Exercise 3: Teacher Notes

Background Information

As we have established, a watershed is an areas of land that drains to a particular point on Earth's surface. The key to identifying watersheds is the delineation of watershed boundaries. Watershed boundaries are determined by the identification of local higher-elevation areas and the lowest elevation point to which the water drains. Precipitation falling on watershed will migrate to the area of lowest elevation due to gravity. One method for determining these higher and lower-elevation areas is by physical visiting a site and inspecting the terrain. This is especially appropriate for smaller spaces (size of a schoolyard for instance) and those that are familiar to students. In addition, for areas that have already been surveyed, topographic maps can provide this information. Please note, while it is important to reinforce that watersheds are based around elevation and movement of water due to gravity, topographic maps can be difficult for younger students.

In addition, to understand the geography of the watershed, it is important to get information on the storage of water in a watershed and movement of water into and out of the watershed. As we have seen with the GeoSandbox, getting information on the storage of surface water is much easier than the storage of subsurface water. In these exercises, we will not focus on measuring stored water.

Getting information on the flow of water into a watershed is as easy as installing a rain gauge and taking measurements. Since you know the depth of water that fell (from the rain gauge) and the area of the watershed (by multiplying its length times its width), you could determine the volume of water that entered the watershed. It is important to consider that a rain gauge gives you measurements for the location where it is installed, and these measurements might not be valid over a large or geographically diverse site. If you have ever had a rainstorm hit your home and not the neighboring town, you understand how this works.

Getting information about the movement of water out of a watershed at the surface is much easier than at the subsurface. At the surface, using a flow meter in a stream or river will allow measurements to be taken. It is also important to know the cross-sectional area of the stream or river (this can change based on the conditions). Since you know the cross-sectional area of the stream (its width times its average depth at one location) and the length that flows by in a second (you can use a flow meter or simply toss a stick in the water and measure how far it travels in a second), you can calculate the volume of water that flows out of the watershed during that second interval. You can then extrapolate this number to any unit of time – one minute, one hour, or one day. Just as with rain gauges, flows are not constant and change over time (this is why automatic monitoring stations are often installed on streams and rivers). Measuring water flow at the subsurface is beyond the scope of these exercises.

While students need experience taking measurements using real equipment, they also need to realize that there is a large network of stations taking these measurements already. For instance, the National Oceanographic and Atmospheric Administration (NOAA) documents rainfall and United States Geographic Survey (USGS) documents flow rates at various stations around the country. Once students have taken measurements and made calculations for their schoolyard watershed, they have a better knowledge base to understand the information provided by NOAA and USGS.

By using maps and taking measurements, calculations can be made about precipitation events and the impacts they will have on flows out of a watershed. As we add more stations and more frequent measurements from each station, we create a more sophisticated understanding for how water moves over various surfaces and infiltrates various substrates. With this increase in data, it becomes necessary to use computers to process the large amount of information. Software has been developed that takes our knowledge of how water moves and allows us to rapidly represent what will happen by entering information about the watershed and precipitation event. We call using computers to represent these events 'modeling'. There are limits to all modeling, as we are not able to capture all information about a site or precipitation event in a few measurements. Therefore, modeling software does not provide us with perfect results. But, as the model improves with the addition of more and better data, it allows us to quickly anticipate which precipitation events could lead to destructive floods or how land use changes (such as installation of parking lots or re-grading of terrain) could adversely impact water quantity or quality in a given location.

One of the most widely used software packages for watershed modeling was developed by the US Army Corps of Engineers and is called HEC-HMS. This software is designed for use by hydrology professionals, and takes some time learn. The Ohio Supercomputing Center (OSC) has created a web application that allows a user to enter basic information and model a watershed and rainfall event using the same basic method as some of those included in HEC-HMS (specifically the SCS curve number approach to modeling runoff, and the unit hydrograph approach to modeling streamflow). One of the key advantages of the interface is that it reduces the number of required measurements necessary to model a watershed. The specific measurements necessary for this interface are: the watershed area, the flow length, the change in elevation of the flow length, the percentage of the watershed occupied by various land uses, and precipitation information. While the web application is simplified as compared with HEC-HMS, it is easily deployed in the classroom (no installation or large manual), runs on computers and tablets with an internet connection, and allows students to focus on critical characteristics of a watershed rather than all of the characteristics that could be measured.

The model produced by the interface provides a graphical output of runoff in two forms. One is hydrograph form, in which the plot is provided in cubic feet per second. The other is bar graph form, in which the plot is provided in cubic feet over one-hour time intervals. Both model outputs are functions of time.

Both outputs provide information on the amount of expected runoff as a function of time, as well as the runoff delay period. The delay is the difference in time between the first incidence of precipitation on the watershed and the first incidence of watershed runoff. The delay as well as the volume of runoff is related to watershed characteristics such as slope and impermeable areas. Storage capacity of a watershed refers to the storage of water in both the surface and subsurface. To understand the lag in streamflow following rainfall, remember that water did not immediately flow out of the GeoSandbox when students began to spray; rather, there was a delay in the flow beginning and it continued after students stopped spraying.

Knowledge of the permeability and storage capacity of a watershed would permit the ability to predict the flooding potential of a particular watershed for a given precipitation event. A flowing body of water (a stream, creek, or river) has a maximum discharge rate before flooding its banks. Flooding occurs when the discharge rate from the landscape flowing into the stream exceeds the maximum discharge rate of the stream. This is also true of underground sewer pipes. If more water from a parking lot or athletic field is trying to enter one end of the pipe than can leave the other end of the pipe, water will back up in the parking lot or athletic field and cause flooding.

Throughout Exercise 3, connections should be made to the GeoSandbox model from Exercise 2 as it is a tangible, small-scale model of a watershed that students already understand.

Introduction

This exercise is broken into two parts. First, students visit a small watershed on the school property, make visual observations, and take measurements in person using a map or aerial photograph of the site. Students then receive information about a past precipitation event and calculate the volume of water that will flow out of the watershed given very basic assumptions. Second, students will use the web application developed by OSC to enter their data and model the rainfall event and its impact in a more sophisticated way. Students can be asked when flooding will occur if the pipe can carry a maximum amount of water per hour.

For our first example (Exercise 3.1), we are using a parking lot adjacent to the Byrd Polar Research Center on The Ohio State University campus. We selected this site because the entire area is viewable on foot with just a few minutes walking, it is easy to identify the boundaries and the lowest point (a berm at the surface makes this easy and we also have diagrams of the storm sewer drainage pattern from the lowest point), and maps and aerial photographs were readily available. Furthermore, the proximity allows site inspection for students to confirm topography or take measurements. We selected two precipitation events that had approximately the same amount of rainfall: one distributed over a short interval of time and the other distributed over a long period of time. At selected points in the exercise, groups will share their results and discuss their methodologies.

For our second example (Exercise 3.2), we look at a larger watershed that could not be visibly inspected nor measured as easily. Thus, students will need to deploy maps (print or digital) and other tools to gather information about the watershed.

Exercise 3.1: Schoolyard Watershed (Runoff at the Byrd Polar Research Center)

Materials

- Schoolyard Site with a Known Drainage Pattern
- Measuring Wheel or Long Tape Measure
- Maps and/or Aerial Photographs of the Site (printed from USGS/Google Earth/Google Maps)
- Rulers
- Transparencies with Grid Pattern (grid can be calibrated to an area, such as 1 acre, on the map)
- Computers or Tablets with Internet Access (if using online maps or aerial photographs from USGS/Google Earth/Google Maps)
- Data from Two Storm Events (NOAA)
- Computers or Tablets with Web Application Page Opened (for modeling)

Advanced Preparation

Site selection is important so that students are able to translate what they learned from the GeoSandbox to a real watershed. Selecting a schoolyard site provides proximity to the classroom and forces students to look at a familiar location in a different way. Maps and aerial photographs should be prepared in advance. While these used to be difficult to procure, Google Earth has made them much more readily available.

Classroom/Field Procedure

Part A

There are a few introductory questions for students provided below. These can be answered using a site visit, inspection of maps and aerial photography, or a combination of the two. Site visits are more powerful. Regardless, students will eventually need to take some basic measurements so that they can calculate the schoolyard watershed area, flow length, and elevation change over the flow length.

Once students are in the schoolyard watershed, they will be provided with an aerial photograph (without legend, compass, or scale) and asked to answer four key questions:

1. What are the boundaries of the watershed? How can you tell?
2. To where does the watershed drain? How did you determine this?
3. What is the area of the watershed? How did you determine this?
4. What percentage of the area of the watershed is impervious? How did you determine this?

Measuring tapes and wheels should be brought along. Students should be encouraged to investigate the area and take measurements. At first, most teams will spend time matching the surroundings with the aerial photograph; teams might to be encouraged to look for major reference points (For some students, connecting what their surroundings on the ground look like from the air will be difficult). Eventually, a few teams will begin to identify the high and low points and agree on boundaries. Depending on your students, it might be best to regroup as a class at this point and discuss the features that allowed students to link the aerial photograph or map to the physical surroundings, discuss the locations of the high and low points, and agree on boundaries.

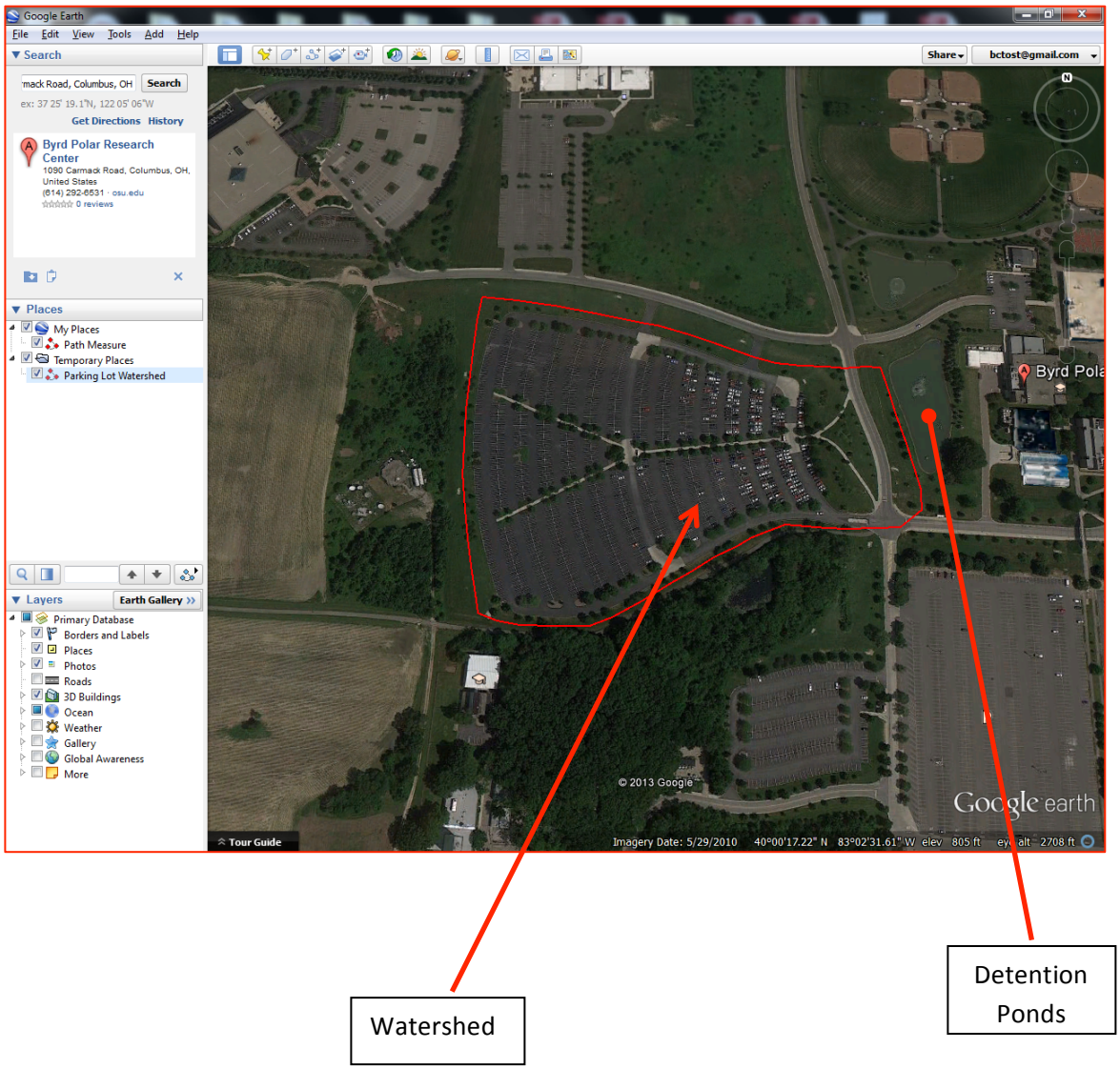
While all four questions build on a conceptual understanding developed during the unit, the first two questions are qualitative and the latter two questions are quantitative and slightly more advanced. Before releasing teams to collect measurements, it might be best to brainstorm how the class could determine the area and percentage of impervious surface. This allows students to leave the gathering with a plan for measurements they will need to take. If the class suggests more than one method, that is fine. Allow some groups to pursue one method and others to pursue the second method. There are multiple ways to arrive at an answer. Calculations can be made and methods discussed more in the classroom, but it is imperative that groups have solid measurements before they leave the schoolyard watershed.

A few examples of how students could calculate the area of the schoolyard watershed include: 1) breaking the watershed into rectangles and triangles, measuring the lengths and widths by hand, using simple geometry to calculate the areas, and then summing the total area; 2)

measuring the length of an object that they can clearly identify on the aerial photograph, using this know length to create a scale, marking known lengths on the map, and then following procedure one; and 3) using a grid transparency that shows 1-acre squares calibrated to the scale on the map and having students count the number of squares that make up the watershed. All of the methods are equally valid. One benefit of giving students a grid transparency is that it can also be used to estimate the percentage of land that is impervious. For example, if students count 20 boxes in the schoolyard watershed and 8 of them are impervious surface, 40% of the schoolyard watershed is impervious surface.

As an example, we will use a parking lot on campus. A simple example of a watershed may be found in the parking lot due west of the Byrd Polar Research Center as shown below. There are many digital tools available for taking measurements and running calculations.

