AC 2008-1725: INTRODUCING REAL-WORLD HYDROLOGY CASE STUDIES INTO AN UNDERGRADUATE CIVIL AND ENVIRONMENTAL ENGINEERING CURRICULUM

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Introducing Real-World Hydrology Case Studies into an Undergraduate Civil and Environmental Engineering Curriculum

Abstract

Hydrology, the study of the movement and storage of water in the environment, originated as an engineering discipline mainly concerned with the estimation of floods and droughts. Since then, hydrology has evolved into one of the earth sciences and deals with water related issues in complex environmental systems at scales ranging from local to global. Current and future water issues require inter-disciplinary scientific approaches to provide solutions to engineering problems, often including significant social components. Climate and land use change introduce non-stationarities into the environment that many of the current engineering tools cannot consider, while a growing population continuously increase the stress on available water resources, particularly in less developed countries. An introduction to hydrology remains an important part of the general civil and environmental engineering curriculum. However, the changes in the science of hydrology have not yet fully propagated into a changed approach to teaching this important subject. We present the results of a three-semester long study in which we introduced real world case studies into a large (70-90 students) civil engineering undergraduate class to achieve this change. Over the past several semesters, students have expressed overwhelmingly positive thoughts on the course adjustments made, including the cases and other active learning elements utilized. We show and discuss evidence of the positive impact on student learning due to the closer link between the course material and real-world examples.

Introduction

Hydrology has evolved from a mainly problem driven, applied engineering discipline to one of the building blocks of the geosciences and environmental sciences. Hydrology deals with watersheds (or units at other scales) as complex environmental systems without losing its focus on real world applications. The complexity of hydrologic investigations has increased over time because of the necessary inclusion of chemical and biological aspects of the hydrological cycle to address topics such as water quality and ecosystem function, as well as a need for awareness for social and ethical issues related to water. At the same time, climate and land use are changing in many regions, causing significant problems for water resources studies. Such changes mean that historical data are not representative for the region anymore, while most engineering approaches are based on the assumption that they do.

As the demands on current and future hydrologists have changed, the concern arises that hydrology training has lagged behind necessary preparation for both research and application [1, 2, 3]. There is evidence of hydrology as a science becoming more interdisciplinary and complex, evolving in its focus due to new scientific findings, computational and technical advances, and new linkages to other disciplines[4, 5, 6]. The importance of hydrology education in this context is supported by results of a recent survey about integrated water resources management in the USA, which found that 86% of 600 survey participants (from industry, government and academia) think that the greatest educational need lies in the area of watershed hydrology and watershed modeling[3]. Demands for an interdisciplinary approach to hydrology education are not new though, having already been voiced over 15 years ago[7, 8].

Hydrologists need to be able to solve complex interdisciplinary problems as discussed above. However, current undergraduate engineering education does not generally provide sufficient training in solving complex problems[9], and also does usually not provide opportunities for students to work in interdisciplinary teams. As a result, students tend to lack the confidence (at the end of their bachelor's degree) that they are capable of tackling the complex problems, which society currently faces. If students are educated in engineering departments, then they also often lack the scientific approach to problem solving required that goes far beyond simply applying existing equations, but requires acts of creativity[10, 11]. There is therefore a need to educate students on scientific and creative approaches to solve hydrological and environmental problems.

Additional issues are relevant if the hydrology education takes place in an engineering department. In a typical undergraduate class in water resources engineering at Penn State University, the majority of the students, while majoring in civil engineering, are not focusing on water. This means that motivating the students to learn the material conveyed becomes crucial, and asking the students to work on extensive projects, which often do not have a clear-cut answer, is difficult. In addition, at Penn State, the average hydrology class size is approximately 80 students, which is a considerable contrast to most US Universities where hydrology classes are considerably smaller as shown by a recent survey[1] (Figure 1). Such large class sizes make it difficult to engage the students and provide meaningful feedback on student understanding.

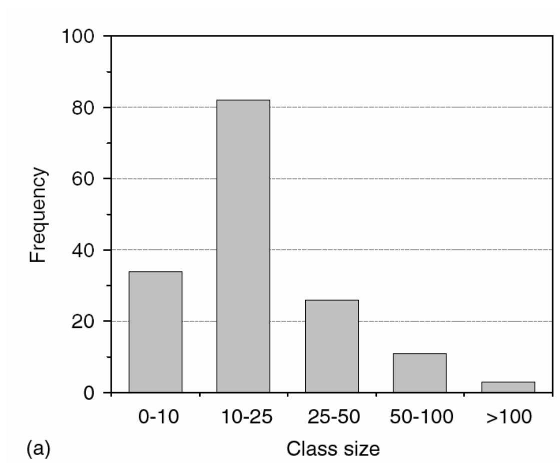


Figure 1. Distribution of class sizes based on a survey of 140 hydrology educators.

