Background Information

Some watersheds have experienced minimal human impact whereas others are highly impacted. The Hellbranch Run watershed in Southwest Franklin County, Ohio discharges to the Big Darby Creek, a state and national scenic river that has been identified by The Nature Conservancy as one of the environment's last great places because of its biological diversity. Hellbranch Run enters Big Darby Creek downriver of the Big Darby's confluence with the Little Darby. As land use in the watershed changes, that diversity is threatened by changes in the streamflow, sediment, and the pollutants that are washed off the land into the stream. The watershed experienced a transformation from forest to farmland when settlers first arrived in Central Ohio and is now experiencing a transformation from farmland to residential and commercial development. The economic downturn of the past few years has slowed the recent transformation.
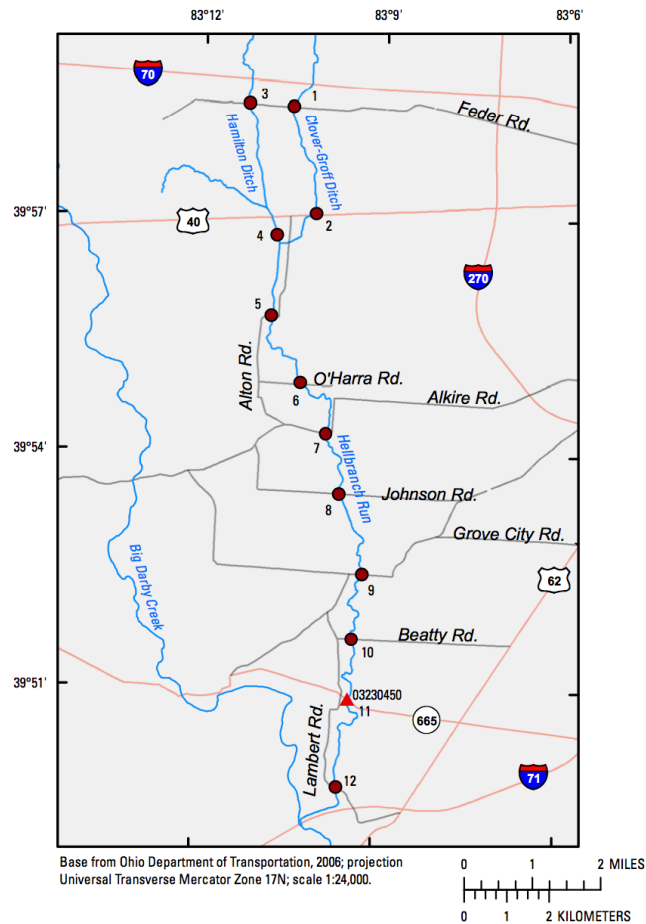
Figure 1. Location of study area.

Map of Hellbranch Run (Provided by USGS Report, 2008)

Introduction

This exercise will use a hydrologic model to project the impacts of land use change on stormwater runoff, flooding, and water quality on the Hellbranch Run watershed. The model used in this exercise is the USEPA Storm Water Management Model or SWMM (http://www.epa.gov/athens/wwqtsc/html/swmm.html). This model is quite sophisticated, and data points beyond those we have been collecting for use in the storm water web application were necessary. Therefore, in order to facilitate this activity, we have defined a number of different land use scenarios, run the model, and provide the inputs and outputs in the form of a Java applet. The model for the Hellbranch Run can be found in the HellbranchApp folder and opened by clicking on HydrologyApp.jar. It is important to note that this file will only allow scenarios to be run on the Hellbranch (inputs cannot be changed to a different watershed) and there are limits to the scenarios that can be run (the precipitation pattern cannot be changed). But students will be able to look at not just the amount and timing of water but materials contained within the water.

Below we describe the overall scenarios, provide a starting exercise, and instructions for using the applet. Depending on the class, you might elect to use the materials in a more open-ended fashion.

Materials
- Maps and/or Aerial Photographs of the Site (USGS/Google Earth/Google Maps)
- Rulers
- Computers Running HydrologyApp.jar
- Information on Development Standards and Infrastructure to Mitigate Runoff

Model Description

Below, you can see a more detailed map of Hellbranch Run. Each of the smaller areas on the map represents a subcatchment in the model. The subcatchments are then assembled into different areas represented in different colors. Those areas are used in our scenarios to reflect possible changes in the land use.