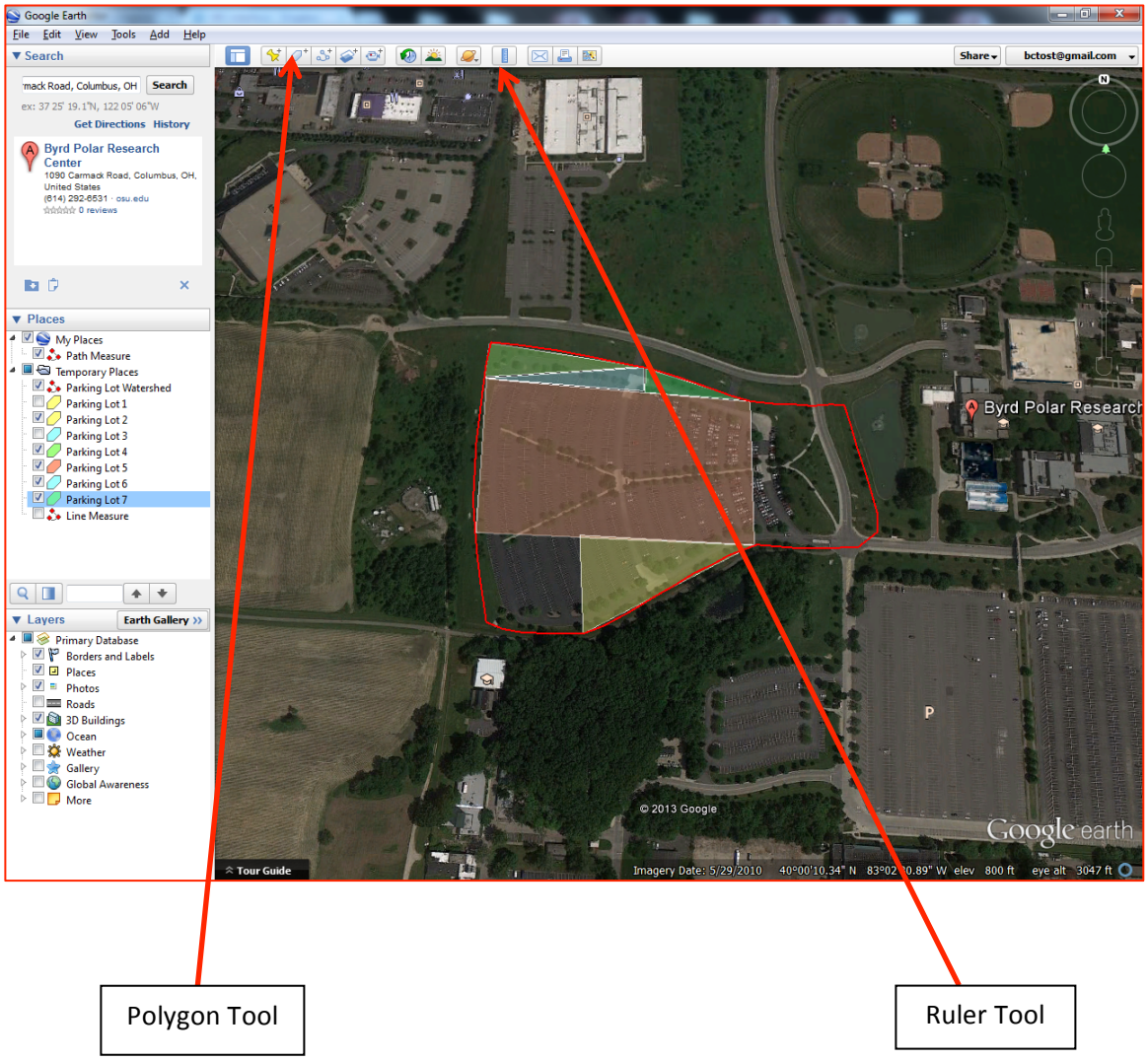
The parking lot comprising the watershed to be modeled is contained within the red box shown below.



NOTE FOR THOSE USING GOOGLE EARTH: Any feature or attribute drawn onto a Google Earth image should be saved. Saving attributes, such as drawn lines for elevation determinations or shapes for areas determinations, is necessary to keep attributes. Otherwise, later manipulations done in Google Earth will clear prior work, requiring work to be re-done.

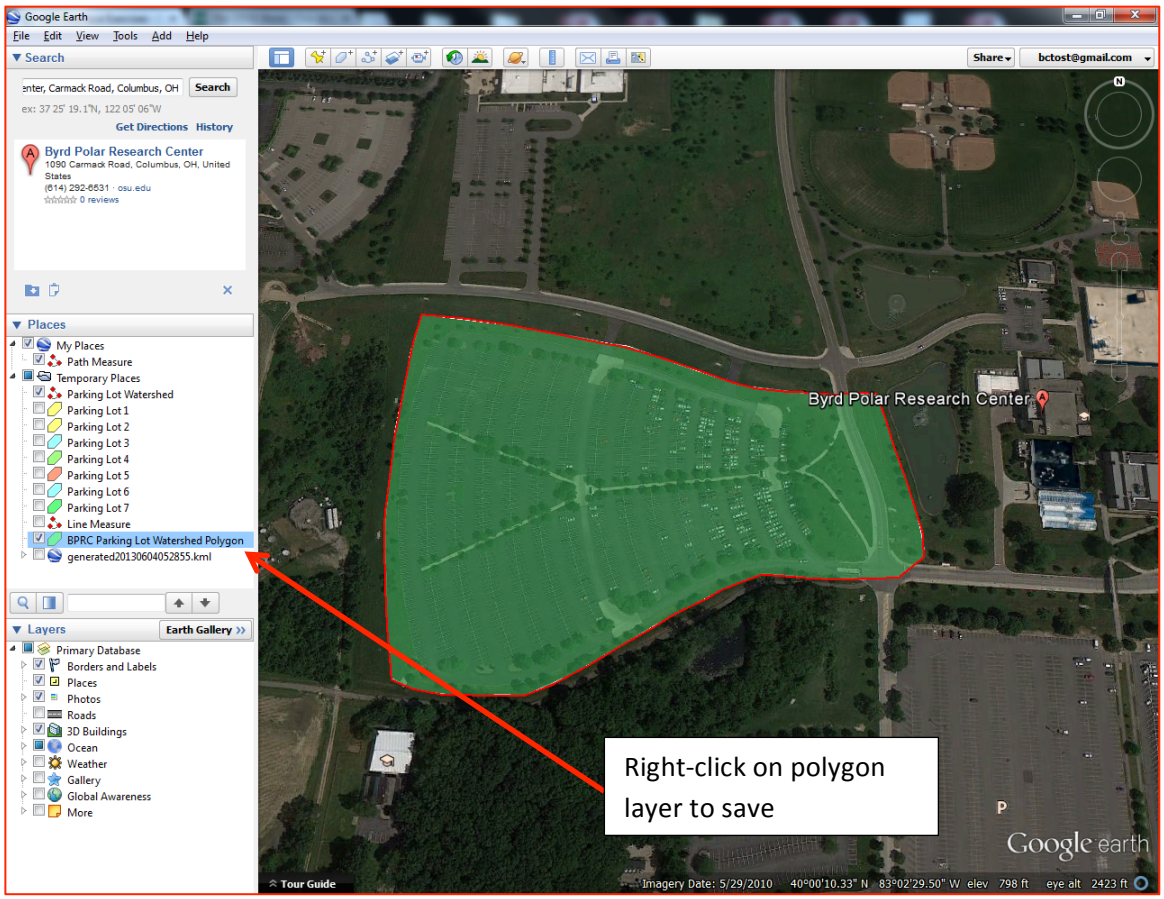
The total land area occupied by the watershed is approximately 16 acres. There are many primary methods for determining the watershed area as described above, but there are also digital methods that are available. The first digital method is to divide the parcel into simple shapes that facilitate area calculations. Polygons are drawn onto Google Earth images by selecting the polygon tool. Points representing the boundaries of each polygon are selected at

the user's discretion. Care should be taken so that drawn shapes are accurate regarding the particular polygon that they are intended to represent. This will permit an accurate estimation of the watershed area. Shapes should be saved onto the Google Earth browser. This second method does not require Google Earth and could be done using a paper map or aerial photo as long as a scale is present. The sides of each shape are measured using Google Earth's ruler tool. The area is then determined using the geometric formula for the particular shape (e.g. square, rectangle, triangle) that has been drawn to fit the shape of the parcel.



The third method, which is especially recommended for watersheds whose shapes do not lend themselves to easy division into simpler shapes, is to draw a single polygon that occupies the entire watershed using Google Earth. This is completed by selecting the "New Polygon" tool and entering points onto the Google Earth image by clicking on the image. A polygon can also be drawn onto the Google Earth image by clicking and dragging the cursor over the watershed boundaries. While Google Earth Pro has the ability to determine areas of polygons, the free

version does not. You therefore need to use another free, online resource to calculate the area of the polygon.

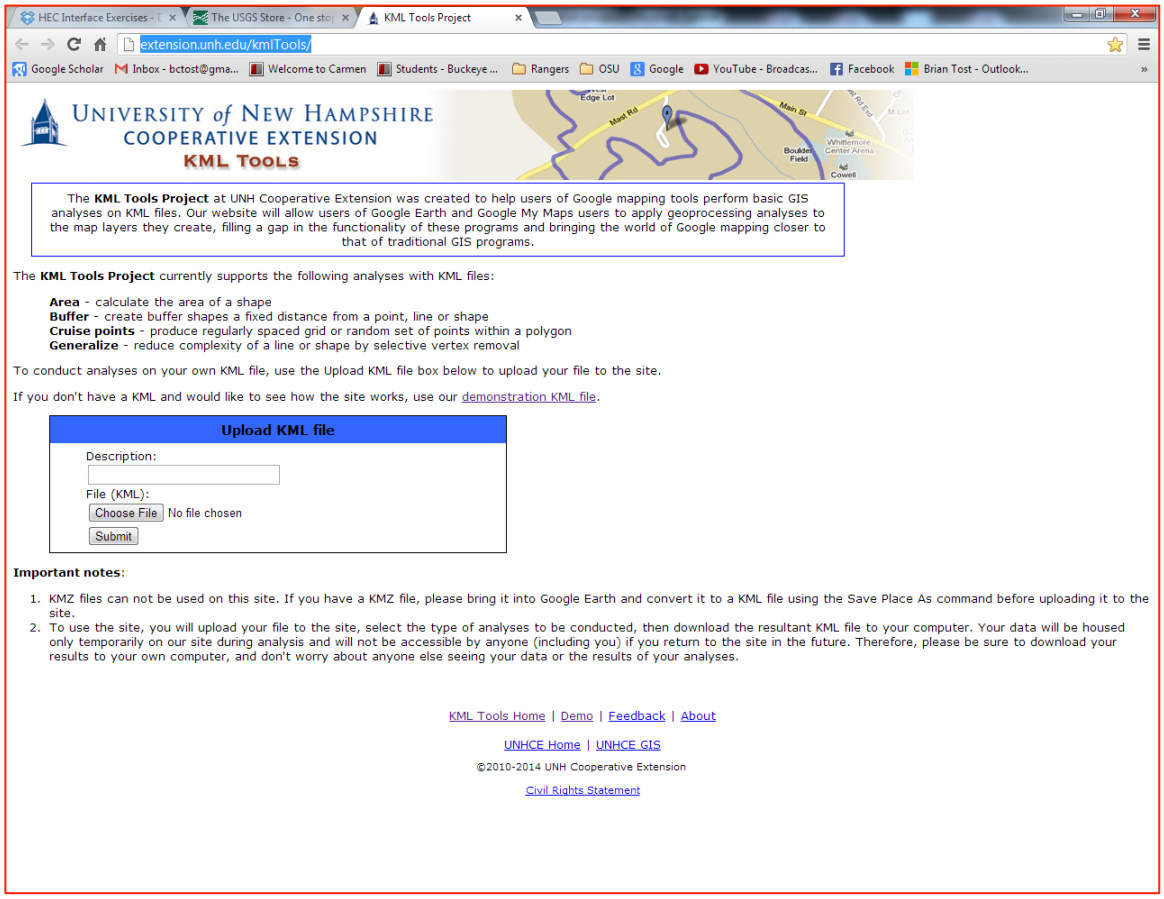


The completed polygon is then saved into the Google Earth browser. The resulting polygon attribute is then saved into a .kml format by right-clicking on the polygon attribute layer and selecting “Save Place As”. Name the polygon and select .kml as the file format.

