

Homework 10. Logan Dry Canyon Detention Basin Design Case Study

Date: 4/14/14

Due: 4/25/14

Section 1: Case Study Introduction

This case study serves as an integrative problem based learning exercise. In it, you will use what you have already learned about hydrology to assess the design of a detention basin, which was constructed to protect a community from flash flooding.

The site of this case study is Dry Canyon (Figure 1), a small and rather steep valley without a *perennial stream* which borders the city of Logan, Utah. Logan is located on the western edge of the Bear River Range, a northern extension of the Wasatch Range in the Rocky Mountains. A detention basin (Figure 2) was recently constructed at the mouth of Dry Canyon to protect the community that lives below from the risk of flooding and landsliding due to excess surface water runoff. Below the detention basin a large stormwater drain was installed beneath mountain road to carry outflow from the detention basin to Logan River. In designing this flood protection system a design hydrograph needs to be determined, then the detention basin and flood conveyance sized to contain this hydrograph. The steps involved are

1. Determine physical characteristics of a the catchment (Section 1),
2. Determine the design rainfall hyetograph (Section 2),
3. Determine the storm hydrograph accounting for infiltration and watershed routing using a Unit Hydrograph (Section 3)
4. Design the detention basin and stormwater conveyance (Section 4).

The aspect of the design done here will be evaluating the tradeoff between the size of the detention basin and the capacity required for the stormwater drain that carries water from the detention basin to Logan River. For this exercise data will be acquired from various sources. Excel will be used for basic data manipulation and analysis, and HEC-HMS will be used to perform the more complex design calculations.



Figure 1. A map of the case study area showing the location of Dry Canyon, approximately 2.2 miles east of the City of Logan.

Background

Flash flooding is a hazard common to Utah's mountains, slot canyons, desert washes, and other such topographic areas featuring hilly terrain where rainfall runoff might be quickly channeled into gullies or ravines. A flash flood is a short-term event characterized by a sudden and rapid rise in stream depth

Logan Dry Canyon Detention Basin Design Case Study

resulting from heavy, localized rainfall. These types of rainfall events also have the potential to weaken soil and cause landslides, another hazard that not only threatens lives but can also be a substantial economic burden. In fact, the most expensive individual landslide in North America occurred in Utah County in 1983 (Schuster, 1996 – UGS, 2007). With a growing population, developing neighborhoods in susceptible terrain has become more common and therefore increased the potential for damage to private property and public infrastructure from floods and slides. The neighborhood at the mouth of Dry Canyon is no exception to this phenomenon as the surrounding area, and much of the state of Utah itself, falls within the high to moderate range on the Utah Geological Survey's landslide susceptibility scale (Figure 3).



Figure 2. Logan Dry Canyon Detention Basin (Photo Courtesy of David Rosenberg)

