## Introducing Teachers to Modeling Water in Urban Environments

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#### **ABSTRACT**

Geoscience educators in K-12 have limited experience with the quantitative methods used by professionals as part of their everyday work. Many science teachers at this level have backgrounds in other science fields. Even those with geoscience or environmental science backgrounds have limited experience with applying modeling and simulation tools to introduce real-world activities into their classrooms. This article summarizes a project aimed at introducing K-12 geoscience teachers to project based exercises using urban hydrology models that can be integrated into their classroom teaching. The impact of teacher workshops on teacher's confidence and willingness to utilize computer modeling in their classes is also reported.

#### **Categories and Subject Descriptors**

Social and professional topics~Computational science and engineering education • Social and professional topics~K-12 education • Social and professional topics~Computational thinking

#### **General Terms**

Teacher professional development; Geoscience education;

#### **Keywords**

Stormwater modeling; Curriculum development

#### 1. INTRODUCTION

Promoting careers in the geosciences to high school students requires hands-on projects that engage the students in solving real problems, introduce the types of work undertaken by geoscientists, and fit comfortably into the existing curriculum. In geosciences, as in most scientific fields, addressing practical problems requires multi-disciplinary skills that include the understanding of scientific principles, the application of

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mathematics, the use of computational tools, and the effective presentation of the results both orally and in writing. Focusing on an applied problem can provide students with the motivation to learn and apply concepts and techniques from all of the relevant disciplines while illustrating the nature of the work undertaken in the geosciences.

Inquiry-, project-, and problem-based (PBL) learning is a recognized strategy to build interest and depth of understanding of science and math concepts [1]. Research has shown that PBL can be more effective in preparing students to integrate concepts, improve retention, and improve achievement on assessments at the state level [4,8,10]. Mathematical models and computer simulations are one approach to creating PBL experiences for students. Models are a key component of the science and math common core standards [6,9].

Teachers' implementation of modeling and simulation in their classrooms is often constrained by their understanding of the underlying principles. K-12 geoscience classes can be taught by teachers who majored in other science disciplines. Even if they came from a geoscience major, teachers may lack the expertise in quantitative modeling to feel comfortable in using models in their classrooms.

To address these issues, we developed a curriculum focused on urban hydrology modeling as part of our effort on a National Science Foundation geosciences education project. The curriculum includes components of data collection, physical models, and computer models of urban hydrology [3]. The materials were presented to teachers in summer workshops in 2013 and 2014. It included the development and presentation of two computer models of urban hydrology. Below, we present a description of the model development and its impacts on teachers' willingness to make them part of their classroom activities.

# 2. SIMPLE MODEL OF STORMWATER RUNOFF

#### 2.1 Adaptation of HEC-HMS Model

Understanding the relationships among rainfall intensity and duration, land cover, and the quantity and distribution of stormwater runoff are keys to a deep understanding of urban hydrology. Urban development creates impervious surfaces that reduce soil infiltration and groundwater flow while increasing surface runoff and the peak runoff of urban streams, often causing flooding. To illustrate these relationships, projects were created using two hydrology models.

The first model chosen for this purpose was the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) of the US Army Corps of Engineers [11]. The model provides options to use several different methods to create simulations of basin-wide stormwater runoff hydrographs. However, the interface and available options are quite complex and probably not suited to novice users. For this reason, we began by creating a Java front end interface that provides only selected options to the user. The data from the interface is then passed to the installed HEC-HMS model to run in batch mode and create an output file. The Java interface then reads this output file and presents the user with graphs of the results and the ability to export the data to a spreadsheet format for further analysis.

Before introducing the models, teachers participated in several exercises that introduced hydrologic modeling concepts and measurements. Teachers were immersed in the inquiry exercises as teams – just as their students would be in the classroom. Participants developed laboratory procedures, reviewed data sets, took measurements, calculated volumes, and presented results.

In the first unit, participants completed a simple experiment with a sprinkler simulating rainfall into a rain gauge and two large soup cans with pea gravel and topsoil as experimental porous media. Measurements were taken to demonstrate the principles of soil retention and runoff as it relates to the type of soil.

