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Integration of a Real-Time Water and Weather Monitoring System into a Hydrology Course

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Integration of a Real-Time Water and Weather Monitoring System into a Hydrology Course

Abstract

This paper discusses the integration of a real-time 24/7 water and weather monitoring lab, LabVIEW Enabled Watershed Assessment System (LEWAS), into a senior level Hydrology course at Virginia Tech. The LEWAS uniquely integrates LabVIEW's data acquisition capability with the water and weather hardware to sense water and weather data in real-time from a local creek that flows through the campus of the university. The goal is to enhance student learning by incorporating LEWAS-based hands-on modules. Three learning modules were developed and implemented: (i) Storm Characteristics Module, (ii) Land Cover-Water Quality Correlation Module, and (iii) Watershed Wiki Module. Implementation details of the modules are discussed. The Wiki module was the most interesting LEWAS-based assignment which entailed assigning teams of students throughout the semester to visit the LEWAS outdoor site and write daily reports on the class Wiki about the unit's performance and the monitoring results. The groups acted as the watershed assessment team for an assigned week, preparing data tables and graphs for weather, flow, and water quality. Two of the most important advantages of the LEWAS are that it is monitoring the watershed in which the classroom is located, and that the data is web-accessible. Challenges encountered in implementing the LEWAS are discussed. Lastly, student perceptions are documented using pre-and post-test survey instruments. This work is supported under the NSF Transforming Undergraduate Education in STEM (TUES) Type I Program.

Introduction

As a part of an ongoing NSF/TUES Type I project, the LabVIEW Enabled Watershed Assessment System (LEWAS) is being integrated into a senior level Hydrology course at Virginia Tech as well as several engineering courses at a neighboring community college to enhance the hands-on components of student activities. The LEWAS has a development history spanning back several years[1-4] and has evolved a great deal from its early beginnings. The development of LEWAS was not explicitly undertaken for improvement of one particular course, but has evolved from a LabVIEW set of exercises into its present full-blown remote data collection lab that is being used for enhancing hands-on learning in a number of classes and water sustainability research[5-6].

Initially in 2007, LEWAS began as a set of LabVIEW (www.ni.com) programming exercises incorporated into the only common course (Engineering Exploration, EngE1024) for engineering undergraduates at the College of Engineering at Virginia Tech. In this course, one key learning objective is to develop and implement algorithms and demonstrate understanding of basic programming concepts. Positive feedback from students regarding LabVIEW instruction led to development of additional curriculum activities targeted at demonstrating real-world applications of LabVIEW. This included a data acquisition (DAQ) learning module and extension of this module to discuss water sustainability concepts by accessing real-time water data from an on-campus creek. Demonstrations of this lab have been presented to ~5,000 engineering freshmen since 2009[1]. Additional grants led to the creation of the LEWAS, and in a case study with 150 engineering freshmen in the spring 2012 semester, 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[5]. The LEWAS has also been used to engage undergraduate researchers in water sustainability studies in an NSF/REU Site program led by one of the authors[7]. It was this success that led to the NSF TUES grant and the motivation to incorporate the lab into a senior level hydrology course and several pre-engineering courses at a local community college. Additional details on development and application of the LEWAS into EngE1024 course are given in various prior publications[1-4].

There is a growing body of work in the field of water quality monitoring. A comparison of several real-time remote monitoring systems with LEWAS is given in Delgoshaei (2012)[5]. Hotaling et al (2012)[8] detail the design, construction, and deployment of water quality sensors to teach STEM principles. Glasgow et al (2004)[9] did a comprehensive review of real-time monitoring applications and sensors. Toran et al. (2001)[10] explored the design of a virtual instrument for water quality monitoring on the internet. Christensen et al (2002)[11] used real-time water-quality monitoring in Kansas streams for nutrients and bacteria. Based on extensive review of literature and one of the authors' discussion with NI experts, it is our belief that LEWAS is a unique LabVIEW-enabled system deployed to monitor water and weather in a real-time from a small urbanized watershed. An ongoing study at University of Northern Iowa is developing an outdoor data acquisition and transmission site for effective teaching of hydrology concepts but this system does not use the LabVIEW software[12].