Logan Dry Canyon Detention Basin Design Case Study

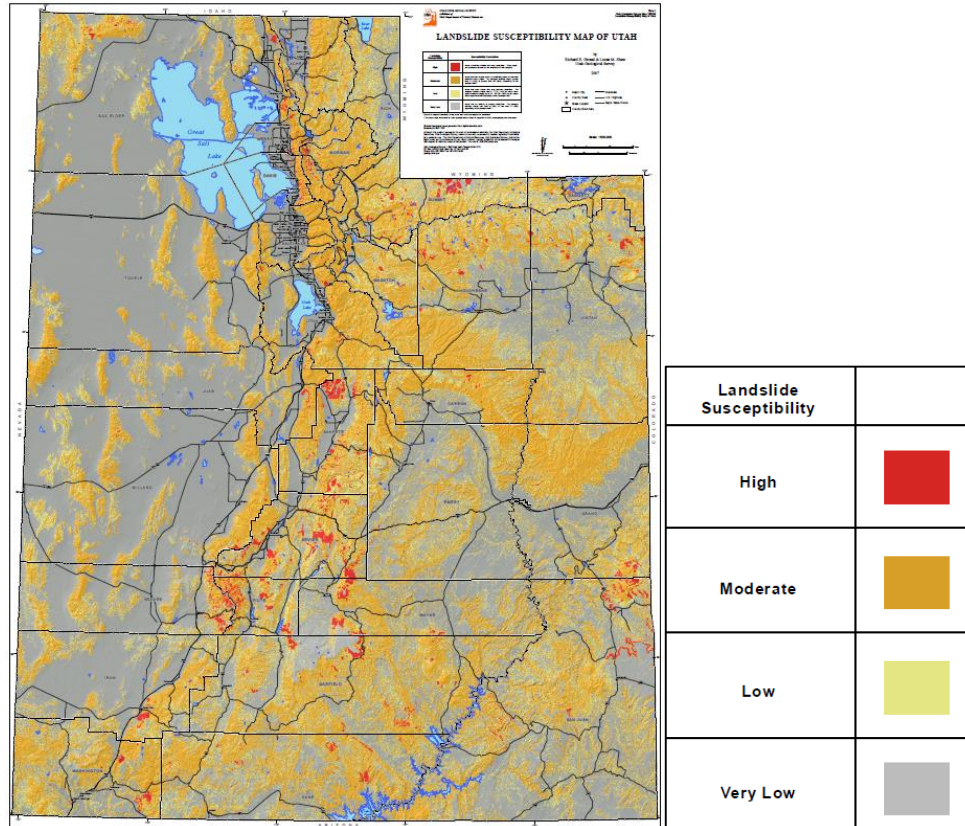


Figure 3. Landslide Susceptibility Map of Utah (UGS, 2007)

Section 1 Activities


1. Recalling the definition of *catchment area*, use the USGS StreamStats website to delineate the Dry Canyon catchment.
 - 1.1. Access the USGS StreamStats website using the following link:
<http://water.usgs.gov/osw/streamstats/utah.html>
 - 1.2. Record the catchment area and slope using the “Basin Characteristics” tool and the catchment length using the “Trace Flow Path within Watershed and Show Profile” tool.

To turn in:

- A computer screen shot showing the Logan Dry Canyon Watershed you delineated using StreamStats
- A table of the following parameters for this catchment, including units:
 - Area
 - Average Slope
 - Catchment length (the longest flow length from the trace tool)

Note that these watershed properties will be used later in the calculation of a synthetic unit hydrograph for this watershed.

Logan Dry Canyon Detention Basin Design Case Study

2. Use the NRCS's SSURGO site (Natural Resources Conservation Service's Soil Survey Geographic database) to determine the soil classification for the Dry Canyon catchment.
 - 2.1. Access the NRCS's SSURGO site (Natural Resources Conservation Service's Soil Survey Geographic database) using the following link:
<http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>
 NOTE: Windows may pop up informing you of updates. They are informational only and require no action other than they must be closed before continuing.
 - 2.2. Use the crosshairs and zoom-in tool to locate Dry Canyon. Then highlight the area of interest (AOI) using the "Define AOI by rectangle" tool  making sure to grab enough of the map surrounding Dry Canyon. NOTE: you will get a "Partial Data" warning; click "close" to continue. Once the AOI is highlighted, click on the "Soil Map" tab at the top of the page. The page should then look something like this:

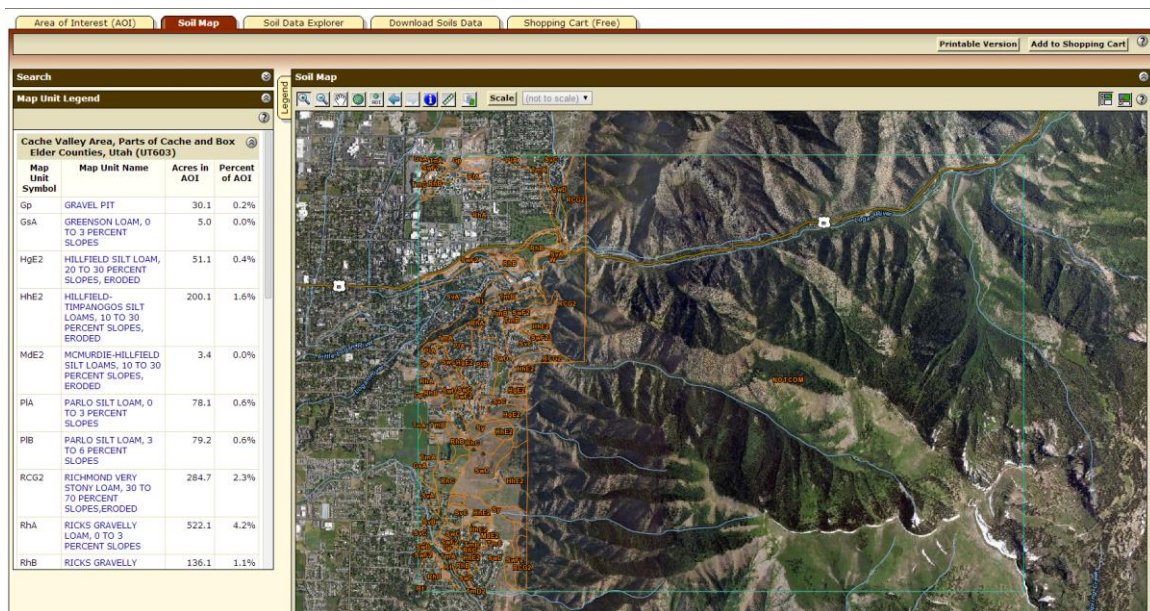


Figure 4. SSURGO soil map.

