es13-WS

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1 CE 3354 Engineering Hydrology Fall 2024 Exercise Set 9

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1.0.1 Purpose :

Build Elevation-Area tables for storage modeling. _____ The Hardin Branch study area (semester project) contains three hydrologic components that are modeled as reservoirs. These are the two SCS reservoirs and the actual highway crossing that can be approximated as a reservoir with multiple culvert outlets (beneath the highway) and a spillway (the highway elevation) approximated as a broad crested weir.

To simulate a reservoir using either level-pool routing (by-hand) or in HEC-HMS, the designer needs to construct ELEVATION-AREA and ELEVATION-DISCHARGE tables for the reservoir element. Both these tables (relationships) can be constructed from the topographic map of the study area.1

Now consider the West Reservoir in the Hardin Branch analysis. Figure 1 is a portion of the topographic map that includes the SCS reservoir.

Figure 1: West Reservoir in Hardin Branch Study

The figure shows the riser elevation as 2075 feet, the spillway elevation as 2087 feet. The dam crest elevation is not explicitly labeled on the map, but 2090 feet would be a reasonable guess. Given that the spillway looks to be 50-100 feet wide, if water goes over the dam crest the designer has bigger worries than some hydrologic inaccuracy.

Suppose we choose to start a an analysis of the reservoir as empty (or just below the riser elevation). The toe (base) of the dam is about 2070 feet. Even if there is water in the reservoir it would drain slowly (hence the 7 days time to drain in the project problem statement) until the riser begins to carry flow.
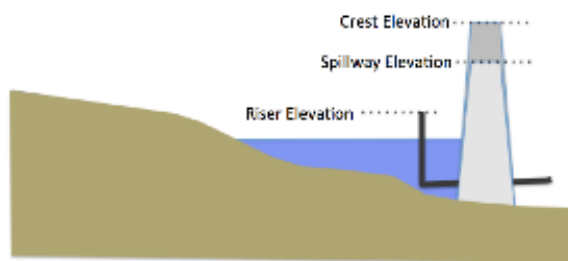

Figure 2: Reservoir impounds water, but outlet works inactive because water is not deep enough yet. Assume for this sketch that water elevation is 2070 feet.

Figure 2 is an elevation view sketch of such a condition, some water is impounded, but there is no outflow because the riser pipe is not submerged and carrying any flow away from the reservoir. Typically all reservoirs leak a little so one could do some groundwater modeling to estimate the time to drain. If the reservoirs are intended to serve as stock tanks, then that's what we want. Impoundment to some elevation so the moo cows have water to drink and poop in, but if the inflow gets too large, the flood wave that would destroy our reservoir is routed through the riser, and if the storm is really big, then the emergency spillway activates.

A typical dry-bottom detention basin design is similar, but we usually provide really small drainage structures (in addition to the riser and emergency spillway) through the toe of the dam (think small drain pipe 4-6-inches in diameter – they don't carry much flow but will drain the reservoir slowly.)

Figure 3 is the topographic map of the pool area associated with 2070 feet (mislabeled in the figure). So this pool area is measured using AcrobatPro, Autocad, or counting squares to produce a pair of values: ELEVATION (in feet), and AREA (in Acres).
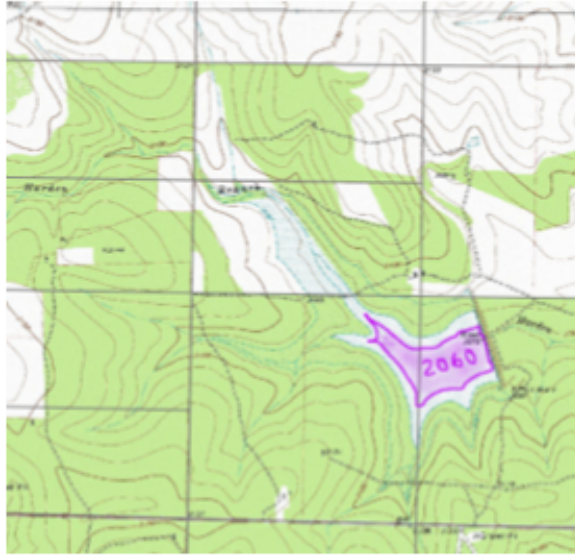
Figure 3: Reservoir impounds water, but outlet works inactive because water is not deep enough yet. Approximate 2070 foot pool area shown (mislabeled as 2060)

Now as our reservoir fills, more pool area is involved as well as the outlet works begin to engage.