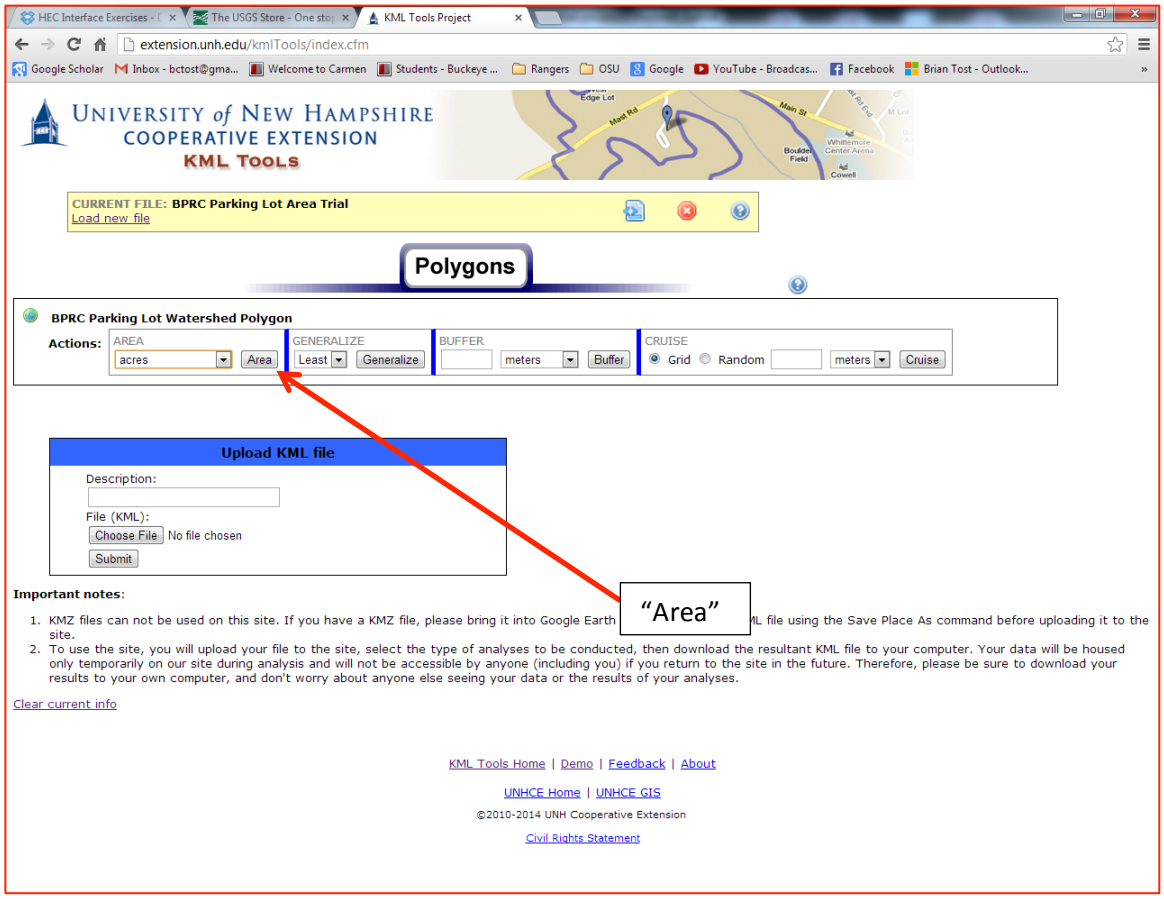
Then, go to the following website, courtesy of the University of New Hampshire:

http://extension.unh.edu/kmlTools/

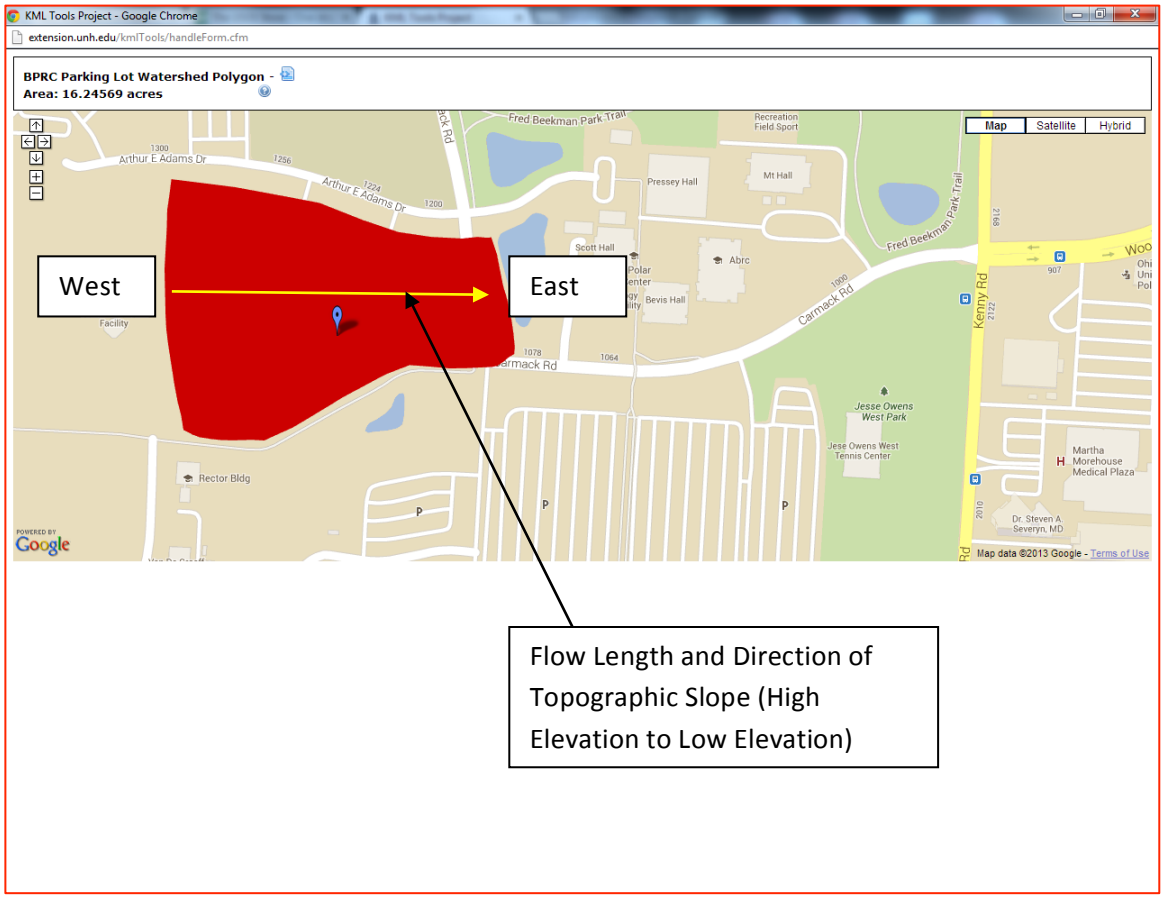
Click on “Choose File” and enter the polygon layer that has been saved as a .kml file. Provide a name the output. Click “Submit”.



The next web page requires selection of the specific computation. In this example, watershed area will be computed.

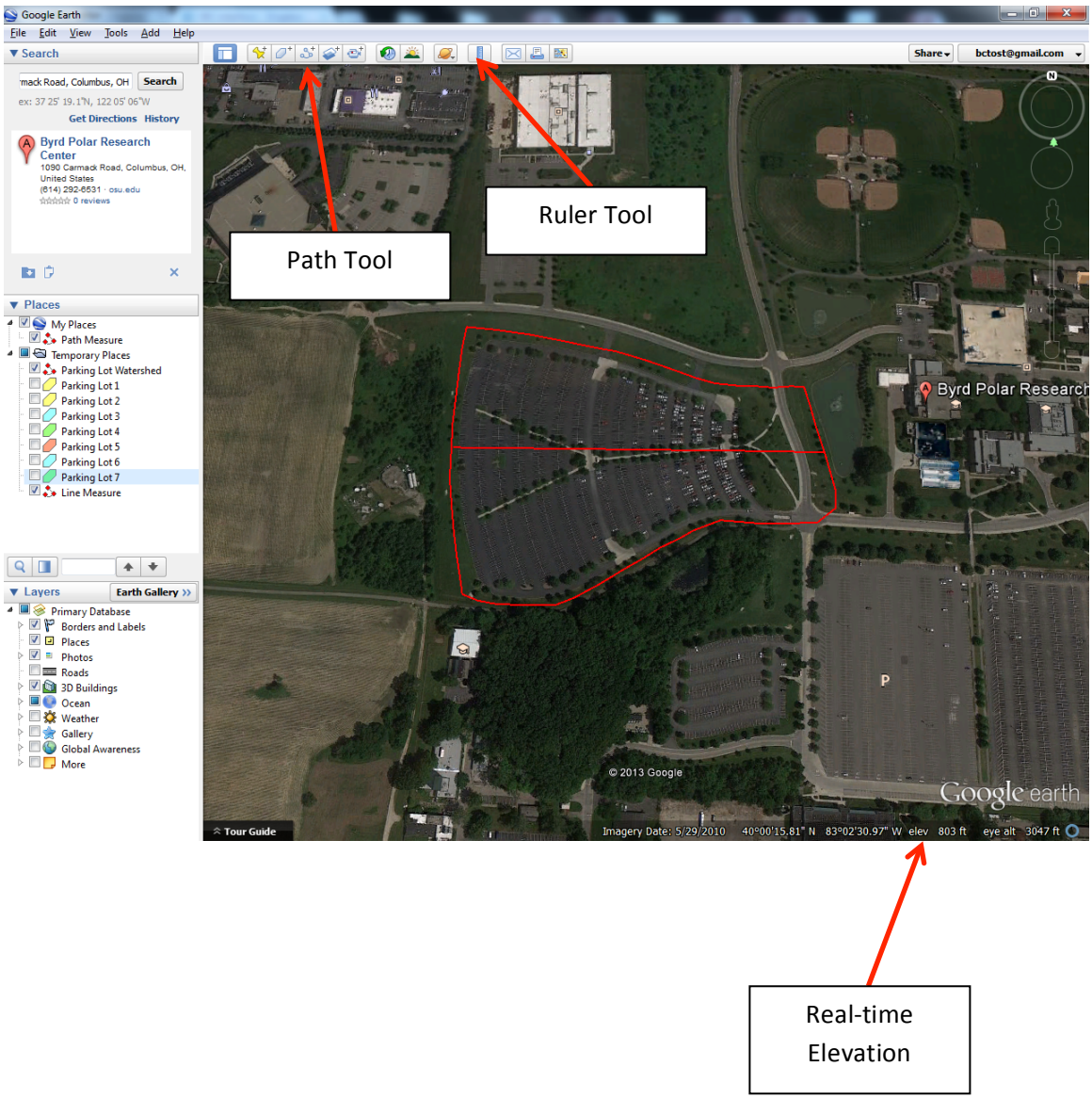


Select the desired unit output for the area computation. For this example, acres will be selected from the drop-down menu. Click on "Area" to execute the area computation. A pop-up window will appear, showing the results of the computation. The area in acres, as determined from the website's algorithm and the watershed polygon, is shown on a map. From this example, there is a slight difference between the areas determined from the University of New Hampshire website and the method of dividing the watershed into shapes (16 acres vs. 16.25 acres). The area difference in this example is not significant. However, as stated earlier, irregularly-shaped watersheds may not lend themselves to easy area determinations by division into simple shapes. The resulting error due to area losses could become significant, especially in larger watersheds. Thus, it is recommended that the UNH website be used for irregularly-shaped watersheds.



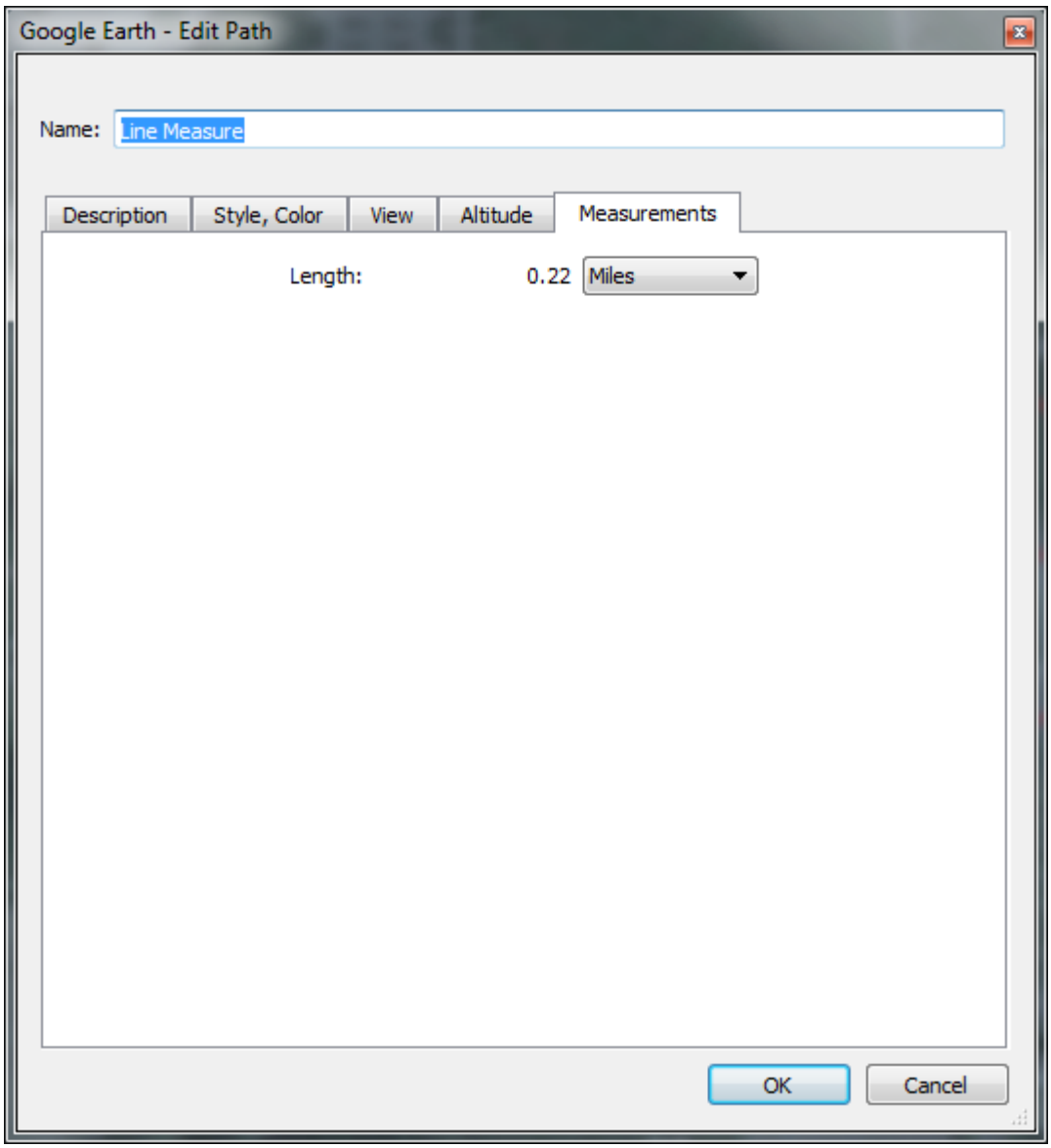
It is also useful to know the elevation difference over the watershed. While students might not initially think this important, it is necessary for the web application calculations and not conceptually difficult to think about how the slope of the land would impact how quickly water flows out of the watershed (think of the speed of water flowing off a steeply pitched roof versus an almost flat parking lot). In our example, the landscape slopes downwards from west to east. Surface runoff in this area will also flow from west-to-east, towards the detention ponds. We need to know the change in elevation from one end of the watershed to the other end and the flow length. In our example, the flow length is assumed to be the west-to-east length of the watershed. When students are in the schoolyard watershed, a simple GPS unit can be used to measure the elevations of the highest and lowest points. The challenge in elevations can be calculated by subtracting. Likewise, the flow length can be measured with a measuring wheel, tape measure, or map with a legend.