The yellow line represents stream channels or pipes that connect the subcatchments to the stream. The natural channel of the Hellbranch runs from north to south, as two tributaries at the north end joining to form the Hellbranch toward the middle of the basin. The other yellow channels are simulations of storm sewers that are assumed to be in place as urban development occurs. The green dots represent inflow points to the stream channel or manholes in the storm sewer system.

The model combines several aspects of the hydrology of the watershed to simulate the fate of water falling on the watershed from a rainstorm. We used the same rainstorm for each model run. When the rainfall gets to the land surface, part of it infiltrates into the soil, evaporates back into the atmosphere, or is intercepted by plants. The remainder becomes runoff. The amount of runoff depends on the nature of the underlying soil and the nature of the land use at the surface. In general as the intensity of land use increases so does the amount of impervious surface and therefore so does the proportion of rainfall that occurs as runoff because it does not infiltrate.

The runoff flows over the surface until it gets to a stream or a drain to the storm sewer system. It then flows down the channel or pipe, accumulating in volume as one goes from the headwaters toward the mouth of the stream. Each section of channel has a certain capacity to transport water. When this capacity is exceeded, flooding occurs. The amount of runoff is predicted by the model as a rate over time or as a total volume.

Runoff water carries sediment and pollutants from the land surface. This includes sediment eroded from agricultural fields and construction sites and organic materials and chemicals that collect on the surface. The model shows outputs of how these levels evolve over time.
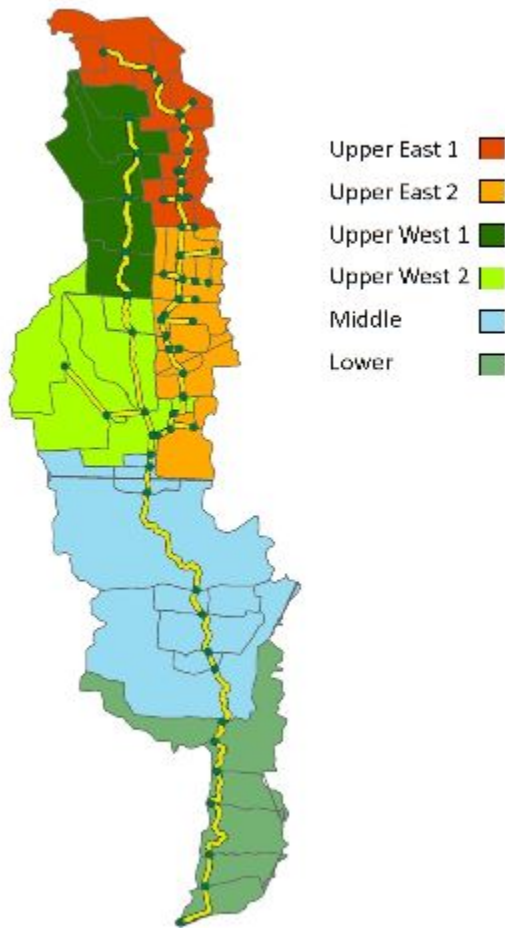
Hellbranch Basin Map Showing Subcatchments, Stream Channels/Pipes, and Inflow Points/Manholes

Development Scenarios

The model is used to create scenarios that simulate different land use distributions and their impacts on runoff, flooding, and water pollution. There are groups of scenarios relating to four major land use categories. The first group is agricultural land uses. As one goes from a landscape that would naturally be forest to one where the land is used for intensive row crop agriculture, the changes in the vegetative

cover and the soil will alter the amount of runoff. Scenarios reflect different portions of each region of the watershed being converted to agricultural uses.

The second set of simulations substitutes low density urban land uses. This would be single-family houses on one-half or one acre lots. Along with the rooftops and driveways, more street surfaces, changes in vegetation, and further alteration of the soils will impact runoff and water pollution levels.

The last two sets of simulations use medium and high-density residential development. Each of these in turn involves denser developments of housing, additional streets, parking areas, and rooftops. The increases in impervious surfaces will then have a dramatic impact on runoff in comparison to the natural state of the watershed.