Additionally, any adjustment (or addition) to the curriculum needs to be in line with the requirements and future directions of engineering. Penn State University has developed the idea of training students to become *World Class Engineers*, and advancing the hydrology related components of the curriculum should go hand-in-hand with this objective. A World Class Engineer is defined as being: aware of the world, solidly grounded, technically broad in thinking (multidisciplinary approaches, probability, verification of analysis), effective in teams, innovative, and successful as leaders (detailed definition can be found at http://www.engr.psu.edu/).

As the demands on current and future hydrologists have changed, the concern arises that hydrology training has lagged behind necessary preparation for both research and application[1]. *Environmental challenges are often exceedingly complex, requiring strengthened disciplinary inquiry as well as broadly interdisciplinary approaches that draw upon, integrate, and invigorate virtually all fields of science and engineering* (National Science Board, Environmental Science and Engineering for the 21st Century, p. xi.). There is evidence of hydrology as a science becoming more interdisciplinary and complex, evolving in its focus due to new scientific findings, computational and technical advances, and new linkages to other disciplines[4,5]. This development requires students to conceptualize and break-down complex interdisciplinary problems into smaller sub-problems, and solve them by finding creative solutions, all aspects that students typically find very difficult and where they do not receive sufficient training[11]. It also requires more in-depth training on understanding watersheds as environmental systems and on using mathematical models for real-world applications including an understanding of the uncertainties involved. These are all subject areas recently found to be critically lacking in the education of students entering water resources related jobs[3]. This development towards more interdisciplinary and science based education requires fundamental changes towards teaching complex problem solving skills in hydrology, in particular for hydrology education in engineering departments.

Statement of current problems:

- Problem difficulty has increased from single-objective engineering problems (e.g. flood peaks) to dealing with complex environmental systems. Current engineering undergraduate students do not learn the necessary problem solving skills to tackle complex hydrologic problems.
- More complex problems require creative solutions utilizing more complex tools, use of complex and realistic data sets, consider environmental change, and often produce higher uncertainty. Students do not get trained to develop complex problem solving skills, or in using hydrological modeling tools and uncertainty analysis.

Our resulting goal is to answer the following question: ***How can We prepare Students better to solve Real-world Hydrology Problems in our Context and in a Changing World?***

Educational Solutions to Prepare Students to Solve Real-World Hydrology Problems

Educators need to develop activities that allow students to obtain the skills necessary in order to be successful in solving real-world hydrology problems. Research has shown that active engagement within course material will improve students' conceptual understanding and their ability to apply knowledge to different situations[12, 13]. As the NRC notes, "Overall, the new science of learning is beginning to provide knowledge to improve significantly people's abilities to become active learners who seek to understand complex subject matter and are better prepared to transfer what they have learned to new problems and settings" (p. 13). In order to be better prepared for problems they might encounter in the future, students need to have active experiences in the classroom with realistic problems.

Active learning elements have been shown to have a beneficial impact on student understanding. Appealing to a wide range of students, hands-on and interactive learning activities largely reinforce conceptual understanding of topics and promote retention better than the traditional, passive approach to classroom education. Undergraduate students who have been involved in discovery and scientific process show improved learning, knowledge retention, problem solving ability, and success in subsequent courses[14].

In order to be successful engineers, students need to learn how to define problems, draw sketches, and break complex problems into parts[9]. While some recommend a separate course in problem solving[15, 16], other researchers recommend having problem solving embedded in a course as knowledge level information (as defined by Bloom's taxonomy) is important for developing creative solutions[9] and to enable creativity[17].

The results of these educational studies support that courses in hydrology should contain active learning elements and sufficient opportunities for students to solve realistic problems from the field.

Introduction of Case Studies in an Undergraduate Class

The study was performed in a civil and environmental engineering undergraduate class called CE 361 Water Resources Engineering. Given the needs of the hydrology discipline and previous relevant research results regarding learning, the existing water resources course in the department of Civil and Environmental Engineering was revised. The original version of the junior level class (with typically about 70 to 80 students) introduced undergraduate students majoring in Civil and Environmental Engineering to hydrology using a control volume approach[18]. As mentioned above, an important characteristic of this class is that the vast majority of students do not have water resources as their main emphasis within civil engineering (only about 12% as seen in Figure 2).

