A laboratory-to-field experience for introductory environmental engineering

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Abstract

In this work, a coupled laboratory and field experience approach is used to teach undergraduate engineers about water quality in an introductory environmental engineering course. Here, a laboratory featuring a traditional water quality test is coupled with laboratory-to-field scale activities incorporating a portable stream table and field site experience. Students first prepare and carry out a chemical oxygen demand test on local water samples. Then, a stream table is used to consider the impact of human and environmental factors on water quality. Using the stream table, students directly interact with the simulated environment, posing and evaluating the impact of hypothetical systems and alterations. Lastly, students participate in biological stream monitoring as a means of discerning water quality at a local site.

Keywords

Environmental engineering, field activities, water quality

Introduction

The introduction to environmental engineering course is a required junior-level undergraduate course for civil engineering majors. This course is also taken as an elective by chemical engineering and biosystems engineering majors. As part of this three-credit course, students participate in three fifty-minute lecture periods, one fifty-minute lab lecture, and one two and a half hour laboratory period each week. One of the objectives of this course is to "understand and interpret typical water quality measurements and criteria". In the classroom, this includes modules on water quality in lakes and rivers with incorporated mass balance components.

This course has an integrated laboratory that includes typical chemical and physical means of water quality assessment including pH, alkalinity, water hardness, turbidity, and chemical oxygen demand. The laboratory additionally includes field trips to local water and wastewater treatment plants.

The goal of this study was to develop new laboratory-to-field scale activities focused on water quality monitoring that link with and extend on the associated lecture materials. This includes building on the concept of surface water quality monitoring which previously contained only physical and chemical monitoring to introduce bacteriological and biomonitoring as means of water quality monitoring. Water quality monitoring of surface water systems is an important means of assessing the health of the body of water for flora and fauna as well as determine if the body of water is fit for recreational use. Typical means of water quality monitoring include physical, chemical and biological monitoring. Chemical and physical monitoring includes pH, total hardness, alkalinity, temperature, dissolved oxygen, and turbidity and are already integrated into existing course laboratories. Bacteriological monitoring uses E.coli and coliforms as a means of detecting contamination. Biomonitoring surveys the benthic and macroinvertebrate organism presence in water bodies where the number and type of different organisms is used to assess stream health and the presence of pollution.

Building on the existing laboratory modules, this work developed new stream table demonstrations to bridge the analytical part of the laboratory with a model environmental system. A new field activity was then incorporated focusing on bacteriological and biological water quality monitoring.

Analytical laboratory

The analytical component of the laboratory includes measurement of the chemical oxygen demand (COD) and comparison with the theoretical oxygen demand. Oxygen demands are linked closely to water quality, impacting plant and aquatic life and indicating pollutant presence and transformation. In a lab lecture period, students are introduced to the concepts of biochemical oxygen demand (BOD), COD, and theoretical oxygen demand including sources of oxygen demand and pertinent regulations. Students discuss and practice theoretical oxygen demand calculations and the typical laboratory methods to measure BOD and COD are presented.

In the laboratory, students measure the COD of a water sample extracted from local surface water using the colorimetric method. In this test, chromate is used as an oxidizing agent where the following reaction occurs,

$$C_nH_aO_bN_c + dCr_2O_7^{2-} + (8d + c)H^+ \rightarrow nCO_2 + 0.5(a + 8d - 3c)H_2O + cNH_4^+ + 2dCr^{3+} \qquad (1)$$

The COD, and amount of organics oxidized, can be calculated using the stoichiometry of equation 1 if the concentration of chromium (II) or chromium (III) is known. These concentrations can be discerned by measuring the sample's absorption of light at two different wavelengths, 400 nm and 600 nm where chromium (II) strongly absorbs light at 400 nm and chromium (III) strongly absorbs light at 600 nm.

To carry out this test, the water sample is first added to a prepared COD vial. The vial is mixed and heated for two hours at 150 C in a digestion reactor. After cooling, the absorbance in measured using a photometer.

Stream table demonstrations

To complement the analytical component of the laboratory, an interactive stream table demonstration was developed. This activity utilizes the Little River Em2 portable stream table that is 2.6 ft x 6.2 ft and contains 150 lb of model media and 27 gallons of water. The table is additionally equipped with a digital flow controller to monitor and control water flow rates, simulated vegetation and rocks, and three types of plastic culverts.

The stream table demonstrations consist of four topic areas: ground-water surface water interactions, sediment transport and erosion, human-environment interactions, and climate change. These topic areas consist of one or more interactive and hands-on components where students are guided to use the stream table, make visual observations, discuss their findings and draw conclusions as a group.

Groundwater-surface water interactions: In this activity, students are introduced to the stream table where the initialized table displays a meandering river with low flow rate. Students, arranged along the edges of the stream table, are asked to 'dig' into the model earth surface. Below the surface, students find the media saturated with water, the model groundwater. The students are asked about the interaction between groundwater and surface water in the model system and the real world. This will be discussed in the context of contaminant fate and transport later in the activity.

Sediment transport and erosion: Students are asked to make some qualitative observations about the interaction of the river with the media at the initial low-flow conditions. The river flow rate is then increased and students are asked to note any changes in the system where the increased flow rate results in sediment transport and bank erosion. As a group, ideas to reduce erosion are discussed and students are given plastic plants and plastic and quartz stones to test their engineering solutions (Figure 1). Varying solutions are examined and the relative success of different approaches discussed.

Figure 1: Students installing culverts (left), experimenting with erosion control (center), and attempting stream restoration as part of the stream table demonstrations using the Little River Em2 Stream Table.

