CEE 6440 – GIS in Water Resources

Labyrinth Weir Flow Analysis & Maps

Term Project

By Nathan Christensen

Fall 2011

Table of Contents

I. Introduction

Labyrinth weirs are hydraulic structures used for measuring flow rate, controlling flood water, and altering flow regime in a channel or river. Because the width of the channel or reservoir in which a weir is installed is often constrained, it becomes necessary to increase the weir length by folding its shape along the central axis, creating a non-linear weir or labyrinth weir (Figure 1). As the length of a weir increases, the spillway discharge increases. This increase changes downstream river hydraulics, upstream hydraulics, floodplain areas, and sedimentation behaviors. For this reason it's important to understand all of the flow characteristics in a river system before a labyrinth weir is designed; hopefully to minimize negative impacts and maintain similar flow regimes to what currently exists.

Figure 1 - Example of a Labyrinth Weir

Since river systems will be impacted by labyrinth installation, it would be useful if ESRI ArcGIS could be utilized as a design tool. The program makes it very simple to visualize geography and watershed information. The NHDPlus (National Hydrography Dataset), available at www.horizon-systems.com/NHDPlus, includes flow direction, flow volume, accumulation, elevation grids, and drainage area for much of the United States. This data, when added to an ArcGIS basemap presents a wealth of information for labyrinth weir designers. The most interesting of which are the flow accumulation, volume amounts, and DEM cross-sections. It would be useful if these data could be utilized as preliminary design parameters for labyrinth weir capacity, especially in rivers where spillways do not exist. The flow amounts could then be run through the DEM cross-sections to model flow and floodplain behavior in HEC-RAS (Figure 2). Are the flows in the National Hydrography Dataset useful, and what other information may be useful to a labyrinth weir designer within these datasets? These questions bring us to the objectives of this term project.