The scenario dropdown menu allows you to select *Agriculture*, *Urban Low Density*, *Urban Medium Density*, and *Urban High Density*. There is a *Scenario Information* button that allows you to see the specific land use pattern under each scenario.
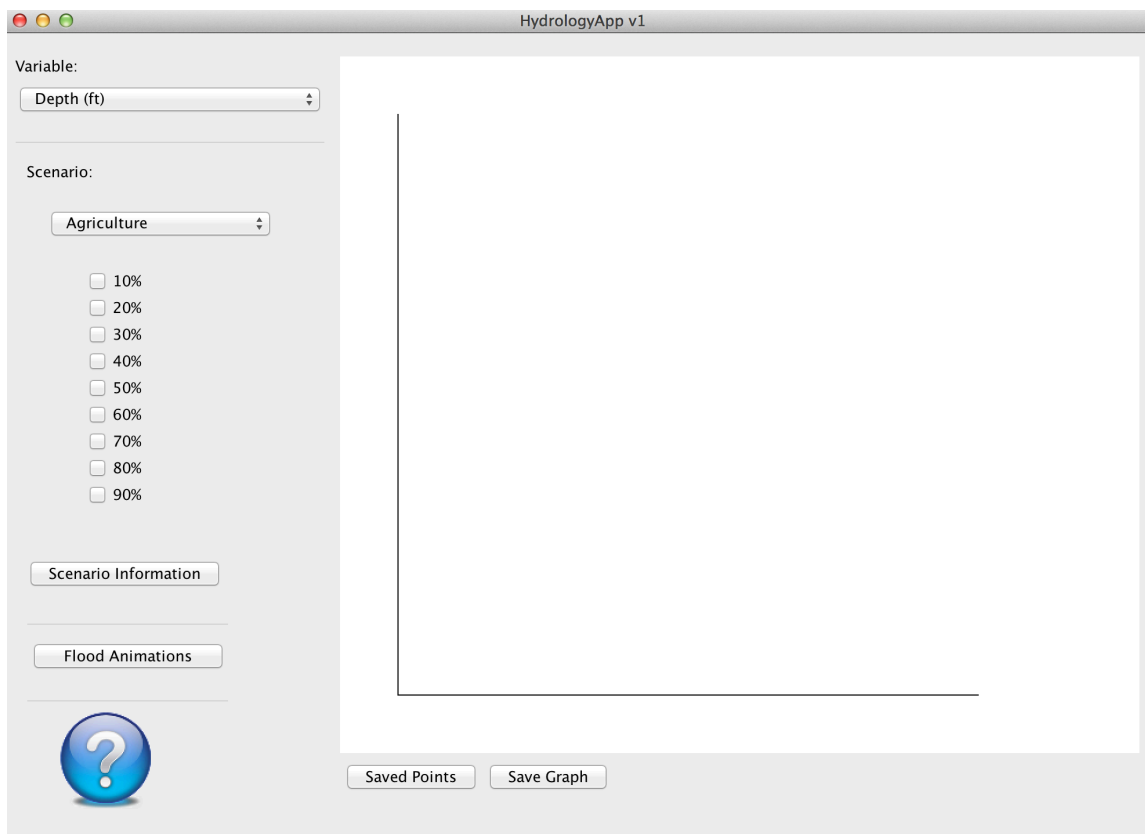

Image of the interface for the HydrologyApp.

| Agricultural Land Use Scenario	Land use	Sub-category of Hellbranch Watershed					
		Upper East 1	Upper East 2	Upper West 1	Upper West 2	Middle	Lower
		%					
10%	Forest	90	90	90	90	90	90
	Agriculture	10	10	10	10	10	10
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
20%	Forest	80	80	80	80	80	80
	Agriculture	20	20	20	20	20	20
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
30%	Forest	70	70	70	70	70	70
	Agriculture	30	30	30	30	30	30
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
40%	Forest	60	60	60	60	60	60
	Agriculture	40	40	40	40	40	40
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
50%	Forest	50	50	50	50	50	50
	Agriculture	50	50	50	50	50	50
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
60%	Forest	40	40	40	40	40	40
	Agriculture	60	60	60	60	60	60
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
70%	Forest	30	30	30	30	30	30
	Agriculture	70	70	70	70	70	70
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
80%	Forest	20	20	20	20	20	20
	Agriculture	80	80	80	80	80	80
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0
90%	Forest	10	10	10	10	10	10
	Agriculture	90	90	90	90	90	90
	Low Density	0	0	0	0	0	0
	Medium Density	0	0	0	0	0	0
	High Density	0	0	0	0	0	0

Details for the agricultural land use scenario for the HydrologyApp. Since you can select the percentage of land under that use, you need to look at the appropriate row for the percentage that you select.

