Investigating the Response of a Small Urbanized Watershed to Acute Toxicity Events via Analysis of High-frequency Environmental Data

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ABSTRACT
This study, conducted over 10 weeks by an undergraduate student in an NSF REU (U.S. National Science Foundation Research Experiences for Undergraduates) program under mentorship of the co-authors, investigates responses of a small urban watershed, located in Blacksburg, Virginia, to acute toxicity events. High-frequency water and weather data were collected using monitoring equipment maintained by the Learning Enhanced Watershed Assessment System (LEWAS) lab, including a weather station, rain gauge, water quality sonde, and an Acoustic Doppler Current Profiler. The location and attributes of local stormwater catchments were surveyed and recorded using GIS software to determine the overall contributing area of the LEWAS lab watershed. This fieldwork resulted in the construction of an accurate stormwater network map, which in turn allowed the identification of sources of sedimentation and other pollution from runoff events. A case study presents the response of the watershed to a winter storm event that resulted in acute chloride toxicity from runoff containing road salts.

KEYWORDS
Water; Stormwater, Urban Watersheds; Watershed Responses; Acute Toxicity; High-frequency Data; Data Analysis; Data Collection; Environmental Monitoring; Flow Measurements; Hydrologic Data.

INTRODUCTION

Stroubles Creek flows approximately nine miles from Blacksburg, Virginia to the New River, and is classified as a second-order stream within the New River Watershed. Since the establishment of communities in the region beginning in 1740, the riparian health of the Stroubles Creek Watershed has fluctuated dramatically.[1] The major land use changes that have occurred as a result of settlement over the past 270 years have impacted the watershed's capacity to endure the ecological consequences of human activity. The Stroubles Creek Watershed has a history of impairment, as defined by the U.S. Environmental Protection Agency (EPA). In 1996, Stroubles Creek was found to be benthically impaired, and TMDL studies in 2003 revealed that sedimentation was a major cause of these impairments.[2, 3] In the past decade, restoration efforts have been implemented to help restore the riparian health of the Stroubles Creek Watershed. **Figure 1** illustrates the location of the watershed including the land use distribution and impaired reach of Stroubles Creek.

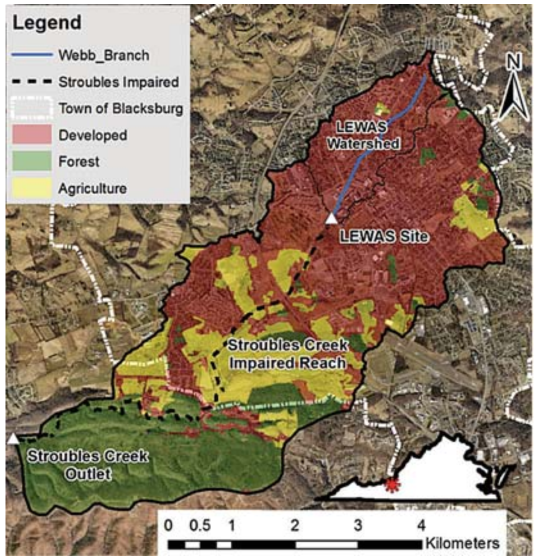

Figure 1. Stroubles Creek watershed land use and LEWAS lab location.

The Learning Enhanced Watershed Assessment System (LEWAS) lab is located on the Virginia Tech (VT) campus in the Webb Branch tributary (2.78 km^2) of Stroubles Creek (25 km^2). The watershed is highly urbanized and subject to flash flood events and urban stormwater pollutants. The lab operates multiple in-situ water and weather monitoring sensors for the purpose of water sustainability research, education, and public outreach. These sensors collect flow, water quality, and weather parameters in high-frequency temporal intervals (0.1 – 3 min) which allow the site to capture ephemeral responses of the watershed to flash events. The LEWAS lab aims to utilize high-frequency data collected in real-time to gain insight into the acute responses of a small urbanized watershed.