The outdoor site of the LEWAS is located on a creek that flows through the campus of Virginia Tech. The watershed (~3 km^2) of this creek (see Figure 1) is fairly urbanized and the creek has been declared impaired for not meeting established water quality standards. Rapid urbanization of this watershed and associated water quality problems provide excellent opportunities for demonstrating use of the latest sensor and computing technologies, embedded into the LEWAS, for promoting water research and education. Figure 1 also shows a flooding scenario at the LEWAS site in the summer of 2012. This is the only real-time data monitoring system on the campus.

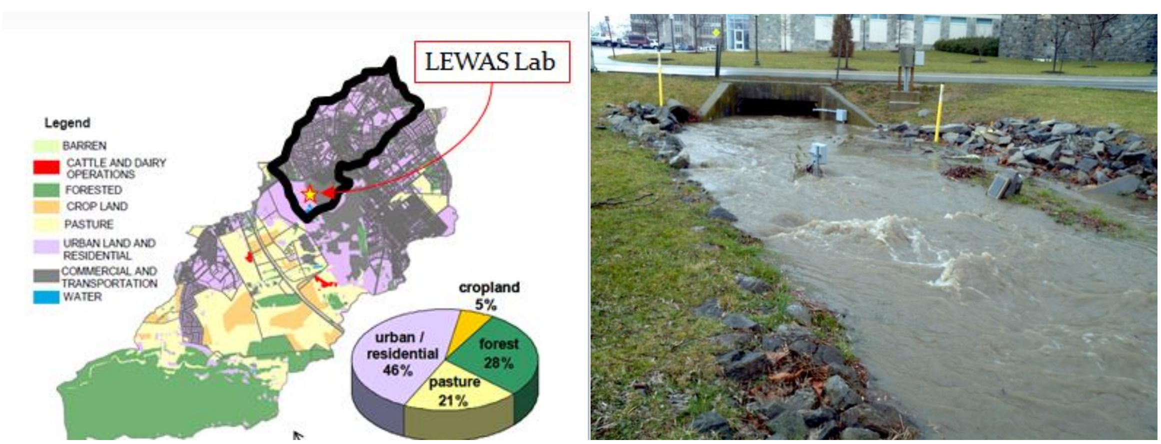


Figure 1: Location of LEWAS outdoor site and a flooding scenario at LEWAS site in summer 2012

The LEWAS uniquely integrates LabVIEW's data acquisition capability with the water and weather hardware. Specifically, LEWAS includes a Hydrolab (water quality sonde) which collects water quality data, a Flow Meter (acoustic doppler type), which measures flow and stage of the stream, and a weather station which collects weather data. This solar powered system is designed to sense the temperature, conductivity, turbidity, dissolved oxygen, and pH of water and weather data 24/7 in time intervals as short as 2 minutes. An embedded computer, cRio, is installed for data processing, communication, and data storage at the LEWAS outdoor site. The data is shared with remote clients via a Wireless LAN.

Data Relevance - A Case Study

One critical point to emphasize to students in all of the classes that are now using LEWAS as part of their learning environment is how relevant and important the data can be. Stormwater quality is an increasing concern for surface water health. The EPA's Stormwater Program governs Municipal Separate Storm Sewer Systems (MS4) across the country and requires reconnaissance of permitted outfalls, including water quality testing. Real-time monitoring is not required, but can detect aberrations in normal water quality parameters. The case study described below is a prime example of the utility of a real-time web-accessible sensor system. The study is used when introducing the LEWAS to students in classes.

