Integrating a Real-Time Remote Watershed Monitoring Lab into Water Sustainability Education

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Daniel S. Brogan is a PhD student in Engineering Education with BS and MS degrees in Electrical Engineering. He has completed several graduate courses in engineering education pertinent to this research. He leads the LEWAS lab development and implementation work. He has mentored two NSF/REU Site students in the LEWAS lab. He assisted in the development and implementation of curricula for introducing the LEWAS at VWCC including the development of pre-test and post-test assessment questions. Additionally, he has a background in remote sensing, data analysis and signal processing from the University of New Hampshire.

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Abstract: The LabVIEW Enhanced Watershed Assessment System (LEWAS) research lab at Virginia Tech (VT) includes an interdisciplinary research group that has developed a real-time watershed monitoring lab in Stroubles Creek on VT Campus. The LEWAS components of water and weather monitoring instruments, renewable power supply, data collection hardware and data processing software are integrated to provide real-time sustainable watershed data on an accessible platform to many types of user groups. The LEWAS lab is being used for watershed sustainability research and hands-on classroom education. The lab has been used in a senior level undergraduate Hydrology course in fall 2012 and spring 2014 by incorporating LEWAS-based hands-on modules into the course. The lab has also been integrated into freshmen level courses at Virginia Western Community College in Roanoke, Virginia. These learning modules introduce students to watershed sustainability concepts, a real world application of LabVIEW, and hands-on data collection and analysis projects. Effectiveness of learning modules is documented through pre- and post-test instruments. Results from both applications e indicated that students benefit from LEWAS-based hands-on learning modules.

Introduction

The LabVIEW Enabled Watershed Assessment System (LEWAS) is a real-time high-frequency watershed monitoring lab with a focus on water sustainability, real-time monitoring research, and educational outreach. Each of these goals are facilitated by an interdisciplinary research team comprised of faculty, graduate and undergraduate students with backgrounds in electrical engineering, chemical engineering, biological systems engineering, environmental engineering, civil engineering, and engineering education. The LEWAS components of water and weather monitoring instruments, sustainable power supply, data collection hardware and data processing software are uniquely designed to provide real-time watershed monitoring data on an accessible platform to many types of user groups.

The LEWAS is a novel lab in which real-time high-frequency water and weather data are used for educational instruction and water sustainability research. The current LEWAS field site is located at the outlet of the Webb Branch watershed, just upstream of a retention pond known as the Duck Pond. The watershed has an area of 2.78 km^2 and is highly urbanized with residential and commercial development encompassing portions of the Town of Blacksburg and Virginia Tech (VT) campus. These conditions enable the lab to study the quick response times of a small urban watershed using real-time high temporal resolution water and weather monitoring equipment. The instrumentation is composed of a multi-parameter Sonde for water quality measurements, and Acoustic Doppler Current Profiler (ADCP) for flow measurements, a weather station, and a camera for supporting visual data. The entire system is run using an embedded computer located at the site and is powered by solar panels which charge two 12 volt batteries connected in series.

As part of an NSF Transforming Undergraduate Education in STEM (TUES) Type I grant, the LEWAS has been integrated into classroom curricula in undergraduate courses at VT as well as at Virginia Western Community College (VWCC). At VT the LEWAS has been used in a freshman level Engineering Exploration course and in a senior level Hydrology course, and at VWCC the lab has been used in two different freshman level introduction to engineering courses. In every course the LEWAS is used to support the classes' goals and objectives through activity-based learning modules which encourage discovery-based learning while promoting water sustainability concepts and practices.

LEWAS classroom modules have been designed around strong theoretical and empirically based research which proposes that people are motivated to learn through remote laboratory environments[1]. LEWAS promotes "active learning" through modules that connect the participants to the field site and motivate them to actively participate in learning activities focused on water sustainability. LEWAS modules connect the student virtually to the field site through the real-time broadcast of high temporal resolution data while also allowing for hands-on learning.

