Enhancing Undergraduate Water Resources Engineering Education Using Data and Modeling Resources Situated in Real-world Ecosystems: Design Principles and Challenges for Scaling and Sustainability

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Enhancing Undergraduate Water Resources Engineering Education Using Data and Modeling Resources Situated in Real-world Ecosystems: Design Principles and Challenges for Scaling and Sustainability

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1 INTRODUCTION

1.1 Background

Recent advances in the remote sensing, data informatics, geospatial visualizations, and numerical computations have resulted in a rapid evolution in research and industrial practices in the field of hydrology and water resources engineering (Gupta, 2001; Hooper & Foufoula-Georgiou, 2008; CUAHSI, 2010). Key elements include advances in new observational settings (e.g. Critical Zone and Water, Sustainability and Climate Observatories), instrumentation, hydrologic information systems (e.g. (Tarboton et al., 2009; Tarboton et al., 2010)) and modeling methods. While such tools and techniques are revolutionizing the capabilities of hydrologic analysis and engineering design, they have yet to be formally introduced into the undergraduate curriculum.

Current approaches to hydrology education focus on idealized textbook examples, which concentrate on introducing isolated unit processes. While it is important to understand these individual system components, these prescriptive instructional methods fail to portray hydrologic systems as comprehensive entities (Wagener et al., 2010). Additionally, these approaches typically lack problem context and neglect the effects that these processes have on both the natural and built environments. The result has been undergraduates who are ill-equipped to approach the complex water-related problems facing today's hydrologist (e.g., sea level rise, subsidence, pollution, and aquifer depletion).

The need for educational reform in hydrology and water resources education has captured the attention of the educational community (e.g., (Bourget, 2006; Wagener et al., 2010; Howe, 2008; Ledley, Prakash, Manduca, & Fox, 2008; CUAHSI, 2007; CUAHSI, 2010; Merwade & Ruddell, 2012; Ruddell & Wagener, 2014)). Such calls for reform focus on introducing key attributes such as new observational settings and instrumentation, hydrologic information systems, simulation models, and practical real-world hydrologic case studies. Examples of such efforts include: the development of web-based learning modules (Habib, Ma, Williams, Sharif, & Hossain, 2012; AghaKouchak, Nakhjiri, & Habib, 2013), computer simulations and games (Siebert & Vis, 2012; Hoekstra, 2012; Rusca, Heun, & Schwartz, 2012), sharing of educational materials via community platforms (Wagener et al., 2012), innovative sensors using hydrology real-world case studies (Wagener & Zappe, 2008; Yadav & Beckerman, 2009), and the use of real-time environmental monitoring to enhance student engagement (McDonald, Brogan, Lohani, Dymond, & Clark, 2015; Brogan, McDonald, Lohani, Dymond, & and Bradner, 2016).

The desire to introduce advanced data and modelling-based activities in undergraduate settings has also been emphasized by the hydrologic community (e.g., (National Research Council, 1991; CUAHSI, 2010)). Despite their inherent uncertainties, computer models are powerful tools used in the analysis and design of complex water resources problems (Beven, 2001) and can provide a multitude of benefits to students that facilitate hypothesis and discovery-driven learning (de Jong & Van Joolingen, 1998). Additionally, using modeling tools and data resources that will be used in a future career promotes motivation and increases knowledge transfer to non-academic contexts (Merwade and Ruddell, 2010). The American Society of Civil Engineers Body of Knowledge defines six levels of achievement for cognitive learning outcomes that are based on Bloom's Taxonomy: knowledge, comprehension, application, analysis, synthesis, and evaluation (ASCE, 2008). While these outcomes are typically attained for the lower levels during undergraduate studies, higher order learning achievements in technical specializations are usually only obtained during a graduate degree or in professional practice. By augmenting classroom lectures with modeling and data-based resources and tools, higher order achievement levels (e.g., apply, analyze, and evaluate) can be promoted at the undergraduate level. Integrating these achievement levels in the undergraduate curriculum will produce graduates that possess practical near-real-world experience and make them more desirable by employers upon graduation.

While the benefits of data and model-based learning in hydrology have been evident since the 1900s, the best way to implement these concepts into the classroom is still a widely debated subject. According to a survey conducted by the Consortium of Universities for the Advancement of Hydrologic Science in January 2010, 75% of educators agree that data and model driven curriculums should not be the primary method of instruction (Merwade & Ruddell, 2010). Instead it should seek to augment traditional theoretical classroom teaching methods (Ruddell & Wagener, 2014). The introduction of modeling and data-based activities in undergraduate courses is also complicated by the fact that, in many universities, hydrology is taught in a single course in which a large portion of materials must be consolidated to encompass all of the diverse areas of the subject (Wagener et al., 2012). While the out-of-class cyber education (e.g., online courses) has been suggested for overcoming in-class time limitations, the requirement of expert assistance in learning how to use associated computational and engineering software poses a scalability problem. To successfully integrate computational models in hydrology education, the National Science Foundation Taskforce on cyberlearning (U.S. National Science Foundation, 2008) recommends a set of criteria to guide the design of such efforts: (a) the interface of the model should be both intuitive and require little to no prior programming knowledge, (b) the model should be highly interactive and visual to assist in understanding the evolution of the system, and (c) models should contain assignments consistent with research on learning and provide teacher feedback. Additionally, Rogers's theory on diffusion of innovation suggests that five characteristics influence adoption: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003).

1.2 Objectives

The overarching focus of this thesis is on introducing data and modeling experiences situated in real-world contexts to the undergraduate water resources curriculum to a) reinforce traditional hydrologic concepts taught in the classroom, b) demonstrate how these unit processes may be combined to solve complex real-world engineering problems, and c) introduce new hydrologic tools and techniques being used in research and industrial settings. The objectives of the study are to:

- Investigate the use of resources provided by large-scale ecosystem restoration efforts (e.g., rich context, societal importance, and data and models) for use in enhancing the undergraduate water resources education
- Implement and evaluate effective pedagogies on active learning to support the introduction of data and modeling concepts at the undergraduate level
- Develop data and modeling learning experiences that take advantage of web-based technologies to enhance undergraduate hydrology and water resources education by (1) facilitating easy access to interactive tools to visualize real-world data in authentic contexts, (2) providing content and problem-solving tasks to engage students in systems and computational thinking, and (3) embedding user support (e.g., screencasts, video demonstrations, textual scaffolds, and formative quizzes) to check student comprehension and provide just-in-time assistance.

- Apply a design-based research methodology to identify design features and attributes that support student-centered learning of hydrology modeling concepts and skills and to inform future iterations of module development
- Generate new knowledge on challenges and obstacles facing the successful propagation, scaling, and adoption of education innovations in hydrology and water resources engineering from the perspective of academia and industry

1.3 Thesis Outline

The study is divided into three main parts presented in Chapters 2, 3, and 4. Each of these Chapters have their own introduction, body, and conclusion. The first part of the study, Chapter 2, presents the development and implementation of six data and modeling intensive learning modules situated in the Chenier Plain of coastal Louisiana. These modules are developed from data and modeling resources made available from current coastal restoration and protection studies in the area and are delivered using case-based, active learning approaches. Chapter 3 presents the development and implementation of two additional modules situated in Pecan Island Louisiana. This portion of the study employs design-based research to guide the iterative process of development, evaluation, documentation, and reflection of the modules' design features which support student-learning in hydrologic modeling concepts and skills. The third portion of the study, included in Chapter 4, focusses on a user-driven approach to understand how such educational innovations in hydrology and water resources can achieve scaleability and sustainability beyond the developing institution. Views from academia and industry are shared regarding current efforts to improve the undergraduate education of water resources and what content and features should be included to promote adoption and buy in from educators, students, and industry supporters. Chapter 5 contains a final summary and discussion and eludes to future work for successfully introducing new technology-supported hydrologic advancements in the undergraduate classroom.

2 UNLOCKING THE EDUCATIONAL VALUE OF LARGE-SCALE ECOSYSTEM RESTORATION PROJECTS: DEVELOPMENT OF STUDENT-CENTERED, MULTI-DISCIPLINARY LEARNING MODULES

2.1 Introduction

The field of hydrology has evolved to become a multi-disciplinary science that covers different physical, chemical and biological processes, spans vastly different settings (inland, estuarine and coastal) and extend across a wide spectrum of spatial and temporal scales. The hydrologic research community has strived to formulate a science vision and research agenda for achieving real advances in the theory and practices of Hydrologic Sciences (Gupta, 2001; Hooper & Foufoula-Georgiou, 2008; CUAHSI;, 2010). Key elements of this agenda include advances in observational settings, information systems, and modelling methods. While such advances are rapidly emerging in research and industrial settings, parallel investments are needed in the educational field, especially at the undergraduate level. Problems facing current approaches to hydrology education stem from the narrow focus on single system components and unit processes, thus lacking the inter-connectivity of various aquatic ecosystems that include streams, rivers, lakes, reservoirs, and wetlands. The spatio-temporal dynamics of hydro-ecological processes that span freshwater and coastal systems are rarely introduced in a formal way producing graduates who are ill-prepared to address the complex problems facing our society (e.g., coastal subsidence, pollution, water management).

Recent decades have witnessed the development and implementation of several large-scale ecosystem restoration projects aimed at understanding the complexities of human-natural coupled systems and how they can be managed to balance economic benefits and preservation of wildlife habitats. Examples of such initiatives include the Florida Comprehensive Everglades Restoration Plan (U.S. Army Corps of Engineers and U.S. Department of the Interior, 2015), the CALFED Bay-Delta Program in California (Healey, Dettinger, & Norgaard, 2008), the Chesapeake Bay Program (Chesapeake Bay Program, 2014), the Puget Sound Ecosystem Restoration Project (Gelfenbaum et al., 2006), and the Louisiana Coastal Master Plan (Coastal Protection & Restoration Authority of Louisiana, 2012). These projects and planning initiatives carry a wealth of resources and potential for enhancing education that have not been fully tapped into, especially at the undergraduate level. For example, they provide (a) natural grounds for introducing multi-disciplinary topics, (b) wealth of data and modelling resources that can support instructors in developing engaging material, and (c) motivating contexts and linkages to societal problems that are not typically covered in today's classrooms. By leveraging these large-scale initiatives, educators can take advantage of the available data, models, case-studies and context richness to develop engaging student learning experiences.

The authors recognize these regional-scale restoration projects as unique, educationally-rich ecosystems and present an example from the Louisiana Coastal Master Plan (LCMP) on how they can be used for undergraduate educational applications. Louisiana's coastal wetlands have been formed historically by the supply of freshwater and sediment deposition from local rivers. However, over the last century the natural build-up of land formation has become unstable due to anthropogenic alterations that have affected the hydrologic regime of the region. Such alterations include the construction of highways and levee systems, dredging of navigational channels, operation of gate and lock structures, and the impoundment and drainage of wetlands for agricultural, industrial, and urban use. The ultimate impact has been a decrease in land formation and an increase in land loss, which has threatened the economy, ecology, and culture of the region.

The coastal land loss crisis currently threatening the Louisiana coast has prompted the development of a multi-billion dollar coordinated effort by local, state and federal agencies to create a set of comprehensive restoration and protection plan to protect and restore the vanishing coastal wetlands. These and other parallel efforts by engineering firms, universities and research institutions have created a wealth of analytical tools, datasets and models which are ideal resources for the development of learning materials and case studies that better represent the actual working environment of hydrologists, coastal engineers and water resources managers. Building on these resources, the authors were able to focus their efforts on the educational aspects of the developments (i.e., how to tailor these resources for classroom applications), rather than on developing the content and tools from scratch. Six case studies, referred to as modules, are developed to cover a variety of hydrologic restoration concepts and proposed projects in the Chenier Plain basin of coastal Louisiana. Additionally, the modules take advantage of recent advances in the fields of geospatial visualization and web-based technologies (Cunningham, 2005; Zia, 2004). This is done by deploying the modules on an interactive online web-platform (www.hydroviz.org). The development of these modules will enable an integrated introduction of several technical concepts connecting ecosystem processes that have been traditionally separated in most educational settings. Instilling in students a more holistic understanding of such processes is key to developing well prepared graduates capable of dealing with the increasing complexity of coastal ecosystems.

This chapter is organized as follows. In the next section, we provide an overview of the Chenier Plain coastal ecosystem where the modules are situated. This is followed by a brief overview of the LCMP-related data and modelling resources that were used to develop the modules. The following section presents the pedagogical and technical approach used to facilitate the use of the LCMP and associated datasets and models for educational purposes. Next, we provide a brief description of each of the six student-centered learning modules, the student activities associated with them, and the expected student learning outcomes. The last section provides the authors' experience in implementing the modules in an undergraduate course, with a discussion of students' views, challenges encountered and final comments for future efforts.

2.2 Ecosystem

The Chenier Plain ecosystem in southwest Louisiana is the specific region under consideration for the development of the modules. It consists of approximately 2,402 mi^2 of fresh, brackish and salt marsh, open water and Chenier habitats (Gammill et al., 2002). This coastal basin is a rather unique system as it captures the transition from inland to coastal/wetland hydrology and actively serves several important ecological and economical functions. Being a multi-use ecosystem, the region faces challenges on how to reach a balanced and sustainable strategy among its various often conflicting functions (e.g., oil and gas exploration, navigation, agriculture, fishing and hunting, and wildlife preservation). From an educational perspective, this ecosystem presents an excellent opportunity to enhance students' learning about fundamental hydrological processes and linkage between hydrologic sciences and engineering and other disciplines including geomorphology, ecology and economics.

Figure 2-1 Chenier Plain Ecosystem

The Chenier Plain is divided into two main sub-basins: the Mermentau Basin, and the Calcasieu-Sabine Basin. Historically, freshwater, and nutrients from upstream basins were supplied to the region via seven major rivers (Figure 2-1). A major feature in this coastal basin is the 1,300-mile Gulf Intracoastal Water Way (GIWW) (Figure 2-1). The GIWW is 12-ft deep by 125-ft wide channel extending along the northern edge of the region (Lehto, Marcantel, & Paul, 1993) linking deep-water ports, tributaries, rivers and bayous (Us Army Corps of Engineers New Orleans District). While the navigational benefits of the GIWW are clear, it inadvertently complicates the regional hydrology by forming a major link between the different sub-basins which have historically existed as distinct systems. Additionally, the GIWW channelizes and diverts the freshwater sheet flow from upland catchments away to the Gulf thus severing freshwater flow to coastal marshes. It may occasionally act as an arterial route for salt water intrusion during times of high tide or drought. To preserve the integrity of freshwater availability in the basin for rice agricultural purposes, five major water control structures (locks and gates) have been established along the perimeter of the area (Figure 2-1). These structures have altered the natural regimes of water and salinity variability, resulting in a semi-impoundment of the entire basin. The basin hydrology has also been impacted by the construction of major highways, which have created hydraulic barriers and prevented the natural gradient flow of water from north to south, eventually resulting in a large impoundment of freshwater in the basin. The lack of freshwater and nutrients from the north and the excavation of large navigation channels, such as the Calcasieu Ship Channel, have led to an increase in saltwater intrusion and vegetation loss in this coastal zone. In an effort to restore the hydrologic regime of the basin and support its various ecosystem services, numerous restoration projects have been proposed and are either under construction or planned for future implementation, including strategies such as freshwater introduction, terracing, marsh creation and marsh management. The students learning modules described in this study are based on some of these proposed projects and how they work to restore the ecosystem.

2.3 Numerical Models and Datasets

2.3.1 Datasets

In studying the Chenier Plain ecosystem, the learning modules rely on and take advantage of the wealth of hydrologic and ecological datasets that have been developed over the years as part of past and ongoing restoration efforts in the region. These include datasets collected and archived by both federal and state agencies, such as the US Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), United States Geological Survey (USGS), the Louisiana Department of Natural Resources (LDNR), and the Louisiana Coastal Protection and Restoration Authority (CPRA). Datasets were also acquired from major wetland monitoring and restoration programs, such as the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), and the Louisiana's Coastwide Reference Monitoring System (CRMS; (Steyer et al., 2003)). Most of these datasets are accessible through online data portals and provide ample opportunities for developing data-driven learning experiences situated in an ecosystem-restoration perspective. A summary of these datasets and their online sources, if applicable, are listed in Table 2-1.

Table 2-1: Sources of datasets used in the modules

Variable	Source	Web Link
Water level	USACE	http://www2.mvn.usace.army.mil/od/lockupdates/mermentaubasin/displayindex.asp
	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#
Rainfall	USACE	http://www2.mvn.usace.army.mil/od/lockupdates/mermentaubasin/displayindex.asp
	NCDC	http://www.ncdc.noaa.gov/oa/climate/climateinventories.html
ET	IWMI	http://www.iwmi.cgiar.org/WAtlas/Default.aspx
Vegetation	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#
Streamflow	USGS	https://maps.waterdata.usgs.gov/mapper/index.html
Salinity	LDNR	http://sonris.com/dataaccess.asp
	USGS	https://maps.waterdata.usgs.gov/mapper/index.html
	CRMS	https://www.lacoast.gov/crms_viewer2/default.aspx#

2.3.2 Mass-balance Model Compartment model

In addition to these publicly available data sources, the learning modules developed in this study also use modeling resources developed as part of the 2012 Louisiana Coastal Master Plan (LCMP) (Peyronnin et al., 2013; Meselhe et al., 2013). These come from a spatially-distributed, mass-balance model that represents the hydrology of the Chenier Plain and simulates flux of both fresh and salt water within the region. Using simulation outputs from this model, students analyze the hydrologic regime (water level and salinity concentration) of the Chenier Plain under existing conditions, and due to proposed future restoration projects. The model represents the entire Chenier Plain with three types of inter-connected compartment cells: channel, open water, and marsh. Each cell is represented by two main physical characteristics: surface area and ground surface elevation or bed elevation for land and water cells, respectively. If a hydraulic connection exists between a pair of cells, these two cells are connected via a link. Each link has three physical dimensions: width, depth and length. There are a total of 162 cells and 397 links in the model covering the entire domain of the Chenier Plain (Figure 2-1). Figure 2-2 shows an example of multi-cell connectivity and how the model represents the complexity of the natural system where a single cell may be connected to multiple neighboring cells, or connected to a single neighboring cell via multiple links.

