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GIS-based Tool for Assessing Hydraulic Performance of Drainage Infrastructure System in El Paso

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GIS-BASED TOOL FOR ASSESSING HYDRAULIC PERFORMANCE OF DRAINAGE INFRASTRUCTURE SYSTEM IN EL PASO

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THESIS

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Abstract

Maintaining a city's storm-water drainage infrastructure system can be an overwhelming effort, especially when data is inaccurate, incomplete, or located in disparate sources. This was the case for the City of El Paso. This research was part of a project funded by the City of El Paso to enhance their GIS storm drainage infrastructure system. For the first task of the project, the GIS software was used to store stormwater drainage data into one convenient GIS file. A GIS framework was created during the first phase of the project. This GIS database contained drainage data (such as location, material, dimensions, capacity, and photo links), inlets, manholes, watersheds, streets, ponds, and basins. This thesis discusses the beginning of a prioritization and maintenance method for the drainage infrastructure system of the City of El Paso that is based on up-to-date inventory and hydraulic performance assessment data. The focus of this thesis was to develop a methodology supported by a GIS tool for assessing and visualizing the hydraulic performance of the city's drainage infrastructure. The tool was developed using Visual Basic and Model Builder. The performance tool calculated expected peak discharges, compared them with the drainage hydraulic capacities, and displayed the results in color-coded maps in GIS. This involved the use of several GIS functions to determine the spatial relationship between watershed and drainage data to find the expected peak discharges. The method was applied to the drainage infrastructure to provide the City of El Paso with a tool to identify weak links in the infrastructure system which would then be evaluated in detail to determine appropriate repairs and improvements.

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Chapter 1 Introduction

Urbanization may alter the natural drainage of stormwater. Therefore, storm water drainage must be designed and built to redirect the water. Water runoff from streets, drop inlets, or small ditches is discharged into larger drainage referred to as major drainage system. With the rapid increase of urbanization comes the responsibility of storm water drainage design and management.

The City of El Paso is located in a dry climate; however, it is prone to flash flooding because of:

- Mountainous terrain
- Complex network of streets and open channels that intersect at often under designed culverts
- High intensity rainfall events

In 2006 the drainage infrastructure of El Paso, Texas was put to the test. During spring and summer of 2006, El Paso received continuous amount of rain throughout the course of one week. On average, the city of El Paso receives less than 2 inches of rain during the month of August but in the year 2006, the media reported that parts of the city were hit with seven inches of rain in one day alone (ABC-7 2007). The unexpected amount of rain led to several areas in El Paso to flood causing destruction in homes, roads, and businesses. TransVista (TxDOT's El Paso District ITS Center) assessed the different types and cost of damages throughout the city. Photographs of the damages were taken. El Paso is divided into five areas, Upper Valley, Westside, Northeast, Central, and Eastside/Lower Valley (Transvista 2006). All five areas had damages during Storm 2006. According to TransVista (2006), the infrastructure that was

damaged amounts to $21 million in public infrastructure, $77 million in private property, and 3.5 million in flood control/ landfill. The number of homes that were damaged was 1,515 of which 295 of those were destroyed and 495 received major damage. Of the 53 commercial properties that were damaged, 15 were destroyed. Because of the damage that occurred during this storm, the City of El Paso began a major effort to repair damages and develop a strategy for the prevention of another flooding disaster. Enhancing the city's infrastructure management and information systems is part of this strategy.

1.1 Objectives

The goal of this study is to enhance El Paso's infrastructure management information systems. The specific objectives are:

- Develop a methodology for assessing the hydraulic performance of culverts and channels using readily available data
- Integrate the methodology (developed under objective 1) into the City's GIS for rapidly visualizing and identifying drainage structures that are likely to fail under various amount of rain

1.2 Thesis Organization

This thesis report will first provide an overview of the research that has been done in this topic discussed in Chapter Two. Second, the city's GIS for drainage infrastructure asset management is described in Chapter Three. Third to be discussed, Chapter Four will be the methodology that was developed to assess and visualize the hydraulic performance of drainage structures throughout the city in GIS. Finally, the Visual Basic for Applications (VBA) tool that was integrated with GIS to determine and visualize the performance of the drainage system

(titled "Performance" tool) will be discussed in Chapter Five with a case study example in Chapter 6 and brief sensitivity analysis in Chapter 7.

Chapter 2 Literature Review

This chapter provides a review of previous literature relating to the need for and capabilities of a flood management system. This includes the need for determining expected peak discharge, the capacity of drainage structures, and benefits and methods for GIS integration.

2.1 Need for Flood Management System

The need for a flood management system which was realized in El Paso after "Storm 2006" has also been recognized in the literature. Burby (2001) describes the need for floodplain management in the article "Flood Insurance and Flood Plain Management: The US experience," with emphasis on floodplain management for the purpose of flood insurance. Burby (2001) explains that "losses from flood hazards in the US are not only large (on average, $115 million per week) but they have also been increasing dramatically (Congressional Natural Hazards Caucus Work Group, 2001; Mileti, 1991; Ryland, 1999)." This is due to the extensive land development that has occurred. Burby (2001) backs this statement by referencing Mileti (1999) that one of the more important causes for flood damage is that "extensive development has occurred in areas with the greatest risk from flood hazards, and the rate of development, rather than decreasing, has actually increased at unprecedented rates over the past 30 years." Burby (2001) goes on to explain the different requirements that are needed to issue flood insurance of which the first is to identify flood hazards. An issue that was encountered was georeferencing and the vast amount of detailed data that was necessary (Burby 2001). From this, one can deduce that georeferencing for a flood hazard management plan is critically important and that a management system should not be excessively detailed, but detailed enough to be useful and functional.

FEMA (2001) published a report which involved updating and digitizing maps. Among the goals of the modernization is to reduce the potential for loss of life and property damage. GIS has also been implemented for watershed delineation. FEMA's goals to modernize the flood mapping by digitizing maps and using GIS shows the increasing role of GIS in flood management systems in the future.

Merwade et al. (2008) discussed the importance of reliable data to determine flood inundation maps and methods for determining the design flow. Several factors must be taken into consideration and will have a certain level of uncertainty such as the terrain, hydraulic models, and historical data for identifying peak discharges. It is for this reason that it is difficult to create a flood management system that uses all the variables to produce results that can be used for design purposes.

Gharaibeh et al. (2006) discuss a methodology for prioritizing among the assets. The decision methodology consists of four steps which can also be applied to storm water drainage infrastructure. The four steps are 1) measure assets performance, 2) establish a relationship between allocated funds and overall performance, 3) develop budget allocation alternatives, and 4) select fund allocations that maximize or minimize certain system performance criteria (e.g., system efficiency). The first of these steps, measuring the asset performance, is applied to this study and includes assessing the hydraulic performance of the each drainage structure at the network level.

The need for a flood management system is also seen by the aftermath of El Paso's "Storm 2006" event. URS Corporation was hired by the City of El Paso to provide an assessment for the failed structures throughout the city and delivered a report of the results and findings titled "Drainage System Evaluation and Audit Report" (URS 2006). URS conducted a

visual field assessment of the damage system and conducted measurements of watersheds and expected peak discharges. The URS report shows many of the factors that must be taken into consideration to determine the performance of drainage structures. However, it is missing the capacity of the individual drainage structures and sections and a framework in which to locate and combine the information into one environment. This thesis contributes to filling this gap through the development of the GIS framework and GIS-based hydraulic performance assessment tool.

2.2 Expected Peak Discharge

A key element of a flood management system is to determine the expected discharge pertaining to an area. "Bulletin 17B of the Hydrology Subcommittee: Flood Flow Frequency" is a manual of guidelines to determine flood flow frequency or expected peak discharge. The Office of Water Data Coordination (1982) divides the guide into six sections of which two were the most useful. These include information to be evaluated and the determination of the frequency curve. For the information to be evaluated the historical data is reviewed to obtain discharge equations. Large amounts of historical data create more reliable frequency determinations. The Office of Water Data Coordination (1982) explains the methods that are used to determine the frequency curve and how it can use annual or partial duration series.

The National Flood Frequency (NFF) Program is a program that compiled all the USGS equations for expected peak discharge and the report was titled "The National Flood Frequency Program, Version 3: A Computer Program for Estimating Magnitude and Frequency of Floods for Ungaged Sites. Ries and Crouse (2002) explain the methods that were used to obtain the seven parameter peak discharge regression equations. These equations were developed using

historical data and using ordinary least squares and weighted least squares methods. The resulting equations were for urban and rural areas from a 2-yr recurrence interval to the 500-yr recurrence interval. Rural area equations have two parameters including evaporation in inches and area. The rural 500-year interval is extrapolated using the log-pearson distribution. Urban area equations have seven parameters which include rainfall amount and watershed characteristics such as slope, area, storage area, basin development factor, impervious surface percentage, and the rural peak discharge for the recurrence interval of interest. "The USGS has been involved in the development of flood-regionalization procedures for over 50 years" and the equations were "tested and proven to give reasonable estimates for floods having recurrence intervals between 2 and 500 years" (Ries and Crouse 2002). It is for this reason that the USGS and NFF expected peak discharge equations were used in this study.

2.3 Drainage Design

Another key element for a flood management system is to determine the capacity of drainage structures. Several documents involving the design of drainage structures were reviewed. These include "Design of Roadside Channels: Hydraulic Design Series Number 4" (Searcy 1965), "Hydraulic Design of Highway Culverts: Hydraulic Design Series Number 5" (Norman et al. 2005), and "Urban Drainage Design Manual: Hydraulic Engineering Circular No. 22" (FHWA 2001). All three were published by the Federal Highway Administration (FHWA) and contain several design specifications for storm water drainage. Searcy (1965) is focused on open channels and is a thorough description of roadside design, including estimation of storm runoff, hydraulics of drainage channels, and design, construction, and maintenance procedures. The methods to determine channel capacity were particularly useful to understand the method in

which channel capacity is determined. The manning coefficient (n) values were used to determine capacity of channels in this study.

The FHWA developed a computer program (named HY-8) for determining the hydraulic capacity of culverts. Norman et al. (2005) provided procedures and guidelines for culvert design that are used in HY-8 followed. Although HY-8 is specifically for culverts, downstream channel capacities are necessary to determine the capacity of culverts. Therefore, Searcy (1965) also shows base guidelines necessary to determine the culvert capacity in HY-8. Norman et al. (2005) first discuss the different culvert shapes, materials and types of flow. The paper goes on to discuss the design considerations including peak design flow, and types of culvert flow. The roadway overtopping section was especially useful since this study is concerned with investigating a no-flood condition that involves no roadway overtopping.

FHWA (2001) considered the urban drainage system as a whole and described the different drainage structures that are necessary in an urban drainage design. FHWA (2001) describes the different drainage systems, minor and major, and discusses the several features and designs that are needed for each. These include inlets, storm drains, and retention ponds. Several types of inlets are discussed as well as the difference in capacity of each. "Urban Drainage Design Manual" shows a complete description of all features that are necessary for storm-water urban system.

2.4 GIS Integration

A Geographic Information System (GIS) is a powerful tool to manage and analyze data referenced to a geographic location. GIS can be used to integrate geographic and tabular data, and to retrieve relevant information in a rapid and effective manner (Chang Albitres 2007). This capability is helpful for an infrastructure management system in order to locate and manage all features in the system. In this study, GIS is used to locate stormwater drainage assets and to determine and visualize the performance of drainage structures.

A report published by ESRI, Inc. (the leader in GIS software) titled "GIS Technology for Water, Wastewater, and Storm Water Utilities" (ESRI 2007), describes the ability of GIS to combine several layers which contain a database and can be turned on or off to give versatility in what is shown. GIS maps are georeferenced and can perform queries based on location or spatial relationship such as features that are near another feature. GIS maps are digital and may be used in the field instead of large paper maps. GIS can also be uploaded to a server and used online to facilitate data sharing among users.

GIS can be customized by programming functions with VBA. Stevens et al. (2007) described the development of a GIS tool for modeling urban growth, which demonstrated the advantages of using GIS for similar tools. Stevens et al. (2007) used a combination of a GIS-based software development kit (SDK) and Visual Basic. GIS can also be customized using a programming system called Model Builder. With Model Builder, it is easier to program since the GIS toolbox is used. A guide or manual on using model builder is available in the ESRI website and is titled "Introducing the ESRI Model Builder" (ESRI). This document gives an overview of Model Builder and examples on how to use this quick programming or customizing

tool. However, because Model Builder uses preset functions from the tool box, it was necessary to use a combination of VBA and Model Builder in this study.