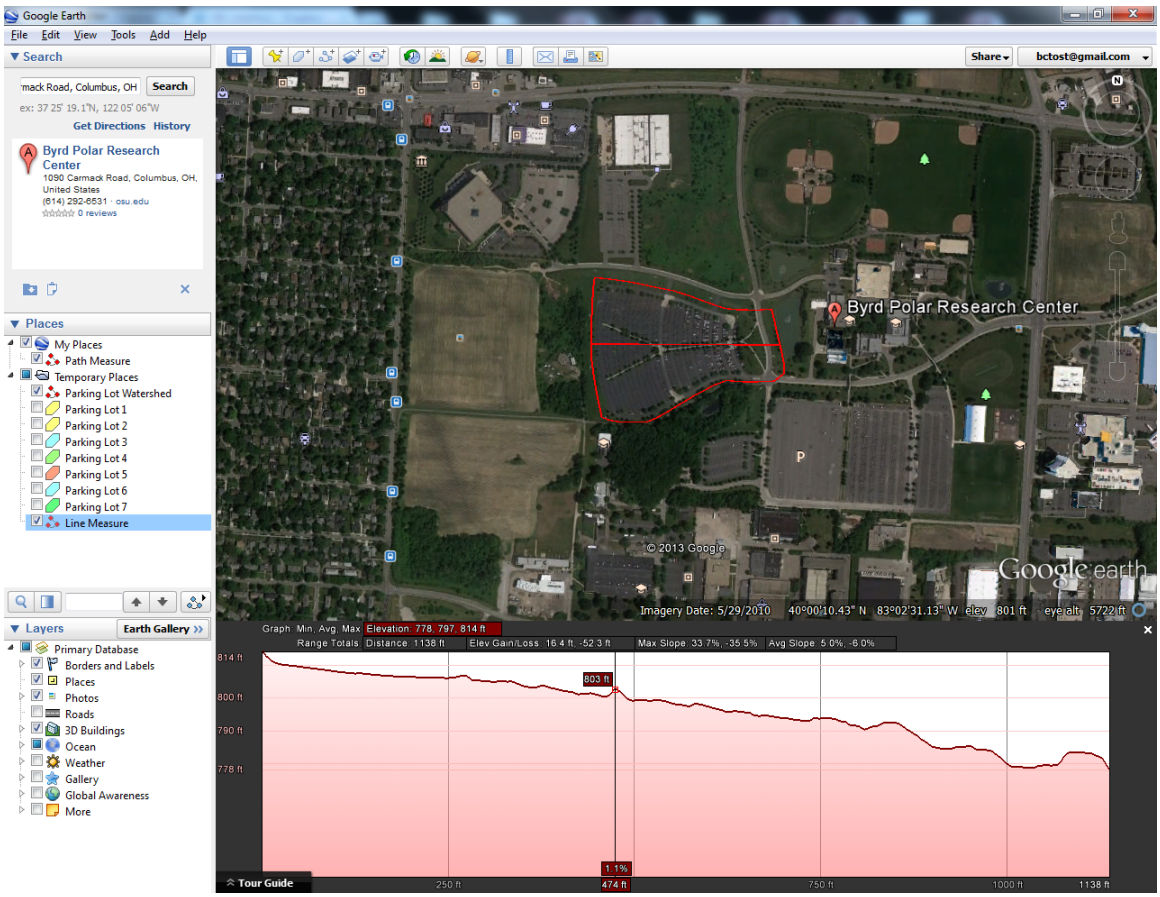
If you would prefer to use digital tools, Google Earth has a Ruler tool that allows you to place endpoints on the landscape easily measure the length between the two points. The elevation change is determined by recording the elevations at the beginning of the flow length and at the end of the flow length. This determination may be done by reading the elevations at the beginning and end of the flow length from the real-time elevation measurements found at the bottom of the Google Earth window. As you move the pointer across the landscape, Google Earth displays the elevation of the pointer's location.



Real-time Elevation

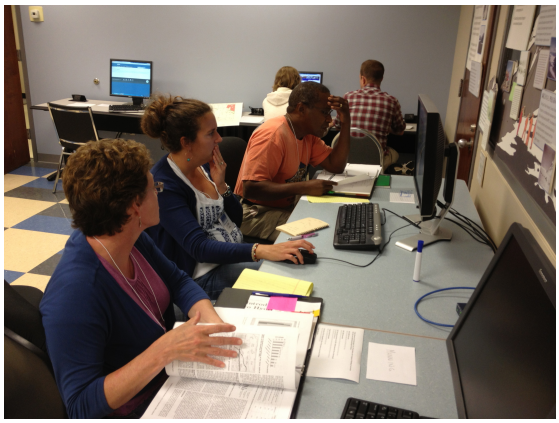
The flow length and elevation change can also be determined by using the Path tool. When you select the Path tool and drawing a path, a window will display the path length in a tab called "Measurements". Elevation changes along the path may also be determined by right-clicking on the saved path and selecting "Show Elevation Profile". The ground surface elevation along the line measure attribute is then immediately shown on the Google Earth image in a separate window.


Google Earth - Edit Path
Name:
Line Measure
Description
Style, Color
View
Altitude
Measurements
Length:
0.22
Miles
OK
Cancel



The beginning and ending elevations may then be recorded from the plot of the elevation profile. The elevation at the beginning of the flow length is 814 feet. The elevation at the end of the flow length is 779 feet. Thus, the change in elevation along the flow length is the difference between these values, which is 35 feet.

From observation of the parking lot, it has been determined that approximately 90% of the watershed is occupied by paved surfaces. Thus, this portion of the watershed will be classified as “Impervious Areas: Paved parking lots and driveways”.



Part B

The next questions to ask students are:

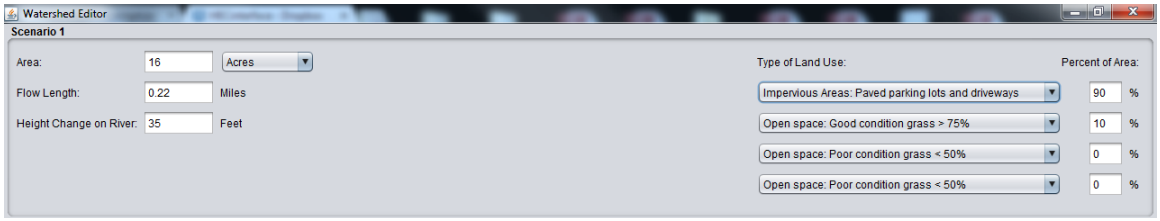
If it rained 1 inch over the next hour on this part of the schoolyard, how much water would strike the schoolyard watershed?
How much water would leave through the surface and subsurface?
How fast would it leave?

The first question can be answered without use of software just by calculating the volume. In addition, we know that the water that enters as precipitation must also leave through the surface or subsurface or be stored. But, without software, it is difficult to estimate an answer to the second question (unless we use the same ratio for surface and subsurface as the GeoSandbox and this will probably not be accurate based on the land use of the schoolyard) and virtually impossible to address the third question. At this point, students know that the substrate matters and that the topography matters.

Students should be guided to answer the first question using a calculation of volume using the surface area of the watershed and 1 inch depth of rain. While this results in a numeric answer, students should be directed to compare this with the GeoSandbox example from the previous exercise. The schoolyard watershed will have a significantly larger volume of water.

Students are now knowledgeable enough in principles of watersheds and have reached the limit of what they can calculate by hand. The class should be asked what information would impact the amount of water that would flow over the surface and subsurface. They will suggest the area, land use pattern (such as impervious surface), change in elevation, and amount and speed of rainfall. If all of these factors are not suggested, we recommend bringing out the GeoSandbox to review the model system and how it emulates a real watershed.

We now introduce students to the online web application as a tool to better represent the movement of water in our schoolyard watershed. The web application can be found online at http://bprc.osu.edu/resources/water_runoff_model/. ***The appearance of this web application has been slightly altered, but all functions used throughout this exercise are still available.**



On the web application window, there are places to enter the watershed area, flow length, and height change. Fortunately, students will have already collected these measurements and

understand why they are important. Measurements that students have previously made are entered into the appropriate fields in the watershed editor under the Scenario tab.

Students should also be reminded about the impact of various substrates on the storage and movement of water from Exercises 1 and 2. In the case of our schoolyard watershed, we need to have categories that represent how water is stored and transmitted through the substrate and then determine the percentage of land in each category. Fortunately, these categories have already been created and well studied. Students will just need to enter the percentage of the area that belongs in each category.

In our example, approximately 10% of the watershed is occupied by the grass berms that surround the parking lot. These areas are kept in good condition, with no apparent un-vegetated areas. These areas will be classified as "Open space: Good condition grass >75%". The other 90% is paved surface that is classified as Impervious Areas. For reference, a table is provided below with qualitative information on various land uses and their relative surface water detention capabilities.

Table Outlining Land Use Descriptions and Relative Surface Water Detention Capabilities

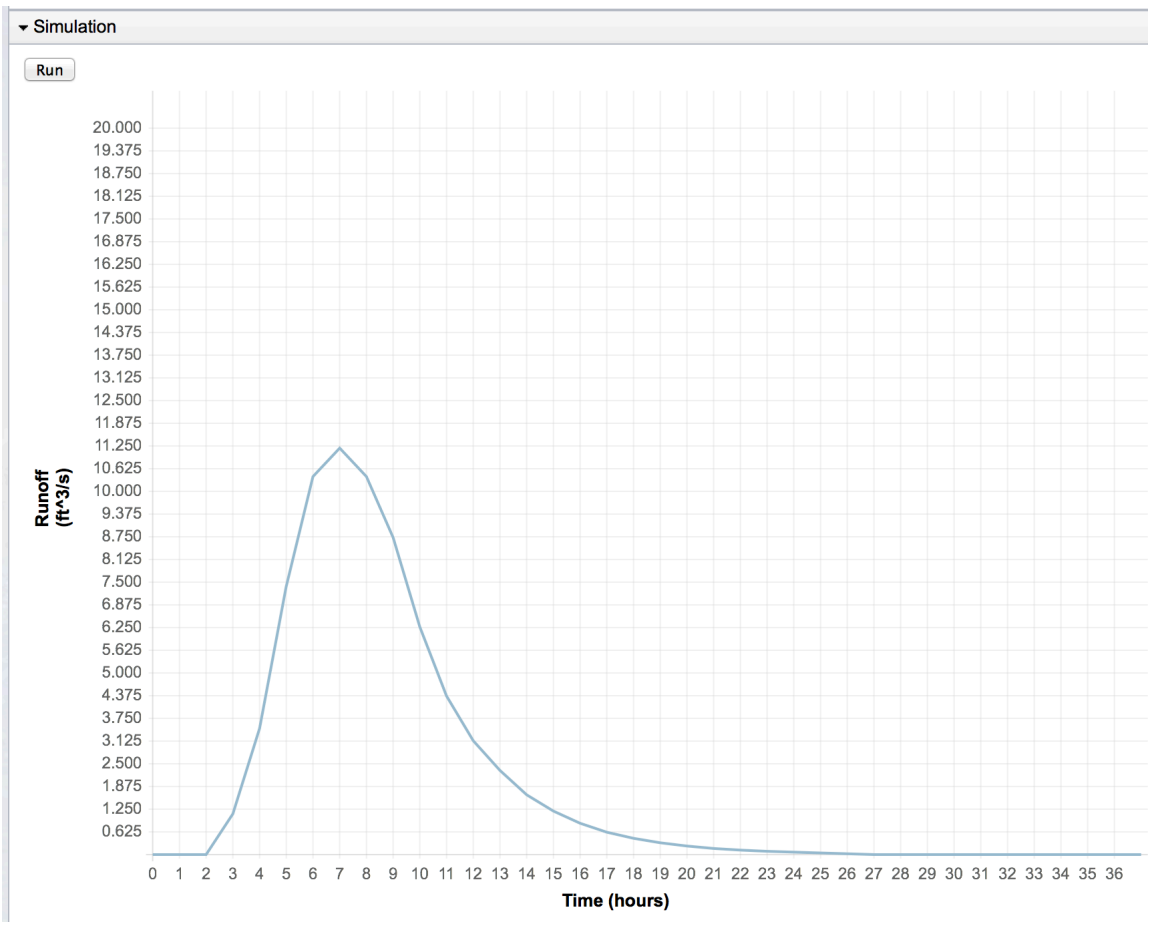
Land Use Description	Relative Surface Water Detention* Capability
Industrial	Low
Commercial and Business Districts	Low
Streets and Roads: Paved with Ditches	Low-Moderate
Streets and Roads: Paved with Curbs and Storm Sewers	Low-Moderate
Impervious Areas: Paved Parking Lots and Driveways	Very Low
Open Space: Good Condition Grass >75%	High
Open Space: Fair Condition Grass 50-75%	Moderate
Open Space: Poor Condition Grass <50%	Low-Moderate

**Detention is the slowing of water from entering a waterway. A number of factors can increase detention of water. Greater detention means a reduced change of flooding during a precipitation event.*

Precipitation

Time	Precipitation(Inches)
1:00	1
2:00	0
3:00	0
4:00	0
5:00	0
6:00	0
7:00	0
8:00	0
9:00	0
10:00	0
11:00	0
12:00	0

Under the Precipitation tab, students should enter 1.0 the first hour of precipitation to represent that 1 inch of rain fell in the first hour. All of the rest of the hours should be filled in with 0 to represent that no additional rain fell.



PLEASE NOTE: The simulation outputs water that passes out of the watershed due to the rainfall event. Thus, it there is a normal base flow, the additional water from the rainfall event would need to be added to the base flow to get the total amount of water passing out of the watershed.

Under the Simulation tab, students should select run. An output can be displayed as a hydrograph output as a line graph (shown above) or can be changed to a bar graph using the "Change to Bar Graph" command located at the bottom of the graphical output. Students will see that the maximum flow does not occur when it is raining and that an elevated flow extends well beyond the time of maximum flow. This pattern should be consistent with their experience from the GeoSandbox.

Students should be told that to better understand what will happen they need more details on the rainfall event (all storms do not have exactly 1 inch that falls over exactly one hour). At this point, students should be given actual data from a rainfall event (example below) and asked to calculate the total volume to fall and the hour window when the greatest volume fell. Once again, the connection to the GeoSandbox should be explicitly mentioned.

