengths of the OWLS Live Data view and are included here. Each of these case studies demonstrates how acute impacts in the watershed would go unnoticed without high-frequency continuously deployed instruments, such as those used in the LEWAS. One of the benefits of continuously recording data at much higher temporal resolutions than can be achieved by traditional, manual, on-site measurements, such as grab sampling, is the ability to observe the impacts of unpredicted acute events in the watershed. Acute events impact the watershed over the course of a few hours or days rather than over the course of months and years. Thus, manual measurements are often unable to observe the occurrence of these events. Other LEWAS case studies include a summer thunderstorm, a different winter storm (McDonald et al., 2015c), sedimentation, weir flow, extremely high flow (https://www.youtube.com/watch?v=bTlFT6lsdzE) and combined water main break & rainstorm (https://www.youtube.com/watch?v=wKXXUr04ul8) case studies.

Figure 9. Images comparing turbidity at typical base flow (left) to turbidity during the June 26 water main break (center), which approached 350 Nephelometric Turbidity Units (NTU). The fish (right) died during or just after the water main break (Dymond et al., 2013, Figures 2 and 4).

Water main break

On June 26, 2012, before the Sonde was continuously deployed and before the flow meter had been fully calibrated, we visually observed intense turbidity at the LEWAS site (Figure 9) despite an absence of rain during the previous two weeks. We deployed the Sonde for two hours after this observance and then walked upstream from the LEWAS site to determine the source of the increased turbidity. We found that a broken water main was the cause of the increase in turbidity. The water main broke at approximately 16:30 and was contained by 21:00 local time (U.S. EST). In total, approximately 760 m^3 of treated drinking water were spilled in the stream during this time (Martinez et al., 2012).

Figure 10 shows the results of this water main break on turbidity and specific conductance from approximately 19:45 to 21:45. This data begins just over three hours after the water main broke. However, the turbidity levels were still roughly one hundred times greater than those recorded at base flows (2-3 NTU) on June 19, 2012, and the evening of June 27, 2012. Likewise, the specific conductance levels were much lower during the break than they were during the same base flow periods (600-650 µS/cm). In the following days, we found a large number of dead fish in and around the stream (Figure 9). The cause was postulated to be either a spike in chloride in the stream, resulting from the influx of drinking water or the increase in turbidity, which may have caused lacerations on the fish's gills and obstructed gas exchange across the gills (Orth, 2012).

This case study emphasizes to students the importance of real-time, high frequency water quality monitoring. For this small stream, the system typically returns to base conditions within one day of