On June 26th, 2012, at approximately 4:30 pm, a water main broke at a location upstream of the LEWAS site. By 9:00 pm, the water spill was contained, but approximately 760 m^3 of drinking water was spilled into the watershed monitored by the LEWAS during the 4.5 hour-long water main break. The images in Figure 2 show the flow conditions at the LEWAS site during normal flow and during the water main break. This event impacted the quality of water in the creek for a few hours and a large number of fish died as a result. Most of the water quality parameters returned to their normal levels within 24 hrs. As seen in Figure 3, at about 3 hours after the water main break, turbidity increased to 300 NTU from a pre-break level of 1-2 NTU. Also, within 24 hrs, the turbidity value returned to its normal base flow range (between 0 and 3 NTU).

Figure 2: LEWAS Site during normal flow and during the water main break

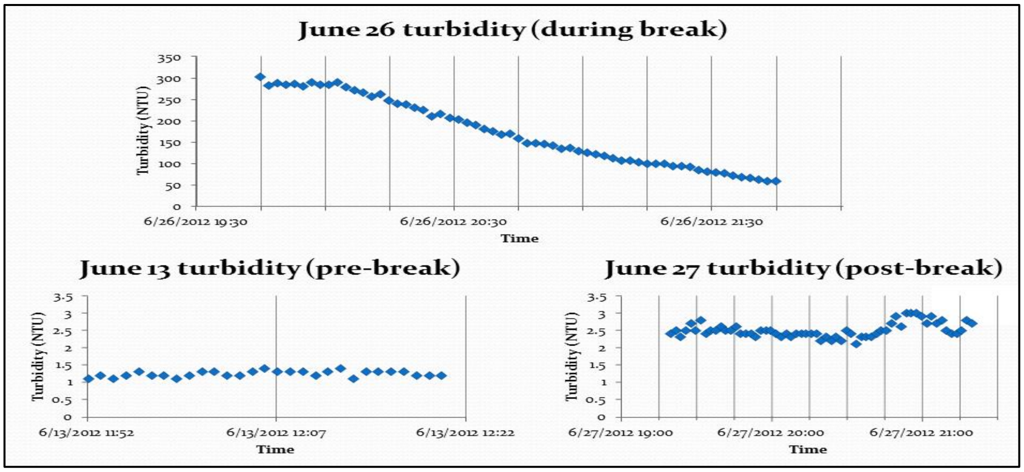


Figure 3: Effect of the broken water main on turbidity measured every 3 min.

Figure 4: Fish kill from the turbidity event

Ecological Impacts: Dead fish were observed all over the creek downstream of the water main break point (Figure 4). After consulting with two experts (one in the Fishery Department and another from the Biological Sciences Department) the dead fish were identified as Blacknose Dace and two possible explanations were given for the fish kill, including the toxicity of the chlorine contained in the drinking water, or suffocation due to the high turbidity. It should be noted that while this event lasted only a few hours, continuous data from the LEWAS provided some reasonable explanation for the fish kill[7].

Integration of LEWAS into the Hydrology Course

Funding of the NSF/TUES program allowed the investigators to develop and implement plans to integrate the LEWAS into the hydrology course as well as two pre-engineering courses at a local community college. An introductory 1-day workshop was organized on August 2, 2012 for introducing the LEWAS to the instructors of these courses. Presentations at the workshop covered design of the LEWAS, procedures adopted to calibrate water and weather hardware, and examples of various applications such as the case study discussed above. Outlines of the LEWAS-based learning modules were developed for the target courses.

The first course to integrate these modules was a Hydrology course during the Fall 2012 semester. Hydrology is an elective course for senior or 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 fundamental concepts in the hydrologic cycle with accompanying computational methods. The topics include basic issues and mechanisms of precipitation, infiltration, evapotranspiration, runoff, and subsurface flow. Special emphasis is placed on surface runoff quantity generation, including flood routing and forecasting and urban hydrology issues. Altering of specific course objectives was not done for the purpose of accommodating the unique learning opportunities that the LEWAS creates. Modifying objectives is an involved process involving the departmental curriculum committee. However, the "Use streamflow and precipitation data from the internet" objective is clearly handled by the lab. Future course objective modification may be considered based on the modules described below that were successfully incorporated into the course.