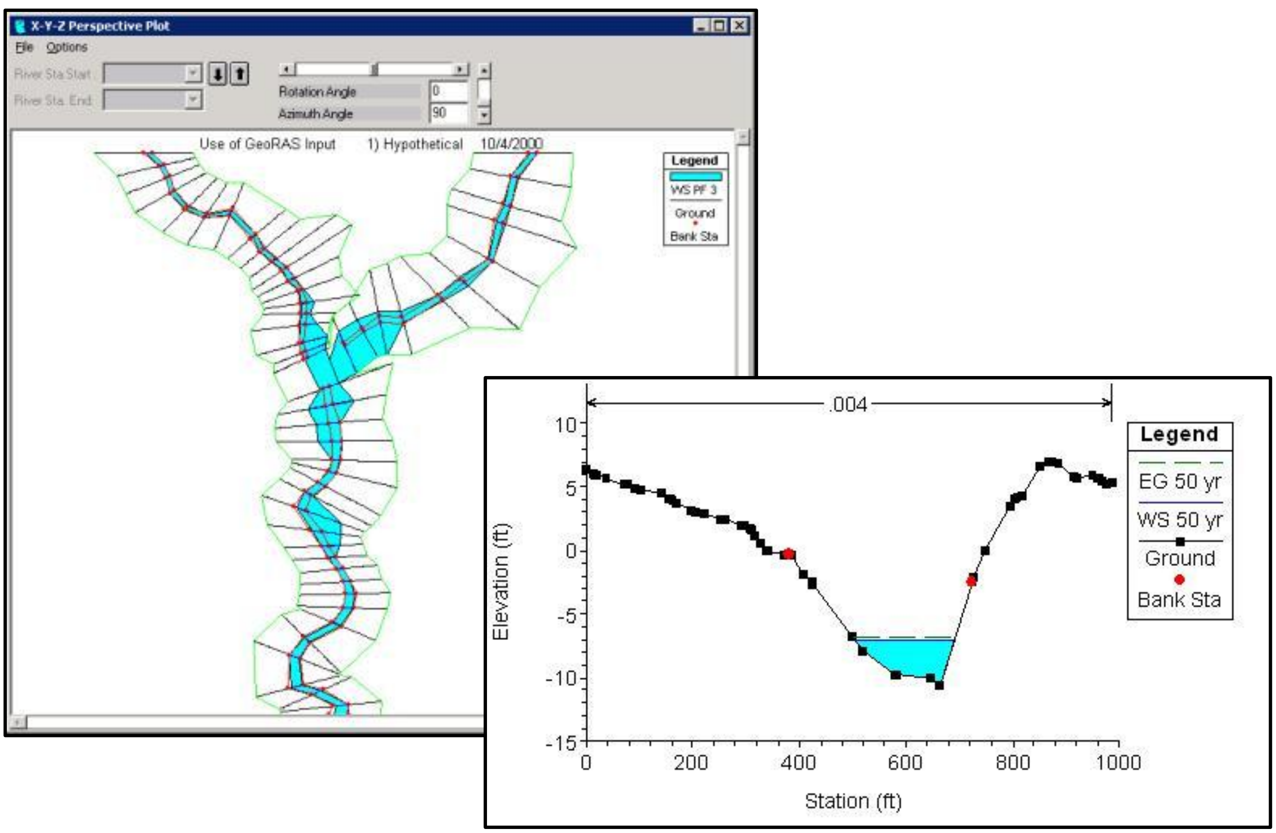


Figure 2 - DEM Cross-Section Possibilities

II. Objectives

A typical weir accommodates 50 to 100-yr flood events; however, for a preliminary labyrinth design it is useful to use a 2 to 5-yr storm event. Since the NHD flow data is based on runoff coefficients and catchment areas it is likely that it will be representative of larger flow events. Therefore, our first objective is:

1) To see if the flow volume and accumulation data from NHDPlus can be used to perform a preliminary design for labyrinth weirs.

In order to accomplish this we will include a variety of weir discharge amounts, tabulated and quantified, to see how they compare to actual stream flow readings. Objective 1 is therefore divided into three parts:

A. Delineate watersheds using a point, just upstream of the weir, for two labyrinth weirs in the Texas Region. Create a nice watershed map for each weir point and identify the flow at each outlet.
B. Explain the flow accumulation table (i.e. runoff coeff. and precip.) and compare GIS "mean annual flow" to recorded USGS flow data.
C. Tabulate the flow differences for 5 weirs in the Texas region and conclude if the NHDPlus flow data can be used as a preliminary design approach flow.

A weir designer must also consider the floodplain for each river. In this project we will analyze the DEM both upstream and downstream of one weir to see how its elevation data may be used. Objective 2 describes this process:

2) Obtain necessary topographic cross-sections, using DEMs, throughout the watershed (especially upstream and downstream of the weir) to be used in future HEC-RAS and floodplain analyses.

However, since a HEC-RAS model will NOT be created for this project, we will expand our exploration of the floodplain by looking at areas of high flow, within a watershed, to identify potential problem areas. Objective 3 explains this purpose:

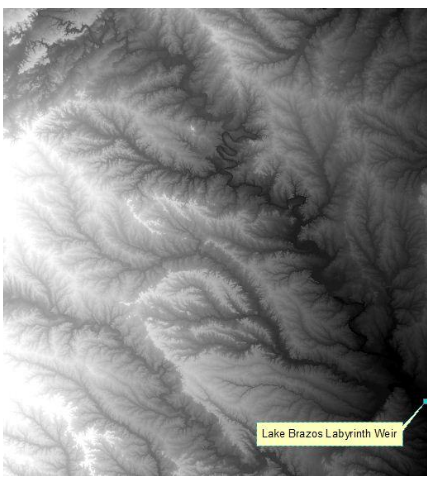
3) Overlay a watershed map with a land-use map to identify problem areas in the floodplain. Cross-sections, flow quantities, and catchment areas will be used to help identify these areas.

III. Methods

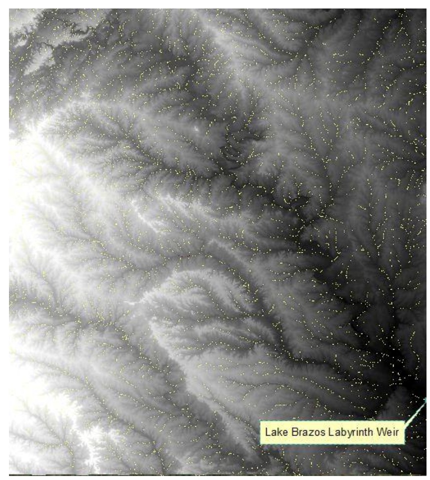
Objective (1)

In order to accomplish Objective 1 (parts A & B); NHDPlus data was downloaded for Hydrologic Region 12 in Texas. The hydrologic units file was replaced by Watershed Boundary Datasets (WBD) from datagateway.nrcs.usda.gov, and flow accumulation data was downloaded from the NHDPlus Catchment Flowline Attribute file. We used the WBD file to represent simple HUC 12 watershed regions, and all data was projected into the NAD 1983 Texas Central State Plane Coordinate system. This was done using the ArcGIS "Project", "Project Raster", and "Batch Project" tools. Originally we used the WGS 1984 datum, but decided to switch to State Plane coordinates in order to treat the analysis as a local project. It was also nice to use feet, instead of the arc unit of WGS. Digital Elevation Models (DEMs) were obtained from seamless.usgs.gov.