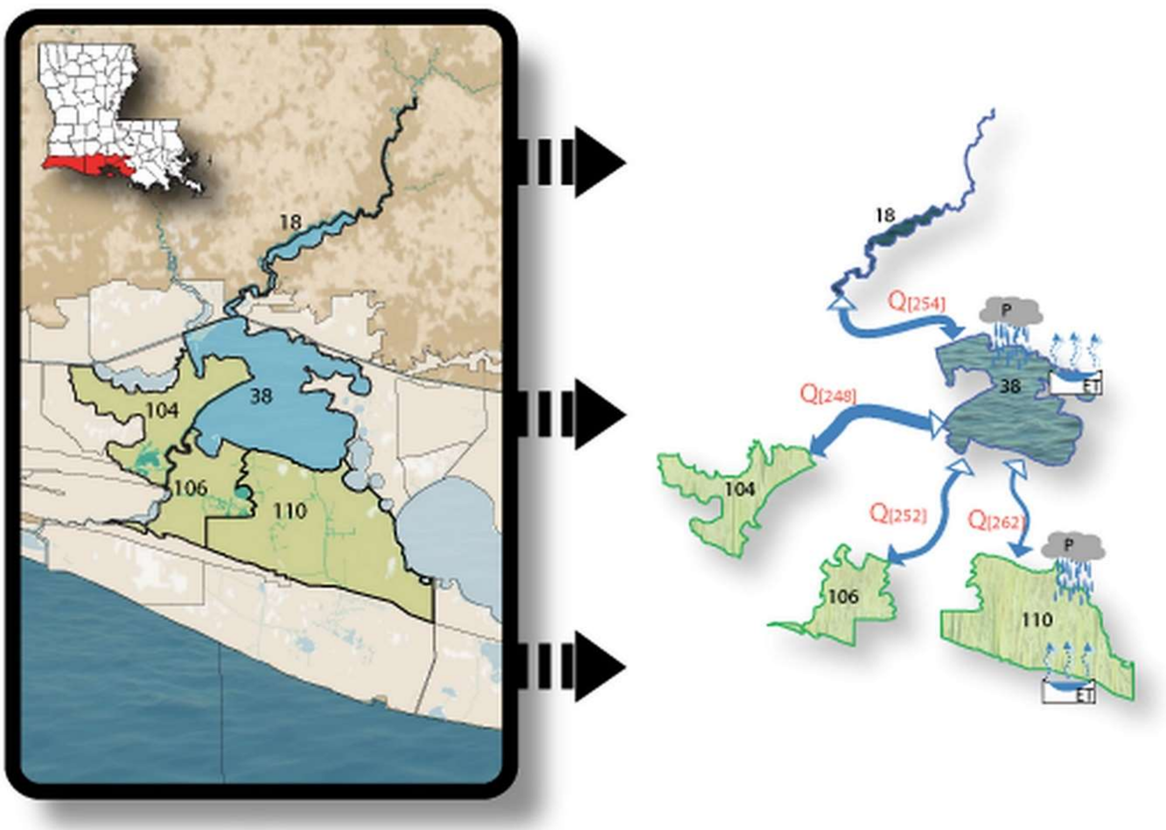

Figure 2-2: Conceptual cell and link configuration used by the hydrology model representing the Chenier Plain ecosystem in coastal Louisiana

If the connection between any two cells is through a controlled structure (e.g., a gate, a weir, or a lock), the flow of water will be calculated using the flow equation of such a structure. If the connection between two cells is not regulated (e.g., flow through an open channel, or via surface drainage or sheet flow), the flow exchange between these two cells is calculated using typical open-channel equations (e.g., Manning's equation).

In addition to the water and salt exchanges between models cells, fluxes also come from exterior sources including upstream rivers, downstream gulf passes, and atmospheric fluxes (precipitation and evapotranspiration). The contribution of the upstream basins is implemented as boundary conditions via streamflow records obtained from USGS stations for seven major rivers flowing into the region. Similarly, on the southern border of the model, a time-series of offshore water levels from NOAA gulf stations are imposed as boundary conditions. The model uses daily time series of precipitation and evapotranspiration that were acquired from online archives of the National Climatic Data Center (NCDC) and the International Water Management Institute (IWMI) World Water and Climate Atlas. The ET rates from this atlas are based on the Penman-Montieth estimation method. The model applies an ET reduction factor in marsh cells to account for the effect of plant coverage.

Applying a mass-balance approach, the water level in each cell at the prediction time step ($y(t_{k+1})$) is calculated using a recursive formula with a time step (Δt):

$$y(t_{k+1}) = y(t_k) + \left[\left(\frac{\sum Q_{in}(t_k) - \sum Q_{out}(t_k)}{A}\right) + P(t_k) - ET(t_k)\right]\Delta t \qquad (1)$$

Where, A represents the surface area of the cell, $y(t_k)$ represents the water level at the previous time step, $Q_{in}(t_k)$ and $Q_{out}(t_k)$ represent inflows and outflows exchanges with neighboring cells, and $P(t_k)$ and $ET(t_k)$ represent precipitation and evapotranspiration fluxes, respectively.

Similarly, the salt concentration in each cell can be expressed using the following equation:

$$C(t_{k+1}) = C(t_k) - \frac{C(t_k)}{V(t_k)}\left(V(t_{k+1}) - V(t_k)\right) + \frac{\Delta t}{V(t_k)}\left(\sum Q_{Salt,in}(t_k) - \sum Q_{Salt,out}(t_k)\right) \qquad (2)$$

Where C represents salt concentration, and $Q_{salt,in}$ and $Q_{salt,out}$ represent the inflow and outflow of salt fluxes, respectively. These salt fluxes are estimated as the product of water fluxes between any two connected cells multiplied and the salt concentration of the contributing cell. The middle term in this equation accounts for the dilution or concentration due to changes in water volume of the cell.

This cell and link configuration (Figure 2-2) provides a continuous coverage of the Chenier Plain allowing for modeling of protection and restoration projects and the evaluation of the long-term effects of these projects on the eco-hydrology of the region. To save model running time which can be inhibitive to student work, model inputs and outputs have been prepared and stored in online database at the same site where students access the modules. Through a geospatial online system, students can selectively download data required for analysis without needing to run the model directly. Once downloaded, students are able to apply concepts and equations of the original model in a more user-friendly and familiar environment such as Microsoft Excel. A spreadsheet software such as Excel provides a more transparent environment for numerical simulations than typical "black-box" models and has a rather moderate learning curve compared to command-line interfaces. By simulating these calculations on a smaller scale students confirm the model's performance and develop a holistic understanding of these basic hydrologic processes and how they can be applied to solve practical real-world engineering problems in a natural ecosystem.

2.4 Active Learning, Web-Based Design

Our design of the coastal-restoration learning modules was informed by educational research on the effectiveness of student-centered, active learning pedagogies. Recent data from the (National Survey of Student Engagement, 2015) suggests that coursework which emphasizes engagement in higher-order learning and the use of effective teaching strategies is more likely to lead to student motivation and success. High-impact strategies include applying knowledge to practical problems and case studies (Bransford, 2000), use of modern technology, visualization and web-based techniques (Zia, 2004), connecting learning to real-world issues and rich contexts (Hoag, Lillie, & Hoppe, 2005; Lundebrerg, Levin, & Harrington, 1999), user-support mechanisms to guide learners through the procedures while addressing a problem (Kolodner, Owensby, & Guzdial, 2004), and developing conclusions based on one's own analysis. These strategies fall under a broad category of pedagogical strategies called *active learning* (Prince, 2004), where students are actively engaged in discussing, analyzing, and collaborating. In particular, the modules were designed using technology-supported, case-based instruction with data, visualization, and simulations.

We adopt a web-based design of the modules (www.hydroviz.org) to primarily target three main attributes: (1) easy access to interactive tools to visualize real-world data in authentic contexts, (2) content and problem-solving tasks to engage students in systems and computational thinking, and (3) embedded user support (e.g., screencasts, video demonstrations, textual scaffolds, and formative quizzes) to check student comprehension and provide just-in-time assistance. To further enrich students' learning experiences, the web interface integrates the content and interactive display of data and model outputs as students explore the domain of each learning module. Figure 2-3 shows how the interface integrates the (1) table of contents and learning tasks, (2) lessons which displays full content (see Figure 2-5 for example content), (3) map displaying the model domain, relevant geospatial data and the spatio-temporal model simulations, (4) tool to toggle base map, and (5) layers of geospatial maps and datasets that can be toggled.

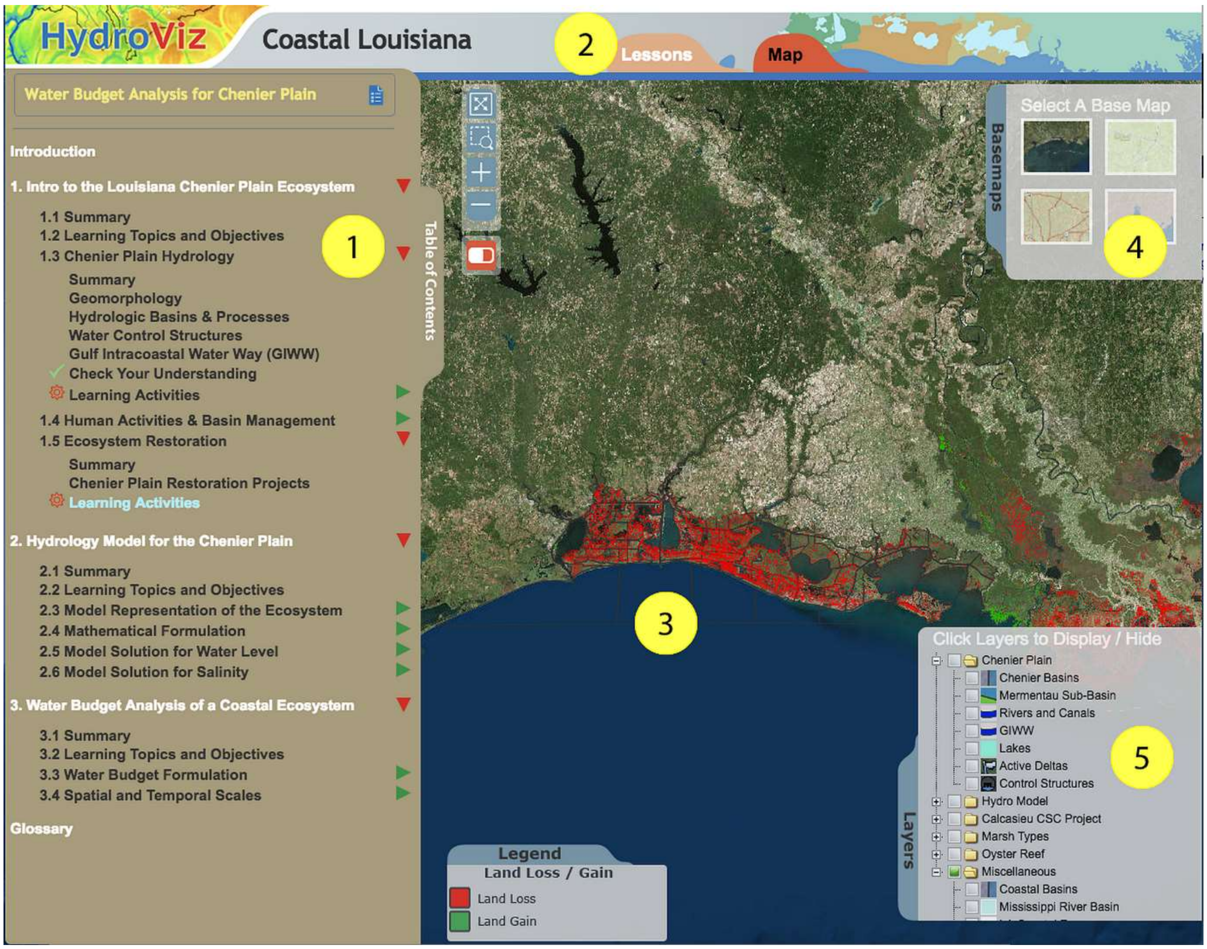

Figure 2-3: Interface of the web-based modules hosted on the Hydroviz platform (www.hydroviz.org).

Interactive access to model output is supported as the user clicks on specific cells on the map (Figure 2-4). When the cell is clicked, the interface determines the surrounding cells thereby displaying associated data in an intuitive format to support student learning.

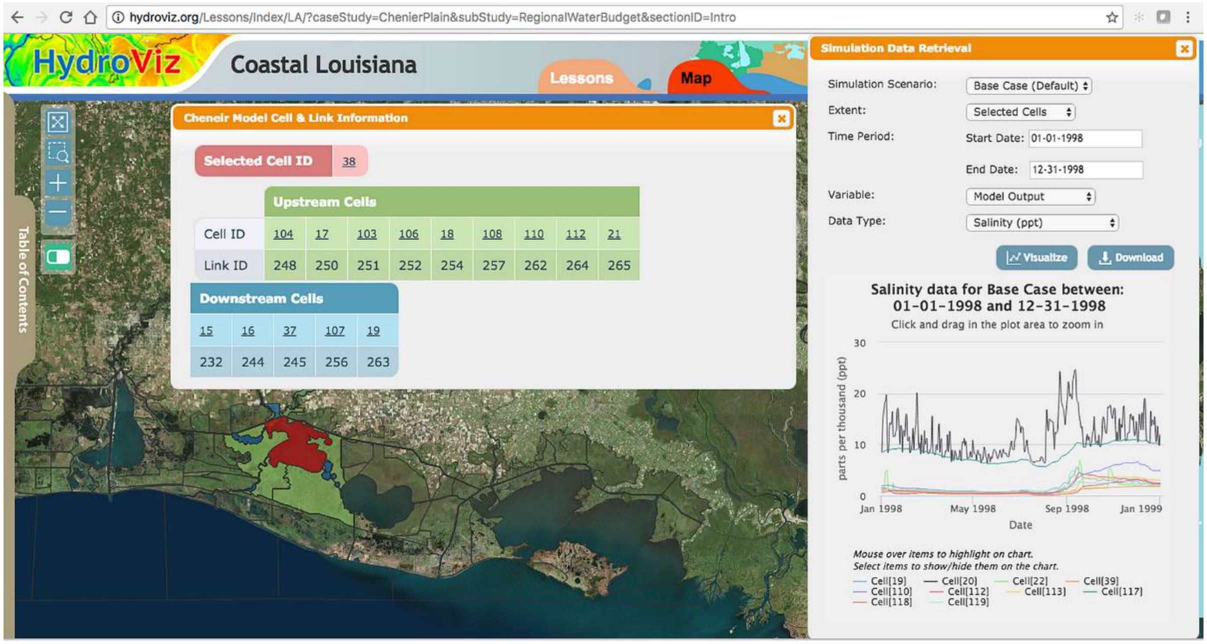

Figure 2-4: Interface illustrating interactive selection and display of model output.

As students advance through the modules, they can “check their understanding” through small interactive quizzes which refer students to sections for further study (see Figure 2-5 item 1). Each main section is followed by a set of quantitative “learning activities” that require students to perform data and modeling-driven analysis for the different modules (presented in the next section). For complex tasks, such as analyzing using geographic information system software and advanced spreadsheet operations, video tutorials and templates are provided (Figure 2-5 item 2).

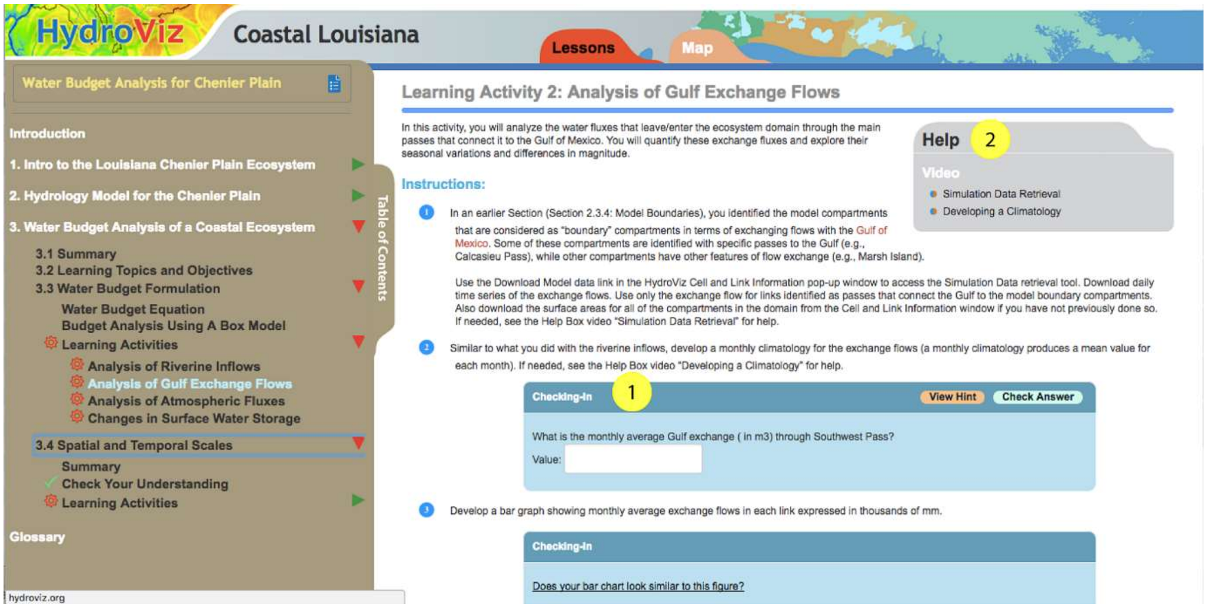

Figure 2-5: Example of Lessons Tab displaying content for each module.

To keep students aware of the overriding context and problem at hand, each module is introduced with a problem statement that provides valuable context for the case study (e.g. deteriorating wetlands in Louisiana's Chenier Plain). A concise list of key topics and expected learning outcomes are also included to support independent learning by the student and ensure their awareness of the knowledge and skills they are supposed to achieve as they complete the modules. To support instructors in implementing the modules, information on target audience, tools needed, suggested grading and rubrics, expected completion time and solution keys are also provided for each module.

2.5 Student Learning Modules

A total of six web-based modules were developed using restoration problems and projects from the Chenier Plain and the Louisiana Coastal Master Plan. The first two modules precede the rest by laying the foundational ground work; the first module introduces the complex coastal ecosystem of the Louisiana Chenier Plain, while the second module describes the mass-balanced model applied to the region for assessing potential impact of restoration efforts. The third module focuses on conducting a regional water budget of the ecosystem to reinforce student's understanding of factors contributing to the fragile hydrologic regime of the area. The fourth and fifth modules take advantage of two proposed restoration projects in the area: Calcasieu Ship Channel Salinity Control Project and Vermilion Bay Oyster Reef Restoration Project. In each of these modules students numerically simulate the physical changes of the project and then observe the relative effects on the environment; e.g., water level, salinity level, habitat suitability index, and tidal prisms. The last module concentrates on connecting the hydrologic regime to vegetation growth in the region. In doing this, students make the connection between water availability, salinity, and marsh health and productivity.

2.5.1 Module # 1: Introduction to the Ecosystem

The first module provides an overall introduction to the Chenier Plain and acts as a precursor to the later modules. This objective of the module is to familiarize students with the natural ecosystem, focusing on its large-scale physical features (e.g. basin delineation, major rivers, marsh types) and the anthropogenic alterations that occurred over the last few decades (e.g. dredging of channels, construction of major control structures, restoration efforts), and the impact they have on system hydrology. Through a series of preliminary data-analysis and literature research activities (Table 2-2), students develop a first-hand comprehension of how the natural processes combined with those resulting from the built environment have led to a persistent deterioration of the ecosystem and thus the need for ecosystem-scale restoration efforts. Such activities include examining the relationship between water level and rainfall variability (Figure 2-6), the effect of lock operations on the water level and salinity in upstream basins, and the implications of drought, excessive flooding and salinity concentration on agriculture.