Dymond, et al. (2013) presented the implementation of LEWAS-based modules into a fall 2012 senior level hydrology course at VT and the resulting student assessment data[2]. The study demonstrated the effectiveness of the LEWAS based modules in the hydrology course for increasing student motivation. Results from this study were used to develop new LEWAS based modules that attempt to support learning outcomes of the courses and increase student motivation. This paper builds upon the previous work by describing the implementation of LEWAS based modules into a senior level hydrology course given in spring 2014 as well as the implementation into freshman level courses at VWCC. Preliminary results from student assessment in the VWCC freshman level courses have indicated that the LEWAS modules did increase student motivation.

Design of the LEWAS Lab

The LEWAS lab is composed of an interdisciplinary group of researchers from a variety of backgrounds all working together to create, maintain and expand the LEWAS lab. Currently there are 4 graduate students and 4 undergraduate students working in the lab, and in the past the lab has graduated 3 graduate students (2 MS, 1 PhD), 6 undergraduate students, and hosted 5 NSF REU students. Students working in the lab have come from a variety of backgrounds including engineering education, electrical engineering, computer engineering, civil engineering, chemical engineering, environmental engineering, biological and systems engineering, biology and chemistry. The LEWAS requires an interdisciplinary team due to the various components and expertise required for a real-time watershed monitoring lab. Power supply and data acquisition require the expertise of personnel from electrical and computer engineering backgrounds while water quality, flow, and weather studies require personnel with environmental, biological, and civil engineering backgrounds. The LEWAS requires synergy among all members to effectively maintain and promote the lab for water education and research.

The LEWAS lab has been designed in multiple phases over the course of 5 years beginning with an alpha version of the lab which tested software and water quality instruments using field sampling methods. During the summer of 2008, water quality data was collected using a water quality Sonde and sent to LabVIEW through a laptop computer acting as a server computer. In the summer of 2009, the next phase of the project employed a CompactRIO embedded computer as a server programmed to run sampling equipment remotely and without user intervention. Construction of the outdoor lab began in Fall 2009 with the placement of a concrete platform and a primary control box (NexSens AVSS Stainless Steel iSIC Enclosure) to house the battery backed electrical power supply system and on-site computing resources. The environmental measurement devices which include a flow meter, water quality Sonde, and weather station were installed at the site along with a solar panel and antenna. Wiring access between all devices was connected through underground PVC piping.

The current LEWAS site has three primary monitoring devices: (i) a Hach MS-5 Sonde that measures temperature, pH, turbidity, dissolved oxygen (DO), oxidation reduction potential (ORP), and specific conductivity, (ii) a Sontek Argonaut-SW Acoustic Doppler Flow Meter that collects stage and index velocity measurements to compute flow at the site, and (iii) a Vaisala Weather Transmitter WXT520 that measures air temperature, barometric pressure, relative humidity, precipitation, wind speed and wind direction. In addition to the measurement devices, an outdoor camera is located at the site to provide supporting visual data. The entire system is run through an embedded computer that collects and sends data from the sensors via a wireless bridge to a database on campus. Power is supplied to the LEWAS site by solar panels which charge two 12 V batteries connected in series. An operational diagram of the lab is illustrated in Figure 1.