- 2.3. Notice the extent of the available soil data for this area; there is almost no data for the Dry Canyon catchment (missing data will be labeled "NOTCOM"). Therefore, the soil type for the main catchment must be extrapolated based on the limited information available.
- 2.4. Information on each soil type listed is available by following the link under the column labeled "Map Unity Name" next to the column labeled "Map Unit Symbol", which is the abbreviation associated with the various soil types found on the map. Save the "Map Unit Description" for 2-3 soil types that best represent the Dry Canyon catchment.
- 2.5. Use the information from Figure 5 and the soil descriptions you saved to determine the appropriate curve number (CN) for the soil in the Dry Canyon catchment.

Logan Dry Canyon Detention Basin Design Case Study

Cover description cover type	hydrologic condition ^{2/}	Hydrologic soil group ^{1/}			
		A ^{3/}	B	C	D
Herbaceous—mixture of grass, weeds and low-growing brush, with brush the minor element	Poor	80	87	93	
	Fair	71	81	89	
	Good	62	74	85	
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor	66	74	79	
	Fair	48	57	63	
	Good	30	41	48	
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor	75	85	89	
	Fair	58	73	80	
	Good	41	61	71	
Sage-grass—sage with an understory of grass	Poor	67	80	85	
	Fair	51	63	70	
	Good	35	47	55	
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, paloverde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

^{1/} Average runoff condition, and $I_a = 0.2s$. For range in humid regions, use table 9-1.

^{2/} Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.

^{3/} Curve numbers for group A have been developed only for desert shrub.

Figure 5. Runoff curve numbers for arid and semiarid rangelands.
Source <ftp://ftp.wcc.nrcs.usda.gov/wntsc/H&H/NEHhydrology/ch9.pdf>

2.6. Calculate the time of concentration based on the SCS Method (section 8.8 in Mays).

- First, calculate the estimated potential maximum retention, S :

$$S = \frac{1000}{CN} - 10$$

Where CN = runoff curve number determined in step 2.5.

- Then, calculate the time lag, t_L :

$$t_L = \frac{L^{0.8}(S + 1)^{0.7}}{1900Y^{0.5}}$$

Where t_L = time lag (hours), S = potential maximum retention, L = hydraulic length (feet) and Y = average watershed land slope (%); L and Y were determined in Activity #1.

- Finally, calculate the time of concentration, t_c :

$$t_c = \frac{5}{3} t_L$$

To turn in:

- Add the following to the table started in Activity #1:
 - soil type you have chosen
 - appropriate curve number, CN
 - calculated lag time, t_L
 - calculated time of concentration, t_c

Note that the time lag and time of concentration give you information on the time scale involved in the hydrograph calculations you will perform later.

Section 2: Precipitation and Surface Water Input

This section will use data from the NOAA Precipitation Frequency Data Server (PFDS) to design a storm hyetograph which will be used to construct the storm hydrograph in Section 3.

Logan Dry Canyon Detention Basin Design Case Study

Section 2 Activities

3. Obtain tabular point precipitation frequency estimates for the Dry Canyon catchment using the DDF curves on the NOAA Precipitation Frequency Data Server (PFDS) site.
 - 3.1. Access the NOAA PFDS website using the following link:
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ut
 - 3.2. Using the map, zoom in to Logan, Utah, and once again locate Dry Canyon. To obtain point precipitation frequency estimates for the Dry Canyon watershed, place the red crosshairs within the watershed boundaries using left-double-click or drag-and-drop. NOTE: If you cannot see the red crosshairs, then left-double-click somewhere on the map to make them re-appear.
 - 3.3. To output the tabular data, you must be in the “PF tabular” tab. Scroll to the bottom of the website; in the “Estimates from the table in csv format” pull-down menu, make sure “precipitation frequency estimates” is chosen; click “Submit”. This will open a new browser tab, which will contain the data from the table in CSV format.
4. Using the tabular NOAA PFDS data, design an event storm hyetograph based on a return period and duration appropriate to the design of a detention basin for the Dry Canyon catchment.
 - 4.1. First, determine the duration of the hyetograph. It should be 5-10 times t_c , the time of concentration calculated in Activity #2. A duration 5 to 10 times t_c gives an upper bound ensuring that an ample design duration is considered that is sure to include the most critical duration. Also decide on a time step. This should be about 5 to 10 times smaller than t_L to ensure that your design storm can sufficiently resolve high rainfall intensities.
 - 4.2. Second, determine the return period for the construction of a detention basin. For simplicity, we will use a return period of 100 years for this exercise. However, it is typically based on local code; for Logan, this information can be found in the Cache County, Utah, Manual of Roadway Design and Construction Standards:
<http://cachecounty.org/assets/departement/publicworks/roads/RoadManual.pdf>
 - 4.3. Finally, use the alternating block method to construct the event storm hyetograph. The idea behind the alternating block method is to construct a hyetograph such that the peak depth occurs at the midpoint of the duration and the falling limbs of the hyetograph successively decrease in depth in a way that when you average over the most intense part of the storm for any duration you obtain the critical rainfall depth for that duration (e.g., in a 60 minute hyetograph, the peak depth occurs at 30 minutes: ..., $x_{t=25\text{min}} = 0.2$ in, $x_{t=30\text{min}} = 0.4$ in, $x_{t=35\text{min}} = 0.3$ in, ..., where x = depth). This method requires some simple math be applied to the tabulated DDF data obtained from the NOAA PFDS site:
 - 4.3.1. First, grab the depths from the required recurrence interval column (aka, the return period chosen in step 4.1) for durations up to the total duration chosen in step 4.1 (e.g. for a 100-yr, 1-hr design storm hyetograph, grab only the depths for 0 through 60 minutes in the 100-yr column).