The flow and water quality at the LEWAS site is highly sensitive to the impacts of urban disturbances and pollutants. The watershed has been heavily developed over time (with approximately 30% of the watershed covered with impervious surfaces) and is prone to channeling large amounts of runoff during precipitation events due to the large area of impermeable surfaces. This runoff can also increase the amount of sediment that is displaced, resulting in erosion and excess sediment deposition. In addition, the runoff introduces pollutants into the aquatic system in the form of chemical compounds, trash, and debris. The type of pollutants present in the runoff is dependent upon climatological, physical, and spatial characteristics of the watershed. For instance, many studies suggest that deicing salts administered in urban areas prone to freezing temperature pose a threat to water quality in terms of chloride toxicity.[4,5] More rural agricultural communities, such as those closer to the outlet of the Stroubles Creek watershed, may have other factors that might be of concern such as pesticides and fertilizers, which can contain high levels of nutrients, such as nitrates and phosphates. In excess, these compounds can cause eutrophication and can impair the ecosystem. Stroubles Creek's history of impairment and the increased urbanization in Blacksburg makes water quality and quantity monitoring an important tool for understanding causes of impairment.

The LEWAS lab hosts a National Science Foundation Research Experiences for Undergraduates (NSF/REU) Site on Interdisciplinary Water Sciences and Engineering. The goal of this site is to engage qualified undergraduate researchers drawn from various academic institutions into a 10-week interdisciplinary research project in water sciences and engineering. Faculty and graduate students from various departments including Engineering Education, Civil & Environmental Engineering, Biology, Geosciences, Crop & Soil Environmental Sciences, and Industrial Design mentor undergraduate researchers. To date, 66 researchers (39 women and 27 men) representing 50+ institutions have graduated from this Site. This study was conducted by one of the REU students from the University of Idaho (lead author) over the summer of 2013. In order to achieve the goal of the study four objectives were established: 1) understand how a real-time, high-frequency monitoring system functions and how to address malfunctions of the components involved in order to maintain a functional monitoring system; 2) investigate sources and travel paths of sedimentation from flash runoff events; 3) delineate a stormwater network map of the Webb Branch watershed to verify the watershed network and area; and 4) investigate how deicing salts are transported through stormwater runoff to the field site and the impact this has on the water quality.

2. LEWAS FIELD SITE

The outdoor site of the LEWAS Lab was chosen due to the location on VT campus and the environmental significance of the creek. This site monitors one of two major inflows to a campus retention facility known as the "Duck Pond," which contains drainage from portions of the town of Blacksburg and VT campus. Over 95% of the land cover in the watershed is urbanized and thus covered with impermeable surfaces that slope (6.5%) towards the watershed outlet at the LEWAS site. The urban runoff from the watershed flows through a four foot box culvert to a natural run of the stream where the LEWAS sensors are located and on into the Duck Pond. Consequentially, the water quality at this location is indicative of not only how anthropogenic activity impacts water quality entering the Duck Pond, but also of the watershed's functionality during flood events.

Water and weather parameters are measured and recorded by multiple in-situ sensors at the outdoor location of the LEWAS lab. The in-situ sensors include a Sontek Argonaut-SW Acoustic Doppler Current Profiler (ADCP) that is mounted on the streambed and measures stage and velocity every minute. Meteorological conditions at the site are recorded with Vaisala Weather Station equipped with sensors capable of measuring air temperature, pressure, and relative humidity every one minute, wind speed and direction every five seconds, and precipitation instantaneously using a piezoelectric sensor that detects the impact of individual raindrops. Water quality parameters including temperature, pH, turbidity, specific conductance, dissolved oxygen, oxidation reduction potential, percentage of saturated dissolved oxygen and total dissolved solids are measured with a Hach MS5 Hydrolab Sonde and collected every three minutes. A tipping-bucket rain gauge has also been installed at the site to verify and calibrate precipitation readings from the weather station. An ultrasonic transducer has been installed to provide an additional flow measurement through stage readings behind a weir located in the culvert upstream of the site. A diagram of the physical layout of the field site is illustrated in **Figure 2**.