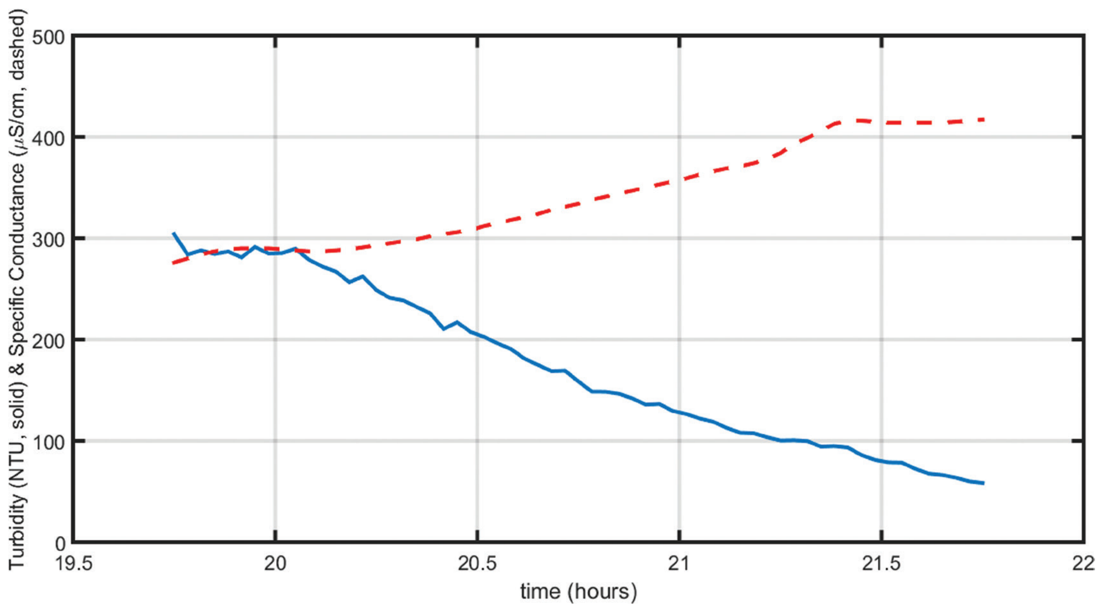

Figure 10. June 26, 2012. Impact of the water main break on stream turbidity and specific conductance levels. Base flow levels measured on June 19, 2012 and the evening of June 27, 2012, were approximately 2-3 NTU and 600-650 S/cm, respectively.

an acute event. Had the equipment not been available and deployed, this event would have gone unnoticed and the next day dead fish would have been found in the stream without any apparent cause. Even with hourly monitoring, this event would have been a blip in the data and could easily have been ignored as an error. However, because LEWAS equipment was deployed and recording data in high frequencies (1-3 minute intervals), the impacts on the watershed could be linked to the water main break. Furthermore, students viewing this case study are exposed to the practical impacts of seemingly innocuous human activity on the natural environment, i.e. adding a large amount of purified drinking water to the watershed.

Case studies allow students to connect what they do in the classroom to the actual environment through experiential learning. Experiential learning refers to learning that occurs as a transformative experience (Kolb, 1984) and can include laboratory experiences such as the OWLS (Cantor, 1997). Students using the OWLS are able to see visual representations of the turbidity alongside pictures of the turbidity in the stream to get an idea of what a certain measurement of turbidity, given in a pollutograph, actually looks like in the stream. Not only can students make this connection with water quality measurements but also with flow, velocity, and stage measurements given by the

ADCP. The ability for students to connect what they are learning in the classroom (pollutographs, hydrographs, and hyetographs) to reality through the OWLS experience is a major advantage of a system like this, and through well-designed integration into the learning environment, such case studies provide the opportunity for students to discuss and interpret the meaning and implications of watershed events.

Winter storm event

The second case study within the OWLS is a winter storm that passed though the Webb Branch watershed on April 4-5, 2013. During this event the LEWAS instruments captured significant changes in water quality at the site due to runoff from road salts and deicing solution. The data within this case study demonstrates the strengths of the OWLS Live Data view (Figure 11). The LEWAS Live Data view shown here using the final interactive storyboard shows four simultaneous parameters.