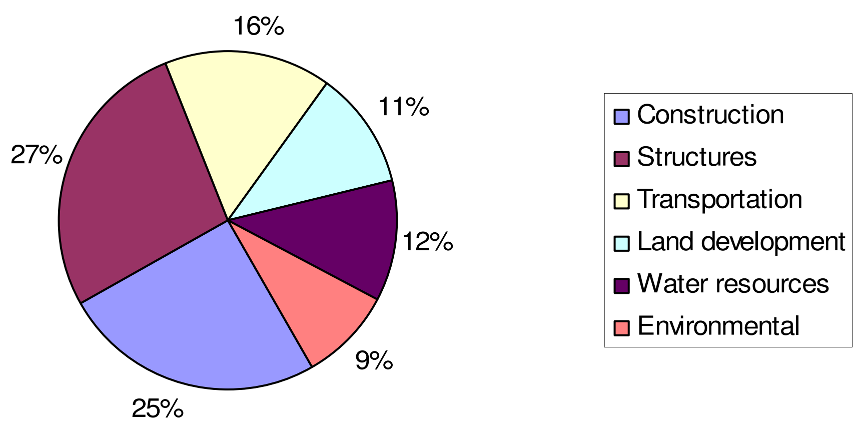
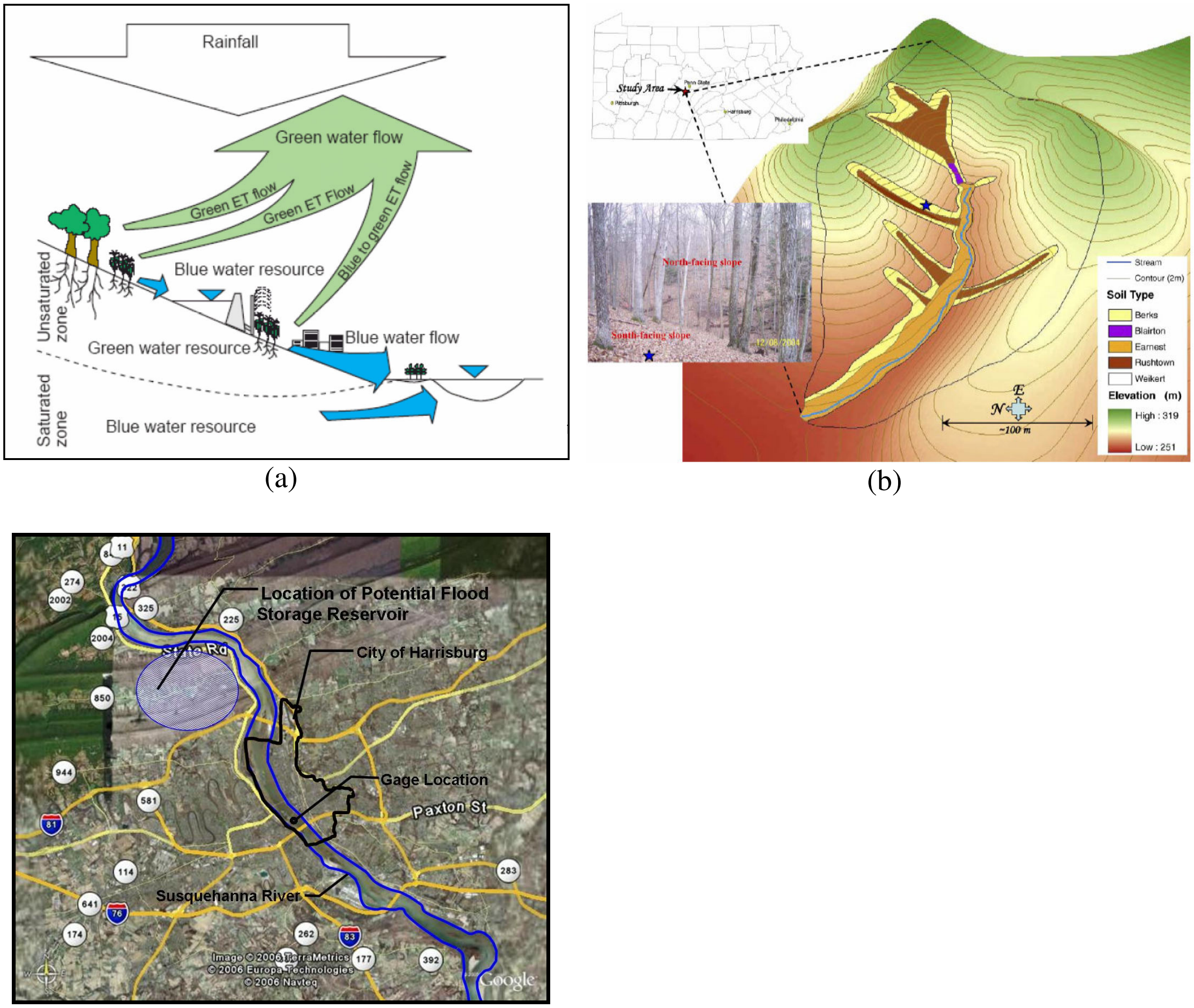