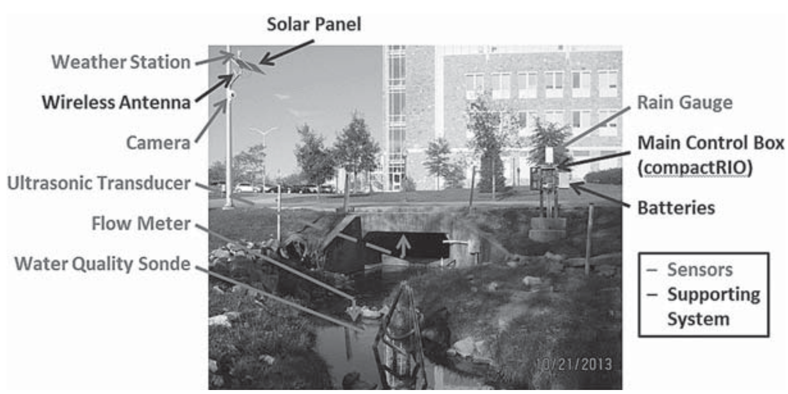

Figure 2. LEWAS lab field site on Stroubles Creek.

Data from the sensors is collected using an embedded computer located in the main control box that runs LabVIEW software and transmits data through the campus wireless network to a database where it is accessed through a live data viewing website (http://www.lewas.centers.vt.edu/dataviewer)[6]. Through the website, the LEWAS lab provides public access to environmental data captured by the sensors in order to increase educational outreach and public awareness of the impact that urbanization has on a local watershed. In fact, as part of the educational outreach of the lab data from the sensors has been used to improve student learning in multiple courses at VT and Virginia Western Community College (VWCC).[7, 8]

3. RESEARCH METHODS

3.1 Maintenance & Calibration

The mechanics of a real-time, high-frequency monitoring system and the complications associated with environmental sensors are two fundamental components of a continuous hydrology lab. Accurate and valid data are only generated by sensors that are in good physical condition and that have undergone meticulous calibration. Routine maintenance tasks (physical cleaning, calibration, electrical rewiring, professional repairs, etc.) are fundamental to a functioning lab. Sustaining an operational monitoring system is a primary research objective in itself, for the collection and quality of any subsequent data is dependent upon the sensors' condition.

Due to the high volume of water that flows past the LEWAS site during significant precipitation events **(Figure 3)**, frequent sonde and ADCP sensor maintenance and occasional repairs have to be performed. These repairs must be completed as efficiently as possible to reduce the amount of time that the site is unmonitored. Routine calibrations require the sensors to be removed from the stream, cleaned in a laboratory environment, and reset with standard solutions for each parameter at approximately three-week intervals. The frequency of calibration is partly determined by the drift in measurements that have been observed since the previous procedure; if an increased margin of error is noted, then calibrations will be performed more frequently.

During high flow events, debris in a variety of mediums (substantial rocks, urban garbage, vegetation, etc.) that has been channeled through the stormwater network arrives at the site and can potentially collide into the ADCP and sonde **(Figure 3)**. This can cause erroneous measurements and sensor damage and disturb the riparian ecosystem by damaging existing habitat and increasing turbidity and other pollutants. Debris that accumulates around or within the sensors must be manually removed to maintain accurate data.

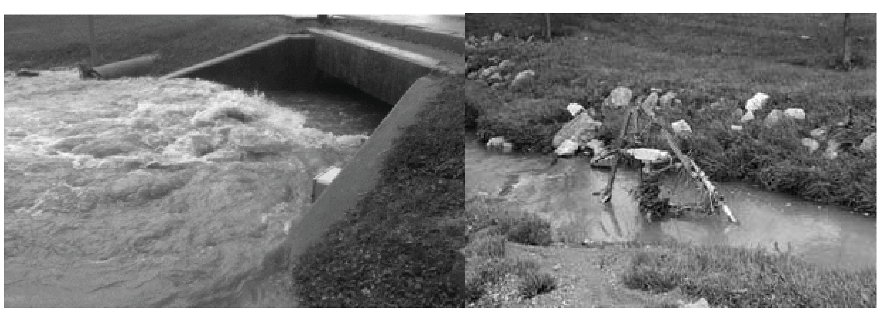

Figure 3. Flooding from rain event at LEWAS field site & Hach MS5 Hydrolab water quality sonde covered in Debris; Sedimentation deposits on south stream bank.