In a second unit, the instructor introduces a miniature watershed, named a GeoSandbox, to provide a conceptual bridge between the schema created in the first unit and the watersheds and models used in the next unit. Students introduce known quantities of water to the GeoSandbox using spray bottles and measure the resulting surface flow and infiltration. The concepts of topography and land use are also introduced. Additional instructional materials are provided to firmly establish the concept of watershed for students who need the support.

Unit three uses a local school yard, with measurements of land use, surface area, and slope, to estimate the flow of water during a rainfall event. Free, online tools, such as Google Earth Pro, Google Maps, and various sites from the U.S. Geological Survey and National Weather Service are also introduced so that students can expand their geographic scope without needing to personally collect every measurement. Detailed instructions for these activities can be found on the project site [3].

With these activities as background, students can then use the simple hydrologic model to explore the relationships between land use, land cover, and the amount of runoff produced during a storm event.

Figures 1 and 2 show the data input windows of the Java interface to the simple hydrologic model. In the first window, the user inputs information on the flow length, elevation change, and area of the watershed. These can be measured from U.S. Geological Survey maps or digital elevation maps. The distribution of land cover is also input. The pull down menus include categories of woodland, agricultural, residential, commercial, and industrial land uses that comprise the surface of the watershed. These in turn are linked to runoff coefficients in the model that are related to the degree of imperviousness of each of the land use categories. This allows the exploration of the impacts of different land use mixes on stormwater runoff.

In the second window, users enter the hourly storm precipitation information for up to twelve hours. Thus, the stormwater of different storm amounts and time distributions could be

compared. For example, students could compare the impact of a sudden downpour lasting only an hour or two to a steady rain with the same amount of rainfall spread over twelve hours.

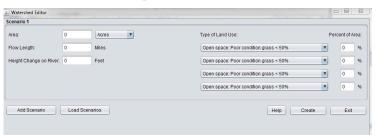


Figure 1: First Data Input Screen for HEC-HMS Java Interface

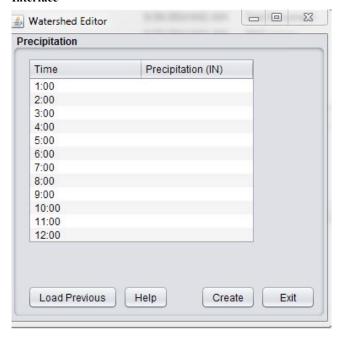


Figure 2: Second Data Input Screen for HEC-HMS Java Interface

Once the input data are created, the applet launches the background model which simulates the stormwater hydrograph for the storm. These data are then read by the applet and display a graphic such as the one in Figure 3.

The interface also allows for up to three scenarios where the user inputs either different land cover data or different storm volumes and distributions. These are then shown on the same graph for comparison purposes as shown in Figure 4. In that example, high density residential land cover was replaced with lower density residential development for the same storm. Data can also be exported to a spreadsheet for further analyses and comparisons.



Figure 3: Output Hydrograph from HEC-HMS Model

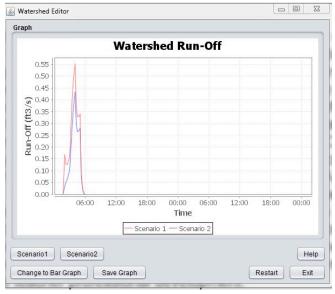


Figure 4: Hydrographs Comparing Two Land Use Scenarios

#### 2.2 Simulating Water Quality Impacts

Real watersheds have complex mixtures of different land uses spread across much larger areas than those can be represented in our simple model example. In addition, the runoff from human disturbed watersheds carries with it a number of pollutants that may also cause environmental problems.

Modeling these conditions requires an expertise level far beyond what most if not all high school instructors. However, illustrating the nature of the conditions and their outcomes should be part of a comprehensive urban hydrology curriculum. To address this challenge, we built a third Java applet that allows exploration of the conditions and outcomes of human development in a real watershed. For this exercise, we used the U.S. EPA Stormwater Management Model [12].

Based on a previous study of the Hellbranch Watershed in central Ohio, a large number of land cover combinations for a single, real storm, were run using PCWSMM, a version of the model with a graphical user interface [7]. The model outputs include a forecast of the runoff as well as the potential pollutant load arising from the storm event. An interface was then created which allows the user to choose one or more land cover scenarios and observe their impacts on runoff and water quality.