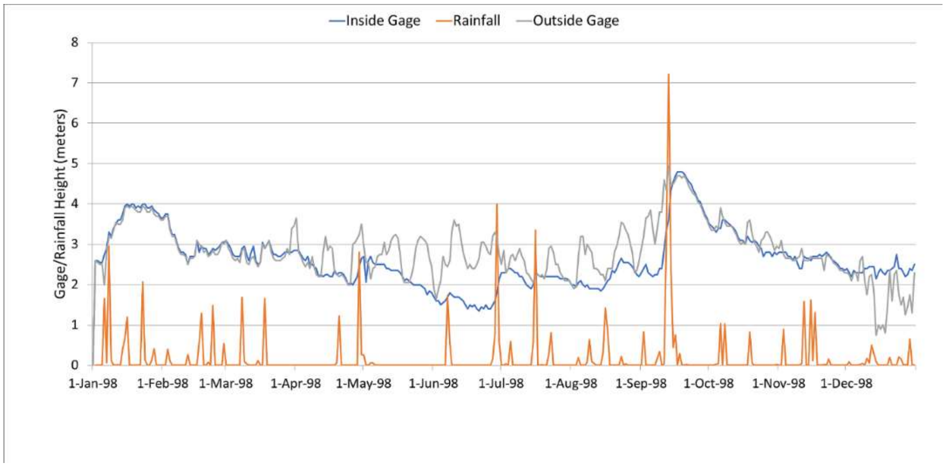

Figure 2-6: Student examine the relationship between local rainfall and variability in water level regime inside the basin and related these processes to the operation of major control structures

Table 2-2. Overview of Learning Module # 1: Introduction to the Ecosystem

Section	Subjects	Learning Activities
Ecosystem Features and Processes	Hydrologic Processes Water Control Structures Gulf Intracoastal Water Way (GIWW)	Analysis of Water Level and Rainfall Variability Analysis of Drainage Regimes
Human Activities and Ecosystem Management	Human-induced Hydrologic Alterations Conflicting Management Needs	Analysis of Salinity Variability and Implications for Agricultural Practices
Ecosystem Restoration	Chenier Plain Restoration Projects	Review of Restoration Strategies

Targeted Student Learning Outcomes

Describe major physical and hydrologic features of the ecosystem
Analyze variability in ecosystem hydrology and major fluxes
Understand role of control structures in coastal ecosystems and their impact on hydrologic variability
Understand effect of human developments on ecosystem hydrology
Develop an understanding of competing demands imposed on the ecosystem by different stakeholders
Understand the purpose of coastal restoration activities
Become familiar with online resources on coastal restoration and use them to demonstrate purpose of various restoration techniques

2.5.2 Module # 2: Hydrology Model for the Chenier Plain

In this module students are introduced to the modeling system that was developed for as part of the 2012 Coastal Master Plan in order to assess and prioritize proposed restoration and protection projects. Students are first presented with detailed information as to how the model is setup to represent the natural environment using a control volume approach. Details are given on the determination of the parameters of model cells, links between cells, model boundary conditions, and control structures operations. The mathematical formulation and numerical solution of the model are then introduced in some detail and students are asked to replicate small-scale results of the model using the previously derived mass balance equations for both water level and salinity concentration. The HydroViz site houses the model results that were produced by the model and the students are asked to re-produce the model calculations using spreadsheet software (Excel) and compare their own calculations to those produced by the model. Due to the large size of the model domain and the large number of cells involved, students perform the calculations over a sub-region of the model domain that is composed of a single basin (cell) and the other basins (cells) that are connected to it. Students calculate water and salt fluxes across the different links and use them to predict changes in daily water level and salinity concentrations. By completing this module, students would have acquired a first-hand knowledge on how spatially-distributed box models can be used to simulate the hydrology of a large-scale coastal ecosystem and changes in its water level and salinity regimes in response to freshwater and saltwater fluxes.

Table 2-3. Overview of Learning Module # 2: Hydrology Simulation Model for the Chenier Plain

Section	Subjects	Learning Activities
Model representation of the ecosystem	Model cells & links	
	Representation of hydraulic control structures	
	Model boundary conditions	
Mathematical formulation	Mass balance equation	
	Single- and multi-box model	
Model solution: Water Level	Discretization of water mass balance equation	Modeling daily changes in water level
	Model simplifications and assumptions	
Model solution: Salinity	Discretization of salt mass balance equation	Modeling daily changes in salt concentration
	Salt flux calculations	

Targeted Student Learning Outcomes
Describe how mass-balance, spatially distributed box models are used to simulate water and salt storages and fluxes in a large coastal ecosystem.
Describe how the simulation model represents physical features of the Chenier Plain as an example of a coastal ecosystem.
List types of model inputs, outputs, and boundary conditions
Describe the mathematical formulation of spatially-distributed box models and their numerical solutions
Apply a numerical scheme to solve model equations
Calculate temporal and spatial changes in water level and salinity across a large coastal ecosystem

2.5.3 Module # 3: Water Budget Analysis for a Coastal Ecosystem

Water budget analysis of large coastal basins provide a basis for understanding the hydrologic and ecologic processes of the ecosystem, its ecological functions and services, and predicting effects of natural and human hydrologic alterations. In this module, students use the output of the spatially-distributed mass-balance model (developed earlier in Module

2) to perform a water budget analysis for the entire Louisiana Chenier Plain ecosystem. They begin by examining the major water budget components: riverine inflows to the system from upstream catchments, tidal exchanges with the Gulf of Mexico, and atmospheric fluxes in the form of precipitation and evapotranspiration. Students develop a monthly climatology (i.e., 20-year average for each month) for each of these hydrologic components and examine their relative magnitudes, seasonal variability, and inter-correlations (Figure 2-7). These boundary fluxes are then used to calculate the change in the surface water storage for the ecosystem by using the continuity equation and treating the entirety Chenier Plain as a single control volume. As part of these activities, students are exposed to how a water budget analysis can be performed at different scales spatially (single basin, region) and temporally (seasonal, annual). Students also develop an understanding of the natural variability in the water budget both at inter-annual and intra-annual scales. Students are then asked to connect such variability to the overall climatology of the region and its historical drought and flood years using indices such as the Palmer Drought Severity Index (PDSI) and its hydrologic version know as Palmer Hydrological Drought Index (PHDI). The module asks students to reflect on their analysis and synthesize their results by answering questions on the dominant water budget components, how the water budget changes seasonally, possible causes of the seasonal variations in the water storage term, the role of riverine inflows that bring freshwater into ecosystem in relationship to water fluxes that exits the system through Gulf passes. Students are also asked to discuss the implications of their observations on the loss of freshwater from the ecosystem and the potential for saltwater intrusion from the Gulf.

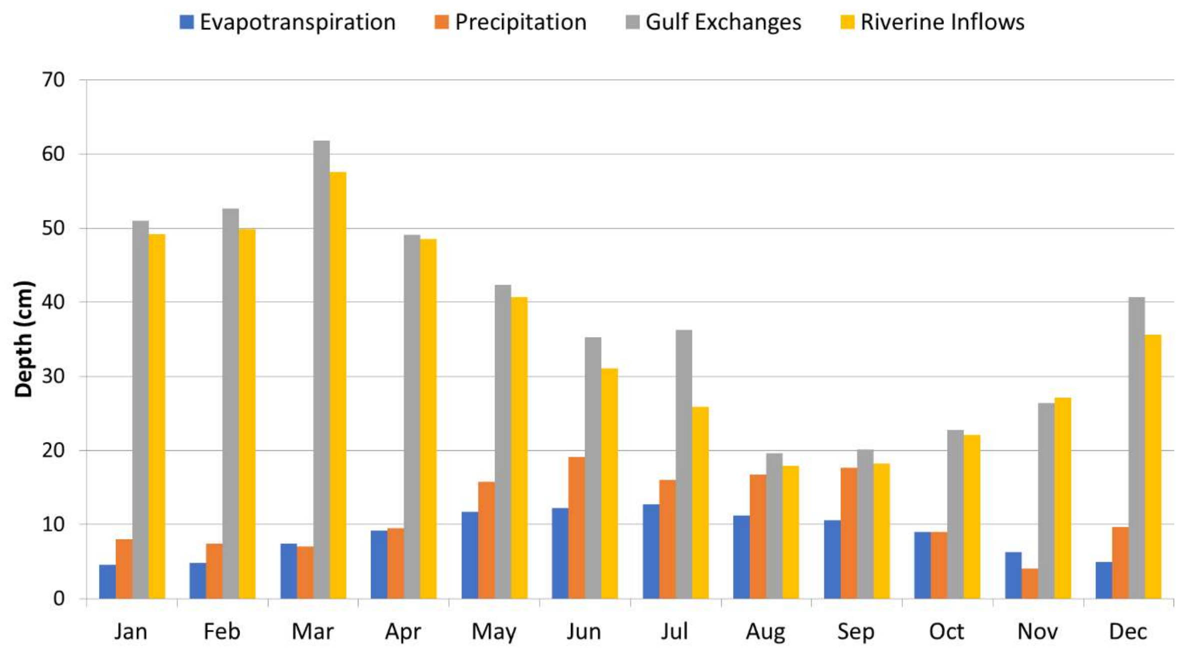

Figure 2-7: Student analysis of seasonal variability in the water budget of the Chenier Plain

Table 2-4. Overview of Learning Module # 3: Water Budget Analysis for a Coastal Ecosystem

Section	Subjects	Learning Activities
Water budget formulation	Water budget equation Budget analysis using a mass-balance spatially distributed box model	Analysis of Riverine Inflows Analysis of Gulf Exchange Flows Analysis of Atmospheric Fluxes Estimation of Changes in Surface Water Storage
Budget scales	Spatial & Temporal Scales	Inter- and Intra-annual variability
Targeted Student Learning Outcomes		
Define main components of a water budget in a coastal ecosystem Formulate and perform a mass-balance water budget analysis for a coastal ecosystem Analyze dominant hydrologic processes for flow exchanges and water level variability in a coastal ecosystem Become familiar with websites that house long-term coastal hydrology datasets Analyze inter- and intra-annual variability in main hydrologic processes Discuss the implications of variability in water budget from an ecosystem service perspective		

2.5.4 Module # 4: Case Study - Calcasieu Ship Channel (CSC) Salinity Control Project

One of the main drivers of coastal wetland loss in Louisiana is saltwater intrusion into fresh and brackish marsh areas. With the excavation of navigation canals and the widening and deepening of existing waterways, saltwater from the Gulf of Mexico can easily penetrate through the shoreline causing plants to die and enhancing soil erosive processes, especially during tropical storms. This situation is best illustrated in the southwestern region of the Chenier Plain where a major navigation waterway (Calcasieu Ship Channel, CSC) is located. This module guides the students through a set of activities (Table 5) to analyze the existing hydrologic conditions in the CSC region, and investigate different alternatives for salinity control measures. The over-riding theme is how to prevent saltwater intrusion from entering Calcasieu Lake through the Calcasieu Ship Channel, while allowing for the continued functioning of the Calcasieu Ship Channel and the Port of Lake Charles.

The module starts with an overview of the project area and analysis of its hydrologic regime, and then moves to a quantitative evaluation of four different alternatives that are proposed for the salinity control measures. Each alternative represents a different method of controlling the quantity of salt water entering the CSC and the surrounding marsh areas. This is achieved using different combinations of hydraulic control structures such as locks, gates, sills, and impermeable control structures (Figure 2-8). Students use the same mass-balance box model described earlier to simulate and analyze the potential impact of the different CSC project alternatives. The module introduces students to how hydraulic structures and their operations can be represented in the model by modifying the connecting links to ensure that the exchange flows have been reduced or increased appropriately based on the type of structure. Next, students will use model outputs for each alternative and assess the impact on key hydrologic attributes such as water levels and salinity concentrations in the project area with and without the proposed alternative. They also quantify the impact on integrative metrics such as the tidal prism and exchange with the Calcasieu Lake and the surrounding wetland areas. The module closes with a set of investigative questions that require the students to reflect on their results and assess the different proposed alternatives considering other factors besides salinity reduction. For example, students reflect on how each alternative might affect navigation through the CSC during construction and over the course of long term operations; which option would likely cost the most, and which alternative appear to require the most coordination with private land owners.

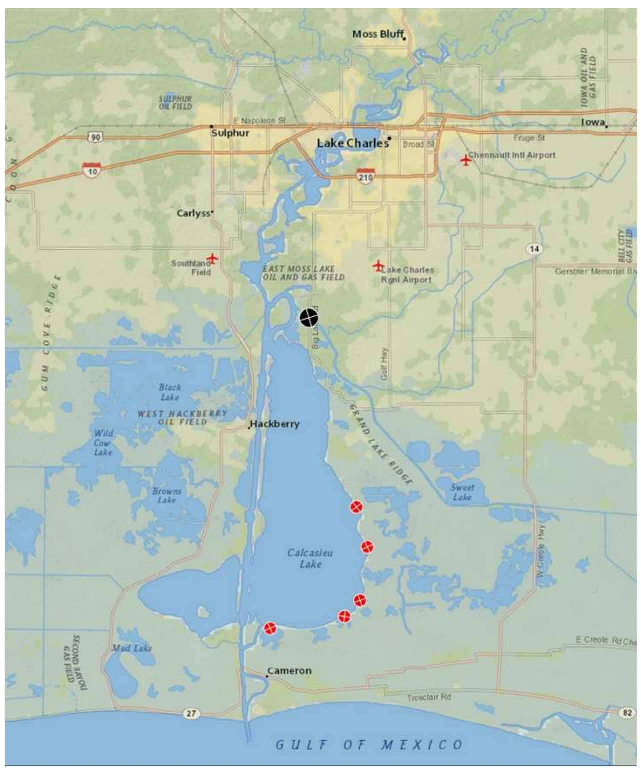

Figure 2-8: Calcasieu Ship Channel showing existing hydrologic connectivity: control structures (red circles), Calcasieu Lock (black circle)

Table 2-5. Overview of Learning Module # 4: Calcasieu Ship Channel (CSC) Salinity Control Project Case Study

Section	Subjects	Learning Activities
Introduction to the Calcasieu Ship Channel Salinity Control project	Project location Need for project Hydrologic features	Analysis of site hydrology
Tidal exchange in an estuarine system	Tidal prism	Analysis of tidal exchange
Modeling project alternatives	Project Alternatives Model modifications Assessment of project alternative impacts	Effect on Water Level & Salinity Effect on Lake Tidal Exchange Comparative evaluation of different alternatives

Targeted Student Learning Outcomes
Identify the overall objectives of a major restoration project and place these objectives in context with reasonable and achievable goals of individual project alternatives
Analyze and quantify the effect of hydraulic structures and other restoration measures on ecosystem performance, specifically the salinity dynamics
Identify and analyze the hydrologic/ecologic factors that are directly and indirectly impacted by the salinity control restoration project alternatives
Discuss tradeoffs in project selection and be able to make recommendations on which project alternative (or alternatives) should be selected and why

2.5.5 Module # 5: Case Study - Vermilion Bay Oyster Reef Restoration Project

Bioengineered oyster reefs are used as a viable restoration measure in many estuarine ecosystems in the US and other world regions. They provide structural protection of shorelines as they act barriers against storm surges, and they also provide ecosystem services in the form of habitat for oyster. As part of the 2012 Louisiana Coastal Master Plan, an oyster reef restoration project has been proposed for the Vermilion Bay in the Teche/Vermilion Basin in the Chenier Plain ecosystem. The proposed oyster reef will be located along the boundary between the West Cote Blanche Bay and the East Cote Blanche Bay (Figure 2-9).

In this module, students perform a modeling-based analysis to investigate how the oyster reef will impact the hydrologic regime in the proposed site, assess whether it can successfully meet its restoration goal, and examine potentially negative impacts it might have on habitat suitability for other key harvesting species that the ecosystem supports. To do so, student use the same model they developed in earlier modules to predict changes in water level, salinity and exchange flows as a result of building the oyster reef in the proposed location. The module guides the students through a series of activities (Table 6) that start with modifying the existing model to simulate the presence of the reef. They do so by changing the hydraulic characteristics of link connecting the two model cells of West and East Cote Blanche Bays, which will be separated by the reef. Pre- and post-project simulations are then performed for two representative years (low versus high sea levels), which also include a large tropical storm that hit the region in 1998. Students analyze the effectiveness of the reef in reducing wave impacts by examining the reduction in the amplitude of water level variability within the bay and the overall reduction in exchange flows with the Gulf, especially during extreme weather events. Students are also asked to examine whether the reef has resulted in an increase in exchange flows in other areas, which can possibly lead to shoreline erosion. Closing the module, students are then asked to reflect on their results and assess whether the proposed reef accomplishes its intended goal, whether there will be any negative impacts, and if the negative impacts outweigh the anticipated benefits, and if they can propose measures by which the negative impacts can be mitigated.

Figure 2-9: Oyster reef restoration project

Table 2-6. Overview of Learning Module # 5: Vermilion Bay Oyster Reef Restoration Project Case Study

Section	Subjects	Learning Activities
Introduction to the oyster reef restoration project	Why oyster reefs Project hydrologic and vegetation regimes	Delineation of project domain Water budget analysis
Modeling an oyster reef project l	Model modifications	Impact on water level variability Impact on salinity
Tradeoff assessment	Desirable versus undesirable impacts Habitat suitability for wildlife species	Effect on shoreline protection Impact on Gulf exchange flows Impact on brown shrimp habitat

Targeted Student Learning Outcomes
Describe the use of oyster reefs as a coastal restoration/protection strategy
Describe use of mass-balance models to represent an oyster reef project and simulate its hydrologic impacts
Analyze water level and salinity patterns to determine the hydrologic impact of introducing an oyster reef project
Analyze the role of oyster reefs during extreme events
Evaluate habitat suitability indices under different hydrologic conditions with and without the oyster reef project
Analyze positive and negative impacts of an oyster reef restoration project on hydrologic regime in the ecosystem and its ecological services

2.5.6 Module # 6: Analysis of vegetation changes

The ultimate goal of coastal restoration projects is to promote the creation and protection of a variety of habitats within the ecosystem. Successful habitat creation relies on our ability to predict which plant communities will result from proposed management and restoration actions. Habitat restoration, creation, and protection are achieved by manipulating hydrologic conditions, mainly flooding and salinity regimes, in order to promote desired plant communities. However, the relationships that govern the response of wetland ecosystems to hydrologic manipulations are quite complex. This module builds a basic understanding of hydrology and vegetation interconnections and provides a quantitative analysis of how the hydrologic regime (e.g., flooding frequency and salinity variability) impacts changes in wetland types, vegetation, and plant species. The module includes interpretation of hydro-ecological field observations, as well as modeling and analysis of hydrologic indices for assessment of marsh health and productivity.

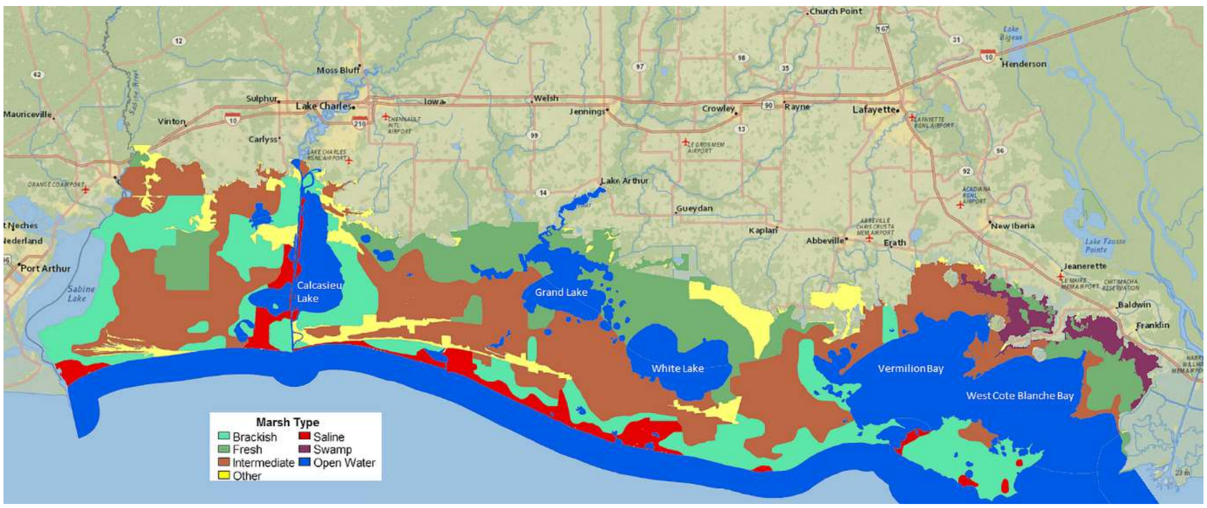

Figure 2-10: Marsh classification based on vegetation types

Table 2-7. Overview of Learning Module # 6: Analysis of vegetation changes due to hydrologic regime alteration

Section	Subjects	Learning Activities
Hydrology regime and marsh classification	Marsh and vegetation types Interactions between hydrology and vegetation regimes	Introduction to the Coastwide Reference Monitoring System (CRMS) Marsh Classification Based on Salinity & Water Level Variability
Vegetation productivity and hydrology	Hydrologic Index (HI)	Assessment of hydrologic stress on vegetation
Modeling changes in submerged aquatic vegetation (SAV)	Regression model for submerged aquatic vegetation	Estimating net changes in submerged aquatic vegetation

Targeted Student Learning Outcomes
Become familiar with a coast-wide monitoring system and access hydrologic and vegetation data online
Describe different methods used to determine and classify marsh and vegetation types
Analyze hydrologic regime (salinity and water level magnitudes and variability) and determine marsh type
Assess the health and productivity of marsh using a Hydrologic Index
Describe the hydrologic drivers of changes in marsh vegetation composition
Estimate changes in vegetation composition using output of a hydrology simulation model

2.6 Class Implementation and Evaluation

Evaluation of educational developments, such as those described in this study, is a critical component that can help assess their actual benefits from a student learning perspective. While a full evaluation and assessment is beyond the scope of this study, we present insights from a pilot-scale implementation of the modules in two elective courses at the University of Louisiana at Lafayette. The class consisted of a mixture of four undergraduate students and five first-year graduate students. The modules were assigned as out-of-class assignments for which students were allotted 1-4 weeks to complete each module, depending on the length and difficulty of the particular module. Upon completion of the modules, students presented and discussed their results in follow-up in-class sessions with their peers and the instructor. Students submissions were graded using pre-developed rubrics which were made available to students to inform them of both what should be submitted and to stress the relative importance of each section of the respective module. With the exception of the "Water Budget Analysis for a Coastal Ecosystem" module, students were able to successfully complete the different learning activities and provide adequate analysis and discussions of the results. The less than satisfactory performance on the basin-wide, water-budget module was attributed to the unusually large datasets and models output associated with this module which can be best approached using some programming skills that undergraduate students typically lack.