Figure 4 is a sketch with the pool elevation a little above the riser elevation. In this situation, pool area is determined as in the above case (different elevation of course!), and the outflow is determined using an orifice equation (or culvert equation if the pipe is horizontal).
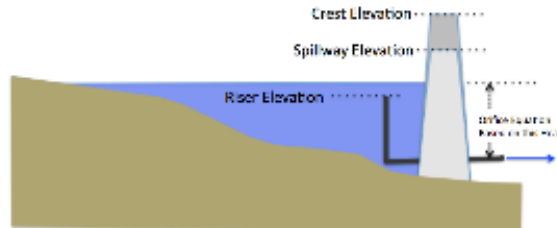

Figure 4: Reservoir impounds water and riser pipe is active.

Figure 5 is the topographic map of the pool area associated with 2075 feet. So this pool area is measured using AcrobatPro, Autocad, or counting squares to produce a pair of values:ELEVATION (in feet), and AREA (in Acres). AT 2075 feet the riser is just beginning to activate, so the outflow rate would be pretty small. As the reservoir further fills (from upstream inflow generated by a storm), then when the pool elevation goes above the spillway, the spillway activates (as well as the already active riser outlet).
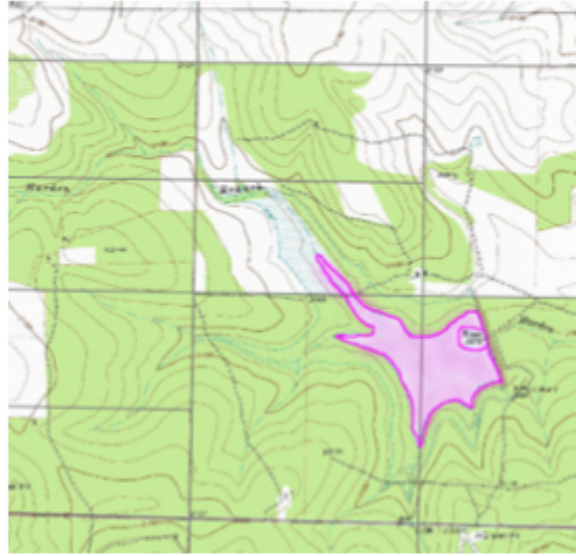
Figure 5: Pool area at water surface elevation 2075 feet.

Figure 6 is a sketch of such a situation. The head on the riser is different than the head on the spillway, hence there would be two different hydraulic equations employed to estimate discharge from the reservoir.
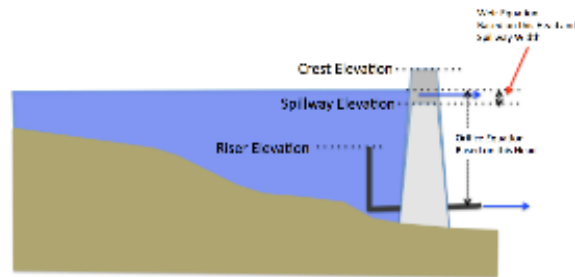

Figure 6: Reservoir impounds water; riser pipe and spillway are active.

Figure 7 is the topographic map of the pool area associated with 2078 feet. So this pool area is measured using AcrobatPro, Autocad, or counting squares to produce a pair of values: ELEVATION (in feet), and AREA (in Acres).
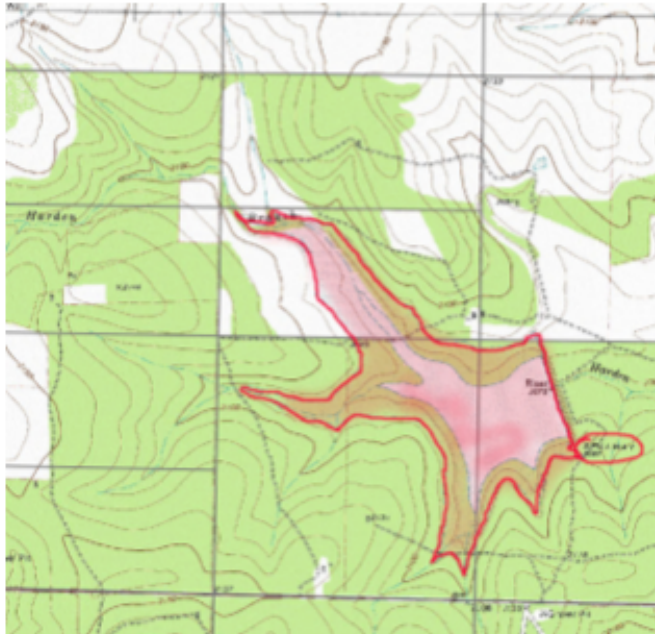
Figure 7: Pool area at water surface elevation of 2078 feet.