Unit four of our activities expanded the view of hydrology to the watershed scale by looking at changes in watershed land use and hydrology for a particular watershed over time. USGS quadrangle sheets and/or aerial photographs are used to identify major changes in land use as well as changes in the water features over time in the Big Darby Creek watershed in Ohio [3]. This provides the basis for thinking about long-term watershed changes that are simulated in the PCSWMM model.

The unit on the SWMM model includes a detailed explanation of the model operation and options, a set of exercises on stormwater runoff and water quality, and links to related materials on the impacts of stormwater on urban stream flooding and water quality [9]. The exercises provide instructions on selecting and comparing a few of the scenarios that illustrate the impacts of urbanization on stream flow and water quality.

Figure 5 is a representation of the watershed showing the subcatchments that were used to specify the land cover scenarios and the channels used in the simulation. Table 1 shows an example of one of the land cover scenarios where medium density residential development is added to most of the watershed subcatchments. In the table, one can see that a significant proportion of the land cover in most of the subcatchments of the watershed are assigned to medium density residential uses. This implies the creation of single family housing at about four units per acre. This also implies the creation of impervious surfaces from streets and rooftops that will impact the volume of runoff coming from those areas.

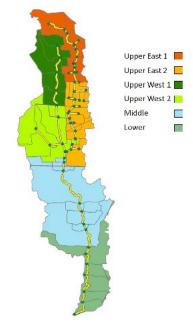


Figure 5: Subcatchments and Stream Network for

The model user can choose the amount of each development type to create in the model run and can then compare a variety of outcomes associated with each of the selected examples. Along with the runoff hydrograph for the storm, the user can also see pollutographs that show the volume of sediments and oxygen demanding wastes that are likely to be carried by that runoff. These are illustrated in figures 6 and 7. Finally, the model has generated a set of runoff videos which illustrate whether flooding will occur at selected locations in the watershed.

The numerical outputs in the form of selected maximum and minimum values can be chosen by the user and saved in a spreadsheet for further comparisons and analysis. The graphs can also be saved in a separate file.

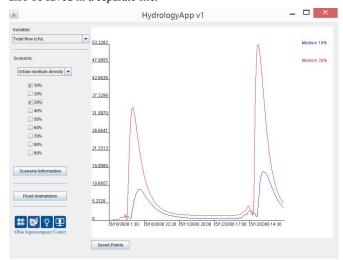


Figure 6: SWMM Hydrograph for 10 and 30 Percent Medium Density Urban Cover

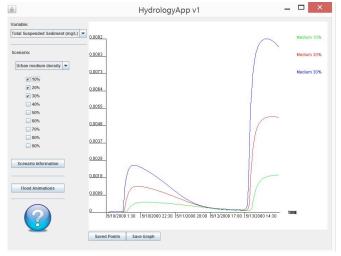


Figure 7:SWMM Sediment Load for 10% and 30% Medium Density Residential Cover

**Table 1: Land Cover Distribution Scenario Example** 

Urban		6.1							
Medium		Sub-category of Hellbranch Watershed							
Develop				T., T., T					
ment	Land use	Upper	Upper	Upper	Upper	Middle	Lower		
Scenario		East 1	East 2	West 1	West 2				
		%							
	Forest	10	10	20	20	20	20		
	Agriculture	80	80	80	80	80	80		
10%	Low Density	0	0	0	0	0	0		
	Medium			_	_	_	_		
	Density	10	10	0	0	0	0		
	High Density	0	0	0	0	0	0		
	Forest	10	10	20	20	20	20		
	Agriculture	70	70	80	80	80	80		
	Low Density	0	0	0	0	0	0		
20%	Medium								
	Density	20	20	0	0	0	0		
	High Density	0	0	0	0	0	0		
	Forest	10	10	20	20	20	20		
	Agriculture	60	60	80	80	80	80		
	Low Density	0	0	0	0	0	0		
30%	Medium								
	Density	30	30	0	0	0	0		
	High Density	0	0	0	0	0	0		
	Forest	10	10	20	20	20	20		
	Agriculture	50	50	80	80	80	80		
	Low Density	0	0	0	0	0	0		
40%	Medium								
	Density	40	40	0	0	0	0		
	High Density	0	0	0	0	0	0		
50%	Forest	10	10	20	20	20	20		
	Agriculture	40	40	80	80	80	80		
	Low Density	0	0	0	0	0	0		
	Medium	U	U	U	U	U	U		
	Density	50	50	0	0	0	0		
	High Density	0	0	0	0	0	0		
	Forest	10	10	20	20	20	20		
		30	30	80	80	80	80		
	Agriculture	0	0	0	0	0	0		
60%	Low Density Medium	0	J	"	U	J	U		
		60	60	0	0	0	0		
	Density	0	0	0	_	0	0		
	High Density				0				
	Forest	10 20	10 20	20 80	20 80	20 80	20 80		
	Agriculture								
70%	Low Density Medium	0	0	0	0	0	0		
		70	70	0	0	0	0		
	Density		_		_	_	_		
	High Density	0	0	0	0	0	0		
80%	Forest	10	10	20	20	20	20		
	Agriculture	10	10	80	80	80	80		
	Low Density	0	0	0	0	0	0		
	Medium	80	80	0	0	0	0		
	Density								
90%	High Density	0	0	0	0	0	0		
	Forest	10	10	20	20	20	20		
	Agriculture	0	0	80	80	80	80		
	Low Density	0	0	0	0	0	0		
	Medium Density	90	90	0	0	0	0		
	High Density	0	0	0	0	0	0		