Karimi & Houston (1996) discuss the benefits of using GIS as a framework that allows the database, visualization, and other tools to be available in one single "integrated environment". Karimi & Houston (1996) focus on the difference between loosely-coupled and tightly coupled modeling. Loosely-coupled models need conversion of data (importing and exporting) with other external programs. In tightly-coupled models all functions are built into GIS. The type of GIS modeling is generally based on the project; however, the integration of different model programs to GIS may be difficult. Tightly coupled models require programming in GIS to perform all functions. In this type of modeling there is no need for file conversions or editing and is generally faster. The downside to this type of modeling is that it is more difficult to change or expand the model. Karimi & Houston (1996) compared uncoupled, loosely-coupled, and tightly-couple models in a case study. Disadvantages and advantages of each model were shown in a table format in *Table 2.1*. These disadvantages and advantages as well as ease of development were considered in the development of the GIS tool of this study.

Table 2.1: Advantages and Disadvantages of the Different Strategies in Integrating GIS and Models

Integration strategies	Advantage	Disadvantage
Loosely coupled	No integration time Each grows on its own Non-GIS-specific	Tedious (importing/exporting output from one to the other) Slow data transfer
Tightly coupled (GIS inside models)	GIS functions are optimized to the exact needs of models. Fast data transfer. High level of integration	Any GIS expansion requires much programming effort. GIS-specific
Tightly coupled (models in GIS)	General system Fast data transfer. High level of integration	Model data and structures dictated by the data and structures of GIS GIS-specific

Chapter 3 GIS Data Integration to Support a Drainage Infrastructure System for the City of El Paso

In 2006 the City of El Paso experienced high amounts of rain throughout the duration of a week. The event was called "Storm 2006". This chapter first describes the destruction that "Storm 2006" flooding caused followed by the description and scope of the project to enhance El Paso's infrastructure management system. This chapter deals with the first task of the project which involved creating a GIS database system to be used as an infrastructure management system.

3.1 Drainage Infrastructure System in El Paso

As previously stated, several areas of the city were damaged or destroyed during "Storm 2006". The City of El Paso recognized the need for improving the existing stormwater drainage infrastructures when assessment of damages showed that one of the main causes of damage was the deficiencies in the existing drainage system (Walton 2006). New developments throughout the city were constructed in subdivisions (normally upstream). This caused some downstream hydraulic structures (normally old) to be under capacity in comparison to their new upstream counterparts (Walton 2006). *Figure 3.1* shows the destruction to homes and private property that was caused by flooding in 2006. *Figure 3.1* shows the destruction and flooding of streets.

(Transvista 2006)

Figure 3.1: Example Destroyed Home and Commercial Building (Destroyed by Flooding in El Paso in 2006).

(Transvista 2006) (Walton 2006)

Figure 3.2: Flooded and Destroyed Streets (El Paso, 2006)

The difficulties in the development and implementation of asset management concepts are that drainage systems consist of "diverse components, are difficult to access and inspect, and are affected by difficult-to-predict forces of nature" (Gharaibeh et al. 2008). The drainage system in El Paso, Texas consists of a combination of open channels, conduits, culverts, drop structures, and dams which makes it difficult to implement asset management concepts. The city estimated inventory of these assets, as of 2006, and the GIS database inventory gathered are summarized in *Table 3.1* (City Budget 2006). In addition the large number of assets and features and complexity of the system make the task of maintaining and managing this drainage system very challenging.

Table 3.1: El Paso Infrastructure Assets as of 2006

Infrastructure Assets	Quantity/Size	
	City Estimates	GIS Database
Storm Water Conduit, miles	810	73.9
Ditches, number	132	32
Inlets, number	2920	5657
Basins, number	277	292
Major Earthen Ditches, number	40	52
Concrete Channels, miles	70	39
Dams, number	14	40

The City of El Paso realized the need for a more efficient asset management system for the drainage system in El Paso. Several meetings were coordinated with the City of El Paso personnel to determine the scope of the project. From these meetings it was known that the City of El Paso had developed GIS layers that contained inventory on these assets. However, the layers were not complete and had gaps of missing information. As a result of these meetings, a

project titled “Enhancements to El Paso’s GIS-based Infrastructure Management Systems” was initiated. The goal of the project was to enhance the City’s infrastructure management information systems which entailed gathering and verifying data, integrating these data with the City’s GIS system, and development of GIS-based tools for rapid assessment and visualization of hydraulic performance. The goal was divided into four tasks. The first Task was to develop a GIS layer for stormwater drainage infrastructure assets, which was completed and published as a previous thesis and journal paper (Elgendy 2008; Gharaibeh 2008). The second task was to develop a GIS-based tool for hydraulic performance assessment and visualization. The third and fourth tasks dealt with street lights and fiber optics, which are not included in this report.

3.2 GIS Data Integration

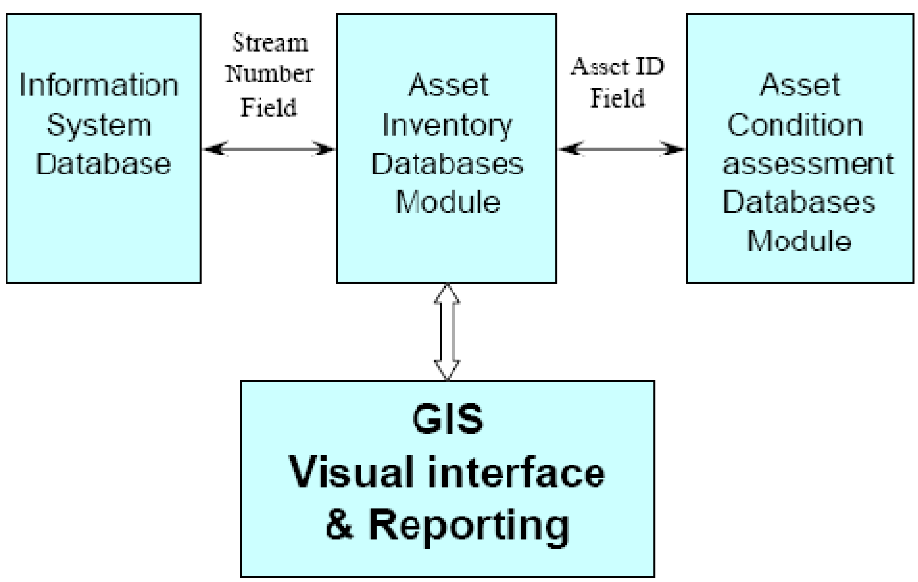
With the aim of combining drainage data into GIS to obtain all drainage data from one single source, a GIS integrated database was created. This task had four additional steps. The steps were:

- Review existing and hard records
- Perform field surveys to verify data
- Integrate data into GIS

3.2.1 GIS Database and Inventory

The GIS-based model was divided into three main models; inventory, condition assessment, and documents modules as shown in *Figure 3.3* (Elgendy 2008). The first step was accomplished during the summer of 2007 where city maps were viewed and storm drainage data acquired. The data acquired from the city maps and drawings formed the GIS inventory database. Among the acquired data were the main features of an asset such as length, type,

material, and typical cross section (Elgendy 2008). The drainage features were divided into smaller sections, or reaches, based on changes in these main features. Each channel was named according to the channel number assigned by the City of El Paso and the reach number. For example, the first section of a channel, say channel number ten, would be named CH10-CHR1. After a change in major drainage features, the next section of the channel would be named CH10-CHR2. This nomenclature was continued throughout all the drainage structures including conduits, culvert, and drop structures. The attribute tables and their descriptions are shown in Appendix A. These inventory attribute tables are representative of the GIS database that was developed in GIS from data available in the City of El Paso's Map Room for each drainage structure in El Paso.



(Gharaibeh et al. 2008; Elgendy 2008)

Figure 3.3: Stormwater GIS-based model.

3.2.2 GIS Integration

The integration to GIS began after the acquired data were entered into an electronic database. Verification of drainage structures included field surveys which consisted of location and basic detail verification such as material, and length. Photographs of the channels were taken to record the condition of channels. The GIS file system was developed by manually drawing the channels, culverts, conduits, drop structures, and pump stations using lines and points and differentiated by color. The database was linked to each section to provide information about that drainage structure section. Each drainage type was assigned to a different layer. The photographs of drainage conditions were saved in a "pdf" file and joined to the GIS database through the use of hyperlinks. Other links that were added to the database included links to a condition assessment form and the HY-8 software program to determine hydraulic capacity.

Chapter 4 Visualization Tool to Assess Potential for Flood

The methodology explained in Chapter 3 was supported with the development of a visualization tool for rapidly assessing the potential for flood throughout the City of El Paso. This was accomplished by creating a program to detect under-designed drainage structures (where capacity is less than peak discharge). The details of the performance tool and programming are discussed in Chapter 5. This chapter deals with the addition and preparation of data that was needed for the visualization tool titled "Performance Tool". The original data from Task 1 were enhanced and addition data included. The new data include the capacity of the channel or drainage structure, the watershed data and watershed pertaining to each channel, and the expected peak discharge.

4.1 Capacity

HY-8 was developed by the Federal Highway Administration (FWHA) to perform hydraulic analysis for culverts. HY-8 Version 7.1 is public domain and uses design properties found in the publication "Hydraulic Design of Highway Culverts: HDS 5". HY-8 computes capacity as a function of several inputs as shown in *Table 4.1*. HY-8 software was used as an "indicator of a culverts hydraulic capacity and is not intended for re-design purposes" (Elgendy 2008).

Table 4.1: HY-8 Input Variables

Discharge Data	**Tailwater Data**	**Roadway Data**	**Culvert Data**	**Site Data**
Minimum Flow	Channel Type	Roadway Profile Shape	Shape	Site data input option
Design Flow	Bottom Width	First Roadway Station	Material	Inlet Station
Maximum Flow	Side Slope	Crest Elevation	Span	Inlet Elevation
	Channel Slope	Roadway Surface	Rise	Outlet Station
	Manning's n	Top Width	Manning's n	Outlet Elevation
	Channel Invert Elevation		Inlet Type	
			Inlet Edge Condition	
			Inlet Depression	

The no-flood scenario was used in this analysis to determine the maximum capacity before the flooding of streets can occur. The no-flood scenario needed a trial and error process. Water was considered to reach only the height of the upstream channel height. The design discharge was changed until water elevation was the same as the upstream channel height without water overflowing onto the street. This study is concerned with applying the capacity process to the entire system, determining the expected peak discharge (for comparison with capacity), and integrating a visualization tool with GIS to rapidly identify under-designed drainage structures.

An example has been provided in *Figure 4.1* and *Table 4.2* to further explain the no-flood scenario that was assumed to determine the capacity of a drainage structure. *Equation 4.1* was used to determine the headwater elevation assuming a no-flood condition. If the culvert had an upstream invert elevation of 3,702.47 feet above Mean Sea Level (MSL) as shown in *Figure 4.1* and a channel height of four feet, then the maximum water elevation the water can reach without flooding the intersecting roadway is 3,706.47 ft (3,702.47+4 = 3,706.47 ft=headwater elevation). The trial design flow used to run HY-8 which results with an elevation slightly less than the

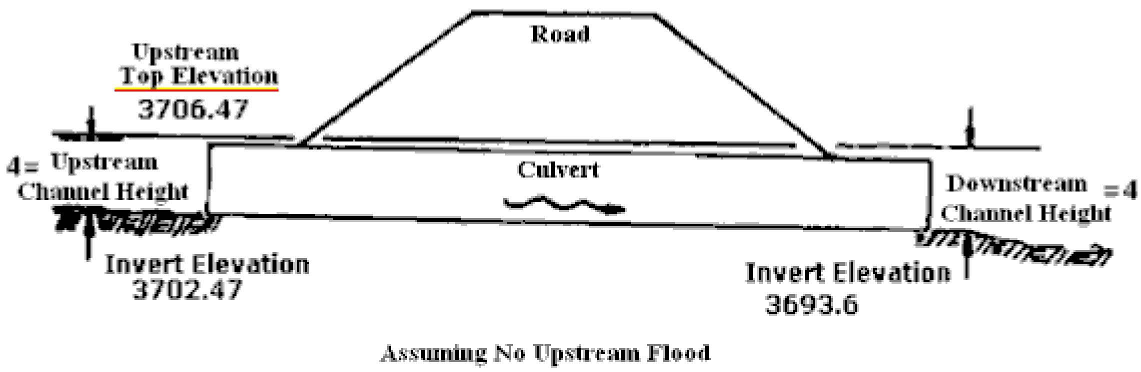
maximum elevation and with zero roadway flow are the correct design flow and capacity. In this example, the capacity is 250 cubic feet per second as shown in the HY-8 results in *Table 4.2*. The trial and error process is shown in Appendix C.

$$Head\ Elevation = \ Upstream\ Culvert\ Elevation + Upstream\ Channel\ Height$$

Equation 4.1

$$Head\ Elevation = 3706.47ft = 3702.47ft + 4ft$$

Equation 4.2



(Norman et al. 2005)
Modified by Gema Camacho

Figure 4.1: Capacity no-flood scenario example

Table 4.2: HY-8 No-Flood Capacity Results Example

Summary of Flows at Crossing - ch40COR1

Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 1 Discharge (cfs)	Roadway Discharge (cfs)
3702.47	0.00	0.00	0.00
3705.80	192.00	192.00	0.00
3706.46	250.00	250.00	0.00
3708.64	576.00	421.06	154.45
3709.04	768.00	447.30	320.44
3709.38	960.00	468.66	491.19

In this way the capacity for each channel, culvert, and conduit was determined using HY-8 and manually inputting the results into the GIS "Capacity" field. The capacity for some features was not possible to determine because of lack of input values. These features are labeled as "Dummy Reaches" and a value of "999999" was entered into the database as place holders. To provide the most visualization possible, in cases where only the upstream channel height elevation was missing, the height of the culvert opening was used as the maximum water height. There were also special cases in the El Paso storm water drainage system that were not simply channel-culvert-channel as the HY-8 was designed for. Therefore, a few assumptions on how to treat these special cases were made to determine the capacity while still maintaining a worst-case scenario. These cases assumptions are described as follows:

1. Conduits that start and end in basins, as in *Figure 4.2* were not taken into consideration because they are not likely to cause any flooding.