In addition to grades, informal interviews were conducted at the conclusion of each course where modules were introduced. The purpose of these interviews was to gather qualitative assessment data on students' perception of the usability of the modules and the design attributes that support their learning experiences (e.g., clarity of instructions, quality and quantity of user support), and on the effectiveness of using the modules as an instructional approach and whether they stimulate students' interests and improve their learning in the field of coastal hydrology and ecosystem restoration. In regards to usability, students expressed an appreciation for the web-based design of the modules and the availability of a geospatial navigation component where they can access the specific sites of the restoration projects and interact with related datasets and model outputs, all in one environment. Student appreciated the map component of the website which allowed them to visually understand the textual context of the modules especially when references were made to the geographical layout of the model domain. Additionally, the overlays allowed self-navigation of the domain and enabled students to locate features necessary in the activities as well as items of personal interest (evidence of intrigue). Design elements that were most valued by the students were the user-support mechanisms embedded into the modules. The concept of the “checking ins” and “check your understanding” quizzes were very popular and students recommended areas within the modules were quizzes could be further implemented to confirm students’ answers and understanding and avoid error-build up, especially when the analysis requires lengthy calculations and simulations. Additionally, students indicated that support mechanisms such as videos, instructional images, and templates were highly useful and likewise requested the inclusion of more in difficult areas of specific activities. Students even suggested including additional forms of support such as warnings in sections where common mistakes are made.

The use of learning activities that stem from actual, large-scale restoration projects as an instructional approach was well received by the students. The inclusion of the first two modules as predecessors of the other modules was deemed an excellent idea for they sufficiently introduced the ecosystem for individuals not familiar with the area and familiarized the students with the structure and concepts of the mass-balance model which were used in the later modules. Students were very grateful for the case-based learning of the modules. They mentioned that the hands-on approach was very appealing and was something not available in their other classes. They felt learning from real-world cases studies that are of regional or national prominence stimulated their interest in the field. Students also cited how these data and modelling-rich learning environments helped them gain skills that would be useful in their future careers. The use of real-world problems and case-based approach was helpful to ground their learning in a systematic fashion, starting from data collection and pre-processing, to modelling analysis and decision making. Specifically, students mentioned their new knowledge of advanced spreadsheet operations and programming and the challenges associated with using large datasets as very beneficial skills for the future. While both undergraduate and graduate students appreciated the learning experiences offered by the modules, their views differed on some issues related to the specificity of the learning tasks. While undergraduate students expressed deep appreciation for the detailed step-by-step instructions, several graduate students mentioned that the instructions were too specific in some areas; which prevented them from being able to approach the problem in their own way. They argued that while the very detailed instructions allowed everyone to get to the final answer, all answers were essentially "clones" of the same approach. In this way, they felt the instructions should be more open-ended so as to not take away from the investigative component of the student-centered approach.

2.7 Summary and Conclusions

This chapter presented the development of a set of undergraduate learning modules that leverage data and modeling resources from large-scale restoration projects and planning studies. Building on the complexity and deep context of these projects, the learning modules immerse students in real-world ecosystem problems and guides them through a series of analysis using data and modeling techniques to determine the relative feasibility and impact of different coastal restoration measures. Students get context-rich experiences in using data and model outputs currently being used in real-world assessment of potential multi-million-dollar projects in coastal ecosystems. In this way students are introduced to the complexities of altering the hydrologic regime of fragile ecosystems, consider cross-discipline ramifications of such alterations (e.g., vegetation, habitat suitability, navigation industry), and develop an appreciation of data scarcity and model complexities and limitations in designing and testing the feasibility of proposed restoration projects.

The modules developed in this study are built using case studies and actual restoration projects in coastal Louisiana. A total of six modules expose students to inter-disciplinary subjects and investigative tasks such as regional-scale water budget analysis, inter- and intra-annual variabilities in hydrologic processes, analysis of alternatives for managing salinity intrusion and navigational needs, hydro-ecologic and social tradeoffs in using restoration projects aimed at attenuating coastal erosive processes, and the impact of hydrologic changes from vegetation and habitat suitability perspectives. As students work on these modules, they are exposed to contemporary topics that deal with social and natural dimensions of ecosystems, and at the same time gain valuable skills on how data and models are being used within the context of large-scale restoration projects.

The modules were subject to a qualitative evaluation in two hydrology engineering elective courses. While large-scale, multi-discipline restoration projects bring exciting and unique learning opportunities that the community should tap into, they also come with developmental and implementation challenges. In the following, we provide a discussion of lessons learned and challenges we encountered that may guide similar future efforts by the hydrology and coastal educational community at large, and hopefully provide a framework for the development of authentic learning experiences that take advantage of the unique resources and societal contexts of coastal ecosystem restoration projects:

- The modules were assigned as independent, out-of-class projects. Students' performance in the different tasks, as well as the feedback received from post-module interviews, provided valuable insights on their perceptions of the educational value of using large-scale restoration projects for educational activities. Overall, students indicated that the modules were an excellent change of pace from traditional classroom topics, and many of them appreciated the exposure to critical ecosystem restoration problems and the role engineers and scientists play within these multi-discipline systems.

- The use of learning modules that are rich in content, large in scope and heavy in use of data and models, can be overwhelming to both students and professors. Students can potentially get overwhelmed by these types of assignments and might develop learning resistance that defeat the intended outcomes. In developing these resources, it is critical to strike the right balance between the level of detailedness and step-by-step procedural instructions that allow successful task completion, and the open-ended directions that promote hypothesis formulation and inquiry-based learning.
- Based on student feedback, user-support and feedback mechanisms were critical in facilitating their work; however, foreseeing where students might make mistakes or need assistance is a challenge. For this reason, developers must be careful to present material with the proper curricular expectations, ensure connections to basic concepts that the students are familiar with, and embed interactive tools to support students' progression through the lessons and activities. Inclusion of user support such as video tutorials, geospatial visualization tools, and formative feedback quizzes can help to reduce the steep learning curves often associated with such approaches.
- When implementing these types of learning activities in a course, much thought should be given to time limitations. To ensure that students do not lose the overall purpose of the project at hand, modules should be able to be completed within a relatively short period of time; on the other hand, students need sufficient time to work through the

activities, analyze and discuss results, and then potentially address mistakes made. If a module is being used to reinforce concepts taught in the classroom, then perhaps it makes sense to introduce the module at the end of the semester; however, this may result in overlap with end of the semester exams and deadlines. This overlap tends to restrict students time and may result in poor performance in module activities and thus reduced educational benefit.

- It is highly recommended that instructors interested in taking advantage of resources available through large-scale ecosystem restoration and planning endeavors approach and collaborate with state and federal agencies that are in charge of these systems, as well as with consulting firms who are engaged in the design and implementation phases. These entities provide unique perspectives to support the formulation of meaningful student problems, and access to the necessary datasets and model outputs. Establishing a working partnership between the educational and agency communities can significantly reduce development effort on the instructors and affords the institution the opportunity to have a significant impact on the undergraduate education and the respective field as a whole.
- Assessing the actual impact on student learning from these types of modules, especially in a quantitative manner, is another challenge. The fact that the inter-disciplinary topics and data and modeling concepts targeted by the modules are not typically covered in traditional curricula, makes it difficult to objectively assess students' performance using well-established methodologies such as the use of control groups. Also, the complex nature of the activities, where students are required to retrieve and pre-process data, use

their judgment and intuition to make decisions, and present and discuss results, may lead them to different paths, thus making assessment and evaluation fairly challenging.

- Finally, dissemination and adoption of the types of modules proposed in this study is yet another challenge. We need to develop a better understanding on how other instructors see the value of such approaches at the undergraduate level, and how much resistance or receptiveness Is expected from students and professors. Other factors relate to how students from other geographical regions appreciate the context of learning content and tasks developed for an ecosystem or a basin outside of their regional proximity. Future efforts that provide answers to these questions may encourage the development of similar efforts that draw from the educational power of large-scale regional coastal ecosystem projects to make a larger impact beyond individual institutions.

3 ACTIVE LEARNING MODULE TO ENHANCE DATA AND MODELING SKILLS IN UNDERGRADUATE WATER RESOURCES ENGINEERING EDUCATION

3.1 Introduction

The use of numerical models and data-based analyses has become an established practice in both industrial and research settings in the field of hydrology and water resources engineering (Beven, 2001). However, the use of these tools in undergraduate water-related courses is largely lagging. The desire to introduce advanced data and modeling-based activities in undergraduate settings has been emphasized by several initiatives within the hydrologic community (e.g., (CUAHSI, 2010; Ruddell & Wagener, 2014)). The use of modeling tools can provide unique benefits to students that facilitate hypothesis and discovery-driven learning (de Jong & Van Joolingen, 1998; Prince & Felder, 2006) and provides a more holistic understanding of materials (Wagener et al., 2010). Additionally, using modeling tools and data resources that will be used in a future career promotes motivation and increases knowledge transfer to non-academic contexts (Merwade and Ruddell, 2010). While the values of data and model-based learning in hydrology have been evident since the early development of hydrologic modeling techniques (National Research Council, 1991), the best way to integrate these concepts and resources into existing curricula is still a widely debated subject. The introduction of modeling and data-based activities in undergraduate courses is complicated by the fact that, in many universities, hydrology and water resources engineering is taught in a single course that encompasses diverse areas of the subject leaving little time for additional material that focus on data analysis and modeling (Wagener et al., 2012). Therefore, the most likely mode for integrating these resources into existing undergraduate water resources classrooms is through assignments (e.g., mini-projects) that rely on independent work by the students, with the instructors playing a supporting role. This strategy of implementation was iterated in a recent survey of hydrology faculty (Ruddell & Wagener, 2014; Merwade & Ruddell, 2010) who indicated that data and model-driven activities should be used as a supplement to augment traditional classroom teaching methods. While this student-centered, instructor-independent strategy offers solutions for overcoming in-class time limitations, it presents challenges for the design of model-based learning resources. The processes involved in model development and application (e.g., setup, calibration, data pre- and post-processing) can be overwhelming to students and the associated learning curves tend to be quite steep, especially when undergraduate students represent the main audience. Therefore, the design of any new modeling-based learning resources should alleviate the need for direct instructor assistance. Such designs can also support the scalability of modeling-based innovations in hydrology education. As suggested by Rogers' theory on diffusion of innovation (Rogers, 2003), and in more recent studies in the field of engineering education (e.g., (Bourrie, Cegielski, Jones-Farmer, & Sankar, What makes educational innovations stick? A Delphi Approach, 2014)), the design attributes of a certain innovation can play a major role in achieving a scalability solution and future adoption by the teaching community.

The current study presents an effort to better understand how data and modeling-based learning activities can be designed using a student-centered approach that potentially lead to a sustainable solution for introducing state-of-the-art research and industry resources into undergraduate hydrology and water resources engineering courses. This chapter presents the development, implementation and evaluation of an active-learning module that adopts a case-based, problem-based approach to introduce hydrologic modeling concepts and skills into undergraduate curriculum. The design of the learning builds on the evidence-based research on how user-support mechanisms, scaffolding and corrective feedback can keep the learning activities interactive (Menekse, Stump, Krause, & Chi, 2013) and thus provide highly effective approaches for improving student learning (Chi, 2009). The study adopts a design-based research approach (Design-based Research Collective, 2003) and implements an iterative process of module development, evaluation, documentation, and reflection. The evaluation focuses on identifying design features and attributes that support student-centered learning of hydrology modeling concepts and skills, and how to reduce the steep learning curves, typical of modeling-based activities, which can render the use of these types of resources rather unappealing for many instructors and students. Another critical, but less appreciated factor that may impact the successful introduction of active-learning material is student resistance (Seidel & Tanner, 2013; Borrego, Froyd, & Hall, 2010; Keeney-Kennicutt, Gunersel, & Simpson, 2008). Therefore, we also attempt to provide insight on students' receptiveness to the use of modeling-based activities such as the one developed in this study and the perceptions they develop after they use it as part of the course. The study formulates a set of design principles to inform parallel and future activities that aim at the development and use of modeling and data-based learning resources in undergraduate settings.

3.2 Case Study on a Hydrologic Restoration Project

Besides the well-established research on the effectiveness of case-based and active-learning pedagogies (Thompson, Ngambeki, Troch, Sivapalan, & Evangelou, 2012; Prince M. , Does active learning work? A review of the research, 2004), the use of actual case studies provides a natural solution for introducing the desired modeling concepts and skills. Using a case-based approach, students are immersed in an active hydrological learning environment, where they are presented with an overall context (technical, environmental, and societal) of the problem at hand, and at the same time, confronted with the limitations in the available data, analytical tools and simulation models. The current study is developed from a real-world hydrologic case study located in Pecan Island, Louisiana. The project was part of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) that aims at the restoration of Louisiana coastal resources. Pecan Island is a small community located in Vermillion Parish, Louisiana (Figure 3-1).

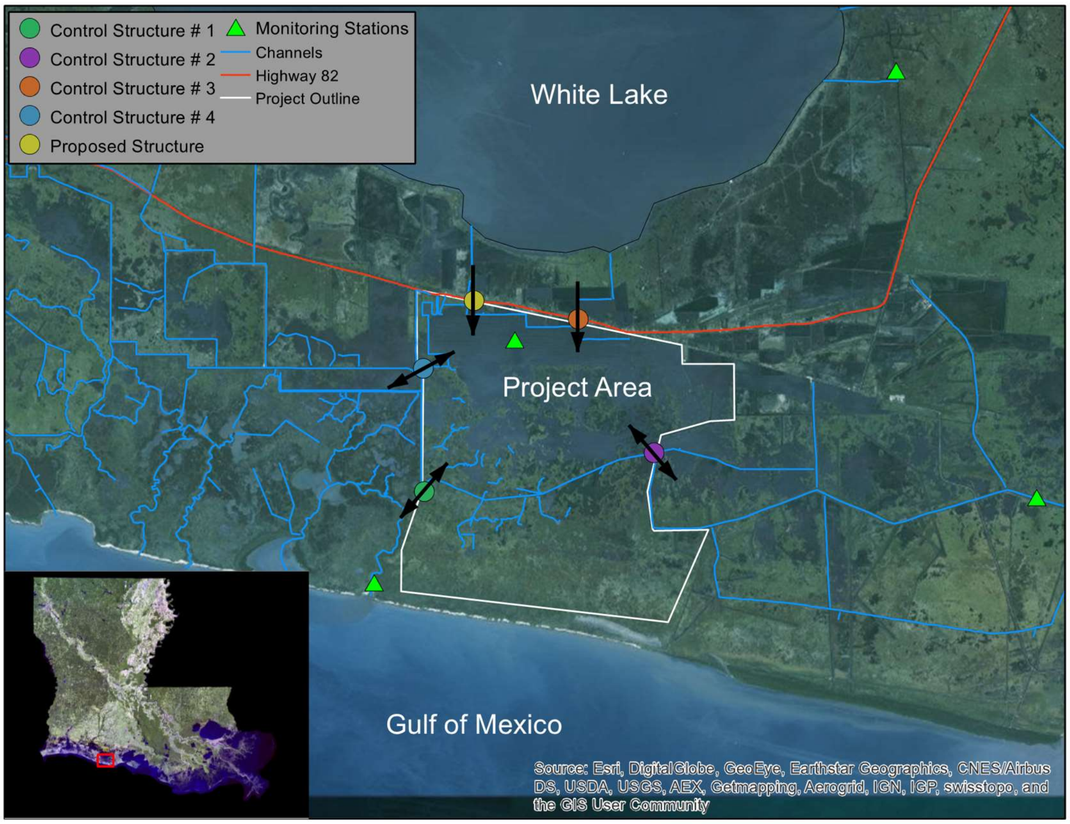

Figure 3-1 Schematic map of the Pecan Island project area showing the project outline (white lines), channels (blue lines), Highway 82 (red lines), hydraulic structures that control water exchange and salt fluxes (dots), and observational stations used to setup and calibrate the model (green triangles).

The island is not fully surrounded by water, but rather sits atop two large chenier ridges. Pecan Island is surrounded by a marsh system and to the north of it lies a large fresh water body, the White Lake. Since early 1900's, the Pecan Island has experienced accelerated land loss resulting from saltwater intrusion from the Gulf of Mexico due to construction of navigation channels and oil and gas access canals, and the severing of freshwater supply from the White Lake due to the construction of major highways. Over the years these modifications have turned the historically fresh-intermediate marsh into an intermediate-brackish marsh and have accelerated the conversion of land into open water. The rate of land loss has been persistently growing, which called for preventative and restoration measures to restore wetlands in the project area. In early 1990's, a hydraulic structure was constructed under Highway 82 to deliver freshwater and nutrients to the marshes within the Pecan Island area. However, with the continued land loss rate in the area, a new hydrologic restoration project was proposed to enhance the introduction of freshwater and sediment from White Lake to reduce salinity levels. The proposed project comprises two main components: (a) excavation of a conveyance channel to deliver freshwater from White Lake to the project area crossing Highway 82, and (b) construction of an additional control structure beneath Highway 82 consisting of four culverts. By adopting this restoration project as a student-driven module, students will be investigating the feasibility and the design of different project components using data and modeling-driven learning activities.

3.3 Module Design

The module design is based on using the following main technical and pedagogical attributes: use of a real-world case study situated in an actual hydrologic setting; and use of community-based resources, including online datasets and freeware simulation models that are typically used by the engineering industry. The module was developed using a web-based design where all the datasets, instructions, learning activities, and supporting materials are integrated and accessible via a publicly available web interface. The module is comprised of two phases and can be accessed at the following two links: (Phase 1: http://hydroviz.org/Lessons/Index/LA/PecanIslandFeasibility and Phase 2:

http://hydroviz.org/Lessons/Index/LA/PecanIslandChannelDesign), both located on the site of the HydroViz learning platform (www.hydroviz.org).