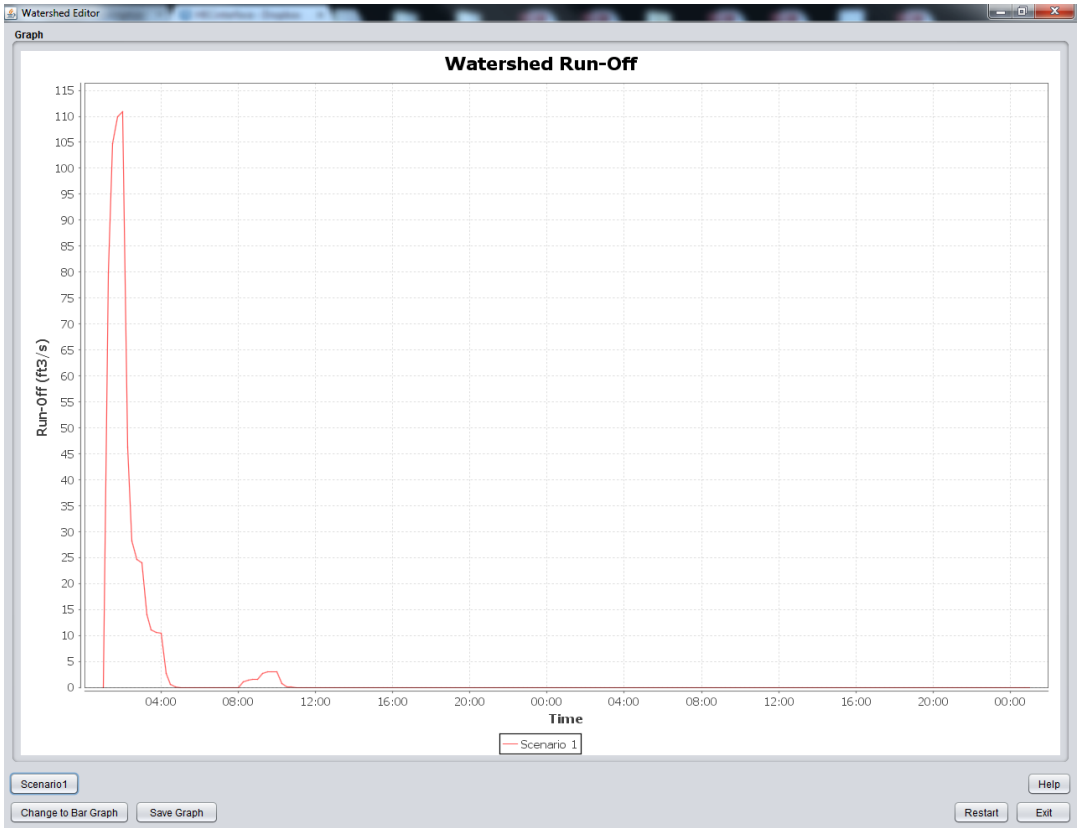
Hourly precipitation data were provided by the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (http://www.ncdc.noaa.gov/). Hourly precipitation data were collected at Port Columbus International Airport for April, 2012. April 26 was selected because varying amounts and frequencies of precipitation were recorded for that day.

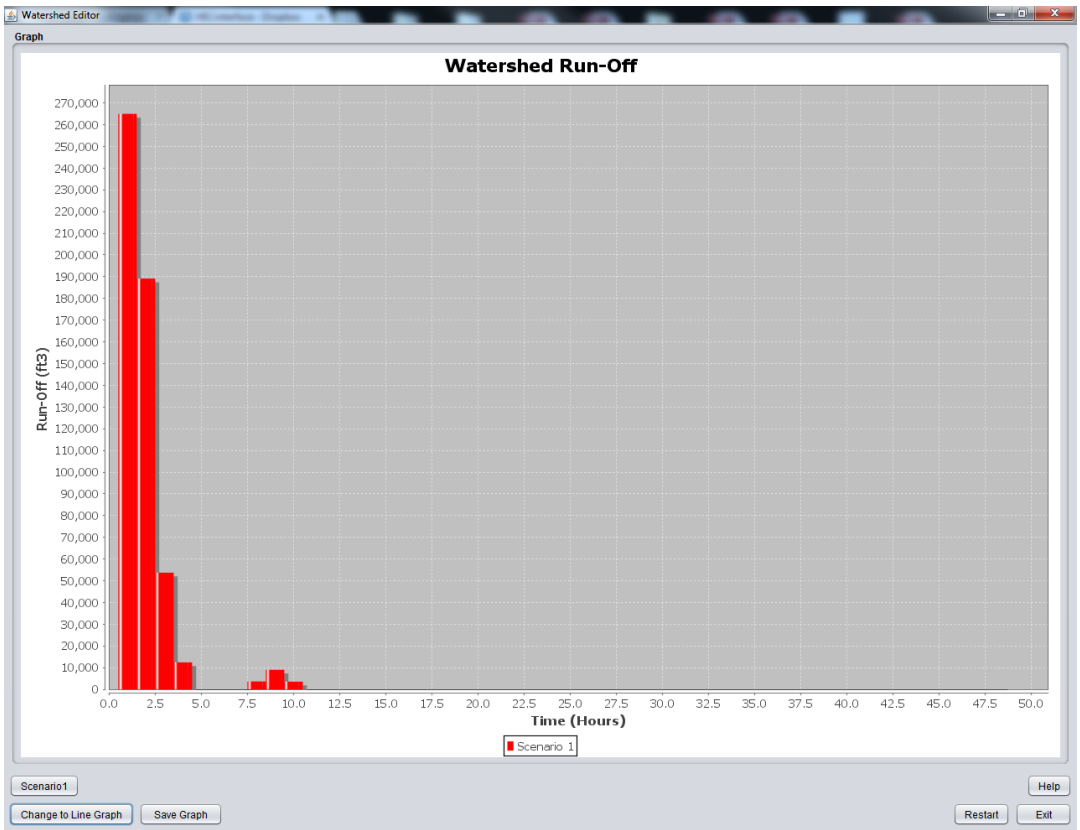
Summary of Hourly Precipitation Data

Date and Hour	Precipitation (Hundredths of an Inch)
April 26, 2012 – 3:00	24
April 26, 2012 – 4:00	74
April 26, 2012 – 5:00	16
April 26, 2012 – 6:00	7
April 26, 2012 – 7:00	0
April 26, 2012 – 8:00	0
April 26, 2012 – 9:00	No Data (assumed zero)
April 26, 2012 – 10:00	No Data (assumed zero)
April 26, 2012 – 11:00	1
April 26, 2012 – 12:00	2
April 26, 2012 – 13:00	0
April 26, 2012 – 14:00	0

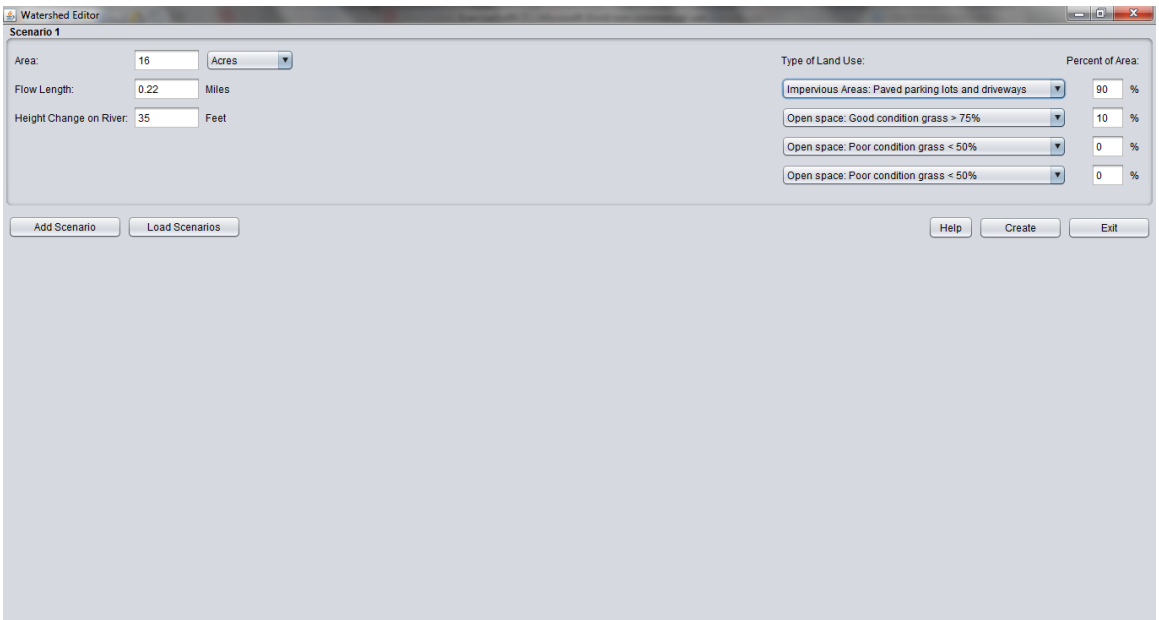
In our example of the parking lot next to the Byrd Polar Research Center, the hydrograph shows that runoff accelerates to its maximum value quickly after precipitation begins falling on the parking lot. This is intuitively correct, as the parking lot is impervious. For the purposes of this exercise, we assume that there is no drainage of the parking lot by storm sewers; thus, we assume that virtually all precipitation falling on the parking lot will runoff as surface discharge.

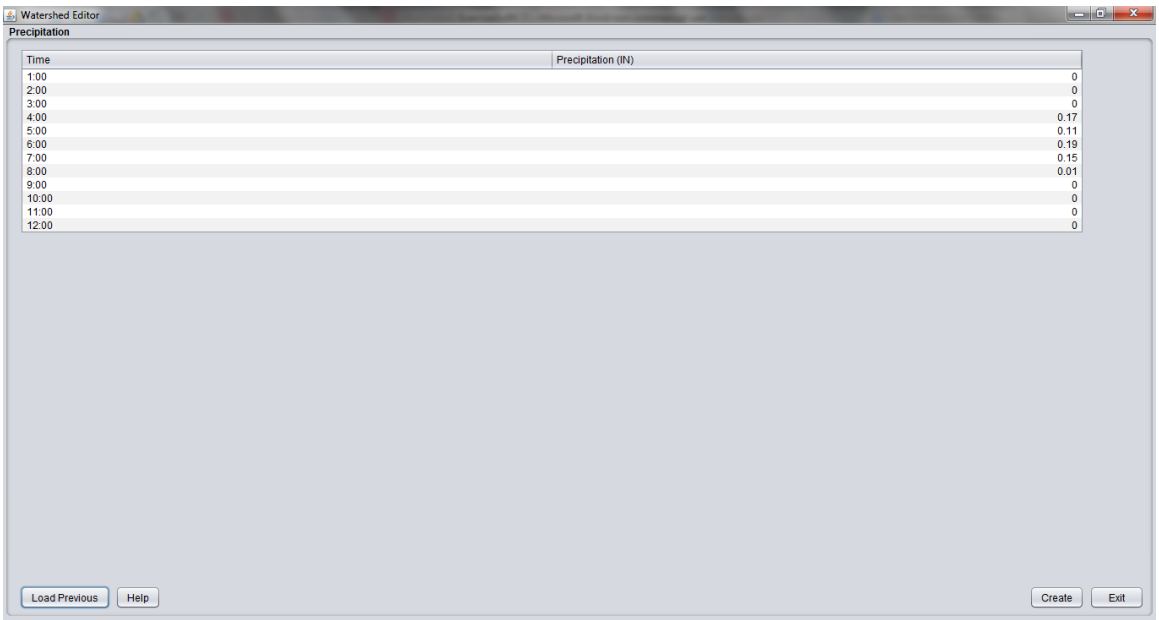
This assumption accounts for the rapid acceleration of discharge, as well as the relatively high discharge rate. Remember, the output can be viewed as a line graph of flow or bar graph of volume.





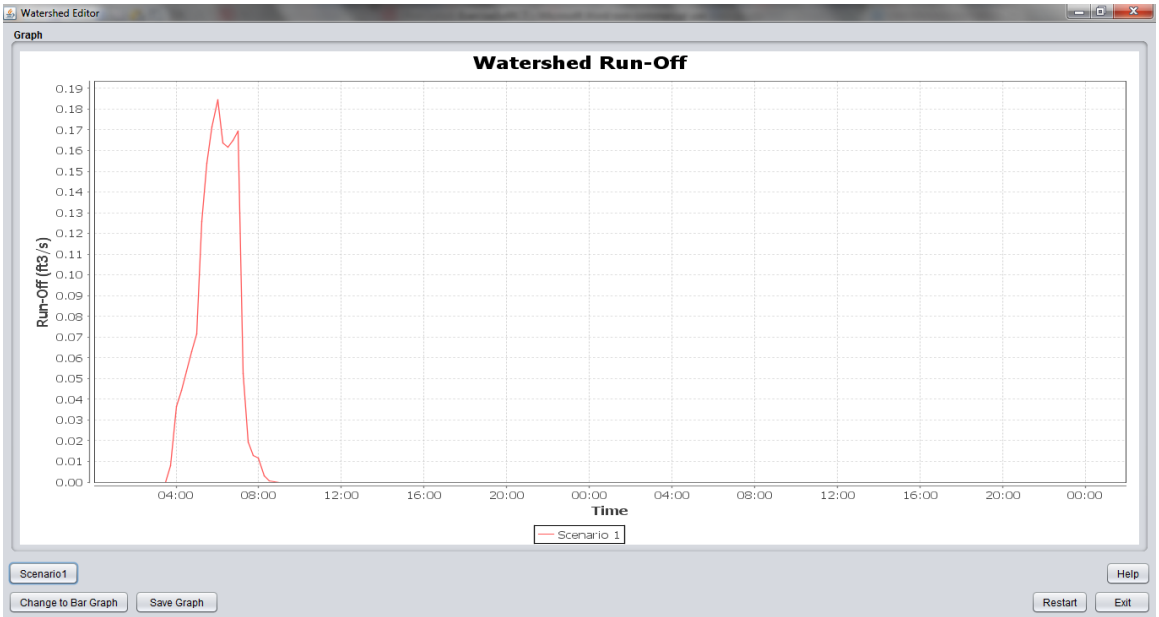
Students will next be provided with a second precipitation event to model and asked to examine both events if the parking lot asphalt was replaced with a grassy surface. Student results should be the basis for a concluding discussion and summary of what was learned. The second precipitation event, that was recorded for February 29, 2012 at Port Columbus airport, is modeled below. This precipitation event was a steady rainfall of moderate volume that lasted for approximately four hours. The scenario and rainfall event are as follows:

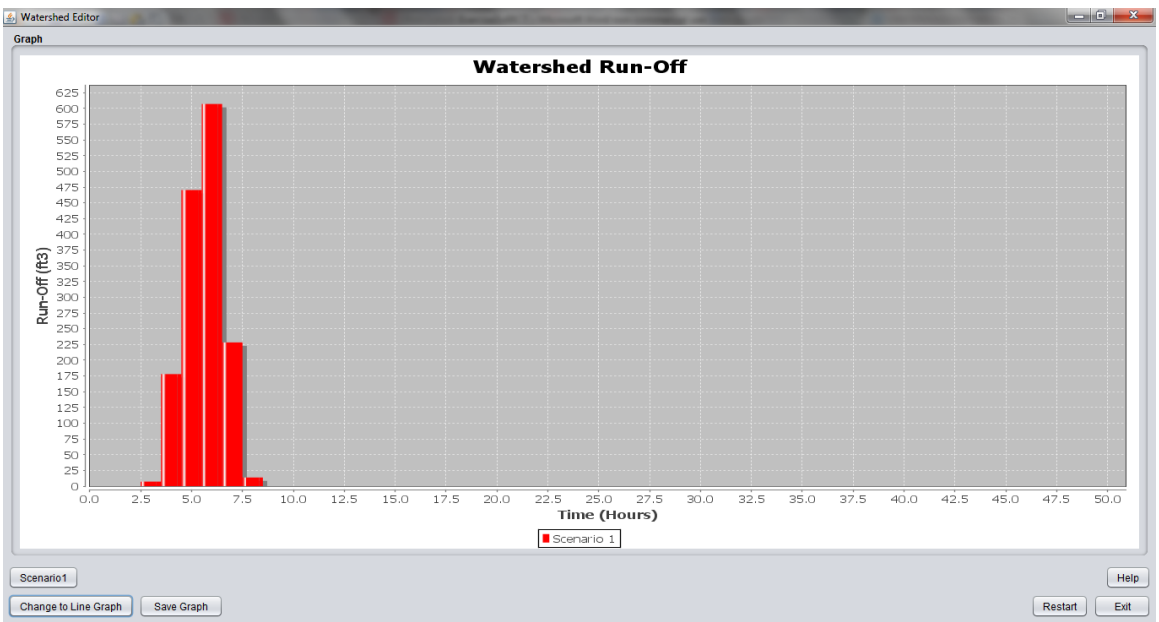




Time	Precipitation (IN)
1:00	0
2:00	0
3:00	0
4:00	0.17
5:00	0.11
6:00	0.19
7:00	0.15
8:00	0.01
9:00	0
10:00	0
11:00	0
12:00	0

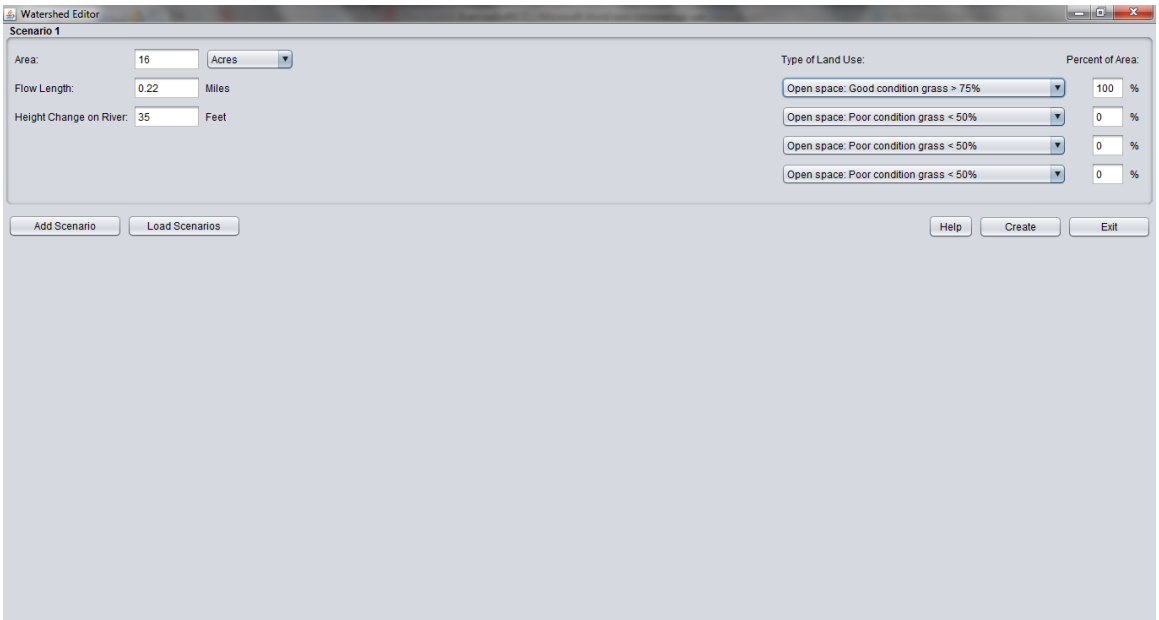
The line graph and bar graph produced are shown below for surface runoff.



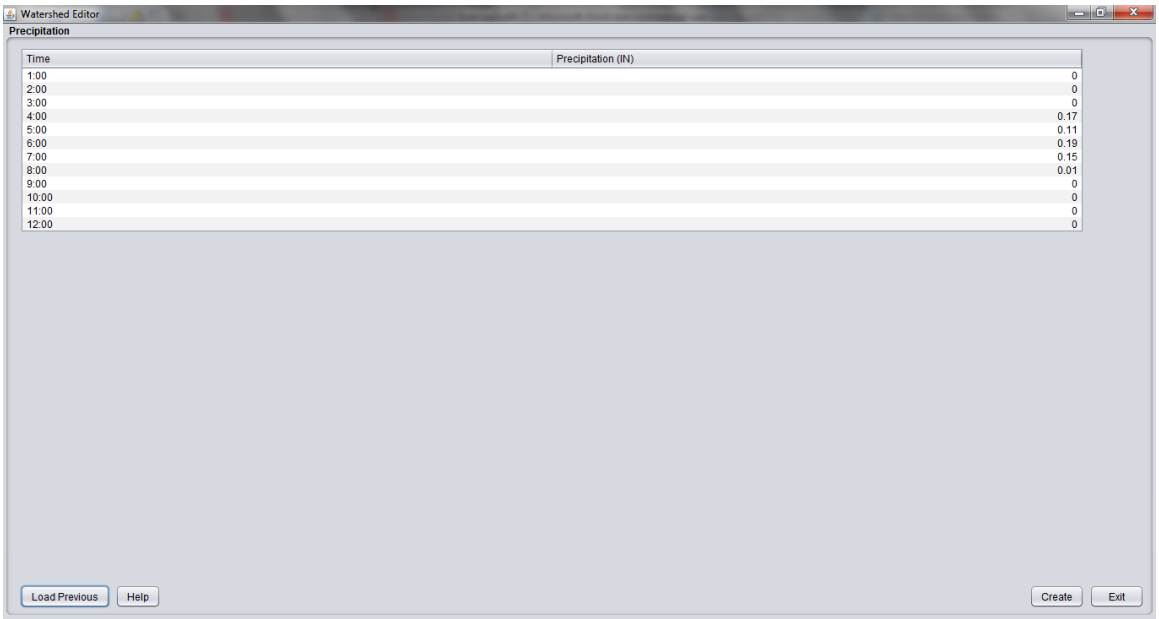


From this example, it is clear that a sustained precipitation event results in a wider discharge peak with a smaller overall volume when compared to the first precipitation event.

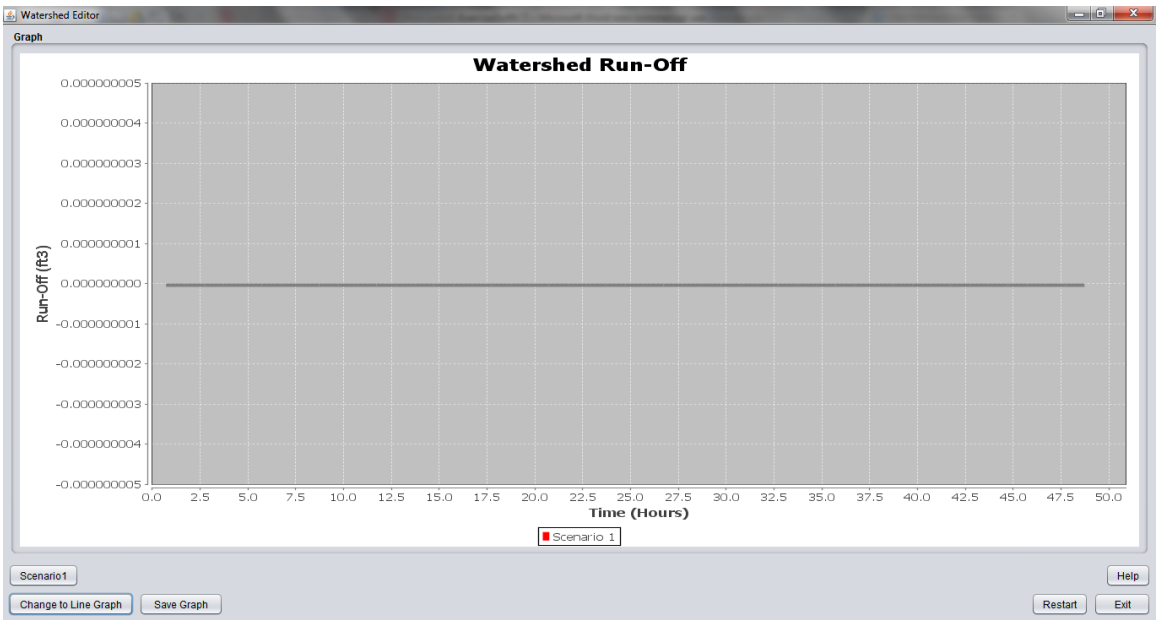
If the parking lot area was re-developed and the resulting land use had a more permeable surface (such as grassy area), the land use percentages would change as shown below.



For the same precipitation event as the previous example.



No measureable surface runoff occurs as shown below.

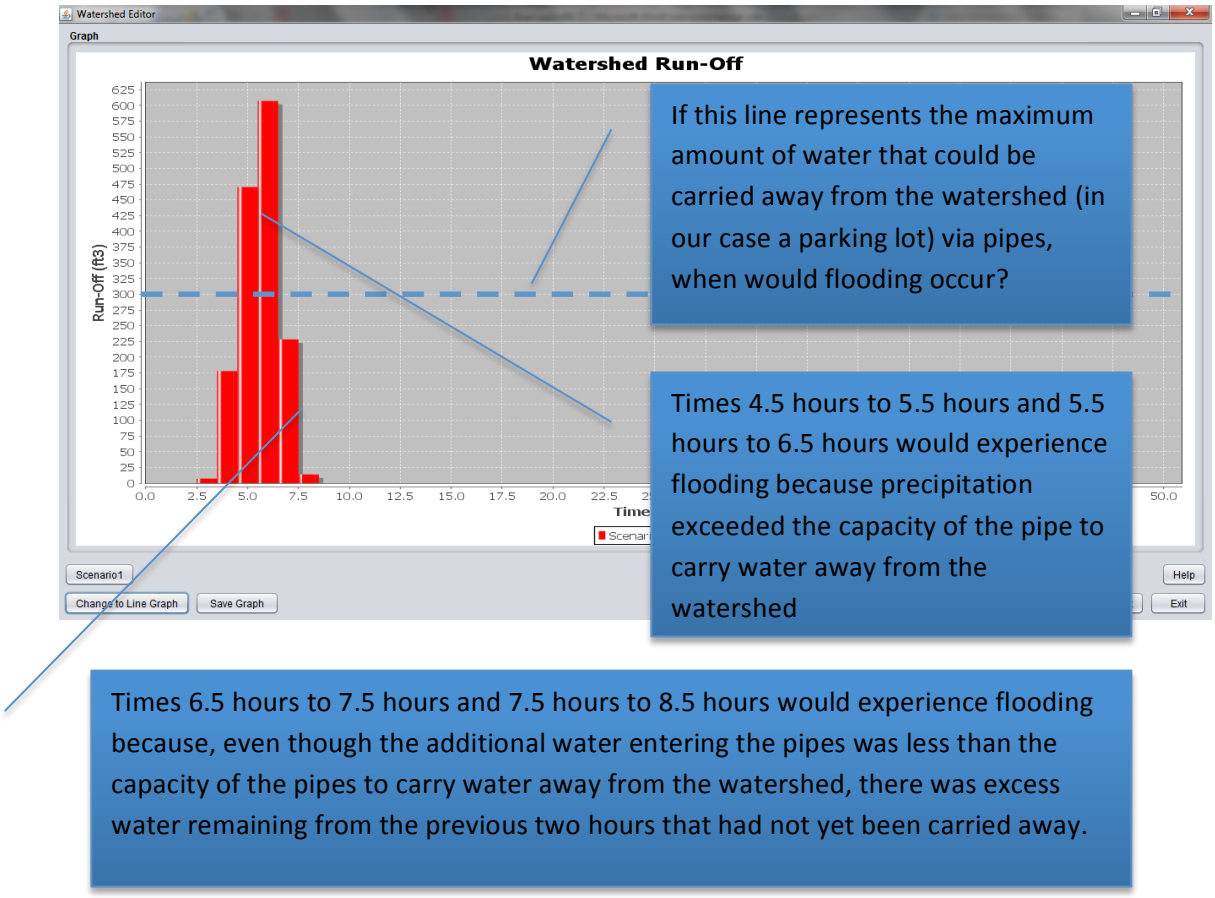


Lastly, students should be asked:

> Will the schoolyard watershed flood in any of the four precipitation events.