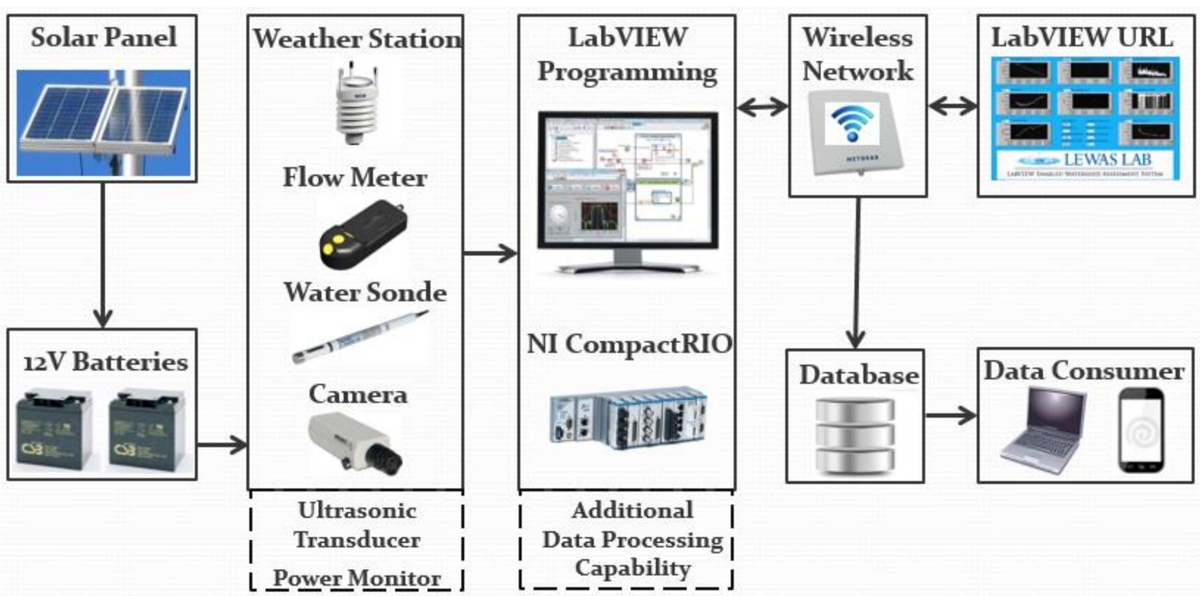

Figure 1. The LEWAS Operational Diagram

Proposed expansion of the lab includes an ultrasonic transducer to take stage measurements behind a weir upstream of the field site (Figure 2). New Raspberry Pi data acquisition hardware with greater expandability and fewer constraints than the current system is also being investigated as a possible addition to the system. In addition, two proposals are under review at the NSF that seek to expand educational outreach and research collaboration between VT and

VWCC to John Tyler Community College (JTCC) and East Carolina University (ECU). These proposals also seek to expand the field site to include another location on VT campus and one at ECU.

LEWAS in Undergraduate Education

A primary goal of LEWAS is to integrate the lab into curricula at all levels of higher and secondary learning to enhance water sustainability education using LEWAS-based hands-on modules. The first use of LEWAS in the classroom was part of an NSF Department Level Reform grant in which students in a freshman level Engineering Exploration class were introduced to the LEWAS system. Students in the class learned the basics of programming, including LabVIEW, and were given a real world application of LabVIEW programing through the LEWAS operating software. Since its first implementation in 2009, demonstrations of this lab have been presented to over 5,000 engineering freshmen at Virginia Tech[3-4].In a case study with 150 engineering freshmen at Virginia Tech in spring 2012, it was shown that having access to real-time water and weather data through the LEWAS improved students' motivation to learn about water sustainability issues[2].