LEWAS Based Hydrology Modules: During the Hydrology course, a presentation was given at the beginning of the semester to introduce the LEWAS and its components, the watershed and outlet, and the purpose of monitoring the stream. Two of the most important advantages of the LEWAS are that the data is collected real-time, and that the data is web-accessible. Also, it is interesting that the LEWAS is monitoring the watershed in which the classroom is located. The goal of integrating the LEWAS into the course was to enhance student learning by incorporating LEWAS-based hands-on modules as the students were learning related hydrologic topics. Three learning modules were developed and implemented. A brief description of the module and its implementation is included below.

(i) *Storm Characteristics Module:* Students were provided rainfall gage and streamflow data from a particular recorded storm at the LEWAS site. The data were used to discuss the rainfall-runoff relationship in a small urbanized watershed. They were asked to plot both a hyetograph and a hydrograph of the data. Next, they subtracted the baseflow of the stream and calculated the direct runoff from the storm. By dividing the direct runoff by the total amount of rainfall that fell during the storm, the students then could calculate the runoff coefficient of the watershed, basically the amount of rainfall that did not infiltrate into the ground, evaporate, or become intercepted by vegetation. As this ratio, or runoff coefficient, is directly related to the type of land cover and development of the watershed, students could verify the soundness of their estimates.

(ii) *Land Cover-Peak Flow-Water Quality Correlation Module:* The LEWAS' capability allows us to teach students about the relationship between land cover, peak flow rate and water quality based on the constituents being measured. Detailed digitized land cover and storm quantity and quality data were analyzed to show how peak flow rates, water quality, and land cover are related. While learning about hydrologic methods to estimate peak flow rates, students 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. They were asked to comment on the types of possible errors and uncertainty that may arise when using these types of coefficients. In addition, students were asked to discuss the impact of the watershed land cover percentages on the water quality parameters being collected, such as dissolved oxygen, specific conductivity, pH, turbidity, and temperature.

(iii) *Watershed Wiki Module:* The LEWAS was employed to motivate students about the importance of monitoring our sustainable resources. The assignment entailed assigning teams of students throughout the semester to visit the outlet monitoring site, and write daily reports on the class Wiki about the unit's performance as well as the monitoring results. The groups acted as the watershed assessment team for the assigned week, preparing data tables and graphs for weather, flow, and water quality. During their week, the students took photos and reported on the weather and water conditions using a class wiki website. They analyzed the data for their particular week in a report, and prepared a report containing data tables and graphs for weather, flow, and water quality. Figure 5 is an example of the types of plots included in the student reports, but many other types of plots were included as well, depicting other water quality parameters and flow rate. They did background research on the normal values of the water quality parameters and cited any notable differences or events and discussed possible reasons for these results. The assignment stressed the difference between simply collecting data and using the data to derive knowledge. Figure 6 shows a screen capture from the Hydrology class wiki from the Fall 2012 semester. The actual wiki can be viewed at https://blogs.lt.vt.edu/cee4304f2012.