#### 2.3 Initial Testing

The entire curriculum was presented at a summer workshop for K-12 geoscience teachers in 2013. This included working through each of the introductory units and a set of exercises using the computer models.

Although the teachers were able to understand the simple hydrologic model and complete the exercises, a number of problems with our approach arose. The installation of the underlying model and the Java applet was difficult. Slight deviation from the installation instructions caused the model to fail. Teachers also pointed out that installation on their school computers would be a problem and thus asked us to try to develop a model with the same underlying goals but with an interface that could be run in a web browser.

A second model using the same underlying modeling approach was developed to run in a browser [2]. Specifically, the Natural Resources Conservation Service (NRCS) Curve Number approach was used to calculate overall runoff volume, and a hydrograph produced using the NRCS unit hydrograph [5], with time-of-concentration calculated from channel slope [5]. Figure 8 shows the model input screen. The web-based model allows the comparison of up to four land cover scenarios and three precipitation scenarios. Output is available as either a bar or line graph and the data can be exported to a CSV file for further analysis. This model was introduced to teachers in a second summer workshop in 2014.

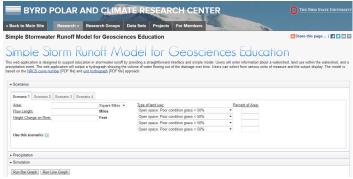


Figure 8: Model Input Screen for Web-based Model

Other critical lessons were learned during the first summer workshop that led to subsequent improvements to the module and Simple Storm Runoff Model for Geosciences Education. First, teachers from the upper elementary and middle school grades indicated that they were more likely to deploy the experimental units 1, 2 and possibly the simple hydrologic model – unit 3. Teachers at the high school level were more likely to deploy units 2, 3, and the watershed scale unit 4 with teachers of advanced courses, such as A.P. Environmental Science, more likely to deploy unit 4 than other teachers. Unit 5, the SWMM model exercise, was seen as applicable to both middle school and high school audiences and was seen as a way to approach land use impacts when time was limited in the classroom or to look at impacts beyond water volume for advanced courses. Rather than look for teachers to deploy all five units of the module, the project team worked with teachers to customize and implement portions appropriate for their curriculum and circumstances.

### 3. Evaluating Workshop Impacts

#### 3.1 Workshop Background

The workshops for geoscience teachers were held in the summers of 2013 and 2014. Teachers were asked to fill out a pre-workshop survey with questions about their background and reasons for attending the workshop. Following the workshop, they also filled out a post-workshop survey with questions concerning the potential impacts of the workshop and workshop materials on their own classrooms, the quality of the workshop, and their overall comments on the experience.

Most teachers wanted to increase the number of real world experiences in the classroom as well as to increase the use of technology in their classrooms. There was also a desire to improve their instruction on the related topics.

#### 3.2 Workshop Outcomes

In advance of the workshop, teachers were asked a number of questions about their preparation to effectively implement instruction related to the workshop content.