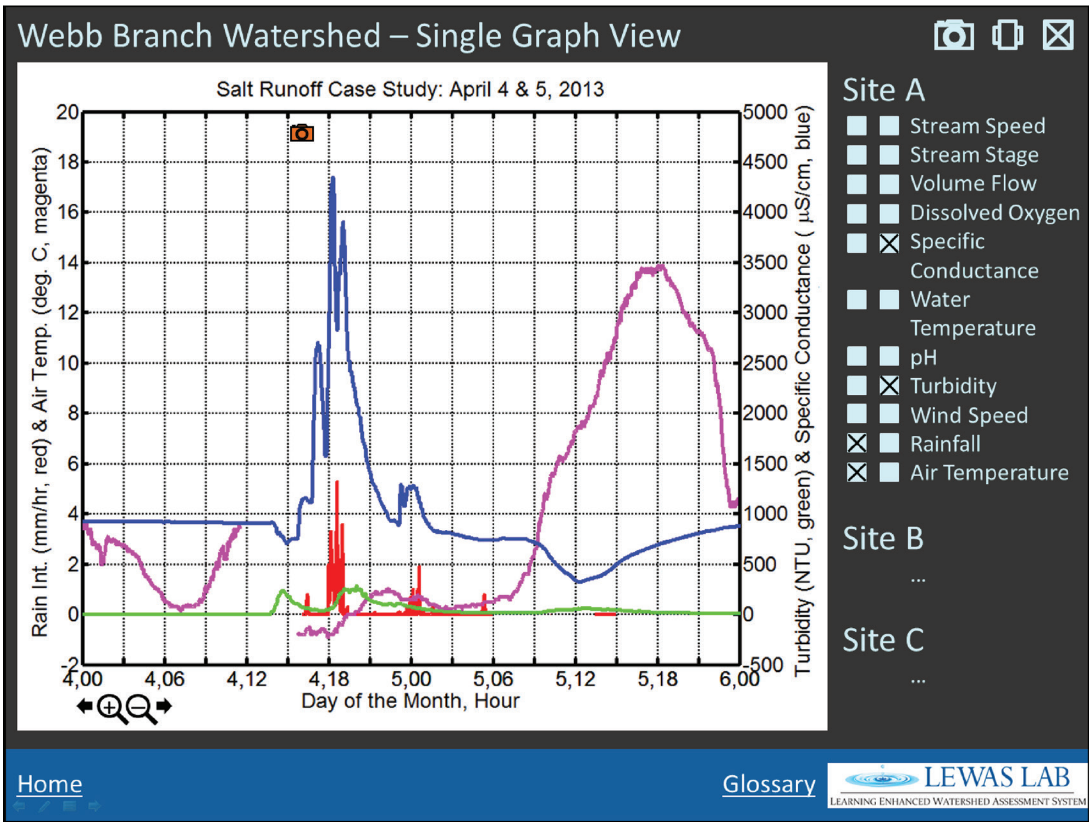

Figure 11. Winter storm salt wash case study interactive graph using the OWLS storyboard.

In the current version of the OWLS, the sample event analysis provided below could be carried out by comparing up to three parameters at a time.

This case study highlights challenges that are often encountered in event analysis, e.g., the data contains temporal gaps, and parameters change in ways that are not typical but represent a particular type of event. Thus, it makes an excellent case study for testing users' understanding of the watershed. It includes a rain event beginning around 14:00 (U.S. EST) on April 4 that quickly changed over to snow, salt runoff that significantly increases the specific conductance later that day, and the appearance of a rain event that is actually snow melt between 09:00 and 18:00 on April 5. An image of the LEWAS field site at 15:42 on April 4 (Figure 12) shows students that it was snowing at the time and had been snowing long enough to cover the ground. This image informs students that the dissolved materials in the water that are changing the specific conductance are road salts and deicing solutions applied to local roads and walkways. This salt and deicing runoff resulted in an acute chloride toxicity event in the stream, which would have gone unnoticed if not for the high-temporal-resolution of the LEWAS data (Clark et al., 2015). These insights about the event can be gained because the user is virtually situated at the field site by the integration of environmental data and time-stamped imagery. This case study provides an example of the type of event analysis that can be achieved by integrating multiple, high frequency sensing instruments

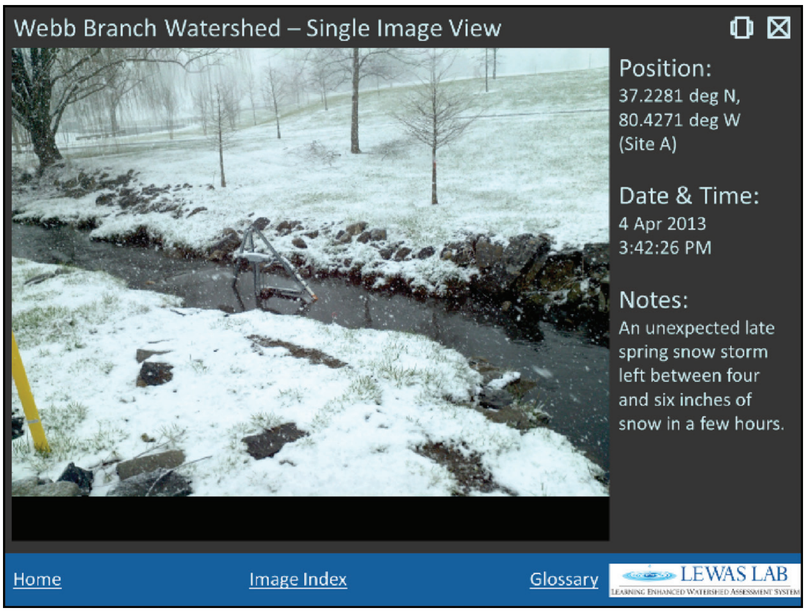

Figure 12. Winter storm salt runoff case study time-stamped image using the OWLS storyboard.

for watershed monitoring and making the data from those instruments available to students via an interactive guided learning system.