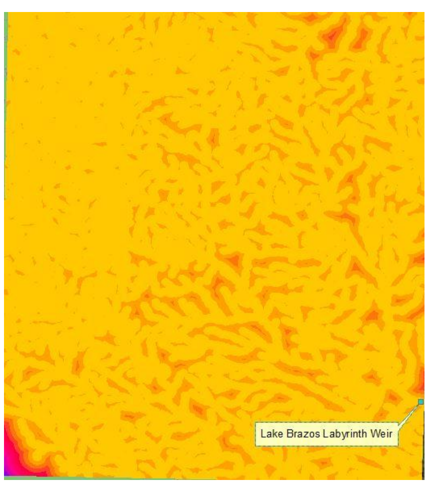
The first watershed delineated was the largest; the outlet point was just upstream of Lake Brazos Dam near Waco, TX. This labyrinth weir receives a large quantity of water in a relatively short period of time. We first uploaded the NHDPlus flowline shapefile, WBD shapefile, and DEM into ArcGIS and projected them. The NHD and WBD data were then downsized to match the region near the weir, and the flowline feature class was turned into a raster, with the "Feature to Raster" tool. Also using the "Greater Than", "Reclassify", "Euclidean Distance", and "Raster Calculator" tools, we were able to recondition the DEM (similar to Exercise 4). This reconditioning makes the raster a "flow direction friendly" raster and is seen in Figure 3.



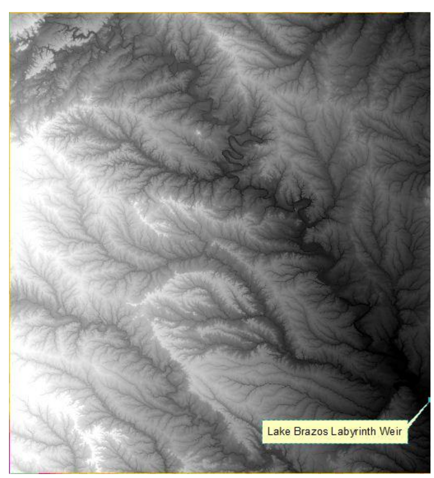
Original DEM Raster



Flowline & Binary Rasters



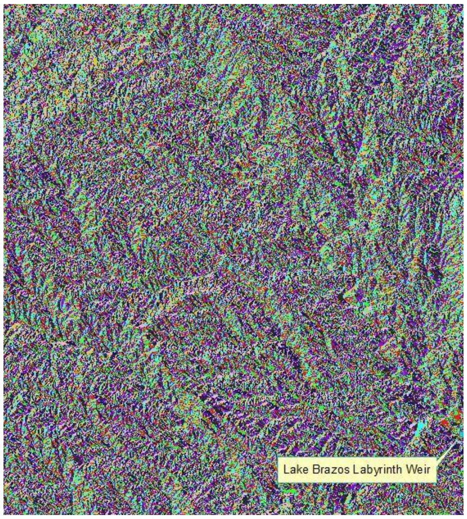
Reclassified w/Distances Raster



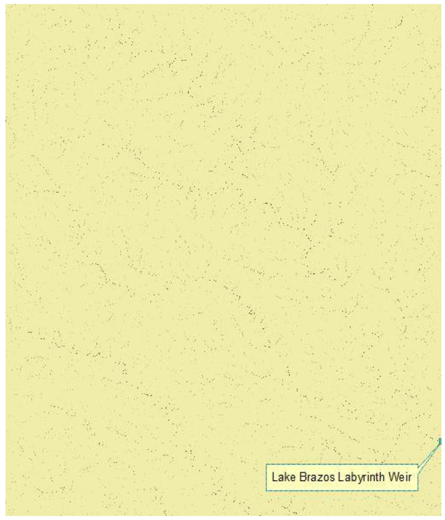
Reconditioned Raster

Figure 3 – Reconditioning Process

In order to assign flow direction to each stream reach we used the "Fill" tool to fill in any raster sink holes and then used the "Flow Direction" tool to show the flow from each cell to the steepest downslope neighbor. The "Flow Accumulation" tool was then applied, and the resulting raster was reclassified with color symbols to show flowlines with greater or less flow. The result is a raster, ready for delineation, using the "Watershed" tool (Figure 4).