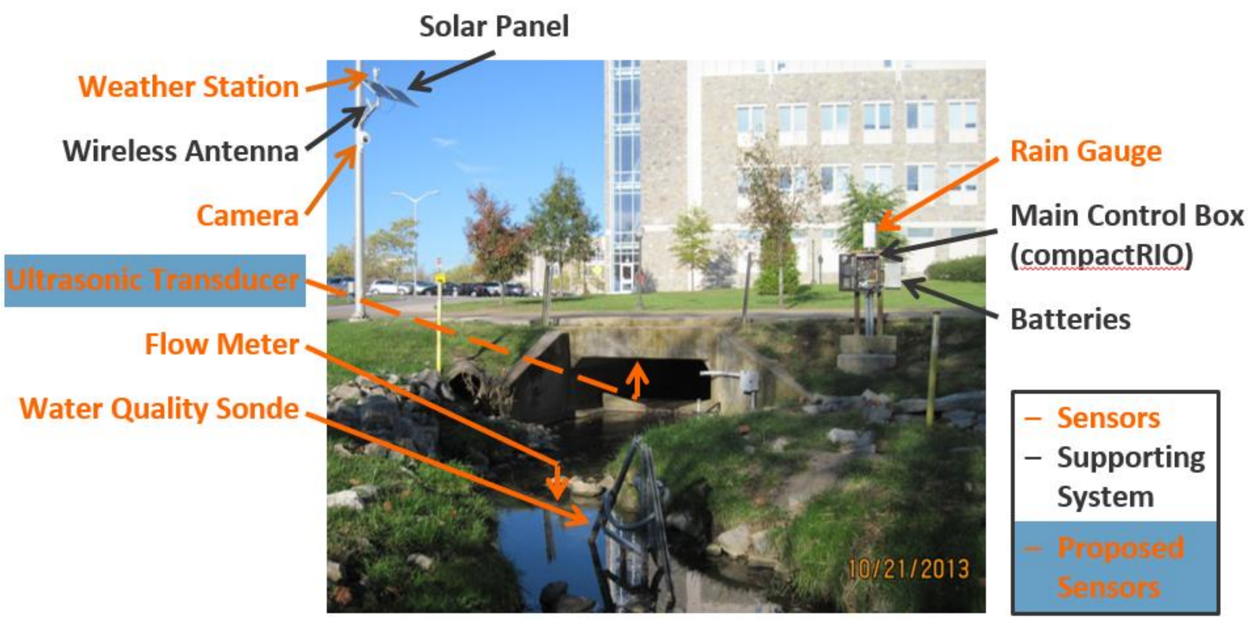

Figure 2. LEWAS Field Site Layout

The LEWAS lab also hosts an National Science Foundation Research Experiences for Undergraduates (NSF-REU) Site on Interdisciplinary Water Sciences and Engineering, which allows undergraduate students from across the country to conduct research under the mentorship of faculty and graduate students for 10 weeks in a stimulating interdisciplinary environment at the host institution[5-9]. The site has been successfully implemented during 2007-2009 and 2011-2013 and has graduated a total of 56 REU participants including 33 women and 23 men. The REU site was recently renewed and will bring 30 REU fellows from across the country to VT over a period of the next 3 years.

In addition, as a part of an ongoing NSF/TUES (type I) program the LEWAS is being integrated into a senior level Hydrology course at VT as well as two engineering courses at VWCC, Roanoke. The goal is to enhance student learning by incorporating LEWAS based hands-on student activities into the curriculum. In these courses, students use data collected at the LEWAS site to understand stormwater flows in urbanized watersheds, the relationship between land cover and water quality, and the importance of sustainable watershed management.

Interest from faculty in various colleges at VT has also resulted in the LEWAS being used in a Civil Engineering Hydraulics course as well as two undergraduate courses in Geosciences. Collaborative proposals have been developed to further use the LEWAS in courses in Geosciences, Biology, Crop and Soil Environmental Sciences and Civil & Environmental Engineering. The following sections describe the implementation of the LEWAS as part of the NSF/TUES grant in a senior level hydrology course at VT and freshman level courses at VWCC. Course modules development, implementation, and outcomes are discussed as well as preliminary results from pre- and post-test surveys.

Senior Level Hydrology Course

The LEWAS has been implemented into a senior level hydrology course at VT during the Fall 2012 and Spring 2014 semesters. Hydrology is an elective course for senior and graduate students and is taught once per year in the fall semester with an enrollment between 30 and 70 students, approximately 10% of whom are graduate students. The course covers the fundamentals of hydrology including basic issues and mechanisms of precipitation, infiltration, evapotranspiration, runoff, and subsurface flow, and accompanying computational methods. Special emphasis is placed on surface runoff quantity generation, including flood routing and forecasting and urban hydrology issues. LEWAS was used to support the course material as an active learning experience for the students to grasp hydrologic concepts with remote data access and hands-on field experience. Specific course objectives such as "Use streamflow and precipitation data from the internet" were supported through the LEWAS module integration.