This case study highlights the ability for the OWLS to provide data in various representations (graphs, pictures, text, etc.) to students through mediation. The medium of data representations is critical to student cognition (Reisslein et al., 2010), and representations have been shown to be vital to engineering problem solving (Jonassen et al., 2006; Litzinger et al., 2010). The multiple forms of representation within the OWLS allow students to gain a deeper understanding of hydrologic and hydrochemical problems. Students are able to see where road salts could be applied to the road through the watershed exploration view and are able to connect that with the change in water quality that they see through the graph view. Students are also able to see pictures of the conditions of the site that day to get an understanding of how much frozen precipitation fell and connect it with hyetographs of rainfall. The importance of making such connections between pictures, graphs, and textual descriptions in the case studies is demonstrated in the following pilot test of the OWLS.

Pilot tests

Pilot studies of the OWLS were conducted during the spring and fall 2014 academic semesters in a senior-level hydrology course and a freshman-level introduction to engineering community college course, respectively. The OWLS was pilot tested in the senior level hydrology course during the spring 2014 semester using a one group pre-test-post-test experimental design. During this course, students were given a pre-test and a post-test assessment in class before and after their use of the OWLS. The post-test included both reworded pre-test questions and additional new questions. A pilot test for OWLS implementation into a community college course was held in the fall 2014 semester using a one group post-test-only experimental design with an in-class assessment after students' use of the OWLS. The pre-test and post-test assessments in the hydrology and community college courses contained a mix of both quantitative and qualitative open ended questions. The qualitative questions concerned students' perceptions of their learning, and the quantitative questions concerned students learning (fill in the answer and multiple choice) and, for the community college course, students' motivation levels.

The limitations to these experimental designs include internal validity threats to history (i.e., an event could occur during treatment that influences the outcomes), maturation (i.e., participants could mature or change throughout the treatment thereby influencing the results), testing (i.e., the pre-test could cause the participants to become familiar with the material), selection (i.e., students in the course will not be randomly selected but are chosen due to accessibility and resource constraints) or interaction effects through a combination of threats (Singleton and Straits, 2010). Despite these threats to validity, these pre-experimental designs (Leedy and Ormrod, 2005) were chosen because each course only had one available section, which would make having a control group difficult due to other internal validity threats. These include diffusion of treatment, where participants in the control group and experimental group communicate with each other inside or outside of class, and compensatory/resentful demoralization, where the control group may be resentful because it does not receive the benefit of access to the OWLS (Creswell, 2009). Non-random sampling may also introduce systematic errors such as selection bias, which may undermine the external validity of the assessments. In addition, the sample of students in each pre-experimental design contains students from a single course and may not be statistically representative of a greater population of engineering students, therefore limiting the generalizability of the results.

Senior-level hydrology course

As a pilot test, we integrated the OWLS into a senior level hydrology course (31 students) as one of six LEWAS-related modules implemented into this course during the spring 2014 semester (McDonald et al., 2014b; McDonald et al., 2015b). These modules were an expansion of three LEWAS-related modules implemented in the course in the fall 2012 semester (Dymond et al., 2013). Analysis of the results of the five other learning modules and preliminary results of the OWLS pilot test from the spring 2014 semester can be found in McDonald et al., 2015b. These six modules have become an integral part of the hydrology course and will continue to be used in coming semesters.