Flow Direction Raster



Flow Accumulation Raster

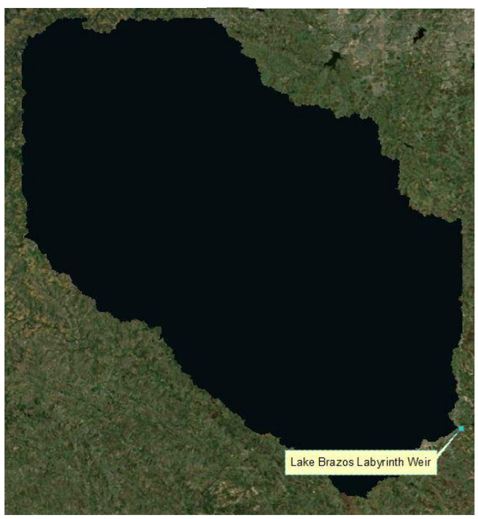


Figure 4 – Delineated Watershed

The "Raster Calculator", "Stream Link", "Watershed", "Stream to Feature", "Raster to Polygon", "Stream Order", and "Zonal Statistics as Table" tools were used to produce a watershed with stream reaches as line features and catchments as polygon features. The end result being a nicely represented watershed with stream reaches and catchments symbolized according to flow amounts (Figure 5). This product makes it very simple to identify streams of high flow and catchments that are supplying that flow.