The following example describes how damage to a sensor results in repair, redeployment, and calibration efforts. In July 2013, the ADCP underwent a series of repairs following severe rain events to address internal electrical damage. The issue became apparent when measurements were not being recorded by the instrument, and it was deduced that the connection between the conduit and the instrument had been exposed to water for a prolonged period of time. This caused water to leak into the instrument, and the pins of the male connector to become corroded **(Figure 4)**. The lack of a functional water-tight seal could have resulted from a number of situations including the accumulation of biofilm around the port preventing a flush seal, debris during storm events impacting the port and breaking the seal, or improper insertion of the cord resulting in a leak.

Figure 4. ADCP flow-meter with corroded biofilm accumulation and corroded conduit pins.

To repair the ADCP, it was removed from the streambed and the build-up of biofilm was removed with a poly-fiber brush. Electrically-conducting silicone spray was deposited into the female ports of the ADCP to create a water-tight seal. The damaged conduit wire containing the connector was spliced together with a replacement cord to achieve the necessary length using a soldering connection. The connector was then inserted into the ports of the instrument.

After the ADCP was returned to the streambed, the stage-area rating of the cross section was calibrated by conducting a new cross-section survey. The streambed is composed of cobbles and pebbles with alluvia-floodplain deposits of stratified unconsolidated silt, clay, and sand with lenses[1]. During a storm event, a stream's cross section can sometimes be altered dramatically due to erosion and sedimentation caused by the high volume and velocity of water passing through. The ADCP estimates flow based on the index velocity method[9] which takes the velocity and stage readings measured by the device and applies them to index-velocity and stage-area ratings respectively. If the cross section of the stream changes due to sedimentation or erosion it will affect the stage-area rating and subsequently the volume of water estimated by the ADCP. A cross-sectional profile survey was performed at the site in two locations (at the ADCP and the calibration cross section) to generate the new cross section of the stream. The cross-sectional profiles were recorded using a Leica Total Station and were imported into Microsoft Excel to generate a new graphic cross section of the stream. **Figure 5** represents the changes to the cross sectional profile of the stream during three separate surveys during the spring of 2012, spring of 2013, and summer of 2013. The surveys are aligned by a benchmark located along the left bank with the vertical datum representing the point of lowest elevation.

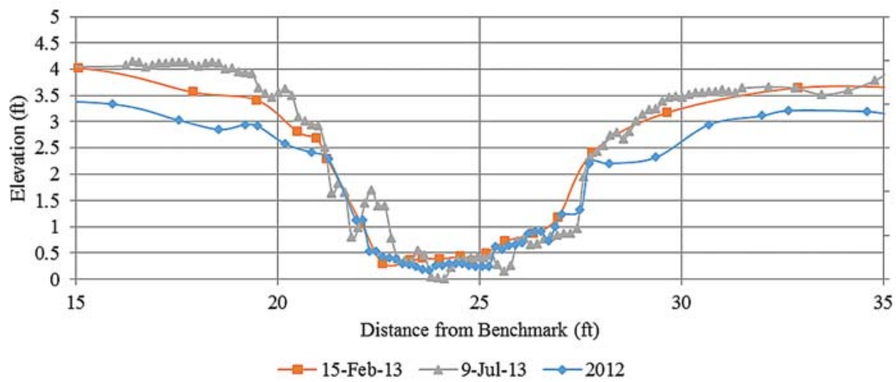

Figure 5. Seasonal comparisons of cross sections of Stroubles Creek.

A Sontek FlowTracker Handheld acoustic doppler velocimeter (ADV) point velocity instrument was used to validate the existing index velocity rating at the calibration cross section. The calibration cross section was chosen downstream of the ADCP cross section at a distance downstream of four to five times the width of the channel. The index velocity rating relates the mean velocity of the stream channel, computed through the ADV measurements, to the index velocity measured by the ADCP. Point velocities were recorded using the ADV along the stream cross section at various intervals to compute mean velocity. The mean velocity was then correlated with the index velocity measurement given by the ADCP to validate the existing index-velocity rating.