Figure 2. The Majority of Students in the Course are not focusing on Hydrology or Water Resources

Changes to the courses started with those to the name and content of the class over the last three semesters to turn it from a traditional Engineering Hydrology class into a course that looks at water resources issues from an environmental systems perspective. The course curriculum includes examination of problems on a global and local scale relating to aspects of the social relevance of water. Homework assignments have been replaced with small case studies that the students can work on in teams of up to three students. For most students this is the first use of case studies in their undergraduate career. The case studies are outlined in Table 1 and Figure 3. Learning objectives start with understanding and using general concepts and end with understanding and using actual applied engineering techniques. While the majority of case studies focuses on geographical areas that the students are familiar with, an explicit attempt is made to include at least one international study.

Table 1. Some details on the case studies introduced.

Title	**Learning objectives**	**Location**
New York City Water Supply	Understand and be able to apply the following concepts: control volume and residence time	New York City water supply reservoir located in the Catskill Mountains
Rainwater Harvesting	Understand and be able to apply regional precipitation estimation, watershed delineation and basic hydrostatics calculations	Pennsylvania
Blue-Green Water in Egypt (Fig. 3(a))	Understand and be able to apply basic land use/land cover analysis for evapotranspiration impact studies, and to understand and apply evaporation and infiltration theory	Egypt
Small-scale Spill/Infiltration	Understand and be able to apply a simple infiltration algorithm, calculation of fluxes in the unsaturated and saturated soil zones	University Park, Pennsylvania
Land Development (Fig. 3(b))	Understand and be able to calculate watershed runoff using the curve number method, the unit hydrograph and a simple channel/reservoir routing scheme	Central Pennsylvania
Design Flood for Control Reservoir (Fig. 3(c))	Understand and be able to apply basic probability concepts and in particular flood frequency analysis	Harrisburg, Pennsylvania



(a) (b) (c)

Figure 3. Case study examples.

Assessment of Case Studies

In order to examine the impact of the curricular changes in CE 361, assessment data was collected during the previous three semesters. The focus of the assessment was in determining if students perceived the changes to be beneficial to their learning. Specifically, the following questions were examined:

1. Do students perceive a strong link between the course material and real-world problems?
2. What are some of the perceived benefits of the case studies for student learning?
3. What changes to the course would help improve student understanding of the course material?

Student responses to the first two questions are discussed in this paper. Each semester, students completed surveys at the start, middle, and end of the semester. The surveys consisted of both open-ended questions and Likert-type or rating scale items. The rating scale included items that measured students' perceptions regarding the relevance of the course to the real-world, ability to think through problems in hydrology, comfort with complex ideas, and interest in the course and field. The full rating scale, a portion of the longer end-of-semester survey, is available in the Appendix. Student responses on the scale were coded using a scale from 1 to 5, with higher scores indicating a more positive endorsement of the item. The open-ended questions supplemented this information by asking students their views of various course elements, including the implementation of the cases. The responses of these open-ended questions were coded to obtain frequencies of common themes.