At 2078 feet the spillway is just beginning to activate, so the outflow rate over the spillway would be pretty small, but the riser pipe has 3 feet of head above its inlet so it would be carrying substantial discharge at this point.

When we get above the top of the dam things get bad – generally we will design the spillway to pass the 100-year storm from the contributing drainage basin upstream of the dam.
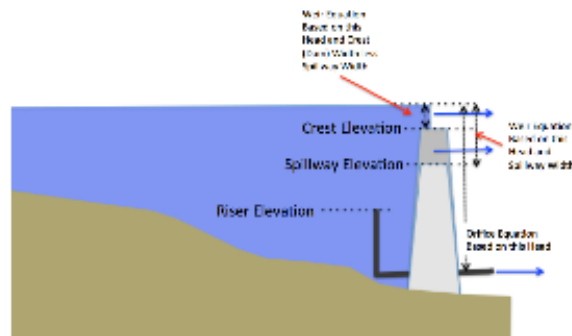

Figure 8 illustrates the Darwinian case – there will be three hydraulic equations each estimating discharge for the three different parts of the outlet works. Flow over the top of the dam (less whatever width is attributed to the spillway), flow over the spillway, and flow through the riser pipe.
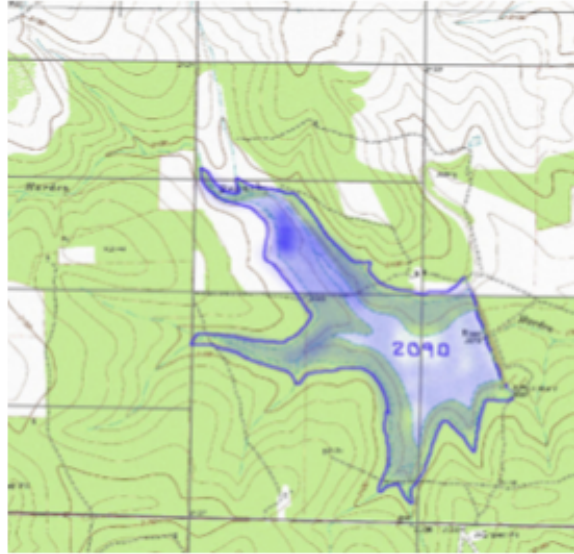
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Figure 9: Pool area at elevation 2090. The spillway would have 2 feet of head and if the dam crest is at 2090 feet and additional rise in water and the entire dam width becomes an active broad crested weir.

Figure 9 is the topographic map of the pool area associated with 2090 feet. So again this pool area is measured using AcrobatPro, Autocad, or counting squares to produce a pair of values: ELEVATION (in feet), and AREA (in Acres).

Finally when the various pool areas are drawn and measured the ELEVATION-AREA table can be assembled for input later into HEC-HMS (or roll-your-own routing table). For example, the West Reservoir depicted would have a table that looks like Figure 10 which relates the pool elevation and pool area.

West Reservoir		
WSE (ft)	Area (sq.mi)	Area (acres)
2065	0.00	0.00
2066	0.01	9.02
2067	0.03	21.82
2068	0.05	34.88
2069	0.08	48.19
2070	0.10	61.76
2071	0.12	75.58
2072	0.14	89.66
2073	0.16	104.00
2074	0.19	118.59
2075	0.21	133.44
2076	0.23	148.54
2077	0.26	163.90
2078	0.28	179.52
2079	0.31	195.39
2080	0.33	211.52
2081	0.36	227.90
2082	0.38	244.54
2083	0.41	261.44
2084	0.44	278.59
2085	0.46	296.00
2086	0.49	313.66
2087	0.52	331.58
2088	0.52	329.60
2089	0.52	329.60
2090	0.52	329.60

Figure 10: ELEVATION-AREA table for West Reservoir in Hardin Branch study area.

Some of the values appear to be static, but actually reflect "rounding" that was employed in formatting the spreadsheet. The choice of using 1-foot elevation changes is analyst pref- erence.

1.1 Exercise 1:

Verify the ELEVATION-AREA table for the West Reservoir in the Harding Branch study area.3 You will need this table for the HEC-HMS model. Explain your choice of "bottom" elevation. Use sketches to show the relationship of elevation to different storage and outflow conditions. Plot the area-elevation curve (area is on the x-axis). Indicate on the plot the elevations where outlet works would activate.