The LEWAS was introduced to the students with a presentation at the beginning of the course that covered the outdoor lab and its components, the watershed, and the purpose of monitoring the stream. Distinct advantages of implementing the LEWAS in a course are that the students become familiar with the watershed in which the classroom is located and students have direct access to the field site located on campus. The primary goals of integrating the LEWAS into the hydrology course were to enhance student learning by incorporating three LEWAS-based active learning modules as the students were learning related hydrologic topics.

The first module to be introduced in the course was the *Storm Characteristics Module*. This module focused on the concepts of hyetographs, hydrographs, rainfall-runoff relationships, land cover, and abstraction. Students were given data from a historical storm captured at the LEWAS site, which included flow and precipitation. Students were then asked to compute a rainfall-runoff coefficient and comment on the values.

The second module to be introduced into the course was the *Land Cover - Peak Flow - Water Quality Correlation Module*. This module focused on the concepts of land cover, storm flow quality and quantity, peak flow rate, and runoff coefficients. While students were learning about the hydrologic methods to estimate peak flow rates, they were given an assignment to evaluate common runoff coefficients such as the Rational Method C and the National Resources Conservation Service (NRCS) Curve Number (CN) based on extensive digitized land cover and soils data for the watershed[10]. Students were asked to comment on the possible error types and uncertainties inherent in common runoff coefficients. Students were also asked to discuss the impact that land cover has on certain water quality parameters tested at the LEWAS site such as temperature, turbidity, specific conductivity, pH and DO.

The *Watershed Wiki Module* was the third LEWAS module in the course and was implemented in order to motivate student learning about the importance of monitoring environmental resources. This module promoted active learning through hands-on group assignments that gave students the opportunity to investigate physical changes in the watershed and draw their own assessments. Students were assigned to teams that took turns throughout the semester to visit the LEWAS field site and write daily reports on the class Wiki about the conditions of the site, performance of the equipment, and the monitoring results. Figure 3 shows students at the field site collecting data as well as an example of a Wiki post. The groups took on the responsibility as a watershed assessment team for an assigned week and prepared data tables and graphs of weather, flow, and water quality data. At the end of the week the teams compiled a report which included data tables and graphs of weather, flow, and water quality data. Students conducted research into water quality parameters and discussed the notable differences or events in which parameters exceeded normal values.

Monday, March 3rd

Date: Monday, March 3, 2014
4:00
Weather: 27°, Wintry Mix / Snow

Surrounding Conditions:
Ground was extremely soft and saturated.
Snow accumulation of approximately 1" in some areas.
Some trash on the stream bank (hubcap still present).

Stream Conditions:
Stream Gage Reading = 19.0 cm
The water height was significantly lower than earlier in the day.
Water was murky with high turbidity.
The device was free of debris.

Figure 3. Hydrology Blog Post. This figure shows an example blog post (right) and a picture of a group out at the LEWAS field site (left).

A survey given in the fall 2012 Hydrology course revealed that LEWAS helped students learn hydrologic concepts and that students found real-time monitoring to be valuable for monitoring the effects of system inputs on the response of an urbanized watershed. Although the overall student response to the LEWAS was positive, the few negative responses were related to students who used the LEWAS when there were no rain events. Significantly, more than half of the students who responded to the post-test would expand the use of a similar lab in hydrology courses they were teaching. Results from the assessments in the hydrology course can be found in Dymond, et al. (2013)[3].

From the feedback received from students in the fall 2012 course, the same are being introduced into the spring 2014 course as well as three new modules. The additional modules will be implemented to further capitalize on the LEWAS' capabilities to reinforce hydrologic concepts. New modules will include:

(i) *Storm Data Water Quality Analysis*: Given a set of weather, flow, and water quality data from a storm, students will discuss why water quality parameters change the way that they do during a storm. This module will attempt to merge the two concepts of water quantity and quality together, which are important for a hydrographer to understand.