2. When two different sized culverts were connected between two channel reaches, shown in *Figure 4.3,* the two treated as one culvert with the dimensions of the smallest sized culvert.
3. Connected conduit reaches with different dimensions as shown in *Figure 4.4* were treated as one long conduit with the dimensions of the smallest conduit.

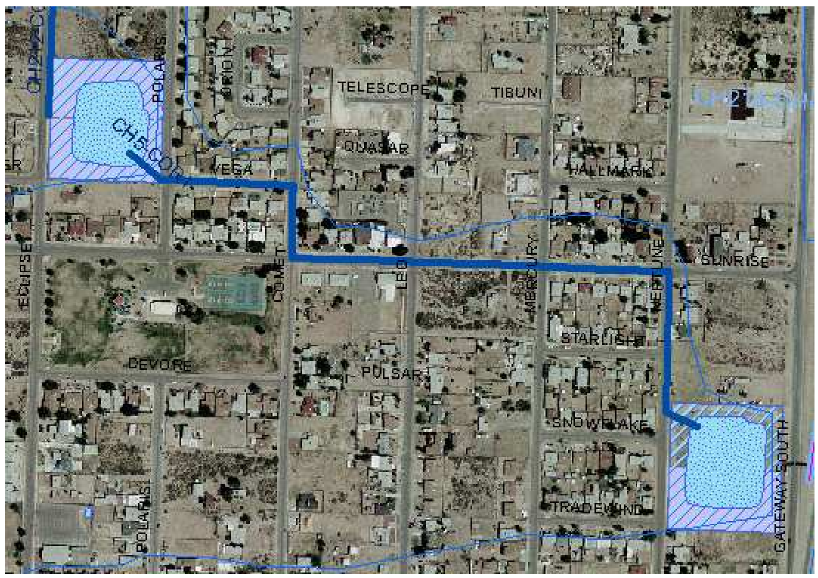


Figure 4.2: Basin to Basin No-flood Assumption

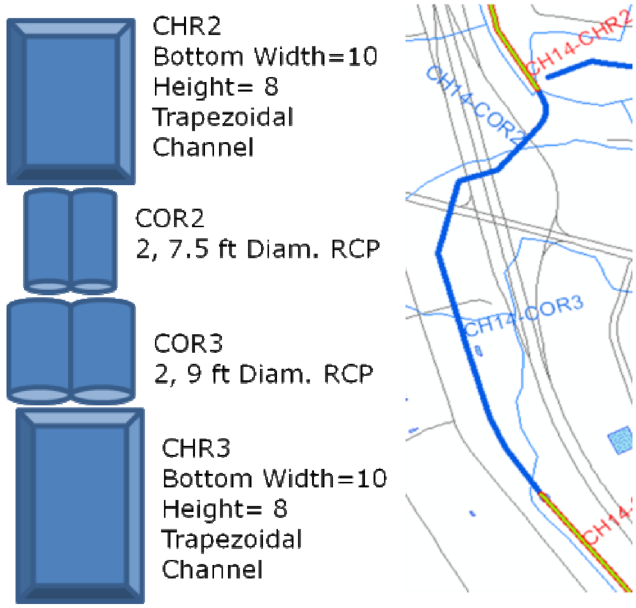


Figure 4.3: Smallest Conduit Dimension Governs Capacity Assumption

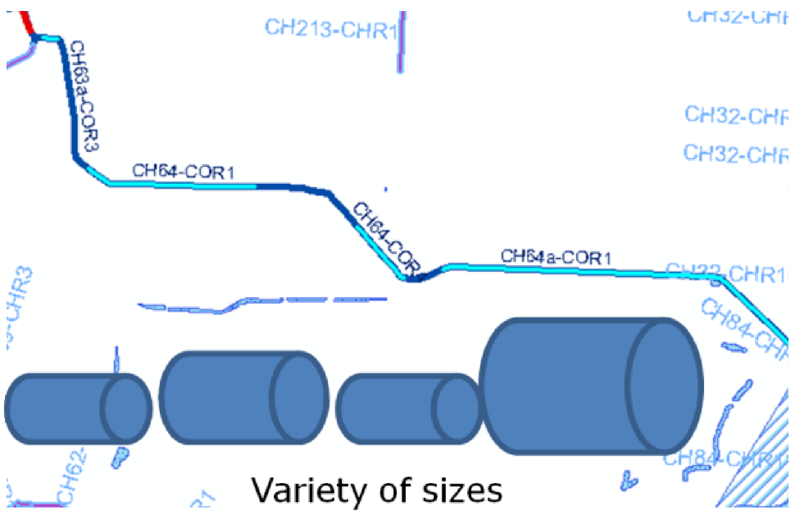


Figure 4.4: Several Conduits Treated As One Long Conduit of Smallest Dimension Assumption

4.2 Determine Watershed Data for Each Channel

A watershed is area of land that catches rain and drains to one point such as a stream based on the topography of the land. In the case of urban areas, the rain must drain to channels or drainage structures. Rainfall on a watershed surface will drain to a major channel. Therefore, the watershed data is necessary to determine the amount of discharge that the channel must be designed to support. Based on watershed data acquired from the URS report, El Paso is divided into 231 watersheds (URS 2006). The watershed data included area, mean annual evaporation, slope, basin storage, basin development factor, and impervious surface and basin types. These parameters are all needed to determine the expected peak discharge. According to Brown et al. (2001) the basin storage (ST) is the percentage of basin occupied by lakes, reservoirs, swamps and wetlands. The basin development factor (BDF) is a measure of efficiency of the drainage basin and the extent of urbanization. Ries and Crouse (2002) determined the BDF by dividing the basin into thirds which are evaluated based on 12 codes. The basin is divided into thirds and evaluated with four characteristics which include channel improvements, channel linings, storm drains, and curb-and-gutter streets. Each characteristic is scored with a 0 or 1. If improvements are not prevalent, a code of 0 is given. Therefore, the higher the BDF, the more improved the basin. The sum of scores for each characteristic and third of the basin yields the BDF factor. The impervious surface parameter is the percentage of storage occupied by impervious surface such as streets and parking lots. A watershed GIS layer was also obtained from URS and was added to the El Paso Drainage GIS file. This file mainly contained the watershed delineations, type, shape, area, and cumulative area. Additional watershed fields were added to include the mean annual evaporation, slope, basin storage, basin development factor, and impervious surface.

These values were manually entered into the GIS database from the values obtained from the URS report.

4.3 Expected Peak Drainage Equations

The expected peak discharge is necessary to determine the maximum flow that the watershed can drain into a channel or drainage structure. These equations are a function of the watershed data that was previously discussed. Equations for different recurrence intervals ranging from 2-yr to 500-yr recurrence intervals are available in the literature (Ries and Crouse 2002). However, the 100 and 500-yr recurrence intervals were used in the El Paso GIS-based stormwater drainage infrastructure management system. The 100-year interval is usually used to determine the design capacity of the channel while the 500 year recurrence interval storm is the most extreme flood discharge computed (Ries and Crouse 2002). “The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year” (Perlman 2008). A 100-year recurrence interval for example, has a one percent chance of occurrence in any given year. Other examples are shown in *Table 4.3.*

Table 4.3: Recurrence Interval and Probabilities of Recurrence (from Perlman 2008)

Recurrence interval in years	Probability of occurrence in any given year	Percent chance of occurrence in any given year
100	1 in 100	1
50	1 in 50	2
25	1 in 25	4
10	1 in 10	10
5	1 in 5	20
2	1 in 2	50

(Perlman 2008)

The U.S. Geological Survey (USGS) peak discharge equations are available for rural and urban type watersheds. The types of watersheds in the obtained layer included rural, urban, pond, and dam type watersheds. There are no expected peak discharge equations available for watersheds that are of basin type "Pond" and "Dam". Only rural and urban peak discharge equations have been developed. The USGS Rural peak discharge equation is shown in *Equation 4.3* where EVAP is the mean annual evaporation (obtained from URS report). A USGS policy before 1989 prohibited the publication of equations for the 500 year flood at ungaged sites. Because of this policy, the rural 500 year interval is extrapolated due to the lack of data. Extrapolation of the available data is performed using a log-pearson distribution. The rural expected peak discharges were obtained from the URS final report to the city. The USGS Urban peak discharge equations are shown in *Equation 4.4* and *Equation 4.5* where A is the cumulative area of the watershed, and RI2 is the 2-hour 2-year rainfall in inches. These equations are implemented in GIS within the "Performance" tool.

Rural:

$$RQ100 = 400A^{0.5}(EVAP - 37)^{0.45}$$

Equation 4.3

Urban:

$$UQ100 = 2.5A^{0.29}SL^{0.15}(RI2 + 3)^{1.76}(ST + 8)^{-0.52}(13 - BDF)^{-0.28}IA^{0.06}RQ100^{0.63}$$

Equation 4.4

$$UQ500 = 2.27A^{0.29}SL^{0.16}(RI2 + 3)^{1.86}(ST + 8)^{-0.54}(13 - BDF)^{-0.27}IA^{0.05}RQ500^{0.63}$$

Equation 4.5

Where,

A = drainage area in square miles

EVAP = Mean Annual Evaporation (inches)

SL = main channel slope in feet per mile

RI2 = the rainfall in inches for the 2-hour, 2-year recurrence interval

ST = basin storage or percentage of the drainage basin occupied by lakes, reservoirs, swamps

IA = percentage of drainage basin occupied by impervious surfaces

RQT = peak discharges in cubic feet per second for equivalent rural drainage basin for the same recurrence interval.

A key parameter is the 2-hour 2-yr rainfall. Rainfall can be a debatable issue because as Perlman (2008) explains, the rainfall may not be uniform for the entire area of the watershed. Sections of the watershed may experience high rainfall while other part may not experience any rainfall at all. El Paso, Texas is divided by a mountain range called the Franklin Mountains, but the precipitation data is obtained from the El Paso Airport which is in a rain shadow (Walton 2006). Therefore, the precipitation data gathered may not apply to other areas especially near the mountainous regions. The "Performance" tool allows for different rainfall values to be used since the 2-hour 2yr rainfall is the input variable. The user will enter the 2-hour, 2year rainfall in inches when the "Performance" tool is used.