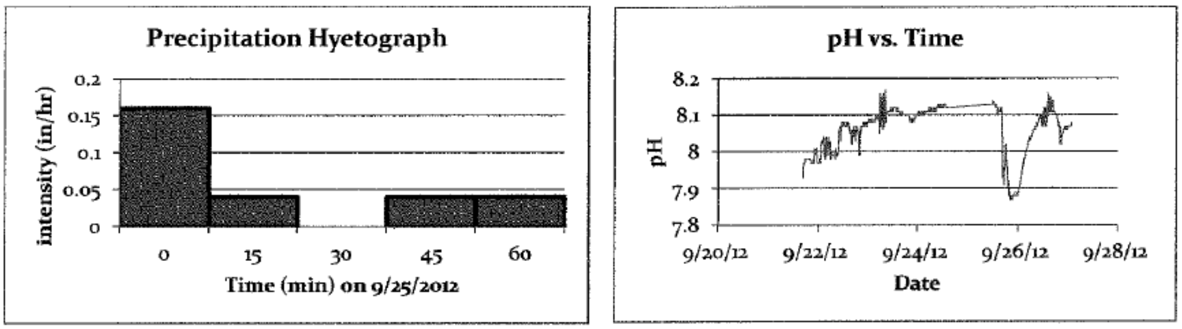
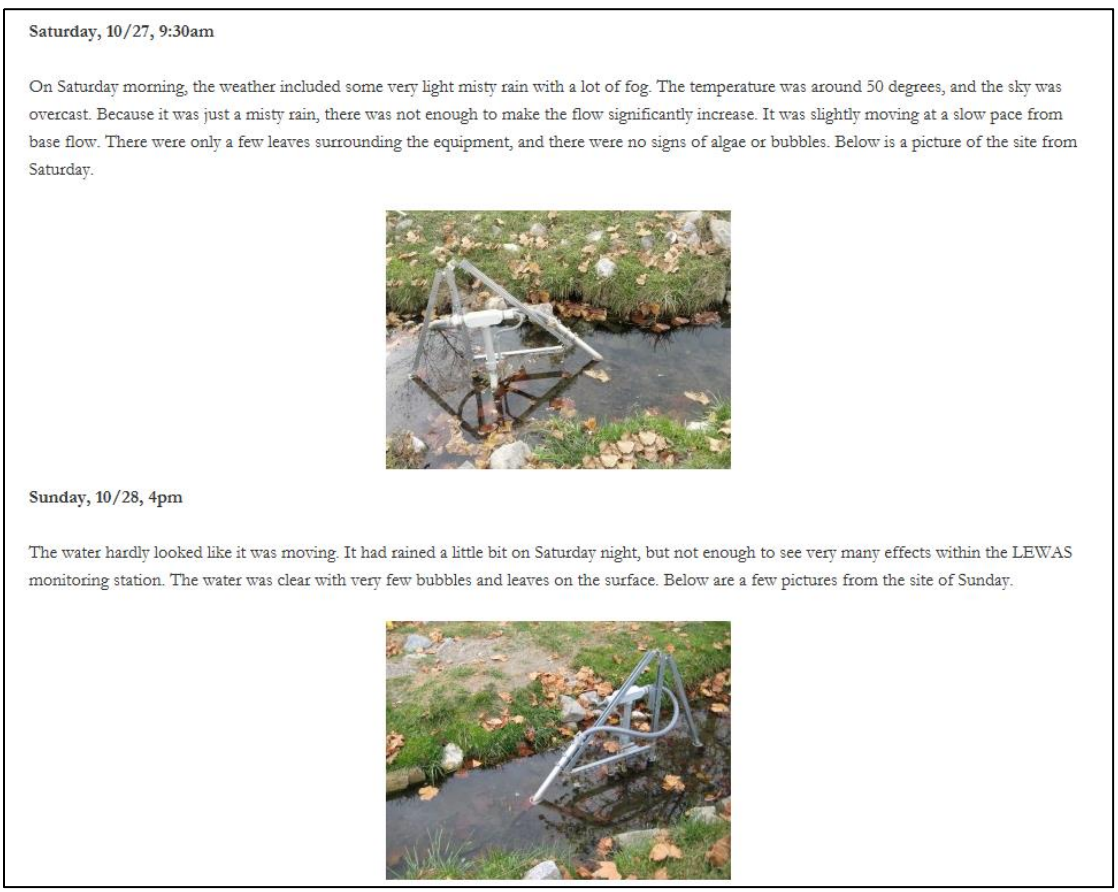


Figure 5: Hydrology class sample graphs



Saturday, 10/27, 9:30am

On Saturday morning, the weather included some very light misty rain with a lot of fog. The temperature was around 50 degrees, and the sky was overcast. Because it was just a misty rain, there was not enough to make the flow significantly increase. It was slightly moving at a slow pace from base flow. There were only a few leaves surrounding the equipment, and there were no signs of algae or bubbles. Below is a picture of the site from Saturday.