This exercise addresses the same area examined in Exercise 4. Therefore, all of the background reading (Darby Creek Accord and Big Darby Town Center Master Plan) are applicable to this exercise.

Modeling the Impact of Land Use Change on Runoff, Flooding, and Water Quality

There are a large number of comparisons that can be made across the scenarios that illustrate the impacts of development on runoff and flooding. For the purpose of illustrating the process, we will compare the runoff and pollution levels associated with a comparison between 70% agricultural land and 70% medium density residential land. The agricultural land assumes that crops are grown on the designated acreage that are typical of central Ohio – corn and soybeans. Medium density residential would include a mix of single family houses on ¼ to ½ acre lots and garden apartments.

To start the application, double click on file labeled HydrologyApp.jar. You should see the application as shown below.
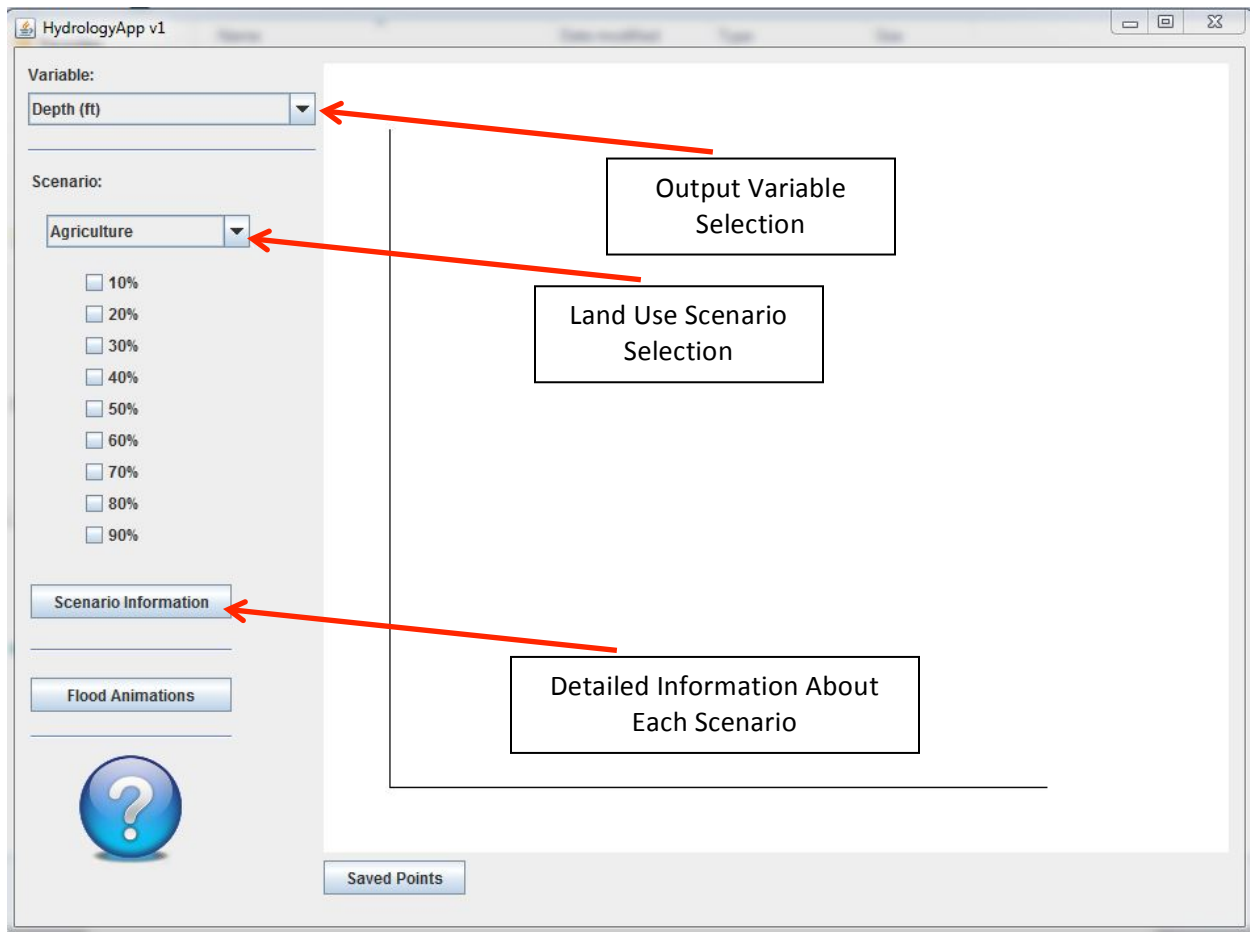
There are two pull-down menus. At the top, one can choose which output variable to plot. The choices are shown below. One can also choose the land use scenario. The land uses are represented by the pull-down shown below.
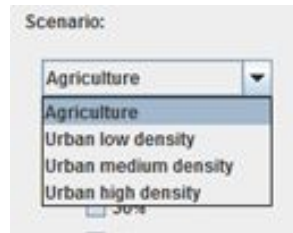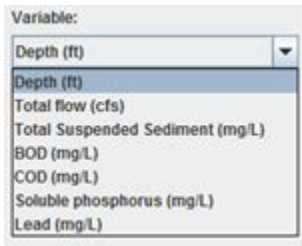
The variables that can be plotted are:

