Adaptable web modules to stimulate active learning in engineering hydrology using data and model simulations

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ABSTRACT
The overall goal of this study is to contribute to the advancement of hydrologic education as a multifaceted discipline. The specific objectives are to deliver visual, case-based, data and simulation driven learning experiences to instructors and students through open source web technologies and community based data and modeling sources. The approach is to use three different regional-scale natural hydrologic systems as educational “observatories” and have the learning experiences embedded within. These hydro-systems (Coastal Louisiana, Florida Everglades, and Utah Great Salt Lake Basin) provide a wealth of hydrologic concepts and scenarios that can be used in many curricula. Several student-centered learning modules are currently under development along with an instructional interface to guide and support the learner and the instructor. The developments also include an instructor’s guide containing adaptation and implementation procedures. The web-based modules are intended to be applicable in a wide range of courses, in different programs within institutions, as well as at different levels within the same program. Independent users will test the system to obtain feedback for necessary revisions and enhance the adaptability of the project.

Keywords: hydrologic education, adaptable web modules, ecosystems, technology
1. INTRODUCTION

The hydrologic community has long recognized the need for a broad reform in hydrologic education.1–8 A paradigm shift is critically sought in undergraduate hydrology and water resource education by adopting context-rich, student-centered, and active learning strategies. Hydrologists currently deal with intricate issues rooted in complex natural ecosystems containing a multitude of interconnected processes. These processes are physical, chemical and biological and cross a wide spectrum of scales. Advances in the multi-disciplinary field include observational settings such as critical zone and water, sustainability and climate observatories, hydrologic information systems, instrumentation and modeling methods.7,8 These research advances in hydrologic theory and practices call for similar efforts and improvements in hydrologic education. The traditional approach in hydrologic education, typically textbook based, has focused on specific engineering applications and/or unit processes associated with the hydrologic cycle with idealized examples, rather than understanding the contextual relations in the physical processes and the spatial and temporal dynamics connecting climate and ecosystems. An appreciation of the natural variability of hydrologic processes will lead to graduates with the ability to develop independent learning skills and understanding. This appreciation cannot be gained in curricula where field components such as observational and experimental data are deficient. These types of data are also critical when using simulation models to create environments that support this type of learning.9 Additional sources of observations in conjunction with models and field data are key to students understanding of the challenges associated with using models to represent such complex systems. Recent advances in scientific visualization and web-based technologies provide new opportunities for the development of more active learning techniques that utilize ongoing research.10,11

The objectives of the current study are to deliver visual, case-based, data and simulation driven learning experiences to instructors and students through a web server-based system. Open source web technologies and data obtained from community-based tools will facilitate wide dissemination and adaptation by diverse, independent institutions. New hydrologic learning modules will be based on recent developments in hydrologic modeling, data, and resources. The modules are embedded in three regional-scale ecosystems, Coastal Louisiana, Florida Everglades, and Utah Great Salt Lake Basin. The new hydrologic education developments will be transferable to independent institutions and

![Figure 1. Hydroviz homepage (http://hydroviz.cilat.org/hydro/).](http://hydroviz.cilat.org/hydro/)
Adaptable both instructionally and technically through a server system with the architecture necessary to support the addition of further developments by the hydrologic educational community.

2. METHODOLOGY

The current study expands on the developments of a pilot study, which resulted in a web-based educational tool called HydroViz (Figure 1 and Figure 2). The purpose of the HydroViz pilot system was to test the applicability of web-based technologies to integrate hydrologic data and simulations of a small-scale watershed to support undergraduate hydrology education. The expansion of Hydroviz presented in the current paper entails a growth in application, from a local scale with a single topic and limited course use to regional scale with multiple learning contents and broad range of curriculum applications at multiple institutions. The basic structure of Hydroviz provides the platform for instructional support and student learning tools. The use of open source and free web-based technologies enables a wide adoption within the learning community. The HydroViz tool uses Google Earth plug-in and its JavaScript API to allow geospatial data layers to be embedded in a webpage that has a similar functionality to Google Earth (Figure 2). This supports the visual and interactive learning by the students. The HydroViz software architecture offers the ability to place and visualize hydrologic technical information on a three-dimensional (3-D) model of Earth. Cascading style sheets (CSS) and hypertext markup language (HTML) describe the look and formatting of each HydroViz web page. With the aid of Google Earth API, it was also possible to create customized buttons and panels for students to interact with and display the data.