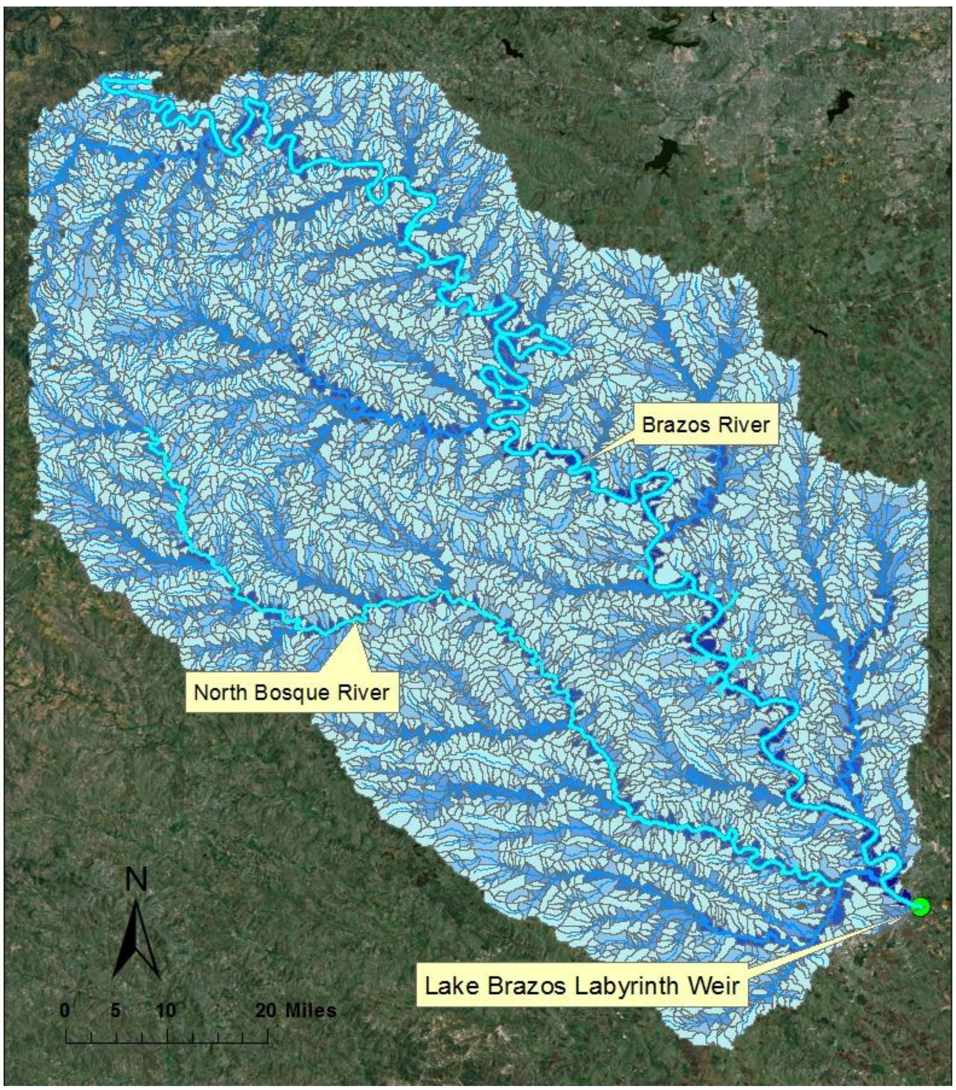


Figure 5 - Brazos Weir Watershed

This procedure can also be followed for any point on a stream segment. Due to time constraints, however, we decided to only perform the same procedure on our smallest weir system at the 19th Street or Elmendorf Labyrinth Weir in San Antonio, TX (Figure 6).

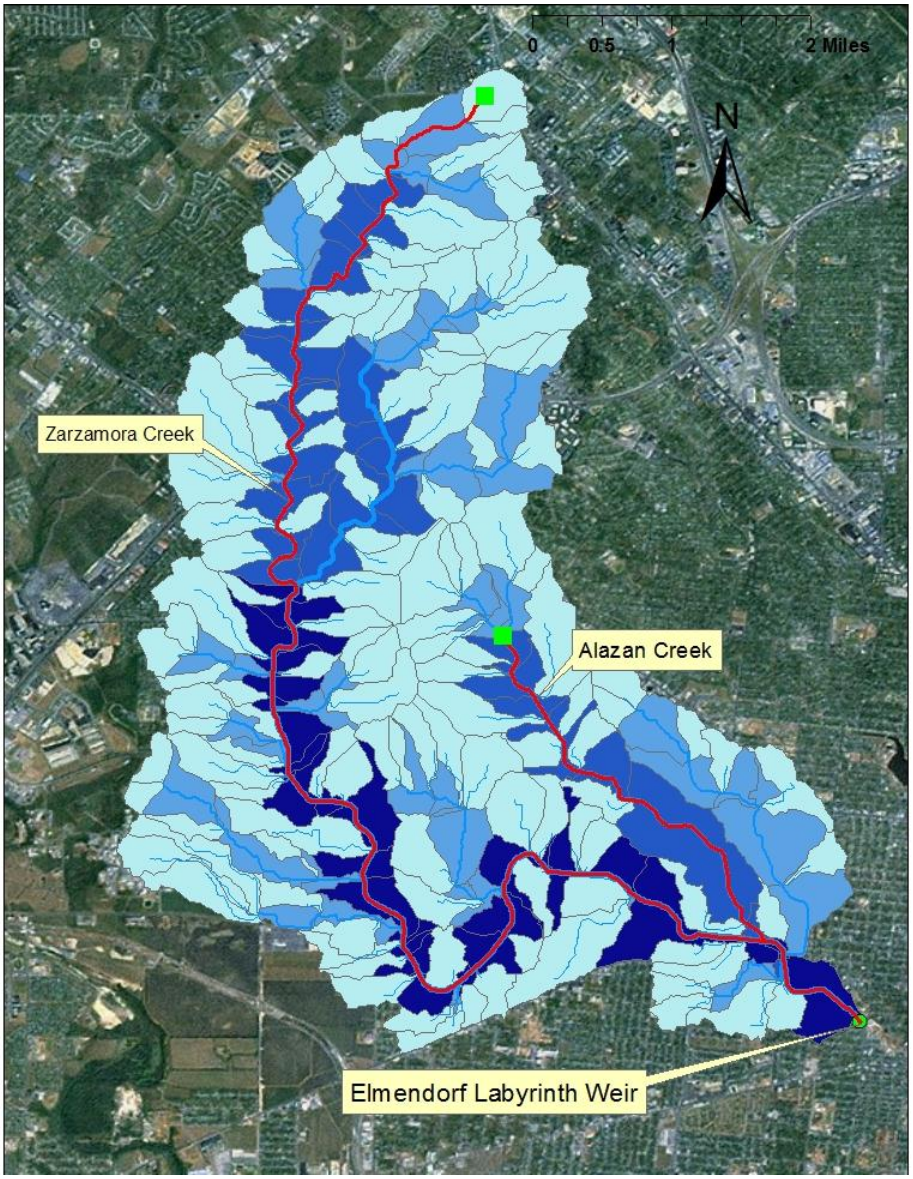


Figure 6 - 19th Street Weir Watershed

For Objective 1 parts B & C the NHDPlus flow accumulation table was joined to the Flowline feature class and a new field was added named Mean_Annual_Flow. This data is assembled by applying a runoff coefficient and precipitation amount to a contained area:

qualities which are embedded into the NHDPlus flow accumulation amount. Unlike the watersheds, we applied this technique to all five labyrinth weirs in the Texas region. A map of the location of each weir was created in ArcGIS and presented in Figure 7.

Figure 7 - Weir Location Map

The mean annual flow immediately upstream of each weir was then compared to the actual USGS flow recorded at stream gages near each point in ArcGIS. These flows were averaged over a period of 50+ years and an actual mean annual flow was compared to the ArcGIS results. Figure 8 is a screen shot of the USGS annual flow table for Sam Rayburn, and Table 1 is a comparison between USGS mean flow and ArcGIS mean flow for all five weirs.

Water Year	00060, Discharge, cubic feet per second
1960	814.5
1961	1,854
1962	1,094
1963	304.5
1964	154.2
1965	444.5
1966	909.3
1967	160.0
1968	801.9
1969	1,509
1970	614.4
1971	222.5
1972	243.0

Figure 8 - USGS Annual Flow for 50 years

Table 1 - USGS vs. NHDPlus Flow Comparison

	NHDPlus	waterdata.usgs.gov	
Labyrinth Weir	Mean_Annual_Flow (cfs)	USGS Mean Annual Flow (cfs)	Percent Diff (%)
Sam Rayburn	954	906	0.05298013
Lake Brazos	2669	2277	0.17215635
19th Street	15	11	0.36363636
Weatherford	30.67	16.8	0.82559524
Ute Dam	429	170	1.52352941
		average % diff =	0.5875795

Objective (2)

For Objective 2 the DEM, discussed in part 1 was used to generate cross-sections of the topography. This was done with the 3D Analyst toolbar in ArcGIS. The DEM was uploaded (in State Plane coordinates) and an imagery basemap was used for geographic reference. Since a DEM contains elevation data we were able to linearly interpolate a 3D slice across each stream reach. This makes it possible to generate a profile graph of the topography. Figure 9 represents a series of linear paths and profile graphs at or near the Elmendorf Weir. These are the topographical cross-sections we are looking for! They can handily be used in HEC-RAS model generation by pushing simulated flow through their profile figure (seen in Figure 2).

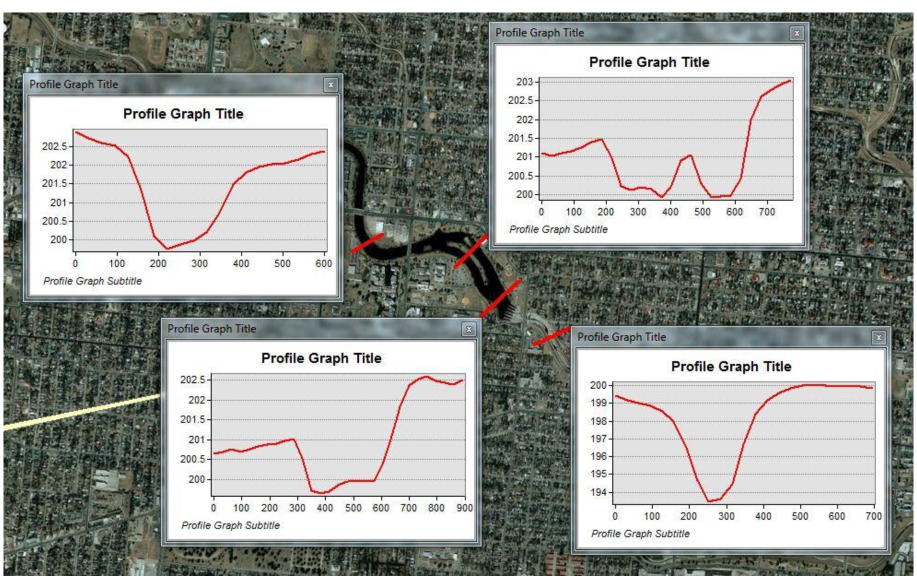


Figure 9 - Profile Cross-sections of Elmendorf Weir

Objective (3)