Maintaining an accurate index-velocity rating is important for valid velocity readings and water quantity computations, as well as for water quality concerns. The velocity in the stream is related to the size of sediment (and any debris or pollutant that it contains) that is physically able to be transported to the catchment location. Knowing the volume of water that is discharged from the LEWAS Lab field site allows projections to be made about the mass of sediment that is being deposited at the Duck Pond, and the mass (rather than concentration) of the measured pollutants passing the LEWAS field site.

3.2 Sedimentation

After ensuring accurate and reliable data from the environmental sensors, an investigation was conducted into the sources of pollutants captured by the sensors. The first pollutant of interest was the large amounts of sediment that are transported through the site during storm events. Substantial sediment deposition that occurs during high flow events at the field site has a negative impact on data accuracy, water quality, and riparian health. The impact of sedimentation on the water quality at the site is indirectly measured through turbidity and total dissolved solids (TDS) measurements collected by the sonde. Turbidity and TDS measure the optical determination of water clarity and the amount of material dissolved in water respectively, and may not be a good indicator of sediment transport is the sediment is coarse. High flow events that increase sedimentation repeatedly resulted in sensors of the sonde getting clogged with a combination of both large rocks and clay-like material and algae, resulting in inaccurate data. To clear the openings of the sensors, a plastic handled dish brush and cotton swabs were used to scrub off the sediment and biofilm after storm events.

An example of the sedimentation at the site is shown in **Figure 6** which illustrates the sediment deposition that accumulated in a culvert located 10 meters upstream of the LEWAS in-stream sensors. The mounds of sediment shown in the figure demonstrate the amount of sediment that is routinely transported through the stormwater network and eventually into the Duck Pond. The Duck Pond has had a history of poor water quality, much of which is attributed to sediment. The pond functions as a large-scale stormwater catchment and was dredged three times in 1950, 1960, and 1986 because of detrimental sediment deposition.[1]

Figure 5. Sedimentation deposits in culvert and weir (looking upstream).

To investigate the sources of sedimentation from flash events that deposit large amounts of sediment near the site, a physical watershed investigation was conducted. Possible sources of sedimentation were documented through geo-tagged pictures during a summer storm event. Pictures captured various sources of sedimentation as well as travel paths of the sediment, such as small streams and stormwater inlets that were visibly transporting and storing sediment during the run-off period. These pictures were uploaded and georeferenced using GIS software to document the most likely sources of sedimentation **(Figure 7)**. This information was combined with stormwater network data described in **section 3.3** to determine leading sources of sedimentation.

Figure 6. Sedimentation survey map.

3.3 Stormwater Network Map

To determine the path that sources of pollutants such as sediment take to get to the LEWAS site, a stormwater network survey was conducted in a portion of the McBryde neighborhood, a residential area just north of the Virginia Tech Campus and part of the contributing watershed. A map of the stormwater catchments and pipes for this portion of Blacksburg did not exist prior to this survey;

however, much of the stormwater network for the LEWAS watershed had already been completed prior to June 2013. Understanding the stormwater network in this region is necessary to determine whether (and if so, how) runoff from the neighborhood reaches the field site. An understanding of the network will allow the routes of sediment loads and other pollutants to be understood, which is useful in eventually developing models that can predict pollutant loads for simulated events.

To begin constructing a stormwater network map, a geographic information system was used to locate catchments in the McBryde neighborhood that were incomplete and needed surveying. A marker was placed at each stormwater infrastructure feature, such as an inlet or outfall, to generate a fieldwork map of the locations to visit in person. While at each stormwater feature, measurements of its attributes (pipe material, diameter, shape, azimuth, depth, type of structure, etc.) were recorded into a handheld ArcPad device and pictures of the stormwater structures were taken with a GPS camera. The catchment locations and corresponding attributes stored on the handheld ArcPad were imported to ArcMap. Custom python scripts were executed within ArcMAP to create a connected stormwater network from the point shapefile imported from the ArcPad[10]. This created a completed stormwater network that allows investigators to connect the travel path of pollutants captured by the LEWAS sensors to their sources.