Bloom's Revised Cognitive Taxonomy was used as a guide to identify water sustainability topics that are appropriate for students at various academic levels and the components of the OWLS that could be used for water sustainability education at those levels (Figure 13). Critical to water sustainability education is the ability to assess the cognitive development of students as they progress. In its report on the Challenges and Opportunities in the Hydrologic Sciences, the National Academy of Sciences states that, "Ensuring clean water for the future requires an ability to understand, predict and manage changes in water quality." (National Research Council, 2012, p.8) The abilities to understand, predict and manage water quality changes can be aligned with the levels of Bloom's revised cognitive taxonomy (A Committee of College and University Examiners, 1956; Anderson et al., 2001). Understanding these changes fits with the second level of this taxonomy, i.e. understanding. Predicting what is going to happen as the result of a particular watershed event matches the fifth level of this taxonomy, i.e. evaluating. Developing watershed management plans requires the synthesis of diverse factors impacting the watershed, which fits with the top level of the revised taxonomy, i.e. creating. Having a high level of cognition about water systems allows individuals to move beyond understanding and solving water sustainability problems to defining water sustainability problems, which allows them to effectively manage water systems (Downey, 2005).

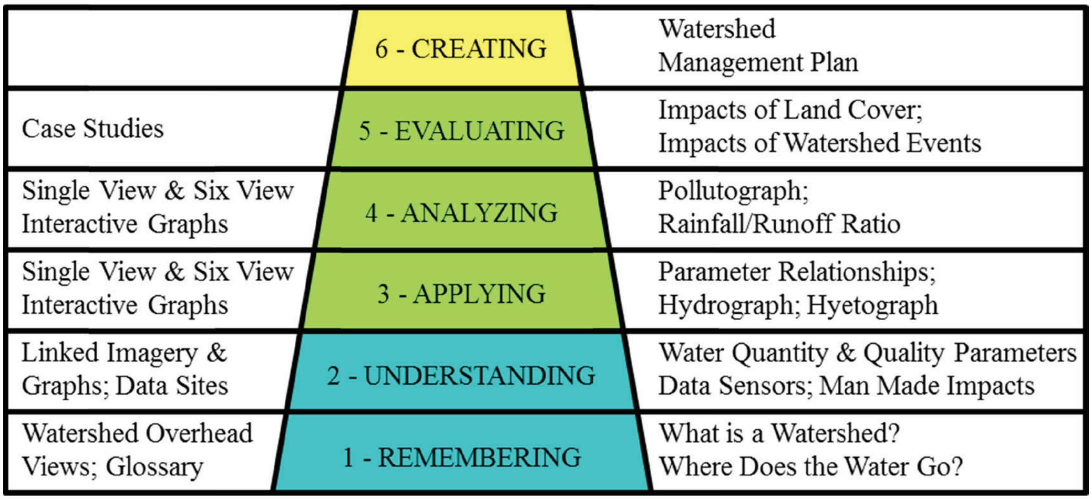

Figure 13. Lesson plan guide including examples of water sustainability education topics appropriate for each level of Bloom's revised cognitive taxonomy and the corresponding OWLS components that are appropriate for learning these topics. Levels 1-2 are applicable to introductory undergraduate courses, and levels 3-5 are applicable to a junior or senior level hydrology course. Level 6 would apply to a graduate-level hydrology course.

The OWLS-based module consisted of the three following primary components: 1) students used the OWLS to view and analyze a "simulated" real-time case study that used historical data and imagery, 2) students answered homework questions related to the watershed, case studies, the data viewer and watershed behavior and 3) students provided feedback on the usefulness of the OWLS (then known as the PIRMS). In total, 31 students completed a pre-test and 30 students completed a post-test based on all six LEWAS-related modules (Table 1). The qualitative questions in the pre- and post-tests were analyzed for codes and themes, and the quality was checked by multiple team members to improve the reliability of the coding process (Leydens, et al., 2004). Students in both the pre-test and the post-test were asked what they perceived to be the added value of a system such as the OWLS that delivers live and/or remote system data to end users regardless of their hardware or software. The primary value of the OWLS anticipated by students in the pre-test was anywhere, anytime access to the data and imagery (42%). This majority greatly increased in the post-test after students were given access to the OWLS through their assignments (80%) (McDonald et al., 2015b), followed by the benefits of easy data visualization and real-time data availability (13% each). Students valued being able to readily access data and connect the graphical representations of data to the real-environment through environmental representations within the OWLS. For example, one student