Once again, students will need some assistance from the instructor in determining what a flood is conceptually and in terms of the movement of water. An appropriate working definition of a flood is a situation in which more water is entering a location than leaving that location and the excess water eventually exceeds a certain depth; this depth is often associated with damage. In

the case of our schoolyard watershed example (the parking lot near the Byrd Polar Research Center), there will be flooding, at least short term, if there is not sufficient drainage in the underground pipes to move the amount of water shown on the bar graph away in each hour of time. It is easy to draw a horizontal line on the bar graph showing the maximum amount of water that could be moved away each hour. If the amount of water exceeds this line on the bar graph, that excess water will remain in the watershed until there is surplus space in the pipes to remove it. An example is shown below. Thus, students will see that the modeling software is critical to understand when flooding might occur in natural systems but also plan for infrastructure installation. It is easy for students to understand how individuals would not appreciate returning to the schoolyard watershed we selected and finding their cars flooded.



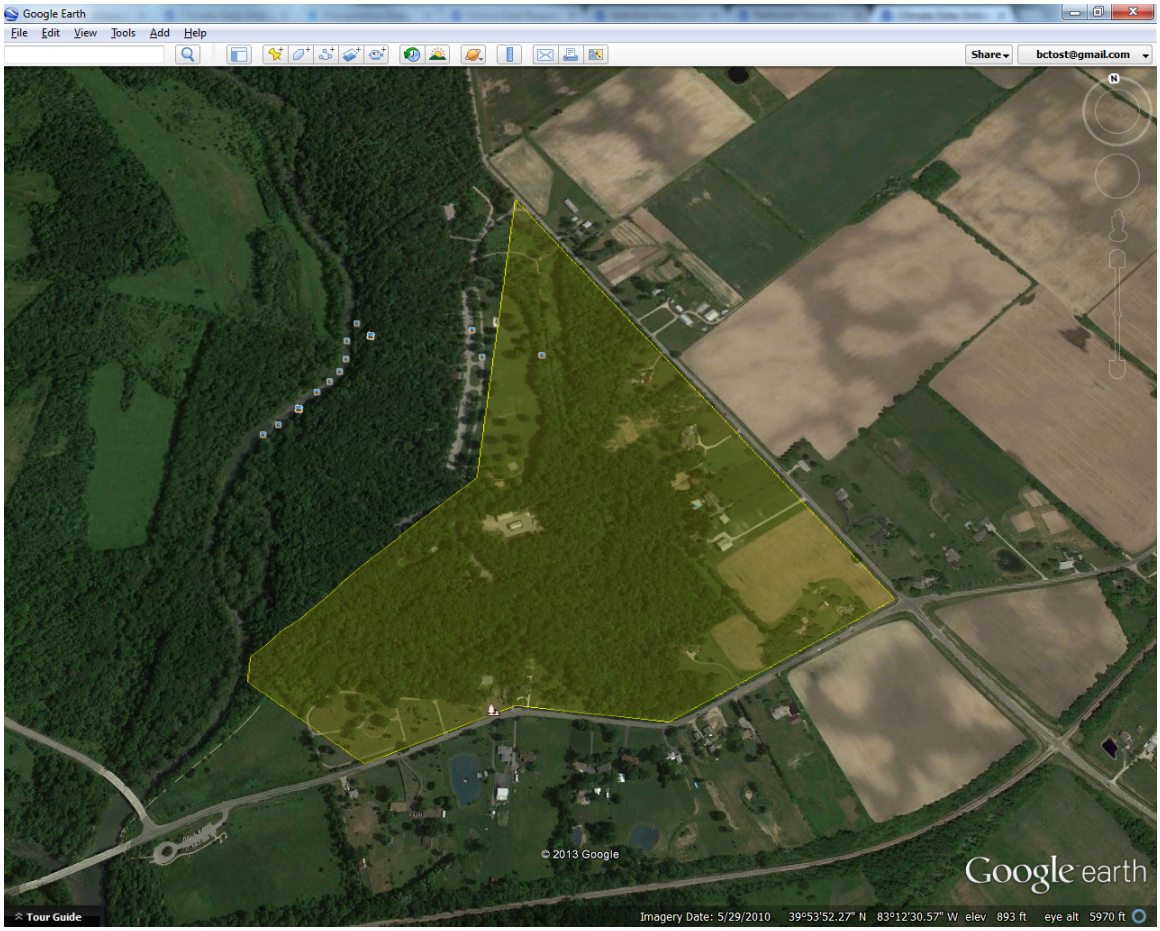
Times 6.5 hours to 7.5 hours and 7.5 hours to 8.5 hours would experience flooding because, even though the additional water entering the pipes was less than the capacity of the pipes to carry water away from the watershed, there was excess water remaining from the previous two hours that had not yet been carried away.

It is not necessary for you to know the exact amount of water that could be carried away from the schoolyard watershed (for instance, we do not know whether the maximum capacity of the pipes from the example schoolyard is 300), but rather provide students with experience thinking about the limits of infrastructure and how much capacity needs to be available for various rainfall events. For instance, it appears that the pipes from the parking lot to the detention pond need to have a capacity of 600 cubic feet each hour during this rain event or flooding will occur.

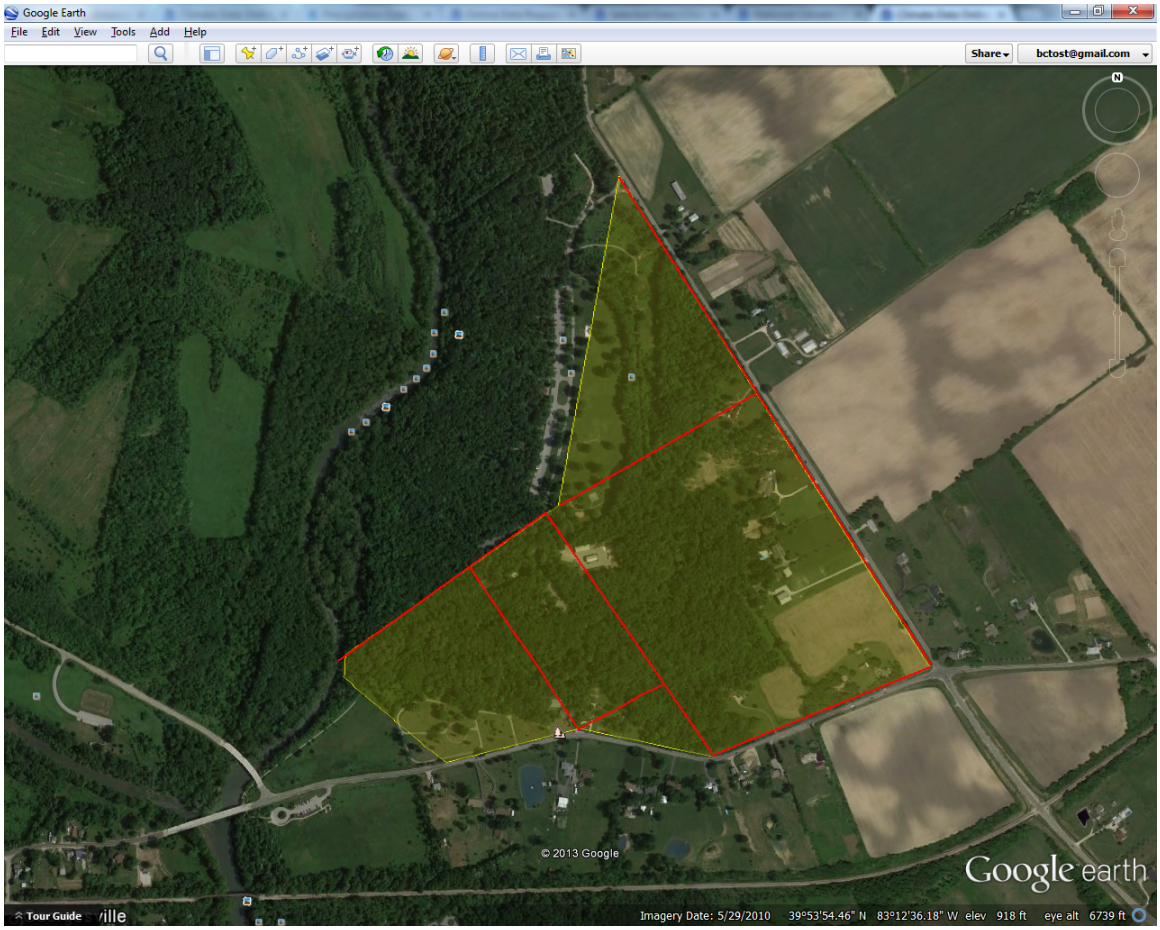
Exercise 3.2: Intermediate Watershed (Drainage on Darby Creek)

This exercise will expand on the concept of the watershed by modeling the drainage area for a small tributary stream. As an example, we have selected a tributary of the Big Darby Creek located just to the north of Alkire Road in Franklin County, Ohio. Students will have a chance to model the same two rainfall events used in the previous exercise in a new location. As watersheds become larger, it is difficult, if not impossible, to walk the entire watershed. In this example, students will see that knowing how to interpret a map or aerial photo can provide time savings and allow analysis of remote areas.

The Big Darby Creek area was accessed using Google Earth. A small tributary stream that feeds into Big Darby Creek was selected as an appropriate example for this exercise. The topography surrounding the tributary was examined. The points of highest local elevation were noted. Lines were drawn through these points and a polygon was created which represents the approximate area of the watershed. The watershed is represented by the area enclosed by the yellow polygon. This task could be done with a topographic map or aerial photo in much the same way that Exercise 3.1 examined the parking lot.

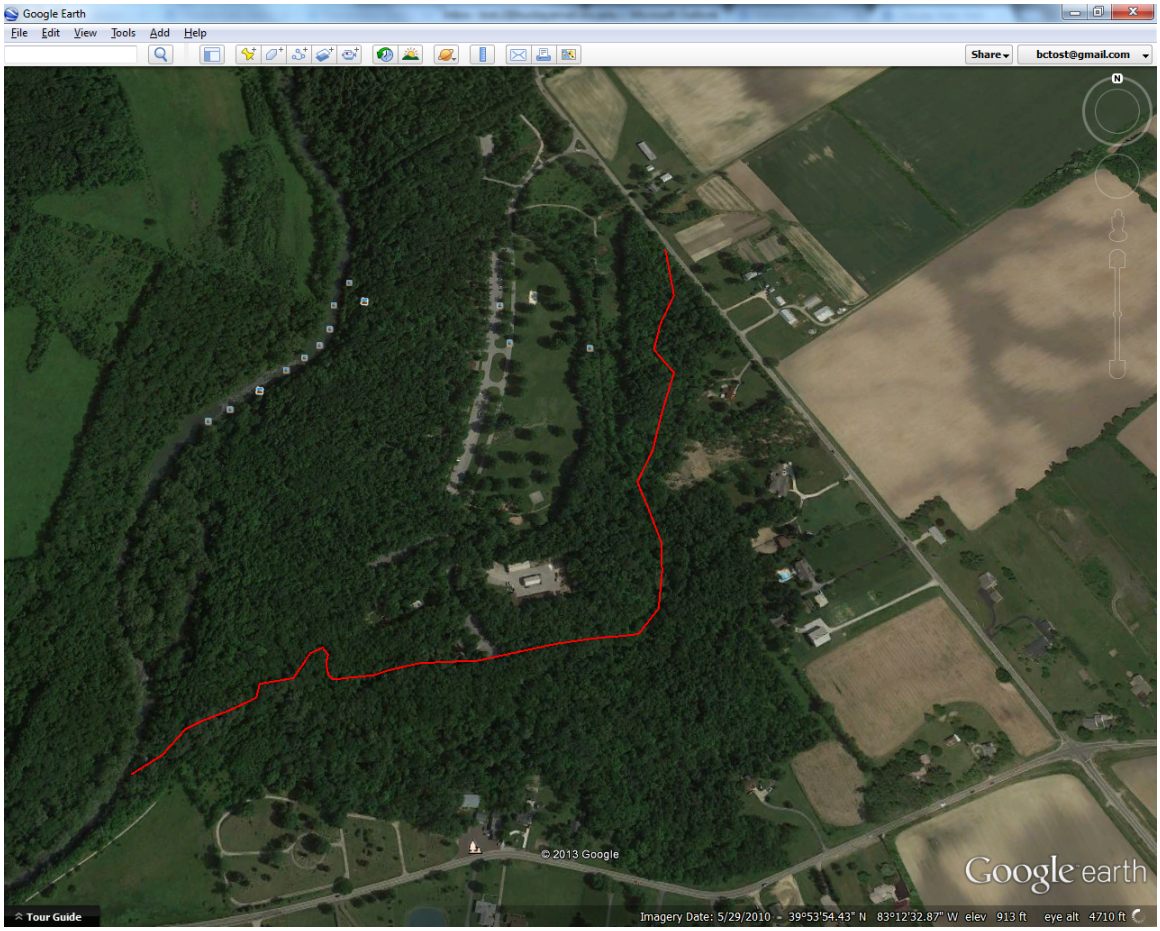


As in Exercise 3.1, the area of the polygon is necessary as an input for the water modeling web application. The area of the polygon is approximated by dividing the polygon into shapes that can easily be measured using Google Earth's ruler tool.



The approximate area of the polygon is 5,400,000 square feet. The HEC Interface requires area input in acres or square miles. Thus, area in square feet is converted to area in acres by dividing by 43,560 square feet per acre. The approximate area of the watershed is 124 acres.

The flow length is determined by tracing the path of the stream using Google Earth's ruler tool.



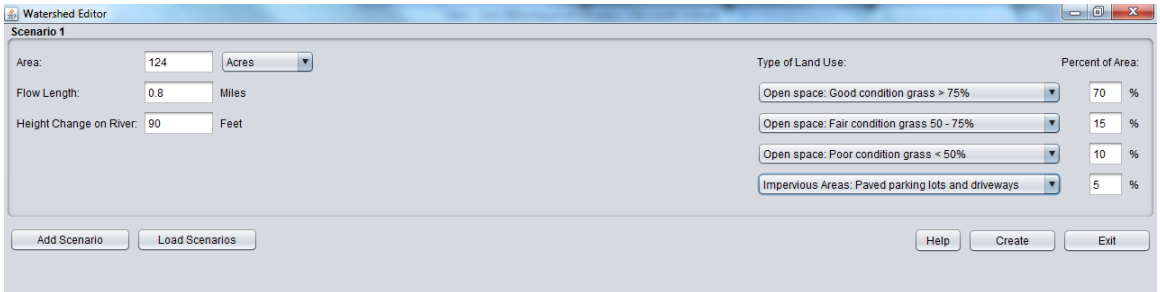
Points are placed on the stream by clicking on the stream. Care should be taken to preserve the curvature of the stream so that a reasonably accurate stream path is generated. Google Earth's ruler tool will connect the points and measure the distance of the created path by connecting the points. The approximate length of the stream is 0.8 miles.