3.4 Acute Chloride Toxicity

The previous research methods allow the LEWAS site to effectively analyze events in the watershed that are captured by the LEWAS environmental sensors. The following case study illustrates how the LEWAS watershed responds to an acute chloride toxicity event from a spring storm occurring over a two day period. Blacksburg experienced a spring storm over March 24–25, 2013, as indicated by the meteorological data collected by the weather station illustrated in **Figure 7**. The weather station detected a drop in air temperature and air pressure and a rise in rainfall intensity during the storm event.

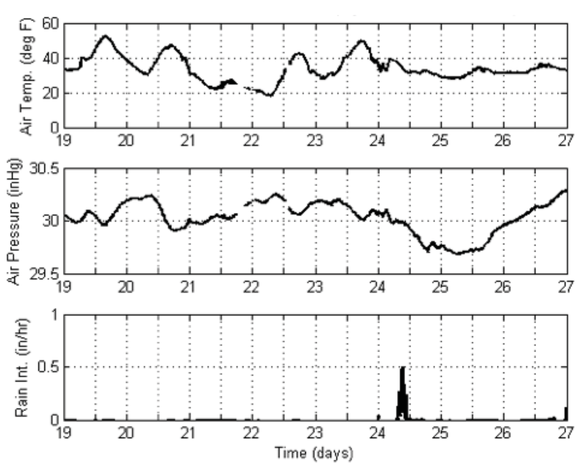

Figure 7. Weather station data for duration of March 24–25, 2013 storm event.

In addition, the water quality sonde captured a significant spike in specific conductance from runoff during the storm. Before this spring storm event, road crews applied road salts and deicing solution on the road and sidewalks in portions of the town of Blacksburg and Virginia Tech campus within the LEWAS watershed. Road salts contain a large amount of sodium chloride (NaCl), which when added to water, dissolves into chloride (Cl^-). The Transportation Planning Engineer and Facilities Operations Director at Virginia Tech were contacted to confirm the chemical composition of the deicing compound Virginia Tech administers (M. Dunn & M. Helms, personal communication, June 22, 2013). According to the Material Safety Data Sheet, the deicing compound is approximately 99% NaCl. This information is necessary to trace the potential sources of chloride from winter storm events. A high concentration of chloride in freshwater systems can have a negative impact on the aquatic health of the ecosystem.[11]

Although chloride is not directly measured by the LEWAS system, specific conductance can be used as a surrogate measurement to estimate the concentration of chloride in the stream. A United States Geological Survey (USGS) study compared 24 stream locations that recorded specific conductance and chloride concentrations in Broad Run watershed in Fairfax County, Virginia and developed a general relationship when the specific conductance is over 1,000 μS/cm, indicating heavy road salt content.[12] This equation was applied to the specific conductance data collected at the LEWAS site:

$$CC = (0.333)SC \quad \textbf{Equation 1.}$$

where CC is the chloride concentration in mg/L, and SC is specific conductance amount in μS/cm. There are limitations to using **Equation 1** as the relationship is not specific to the LEWAS site. However, given that this equation was developed in a similar watershed at various locations under similar conditions, it can give a general idea of the trends and possible chloride exceedances during a storm event at the site after a heavy road salt application.

4. RESULTS AND DISCUSSION

A significant portion of the McBryde neighborhood's stormwater conduits was successfully mapped out over the course of this summer investigation, thus improving the understanding of the contributing Upper Stroubles Creek watershed area. **Figure 8** shows the portion of the McBryde area (0.44 km^2) that was mapped as a result of this work in relation to the entire LEWAS watershed.

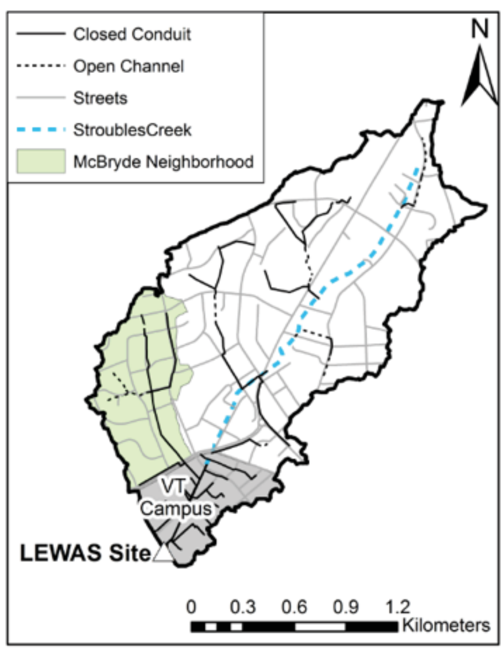

Figure 8. Portion of McBryde stormwater network system mapped during summer 2013.