> Depth: the estimated depth of runoff in feet from the watershed
> Total Flow: the total flow of water in that section of pipe or channel in cubic feet per second
> Total Suspended Solids: the estimated amount of sediments carried into the stream with the stormwater runoff
> BOD: the estimated amount of organic materials that will use oxygen as they are decomposed as measured by the biochemical oxygen demand
> COD: the estimated amount of chemical wastes that will use oxygen as they are decomposed as measured by the chemical oxygen demand
> Soluble Phosphorous: the estimated amount of soluble phosphorous carried into the stream with the runoff
> Lead: the estimates amount of lead that is carried into the stream with the runoff

Each of the variables listed can impact the quality of the watershed. For example, higher total flows can result in scouring of the drainage, high levels of total suspended solids can increase mortality of organisms such as freshwater mussels, and soluble phosphorus can contribute to algal blooms. The scenarios allocate the selected land uses to the various watershed subcatchments. If you click on the Scenario Information button on the main screen, it will describe each scenario in more detail.

There are two ways to approach use of this online instructional tool. One option is to provide students with the tutorials below, have students respond to the questions, and use their responses to entertain a class discussion on the patterns we see between land use, water flow, and pollution levels. A second option is to allow students to explore on their own and look for patterns based on land use. The same concluding discussion can happen afterwards.

Exercise 5.1 – Runoff and Flooding
With any particular land use scenario selected, the model output is graphed showing the volume or amount of a range of variables over time at the watershed outlet. For our example, let's choose the total flow, the agriculture scenario, and check the 70% box. You should see the graph of the stream discharge over time for the storm being simulated. You should note that the storm is uneven producing a minor and major peak in runoff associated with the rainfall timing.

With agriculture, the flow is still modest showing a peak flow about 0.54 cfs. The application allows us to save selected points for further analysis. Let's save the peak flow under this scenario. Using your mouse, click on the point that represents the largest flow for this scenario. Notice that the point information is labeled at the bottom of the screen with the amount and the time and date when it occurred. Click the Save button to save this point.

Now let's change the scenario to urban medium density. Let's check 70% again to simulate the impact of changing all of the agricultural land to urban use. Notice the major change in scale, now showing the graphs of both scenarios on the same axes. Let's click on the peak for the urban scenario and save that point as well.