Pre-test Questions (n = 31)
What would be the added value of a product that delivers live and/or historical remote system data (visual, environmental, geographical, etc.) to end users regardless of the hardware (desktop, laptop, tablet, smartphone, etc.) and software (Windows, Linux, iOS, Android, etc.) platforms of their choice?
Accessibility (13), Greater information (8), Real-time data (7)
Post-test Questions (n = 30)
What is the added value of the OWLS that delivers live and/or historical remote system data (visual, environmental, geographical, etc.) to end users regardless of the hardware (desktop, laptop, tablet, smartphone, etc.) and software (Windows, Linux, iOS, Android, etc.) platforms of their choice?
Accessibility (24), Data visualization (4), Real-time data (4)
The OWLS helped you to learn hydrology concepts. (circle one) {Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree}
Strongly disagree (0), Disagree (0), Neither agree nor disagree (1), Agree (22), Strongly agree (7)
Please describe any parts of the OWLS that were difficult to use and recommend improvements.
Usability (5), Data visualization (5), More pictures (3)

Table 1. OWLS-related pre-test and post-test questions and assessment results for the hydrology course.

stated that "*the added value as I see it is the ability to monitor data in the field, on the roads, and in the office*". Additionally, student perceptions of the usefulness of the OWLS was high with twenty-nine of thirty students completing the post-test (97%) either agreeing or strongly agreeing that the OWLS helped them to learn hydrologic concepts (McDonald et al., 2015b). Finally, when asked what difficulties and recommendations they would make, students made suggestions related to the usability of the system, improvements to the data visualization components, and inclusion of more pictures. One student observed, "*Being able to view more than two parameters at a time would be helpful.*" In response we have added the ability to concurrently show a third parameter to the LEWAS Live Data view. Another student stated, "*If you could download data straight to Excel, that would be useful.*" This concern has been addressed by adding the option of downloading data in CSV format to the current version of the OWLS. Other changes that were suggested by students and incorporated into the current version include the ability to select from multiple time scales and the ability to refresh the graph without changing menu parameters. One final area suggested by multiple students was the addition of more photographs into the OWLS. We are addressing that suggestion by adding the live camera and, in the near future, integrating these images into the historical archive.

Community college course

The results from the pilot study in the community college course (n = 27) consist of students' qualitative perceptions of their learning, quantitative measures of students' learning and quantitative

Post-test Questions (n = 27)
What value, if any, do you see in real-time monitoring of water quantity and quality? *Track changes in data (11), Public benefits (6), Real-world data (4)*
How did this system help you learn the effects of man-made activities on water quality and quantity in a watershed? *Data trends reflect man-made impacts (7), Real-time data tracking of events (5), Specific case studies (5)*
How can the LEWAS be used to educate the public about watershed health? *Increase awareness of human impacts (9), Illustrate cause-effect relationships from events (9), Influence public decisions (7)*
If you were designing an introductory engineering course, in what way(s), if any, would you incorporate a system similar to LEWAS into the course? Why? *[No specific themes]*

Table 2. Qualitative post-test questions and assessment results for the community college course.

measures of students' motivation. The motivation questions provide a base level for 2015 implementations and will be discussed in a future paper. The qualitative open-ended questions are shown in Table 2. Open-ended qualitative questions were used to gain a greater insight into the student perceived learning through reflection and application questions. For example one reflection question asked "What value, if any, do you see in real-time monitoring of water quantity and quality?", the majority of students found value in being able to track continuous changes within the data. One student stated that "*[I] was able to see changes in the data and was able to learn from that.*" Others indicated that the data was valuable to the public and that the real-world data was of the greatest value. Overall, students indicated that they found real-time monitoring, such as that from the LEWAS, to be valuable.

To determine how the students felt the system linked human activities to the environment, another reflection question asked, "How did this system help you learn the effects of man-made activities on water quality and quantity in a watershed?" The majority of students indicated that they learned from viewing the trends from the LEWAS data that reflected man-made impacts. One student stated, "*By monitoring the water we can measure what effect man-made activities have on our environment*." Other students indicated that real-time tracking of events and the specific case studies from the OWLS helped them to understand the effects of man-made activities on the watershed.