(ii) *Flow Computations:* Part of the proposed expansion of the lab is to include additional flow measurement devices to validate flow data from existing sensors and evaluate uncertainties within flow measurement devices and methodologies. Students can manually measure field flows using their own stage measurements and previously developed stage-discharge relationships. The students can then compare their estimates to the weir flow measurements delivered by the ultrasonic transducer and the index velocity flow measurements delivered by the ADCP.

(iii) *Soil Saturation Impacts:* An important hydrologic concept for students to understand is the effect that antecedent soil moisture conditions have on infiltration and runoff rates. Students will be given storm flow data from consecutive versus standalone storms and asked to calculate the impact of antecedent soil conditions on stormwater runoff.

Freshman Community College Courses

The LEWAS was designed as an educational outreach tool to promote water sustainability concepts through discovery based classroom modules that utilize a remote laboratory environment. Through real-time data acquisition and display via the LabVIEW website, the LEWAS simulates a remote laboratory where students can virtually situate themselves at the LEWAS site. These modules were built upon previous empirical research developed by LEWAS members that suggest that access to real-time data improve a student's understanding of water sustainability concepts[2]. The LEWAS modules were developed and implemented first in two freshman level courses the local community college in the spring 2013 semester, and again in the fall 2013 semester. In total approximately 90 students were exposed to the LEWAS modules.

Classroom LEWAS modules were implemented over a two-week period in four class periods. The modules were developed to support the class goals and outcomes through a real world application of LabVIEW programming, data acquisition, and data analysis. In each of the classes (EGR 120 and EGR 124) students were introduced to the basics of engineering including statistical analysis and LabVIEW programming. The modules had four sessions which introduced the students to water sustainability concepts, data acquisition, data analysis, and LabVIEW programming through the LEWAS lab. The learning objectives of the classroom module were to introduce students to a practical application of LabVIEW, problem solving strategies via LabVIEW and Microsoft Excel software, hands on data collection, hand calculations and unit conversions, basics of water quality monitoring, water sustainability, and ethics.

The first session introduced students to basic water sustainability concepts including the water cycle, watersheds and runoff, pollution, and ecosystem functions. Students were exposed to the impacts of urbanization and development on surface water quality and introduced to different water quality parameters. Students were then given LaMotte water quality testing kits to use at a location of the Roanoke River that is near the campus, easy to access, and close to a USGS flow station so that students could later calculate pollutant loads (Figure 4). The students were paired into groups and assigned to test the water for 7 different factors (pH, dissolved oxygen, biochemical oxygen demand, temperature, turbidity, and phosphate) at the site over the two week period (twice for each group)

The second session introduced students to stormwater water quality best management practices and the LEWAS lab field site, including the instrumentation used, use of LabVIEW in communicating with instruments, interesting case studies captured by LEWAS, and the real-time LEWAS data viewer. The third session had students use data from the LEWAS lab as well as data they collected at the local river to solve simple water quality questions. The computations included determining pollutant loads using a water quality parameter concentration and flow rate, computing a rainfall/runoff ratio using watershed area, precipitation, and flow, and using data to make inferences and draw conclusions as to what is happening in a watershed.

The fourth and final session had students use all of the data they had collected at the Roanoke River as well as LEWAS data to compute population statistics such as mean and median, plot the distribution of the entire classes data, and make simple statistical inferences. Students used LabVIEW and Microsoft Excel to complete the in-class exercises. The students were also required to blog about their experiences in collecting data with their group at the Roanoke River site. Students described the site conditions that day, including conditions of the stream and weather, and posted their results with descriptions of the parameters they tested for.

Students were given a pre-assessment questionnaire before the LEWAS-based modules and a post-assessment questionnaire after completion of the modules. Table 1 contains the pre-assessment questions along with some of the results and example responses from the spring 2013 assessment. Preliminary results from the pre and post-assessments given to the students in the fall and spring 2013 courses indicate that the LEWAS modules had a positive impact on student motivation and learning outcomes. The majority of the students did not know where the water at their location at the Roanoke River ultimately drained to and only 1 student knew where the water at the LEWAS site ultimately drained to. Students also anticipated scheduling, quality of data, and lack of understanding to be the major difficulty in their two week assignment to monitor flow at the Roanoke River site.