Solution

Elevation-area values were determined as illustrated in Figures 29-32.   First a pool elevation was selected, then the surface area inundated by that elevation was determined using Acrobat Pro area measuring tools and then converted into acres. The resulting elevation-area values were then entered into HEC-HMS.
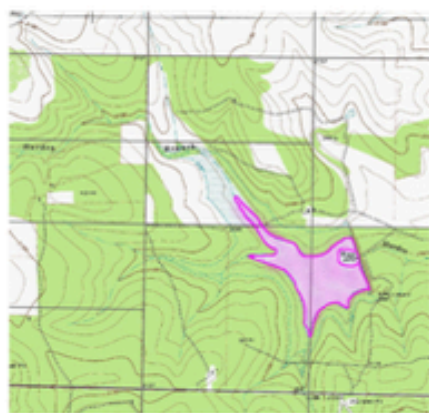
Elevation-area tables were determined for three locations: North Reservoir, West Reservoir and the US-87 Crossing (treating the roadway embankment as a dam, and the culverts as outlet structures.
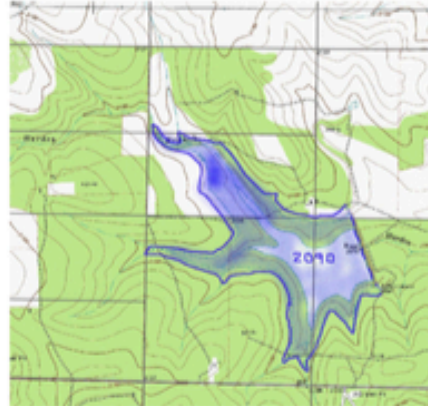

Figure 29. Pool area for West Reservoir at elevation 2060 ft.

Figure 30.   Pool area for West Reservoir at elevation 2070 ft.

Figure 31. Pool area for West Reservoir at elevation 2075 ft.

Figure 32. Pool area for West Reservoir at elevation 2090 ft.

The West reservoir elevation-area table was determined in a fashion described above – different elevations were selected, then the pool area behind the berm at that elevation was determined using Acrobat Pro Measuring Tools.

Table 7. West Reservoir Elevation-Area Data

West Reservoir Elevation-Area	
Pool Elevation (feet)	Surface Area (acres)
2065	0.00
2075	115.20
2080	235.52
2087	329.60

1.2 Exercise 2:

Construct an ELEVATION-AREA table for the North Reservoir in the Harding Branch study area. You will need this table for the HEC-HMS model. Explain your choice of "bottom" elevation. Use sketches to show the relationship of elevation to different storage and outflow conditions. Plot the area-elevation curve (area is on the x-axis). Indicate on the plot the elevations where outlet works would activate.

Solution

The North reservoir elevation-area table was determined in a fashion described above – different elevations were selected, then the pool area behind the berm at that elevation was determined using Acrobat Pro Measuring Tools.

Table 6. North Reservoir Elevation-Area Data

North Reservoir Elevation-Area	
Pool Elevation (feet)	Surface Area (acres)
2055	0.00
2065	61.44
2070	115.2
2076	192.0

Table 6 lists the pool elevation in feet and associated inundated area in acres.

1.3 Exercise 3:

Above you constructed the tables for the West and North Reservoirs. Here you are to do the same, except the "reservoir" is the proposed bridge and its embankment at the crossing on US-87.

Construct an ELEVATION-AREA table for the US-87 highway crossing in the Harding Branch study area. You will need this table for the HEC-HMS model. Explain your choice of "bottom" elevation, and spillway elevation. Use sketches to show the relationship of elevation to different

storage and outflow conditions. Plot the area-elevation curve for the crossing structure (x-axis is area). Indicate on the plot the elevations where the culverts would become active (carry flow) and when the road surface (spillway) would become active.

Solution

Figure 37 is s cross-section view looking downstream at the US-87 Crossing (US-87 Reservoir Outlet) with the existing 2-barrel system depicted. The road profile is the grey region that slopes down to the top of the culverts then back up.
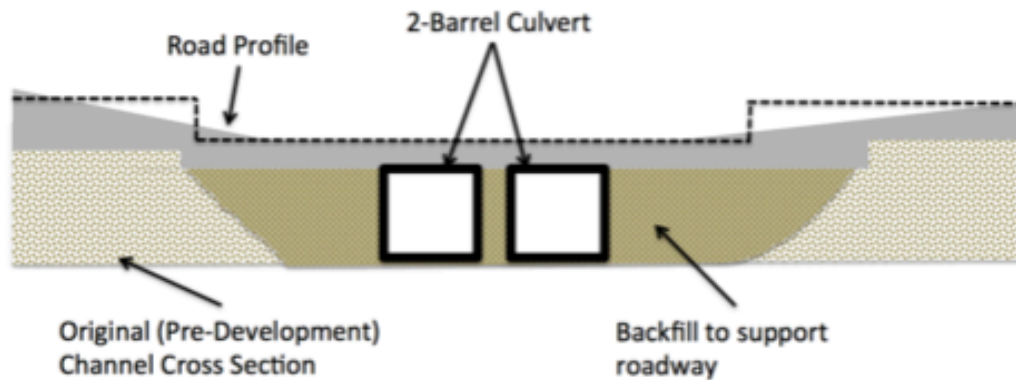