Two other questions asked the students how they would apply the LEWAS in other contexts. The first question asked the students to indicate how the LEWAS could be used to educate the public about watershed health. This forced the students to synthesize their experience with the LEWAS and apply their knowledge in new ways to help to educate others. The majority of students felt that the LEWAS could be used to increase awareness of human impacts to the environment and to illustrate the cause and effect relationship from events. The second question asked the students in what way, if any, they would incorporate the LEWAS into other courses. No themes emerged from the data but only 3 out of 27 students indicated that they would not use it in their course. Others who indicated that they would use it cited specific examples such as one student who stated "*I would have them split into teams and test the river once a week*" and another who stated "*I would definitely show the LEWAS system as a final project..*"

Results from the quantitative multiple-choice assessment are difficult to interpret given that there was not a control group to serve as a comparison for the course. The assessment focused on questions that students would understand based on their experience with the LEWAS and OWLS, such as "What weather parameter correlates with temperature at the LEWAS site?" Six total questions were asked and the students averaged 40% correct responses. One interesting result was that the students scored significantly better (60% correct) on the question that focused specifically on the effects of water quality at a nearby river, where they took their own samples, versus other questions that focused on the LEWAS site and data they obtained through the OWLS. This could indicate that student learning is improved with hands-on data collection and field experience in a local river.

Overall, the assessment results indicate that a majority of students felt that the OWLS assignment was valuable and relevant to their coursework. The interpretation of the results should consider the limitations of the experimental design including threats to internal validity discussed above. Even so, these pilot tests provide useful information that can be used to improve the OWLS modules and assessment procedures for future courses. Results from spring and fall 2015 assessments will provide valuable information regarding the impact that the OWLS has on learning and motivation in university and community college students.

FUTURE WORK

Our future plans for the LEWAS are four pronged: (1) maintaining and upgrading the LEWAS, (2) increasing the capabilities of the OWLS and diversifying research applications of the LEWAS data, (3) integrating additional measurement sites into the common database, and (4) expanding use of the LEWAS data via the OWLS to new groups of users. Beyond the maintenance issues described earlier in the paper, we will continue to upgrade the instruments in the LEWAS as superior technology becomes available and as aging instruments wear out. We will include increased graphing capabilities, additional case studies, additional geographic setting information and an introductory tutorial in future versions of the OWLS. Additionally, we will add anonymous user tracking to investigate the paths users choose to navigate through the OWLS for solving LEWAS data-based problems (fall 2015 pilot test). In an NSF/Improvement of Undergraduate STEM Education (IUSE) proposal, we have collaborated with a number of colleagues from Geosciences, Biology, and Environmental Sciences within Virginia Tech and VWCC to introduce the capability of the LEWAS and the OWLS into their courses and expand the scope of ongoing engineering education research to include subjects from a variety of disciplinary backgrounds. Additionally, we have established collaboration with multiple institutions outside Virginia Tech including East Carolina University (ECU) and University of Queensland (UQ), Australia, to enhance the scope of case studies, available through the OWLS, to cover high frequency environmental monitoring issues from their regions. A faculty member from ECU has attended two workshops at Virginia Tech to learn about the LEWAS and is currently implementing a LEWAS-type system that will monitor a stream with a relatively larger watershed flowing through the campus of ECU. Likewise, three faculty members from the UQ have visited with us to learn about the LEWAS and are in the process of setting up a similar system on their campus. In summer 2015, first three authors were invited to conduct a one-week engineering education workshop at KLE Technological University in India, and one of the goals was to begin the process of establishing a LEWAS-type lab on the campus of this university. Preliminary work in this direction is in progress. Such efforts will certainly grow the diversity of the users and will provide case studies exploring the potential of high frequency environmental monitoring data from a variety of geographical contexts, thus enriching the learning experiences of students.

CONCLUSIONS

The combined LEWAS-OWLS learning tool provides a data creating and sharing infrastructure that collects, integrates, and stores real-time high-resolution environmental monitoring data and imagery. The system makes the data available to users at anytime from anywhere they have internet access via a software and hardware platform independent environmental learning system driven by HTML5. Through the OWLS, users can explore the watershed, examine case studies and visualize historic and real-time parameters. The development and continued operation of the LEWAS has included several practical challenges similar to those that others are likely to experience when developing their own environmental data creation systems.