Sunday, 10/28, 4pm

The water hardly looked like it was moving. It had rained a little bit on Saturday night, but not enough to see very many effects within the LEWAS monitoring station. The water was clear with very few bubbles and leaves on the surface. Below are a few pictures from the site of Sunday.

Figure 6: Hydrology class wiki screen capture

At the end of the semester, students were asked to compile a report on the 8 weeks of group observation of the LEWAS site and the data collected during this time. They analyzed the data over this period and made recommendations on the operations of the unit, such as regular cleaning and calibration of the Flow Meter and inspection and cleaning of the Hydrolab shown in Figure 6 which seemed to catch debris easily. By inspecting the data, students were able to report a suspicious incident of water quality change during the semester. Figure 7 shows an 8-week plot from a student report of the dissolved oxygen in the stream, indicating the overall rise in DO as the temperatures decreased during the fall semester.

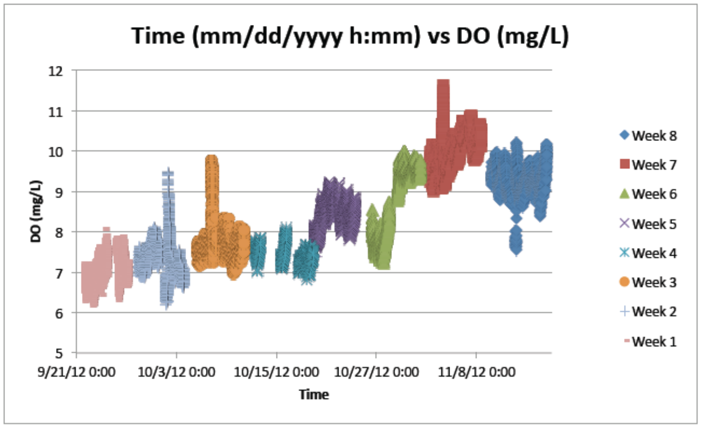


Figure 7: 8-week Dissolved Oxygen plot from a student report

Of the three modules developed and implemented during the Fall 2012 Hydrology course, the wiki exercise seemed to be the most successful as it took the students out into the field to visit the LEWAS equipment and underscored the importance of monitoring our sustainable resources.

Challenges in Operation of the LEWAS

Although the system was partially operational in July 2012 (Figure 8), failure of a key component caused several challenges in the Fall of 2012. As of July, the solar charging system was powering the cRio and all three measurement instruments (i.e., flow meter, water quality sonde, and weather station). At that time, the weather station was being operated via the cRio, while data collection for the sonde and flow meter was being accomplished via each instrument's internal storage. These data were processed in MATLAB and stored in a text file and/or MS Excel formats. However, by late August, intermittent power failures were observed several times at night. Since a large portion of the semester was required to determine that the cause of the power failures was deterioration of one of the system batteries, a temporary data collection protocol was implemented to obtain data for use in this course. The temporary data collection system required that 12V batteries be charged in the lab and transported to the field site twice a week in order to power the sonde and flow meter. The weather station data could not be recorded without the 24V supply required to run the cRio, and the temporary batteries were not sufficiently powerful to run the cRio on the twice a week cycle. Instead, students used weather data from other weather stations in the vicinity of the field site (but not within our watershed). The sonde and flow meter data were processed in MATLAB and provided to the students in the Hydrology course in MS Excel format once each week. In addition to the battery failure, the sonde began to fail intermittently late in the second half of the semester. This resulted in the frequent loss of one or two days' worth of data every week. At the time of this writing, the sonde has been sent for repair and new deep cycle system batteries have been ordered.

Ultimately, data from all three sensors will be processed through the cRio for web publishing and data storage and distribution (Figure 9).