The stormwater network maps created as a result of the survey process ultimately provide a visual explanation of how pollutants and sediment arrive at the LEWAS lab field site. Knowing the path that a pollutant travels can allow estimates to be made of time that lapses between a pollutant entering a given conduit and its presence recorded by the sensors at the monitoring site. By using the stormwater network map in **Figure 8** along with knowledge of the land cover, investigations into possible sources of pollution captured by the sensors can be conducted.

As an example, the stormwater network data along with the watershed sedimentation survey was combined to provide clues to the probable sources of sedimentation during flash storm events. The stormwater network map was used to properly delineate the watershed area, which provided the area of possible pollutant sources within the town. The geotagged photos within GIS were used to determine possible sedimentation source locations within the watershed and the stormwater network was used to determine the routes for each source. This information was finally used to map highly probable areas that contribute to sedimentation at the field site. The leading sources of sediment runoff within the watershed were identified as construction sites and gravel parking lots, many of which are adjacent to the main reach of Webb Branch. These sources were found to contribute sediment during flash storm events that cause spikes in turbidity and deposits of sediment at the site and in the Duck Pond, which will again require dredging and channel modifications over time. Identifying these sources can help lead to solutions by informing stormwater managers and decision makers about sedimentation impairments within Webb Branch watershed.

Results from a case study of a spring storm event suggest that there are substantial environmental consequences to the application of road salts and deicing solutions in the LEWAS watershed. The water quality sonde recorded multiple spikes in specific conductance at the field site during the March 24–25, 2013 storm event. Specific conductance represents the ability of water to conduct electrical current and can be used as a surrogate to approximate the amount of chloride in the water due to deicing solutions. **Figure 9** shows the estimated chloride concentrations over the duration of the runoff event as well as the EPA recommended acute toxicity limit. Acute chloride toxicity is the potential exceedance of a species tolerance to chloride caused by a sudden, one time, and high exposure. The U.S. Environmental Protection Agency (EPA) sets recommended limits of pollutants that are toxic in acute exposures for various freshwater organisms. The EPA quantifies an acute toxicity level for chloride as 860 mg/L[11]. As illustrated, the chloride concentration exceeded this limit on multiple occasions, indicating that the system was experiencing an acute toxicity event. (Unfortunately, the ADCP was not functioning during this event so the LEWAS was only able to capture water quality data.)

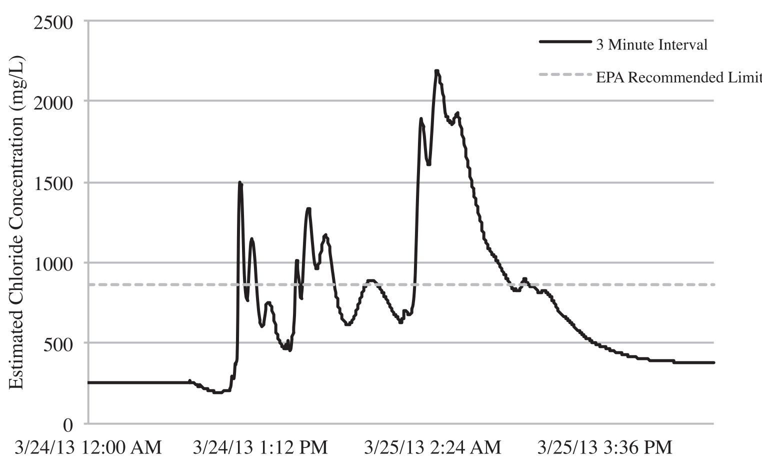

Figure 9. Measured chloride concentrations vs. EPA recommended concentration.