We now want to save our points and the graph to be used in our report about the scenarios. First, click on the Saved Points button. You should see the pop-up window as shown below.
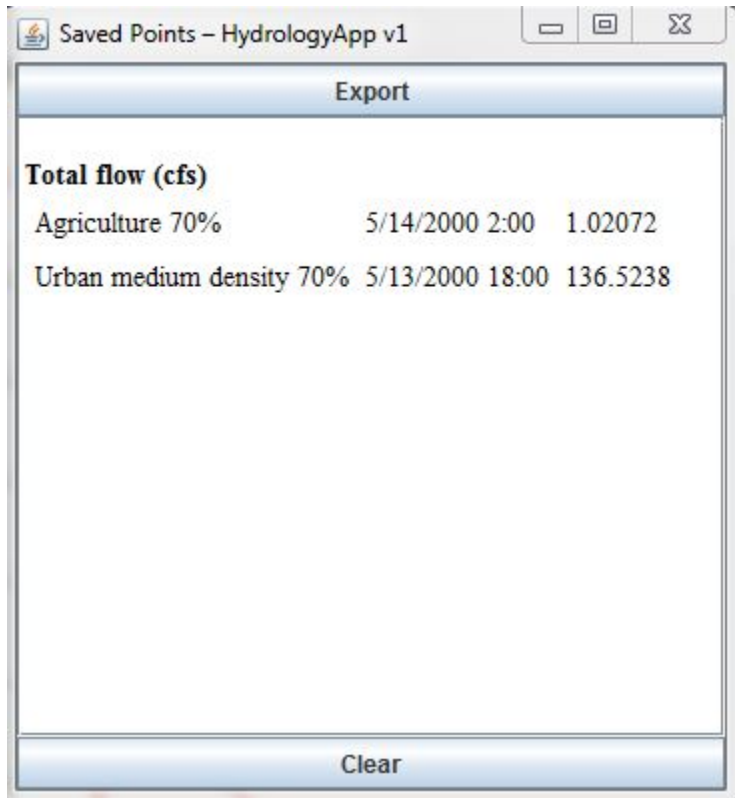
You can review all of the saved data points in the pop-up window or export them for use in a report. Click on the Export button to save your point data to a comma separated value file. Give the file a name relating to this scenario such as ag_urban70. Make sure you save it into a known folder. (You may want to start a new folder to save all of the files from this exercise).

Let's also save the graph by clicking on the Save Graph button. We want to save it as an image and put that file into the same folder where we saved the points. We also have the option of saving the entire contents as a comma separated value file is we want to have the entire data set.

To see an illustration of the flow of the stream and the potential for flooding under these scenarios, click on the Flood Animations button. A directory showing all of the flooding animations will open in a separate window. Double click on the file called Agr70.avi representing the agriculture, 70% scenario. If the animation fails to start, you may need to install a codec that is available at http://www.techsmith. com/codecs/tscc/default.asp. See the help file for more information. Otherwise you will see a screen as shown below.
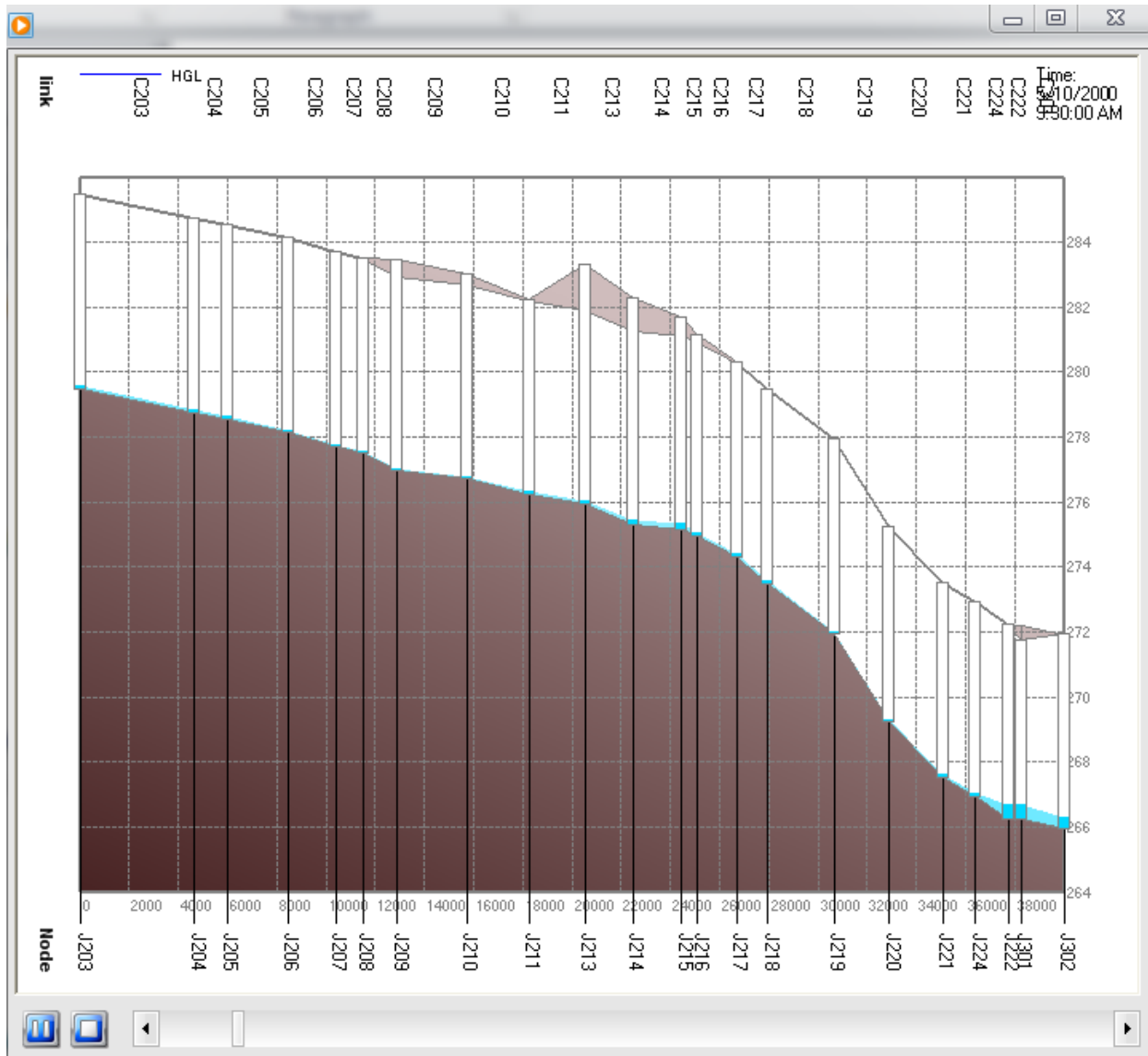
The animation represents an exaggerated view of the channel slope going from the upstream point labeled as J203 to the mouth of the stream labeled as J302. The blue wave represents the amount of flow in the over the period of the storm. The upper line represents the capacity of the stream channel at each point along the stream. If the blue water flow goes above the top line, it indicates that the stream will flood under that scenario. In the animation, a red dot will appear at the time of the flood.