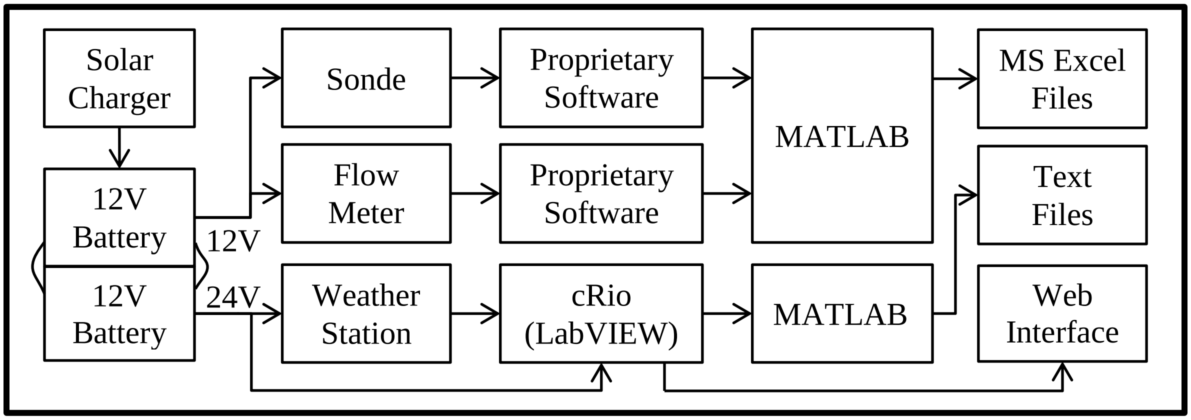


Figure 8. Partially operational LEWAS data flow diagram in July 2012

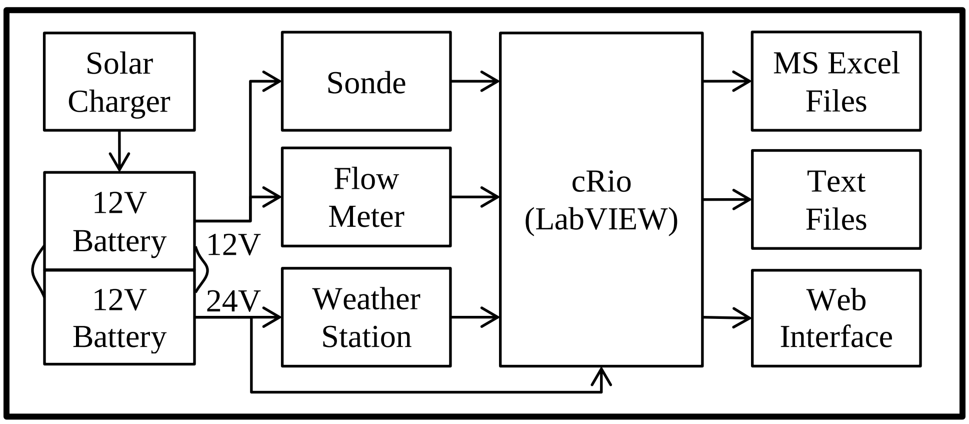


Figure 9. Fully operational LEWAS data flow diagram

Assessment of Instruction

Students were given an assessment questionnaire early in the semester (pretest) following the introduction to the LEWAS and another questionnaire following completion of the LEWAS-based Hydrology modules (posttest). The pretest and posttest questions are shown in Tables 1 & 2, respectively, with student responses to selected questions. Twenty seven students completed the pretest and twenty six students completed the posttest. Student responses to several of the questions were categorized by theme. For the small number of occurrences when a student response addressed multiple themes, the theme addressed first was designated the primary theme of the student response. A summary of the results follows.

- Concerning the means by which the LEWAS helped students learn hydrologic concepts (pretest and posttest question 1), twenty three students in both the pretest and posttest indicated that the use of data from an actual hydrologic system would help/helped them learn these concepts. Although the majority of students indicated that the LEWAS was beneficial in helping them learn these concepts, three students indicated in the posttest that the LEWAS was not very useful for their learning. The common theme of these three students was a lack of rain events during the weeks that they observed the system.