Human-environment interactions: This activity focuses on the interactions between the built and natural environment. First, students are given houses and asked to place them in their desired location. To increase transportation in the community, the students are then tasked with installing box and round culverts to make bridges across the river (Figure 1). Near bridges, erosion and scouring are common problems and students look for these near their installed infrastructure. Culvert sizing is additionally challenging where undersized culverts result in upstream backups and downstream scouring. Culvert height is another important design parameter where high culverts interrupt ecological flows and result in scouring and low culverts can become clogged with sediment. Students look for these design challenges and resulting negative implications in their infrastructure, adjusting their designs as needed.

Pollutants often enter rivers at point sources along stream or river banks. Pollutant spills are demonstrated in the stream table by adding a plug of dyed water at a point along the river bank.

Students are asked to observe the fate and transport of the pollutant over time and change in concentrations over time. As the dyed water mixes with the bulk water, the concentration of the pollutant decreases. With the flowing water, the pollutant is carried downstream and the dye can be seen throughout the downstream section. This activity is repeated, this time with the pollutant 'spilling' on the land surface. Once again, the students observe the pollutant in the river downstream. The interactions between groundwater and surface water are discussed, where the students 'dig' into the media and find dye in the ground water as well. The group then considers the cause of the observed transport phenomena in terms of ground-water surface water interactions and advective and diffusive transport.

Climate change: One of the anticipated adverse effects of climate change is increased frequency and intensity of storms [1]. Students are asked to consider the impact of climate change on the natural and built environment in the model system where many infrastructures are often designed for 10 to 25-year floods [2]. To simulate a strong storm, the flow-rate of the river is increased and students note the corresponding impacts on the natural and human-impacted systems. Students will observe increased erosion throughout the system, scouring near culverts, and bank failure. Repetitive strong storms are additionally be simulated by decreasing and increasing the flowrate in succession.

Field activity

Laboratory activities are complemented by biological stream monitoring at a local field site in collaboration with Alabama Water Watch (AWW), a program of the Auburn University Water Resources Center. Alabama Water Watch is volunteer based citizen science program focused on water quality monitoring in Alabama. This program trains volunteers to become water quality monitors, evaluates surface water across Alabama, and collects, maintains and distributes water quality monitoring data via the AWW website.

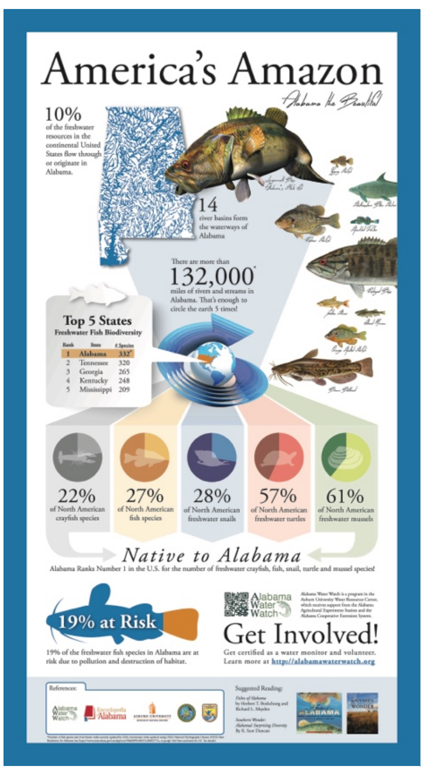

Figure 2: An introduction to Alabama waterways from the Alabama Water Watch.

As part of the field site activity, students visit a local river or stream where students in Spring 2018 visited the Parkerson Mill Creek upstream of the wastewater treatment plant with Alabama Water Watch personnel (Figure 3). Students are first familiarized with regional watersheds where Alabama has over 132,000 miles of rivers and streams and large biodiversity (AWW, Figure 2).

Students are then introduced to bacteriological and biomonitoring as a means of assessing water quality. In streams and rivers, there may be bacteria present that enhance the native environment or result in adverse effects. In the bacteriological monitoring test, E.coli and general coliform bacteria are evaluated and serve as indicators of fecal contamination. To carry out the bacteriological monitoring test, students collect samples from the stream with AWW personnel to be incubated for the test. As the incubation step requires more time than the duration of the laboratory, students examine previously incubated plates from the site and compare them to the water quality standards.

Figure 3: Students in the introduction to environmental engineering class in Spring 2018 carrying out bacteriological stream monitoring in collaboration with the Alabama Water Watch. Photos depict students collecting (left, right) and sorting (center) benthic macroinvertebrate organisms as a means of assessing water quality.

Benthic macroinvertebrates are often used as a means of assessing water quality as they are abundant in surface waters, relatively immobile (e.g. compared to fish), and carry out most of their lifecycle in the river or stream. These macroinvertebrates vary in their tolerance to pollution where some organisms are extremely sensitive to pollution, indicating good water quality if present, and others are pollution tolerant [3]. With AWW personnel, students learn how to properly collect and benthic organisms from the site. Collected organisms are then sorted into groups based on their tolerance to pollution. At the end of the sampling period, organisms are counted and used to determine the biotic index. Data from the stream monitoring activity is then added to the AWW website where it is publicly available.

Outcomes

The introduction to environmental engineering course has several course objectives including one to "understand and interpret typical water quality measurements and criteria." The lab to field activities described above are aimed to supplement lecture material with hands on interactive activities to engage students and enhance student learning associated with this course objective. To date, the feedback from students has been positive and an in-depth assessment is in progress.

References

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