Looking at the animation for 70% agricultural land, will there be a flood following this storm? Open the Medium_70 animation and compare what happens to what you saw in the agricultural illustration. Will there be a flood after this much urbanization takes place?

Questions

Using the data, graph, and other information about the scenarios you have examined, write a short report that answers the following questions.

1. Describe the underlying land use scenarios comparing the impacts you would expect them to have on stormwater runoff.
2. Compare the actual impacts of the scenarios on the flow and peak flow in the stream. Does either of the scenarios lead to flooding? What are the changes in the land that cause these changes? Describe those changes in terms of alteration of the portions of the hydrologic cycle (interception, infiltration, evaporation, transpiration, runoff).
3. Using these websites, describe at least two ways to avoid the dramatic increases in runoff resulting from urban development:
   http://www.cabmphandbooks.com/Documents/Development/Section_4.pdf
   http://www.epa.gov/owow/nps/lid/video.html
   http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_
        measure&min_measure_id=4

Optional Calculations

Import your peak flow points to a spreadsheet. Calculate the percentage change in peak flow between the scenarios with the agricultural scenario as the level for comparison.

Exercise 5.2: Water Quality Impacts

Another way to look at the impacts or development is in terms of the pollutants that are carried to the stream with runoff water. We can use the same tools to compare the pollution impacts of our scenarios. Following the procedures in Exercise 5.1, graph and capture the data comparing the Total Suspended Solids for the Agriculture and Urban Medium Density 70% scenarios. Do the same thing for the BOD loads.

Questions

1. Compare the impacts of the two scenarios on TSS and BOD.
2. Using the websites below, describe at least one source of each pollutant from each land use.
3. Using the websites below, describe two techniques that can be used to reduce the pollution levels from agricultural land and two for urban land.
   http://water.epa.gov/polwaste/nps/
   http://water.epa.gov/polwaste/nps/agriculture.cfm
   http://water.epa.gov/polwaste/nps/urban.cfm

Workshop participants taking part in a site visit, guided by geoscience professionals, to a watershed being restored to natural flow and revegetated following the removal of a lowhead dam.