In order to compute peak discharge using the "Performance" tool, new fields were added to the watershed layer to include the peak discharge equations for rural and urban peak discharges at the 100 and 500 year intervals. The watershed data and expected peak discharge

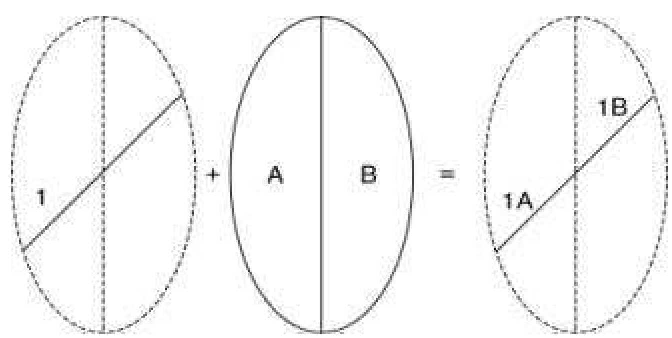
are part of the watershed database as shown in *Table 4.4*. The results for the rural 100 year interval are calculated by the "Performance" tool and the results are stored in GIS in the R100_CFS field. The rural 500-year interval is manually input in the RQ500_CFS data field; the urban 100 and 500 year intervals is calculated by GIS and recorded in the UQ100_CFS and UQ500_CFS data fields, respectively. Additional attributes that were added into GIS for use by the "Performance" tool include PERFORM 100, PERFORM 500, P100ZONE, and P500ZONE. These attributes are used for visualization as discussed in Chapter 5.

Table 4.4: Watershed Attributes

Filed Name	**Description**
BASIN_ID	Basin ID
STREAM_NAM	Stream Name
CUM_SQMI	Cumulative Watershed Area, Sq. Mi
TYPE	Type of Basin
BDF	Basin Development Factor
IA_PERCENT	Impervious Surface
RQ100_CFS	100 yr Rural Expected Peak Discharge, cfs
RQ500_CFS	500 yr Rural Expected Peak Discharge, cfs
UQ100_CFS	100 yr Urban Expected Peak Discharge, cfs
UQ500_CFS	500 yr Urban Expected Peak Discharge, cfs
PERFORM100	100 yr Performance, cfs
PERFORM500	500 yr Performance, cfs
P100ZONE	100 yr Performance Class
P500ZONE	500 yr Performance Class
EVAP_IN	Mean Annual Evaporation, in
ST_PERCENT	Basin Storage %
RI2_IN	2 hr, 2 yr Rainfall Intensity, in
W_COMMENTS	Watershed Comments
SHAPE_LENGTH	Watershed Shape Length
SHAPE_AREA	Watershed Shape Area

4.4 Intersection Tool

The new watershed data would still only give information of the watershed but had no relation to the channels. The amount of rainfall in a particular watershed would drain to a specific channel. Therefore, the channels and watersheds had to be spatially related. GIS has several integration and overlay methods which combine the geometries and attributes of layers to create a new output or shape file (Chang 2008). The new shape file will contain data from both layers. For example, in the case of a polygon-on-polygon overlay operation (see *Figure 4.5*) the first layer is a line segment and the second layer is an oval divided in two sections. This is the exact case for channels and watersheds. The line represents the channel or drainage structure and the oval represent two watersheds that can represent different sections of the channel. When the layers are added by an overlay method, a new layer is created that shows the channel segment divided into two and it will contain attribute data from both channels and watershed combined.



(Chang 2008)

Figure 4.5: Polygon-on-Polygon Overlay Operation (from Chang 2008)

Overlay method include union, intersect, symmetrical difference, and identity. The intersect tool was chosen to obtain data that contained attribute data from both layers, so only the area common to the two layers are considered. The intersect tool was used to combine the existing Channels, Conduits, Culverts, and DropStructure layers with the watershed layers. The new layers were named "ChannelsWatershed", "ConduitsWatershed", and "DropstructuresWatershed". Each layer contained their original drainage attribute database and the watershed database combined into one layer. An example of the "ConduitsWatershed" layer, the intersecting final attribute data is shown in *Table 4.5.* Other tables are shown in Appendix A.

Table 4.5: ConduitsWatershed Layer Attribute Fields

Filed Name	**Description**
REACH	Conduit reach name
DWG_NO	Drawing number as in the map room
PHOTO	Hyperlink to a set of digital photos for this reach
LENGTH	Length measured from the GIS
CHNLNO	Channel number as per the street department map
CHANNEL	Channel name
TYPE	Channel type
FROM_FTR	Name of the upstream feature
TO_FTR	Name of downstream feature
STRT_ST_FT	Starting station as shown on drawings in feet
END_ST_FT	Ending station as shown on drawings in feet
LENGTH_FT	Length = End station - start station
UP_ELEV_FT	Upstream elevation in feet
DN_ELEV_FT	Downstream elevation in feet
CONST_DATE	Construction year
LONG_SLOPE	Longitudinal slope
MATERIAL	Conduit material
CO_TYPE	Conduit cross section shape
NO_OPENIN	Number of openings
WIDTH	Width of one opening
HEIGHT	height of one opening
ANALYSIS	Hyperlink to run the HY-8 software for hydraulic analysis
CFS	Capacity in Cubic feet per second
COMMENTS	Comments
BASIN_ID	Basin ID
STREAM_NAM	Stream Name
CUM_SQMI	Cumulative Watershed Area, Sq. Mi
TYPE	Type of Basin
BDF	Basin Development Factor
IA_PERCENT	Impervious Surface
RQ100_CFS	100 yr Rural Expected Peak Discharge, cfs
RQ500_CFS	500 yr Rural Expected Peak Discharge, cfs
UQ100_CFS	100 yr Urban Expected Peak Discharge, cfs
UQ500_CFS	500 yr Urban Expected Peak Discharge, cfs
PERFORM100	100 yr Performance, cfs
PERFORM500	500 yr Performance, cfs
P100ZONE	100 yr Performance Class
P500ZONE	500 yr Performance Class
EVAP_IN	Mean Annual Evaporation, in
ST_PERCENT	Basin Storage %
RI2_IN	2 hr, 2 yr Rainfall Intensity, in
W_COMMENTS	Watershed Comments
SHAPE_LENGTH	Shape Length
SHAPE_AREA	Shape Area

Chapter 5 Performance Tool to Assess Hydraulic Performance of Drainage Infrastructure System Components

A great benefit of a storm water drainage infrastructure system in GIS is that all storm water drainage data is available in one information system. To further enhance the benefits of the GIS storm water drainage infrastructure system, a prioritization method should be included. The purpose of the "Performance" tool is to quickly assess and visualize the hydraulic performance of the individual drainage features. Performance is assessed by comparing the expected discharge and capacity of the channel or drainage structure at user-defined 2-hour 2-yr inches of rainfall. This chapter deals with the steps undertaken to develop the performance tool. These include the addition of fields in the GIS database related to the performance of the system, the method of detecting the failed drainage, and the VBA code.

5.1 Definition of Failed Drainage

The main purpose of a drainage structure is to collect rainfall that is drained from the watershed area and direct the flow to a detention basin. If the capacity of the drainage structure is not adequate for the expected discharge, then the channel or drainage structure can overflow causing flooding. Therefore, the performance of the drainage structures is based on the capacity relative to the expected peak discharge. Performance was defined as the difference between capacity and expected peak discharge as shown in *Equation 5.1*. Failure of a channel occurs when the calculated capacity for the channel is less than the expected discharge (as shown in *Equation 5.2*). If the capacity of the channel is greater than the expected peak discharge, shown in *Equation 5.3*, then the drainage design is considered adequate.

$$Performance = Capacity - Discharge_T$$

Equation 5.1

$$If\ Performance = < 0\ = Capacity < Expected\ Discharge_T = Failure$$

Equation 5.2

$$If\ Performance = > 0 = Capacity > Expected\ Discharge_T = OK$$

Equation 5.3

Performance was calculated using both the 100 and 500 year interval peak discharge equations. Therefore, the new fields added to the watershed layer and ultimately the "ChannelsWatershed", "ConduitsWatershed", etc, were "PERFORM100" and "PERFORM500" to store the results of *Equation 5.1*.

A number and color coding method was developed to quickly visualize the performance of the entire storm water drainage system. Performance results were number coded as shown in *Table 5.1* and saved into new data fields named "P100ZONE" and "P500ZONE". The "P100ZONE" data field contains the number code for the 100-yr interval and the "P500ZONE" data field contains the number code for the 500-yr interval. The same number coding applied to both recurrence intervals.

Table 5.1: Performance Number Coding

P100ZONE, P500ZONE		
1	PERFORM > 0 (+)	OK
2	PERFORM <0 (-)	FAILS
9	Dummy Reach	No Channel Info
0	Dam or Pond	Equations NA

The next step was to color code the results for quick and easy visualization. It is possible for a drainage feature to be adequate given an amount of rainfall for 100-yr interval but not for the 500-yr interval. The performance for the 100 and 500-yr zones are of interest, therefore the visualization took both of those intervals into consideration by grouping and color coding the result of the combinations. The combination events for the 100 and 500-yr intervals were color coded and numbered as shown in *Table 5.2*. For example, the event "1, 2" is the event in which the drainage structure is adequate at the 100-yr interval, which is designated by 1, but fails at the 500-yr interval, designated by 2. Similarly, the event "1, 1" is the event in which the drainage structure is adequate for both the 100 and 500-yr intervals.

Table 5.2 P100ZONE, P500ZONE Color Code

P100ZONE, P500ZONE		Definition
(purple)	0,0	Performance cannot be determined (Dam or Pond)
(green)	1,1	No Failure at either 100-yr of 500-yr interval
(yellow)	1,2	Failure at the 500-yr interval
(red)	2,2	Failure at both the 100-yr interval and 500-yr interval
(pink)	9,9	Performance cannot be determined (No data)

5.2 Integration of the Performance Tool into GIS

The “Performance” tool was programmed using Visual Basic and added as a new tool to the GIS toolbar. GIS Arc objects can be programmed using model builder and the integrated visual basic program. The VBA program calculates the expected discharge for each channel based on the rainfall input, compares the results with the capacity, and displays the results by number code in the database and color on the GIS map. The calculations were programmed using the “calculate” command.

The algorithm and logic of the “Performance” tool are illustrated in *Figure 5.2*. The first step in the program is to compute the expected discharge and display the result in the corresponding field in the database. The program calculates the expected discharge for rural and urban equations at the 100 and 500-yr intervals shown earlier in *Equation 4.3, Equation 4.4, and Equation 4.5* and saves the results in the GIS database in the corresponding fields (RQ100, RQ500, UQ100, and UQ500). The second step in the performance tool is to calculate the performance of the channel (*Equation 5.1*) which is saved in the field “PERFORM”. The performance of a channel depends on using the correct expected discharge, urban or rural, which required conditions to be programmed to determine the type of watershed for each channel. As previously mentioned, the watershed types were rural, urban, dam, and pond. GIS was programmed to recognize the type of watershed to compute the necessary equations for the “PERFORM” field. The next step was to number code the results as per *Table 5.1*. GIS was programmed to recognize the value of “PERFORM” and display the number codes for the 100 and 500-yr interval in the corresponding fields for PZONE100 and PZONE500. The final step was to color code the results as per *Table 5.2.*

An example of the final result after using the Performance tool is shown in *Figure 5.1* where the channel shows all three different levels of performance. The green sections of the channel are adequate for the both recurrence intervals. The yellow section shows an event where the drainage structure is adequate for the 100-yr recurrence interval but fails for the 500-yr recurrence interval. The red section shows an event where the drainage fails at both recurrence intervals.