As illustrated in Figure 3-2, the web-based design leverages the power of open-source geospatial visualization and navigation technologies by embedding an interactive map within the same interface so that students can navigate project site, download data, and perform geospatial analysis. Recent research has shown that involving students in making predictions followed by observations, reflection, and discussions can increase their learning (Prince & Felder, 2006; Crouch, Fagen, Callan, & Mazur, 2004). Therefore, the module adopts an active-learning and student-centered approach and uses a set of student-driven "Learning Activities" that incorporate deeper student inquiry. These learning activities are grouped into two main phases of the restoration project. The first phase, "Feasibility Study", concentrates on developing a mass balance model to determine the feasibility of the freshwater introduction project. The second phase, "Hydraulic Design", concentrates on using a one-dimensional unsteady flow model to assist in the hydraulic design of a proposed conveyance channel. The first phase of this module uses an instructional scaffolding technique to guide students through the construction of a numerical model in a spreadsheet environment (Microsoft Excel). Employing a familiar spreadsheet program in the development of a model mitigates the amount of uncertainty that students encounter and thus promotes confidence in their ability to succeed. Additionally, the use of a spreadsheet makes the model formulation and development transparent and more intuitive to students, as opposed to the more commonly used "black-box" presentations. The industry-standard river analysis software (HEC-RAS) was chosen for this module due to its free availability, wide use in the engineering profession by government agencies and private firms, and its user-friendly graphical interface. These easy-to-use interfaces, as opposed to command-line interfaces, are pertinent in developing educational modeling activities because they reduce the learning curve of the model and allow focus to be centered on fundamental modeling concepts and model development (Seibert and Vis, 2012b). Both phases of the module are nested within a highly visual and interactive web-based environment that provides formative feedback, making the module almost exclusively student-centered. The modular design of the activities allows for the two phases to act independently of one another and may be attempted with no regard to sequence.

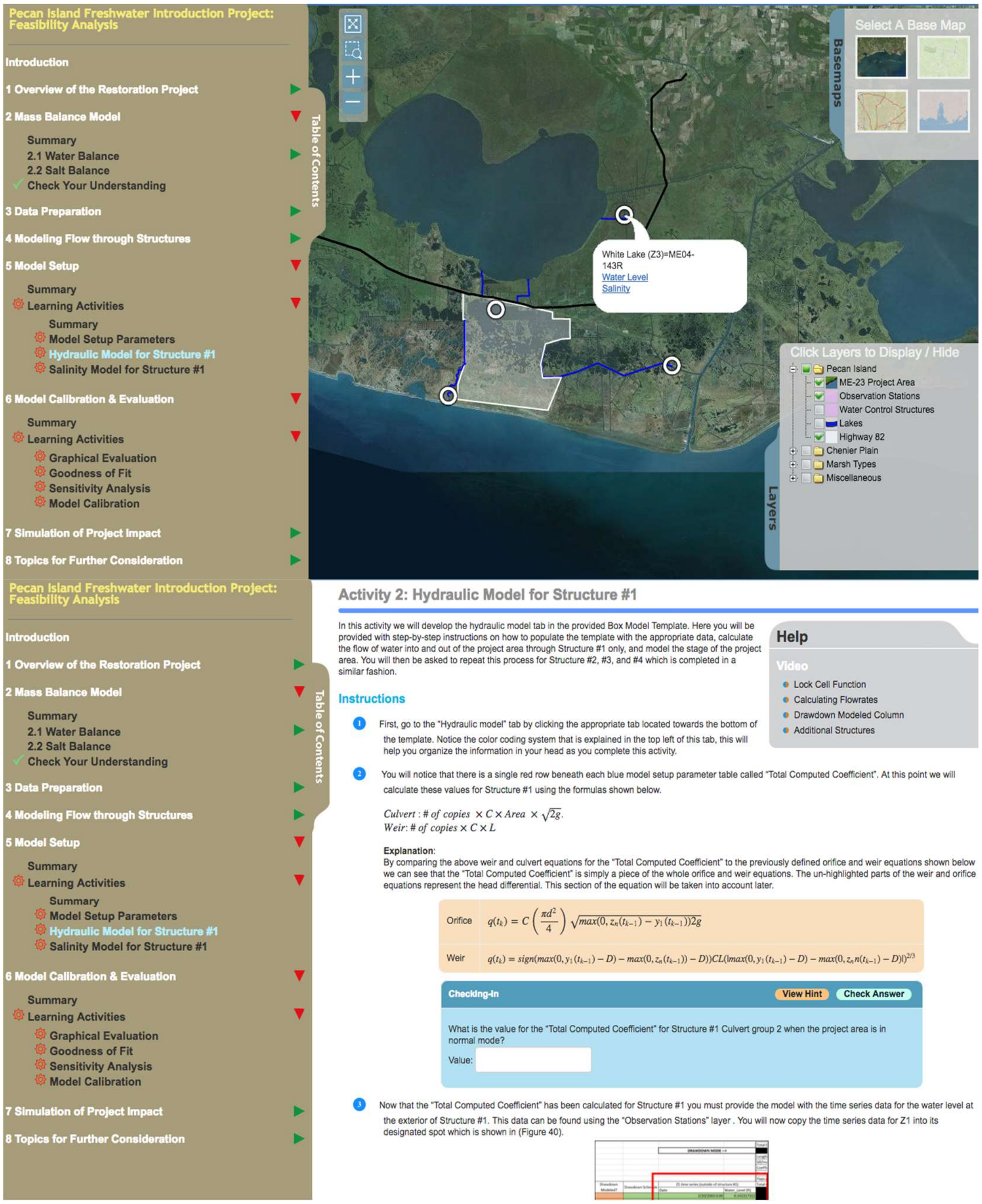

Figure 3-2 Web interface of the Pecan Island restoration project module, including a collapsible “Table of Contents” and a “Map” and a “Lessons” tabs. The Map tab (top panel) provides a navigable spatial display of the project area with access to different layers and downloadable datasets. The Lessons tab (lower panel) provides the contents of each section and the learning activities associated with it, detailed instructions on student tasks, a set of Help resources, and Checking-In questions with hints and immediate feedback embedded within each learning activity.

Intended to facilitate the self-driven learning process, student support is embedded within each learning activity in the form of formative feedback, screencasts and templates

(Figure 3-2). Sample plots and hints are provided for key steps throughout the activity to avoid error buildup and help students proceed in the right track. The module provides student support through "Help Box" that contains three features: instructional videos, templates, and rubrics. Instructional videos are used to visually demonstrate how a technique or procedure should be completed. Templates are supplied to demonstrate and promote structure and organization when students work with large data sets and model setup. Rubrics are provided in the module to inform students of deliverables and demonstrate the importance of sections with respect to other sections and the module as a whole. To provide students with assurance throughout the module while persistently enforcing the concept of self-learning, a series of immediate feedback mechanisms in the form of short quizzes are provided. This is done primarily through multiple-choice, matching, and brief fill-in-the-blank quizzes referred to as "Check Your Understandings" (Figure 3-2). After completing the quiz, students are immediately furnished with the correct answers, to enable them to review their answers and self-evaluate their understanding of the material before progressing further. In addition to Check Your Understanding quizzes, the module also includes fill-in-the-blank type questions referred to as "Checking-Ins". While Check Your Understandings usually appear after a highly informative section or activity, Checking-Ins are usually incorporated in the middle of learning activities to ensure that students are on the right track.

3.4 Student Learning Activities

As explained earlier, the module is composed of two phases. For organization, each phase is subdivided into several sections, and contains sets of Learning Activities that engage students in active learning by requiring them to independently use datasets, apply equations, and develop models and interpret their results. Step-by-step instructions and illustrations are provided throughout each activity.

3.4.1 Phase 1: Feasibility Study

This phase provides students with insight on the goals of the coastal restoration project, and immerses them in data and modeling-driven experience to assess the feasibility of the proposed project. In this phase, students develop and apply a box model to conduct a water and salt-budget analysis and assess the feasibility of a proposed restoration project in a complex marsh ecosystem. Box models have fairly low computing demands and thus can be used to perform a suite of long-term simulations within reasonable time frames, which is an attractive feature from a student learning perspective.

3.4.1.1 Model Formulation

The main concept behind the model is the law of conservation of mass. This concept is applied by establishing a control volume (project area), and then identifying and quantifying the main hydrologic fluxes (water and salt) into and out of the delineated project area (Figure 3-1). This leads to the following mass balance equation for predicting temporal changes in water level (y) and salinity concentration (C_{salt}):

$$y(t_{k+1}) = y(t_k) + \left(\frac{1}{A}\right)[Q_{in}(t_k) - Q_{out}(t_k) + A(P_{in}(t_k) - ET(t_k))]\Delta t \quad (1)$$

$$C_{Salt}(t_{k+1}) = C_{Salt}(t_k) + \frac{\Delta t}{A\,y(t_k)}\left(Q_{Salt,in}(t_k) - Q_{Salt,out}(t_k)\right) \quad (2)$$

Where Q_{in} and Q_{out} represent water fluxes (inflow and outflow) into and out of the project area, respectively [L^3T^{-1}]; $Q_{Salt,in}$ and $Q_{Salt,out}$ represent salt fluxes into and out of the project area, respectively [MT^{-1}]; A is the surface area of the project domain [L^2]; P and ET represent the precipitation and evapotranspiration depths [L]; Δt is the model computation time step [T]. Water flux (Q) is assumed to occur across four control structures that reside along the perimeter of the project area (Figure 3-1) and is estimated based on the hydraulic and geometric characteristics of each structure and the head differentials (see an example of one of the structures in Figure 3-3). The model is designed so that students can code prior specification of structure parameters and incorporate a series of “checks” to dynamically model changes in structure operation throughout the simulation. Using a pre-specified initial condition on water level and salinity concentration inside the project area, the model proceeds in a time-series mode to predict water level and salinity concentration at the next time step using Eq. (1) and Eq. (2), respectively.

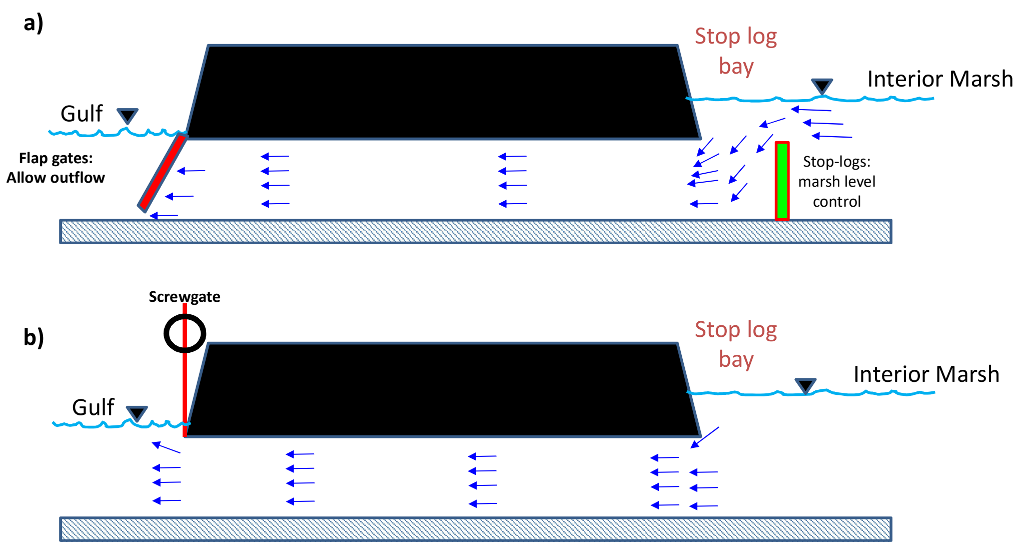

Figure 3-3 Diagram of Control Structure # 1 on Rollover Bayou that controls flow between the project area and the Gulf of Mexico. The structure is composed of (a) 8 culverts with flap gates (Gulf side) with 8 stop log bays (project interior), and (b) One culvert with a screwgate (Gulf side).

3.4.1.2 Data Acquisition and Pre-processing

Students are first asked to delineate the project domain using aerial maps and tools from a GIS software. To implement the model calculations, students need to furnish several datasets that cover the entire simulation period, including: (a) precipitation and evapotranspiration over the project area, (b) water level and salinity concentration at the project-exterior site of each structure to serve as boundary conditions, and (c) water level and salinity concentrations inside the project area, which represent the model predictands that are necessary for model calibration. These datasets are available from hydrologic monitoring stations within the vicinity of the project area (Figure 3-1) and can be accessed through the Strategic Online Natural Resources Information System (SONRIS) (Louisiana Department of Natural Resources).

3.4.1.3 Model Setup, Calibration and Sensitivity Analysis

Using the aforementioned equations, datasets, and spreadsheet modeling environment, students can now set up an un-calibrated box hydrologic model of the project area. To support students in completing the modeling tasks, a color-coded spreadsheet template is furnished with some example calculations, along with several illustrative screencasts. Students then code the rest of the model equations and calculate water and salt exchanges for each control structure, to eventually predict the water level and salinity concentrations inside the project area. The model can be calibrated using a set of user-specified metrics that quantify the model ability to re-produce certain attributes in actual observations water level and salinity concentration. Three performance metrics are considered: Root Mean Square Error (RMSE), Bias, and coefficient of efficiency (E). Prior to calibration, students are asked to perform a sensitivity analysis to evaluate how sensitive the model is to the different flow and structure parameters. Using the three statistical metrics as a proxy of the model performance, students calibrate the model by changing coefficients of the hydraulic structures to minimize the differences between model predictions and the corresponding observations (Figure 3-4). To expedite this process, students use an optimization algorithm available through the spreadsheet software.

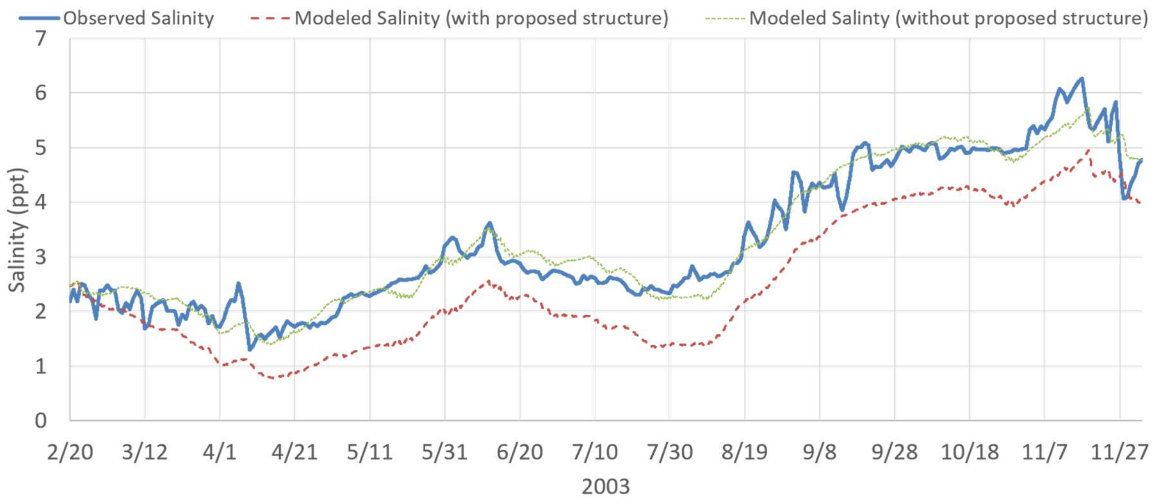

Figure 3-4 Results of the mass-balance model comparing predicted salinity with and without the project to the observed salinity gathered from the coastal monitoring stations.

3.4.1.4 Evaluation of Project Impact

Students implement the new freshwater diversion structure into the mass-balance model and produce new water level and salinity predictions under the proposed project conditions (Figure 4). Students evaluate the impact of the restoration project by analyzing the following questions: Does the project result in the desired salinity reduction? Is the salinity reduction significant enough from an ecosystem perspective? Is the salinity reduction significant enough from a model uncertainty perspective? Does the project have any negative impacts on the ecosystem? Students are then asked if they would be a proponent or opponent of the model adopted in the project. This is followed by a discussion of uncertainties and limitations encountered in modeling, how to determine which questions can and cannot be answered given a particular model, and what should be conveyed to clients about the model and its uncertainties.

3.4.2 Phase 2: Hydraulic Design

In this phase, students use the HEC-RAS river analysis software and develop an unsteady, one-dimensional model to design the diversion channel and the configurations of the inline hydraulic structures in order to meet the flow demands of the freshwater introduction project. Concurrently, students acquire invaluable experience in constructing a hydraulic model with software that is frequently used in industry, as well as an open source geographic information system (QGIS) that is widely used in many water resources applications.

3.4.2.1 Data Pre-Processing

Students initiate the development of the HEC-RAS model by using a freeware geographic information system (QGIS). Students acquire a LIDAR-based Digital Elevation Model (DEM) of the project area and delineate the freshwater channel and its cross sections. LIDAR-based cross sections are combined with field survey data of the existing channel to produce the existing-condition model in HEC-RAS.

3.4.2.2 Implementing the New Channel

Starting from the existing-condition model, students produce a model for the proposed diversion channel. To enhance students' appreciation of economic factors in design of engineering projects, the module asks students to do a cut and fill calculation from which a cost analysis is conducted. An inline-bridge and culvert structure is then implemented in the model to simulate the construction of the new culverts to be placed in the diversion channel underneath the highway that separates the project area from the upstream lake (Figure 3-1). To evaluate how different channel properties can affect the flow capacity of the channel, the module asks students to simulate different variations of channel material and roughness, channel dimensions, as well as the size, shape, and number of culverts installed under the highway.

3.4.2.3 Unsteady Simulations and Channel Design

Unsteady flow simulations can be run for each channel and structure configuration. Students evaluate the results by examining stage and flow hydrographs, plan profiles, and several other model outputs. This evaluation is supported by a number of conceptual questions that assist students in observing relevant output data and direct them towards conclusions about the significance of channel properties. The channel's ability to meet project goals is assessed for each channel configuration based on total volume of freshwater introduced, number of days of freshwater introduction, average inflow, and ability of the channel to handle the capacity without flooding.

3.5 Module Implementation, Evaluation and Improvement

The module was subject to several iterations of implementation, evaluation and improvements. The primary focus of the evaluation was on assessing the module effectiveness from a student usability perspective. A secondary emphasis was on assessing how the module supports student learning and enriches their experiences with modeling-based hydrologic analysis using real-world case studies.

3.5.1 Evaluation methods, questions and data sources

The design and evaluation of the Pecan Island module were guided by an overall framework on design-based research (Design-based Research Collective, 2003). Design-based research has demonstrated its potential as a research methodology suitable to guide the design of technology-enhanced learning environments (Wang & Hannafin, 2005). The adoption of this approach serves two main purposes: (a) it provides solutions to problems encountered in designing and developing the educational intervention, and (b) more importantly, it helps identify design principles and factors that contribute to successful expansion and adoption by a multitude of users. An improvement-focused evaluation model (Posavac & Carey, 2003) that allows for continuous identification and resolution of development problems was used as part of module assessment.

The following set of research questions guided the evaluation experiment of the Pecan Island module:

- To what extent does the module design facilitate students' ability to independently complete the different modeling development and analysis tasks? (Usability)
- Is there adequate student support and feedback? When is it needed? How helpful is it? (Usability)
- What module attributes contribute to or interfere with learning? (Usability)
- How receptive are the students to the use of the module as part of their course, and how do they perceive its value? (Student Resistance)
- To what extent does the module support student learning and acquired skills in the area of hydrologic modeling and design applications? Does it enhance their interest in the subject matter? What is the potential for transferability of the learning outcomes and skills gained from this particular activity to other hydrologic settings and basins? (Student Learning)

The module was implemented and evaluated in two rounds as part of two undergraduate engineering courses. The first round was conducted in Spring of 2015 in a senior-level elective course on coastal hydrology consisting of 10 students. The purpose of this preliminary round of implementation was on formative assessment in which data was gathered from two sources: online student surveys where students reflected on their perceptions of the module, attributes they found valuable, and any comments they wanted to share; and informal interviews with students, graduate assistant and instructor. Such qualitative data helped gain insight on why and how the module worked or failed to work and explain how and why student learning took place, and thus generate students' perspective for module enhancement.