From an educational standpoint, the OWLS provides an integrated visual and graphical data environment that virtually situates students from all over the world at the LEWAS site. Case studies that integrate data from the LEWAS within the OWLS interface provide practical examples of the impacts of both natural and manmade environmental events. Because of the platform-independence of the OWLS, data from the LEWAS and other future collaborative locations can be used by students across the globe to learn about a diverse set of watershed environments to which they would not be otherwise exposed. Preliminary results from the OWLS pilot test (n=31) in the hydrology course indicate that 80% of students valued the anywhere, anytime access to the data and 97% of students believed that access to the OWLS helped them to learn hydrologic concepts. Preliminary results from the community college pilot test (n = 27) indicate that, although students showed a limited amount of learning in multiple choice questions, a majority of students felt that the OWLS assignment was valuable and relevant to their coursework. Results from spring and fall 2015 implementations of the OWLS in these courses will clarify and expand on the results contained here.

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AUTHORS

Daniel S. Brogan is a doctoral candidate in the Department of Engineering Education at Virginia Tech. Working under Dr. Vinod K. Lohani, he has had a leading role in the development and implementation work of the Learning Enhanced Watershed Assessment System (LEWAS) for more than three years. His dissertation research involves the development and classroom integration of the Online Watershed Learning System (OWLS) (http://www.lewas.centers.vt.edu/dataviewer/), which serves as a user interface to the LEWAS data. He received his bachelor's and master's degrees in electrical engineering from the University of New Hampshire.

Walter McDonald is a PhD Student, co-advised by Drs. Dymond and Lohani, in the CEE program at Virginia Tech with a focus in water resources engineering. He received a B.S. in Civil Engineering from Texas Tech University and a M.S. in Civil Engineering from Texas A&M University. He has had extensive training in hydrology and currently works in the LEWAS where he conducts water sustainability research. He has also developed and implemented curricula for introducing the LEWAS into two freshman level courses at Virginia Western Community College and numerous courses at Virginia Tech.

Vinod K Lohani is a professor in the Engineering Education Department and an adjunct faculty in the Civil and Environmental Engineering at Virginia Tech. His research interests are in the areas of sustainability, computer-supported research and learning systems, hydrology, and water resources. Currently, Dr. Lohani leads an NSF/REU Site on "interdisciplinary water sciences and engineering" which has already graduated 76 excellent undergraduate researchers since 2007. This Site is continuing for the third cycle during 2014-17. He also led an NSF/TUES type I project (2012-15) in which the LEWAS was integrated into a senior

level Hydrology course at Virginia Tech, and a couple of engineering courses at Virginia Western Community College, Roanoke for enhancing water sustainability education. He is a member of ASCE and ASEE and has published 80+ refereed publications.

Randy Dymond is an Associate Professor of Civil and Environmental Engineering at Virginia Tech. With degrees from Bucknell and Penn State, Dr. Dymond has more than 30 years of experience academics, consulting, and software development. He has taught at Penn State, the University of Wisconsin-Platteville, and has been at Virginia Tech for 18 years. Dr. Dymond has published more than 90 refereed journal articles and proceedings papers, and been the principal or co-principal investigator for more than 120 research proposals from many diverse funding agencies. His research areas include urban stormwater modeling, low impact development, watershed and floodplain management, and sustainable land development. He teaches classes in GIS, land development, and water resources and has won numerous teaching awards, at the Departmental, College, and National levels.

Aaron Bradner has an MS degree from Virginia Tech in Crop and Soil Environmental Science. His MS research (co-advised by Dr. Lohani) focused on high-resolution, real-time monitoring of various water quality parameters in a local urban stream and analyzing the effect variations in these parameters had on the concentration of chemical pollutants within the stream. At NEON, Inc., he is the lead aquatic scientist in the Appalachian domain. His current work focuses on observational science involving aquatic chemistry, hydrology, and biodiversity assays in headwater streams.