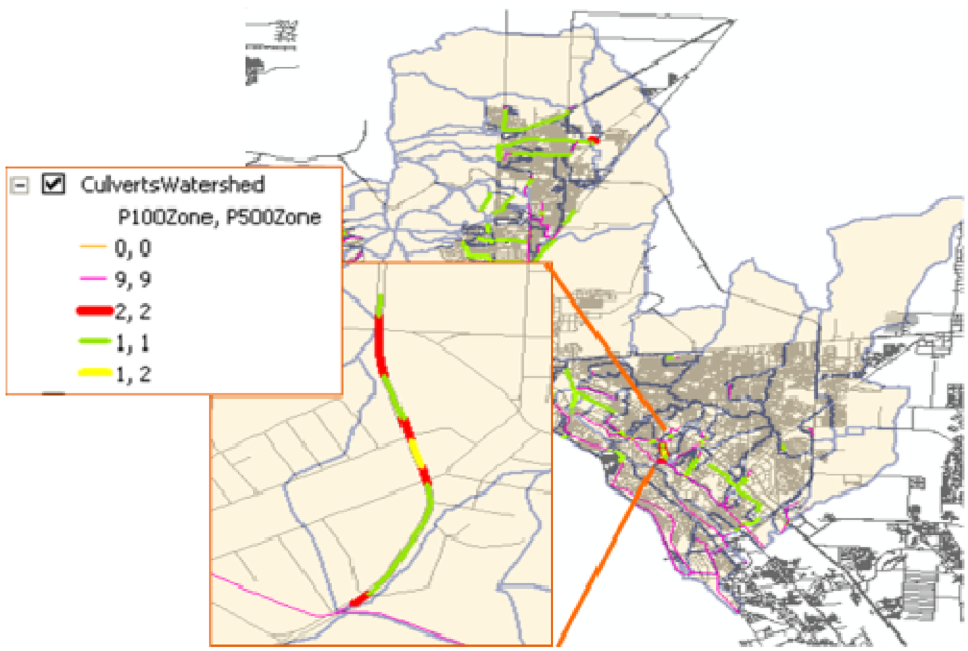


Figure 5.1: Display of Performance Result in GIS

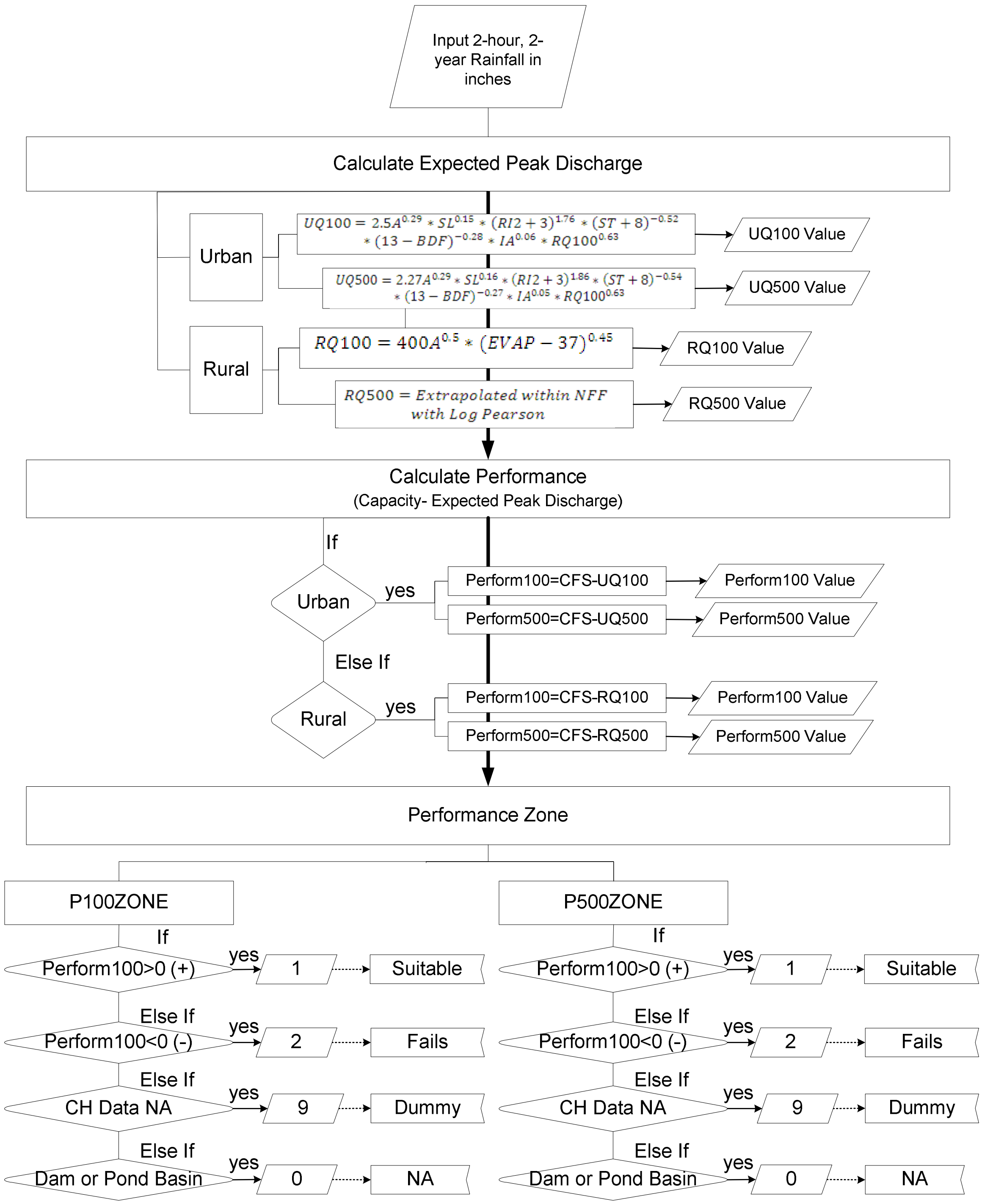


Figure 5.2: VBA Program Flow Chart

In addition to the Performance tool, a tool to facilitate editing of the drainage system was created. The tool was titled “Update Layers” tool and allows for editing to be done on the original layers: Channels, Conduits, DropStructures, and S_Hydro_Basin (Watershed). The updating tool performs the intersection of layers necessary for the performance tool and in that way updates the new performance layers (ChannelsWatershed, ConduitsWatershed, etc.) to display the same features shown in the original layers. The Model Builder tool in GIS was used to create the intersections and VBA was used to integrate it as a tool in GIS.

As an example, if a new channel is to be added to the system, the channel would be added with the Editor tool on the “Drainage” layers which include channels, conduits, and drop structures. Once the channel is added to the Channels layer, the updating tool can be executed to reflect the changes in “ChannelsWatershed”. *Figure 5.3* shows the new channel circled in red which will be reflected in “ChannelsWatershed” after running the “Update Layers” tool. *Figure 5.4* shows the channel before and after the updating layers tool. The top picture shows the channel feature only, as the channel does not yet exist in “ChannelsWatershed”. The bottom picture shows the same channel after the updating layers tool was executed with channel in the “ChannelsWatershed” layer shown as a thin purple line. When the “Performance” tool is run, it will include the new channel as well.

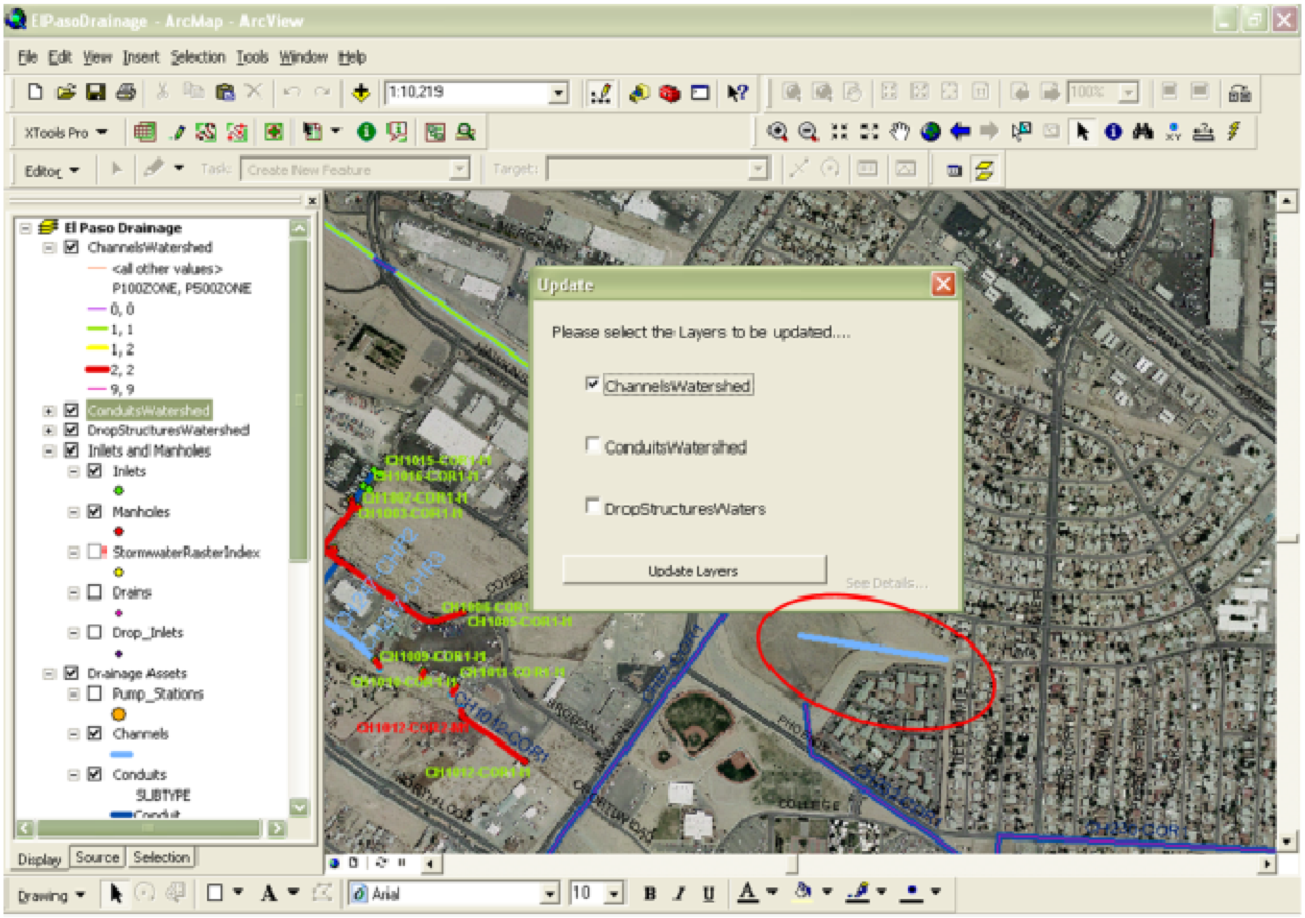


Figure 5.3: Update Layers tool

Figure 5.4: Update Layers Tool Results

Chapter 6 El Paso GIS Storm Water Drainage System

This chapter presents a summary of the layers added to the El Paso drainage infrastructure GIS file and demonstrates the use of the "Performance" tool and "Update Layers" tool.

The layers that were added to the El Paso Storm Water GIS file were grouped into categories. These categories include Drainage, Performance, Watersheds, Inlets and Manholes, Ponds, Streets, and Aerials. The first three groups of layers are necessary for assessing the performance of the drainage system. The watershed group layer contains only the watershed database. Drainage structures such as channels, conduits, and drop structures form the Drainage layers. The Performance group includes the layers that result from the intersection of watershed and drainage layers; "ChannelsWatershed", "ConduitsWatershed", and "DropStructuresWatershed". *Figure 6.1* shows an area of El Paso with various drainage assets. To determine the performance of the channel, the "Performance" tool is used by clicking on the tool which has been docked on the GIS toolbar for easy access and the 2-hr, 2-year recurrence interval is entered. The Performance tool calculates the expected peak discharges based on the rainfall amount. The performance and the coding for each drainage feature are displayed on the GIS map. *Figure 6.2* shows the results of the performance tool with a 1 inch 2-hr, 2-yr rainfall event. Results show that the features displayed in red will fail at the 100 and 500-yr intervals. The culverts and conduits for this particular channel all fail with 1 inch of 2-hr, 2-yr rainfall. The corresponding sections of the database are shown in *Table 6.1* and *Table 6.2* and show the calculated results of the performance tool including the final outcome of determined failure. *Figure 6.3* shows increase in red and yellow sections of this drainage symbolizing failure as the rainfall increases from 1.5 inches to 2 inches for the 2-hr, 2-yr rainfall.