The change in elevation along the path of the stream may be determined by accessing the elevation profile of the path traced along the stream. The highest elevation of the stream is 913 feet. The lowest elevation of the stream is 823 feet. Thus, the change in elevation along the path of the stream is 90 feet.

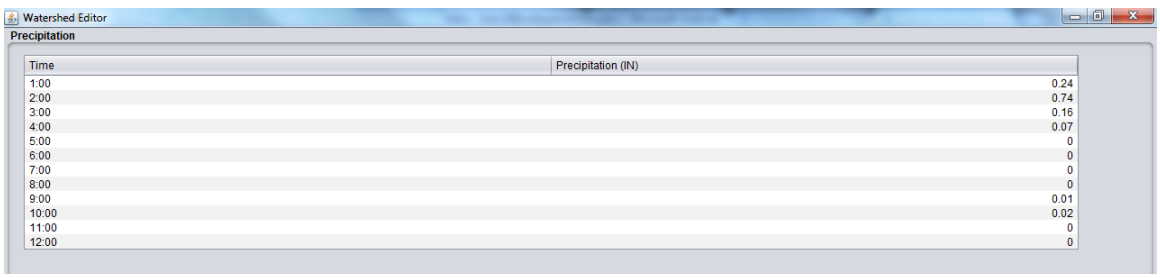
From observation of the imagery on Google Earth, the majority of the watershed drained by the small tributary stream is forested land, which is considered to be "Open space: Good condition grass >75%". The approximate percentage of land with this classification is 70%. Also from observation, approximately 15% of the area drained by the small tributary stream is non-forested, grassy area. These areas will be classified as "Open space: Fair condition grass 50-75%". Approximately 10% of the area drained by the small tributary stream appears to be agricultural land developed for crops. These areas will be considered "Open space: Poor

condition grass <50%". Approximately 5% of the area appears to be occupied by impervious surfaces such as houses and driveways. These areas will be classified as "Impervious Areas: Paved parking lots and driveways".

The scenario values are input into the web application interface.



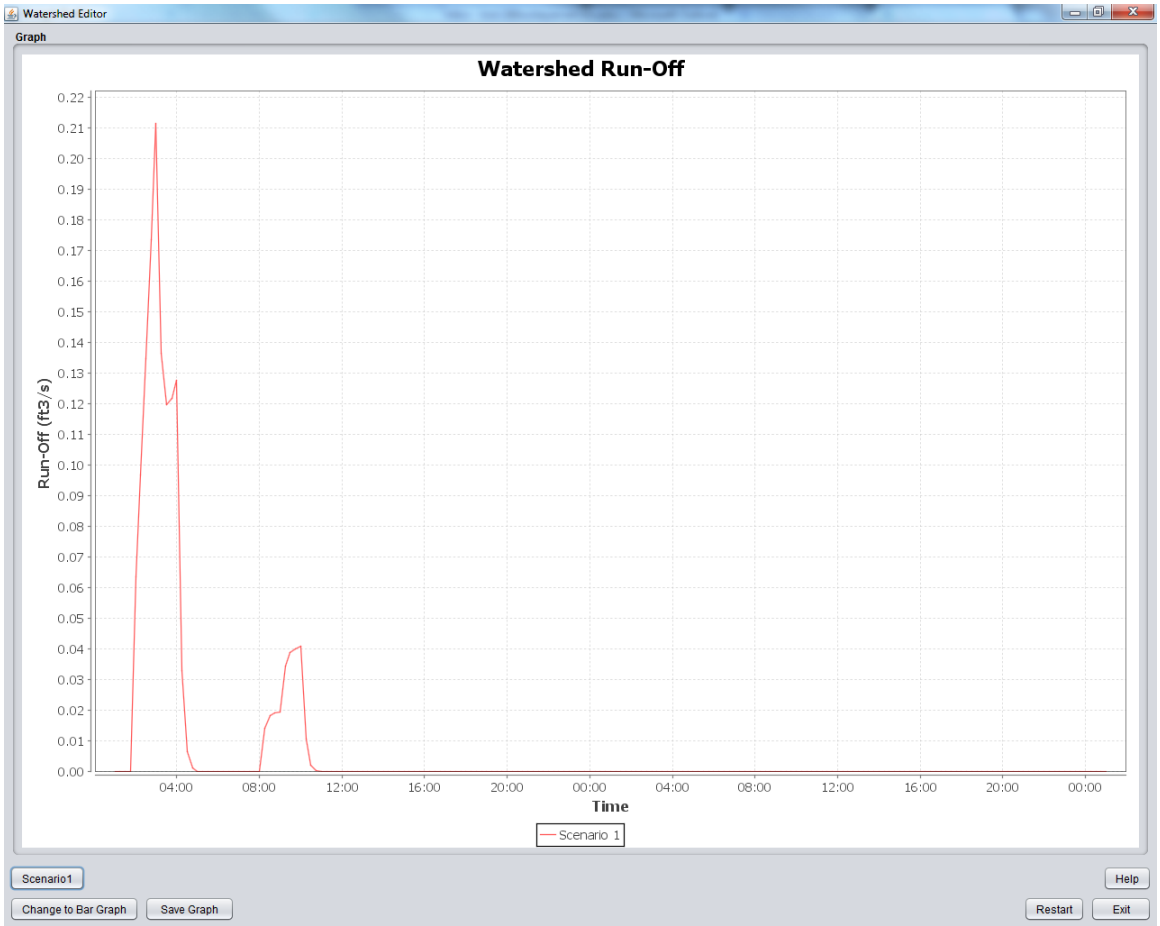
The same precipitation information from the rainfall events used in Exercise 3.1 will be used in this exercise.



Time	Precipitation (IN)
1:00	0.24
2:00	0.74
3:00	0.16
4:00	0.07
5:00	0
6:00	0
7:00	0
8:00	0
9:00	0.01
10:00	0.02
11:00	0
12:00	0

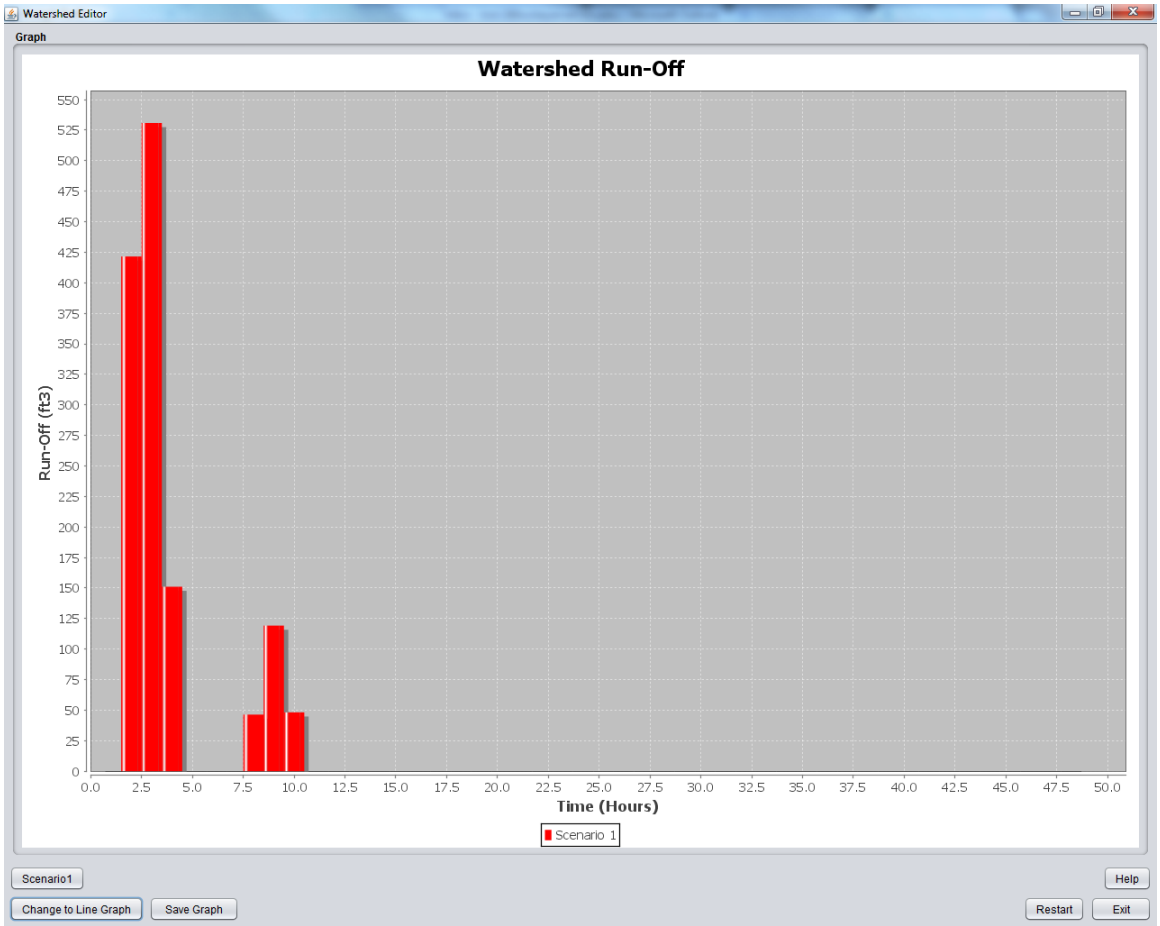
When the model is run, the web application produces the graphical output of the model.

Hydrograph output for the small tributary stream



The delay for this exercise is significantly longer than that for exercise 3.1. It takes approximately 45 minutes from when precipitation first falls on the watershed for runoff to manifest itself. This is correct as the majority of the watershed area is forested land, which will attenuate runoff to a significantly greater degree than a mixture of agricultural land and impervious surfaces. The maximum discharge for this scenario is significantly less than the maximum discharge modeled for Exercise 1. This is also correct, as forested land that is in good condition has a greater capacity to retain water than land in poor condition and land covered with impervious surfaces.

Bar graph output for the small tributary stream



This process should be repeated for the intermediate watershed for the second rainfall event used in Exercise 3.1.

Additional Support Materials

If students need additional instructional support in the structure of floodplains, the process of flooding, or details about the movement of water in streams/rivers and measurement of the discharge, a free tutorial is available at http://www.sciencecourseware.org/VirtualRiver/.

For comparison, the tables below provide discharges (rates of water moving down the river in cubic feet per second) for a range of rivers around the United States and average annual precipitation (in inches) for each of the states. Since discharges for a river may vary throughout the year, ranges are provided. Remember, rivers that are shallow could have high discharges because they are very wide and/or have water that is moving rapidly. Therefore, we listed discharges rather than water depths to make the comparison fair.

Month	Darby Creek @ Darbyville	Scioto @ Chillicothe	Ohio @ Cinncinnati
January	758	5,540	125,000
February	771	5,760	161,000
March	993	7,380	144,000
April	840	6,050	132,000
May	610	4,410	68,400
June	470	3,450	16,900
July	248	2,130	10,300
August	148	1,430	80,800
September	103	1,080	13,400
October	124	1,150	23,100
November	270	2,139	17,100
December	508	3,790	78,900
Total	4,850	36,929	870,900
	Oct, 1921 - Sep, 2013	Oct, 1920 - Sep, 2012	Oct, 1928 - Sep, 2013
Month	Ohio @ Louisville	Mississippi @ Memphis	Mississippi @ Vicksburg
January	169,000	529,000	69,500
February	192,000	636,000	789,000
March	243,000	770,000	934,000
April	203,000	827,000	1,070,000
May	149,000	667,000	1,260,000
June	88,100	513,000	924,000
July	57,200	399,000	714,000
August	44,200	281,000	490,000
September	36,600	241,000	384,000
October	40,300	252,000	418,000
November	73,400	305,000	475,000
December	128,000	423,000	624,000
Total	1,180,800	5,843,000	7,217,500
	Oct, 1928 - Sep, 2013	Jan, 1933- Sep, 1990	Jan, 2008- Sep, 2013
	*Data is given in cubic feet per second		
	**All monthly averages obtained from USGS via waterdata.usgs.gov/nwis		

Month	Hudson @ Albany (Green Island)	Colorado @ Lees Ferry	
January	14,300	9,800	
February	14,100	9,850	
March	22,600	10,500	
April	30,600	15,900	
May	18,600	27,500	
June	11,100	32,300	
July	7,420	18,300	
August	6,430	13,300	
September	6,920	10,900	
October	10,100	9,570	
November	14,000	9,790	
December	16,100	9,650	
Total	149,670	166,860	
	Mar, 1946 - Sep, 2013	Oct, 1921 - Sep, 2013	
	*Data is given in cubic feet per second		
	**All monthly averages obtained from USGS via waterdata.usgs.gov/nwis		

State	Inches	State	Inches
Alabama	58.3	Montana	15.3
Alaska	22.5	Nebraska	23.6
Arizona	13.6	Nevada	9.5
Arkansas	50.6	New Hampshire	43.4
California	22.2	New Jersey	47.1
Colorado	15.9	New Mexico	14.6
Connecticut	50.3	New York	41.8
Delaware	45.7	North Carolina	50.3
Florida	54.5	North Dakota	17.8
Georgia	50.7	Ohio	39.1
Hawaii	63.7	Oklahoma	36.5
Idaho	18.9	Oregon	27.4
Illinois	39.2	Pennsylvania	42.9
Indiana	41.7	Rhode Island	47.9
Iowa	34.0	South Carolina	49.8
Kansas	28.9	South Dakota	20.1
Kentucky	48.9	Tennessee	54.2
Louisiana	60.1	Texas	28.9
Maine	42.2	Utah	12.2
Maryland	44.5	Vermont	42.7
Massachusetts	47.7	Virginia	44.3
Michigan	32.8	Washington	38.4
Minnesota	27.3	West Virginia	45.2
Mississippi	59.0	Wisconsin	32.6
Missouri	42.2	Wyoming	12.9

*Average total yearly precipitation for each state.

**Based on data collected by weather stations through each state from 1971 to 2000 and provided by NOAA's National Climatic Data Center.