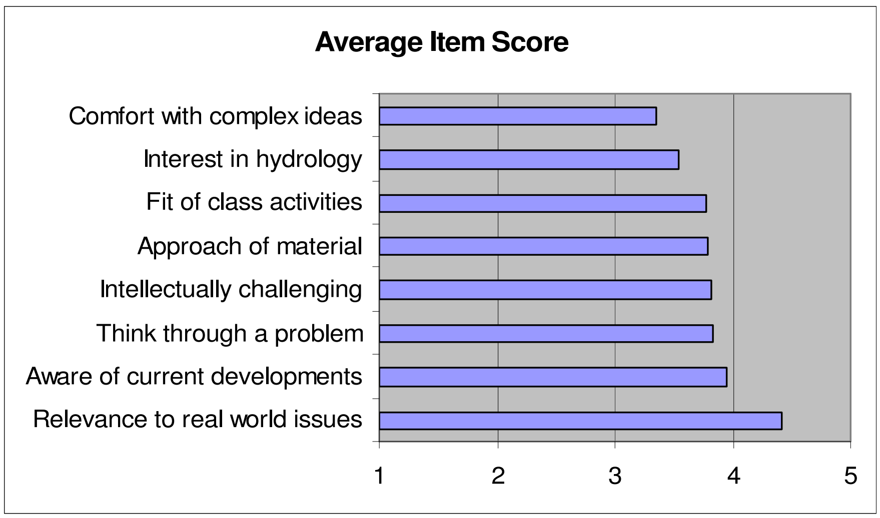


Figure 4. Average item scores for rating scale in CE 361.

Figure 4 displays the average item scores for the rating scale, sorted from lowest to highest means. The highest rated item on the Likert-type scale was when students were asked to rate their level of agreement regarding their understanding of "the relevance of this field to real world issues." A total of about 95% of the students generally agreed or strongly agreed with this statement. This very positive perception of the relevance of the course material to the real world was supported by responses on the open-ended questions which asked students to describe their ability to make connections to real-world situations. On one of these corresponding open-ended questions, almost every single student expressed a positive statement regarding the ability to make connections between the course and the real-world, based on in-class examples and case-studies used. A representative student response was this one: *The case studies show how the material we learn is applied in real life, so we can now say, "I know how to do that."*

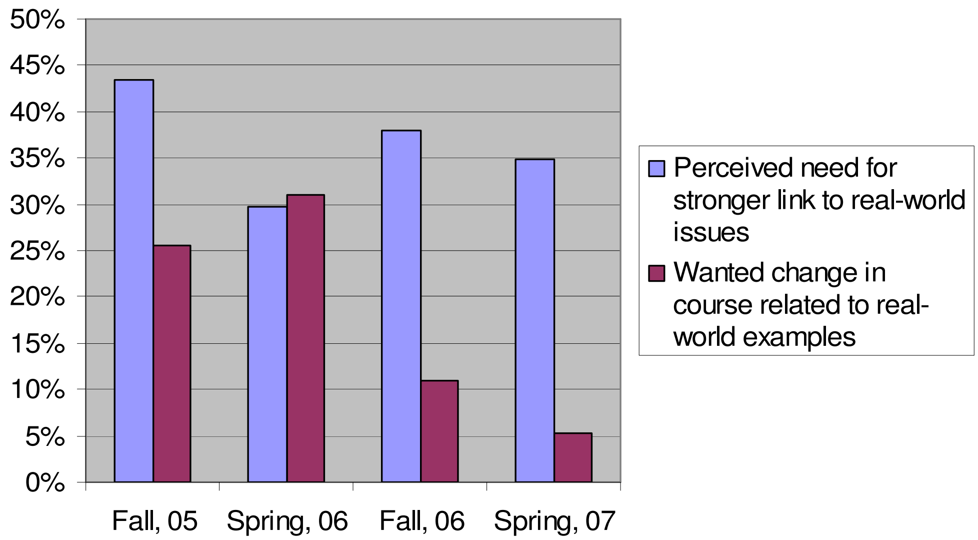


Figure 5. Frequency of student comments relating to real-world examples across four semesters of data

As displayed in Figure 5, the number of sentiments regarding the perceived need for additional examples related to real-world events, as found in the open-ended comments, has decreased across the previous four semesters. The cases were initially implemented in the spring of 2006. The first question asks students, "Do you feel that there needs to be a stronger link between the class material and real life? Responses were coded as yes or no; percentages displayed in the figure are based on the number of students who responded to the item. The number of students who said yes to this item decreased from approximately 42% in the baseline semester in which cases were not used to 30%-35% in semesters in which the cases were used.