Logan Dry Canyon Detention Basin Design Case Study

4.3.2. Notice that the time step between the durations provided is not consistent (e.g., 5 min, 10 min, 15 min, 30 min, 60 min, ...). The alternating block method requires the time increments be equal. Therefore, use linear interpolation to create a list of depths that increment with a repeating time step (e.g., if the repeating time step = $\Delta t = 5$ min, then the interpolated depths would be calculated for 5 min, 10 min, 15 min, 20 min, 25 min, ...).

4.3.3. Keep in mind the list of depths you just interpolated are cumulative, not incremental. The alternating block method requires the depths be incremental, not cumulative. Therefore, create a list of incremental depths from the list of depths you just interpolated. To do this, simply calculate the difference between each successive depth as follows: $\Delta x_1 = x_{t=5\text{min}} - x_{t=0\text{min}}$, $\Delta x_2 = x_{t=10\text{min}} - x_{t=5\text{min}}$, $\Delta x_3 = x_{t=15\text{min}} - x_{t=10\text{min}}$, $\Delta x_4 = x_{t=20\text{min}} - x_{t=15\text{min}}$... $\Delta x_n = x_{t=D-\Delta t 5\text{min}} - x_{t=D\text{min}}$.

4.3.4. Next, order the incremental depths as follows: ... Δx_7 , Δx_5 , Δx_3 , Δx_1 , Δx_2 , Δx_4 , Δx_6 ... This step is where the name alternating block method comes from.

4.3.5. Finally, plot the hyetograph and calculate a cumulative rain depth. Your plot should look something like this:

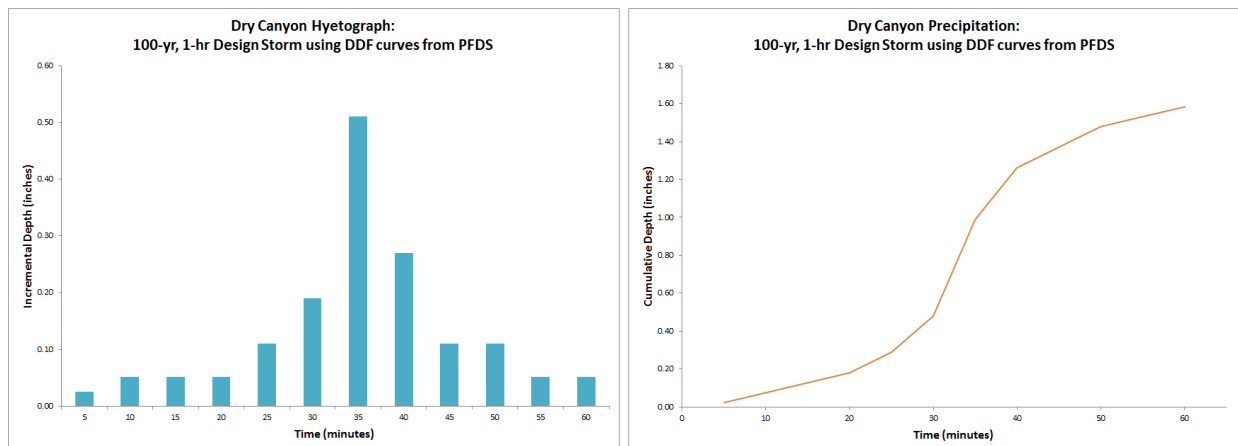


Figure 6. Hyetograph and cumulative depth plots constructed using the alternating block method.

To turn in:

- Plots of the incremental depth and cumulative depth design hyetographs determined following the procedure above. Plots should include: descriptive title, axis labels, and appropriate units.

Section 3: Storm Hydrograph Computation

This section will use HEC-HMS to construct the storm hydrograph which will be used in design of the detention basin in Section 4.