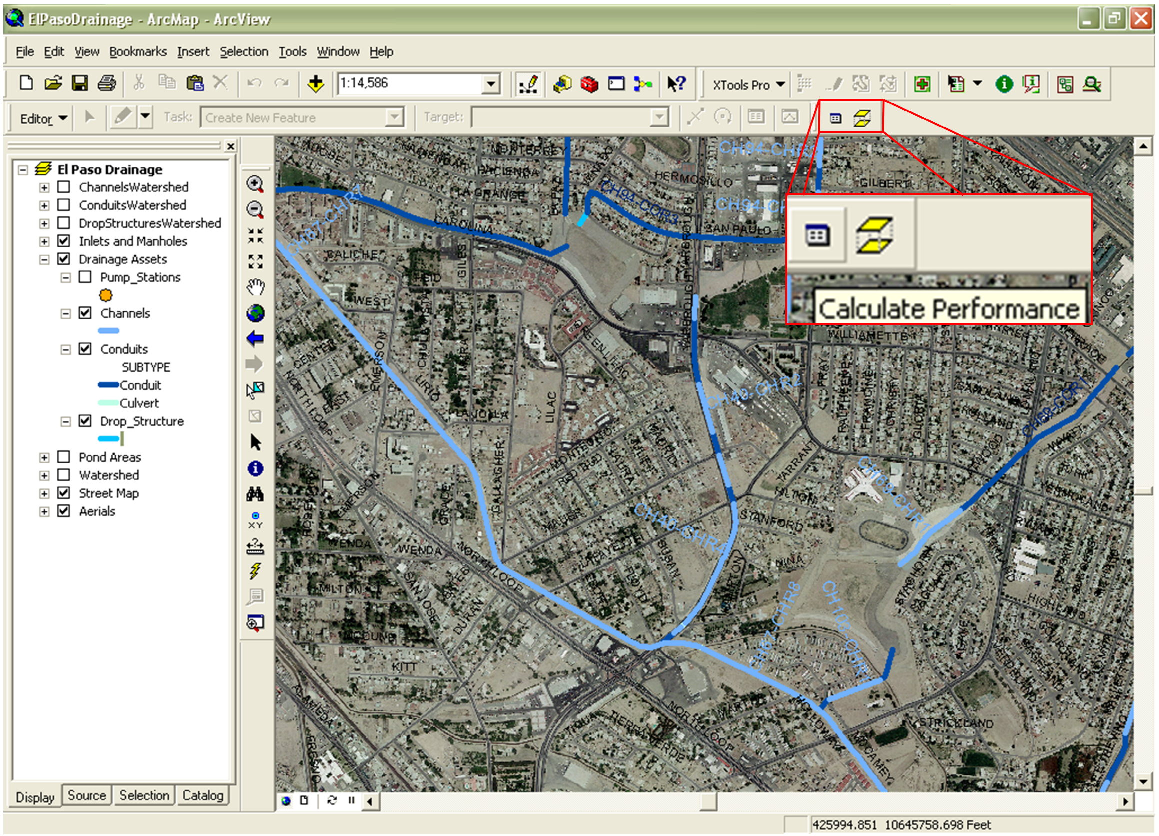


Figure 6.1: Selection of an Example Channel for Performance Assessment

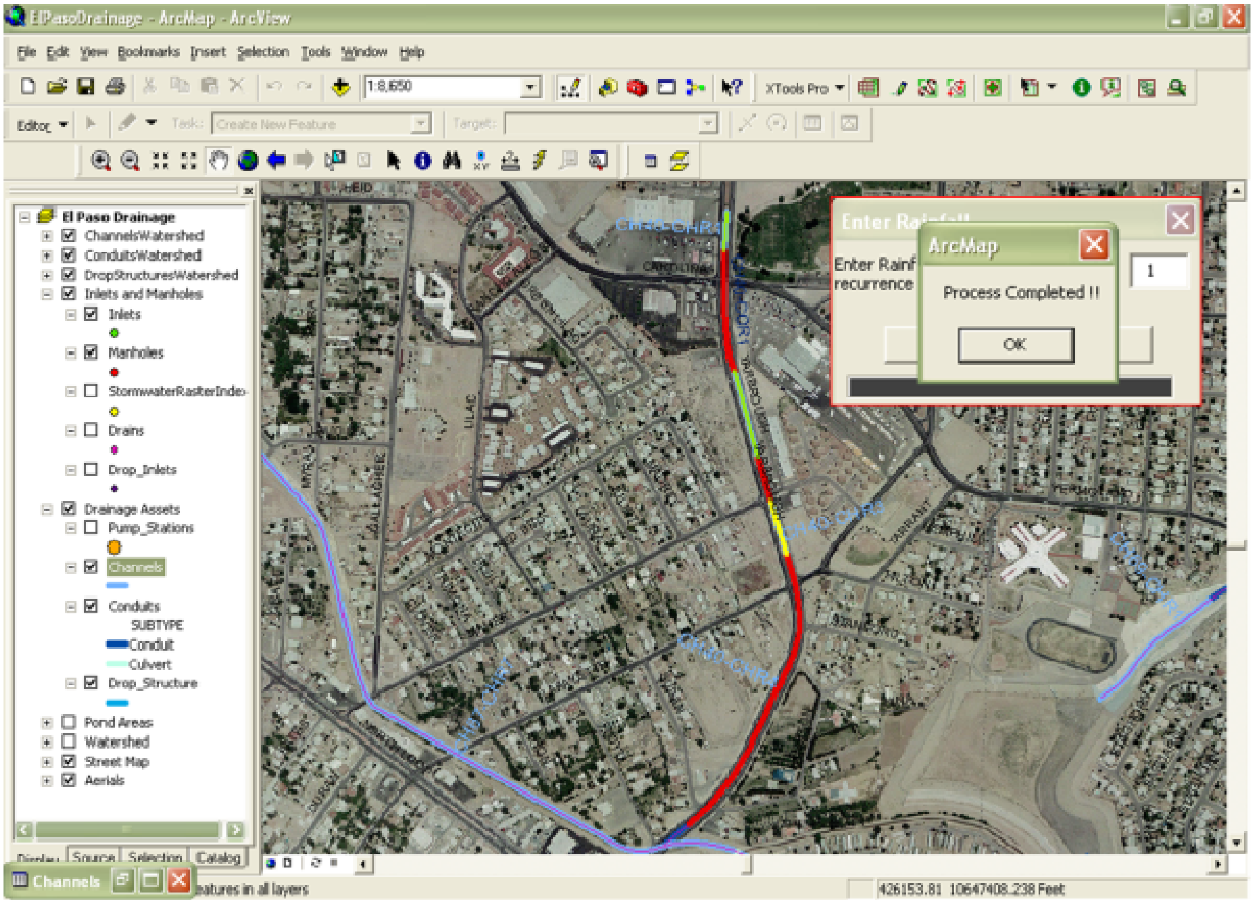


Figure 6.2: Selection of an Example Channel for Performance Assessment with 1 inch 2-hr, 2yr rainfall

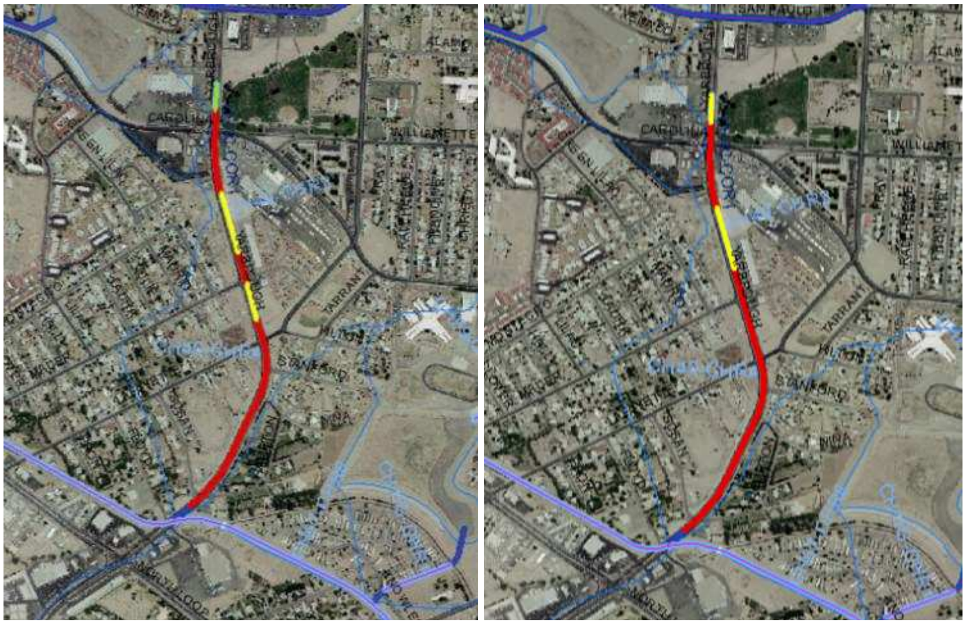


Figure 6.3: Selection of an Example Channel for Performance Assessment with 1 inch and 2 inch 2-hr, 2yr rainfall respectively

Table 6.1: Results of Performance Assessment of Channels (1 inch 2-hour, 2-yr rainfall)

Feature Reach	100-yr Rural Expected Discharge, cfs	500-yr Rural Expected Discharge, cfs	100-yr Urban Expected Discharge, cfs	500-yr Urban Expected Discharge, cfs	100-yr Performance, cfs	500-yr Performance, cfs	100-yr Performance Result Code	500-yr Performance Result Code
CH40-CHR1	1505.214	2560.000	1215.731	1751.831	1022.269	486.169	1	1
CH40-CHR2	1505.214	2560.000	1153.444	1656.259	722.556	219.741	1	1
CH40-CHR3	1505.214	2560.000	1091.444	1561.470	469.556	-0.470	1	2
CH40-CHR4	1505.214	2560.000	901.972	1274.104	-78.972	-451.104	2	2
CH40-CHR5	1505.214	2560.000	822.238	1154.329	-216.238	-548.329	2	2

Table 6.2: Results of Performance Assessment of Conduits and Culverts (1 inch 2-hour, 2-yr rainfall)

Feature Reach	100-yr Rural Expected Discharge, cfs	500-yr Rural Expected Discharge, cfs	100-yr Urban Expected Discharge, cfs	500-yr Urban Expected Discharge, cfs	100-yr Performance, cfs	500-yr Performance, cfs	100-yr Performance Result Code	500-yr Performance Result Code
CH40-COR1	1505.214	2560.000	1201.691	1730.259	-951.691	-1480.259	2	2
CH40-COR2	1505.214	2560.000	1127.357	1616.333	-797.357	-1286.333	2	2
CH40-COR3	1505.214	2560.000	923.740	1306.929	-593.740	-976.929	2	2
CH40-COR4	1505.214	2560.000	999999.000	999999.000	999999.000	999999.000	9	9
CH40-CR1	1505.214	2560.000	949.922	1346.479	-619.922	-1016.479	2	2

The performance tool calculates and displays the results for the complete drainage system of the City of El Paso for which data was available. Unfortunately, data was available for only 23% of the drainage system. Of these, 14% are channels, 6% are conduits and 3% are culverts. This makes it difficult to determine trends relating drainage characteristics and failure of the drainage structures. A preliminary analysis of tendencies was reviewed with the data available by looking for similar characteristics of the structures in the three performance categories. The tendencies found for channels were width, height, slope, and area. *Figure 6.4* shows bar graphs of these tendencies as the rainfall increases. Channels with larger width and height are less likely to fail. Channels with small area are also less likely to fail. This is also shown in the sensitivity analysis in the next chapter. A low slope seems to have a tendency of failure up to one inch of rainfall. These are preliminary tendencies which should be further analyzed when more data is added to the database.

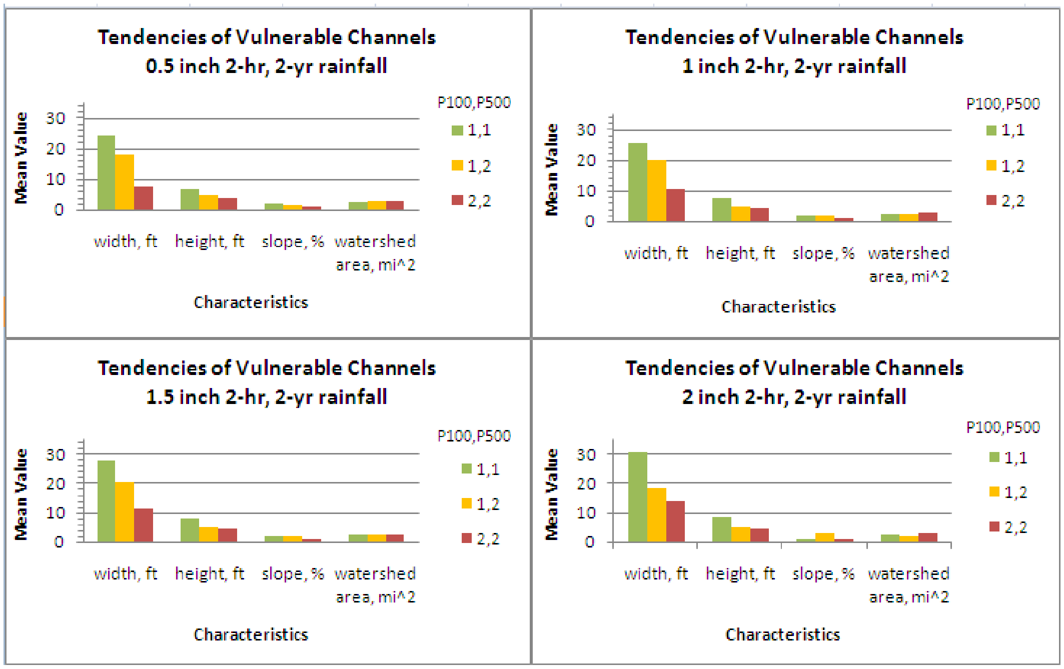


Figure 6.4: Tendencies of Vulnerable Channels

In addition, the drainage system can be compared to the inventory of disasters as observed by URS (2006) during their field survey study. Several of the damaged drainage structures were being newly constructed at the time of data gathering and field survey of this project so these results cannot be fully compared with the damages in 2006. An example of the results of URS disaster areas are shown in *Figure 6.5* and compared with the results obtained from the GIS "Performance" tool with 1 inch 2-hr, 2-yr rainfall as shown in *Figure 6.6.* Several of the disaster areas are not calculated by the performance tool due to lack of data (as new construction was taking place). The URS disaster areas and areas of performance failure are similar such as those circled drainage structures. A look at the system as a whole, *Figure 6.7,* shows several drainage structures in the El Paso drainage system are shown in red indicating that

these structures and areas of the city could fail with a 1 inch 2-hour, 2-yr rainfall and should be viewed in more detail to prevent flooding.