3. STUDY SITES

The learning experiences developed in this study are embedded in three US regional-scale natural hydrologic systems that are used as educational “observatories”. These natural hydro-systems include Coastal Louisiana, Florida’s Everglades, and the Great Salt Lake Basin in Utah. These sites provide a wealth of hydrologic concepts and scenarios that can be used in most water resource and hydrology curricula. The study develops several learning modules based on the three hydro-systems covering subjects such as: water-budget analysis, hydrologic effects of human and natural changes, climate-hydrology teleconnections, and water-resource management scenarios. These settings contain case
studies of course topics related to particular aspects of the location, and they can be used to demonstrate the inter-connectivity of the processes in a large-scale system.

3.1. Coastal Louisiana
The Coastal Louisiana system (Figure 3) provides ideas and situations involving the link between hydrology and ecosystem response and the complexities of estuarine ecosystems. The opportunities for learning about the fundamental hydrological processes and the connections between engineering, hydrologic sciences and other disciplines are unprecedented in the Louisiana coastal zone. This zone is a unique transition from inland to wetland/coastal hydrology and serves many functions, both ecological and economical. Balancing the often-conflicting functions of the multi-use ecosystem has led to much data and modeling research. Modeling tools already developed for coastal restoration and protection strategies for this region will be used in the modules to promote student’s understanding of the complexities of this particular system and the linkage between ecology and hydrology.

Figure 3. Map of Coastal Louisiana showing the domain and boundaries of the computational models.

3.2. Florida Everglades
The Florida Everglades system (Figure 4) provides opportunities to demonstrate human and ecosystem responses to climate change in a setting of resource management. This system has seen a large scale changes to hydrology, is undergoing a large restoration effort and has one of the most progressive water management practices. The wealth of detailed regional-scale hydrological and ecological models provides ample opportunity for students to investigate the dependency of regional water resource management and ecosystem on uncertain future climate changes.

3.3. Great Salt Lake Basin
The Great Salt Lake Basin system (Figure 5) presents concepts and situations related to semi-arid mountain and snowmelt driven hydrologic processes and water resources management. In this region, typical of the western U.S. where population growth is rapid, water resource management is critical. With the wealth of historical data in the area, opportunities for learning include a terminal lake and the interconnected issues of water level, salinity and evaporation, water storage and water diversion for human use.

4. DEVELOPMENT OF LEARNING MODULES
Several learning modules are developed based on the three real-world hydrologic systems described above. The learning modules for the Coastal Louisiana system include:
Module 1.0: Introduction to the system. In this module, students learn about the geological history and the current state of the system. Students will learn about the hydrologic processes that dominate the ecosystem and the manmade features that significantly affect the system.

Module 1.1: Ecosystem response to changes of freshwater inflows. Students will use data and modeling tools embedded in HydroViz to examine concepts related to the impact of freshwater inflows on the ecosystem response and the water budget of the ecosystem.

Module 1.2: How coastal marshes cope with Climate Change. Students will learn and analyze the mechanisms by which coastal marshes cope with climate change and subsidence focusing on three concepts: sea level rise, change in temperate, and subsidence.
Module 1.3: Can/how natural and engineered restoration measures help in preserving ecosystems? Students will use numerical experimentations pre-populated in the HydroViz system to examine how natural and engineered restoration measures can be used as strategies for protecting and reducing risk to ecosystems. Students will quantify the impact of these alterations.

Module 1.4: Impact of altering nutrient loading of the Mississippi River on the Gulf hypoxia. Students will alter the nutrient loading of the Mississippi River and quantify the impact on the spatial and temporal patterns of nutrient concentrations in the Gulf of Mexico.

Module 1.5: Impact of altering riverine sediment load on subsidence of deltaic system. Students will analyze the impact of altering the sediment load of the Mississippi and Atchafalaya Rivers and the impact on the subsidence of the deltaic system.

Modules 1.0 and 1.1 are currently under development. Module 1.0 is built around the Louisiana Coastal zone in general, covering topics ranging from identification of marsh types and hydraulic structures, to the socio-economic characteristics of the region. This module contains student activities using shapefiles and Google Earth and other tools and Internet data resources. The students will manipulate various GIS layers to identify structures and features that have impacted the natural hydrology of the region, calculate discharges and inflows, compare historical imagery to analyze changes in the region regarding marsh type, waterway capacities, sea level rise, subsidence and land loss. Other example students’ activities include analysis of historical tide data and examining the change in sea-level at a particular location. The students will also investigate the relationships between hydrologic conditions such as flooding duration and frequency and salinity to vegetation types and productivity.

Module 1.1 is centered on a water budget analysis of one region of the Louisiana Coastal Zone, called the Chenier Plain (Figure 6). In this module the students will access use stage and discharge information for selected waterways. Using this information in conjunction with simulation from a mass-balance compartment-type model embedded within the module, the students analyze the water budget for an entire section of the Louisiana coastal zone on both an intra-annual and an inter-annual basis. The system-wide analysis includes identification and discussion of seasonal patterns and causes, identification, calculation and discussion of dominant water budget components, and calculations regarding the storage component of the water budget. Students will also investigate the water budget at a smaller, model compartmental scale for two types of areas, water and marsh (Figure 7).