The second question shows a more dramatic impact of the cases on the students. This question asked students, "What changes should be made to the course to enhance student learning?" This item was again coded to identify common themes. The item was intentionally written in an open format to avoid prompting students to respond in a particular direction. The frequency of times that students mentioned "real-world" or "real-life" examples or connections was coded and tracked across the semesters. Across the four semesters, this number decreased dramatically with very few (only 3 students) requesting more real-world examples in the spring of 2007. When asked what benefits the cases had for their learning, many students listed relevance to real life. For example, the following quotes are representative examples of the types of comments that students wrote:

- *The cases actually made me feel as though I was an engineer assigned to a specific task that needed to be solved.*
- *The [cases] gave real examples of hydrology issues and made me think as a real engineer not just an engineering student.*
- *The cases were helpful to my learning because they showed me how the material we learn in class can be applied to the real world.*

While it may be surprising that 30-35% of the students still perceive the need for a stronger link to real-world activities, students did still seem to recognize that the course contains many examples and real-world elements. One reason that the percentage is still high is that some students expressed resistance to learn derivations and theoretical material. For example, one student said, *I think a lot of this is too formula based and [I have] no idea how this goes on in the real world.* Some students also said they wanted more examples related to their particular specialization in civil engineering. As one student stated, I *guess it would be nice to know how water resources may impact civil engineering, more specifically design of structures or construction management.* A couple students said that a little more real world application wouldn't "hurt" but that the course already had a lot of connections. Another reason that the percentage is still high is that some students misinterpreted the question. While the question specifically asked if there needs to be a **stronger** link to real-world examples in the course, based on some of the responses, it appears that some students read the question as "Do you think there needs to be a **strong** link to real-world examples?" We plan to revise this item in future surveys to avoid this misinterpretation.

While not one of the highest rating items on the rating scale, some students expressed that increased interest and attention is one of the benefits of completing the case studies. For example, the following are examples of student quotes related to interest and attention:

- *They captivated me and therefore stole my attention.*
- *It makes the class experience more interesting.*
- *Stimulated thinking a little more.*

A couple of students noted that the cases encouraged creative thinking. For example, one student noted that the cases, *made you think outside of the box and research a little more about the problem.*

The cases appeared to have less impact with students' level of comfort with complex ideas in hydrology. Only 45.5% reporting feeling comfortable with complex ideas in the field although 74.2% felt that they could think through a problem or an argument in hydrology. The case studies used were purposefully short (as otherwise infeasible with an 80 student class), which means that the level of complexity of the problem addressed is limited. They therefore provide a starting point, but do not fully achieve teaching students the complex problem solving skills they may need in their future careers.

Conclusions and Remaining Challenges

The changes to the course have evidence to support a positive impact on student learning, by better linking the course material to real-world examples. The cases provide a practical method for introducing real-world issues in a large class of students who are not necessarily focusing on hydrology or water resources. While necessarily more simplistic than a true engineering problem one might encounter in the field, the cases are a starting point to introduce complex interdisciplinary problems to civil engineering students.

Over the past several semesters, students have expressed overwhelmingly positive thoughts on the changes, including the cases and other active learning elements utilized. The data from the assessment supports that the students feel more of a connection from the course material to real-world issues. Some preliminary evidence suggests that the real-world problems increased motivation, attention, and interest in the material.

Whether or not students are more capable of tackling complex problems in hydrology following graduation is still unclear. Students' ratings in their confidence to tackle these problems did not appear to increase across the semesters. However, once out in their careers, the students may realize that the case experiences prepared them for the types of problems they are likely to face. Longitudinal studies are necessary in order to better understand the impact of cases such as these on students' confidence and ability to approach complex engineering problems.

Some challenges still remain in developing the undergraduate course to meet the needs of the discipline. Some students have expressed resistance to learning about international issues. As mentioned above, the locations in the cases were sometimes local but other times international. Surprisingly, some students did not enjoy learning about issues going on outside of the United States. As one student said, *Some [cases] are applicable. I am not a humanitarian and do not care about other countries too much. They are interesting to me when they relate to our country. Because I don't plan on leaving the country as I'm older.* Another student made the following comment: *Make them more applicable to local problems, not about problems elsewhere in the world.* Given the emphasis on developing the global and international awareness of engineering students, the resistance to the international cases is disheartening. This semester, we plan to launch a study that further examines students' resistance to learning about international experiences.

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APPENDIX

Student Rating Scale

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1. I find this course intellectually challenging and stimulating.					
2. My interest in hydrology/water resources has increased as a consequence of this course.					
3. As a result of this course, I am aware of current developments in hydrology/water resources.					
4. I understand the relevance of this field to real world issues.					
5. I am able to think through a problem or argument in hydrology/water resources.					
6. I feel comfortable with complex ideas in hydrology/water resources.					
7. The way that the material was approached was helpful to my learning.					
8. The class activities and assignments fit together in a way helpful to my learning.					