Teachers were highly confident in managing the use of hands on materials in their classes, implementing inquiry or problem-based learning, and developing assessments to measure specific learning outcomes. They were much less confident in their ability to describe the movement of water through a watershed or to measure that movement. Perhaps most significantly, very few teachers were confident in their ability to use computers to model the movement of water through a watershed prior to the workshop.

The post-survey on the same questions serves as one measure of the impact of the workshops and the related modeling materials. This is shown in Table 2.

Table 2: Post Survey Opinions on Workshop Impacts

	Teachers 2013 End-of-Summer N=15		Teachers 2014 End-of-Summer N=5	
	N	%	N	%
Locate ideas for geosciences lessons and units either online or in print.	15	100.0	5	100.0
Apply the principles of the inquiry cycle (ask question, design experiment, conduct experiment, collect data, analyze and draw conclusions, and share).	15	100.0	5	100.0
Locate geoscience professionals to collaborate on lessons or serve as guest speakers.	15	100.0	5	100.0
Describe the movement of water through a watershed.	15	100.0	5	100.0
Measure the movement of water through a watershed.	15	100.0	5	100.0
Use computers to model the movement of water through a watershed.	15	100.0	5	100.0
Collaborate with other teachers on the development of geosciences lessons and units.	14	93.3	5	100.0
Use mathematics as part of a science lesson.	13	86.7	5	100.0
Use science as part of a mathematics lesson.	12	80.0	5	100.0
Implement inquiry or problem-based learning.	15	100.0	4	80.0
Incorporate geosciences lessons and units into my curriculum.	15	100.0	4	80.0
Apply the principles of the design cycle (identify problem, design solution, build solution, test, evaluate, and share).	14	93.3	4	80.0
Inform students about career opportunities in the geosciences.	14	93.3	4	80.0
Organize a field trip to a site related to geosciences or geosciences careers.		86.7	4	80.0

There are a number of observations that can be made by comparing responses before and after the workshop. All of the items that had a lower percentage of agreement on the pre-survey increased markedly to nearly 100% or 100% agreement. These include the ability to locate ideas for geosciences lessons, the description and measurement of the movement of water through a watershed, and the use of mathematics in a science lesson. Most important from the perspective of the computer models, 100% of both groups of teachers felt they could use computers to model the movement of water through a watershed.

The success of the effort is also reflected in some of the openended comments from teachers:

How to use real time data to model events. How to connect curriculum to local issues in community. Field trips improved my personal understanding. Other teachers' ideas! The lesson plans (i.e. watershed modeling, Geo Sandbox, etc.) were definitely awesome inquiry and project-based ideas to add to my toolbox. The potential for continued collaboration in workshops or perhaps a distance-learning course for STEM students was also great.

Learning how to access all the data through software, etc., as this is exactly what common core is looking to do. Also, the information about Darby watershed as it is in my backyard and this ignited my curiosity to investigate more.

#### 4. CONCLUSIONS

Although our sample size is small, our experience with creating and testing computer models for use in K-12 geosciences classrooms leads to several important conclusions.

First, computer models for classroom use should avoid components that involve any installation complexity. Teachers generally lack the computer expertise to trouble-shoot problems with the download and installation of complex software as evidenced by our first attempt at creating a stormwater runoff model. Moreover, such installations may be impossible on school computers. Models that are available online or entirely self-contained as applets are much more likely to be used successfully in the classroom.

Second, and perhaps most important, the majority of teachers lack the modeling and simulation expertise required to feel confident in using computer models in their classroom. Although all of our participating teachers were seeking materials that meet the new science standards, very few were confident in the use of computer models as part of that effort. The completion of a professional development workshop that provided examples and help in understanding how the models worked resulted in a dramatic change in their confidence and attitudes toward using computer models in their classrooms. The workshop included building a conceptual framework of the geocscience processes that aided in the understanding of the more abstract modeling activities. If we truly want to integrate computer modeling and the related analysis skills into the K-12 curriculum, it will require a concerted effort to provide existing teachers with similar professional development experiences and the integration of those materials into the preservice teacher curriculum.

Our hope is that the release of these curricular materials, along with models that are relatively easy to implement in the classroom, will encourage more teachers to incorporate them into their curricula.

#### 5. ACKNOWLEDGMENTS

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