The learning modules for the Everglades include:

Module 2.1: Ocean-Atmosphere teleconnection and regional hydrologic variability. This module focuses on the connections of hydrologic processes to their climate progenitors in dynamic systems. The module will also provide an introduction to basic statistical concepts on correlation and regression.

Module 2.2: Connection of hydrologic processes to climate progenitors and ecosystem outcomes. Students will use the SFWMD hydrologic models to analyze the links between the historical climate to the modeled hydrology and the resulting ecosystem outcomes.
Module 2.3: Sensitivity of natural hydrologic systems to human-imposed management strategies. Students will take a subset of the full system that includes a representation of the managed and the natural system components, and explore the system sensitivity to parameter uncertainty, and to changes in operational strategies.

The learning modules for the Great Salt Lake Basin include:

- **Module 3.0: Overview of the Great Salt Lake Basin.** Students will investigate and analyze the hydrologic processes and water resource issues in the Intermountain Region using various resources on the web and common practices and data analysis tools.

- **Module 3.1: Precipitation, Snow and Surface Water Input.** Students will use the data and modeling tools embedded in HydroViz to examine temporal and spatial patterns of precipitation inputs into the basin as a function of elevation and its form (rain or snow) based on temperature.

- **Module 3.2: Surface Water Input-Runoff relationships:** Students will examine relationships between surface water input (rainfall or snowmelt) and the watershed streamflow response.

- **Module 3.3: The Great Salt Lake.** Students will examine water and salinity budgets of the Great Salt Lake. Changes in lake volume in comparison to inputs will be used to infer lake evaporation from mass-balance analysis and compared to meteorological-based estimates.

- **Module 3.4: Impact of population growth and development.** In this module students will compare a pre-developed state of the Great Salt Lake Basin system with post-development hydrology.

The modules for this system are developed using a mixed case-based, problem-based approach. The case studies and the corresponding subject matter are shown in Table 1.

**Table 1. Case studies.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Logan Dry Canyon Study</th>
<th>Bear River Water Resources Study</th>
<th>Great Salt Lake Mineral Pond expansion study</th>
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<tr>
<td>Context</td>
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<td>✓</td>
<td></td>
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<tr>
<td>Precipitation &amp; surface water input</td>
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<td>✓</td>
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<td>Runoff generation</td>
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<td>Terminal Lake</td>
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<td></td>
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<tr>
<td>Human interactions</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
For example, the Logan Dry Canyon case study (Figure 8) takes the students through the process of determining the size of a flood detention basin to be located at the mouth of Logan Dry Canyon in Utah. This process begins with analysis of historic rainfall data obtained from the National Climatic Data Center (NCDC) and the development of Intensity-Duration-Frequency curves to ultimately construct a design storm. Within the analysis, a snowmelt model will be used to augment the runoff calculations. The design storm will then be used to design the detention basin sufficient to protect nearby residents from flood. Students also examine the translation of precipitation into runoff and calculate runoff generation by various methods and investigate the similarities and differences among the methods.

5. CONCLUSION AND FUTURE WORK
The current project contributes to improving undergraduate hydrologic education through developments of learning experiences that rich in data and simulations. The new learning experiences are embedded in three natural hydro-systems which include Coastal Louisiana, Florida’s Everglades, and the Great Salt Lake Basin in Utah. These sites provide a wealth of hydrologic concepts and scenarios that can be used in most water resource and hydrology curricula. The study develops several learning modules based on the three hydro-systems covering subjects such as: water-budget analysis, impact of human and natural changes on hydrologic regimes, effect of climate factors on the hydrologic response, and design and testing of water-resource management scenarios. These modules are web based and are intended to be applicable in a wide range of courses, in different programs within institutions, as well as at different levels within the same program. This breadth and depth is designed to enable wider adoption within different curricula and programs. After completing the development of different learning modules from the three systems, future effort of the study will focus on developing an instructional interface to give critical guidance and support to the learner. This guidance is crucial when learning situations involve real-world cases and to promote consistent student performance. An instructor’s guide containing adaptation and implementation procedures to assist instructors in adopting and integrating the material into courses and provide a consistent experience is also under development. An improvement-focused model for evaluation will be conducted in an iterative process of design, implementation, evaluation and redesign. Monitoring of the project will provide assessment of effectiveness on usability, student learning and adaptability.

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REFERENCES