The second round of class implementation provided summative assessment data and was conducted in a required course on Engineering Hydraulics that consisted of 29 students. The summative analysis was based on both quantitative and qualitative data. The first source of quantitative data was based on analysis of numeric grades earned by the students after they solved the learning activities embedded within the module. The second source of quantitative data was based on Likert-scale responses to online student survey questions. These online surveys were used to gather data on students' perceptions of the module's attributes and how they impacted their experiences as independent learners. The survey included 32 items, with a 5-point Likert scale that were mapped to answers ranging from "Strongly disagree" to "Strongly agree." The survey included several questions on students' experiences in using the different datasets and modeling software required by the module. The survey instrument also included several items related to students' perceptions of various design attributes of the module such as its web-based accessibility and geospatial mapping features. The survey also gathered data on students' perceptions of the help resources, feedback, and self-checking mechanisms that were embedded within the module design. In addition, the survey included a few questions on whether the module contributed to their appreciation of the use of numerical models in hydrologic analysis. Finally, the survey gathered students' overall perceptions on how the module fits with the course and whether the module's heavy data and modeling components have interfered with their learning. The survey was also designed to include text fields for students to enter additional comments they may have. The survey questions were occasionally followed by a set of informal interviews with the students and the teaching assistant to provide further insight on specific students' responses to the survey questions (Miles & Huberman, 1994).

3.5.2 Evaluation Results

3.5.2.1 Usability of the Module

Formative evaluation data on module usability indicated that while students enjoyed the case-based module as a supporting tool for the class, they reported some problematic areas in the module (e.g., confusing calculations; complex spreadsheet coding) and voiced what might be improved to enrich their learning experiences. Students also commented that the project was not easy to implement without clear instructions and that they would favor specifics in the data analysis and modeling tasks assigned to them. They would like to have some feedback mechanisms to help them check whether the answers they obtained were correct so as to avoid the ripple effect of error-buildup without knowing them. Based on the first round of evaluation, we conducted frequent periodic reviews of the user interface from a student perspective. We had the following questions in mind while reviewing the module: how easy can students use the module tools? Is it easy for a student to find directions on what tasks to complete and how? Is student support and feedback helpful? These reviews resulted in a major re-design of the module as follows. First, the overall format of the module and its hierarchy was revised to follow a well-structured flow where each section is composed of the following sub-sections: a summary; background information on the theory and methodologies required to understand the section; a multiple-choice quiz assessing students' understanding of basic concepts covered in the background section; and a set of learning activities with clearly defined and illustrated textual and graphical instructions on the required analysis and synthesis along with what students are expected to complete and submit for evaluation. The second set of revisions focused on adding more mechanisms for student support and just-in-time help, including the following: specific task instructions to alleviate student confusion and anxiety; a help toolbox to provide supportive links such as downloadable resources and how-to video tutorials; spreadsheet templates posted on the site to provide students with a guided structure on how to set up and implement the model.

Following these revisions, the summative evaluation phase was based on module implementation in a required undergraduate senior course on Engineering Hydraulics (number of students = 29; Table 3-1). According to the survey results, students cited the following attributes as the most helpful for their learning:

- Video Tutorials and other supporting figures: These were the most valued elements of the module design. Students perceived that tutorials were instrumental to their understanding of the concepts and served as guidance to successful completion of their tasks. They also indicated that other visual elements (e.g., graphics, example graphical results) helped them visualize the problem solving process. One student responded saying "The videos and pictures lessened the possibility of error and allowed the student to spend more time comprehending and analyzing the material; without these attributes the project would not be an effective 'self-learning' module."
- Checking-In Questions: Students emphasized the value of these interactive questions as a mechanism that provides immediate feedback to confirm their learning and identify any informational gaps before they move to the following sections.

- Interactive Map: Similar to the commonly used web map apps, students appreciated this design attribute of the module interface to help them keep a continuous sense of context, visualize the different components of the proposed project, and access necessary datasets.
- Synthesis Questions: While students showed appreciation for the detailed step-by-step instructions, they commented that without the synthesis questions at the end of the module the overall objective of the proposed project would have been lost. They methodically followed the instructions without the big picture or end goal in mind until posed with the synthesis questions which forced them to reflect upon what they had done and for what purpose.

Table 3-1 Student Survey Results on Module Usability

• How do you like the overall design of the Module interface and its main elements (Table of Contents, Map tab, and Lessons tab)? (Don't like it …Like it very much)	4.28
• Rate the helpfulness of the “Checking-In” questions in the middle of each section (Not helpful at all … Very helpful)	4
• Rate the effectiveness of the Check Your Understanding question sections in improving your learning (Not effective at all … Very effective)	3.76
• Rate the helpfulness of the interactive Module map (indicated by the red “Map” tab on the main page of the module) (Note helpful at all … Very helpful)	3.90
• Rate the helpfulness of the “Help” toolbox that contains (“Videos” and “Templates”) for understanding and completing the module tasks (Note helpful at all … Very helpful)	3.72
• Provide examples of specific Module attributes that you liked the most.	

Students offered their suggestions for usability improvement. First, overwhelmingly, students requested that more video tutorials and screenshots should be included to supplement the instructions. Second, students suggested to provide further capabilities of self-check-ins to avoid the irreversible error buildup at the latter stage of the project. The graduate teaching assistant, who participated in developing the module and in administering it to the class, had similar perceptions for improvement. He contemplated on the proper combination of support mechanisms that might work best for students to adapt to students' different learning styles (e.g., video tutorials and screen captures, coupled with textual description and detailed step-by step instructions). He also considered lowering the scope of the vocabulary in the instructions to make them appropriate for inexperienced undergraduate students new to the area of numerical modeling and their applications.

3.5.2.2 Student Receptiveness to Module and Perception of its Value

Based on the formative and summative evaluation data from surveys (Table 3-2) and interviews, a majority of the students regarded the amount of details, procedures and calculations overwhelming, but worthwhile from a learning experience perspective. Students indicated that technology-enhanced, data-driven pedagogy using local real-world projects can support their learning beyond traditional textbook problems, and can serve as a meaningful supplement to classroom instruction. Students also appreciated the opportunity where they could put together their technical knowledge to address real-world water problems native to the region. They also strongly agreed that the use of models and datasets in the project was conducive to their learning process (Likert rating 4.17), and did not interfere with their overall learning process (Likert rating 2.62). Moreover, students strongly agreed that the modeling-based project was a valuable component to the course (Likert rating 4.12). However, several students had difficulties in completing some of the modeling tasks, especially those that deal with programming the hydraulic structures and the salinity prediction parts of the model. These difficulties are mainly attributed to students' lack of programming skills, indicating a critical student-related challenge for introducing modeling-based activities.

Table 3-2 Student Survey Results on their overall perception of the module as a learning tool

• Rate the effectiveness of this approach in supporting your learning. (Not effective at all … Very Effective)	4.07
• This project has provided a more practical application compared to traditional course work. (Don't agree … Strongly Agree)	4.55
• The use of models and datasets as was done in this project has been conducive to the learning process. (Don't agree … Strongly Agree)	4.17
• The use of models and datasets as was done in this project has interfered with your overall learning process. (Don't agree … Strongly Agree)	2.62
• This modeling experience improved my interest in the field of water resources engineering in general (Don't agree … Strongly agree)	3.96
• This modeling-based project has been a valuable component to this course (Don't agree … Strongly agree)	4.12

To better understand students' perceptions of the module, we asked them to describe their overall impression of the module and whether it contributed positively to their overall learning in this class and for future career. Overall, students appreciated the privilege of being immersed in a computer-based media-rich learning environment. They perceived that the module enabled them to get insight into water engineering concepts learned in the class and apply them in real-world project in their own state. They appreciated the opportunity of being exposed to modern software and tools, and the opportunity to synthesize their learning of the different components covered in the class.

Meanwhile, students shared some factors that might have hindered their learning gain, mainly on the timing of introducing the module and the time allotted for students to complete the learning activities. Although they perceived the project should be done toward the end of the semester after being exposed to all concepts, they felt being rushed through the activities, stressed out, and frustrated when extra guidance was needed. Because of the time constraints, some felt that they lost the opportunity to synthesize and reflect on their learning. All of these might have helped explain the relatively low performance in students' last project submission, as compared to the performance achieved in their first two submissions. They recommended that the module be introduced earlier in the semester, and carried out throughout the semester to allow them enough time for learning. This module was assigned to the students as an independent, self-driven project over a period of three weeks, one week for each pair of sections. The relatively short time was intentional so that the integrity of the module and its problem- and project-based value is not lost because of its being spread over a long time. Keeping the overall time to completion relatively short was important so that students did not lose the overall goal of the project. Nevertheless, we noticed that students needed more time to reflect on their results and synthesize them into useful results, and possibly make revisions and corrections to their data and models. This was also echoed by the graduate teaching assistant during one of the interviews who indicated that when students feel limited on time, they simply state the obvious facts from the datasets and graphs, but not necessarily what they mean in an actual hydrologic sense.

3.5.2.3 Support of Student Learning

A summative evaluation was conducted after major revisions were made to the module design and contents as described earlier. The summative evaluation (n = 29) on the module potential to support student learning was based on assessing students' solutions to the tasks assigned as part of the module (Table 3-3) and their responses to online surveys (Table 3-4). Student solutions were grouped into three main submissions. Table 3-3 shows students' average scores for each submission. These scores were determined using rubrics that were developed based on expected student learning outcomes. Students' average grades were far above 80% for all sections except the last submission. The lower performance on the last section can probably be attributed to the rather inadequate time available to the students to complete this section as they approached the end of the semester.

Table 3-3 Average Grades (29 students) for Different Sections of the Pecan Island Case Study.

Submissions	Average Grade by Percent
Overview of the Restoration Project	99.6%
Gathering Topographical Data	94.8%
Establishing Existing Conditions	89.2%
Submission 1	**92.4%**
Synthesizing the Proposed Channel	87.7%
Modeling One-dimensional Unsteady Flow	90.3%
Submission 2	**88.5%**
Evaluating Channel Design	76.9%
Submission 3	**76.9%**

The survey results (Table 3-4) that focused on direct learning outcomes showed that students perceived that the module moderately contributed to their learning on how to perform various hydraulic tasks. For example, they indicated they could comfortably set up a HEC-RAS hydraulic model (Likert rating 4.08), perform hydraulic simulations and interpret model results (Likert rating 3.69), somehow identify strengths, weaknesses, and limitations of hydraulic models (Likert rating 3.31), and comfortably describe basic terms and vocabulary used in hydraulic analysis and modeling (Likert rating 4). Students also found it fairly easy to use some industry-standard tools and software such as GIS (Likert rating 3.73) and HEC-RAS (Likert rating 3.12), and Lidar data (Likert rating 3.85). The three moderate ratings related to tools and software echoed students' suggestions for more video tutorials, screenshots, and crystal clear instructions to guide their task accomplishment while applying them.

Table 3-4 Student Survey Results on Impact of Module on Student Learning

• Describe goals of a freshwater introduction project within a coastal ecosystem. (Didn't contribute at all … Contributed significantly)	3.85
• Use GIS software to develop topographic/geometrical datasets for hydraulic analysis. (Didn't contribute at all … Contributed significantly)	4.04
• Setup HEC-RAS model, including geometry, boundary conditions, channels and structures for a project of interest. (Didn't contribute at all … Contributed significantly)	4.08
• Perform hydraulic simulations and interpret model results. (Didn't contribute at all … Contributed significantly)	3.69
• Identify strengths, weaknesses, and limitations of hydraulic models. (Didn't contribute at all … Contributed significantly)	3.31
• Describe basic terms and vocabulary used in hydraulic analysis and modeling. (Didn't contribute at all … Contributed significantly)	4.0
• Describe the value of hydraulic numerical models as engineering tools and appreciating their strengths/weaknesses? (Don't agree … Strongly agree)	4.04
• Rate the following hydraulic analysis tools (Not easy to use … very easy to use) QGIS 3.73; HEC-RAS 3.12; LiDAR data downloader	3.12

A critical aspect of evaluating student learning using data and modeling-based material is whether students can transfer the learning outcomes and skills gained from a particular project into other hydrologic settings. An explicit assessment of this aspect is not trivial and may require, for example, that the module be applied in a whole new case study in a different basin to gauge students' abilities to successfully formulate and analyze the newly posed hydrologic problem. While this is clearly beyond the scope of this study, the surveys conducted after the completion of the module provided some insights in the transferability of students' learning (Table 3-5). After being exposed to the module, students perceived that they were moderately confident in their capability in completing the key tasks of this module in other projects or in other locations (Likert-scale 3.62); the hands-on experience with the module, to some extent, helped build their skills to develop numerical models and interpret their results (Likert-scale 3.5); and they perceived that they will feel confident in applying numerical modeling concepts and tools after graduation at their first job (Likert-scale 3.96).

Table 3-5 Student Survey Results on Potential for Learning Transferability

• How confident do you feel about being able to complete the key tasks of this project in other projects/locations (Not confident at all … Very confident)	3.62
• This module improved building my skills to develop and use numerical models" (Don't agree … Strongly agree)	3.5
• This project has been effective in introducing me to numerical modeling concepts and tools to the extent that I will be less timid using them after graduation (at your first job). (Don't agree … Strongly agree)	3.96

3.5.2.4 Recommended Design Principles

Design principles are needed to address unresolved methodological issues in design-based research. For this reason, and based on the findings of our research, we recommend the following design principles with the intention to guide instructors interested in developing modeling and data-driven, technology-enhanced learning material in the field of hydrology and water resources engineering:

Principle 1: Develop technical content with a well-balance coverage that includes informational background, clearly-defined instructions to the user as to how to implement the different tasks, procedural specifics in detailed fashion as needed, but without compromising the student-centered discovery aspects of material.

Principle 2: Provide seamless integration of student interactive feedback mechanisms throughout the module to facilitate their progress throughout the complexities inherent with data analysis and modeling tasks.

Principle 3: Provide multifaceted just-in-time support mechanisms in various modalities within the module to engage students and support independent learning, for example, text-based instruction, screen captures, video tutorials, and audio explanation.

Principle 4: Provide synthesis-type questions to support student reflection of the overall purpose of the analysis, ensure higher-order learning outcomes, and avoid potential of students getting overwhelmed with fine details and procedural steps, typically encountered in engineering modeling-based analysis.

3.6 Summary and Concluding Remarks

This paper presented the design, evaluation, documentation and reflection of a web-based undergraduate engineering learning module that focuses on the use of numerical modeling to analyze and design water resources engineering projects. The module follows a case-study approach by using an actual hydrologic restoration project that introduces freshwater into the Pecan Island coastal basin in south Louisiana, USA, to alleviate saltwater intrusion caused by natural factors and human activities. The module has two main phases: a feasibility analysis phase that assesses the potential of reducing salinity using freshwater diverted from a nearby lake, and a hydraulic design phase for the freshwater diversion canal. Through the module, students use actual hydrologic data available from several water resource agencies to develop two types of models: a mass-balance model that simulates the transport of water and salt and predicts changes in stage and salinity concentrations due to a freshwater introduction project; and a hydraulic model that simulates subcritical unsteady flow in the proposed freshwater diversion channel. The module was developed using an active learning approach where students perform a set of quantitative learning activities that involve extensive data and modeling analyses. The module develops students' knowledge and skills on the use of research and practice-based engineering analysis and modeling tools including open-source geographical information systems (GIS) tools, hydraulic modeling tools (e.g., HEC-RAS), as well as advanced data analysis operations in spreadsheet software. Upon completing the module, students develop knowledge application, technical, investigative, and critical thinking skills that involve concepts on model formulation, numerical solutions, parameter calibration, sensitivity analysis, and the use of models to simulate a hydrologic system and assess the feasibility of a proposed engineering project.

The implementation and evaluation of the module focused primarily on investigating (a) the design attributes and implementation strategies of data and modeling-based learning modules that facilitate students' user experiences; and (b) the receptiveness and perceptions of students to these resources and their learning values. These factors are critical in achieving sustainable solutions by the wider water resources teaching community for integrating modeling-based learning activities into undergraduate curriculum. Based on students' responses to online survey and informal interviews, as well as the grades they received in the different tasks of the module, the following conclusions could be made. The technical design attributes that appealed the most to students included the following: the web-based design that integrates educational contents, datasets, and learning activities all in one environment; the use of an interactive map environment embedded into the module interface to provide geographical context for the project; the availability of several user-support and help resources in the form of video tutorials and templates for complex operations; and availability of self-checking mechanisms embedded throughout the module activities. These latter aspects were identified as key features that facilitate students' self-learning and independent completion of tasks, while still enriching their learning experiences when using data and modeling-rich applications. Despite the extensive effort required to finish the module, most students expressed their appreciation of the module activities in contributing to their learning in different aspects of the subject matter. The module attributes that were highly cited by students in terms of their learning effectiveness and potential value for future careers included the following: exposure to and developing skills on concepts and applications of numerical modeling; application of modern engineering data analysis techniques; use of real-world hydrologic data and exposure to complexities related to data sizes and formats; and appreciation of uncertainties and challenges imposed by data scarcity and lack of adequate observations at scales needed for modeling.

Despite the overall positive experience expressed by the students, the evaluation results pointed out three main issues that are most critical for the successful implementation and long-term sustainability of these types of modeling-based activities: (1) instructional design and presentation of technical content, (2) user support mechanisms embedded in the learning environment, and (3) module length and course timing issues. First, given that the module was developed as a content-rich learning experience with extensive set of self-driven activities, students cited some problems in following the detailed instructions while staying oriented with the "big picture" and the overall flow of the different analysis tasks. Unlike traditional textbooks, the use of a web-based design and abundance of information and resources that it can accommodate, might adversely lead to some of the confusion expressed by students in following the instructions. Second, the aforementioned content instruction problems can be alleviated by providing various embedded support mechanisms, for example, higher-level site guidance in the form of an overall module tutorial and additional student support and help resources (screencasts, templates, step-wise feedback to students). Researchers have long realized that intrinsic/embedded supports are the most effective and least expensive approach in enhancing performance in any computer-based learning systems (Merienboer, Kirschner, & Liesbeth, 2003; Raybould, 2000; Villachica & Stone, 1999). As yearned by students who participated in the module evaluation, multi-faceted and various levels of intrinsic/embedded support mechanisms including video tutorials, screencasts, textual instructions, and indexed site map hold the potential in enriching their learning experiences and enhancing their learning gains. When intrinsic/embedded supports are well integrated into the interface structure, content displays and tasks, access to such supports will not break the flow of learning. In our future iteration of module improvement, efforts will be spent in exploring more effective practices of providing intrinsic/embedded support mechanisms. Third, another challenge that impacts the successful implementation and effectiveness of content-rich modules such as the one described in this study is due to time limitations. It is noted that this module (and others that follow similar pedagogical approach) is designed as a course enrichment supplement, rather than a replacement to an existing curricula or textbook. Nevertheless, the design of a meaningful case-based module brings inevitable elements of content length and thus the need for often-long completion time. Adding to time-related issues is the fact that investigative-type tasks associated with such learning modules (e.g., model calibration and evaluation, model revisions, identification of questionable data, project scenario analysis) often require additional time of reflection where students assess where mistakes could have been made or where revisions need to be introduced to their models. Striking a balance between a module length that is adequate enough to result in a deep learning experience on the one hand, and a relatively concise and focused module so that students do not lose the overall goal of the project and to ensure reasonable completion times within course constraints on the other hand, is a key aspect behind developing student-centered modeling-based learning modules at the undergraduate level.