Logan Dry Canyon Detention Basin Design Case Study

Section 3 Activities


5. Determine the Green-Ampt parameters based on the soil type found in Activity #2:
 - 5.1. Green-Ampt parameters for different soils are given in Mays Table 7.4.1 (Page 317). Select a soil type from this table that seems most representative of what you have determined about the soils in this basin and record the following parameters: conductivity, suction, saturated content (porosity), and effective porosity. For this exercise, residual moisture content will be used in place of initial moisture content. Note the units you are working in.

Note that this approach of using tabulated soil values is approximate and introduces uncertainty. In a more comprehensive design soil tests to better quantify soil properties should be considered. The US Army study on Dry Canyon reports soil texture information in page 4. You are welcome to use this with the soil texture triangle (Mays Figure 2.2.3) to determine soil texture class for use in determining Green Ampt parameters. The design studies for the detention basin also report a number of soil tests. This information is hard to interpret, but you are encouraged to look at this too in determining infiltration parameters.



To turn in:

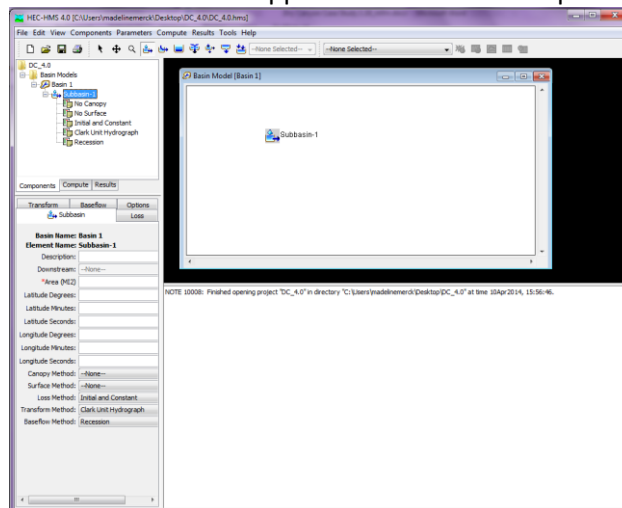
- *Add the Green-Ampt parameters for Dry Canyon to the table started in Activity #1:*
 - *conductivity*
 - *suction*
 - *saturated content (porosity)*
 - *effective porosity*
 - *residual moisture content (in lieu of initial moisture content)*
6. Use HEC-HMS to construct a storm hydrograph based on Green Ampt losses and the SCS Unit Hydrograph transform method.
 - 6.1. If you do not already have HEC-HMS loaded on your computer, then visit the main HEC-HMS website, <http://www.hec.usace.army.mil/software/hec-hms/>. From this page, you can access downloads and documentation, including current and archived versions of HMS, User's Manuals, Quick Start Guides, and more.
 - 6.2. Open HEC-HMS by double clicking the desktop program icon or through the start menu. The program screen will then appear.
 - 6.3. Open a project by clicking File on the menu bar:
 - For existing projects, click Open and select from existing projects.
 - For new projects, click New:
 - Create a project name (e.g., Dry Canyon)
 - Select the folder where the project work will be stored
 - Provide a description
 - Select the units to use
 - Click Create
 - 6.4. Create a basin model as follows:
 - On the menu bar, select Components -> Basin Model Manager -> New

Logan Dry Canyon Detention Basin Design Case Study

- Provide a basin name and description
- Click Create
- The folder Basin Models appears in the Watershed Explorer (on left of screen) under the project name
- Close the Basin Model Manager (click  to close windows)

6.5. Set up the basin structure:

- Expand the folder Basin Models until a small watershed icon  will appear labeled with the basin model name.
- Click on the icon. This results in 3 changes on the screen: (i) it will make active the watershed creation tools under the menu bar (to the right of the magnifying glass: Subbasin, Reach, Reservoir, Junction, Diversion, Source, and Sink creation tools); (ii) in the lower left corner in the Component Editor, information may be input to the Basin Model; and (iii) the Basin Model template appears in the Desktop area. It is in this space that the basin model will be set up with the Watershed Creation tools.
- Click on the Subbasin Creation Tool . Click within the desktop area to place the subbasin. A popup will appear in which a subbasin name and description may be input. Click Create when finished. A subbasin feature appears on the basin template.



6.6. Input basin element information:

- Click on the element either in the conceptual basin created in the Desktop area or in the Watershed Explorer. The appropriate input fields appear in the Component Editor in the lower left corner. Refer to previous activities within the Dry Canyon module for details about the watershed.
- Click on Subbasin-1. Initially, there are 5 tabs in the Component Editor (Left-hand corner). These tabs will appear/disappear depending on the methods selected. Fill in the tabs as follows:
 - Subbasin: Description and Downstream should already automatically populate with information from the Desktop but may also be entered or edited here.
 - Area = value from Activity #1, pay attention to units
 - Canopy Method = None
 - Surface Method = None
 - Loss Method = Green and Ampt
 - Transform method = SCS Unit Hydrograph

Logan Dry Canyon Detention Basin Design Case Study

- Baseflow Method = None
- Loss: Enter the values for the Green-Ampt parameters determined in Activity #5 and Impervious (%) = 0%.
- Transform: Enter the time lag, t_L , determined in Activity #2. Note the units.
- Save the project.