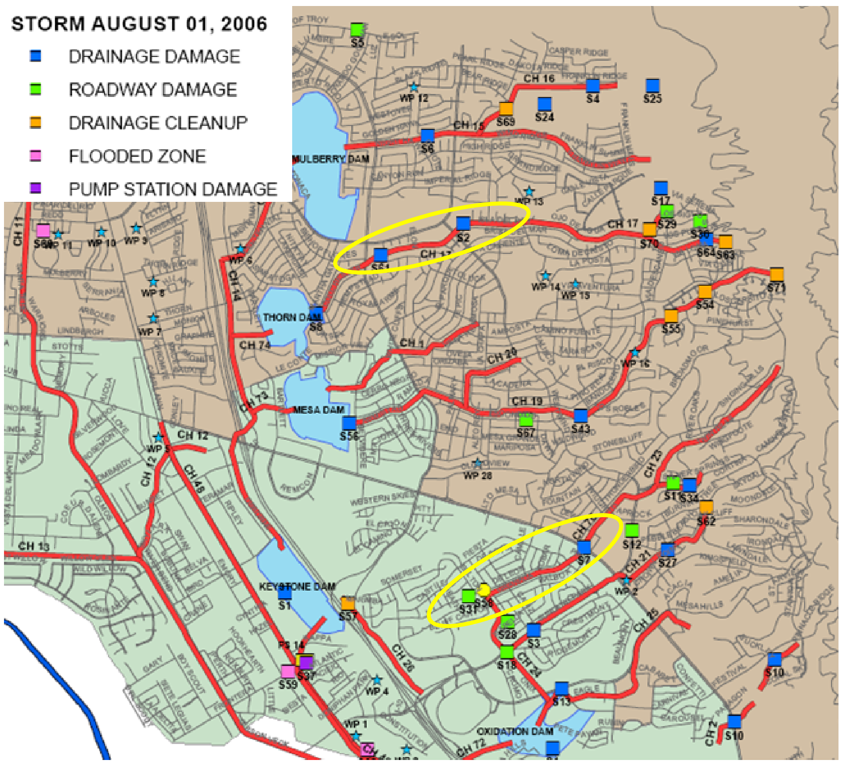


Figure 6.5: URS (2006) Disaster Areas

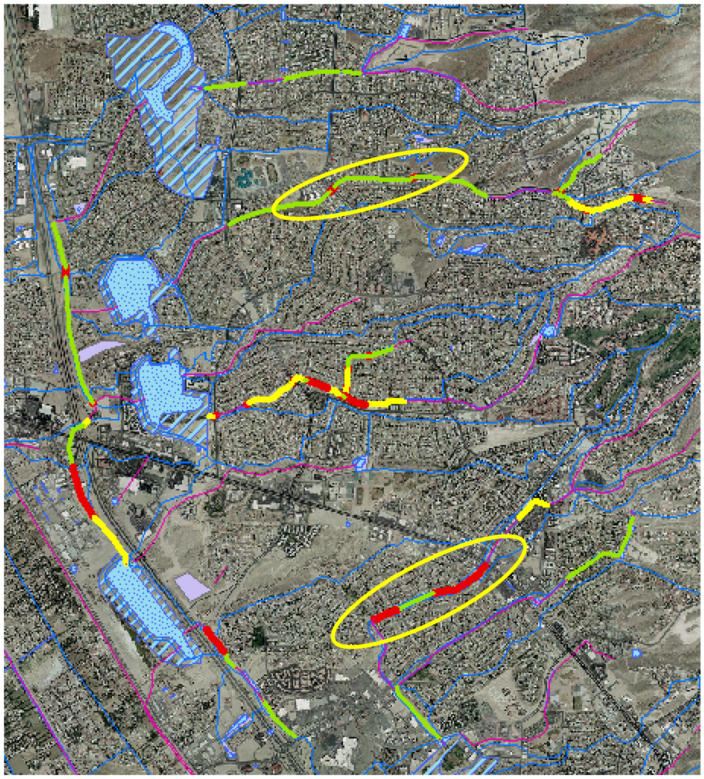


Figure 6.6: City of El Paso Westside Drainage with 1 inch 2-hr, 2-yr rainfall

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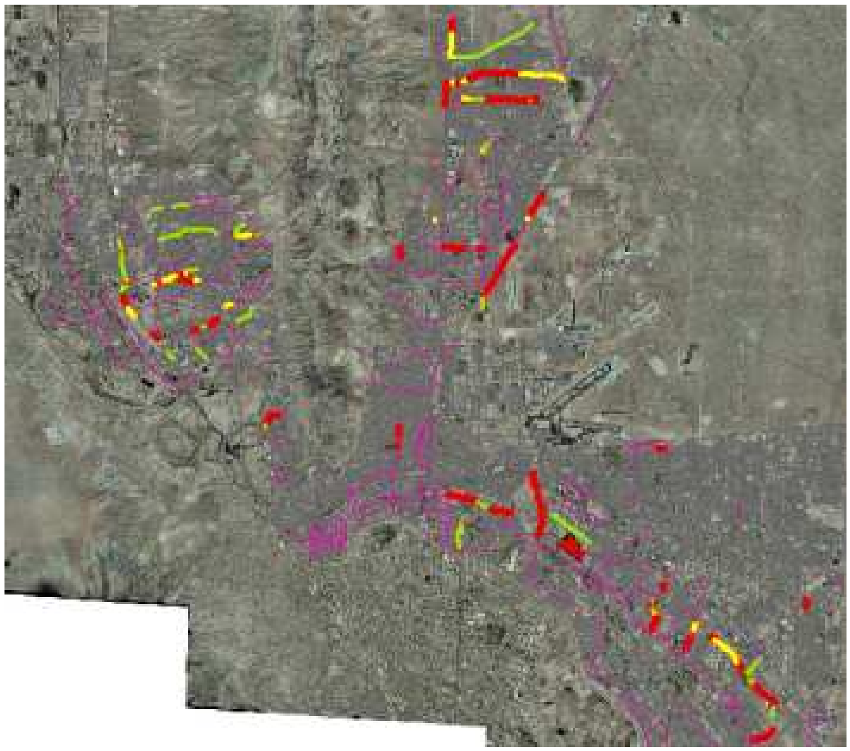

Figure 6.7: Performance Assessment of Drainage System for El Paso, TX (1 inch 2-hour, 2-yr rainfall event)

Chapter 7 Sensitivity Analysis for Flood Damage

Brief sensitivity analyses for the USGS equations were performed to determine the effect the parameters have on the expected peak discharge for the urban 100 and 500-yr recurrence intervals. The sensitivity analysis was performed by varying individual parameters by 1 % while keeping all other parameters constant. The percent change was then calculated and plotted for each change and for each parameter. Values of the actual GIS database were used to determine the range of values used in this sensitivity analysis. For example, the minimum value for watershed area in the GIS database was 0.008 square miles and the maximum area was 47.326 square miles. The value of the "area" parameter in the sensitivity analysis was increased by one percent starting at 0.008 square miles and ending at 47.326 square miles. The slope of the channel was increased by 1% starting at 0.242 and ending at 210.618. The sensitivities of the other parameters were evaluated in a similar manner. The graphical results for the 100-yr expected peak discharge are shown in *Figure 7.1* and *Figure 7.2*. *These r*esults also show that the cumulative area of a watershed has by far the greatest effect on the expected peak discharge. As the area of the watershed increases, the expected peak discharge will also increase. *Figure 7.2* shows a closer view of the remaining parameters. These results show that the best way to maintain a low peak discharge is to increase the percent of storage in the watershed, minimize watershed area, and reduce slope. Results are similar for the 500-yr recurrence interval. The difference is that the "RQ500" value is extrapolated (rather than obtained from an equation as "RQ100" (which is a function of area and mean annual evaporation, *Equation 4.3*).