Learning is a process that involves multifaceted changes in student attitudes, beliefs, capabilities, knowledge structures, mental models, and skills (Spector, 2001). Technologies as evidenced in this study alone will not adequately contribute to students' understanding and performance in hydrologic/hydraulic problem solving. What matters more is how technologies are pedagogically applied in the learning environment. Although technology-enhanced pedagogies have not yet been widely embraced in higher education (Strauss, 2005), the design, development, and implementation of our modeling case study will hopefully shed some light on how judicious technology-enhanced pedagogies can exert its potential in helping students not only enrich their learning experiences, but also enhance their academic performance and their impact on future careers in the field of hydrology and water resources. As pointed out by (Borrego et al., 2010), student resistance was a consideration in faculty's decisions to adopt a certain engineering learning innovation. Our study indicates the importance of addressing these usability and student-support issues in order to increase students' ability to work on activities independently, reduce their resistance to the new material and its typically heavy computational and data analysis loads, and thus eventually increase the instructor's interest and commitment to integrate these types of resources into the undergraduate curriculum.

3.7 Limitations and Future Research

The research findings in this study were generated from data including Likert-scale surveys, student performance grades, informal interviews, and text-response surveys. The case study primarily reveals students' perceptions of the module's usability, as well as its potential in enhancing students' knowledge transfer and learning gain in hydrology. However, because of the design-based research focus, the study did not explicitly address module impact on achieving or improving students' learning outcomes in a quantitative fashion exemplified by, for example, control-treatment evaluation. Future efforts will focus on addressing this important evaluation aspect of modeling-based learning innovations. We also plan to conduct qualitative research examining how and why the modeling-enhanced pedagogy improves students' learning in the field of hydrology and water resources engineering classes. While the current study focused on student-related factors in terms of usability and potential resistance, faculty-related factors are equally important. According to the survey conducted on engineering departments in general (Borrego et l., 2010), faculty issues play a more complex role in how educational innovations are adopted. Therefore, future studies should focus on addressing important faculty limitations such as the time required to prepare or manage new innovations, especially those that require labor-intensive efforts such as the case for modeling and data analysis, and a better understanding of the types of faculty-support mechanisms that can potentially reduce their own resistance to developing and adopting new teaching innovations and tools in water resources engineering.

4 TOWARDS BROADER ADOPTION OF EDUCATIONAL INNOVATIONS IN WATER RESOURCES ENGINEERING: VIEWS FROM ACADEMIA AND INDUSTRY

4.1 Introduction

Recent years have witnessed significant research and technological advances in the fields of hydrology and water resources engineering. While these developments have had a large impact in research and industry, they have not yet been incorporated into the undergraduate engineering curriculum. The result has been graduates who are well versed in concepts and theory presented in traditional textbooks, but are not well prepared to use the tools and techniques that are reshaping the profession. A recent review of the literature on hydrology engineering education (Ruddell & Wagener, 2014) emphasized the need for formalized approaches to reform hydrology and water resources engineering education. These desired reforms call for tapping into discipline-based research advances on data, modeling and information systems; exposure to modern tools used in engineering practices; adoption of sound educational strategies such as active-learning; and use of real-world case studies to deliver authentic learning experiences. Examples of recent educational developments that strive to achieve the desired changes in hydrology and water resources engineering include development of web-based learning modules (Habib, Ma, Williams, Sharif, & Hossain, HydroViz: design and evaluation of a Web-based tool for improving hydrology education, 2012; Yigzaw, Hossain, & Habib, 2013), computer models and simulation games (AghaKouchak, Nakhjiri, & Habib, 2013; Siebert & Vis, Teaching hydrological modeling with a user-friendly catchment-runoff-model software package, 2012; Hoekstra, 2012; Rusca, Heun, & Schwartz, 2012), sharing of educational materials via community platforms (Wagener et al., 2012), use of hydrology real-world case studies (Wagener & Zappe, 2008; Yadav & Beckerman, 2009), use of geospatial and visualization technologies (Habib, Ma, & Williams, Developoment of a web-based hydrologic educaiton tool using Google Earth resources, 2012) and the use of real-time environmental monitoring to enhance student engagement (Brogan, McDonald, Lohani, Dymond, & and Bradner, 2016; McDonald, Brogan, Lohani, Dymond, & Clark, 2015). However, these efforts remain largely at the scale of individual efforts and the majority fall short of meeting scalability, sustainability and adoption beyond an individual project or few institutions. This reoccurring problem on the lack of sustainability and community-level adoption of innovative education material has been a major concern in the field of engineering education and other STEM fields (McKenna, Froyd, King, Litzinger, & Seymour, 2011; Singer, Nielsen, & Schweingruber, 2012). Barriers to adoption are attributed to several issues such as characteristics of the innovation, faculty and student factors, and institutional cultures and resources (Rogers, 2003; Heywood, 2006; Hardgrave, Davis, & Riemenschneider, 2003). According to Rogers's (2003) theory on diffusion of innovation, five characteristics of innovations were cited as factors that influence adoption: relative advantage, compatibility, complexity, trialability, and observability. The ease to implement and ease of use were also cited by (Compeau, Meister, & Higgins, 2007; Bourrie, Cegielski, Jones-Farmer, & Sankar, Identifying characteristics of dissemination success using an expert panel, 2014) as important factors. In a survey of U.S. engineering departments, (Borrego, Froyd, & Hall, 2010) identified several faculty issues that affect adoption of engineering education innovations, including faculty time for preparation and management of labor-intensive innovations, faculty resistance to change, and skepticism regarding evidence of improved student learning. While these factors apply across the general field of engineering education, there is a need to identify discipline-specific factors that may hinder or facilitate adoption of innovations. As suggested by Rogers (2003), the value of a certain innovation varies according to the specific engineering discipline, simply due to the specific technical skills and educational content that pertain to the discipline. The likelihood of adoption increases among peers of the same discipline as they share their own developments and communicate experiences in using and deploying the new innovations. Therefore, research on innovation adoption and diffusion has been recommended at the discipline and sub-discipline scales as a strategy for understanding the effectiveness of engineering education initiatives and their adoption potential (Henderson et al., 2015; Finelli et al., 2014; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Examples of pioneering efforts that focus on specific engineering disciplines are found in the fields of chemical engineering (e.g., (Prince, Borrego, Henderson, Cutler, & Froyd, 2013)), electrical and computer engineering (Froyd, Borrego, Cutler, Prince, & Henderson, 2013; Shekhar & Borrego, 2016), and cross-field comparative assessments (e.g., (Cutler, Borrego, Henderson, Prince, & Froyd, 2012)). Each engineering discipline has its own social system that controls the culture of adopting new educational innovations (Lattuca & Stark, 1995; Wankat, Felder, Smith, & Oreovicz, 2002), and hydrology and water resources engineering is not an exception in this regard. The study is motivated by the persistent challenges and low-rates of adoption of recent educational developments in the field of hydrology water resources engineering that are based on the use of innovative, evidence-based instructional practices such as data and modeling-driven approaches. The qualitative results of this study are based on a set of 100 informal, open-ended qualitative interviews (Patton, 1990) with water resources faculty and engineering professionals. These interviews were conducted through participation in a National Science Foundation (NSF) program called Innovation Corps for Learning (I-Corps L; (Chavela

Guerra et al., 2014; Smith, Chavela Guerra, Mckenna, Swan, & Korte, 2016), which adopts a Lean LaunchPad methodology of entrepreneurial immersion, hypothesis-driven customer discovery, and business model validation (Blank & Dorf, 2012; Osterwalder & Pigneur, 2010). The particular focus of this study is on developing a user-driven perspective on the propagation, scaling and adoption of education innovations. This chapter provides insights on needs, motivations and hindering factors that affect hydrology and water resources engineering faculty as developers and potential adopters of educational innovations in this field. Such insights can be used to inform ongoing and future developments of water resources engineering education innovations and avoid the undesirable paths of lack of discovery, broad adoption and long-term sustainability.

4.2 Methodology

4.2.1 Overview of I-Corps L and Customer Discovery

To help educational researchers better produce sustainable and scalable STEM innovations, technologies, and curriculums, the National Science Foundation (NSF) has developed a program called I-Corps for Learning. A variant of the original I-Corps program that was developed to foster the commercialization of NSF funded research, the goal of the I-Corps L is to demonstrate how business techniques can be applied to successfully launch educational innovations into commercial use. The idea is that before expending a significant amount of resources on an innovation, the developer should first confirm that people are willing to use it because it solves a specific problem or satisfies a certain need. The only way to test the viability of the innovation prior to investing exuberant amounts of time and money is to “get out of the building” and talk to potential customers, or users in the more general sense. This is known as the “customer-discovery process”. Customer discovery is the key to success for any startup and is the core of the NSF I-Corps program. The idea is to develop a full understanding of entire users' ecosystem, identify their pains, and how they currently manage the problems they are facing. Once the needs of users are identified, revised and verified, the next step in the I-Corps process, which is not covered in this paper, focuses on formulating a value proposition and looking for a businesses model on how to further pursue the proposed innovations, including market size and cost and revenue structures.

Adopting the I-Corps L approach, we present the results of 100 interviews that we conducted with potential end-users, influencers, recommenders, and decision makers in the area of water resources engineering education. The purpose of the interviews is to reach a deep understanding of the needs of potential end-users and the challenges they face. The interviews were designed with a customer-centered approach, rather than a developer or a product-centered mindset. Using an informal, open-ended interview design (Patton 1990), the interview questions were fairly short and not overly specific to allow the interviewee to be the center of the conversation. The interviews were conducted with an open mind and adaptable approach to listen carefully to what the interviewee is saying while trying not to put words in their mouth. Interviews were conducted either in person, over the phone, or via a teleconferencing venue, and ranged from 30-60 minutes, averaging approximately 45 minutes. The range of people interviewed in the current study was quite broad to capture the landscape from as many different points of view as possible. Generally, the interviews were divided into two main categories: academia and industry. The following are brief summaries of each category, including distinction of user segments within each group and what was inquired during the interviews.

4.2.1.1 Interviews with Academia

Academia, in the context of this paper, refers to all persons associated with post-secondary engineering educational institutions. This includes: civil engineering instructors teaching hydrology and water resources courses, geoscience instructors teaching hydrology-related courses, department heads, and other educational researchers in the same area. The main questions we asked when talking to academia were: do universities instructors currently use emerging technologies in the undergraduate classroom; if so in what way and if not why not; what type of pedagogies are currently being used in the classroom; is there a need to reform the undergraduate hydrology and water resources curriculum; do instructors look for innovative educational material to use in their classroom and if so where do they look; what are the issues with teaching engineering-industry tools and techniques in the classroom; what is the incentive for instructors to improve their teaching methods using innovative contents and new resources; what are the challenges of developing material that encompasses this content; do students like the chalk-and-talk method or prefer more student-centered approaches? The sample domain of the interviews in academia was wide-spread and encompassed many different types of universities (e.g., education versus research-intensive), a large spatial distribution covering the US, and persons of varying specializations within the overall domain of water resources, gender, experience, and age.

4.2.1.2 Interviews with Industry

Talking to engineering professionals from industry was important for two main reasons. The first was for an assessment of the preparedness of graduating students to perform on the job and what their strengths and weaknesses are coming from undergraduate programs. Secondly, it was of interest to discover what type of post-graduation training they find necessary, what form it takes and how it is provided. These concerns/questions are stated modestly here but were each investigated thoroughly throughout the interviews and provided grounds for which many additional questions emerged. From industry, several different perspectives were sought: that of the junior engineer (1 to 3 years of experience), the senior engineer; and upper management. The junior engineers were fresh out of school and could easily provide insight into the transition from undergraduate setting to the work place from a first-person point of view. The distinction between knowledge obtained in undergraduate settings and that obtained during post-graduation training is still fresh and clear to them. Senior engineers provided a third-person perspective on the transition of recent graduates to the workplace, giving insight on the evolution of the young engineers. The managerial perspective, of course, provide logistic information associated with the training and professional development of engineers. To capture the full spectrum of industry, both private and public sectors were considered along with the size of each entity; e.g., small, medium, and large sized consulting firms, as well as different state and federal water resources engineering agencies. Overall, industry provided a means to gauge the past and current knowledge of engineers as they progress in their career, an overview of the current post-graduation training and professional development strategies, and insight to potential partnerships with universities to use advances from the professional field and enhance undergraduate education.

4.3 Results

This section provides a synthesis of the views we gathered from the 78 interviews. The summary below reflects the views of the majority; distinctions are made when a clear consensus does not exist.

4.3.1 View from Academia

A total of 42 interviews were conducted with university professors teaching water resources related courses in engineering and geosciences departments. The authors first try to decipher the motivation underlying the desire to enhance the undergraduate hydrology education, then discuss challenges associated with developing, discovering, and using innovative resources and materials.

4.3.1.1 Motivators: What motivates instructors to incorporate innovative teaching materials?

From the faculty interviews, it is apparent that there is in fact an expressed need for educational reform in the field of hydrology and water resources engineering. While the need is clear, the motivation to act is nebulous. Presumably obvious incentives such as program accreditation, performance reviews, and pressure from superiors (deans/department heads) do not seem to be the predominant factors. Instead, the driving force, for those who are showing initiative, seems to be personal disposition. The two factors that were observed to influence tendency to participate in innovative strategies for reforming the undergraduate hydrology and water resources education were instructor's experience, and instructor's priorities, i.e., research or teaching.

Young or inexperienced instructors tend to be very ambitious and full of vigor and are likely to strive to bring something new to their classrooms. Additionally, they are more accustomed to quickly adjusting their ways to take advantage of new advancements. Often, they are in the process of developing their courses and want to do so in a way that is most effective and well informed by recent educational research. In contrast, the experienced instructor who has been teaching for many years, already has a working curriculum that has been developed, used, and proven many times over. This reluctance to change is logical, well understood, and is often hard to argue with especially given the lack of tangible incentives. The argument is, however, that such teacher-centered techniques have been proven substantially less efficient in transferring knowledge compared to more contemporary student-centered approaches.

The variability in priorities amongst universities can play a major role in course content and method used in presenting course content. These priorities are often more apparent at the level of the individual role or position of individual professors within a university, i.e., emphasis on instruction or research. Professors with high emphasis on teaching tend to adopt new pedagogies and expand the content of their courses more so than those with more research focused obligations. The obvious reasoning behind this is the way in which the universities evaluate professors, with distribution of focus being allocated to effective instruction or research productivity. From the perspective of the researchers, why invest the time and effort of improving a course when the time could better be spent on research, which will have the benefit of improving their professional perception and career advancement. The inverse here, of course, applying to those with high teaching emphasis. Nevertheless, and apart from immediate incentives, the interviews indicated that the main source of motivation to improve course content and teaching strategies is self-created and derives from one's desire to excel at endeavors associated with his or her career. Achievement, self-esteem, and self-efficacy play a large role in this.

4.3.1.2 Hindering Factors: what hinders developing and using innovative educational resources?

There are many challenges expressed by the academic community when it comes to sustainable development and use of innovative materials in hydrology and water resources engineering education. These issues have been summarized into 5 categories: time limitations, steep learning-curves, refurbishing requirements, rigidity of material, and lack of assessment data. The importance and relevance of each of these challenges are discussed in the following sections. These are the main 'pains' expressed by university professors. It should be noted that these challenges are not additive, rather they are highly interactive; i.e., a solution to one may provide a means for overcoming another or, conversely, have adverse effect on the other.

Time Limitations

Many instructors see the need for restructuring of the current curriculum but are either too busy or are not knowledgeable enough to develop new material that addresses emerging research and industry advances in the field, such as modeling and data analysis techniques. Developing innovative resources is difficult because it requires a knowledge in both the subject matter and on educational research. Finding effective pedagogies (e.g., active-learning strategies, problem based learning, etc.) which complement a subject and then structuring material in a way that is presentable to students can be challenging and may consume months of time.

Aside from time of development, there is also a time requirement for implementation. It is the opinion of most professors that contemporary material and methods should not replace traditional material; rather, it should augment or supplement it. It is easy to see how this translates to more lesson preparation time, strain on class time, more out-of-class time with students (office hours, email communication, etc.), and evaluation and assessment time. An obvious solution is to use peer-developed material. While this solves the pain of developing one's own material, many of the other pains persist and some magnified. For instance, using peer developed material that uses an unfamiliar software, project, or dataset, may present a learning curve for the professor who is implementing it.

Steep Learning Curves

Many of the interviewees expressed the opinion that a large turnoff for them are the steep learning curves often associated with learning how to use new, unfamiliar tools and techniques that are part of the innovative resource. Additionally, incorporating these advancements in the classroom is problematic for students as well due to the difficulty in learning how a tool or software works, which might generate student resistance to the new resources. Students must be trained to use a computational model, a GIS tool, or other software before they can apply it in a useful way. Effectively using computational tools and models is not straightforward and is considered an art by the community because of the deep knowledge and experience required to manipulate the tool to perform a certain way. Many of these tools are rather crude and are far from intuitive, and even those with friendly graphical user interfaces are still ages behind the easy-to-use mainstream software that students are accustomed to (e.g., online maps, spreadsheet and word processing software). In recent years, huge strides have been made in making such tools more user friendly but this has resulted in the generation of black-box type of models. These models, if not properly introduced to students to better understand their inner workings can often lead to serious misuse or faulty interpretation of results. It was also noted that the steep learning curves are not only associated with software use, but also with the use of case-studies and real-world projects situated in specific regional basins that may not be familiar to the instructors. Despite their educational value, region-specific case studies often require the instructors to learn about the particular basin and the hydrologic problems that pertain to that basin, which might render these peer-authored resources less practical to adopt.

Updating and Refurbishing

Another issue with developing material focused on modeling and data analysis is the rate at which they become obsolete. This high turnover rate is directly related to the updating of software and data which is often done nearly every year. Changes to website interfaces and data online portals of major agencies that provide water resources datasets can cause rapid turnover of educational developments. To sustain this pace, data and modeling-based educational material must be updated frequently which requires time and effort from the instructors. Compared to their current textbooks which receive updates only every 3-5 years and still are only slightly modified forms of the previous versions, materials that are dependent on dynamic resources require continuous adaptation. Additionally, updating of the materials is needed after feedback is received from students or other users. These usually take the form of assessment data, expansion or inclusion of supporting material and improvement to the design of the new resource. Therefore, the ability to easily and quickly update material is a critical feature that must be available to effectively sustain and scale new educational material that emphasize the use of technology and research advancements.

Lack of Modularity and Customizability

From the interview responses, it seems that most instructors, especially those who are more experienced, have well-developed courses and are simply looking for material that reinforces or supports their current curriculum. For their purpose, these resources should be very modular. As one person said, "I need resources that are not 'too rigid', that are 'loose' in format and content; I am looking for 'a la carte' items, and not the 'whole menu'". In contrast, there were those interviewees who were either just beginning their career as an educator or were looking to offer additional courses. These individuals are interested in material to build their class around and therefore may be looking for larger more holistic resources that can still be customized to their specific needs (e.g., different datasets, or hydrologic basins).

Material that is not tailored to the specific need of the implementing professor (in content or format) presents additional challenges for development and adoption. For example, will the material be presented during the lecture portion of the class, during laboratory time, as a homework assignment, or as a class project. Each option has its own benefits and challenges; for instance, including new material in the class or in the lab may prove difficult given time constraints and pre-existing course material. On the other hand, it allows the instructor to interact with students and readily provide expert guidance. This, of course, is made more difficult if assigned as an out-of-class assignment. In such cases, it is important for the developer to provide additional user support, specific to the needs of the "local" students to supplement the absence of the instructor (e.g., detailed instructions, screenshots, videos, templates). Conversely, providing too much support can result in adverse learning effects, where students follow steps blindly and without thinking about what they are trying to accomplish.

The ability to modify (add or subtract) material easily is a desirable artifact expressed by the sampled population of interviewees. This allows instructors to grab only a subsection of an existing resources and easily apply it to their needs e.g., changing the region of a case study, removing a section that is outside of the scope of the current class, rewording a statement, or adding or removing user support.