6.7. Input Hyetograph:

- On the menu bar, select Components -> Time Series Data Manager,
- Data Type: Select Precipitation gage, click New, provide name and description, click Create, and close. A folder Time Series Data is added to the Watershed Manager.
- Expand the folder out to Gage 1. Click on the storm event dates to enter hyetograph data and information.
- Fill in the following tabs:
 - Time-Series Gage: Units = Incremental inches, and Time Interval = 5 minutes
 - Time Window: start to end time should allow enough time for the rainfall event as well as the runoff response (e.g., double the rainfall duration).
 - Table: cut and paste incremental depths from the hyetograph created in Activity #4
- At the end of the precipitation event, input zeroes for any remaining time increments.
- Save the project.

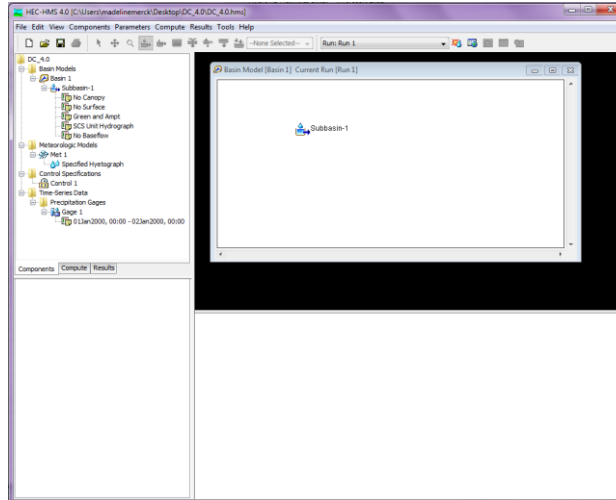
6.8. Meteorologic Model Manager:

- On the menu bar, select Components -> Meteorologic Model Manager -> New; fill in the name and description and click Create. A folder Meteorologic Models is added to the Basin-1 schematic in the Watershed Explorer.
- Expand the folder out to Met 1.
- Fill in the following tabs:
 - Meteorology Model: Precipitation = Specified Hyetograph; Shortwave, Longwave, Evapotranspiration, Snowmelt = None; Replace Missing = Abort Compute; select the appropriate units
 - Basins: Basin Model = basin model name; Include Subbasins = Yes
- For Specified Hyetograph (under Met 1): Gage = Gage 1
- Save the project.


6.9. Model Control Specifications:

- On the menu bar, select Components -> Control Specifications Manager -> New; fill in the name and description and click Create. A folder Control Specifications is added to the Basin-1 schematic in the Watershed Explorer.
- Expand the folder out to Control 1.
- Fill in the following tabs:
 - Control Specifications: start to end time should equal that given for the hyetograph in step 6.7; Time Interval = 5 minutes.
- Save the project.

Logan Dry Canyon Detention Basin Design Case Study



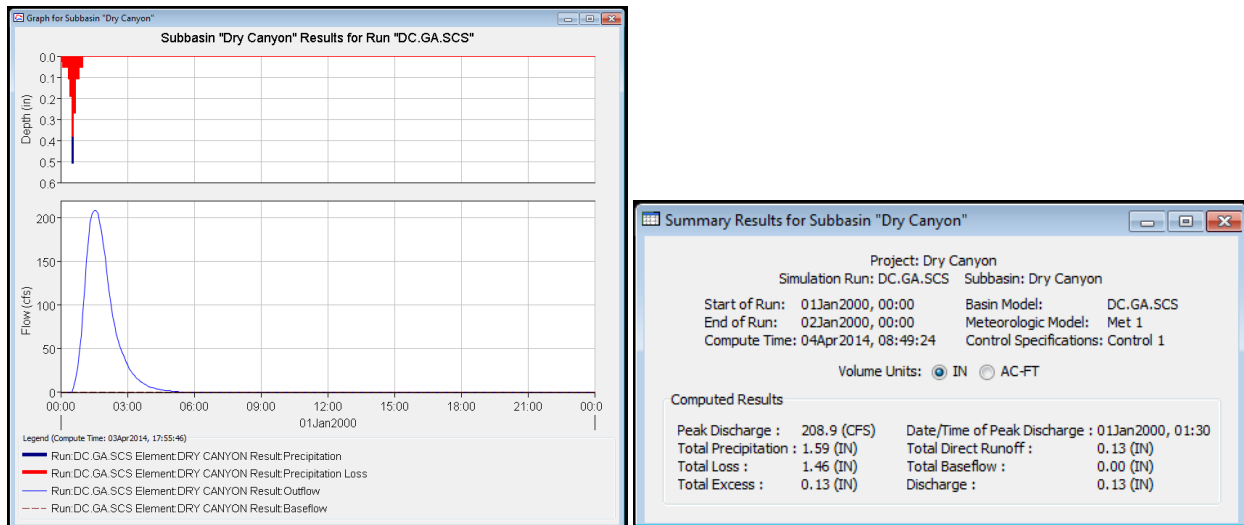
6.10. Running Simulations:

- On the menu bar, select Compute -> Create Compute -> Simulation Run.
- To create a simulation run:
 - give the simulation a descriptive name, click Next
 - select a basin model, click Next
 - select a meteorological model, click Next
 - select a control specifications model, click Finish
- Click the Compute Current Run button  to run the simulation in the Run dropdown menu.
- A message box appears saying that HEC-HMS is finished computing your simulation run; close the message box.
- If the simulation does not compute to 100%, then check the errors that appear in red in the message area below the Desktop. Correct any mistakes, save the project, and rerun the simulation.

6.11. Viewing Results:

- To view graphical and tabular results, click on the “Results” tab in the Watershed Explorer area.
- Select the Run you want to review the results.
- Output for any component of the basin may be observed by clicking on the component & selecting the output format type. More than 1 type may be viewed at once.

Logan Dry Canyon Detention Basin Design Case Study



To turn in:

- Screen shots of the following HEC-HMS output results for Dry Canyon (subbasin): hydrograph and summary table (like the examples above).



Section 4: Detention Basin Design

This section will use HEC-HMS and the storm hydrograph from Section 3 to analyze the trade-off between capacity of the storm drain conveyance and required size of the detention basin. For simplicity we will model the outlet using an orifice. A large orifice releases water more rapidly into the downstream storm drain and builds up less water in the detention basin. A small orifice has the opposite effect of building up more storage in the detention basin and releasing a smaller discharge downstream. For a smaller orifice smaller storm drain capacity but large detention basin is required. For a large orifice a large storm drain capacity but smaller detention basin is required. This exercise will use three different orifice sizes for the detention basin outlet control in HEC-HMS to evaluate this trade off.

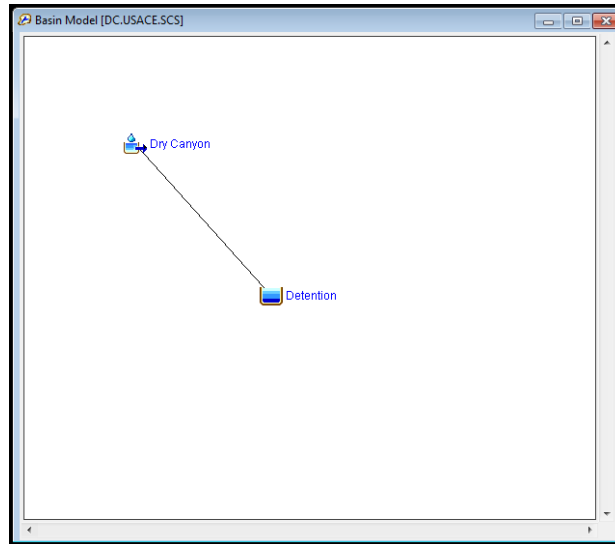
Section 5 Activities

7. Use HEC-HMS to determine the size of the detention basin based on various outlet sizes

7.1. Add a detention basin to the basin model as follows:

- Click on the Reservoir Creation Tool . Click within the desktop area to place the reservoir. A popup will appear in which a name and description may be input. Click "Create" when finished. A reservoir feature appears on the basin template.
- Connect the subbasin and reservoir: select the arrow pointer , right-click on the upstream object (in this case, the subbasin); select "Connect Downstream"; complete the connection by clicking the crosshairs on the reservoir. A thin black line should now connect the two and the Desktop should look like this:

Logan Dry Canyon Detention Basin Design Case Study



- 7.2. Before filling in the reservoir tabs, the reservoir storage-discharge relationship must be entered as paired data.
- The area of the level bottom of the detention basin is given along with the slopes for all sides of the basin (Figure 7). Use this information to develop a relationship between the water surface elevation within the basin and the water surface area at that elevation. Extend the elevation such that there can be no overtopping of the detention basin (if it were to overtop, HEC-HMS would not be able to complete the simulation run; extend it high enough to complete all simulations). Note: 1 acre = 43560 ft²
 - On the menu bar, select "Components" -> "Paired Data Manger".
 - Select Elevation-Area Function from the Data Type pull down menu and click "New"; fill in the name and description and click "Create." A folder "Paired Data" is added to the basin model schematic in the Watershed Explorer.
 - Expand the folder out to "Table 1"
 - Fill in the following tabs:
 - Paired Data: Data Source = Manual Entry; Units = FT:AC
 - Table: populate the table with the elevation-area function.
 - Save the project.