Figure 4. Community College Students. Students in the classroom being introduced to the LaMotte test kits (top), and students at the local river field site collecting data (bottom).

Table 1. Community College Spring 2013 Pre-Assessment

The water flowing in the Roanoke River ultimately drains into *Atlantic Ocean (13/28)*
The water flowing at the LEWAS Site (Blacksburg) ultimately drains into *Gulf of Mexico (1/28)*
How can this system help you learn the effects of man-made activities on water quality and quantity in a watershed?
*"By monitoring the measurements over a period of time, the measurements can be used to interpret the effects of activities of how that relates to water quality and quantity"**
How can this system help educate you about sustainable development? (Sustainable development is defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. *"So we can learn how to properly use the watershed without destroying it for future generations to come"**
What difficulties do you anticipate in your two week assignment to monitor the water quantity, quality and weather parameters? *Scheduling (6) Weather (2), Lack of Understanding (3), Equipment (1), Quality of Data (5), Unknown (1), None (3)*
How can this system be used to educate the public (who won't have your hands-on experience) about sustainable development? *"It can be used to educate the public about how are human activity can affect the water quality and how that effect the future generations."**

*Example Response

The post-assessment questions and portions of the results and example responses are given in Table 2. The overall response from students about the LEWAS module was positive, with many indicating that they enjoyed the hands-on, active learning experience. The post-assessment results show that the vast majority of students understood where the water in the Roanoke River and the LEWAS site were ultimately draining to. Many students indicated that the LEWAS module helped them learn the effects of man-made activities on a watershed and helped to educate them about sustainable development. The majority also indicated that there is value in real-time monitoring of water quality and quantity data. Results from these assessments are being used to drive further educational research and improve upon LEWAS modules for the 2013-2014 academic year at VWCC.

Table 2. VWCC Spring 2013 Post-Assessment

1) The water flowing in the Roanoke River ultimately drains into *Atlantic Ocean(8/12)*
2) The water flowing at the LEWAS Site (Blacksburg) ultimately drains into the *Gulf of Mexico (10/12)*
3) How did this system help you learn the effects of man-made activities on water quality and quantity in a watershed? *"The man-made activities made real, measureable differences in the water quality in our watershed. These differences can have a huge effect on organism survival."**
4) How did this system help educate you about sustainable development? (Sustainable development is defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs *"I learned there are many ways that have been developed to lower the amount of runoff in urban areas."**
5) What difficulties did you experience in your two week assignment to monitor the water quantity, quality and weather parameters? *Scheduling (6), Weather (2), Lack of Understanding (1), None (3)*
6) How were these difficulties different from the difficulties that you expected to experience when you began the assignment?
7) How can this system be used to educate the public (who don’t have your hands-on experience) about sustainable development? *"Show how our actions really do impact the ecosystem around us."**
8) In your own words, contrast how water flow and quality are monitored at the LEWAS site in Blacksburg and at your field site in Roanoke. *"LEWAS: high resolution can be checked anywhere, has to estimate some chemical from electrical equipment. Roanoke: Requires people to collect samples very low resolution depending on manpower can do all chemical tests."**
9) What value, if any, do you see in real-time monitoring of water quantity and quality? *Better Data Quality (2), Effects of inputs (5), Public Awareness (1)*

*Example Response

Results and Future Work

Overall, analysis of assessment data from both courses indicates that students benefited from having access to a remote real-time watershed monitoring system. The majority of students had positive reviews about the overall experience of interacting with the LEWAS lab, with a few negative responses related to time management with group members. The LEWAS modules will continue to be improved upon and used in EGR 120 and EGR 124 courses at VWCC during the 2013 – 2014 academic year as well as in the hydrology class at the university in the spring of 2014.