- The primary difficulties expected by the students in the pretest (question 3) were not understanding what was measured (10 students) and having to make observations in bad weather (7). However, in the posttest (question 3), these were noted by two and no students, respectively. Rather, scheduling (5) was the most common difficulty expressed by students in the posttest.
- Although the lack of live data was listed as an expected difficulty in the pretest by three students, and the live data website was offline for most of the semester due to the system battery failure, only one student listed the lack of live data in the posttest as a source of difficulty. Perhaps the most interesting source of difficulty was provided by three students who found it difficult to visually assess the creek's water quantity and quality for comparison with the LEWAS data.
- Overall, at the completion of the modules (posttest question 7), the students found real-time monitoring of water quantity and quality to be valuable for monitoring the effects of system inputs (16), system modeling (4) and providing educational data (4). Likewise, concerning the use of a similar system in a hydrology course of their own design (question 8), nine students indicated that they would use a similar implementation and fourteen students indicated that they would expand the use of a similar lab in their own course. Among these fourteen, six students would increase the frequency of its use in the course, five students would increase the number of course topics it was applied to, and three students would increase the number of field sites/sensor types. The single student who would not use a similar lab in his/her hydrology course noted that the system was not very useful for learning if there were no rain events.

1)	How can this system help you learn hydrologic concepts? *Response themes: real-world data (23), monitoring watershed events (3), blank (1)*
2)	How can this system help educate you about sustainable development?
3)	What difficulties can you anticipate in your one week assignment to monitor the water quantity, quality and weather parameters? *Response themes: not understanding what was measured (10), bad weather (7), lack of live data (3), unknown source of variations (2), availability for field visits (2), lack of rain (2), blank (1)*
4)	How can this system be used for advancing research questions relevant to hydrology?

Table 1. Pretest questions with response themes and frequencies in italics

1)	How did this system help you learn hydrologic concepts? *Response themes: real-world data (23), not very useful/lack of rain (3)*
2)	How did this system help educate you about sustainable development?
3)	What difficulties did you experience in your one week assignment to monitor the water quantity, quality and weather parameters? *Response themes: availability for field visits (5), unknown source of variations (4), none really (4), lack of rain (3), visual assessment (3), errors from debris/trash (2), not understanding what was measured (2), lack of live data (1), crossing the street (1), blank (1)*
4)	How were these difficulties different from the difficulties that you expected to experience when you began the course?
5)	How can this system be used for advancing research questions relevant to hydrology?
6)	In your own words, describe how water flow and quality are monitored.
7)	What value, if any, do you see in real-time monitoring of water quantity and quality? *Response themes: monitoring effects of inputs (16), system modeling (4), real-world data in class (4), blank (2)*
8)	If you were designing a hydrology course, in what way(s), if any, would you incorporate a system similar to LEWAS into the course? Why? *Response themes: similar using real/hands-on data (9), similar but increase frequency of use in course (6), similar but expand number of topics used for (5), similar but add field sites/sensors (3), would not use/need rain events for it to be useful (1), blank (2)*

Table 2. Posttest questions with response themes and frequencies in italics

Summary and Future Work

A real-time water and weather monitoring system, the LEWAS, has been implemented on the campus of Virginia Tech. This unique system is serving as an excellent demonstration site to show integration of water and weather monitoring hardware and LabVIEW software for water sustainability research and education. The learning modules implemented into the Hydrology course will be modified based on the feedback received from the students. 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 posttest would expand the use of a similar lab in hydrology courses they were teaching. These concerns and recommendations can partially be addressed by reorganizing the scheduling of student field site visits. From an assessment standpoint, the pretest and posttest question responses did not clearly distinguish whether it was the real system data or the real-time availability of the data that students found to be beneficial. Future assessments will be designed to distinguish between these categories. In the spring 2013 semester, the LEWAS will be integrated into two engineering/technology courses at a neighboring community college. Work is continuing in the LEWAS lab to establish standards to calibrate the water and weather hardware deployed in real-time monitoring. Also, research is ongoing to develop procedures for the LEWAS data access and visualization on mobile devices and in platform independent Web browsers for water sustainability education.

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