Figure 37. Existing 2-Barrel Culvert System

Figure 38 is s cross-section view looking downstream at the US-87 Crossing (US-87 Reservoir Outlet) with the proposed 4-barrel system depicted.
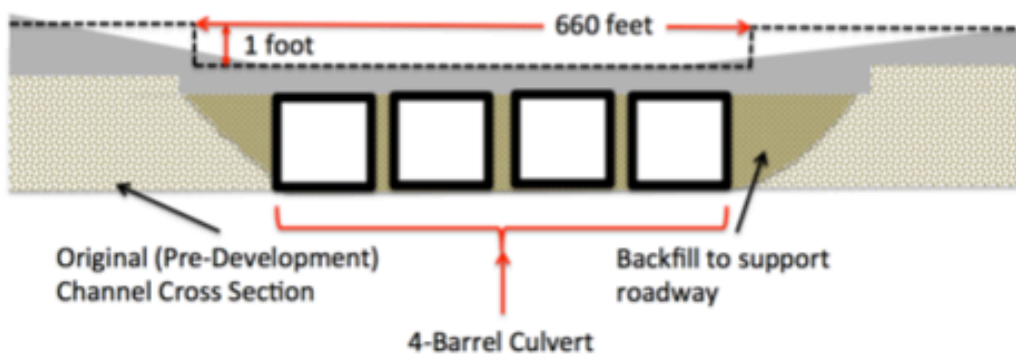
Figure 38. Proposed 4-Barrel Culvert System

Figure XX is a side –view of the roadway crossing showing the embankment and the culvert system, along with the elevations of the upstream end of the culvert, the top of the culvert, and the roadway elevation.

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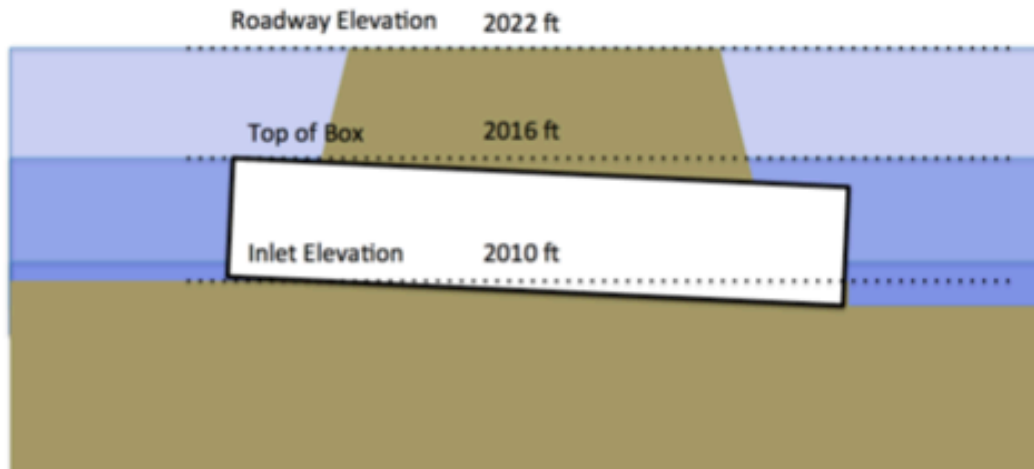
Figure 39. Elevation View of Culvert through Embankment

The US-87 Forebay reservoir elevation-area table was determined in a fashion described above – different elevations were selected, then the pool area behind the berm at that elevation was determined using Acrobat Pro Measuring Tools.

Table 8. Elevation-Area for US87 Crossing

US-87 Forebay Elevation-Area	
Pool Elevation (feet)	Surface Area (acres)
2010	0.00
2020	3.29
2030	115.00

Table 8 lists the pool elevation in feet and associated inundated area upstream of the culvert in acres.

Discharge from the culvert is computed using HEC-HMS outlet structures. The two structures are culvert outlet and a spillway. Figure XX shows the 2-barrel culvert specifications. To simulate the 4-barrel system, the number of barrels is changed and the program run again.

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