Logan Dry Canyon Detention Basin Design Case Study



Figure 7. An aerial view of the existing detention basin at the mouth of Dry Canyon. The bottom of the basin (125'x150') is level ground. The sides A, B, C, and D are sloped 1:2, 1:2, 1:5, and 1:1, respectively. All dimensions given are approximate.



Figure 8. The outlet structure for the Logan Dry Canyon detention basin. Not visible is the single outlet culvert. (Photo Courtesy of David Rosenberg)

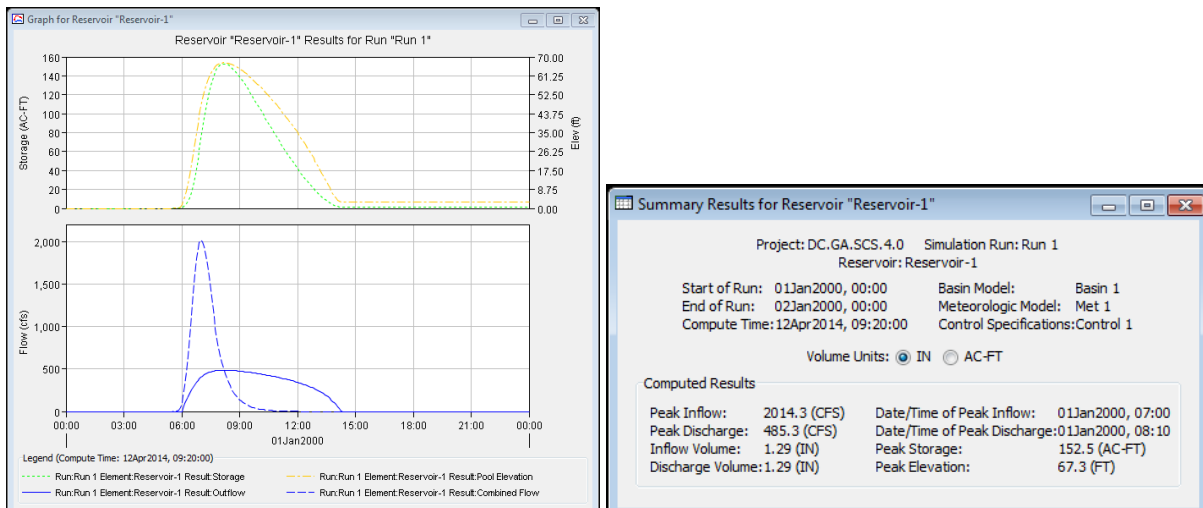
7.3. Fill in the Reservoir tabs:

- Return to the reservoir feature (expand the appropriate basin model or click on the reservoir on the Desktop). Fill in the following tab:
 - Reservoir: Downstream = None; Outflow Method = Outflow Structures; Storage Method = Elevation-Area; Elevation-Area Function = Table 1; Initial Condition = Elevation; Initial Elevation = 0; Outlets = 1; leave the rest in default.
- Further expand the reservoir folder to Outlet 1. You will be running three separate simulations with three different outlet sizes. The edge outlet will be 1 ft off the bottom of the basin. Fill in the following tab:
 - Outlet 1: Method = Orifice Outlet; Direction = Main; Number of Barrels = 1; Coef = 0.6;

Logan Dry Canyon Detention Basin Design Case Study

Center Elevation and Area will change based on outlet size:

- 1st simulation: 3 ft diameter
- 2nd simulation: 4 ft diameter
- 3rd simulation: 5 ft diameter
- Save and run the project for each outlet size. If the simulation does not compute to 100%, then check the errors that appear in red in the message area below the Desktop. It is possible that the elevation-area function does not extend to a high enough elevation. Correct any mistakes, save the project, and rerun the simulation.



To turn in:

- Screen shots of the following HEC-HMS output results for each of design capacities of the Dry Canyon detention basin (reservoir): hydrograph and summary table (like the examples above).
- Prepare a table that for each orifice size gives the following
 - Required detention basin depth
 - Required capacity for downstream storm drain
 - The fraction of the total volume of the storm runoff hydrograph stored in the detention basin when it is at maximum capacity

Note that the fraction of total volume of the storm runoff hydrograph stored in the detention basin is of interest because a large fraction of runoff may be sediment laden due to high erosion and another consideration in the design is settling of sediment in the detention basin to reduce sediment inputs to the storm drain and Logan River.

To turn in:

Review the Army Corps and Consulting Engineer reports on the design of this detention basin and write a 1 to 2 page assessment of the similarities and differences between the actual design and your analysis.

Note that the army and consulting reports related to this detention basin are lengthy and detailed. I do not expect you to review everything in these reports. Just focus on those elements that relate to what this exercise covers and skim/skip the rest. I plan to provide guidance later as to specific pages from these reports that you should look at.