Lack of Assessment Data

The assessment of innovative educational developments is an invaluable product of implementation and is a critical aspect of successfully scaling an innovation. As expressed by the interviewees, many professors are reluctant to implement new resources due to lack of assessment data. Instructors want proof that the material is effective before implementing it in their class. This becomes a bit of a conundrum especially for pilot efforts which have yet to be tested. It seems you need assessment data to obtain assessment data. Typically, developers attain initial assessment data from their own institution, however, this is usually a rather limited sample size and results of the developer-implementation generally contains some level of biasness. Furthermore, it is somewhat difficult to assess the impact of such approaches on student learning especially when non-traditional material is being introduced such as data and modeling techniques.

4.3.2 Views from Industry

Industry needs skilled graduates who are capable of applying hydrologic concepts taught in the classroom to practical real-world engineering problems. In today's technology driven society, and with the recent advancements in data and hydro-informatics, this often requires a deep knowledge of a number of computer applications, data processing tools, and simulation models. A total of 36 practicing engineers, representing different experience levels and roles (juniors, seniors and upper management) were interviewed. A summary of recurring topics of discussion are presented here.

4.3.2.1 Preparedness of Recent Graduates

According to the sampled population of senior engineers and managers, young engineers in hydrology and water resources must be able to use, understand, and develop models; interpret and analyze data; and effectively identify and communicate key findings. In regards to modeling, skills should not be specific to a particular software, rather they should be adaptable, broad, and general. Engineers should understand basic concepts of model setup and identification and preparation of input data; how to specify parameters, constraints, and computational time-steps; how to analyze results; and they should have some theoretical knowledge underlying the model. Understanding when and where assumptions and approximations should be made, what sources of uncertainties exist, and being aware of and able to articulate limitations of a modeling analysis, are important concepts that should be instilled in young engineers, but are not generally encountered by the majority of graduates. General knowledge of numerical modeling concepts is a more desirable attribute than detailed training in a specific software. Priority here is given to the former due to the large variation of tools and models used among consulting firms.

In addition to modeling and data analysis skills, professionals in industry expressed that young engineers coming out of undergraduate typically have underdeveloped engineering soft skills, such as communication, creativity, adaptability, and collaboration. While the interviewees acknowledged that such skills are usually hard to teach in traditional classrooms, they expressed that the use of case-based, data and modeling-driven student projects, developed through collaboration with industry, present some unique opportunities to introduce these types of skills into the undergraduate curriculum.

A multitude of young engineers interviewed showed great excitement when approached with the discussion of the undergraduate curriculum. While many felt that their undergraduate degree adequately prepared them for their first job, they stated that their knowledge on the use of computer models and related tools was lacking. They were quick to clarify, however, that it was not lack of conceptual or fundamental knowledge, but simply the lack of applicability within real-world hydrologic problems. While this couldn't be directly associated with a specific reason, it is reasonable to attribute it to the lack of context and open-ended problems in traditional textbook problems. Building on this, the interviewees complained that textbook problems often focus on using idealized and fairly narrow examples and lack the overall context of how hydrologic analysis can be pursued using data analytics and modeling approaches. This may inhibit young engineers from seeing the big picture of how different processes come together to solve large water engineering problems. In addition to having trouble with problem formulation, it seems that young engineers have trouble interpreting results and their meaning in the scope of the project at hand. Being able to contemplate the practical physical meaning of numerical or graphical results is just as important if not more important than performing the analysis.

4.3.2.2 Post-graduation Training and Professional Development

The development of skills associated with discipline-specific tools and techniques, engineering soft skills, practical interpretation of numerical results, and formulation of solution procedure from contextual information, is a long-term process that doesn't end at the undergraduate level, but progresses slowly over several years of post-graduation training. Through observing current on-the-job training practices, our interviews with industry members were also intended to identify attributes that might be leveraged and built upon in teaching these skills at the undergraduate level.

Our interviews with senior engineers and training managers indicated that training is obtained in the majority of consulting firms through informal techniques that uses a mentor/apprentice approach whereby a junior engineer works closely under a senior engineer until skills have been sufficiently mastered. This 'learn on the job training' with expert guidance is considered by many firms to be the most effective method of training even compared to more formalized training courses. In addition to being effective it is also considered efficient from a billable hour stand point; however, the tradeoff here is the extra burden that it puts on the senior engineer.

A second frequently-used approach involves referring to use of previous projects. If a current project is to an extent similar to a past project many firms will use this archived project to demonstrate the design process. The junior engineer can then use this past project as a sort of template or guide for designing the current project. Many firms, however, proceed with caution when this training method is used because past projects often have assumptions or design criteria that may not be always applicable to future project. Combining the two approaches is also a viable option where past projects, with input from senior engineers, can be packaged into in-house formalized training material. Investing time to develop such training material would reduce the time requirement of senior engineers in the future while still providing junior engineers with expert advice embedded into standalone training resources. The issue with this investment is that many small firms do not hire engineers at a rate that would have a timely payoff and the evolution of the tools and techniques of the industry is such that the developed material would be obsolete within a short span of time; this is in many aspects analogous to challenges with developing educational innovations. While this approach does not seem a viable option for small firms, there is already evidence of this practice in larger engineering firms. Larger firms have the need (large hiring rate) to justify development of such material and the resources in terms of time and manpower to maintain them. Other training opportunities, which are not frequently used due to cost factors, are obtained via online courses, participation in workshops, and even hiring a consultant to provide in-house training.

4.4 Conclusions

Keeping pace with field-specific advances in research and industry has been a huge challenge confronting STEM education since the dawn of the digital age; however, due to the technologically-savvy, highly-visual students of today, and with the recent educational research on effective pedagogies, impactful solutions are beginning to emerge. In many STEM disciplines this is evident with packaging of multimedia content with traditional textbooks, the development of web-based and interactive material by publishing companies, and non-profit educational organizations that provide open-source educational contents. In the field of water resources engineering education, recent efforts focused on aspects such as the use of effective discipline-specific pedagogies (e.g., case-based, student-centered, and active learning approaches), incorporation of research and industry-standard tools and techniques through using data and model-driven experiences, and collaborative efforts to develop a more unified curriculum. While such solutions are promising, resistance to adoption and implementation is still observed, which will eventually undermine the long-term sustainability of proposed educational innovations. To gain further insights into this critical issue, the current study engaged in an interview-based process through talking to potential customer segments (e.g., end-users and decision makers). The focus was on identifying key components and possible opportunities that affect the successful development, adoption and scaling of emerging innovations, such as; faculty motivators and hindering factors; potential partnerships, industry perspectives on preparedness of recent graduates, and potential supporting resources.

The qualitative interviews of this study indicated that while there is a lack of tangible motivators in place for faculty to engage in such educational innovations, two variables seem to contribute to instructors' receptiveness to innovative educational approaches: instructor experience and instructor research-versus-teaching emphasis. The existing lack of palpable incentives for improving educational practices in the field of water resources, suggests that achieving the desirable educational reforms in this field will always remain in the hands of faculty members who are personally and professionally motivated to pursue such efforts.

Results from interviews with water resources engineering faculty members identified key hindering factors for developing and adopting educational innovations in the field (Table 1), including: time limitations, steep learning curves, continuous refurbishment, rigidity of material, locality of case studies to specific hydrologic basins and datasets, and lack of assessment and evaluation data. These findings point out the critical, yet often-missing elements of user-support mechanisms to instructors who have the intention to adopt innovations. The expressed need for instructor-support, both as built-in features of the innovation (e.g., rubrics, assessment methods) and as post-development support (e.g., follow-up support to resolve problems), agrees with the recently proposed model on “design for sustained adoption” (Henderson et al., 2015). The need for innovative resources that introduce research and practice tools was iterated in interviews with industry members who indicated that young engineers have problems formulating solution procedures from context, lack familiarity with real-world hydrologic data, and have a deficient knowledge of emerging analytic tools and modeling techniques that are increasingly used by industry to solve water resources problems. Based on the views and insights gathered during this study, the following innovation design and dissemination recommendations are formulated (Table 1). To enhance the potential for adoption and scaling of water resources engineering educational innovations, the material should be easily adaptable and flexible in nature, have mild learning curves (for instructor and students), and have a modular design to easily fit into current course curriculum. Additionally, material should be consistently maintained and improved to keep up with the upgrading of models, data, and other technologies. Incompatibility of the structure, format, or content of educational innovations with existing work flow of the class requires extensive time and effort to overcome and often results in non-adoption. Secluded development of educational material often results in incompatibility problems, lack of sufficient assessment data, and may also contribute to insufficient updating of material. Following an innovation development approach that is based on continuous and iterative feedback from potential faculty users holds a great potential for successful adoption (Khatri et al., 2016). Similarly, collaborative efforts and sharing of innovations and learning resources amongst universities can potentially result in the development of assessment data that encourages independent adoption as well as distributing the time and effort of development and upkeep. Furthermore, co-developed material that is well balanced between research specialties of the collaborators may present unprecedented opportunities for students' learning. The need for long-term, post-development maintenance and user-support is undoubtedly challenged by lack of continuous streams of financial resources. Educational innovations are typically funded by time-limited federal and state grants, which calls on the water resources educational community to look for non-conventional funding mechanisms. Examples include avenues such as digital publishing of case-studies and associated datasets and models, possibly as supplements to textbooks, or as standalone web resources. These opportunities are increasingly being sought by other science and engineering fields and could potentially offer solutions for sustaining and growing the desired resources. Talking with practicing professionals revealed many untapped resources which may be taken advantage of by the water resources engineering faculty through collaborations with industry. By contributing educationally-rich resources such as case studies, datasets and existing models, industry can support instructors by easing the time and effort associated with developing educational innovations, and simultaneously contribute to molding the water resources engineering educational curriculum by early instilling into graduates the expectations and skills desired by in the industry. Interestingly, there exist many similarities between developing and implementing educational innovations and professional training practices, e.g., refurbishing requirements of formal training resources and educational innovations; criteria for choosing training material and criteria for implementing educational innovations (time and convenience); and the use of web-based training courses and web-based technologies for university educational innovations. Studying these similarities to identify common interests and parallel challenges offer more reasons for investing in academia-industry collaborations and partnerships that can be mutually beneficial for both sides. Models of such collaborations exist in capstone classes, internships, and co-ops, and can be extended to additional classes where data and modeling resources, for example, can be co-developed and used both by students as well as by junior engineers for early training purposes.

The current chapter aimed at communicating key roadblocks and potential remedies to the larger water resources engineering educational community to inform ongoing and future innovational development efforts towards more scalable and sustainable solutions. Despite the fairly diverse sample of educators and professionals interviewed in terms of institution type and geographical distributions, the results of the current study can be further substantiated and validated by sampling a larger number of institutions, and by quantitatively stratifying and analyzing the data according to the archetypes of the interviewees.

5 SUMMARY AND CONCLUSIONS

The overall goal of enhancing the undergraduate hydrology and water resources education with data and modeling activities was achieved in three ways: (1) resources from research and industry settings were combined with effective active learning pedagogies and delivered via web-based learning modules; (2) a design-based research methodology was applied to the development of the modules to identify attributes that contributed to the usability of the modules, students' receptiveness of the modules, and students' learning of hydrologic modeling concepts; (3) a 'customer discovery process' was used to identify key limitations of the development and implementation of educational innovations in the hydrologic sciences from the perspective of instructors and practicing professionals.

In summary, the study presented the development, implementation, and evaluation of eight web-based, student-centered modules designed to enhance the undergraduate hydrology and water resources education. The first six modules leveraged data and modeling resources from the large-scale efforts aimed at protecting and restoring the coast of Louisiana including simulation output from the 2012 Louisiana Coastal Master Plan Eco-Hydrology Model. The modules build on the complexities and deep context of the restoration efforts to immerse students in the deep context of the problems and then guide them through a series of data analysis and modeling activities. The latter two modules, Pecan Island Phase 1 and 2, were developed, implemented and evaluated using a design-based approach to investigate the design attributes and implementation strategies that are most conducive to students' learning of hydrologic modeling and data analysis techniques. The two modules guide students' through a series of highly technical activities involving model formulation, numerical solutions, parameter calibration, sensitivity analysis, and use of models to simulate a hydrologic system and assess the feasibility of a proposed engineering project. Upon completion of the modules students' user perspectives were obtained through a series of Likert surveys, informal interviews, classroom discussions, and graded submissions. The focus of the evaluation was on the usability of the modules and on students' receptiveness and perception of the modules learning value. The last part of the study sought insight from academia and industry on needs, motivations and hindering factors that affect hydrology and water resources engineering faculty as developers and potential adopters of educational innovations in this field. Such insights can be used to inform ongoing and future developments of water resources engineering education innovations and promote, broad adoption and long-term sustainability. The conclusions drawn from the study are summarized as follows.

- Students' performance in the different tasks, as well as the feedback received from post-module interviews, provided valuable insights on their perceptions of the educational value of using large-scale restoration projects for educational activities. Overall, students indicated that the modules were an excellent change of pace from traditional classroom topics, and many of them appreciated the exposure to critical ecosystem restoration problems and the role engineers and scientists play within these multi-discipline systems.
- Given that the modules were developed as a content-rich learning experience with extensive set of self-driven activities, students cited some problems in following the detailed instructions while staying oriented with the "big picture" and the overall flow of the different analysis tasks. Unlike traditional textbooks, the use of a web-based design and abundance of information and resources that it can accommodate, might

adversely lead to some of the confusion expressed by students in following the instructions. In developing these resources, it is critical to strike the right balance between the level of detailedness and step-by-step procedural instructions that allow successful task completion, and the open-ended directions that promote hypothesis formulation and inquiry-based learning.

- Based on student feedback, user-support and feedback mechanisms were critical in facilitating their work; however, foreseeing where students might make mistakes or need assistance is a challenge. For this reason, developers must be careful to present material with the proper curricular expectations, ensure connections to basic concepts that the students are familiar with, and embed interactive tools to support students' progression through the lessons and activities. Inclusion of user support such as video tutorials, geospatial visualization tools, and formative feedback quizzes can help to reduce the steep learning curves often associated with such approaches.
- The design of meaningful case-based modules brings inevitable elements of content length and thus the need for often-long completion times. Adding to time-related issues is the fact that investigative-type tasks associated with such learning modules (e.g., model calibration and evaluation, model revisions, identification of questionable data, project scenario analysis) often require additional time of reflection where students assess where mistakes could have been made or where revisions need to be introduced to their models. Striking a balance between a module length that is adequate enough to result in a deep learning experience on the one hand, and a relatively concise and focused module so that students do not lose the overall goal of the project and to ensure reasonable completion times within course constraints on the

other hand, is a key aspect behind developing student-centered modeling-based learning modules at the undergraduate level.

- Assessing the actual impact on student learning from these types of modules, especially in a quantitative manner, is another challenge. The fact that the inter-disciplinary topics and data and modeling concepts targeted by the modules are not typically covered in traditional curricula, makes it difficult to objectively assess students' performance using well-established methodologies such as the use of control groups. Also, the complex nature of the activities, where students are required to retrieve and pre-process data, use their judgment and intuition to make decisions, and present and discuss results, may lead them to different paths, thus making assessment and evaluation fairly challenging.
- It is highly recommended that instructors interested in taking advantage of resources available through large-scale ecosystem restoration and planning endeavors approach and collaborate with state and federal agencies that are in charge of these systems, as well as with consulting firms who are engaged in the design and implementation phases. These entities provide unique perspectives to support the formulation of meaningful student problems, and access to the necessary datasets and model outputs. Establishing a working partnership between the educational and agency communities can significantly reduce development effort on the instructors and affords the institution the opportunity to have a significant impact on the undergraduate education and the respective field as a whole.
- There is a lack of tangible motivators in place for educational improvements in hydrology and water resources, two variables seem to contribute to instructors'

receptiveness to innovative educational approaches: instructor experience and instructor research-teaching emphasis. The existing lack of palpable incentives for improving educational practices in the field of water resources, suggests that achieving the desirable educational reforms in this field will always remain in the hands of faculty members who are personally and professionally motivated to pursue such efforts.

- Key factors that hinder the development and adoption of educational innovations in hydrology and water resources engineering, as made evident by academia feedback, include: time limitations, steep learning curves, continuous refurbishment, rigidity of material, and lack of assessment data. To successfully achieve large scale adoption of educational innovations these hindering factors must be addressed. It is expected that collaborative efforts between universities may be the key to relieving much of these unattractive factors.
- While the student perspective is important to consider when developing module content and usability features, an instructor perspective is important to consider for adoption purposes. Providing support for instructors that assist in overcoming hindering factors and promote motivation will be essential in successfully scaleing and sustaining educational innovations in hydrology and water resources engineering.
- Industry indicated that young engineers have problems formulating solution procedures from context, lack familiarity with codes and specs, have underdeveloped engineering soft skills, and have a deficient knowledge of analytic tools and techniques used on the job. It is hypothesized that the lack of context and open-ended problems in traditional textbooks may be to blame for many of these shortcomings.

Interviewees complained that textbook problems often focus on using idealized and fairly narrow examples and lack the overall context of how hydrologic analysis can be pursued using data analytics and modeling approaches.

- Through contributing resources such as case studies, datasets and existing models, industry can exhibit work being done in post-graduation careers while simultaneously providing instructors with resources from which educational material can easily be developed thus easing the time and effort-associated pains of developing educational innovations. Additionally, there exist many similarities between developing and implementing educational innovations and training practices. Studying these similarities may better inform instructors and developers as to what attributes are most beneficial, effective, and attractive.

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ABSTRACT

Recent research and technological advances in the field of hydrology and water resources call for parallel educational reforms at the undergraduate level. This thesis describes the design, development, and evaluation of a series of undergraduate learning modules that engage students in investigative and inquiry-based learning experiences and introduces data analysis and numerical modeling skills. The modules are situated in the coastal hydrologic basins of Louisiana, USA. Centered on the current crisis of coastal land loss in the region, the modules immerse students in a suite of active-learning experiences in which they prepare and analyze data, reproduce model simulations, interpret results, and balance the beneficial and detrimental impacts of several real-world coastal restoration projects. The modules were developed using a web-based design that includes geospatial visualization via a built-in map-interface, textual instructions, video tutorials, and immediate feedback mechanisms. Following pilot implementations, an improvement-focused evaluation was conducted to examine the effectiveness of the modules and their potential for advancing students' experiences with modeling-based analysis in hydrology and water resources. Both qualitative and quantitative data was collected including Likert-scale surveys, student performance grades, informal interviews, and text-response surveys. Students' perceptions indicated that data and modeling-driven pedagogy using local real-world projects contributed to their learning and served as an effective supplement to instruction. The evaluation results

also pointed out some key aspects on how to design effective and conducive undergraduate learning experiences that adopt technology-enhanced, data and modeling-based strategies, and how to pedagogically strike a balance between sufficient module complexity, ensurance of students' continuous engagement, and flexibility to fit within existing curricula limitations. Additionally, to investigate how such learning modules can achieve large scale adoption, a total of 100 interviews were conducted with academic instructors and practicing professionals in the field of hydrology and water resources engineering. Key perspectives indicate that future efforts should appease hindering factors such as steep learning curves, lack of assessment data, refurbishment requirements, rigidness of material, time limitations.

BIOGRAPHICAL SKETCH

Matthew Wayne Deshotel was born in San Antonio, Texas, on May 29 1992, to Bobby and Susie Deshotel. He graduated North Vermilion High School before enrolling at the University of Louisiana at Lafayette. Matthew obtained a Bachelor of Science in Civil Engineering in May of 2015. He also completed his Louisiana E.I.T. certification in the spring of 2015. In the fall of 2015, Matthew began his pursuit of a Master of Science in Engineering with an option in Civil Engineering and will complete his degree in spring of 2017.