An additional LEWAS-based tool called the Platform Independent Remote Monitoring System (PIRMS) will be implemented into the classroom modules beginning in the spring of 2014.

PIRMS has been under development since January 2013 and is an interactive watershed exploration tool that broadcasts live data from each field site through an engaging platform that encourages users to visually explore the LEWAS watershed. PIRMS is designed around strong theoretical and empirically based research which proposes that people are motivated to learn through remote laboratory environments. PIRMS promotes active learning through applications which connect the participants to the field site and motivate them to actively participate in learning activities focused on water sustainability.

The PIRMS uses an HTML5 driven web interface to deliver 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 as seen in Figure 5. The versatility of PIRMS across platforms makes it accessible to any potential user as long as they have internet access. PIRMS is an adaptable tool which can be used by educators, students, professionals, and the general public. The ease of use will expand LEWAS' reach beyond those directly involved in STEM fields to broaden participation and interest in water sustainability research. Moving forward, the PIRMS will be key to supporting classroom module development and educational integration in continuing LEWAS-based instruction. A companion paper at this conference provides details of the PIRMS including its current status of development[11].

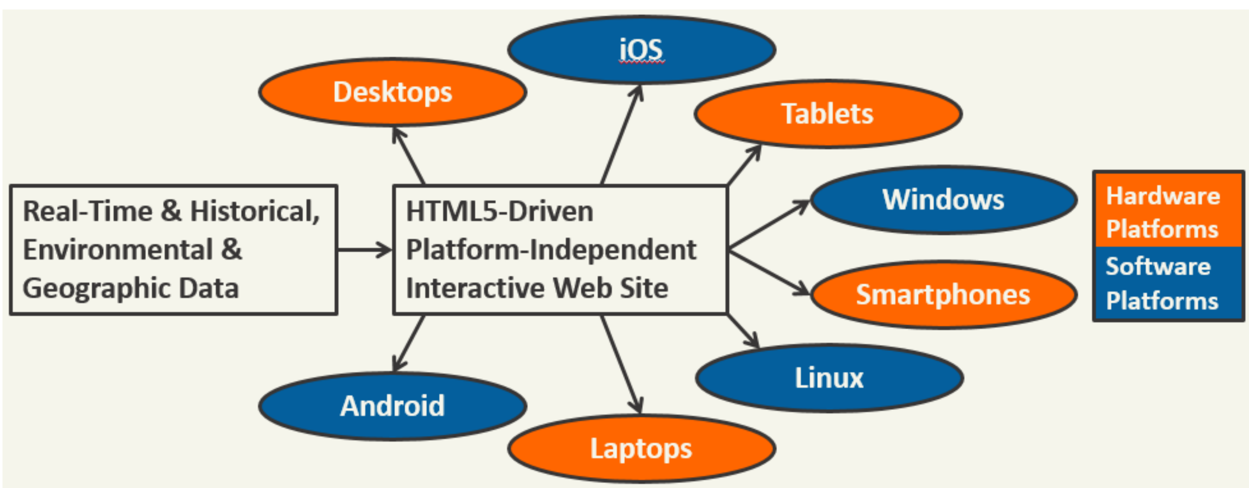

Figure 5. PIRMS Concept Diagram

The LEWAS modules have proven the usefulness of a remote real-time watershed monitoring lab in water sustainability education across several levels of higher learning. Multiple courses throughout various disciplines and levels of education have used the LEWAS system to support classroom goals and achieve desired outcomes. Preliminary results indicate that the LEWAS has positively impacted student learning and motivation through active learning and discovery based laboratory modules that encourage student exploration and understanding of water sustainability concepts. The educational outcomes from the LEWAS modules have formed the backbone for further research into student learning and the benefits of real-time watershed monitoring labs in K-12 and higher education. Future work will include design of an interactive virtual platform to view and explore watershed data as well as additional collaborations to bring classroom modules to more courses at VT, VWCC, and other schools and universities.

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