In addition to the EPA recommended limit, the toxicity thresholds of key indicator species can be used to determine the impact of the chloride. A professor in the Virginia Tech Biology Department explained that the fathead minnow (*Pimephales promelas*) is frequently used as an indicator species by researchers to gauge the health of a riparian ecosystem (J. Webster, personal communication, July 10, 2014). The acute toxicity limit of a fathead minnow, as determined by the EPA, is 860 – 2790 mg/L[11]. Because the fathead minnow is frequently found in Stroubles Creek, these high chloride concentrations are of concern and suggest that this event most likely created an environment that was toxic to the fathead minnow.

The survey of the stormwater network and land cover of the watershed helps to determine the sources of chloride in the system. The proximity of the LEWAS Lab field site (and ultimately the Virginia Tech Duck Pond) to a main road is a contributing factor to the sudden spike in specific conductance, as there is very little distance between runoff that originates on the adjacent road where road salts are applied and the monitoring system, consequently eliminating the opportunity for natural ground filtration. The phenomenon of ground filtration is also diminished in a man-made conduit system, where the pipes are usually made of impermeable materials, such as corrugated plastic or concrete. Understanding the characteristics of a watershed's stormwater network system allows the likelihood of processes such as ground filtration to be determined; if the runoff does not have the opportunity to be channeled over land, it is likely to be more concentrated with pollutants and sediment.

The results of this study help to quantify the impact that deicing solutions and road salts have on the water quality entering the Duck Pond facility. The results suggest how an urban practice — the act of salting roads — can impact the local watershed. When freezing precipitation melts due to contact with road salts, the water carries these salts through the stormwater network and into the stream. When sodium chloride comes into contact with water it dissolves into chloride ions, which cannot be removed with structural Best Management Practices (BMPs). The only solution to improve water quality that is contaminated with high levels of chloride is to dilute it. Although human safety during winter storms is of the highest importance, decision makers can use this information to try to optimize the application of deicing solution and road salts in order to promote human safety while mitigating the impact to the environment.

5. CONCLUSION

During the 10-week NSF REU program, an undergraduate researcher had the opportunity to use real-time, high-frequency watershed monitoring data to analyze sedimentation and acute chloride toxicity from flash watershed events. The sensors that provide data in real-time require a great deal of maintenance, but providing reliable water and weather data in a riparian ecosystem is essential to understanding the relationship between a city and its watershed. This investigation of the LEWAS watershed is ongoing, and it is recommended that the following action items be addressed to continue this research.

- The sonde's sensors should be cleaned daily of debris and calibrated more frequently (every two weeks) to ensure that the sensors are not subject to repeat damage.
- A LEWAS Lab member should visit the field site during the winter months (especially following a snowstorm) to look for fish kills. This could strengthen the hypothesis that road deicing salts are creating a hostile environment for aquatic organisms.
- In addition, grab samples should be taken throughout a winter storm event and analyzed for chloride concentrations to develop a regression equation between specific conductance and chloride that is specific to the LEWAS site.
- A chronic chloride toxicity analysis should be performed during the winter to provide an idea of how the system responds to pollutants over the course of several days or weeks.

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ABOUT THE STUDENT AUTHORS

Holly A. Clark is in her sixth year of undergraduate study at the University of Idaho. She is pursuing Bachelor of Science degrees in both Environmental Science (with a physical science emphasis) and Music History and Literature (with a clarinet emphasis). She will graduate in May 2015.

PRESS SUMMARY:

A 10 week U.S. National Science Foundation Research Experiences for Undergraduates study investigated responses of a small urban watershed, located in Blacksburg, Virginia, to acute toxicity events. High-frequency water and weather data were collected using monitoring equipment maintained by the Learning Enhanced Watershed Assessment System (LEWAS) lab, including a weather station, rain gauge, water quality sonde, and an Acoustic Doppler Current Profiler. Stormwater infrastructure fieldwork resulted in the construction of an accurate stormwater network map, which in turn allowed the identification of sources of sedimentation and other pollution from runoff events. A case study presents the response of the watershed to a winter storm event that resulted in acute chloride toxicity from runoff containing road salts.