We also utilized the USGS seamless server to obtain land use mapping. The 2006 land use map shows areas of population as red, rural areas with yellow, farm lands with brown, and forestry with green. The land use map overlaid on our catchment and stream reach layers allows us to pinpoint problem areas in the floodplain. By combining what we know about the flow in each stream reach, and DEM cross-sections, we should be able to identify quick rising areas of the streams. Figure 10 shows a zoomed in portion of the Brazos River, with marked areas of particular concern and accompanying cross-sections. Widespread, heavy rain would make these areas near Waco, TX particularly difficult if the labyrinth weir did not exist. According to the Brazos River Authority, the weir has created small problems for some of these areas.

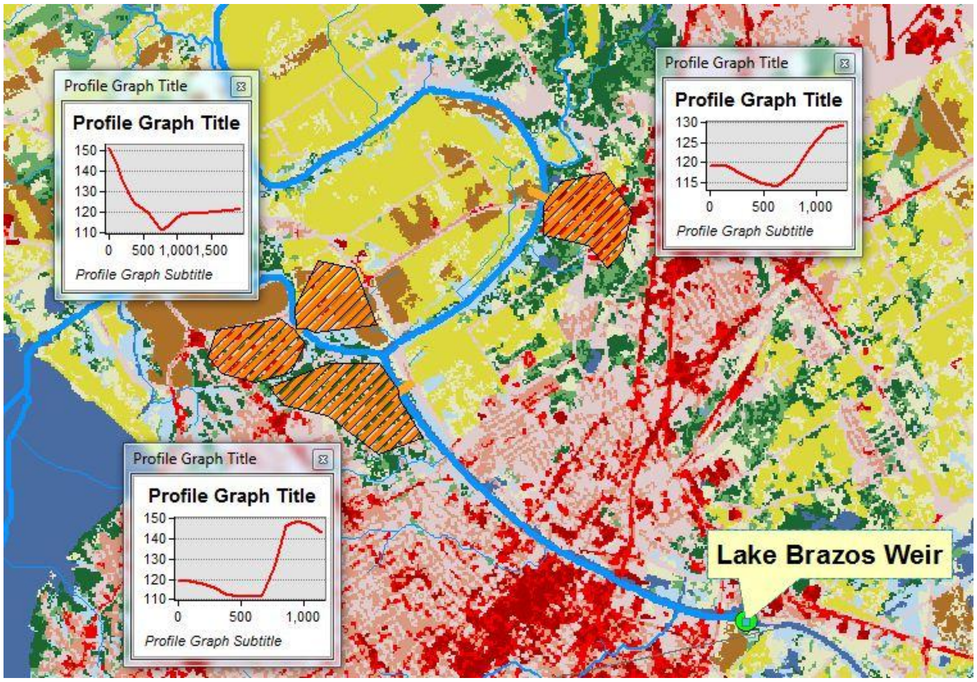


Figure 10 – Potential Problem Areas Impacted by Weir

IV. Results & Discussion

The efforts of this project have been quite useful. We determined that the flow from the NHDPlus data is an average of 59% higher than the actual recorded mean flow from the USGS. In all cases the NHD flow was higher than the actual recorded flow. The reason for the difference is probably due to the runoff coefficient. A runoff coefficient is only somewhat accurate and does not take all soil types into account. Catchment areas are also slightly different in the real world (non DEM), and removal of water from the stream source is not taken into account at all. Accordingly, it makes sense that the actual mean flow will be lower than what is generated in GIS. Important, however, is that it IS very appropriate to use NHD flow data as a preliminary design amount for designing a labyrinth weir. The cross-sections can also be quite useful for modeling in HEC-RAS, and the land use map in combination with the cross-sections actually proved to be quite accurate for identifying problem areas. GIS is definitely a tool that should be used in preliminary design

V. Conclusion

Labyrinth weir and spillway designers must balance a well-built hydraulic model with an understanding of watershed management. The natural river system, as well as population centers, and floodplains can all be affected by the installation of a weir. ArcGIS would be an excellent tool for developing a preliminary design. It can provide above average flow calculations, quick topographic cross-sections, impact areas maps, and other useful design information. Used together, this data can be applied to differing model applications and community planning.