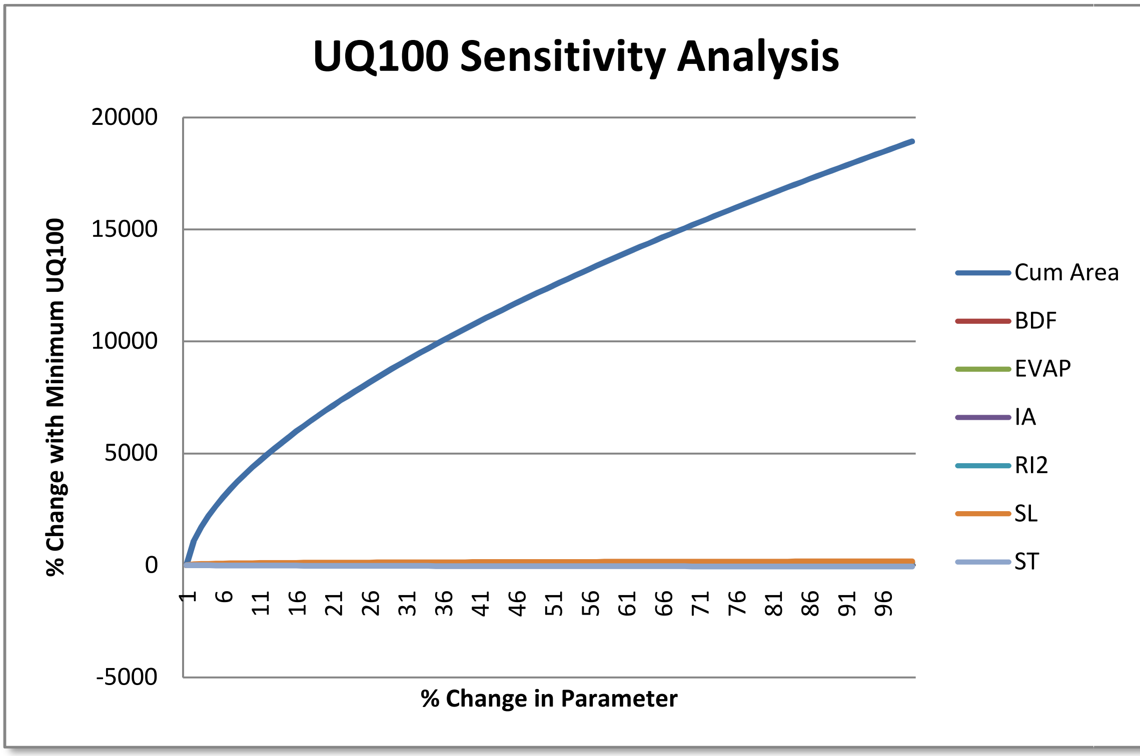

Figure 7.1: UQ100 Sensitivity Analysis

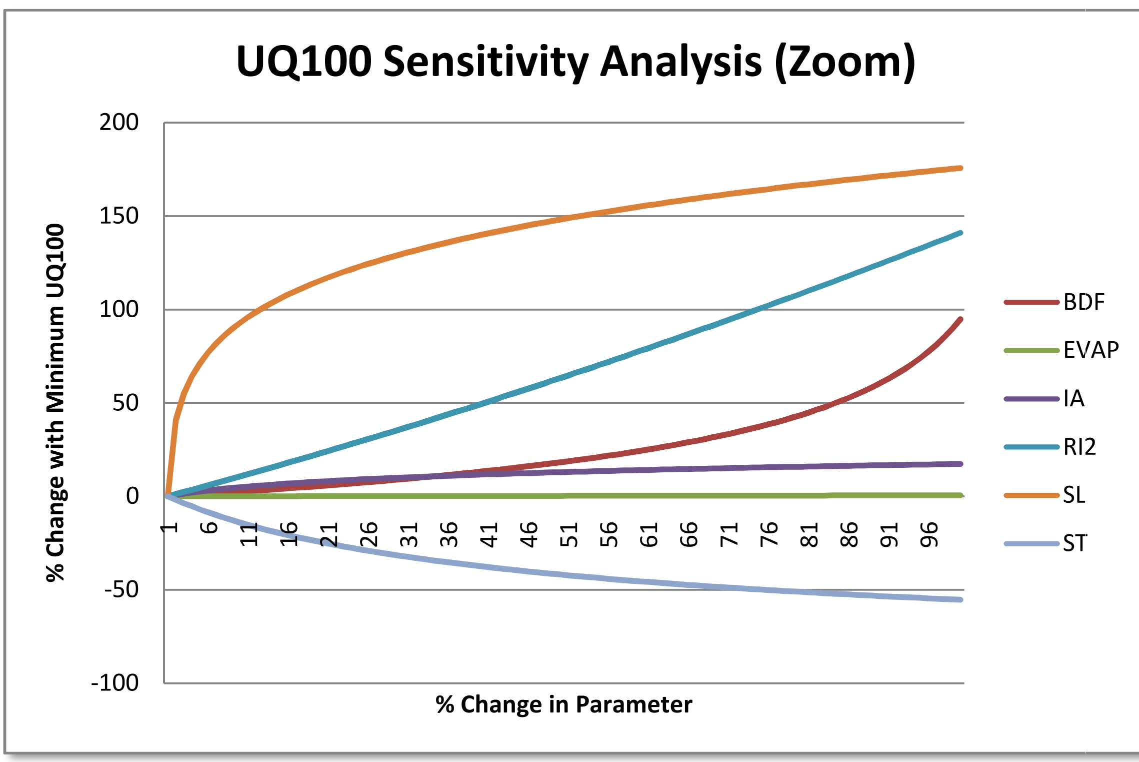

Figure 7.2: UQ100 Sensitivity Analysis (Zoom)

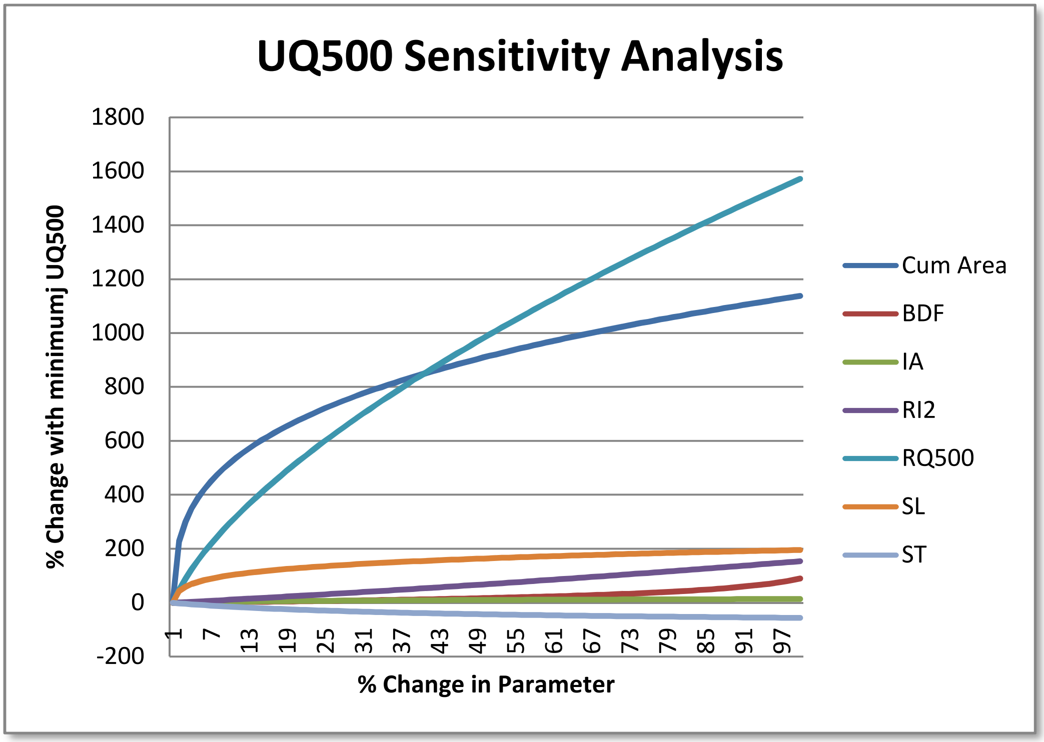

Figure 7.3: UQ500 Sensitivity Analysis

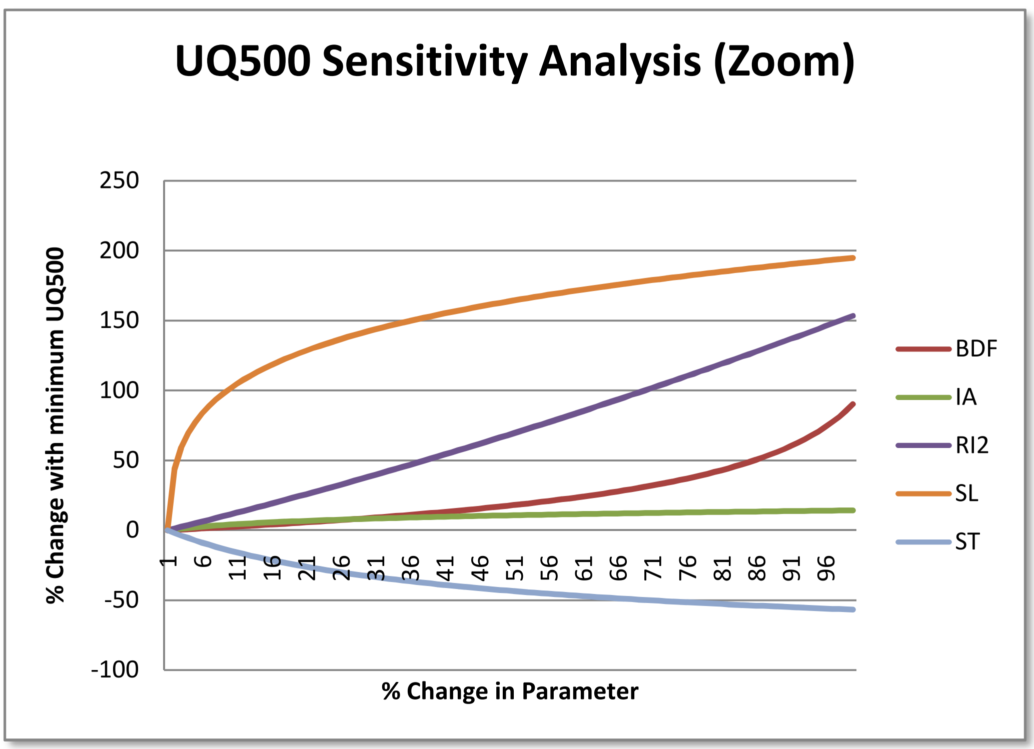

Figure 7.3: UQ500 Sensitivity Analysis (Zoom)

Chapter 8 Summary, Conclusions, and Recommendations

8.1 Summary

A GIS-based tool for assessing and visualizing the hydraulic performance of the drainage system in El Paso was developed. The ultimate goal is to provide the City of El Paso with a methodology and a tool that can be used to identify drainage assets of high risk failure due to flooding so that more detailed evaluation of these assets can be performed. The "Performance" tool was integrated into GIS to determine and visually display drainage structures which are under-designed by calculating and comparing the expected peak discharge to capacity. . The "Performance" tool uses user-defined amount of rainfall (expressed in terms of 2-hour, 2-year inches of rainfall). This allows for the "Performance" tool to be dynamic and allows for comparison of the performance of the drainage system under various scenarios of rainfall. The "Performance" tool has been used to identify the weak links in the drainage system of the City of El Paso. This can aid the City engineers to take preventive measure for areas which show under-designed drainage structures.

The "Update Layers" tool was developed to automatically update the GIS layers and database as the drainage system expands (and thus the database and maps need to be updated accordingly). This will allow for including new drainage structures in the "Performance" tool calculations and results.

8.2 Conclusions

The main conclusions of this study are:

- The benefits of GIS to public works agencies can be greatly enhanced by integrating engineering analytical tools into their GIS.
- The integration of data management tools into GIS may be necessary for running engineering analyses in GIS
- Width, Height, Slope and Area show tendencies related to failure of the drainage. Special detail should be given to these characteristics in further assessment and design.
- A visual observation of GIS maps shows that the areas of drainage failure calculated by the "Performance" tool match the disaster areas that were observed in the field in 2006.
- The City of El Paso can use the developed GIS and integrated tools to analyze the drainage system, identify drainage structures that are vulnerable to flooding, and take corrective repair actions before disaster strikes.

8.3 Recommendations

Based on the work conducted under this study, the following recommendations are offered:

- Missing data should be obtained and updated into the GIS to understand the performance of the entire drainage system.
- Assess the performance of the City's entire drainage system using the methodology that was developed under this study. This will help the City engineers identify vulnerable culverts and channels that can potentially flood under various rainfall scenarios.
- To complete the drainage system, ponds and dams, should be considered as they were not considered in this project.
- Life cycle cost analysis tools can be integrated into the GIS to aid in the evaluation and prioritization of potential alternatives for improving the drainage system (specifically, drainage structures that have been found to be under-designed). This project shows the beginning of a prioritization and maintaining method for the drainage infrastructure system of the City of El Paso.
- Collect reliable rainfall data. For example, real time data can be collected by adding sensors that measure water elevation in various drainage structures.

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Appendix A: Data Dictionary

Table A. 1: Data Dictionary for Channel Attributes

Filed Name	Description
REACH	Open channel reach name
DWG_NO	Drawing number as in the map room
PHOTOS	Hyperlink to a set of digital photos for this reach
LENGTH	Length measured from the GIS
CHNLNO	Channel number as per the street department map
CHANNEL	Channel name
CH_TYPE	Channel type
FROM_FTR	Name of the upstream feature
TO_FTR	Name of downstream feature
STRT_ST_FT	Starting station as shown on drawings in feet
END_ST_FT	Ending station as shown on drawings in feet
LENGTH_FT	Length = End station - start station
UP_ELEV_FT	Upstream elevation in feet
DN_ELEV_FT	Downstream elevation in feet
SLOPE	Longitudinal slope
CONST_DATE	Construction year
CH_MAT	Main channel lining material
OVER_MAT	Overbank lining material
W1_FT	Main channel bed width in feet
H1_FT	Main channel height in feet
SS1L	Main channel left side slope
SS1R	Main channel right side slope
W2L_FT	Left overbank width in feet
H2L_FT	Left overbank height in feet
SS2L	Left overbank side slope
W2R_FT	Right overbank width in feet
H2R_FT	Right overbank height in feet
SS2R	Right overbank side slope
CFS	Capacity in Cubic feet per second
COMMENTS	Comments

Table A. 2: Data Dictionary for Culvert Attributes

Filed Name	Description
REACH	Culvert reach name
DWG_NO	Drawing number as in the map room
PHOTO	Hyperlink to a set of digital photos for this reach
LENGTH	Length measured from the GIS
CHNLNO	Channel number as per the street department map
CHANNEL	Channel name
TYPE	Channel type
FROM_FTR	Name of the upstream feature
TO_FTR	Name of downstream feature
STRT_ST_FT	Starting station as shown on drawings in feet
END_ST_FT	Ending station as shown on drawings in feet
LENGTH_FT	Length = End station - start station
UP_ELEV_FT	Upstream elevation in feet
DN_ELEV_FT	Downstream elevation in feet
CONST_DATE	Construction year
LONG_SLOPE	Longitudinal slope
MATERIAL	Culvert material
CU_TYPE	Culvert cross section shape
NO_OPENIN	Number of openings
WIDTH	Width of one opening
HEIGHT	height of one opening
ANALYSIS	Hyperlink to run the HY-8 software for hydraulic analysis
CFS	Capacity in Cubic feet per second
COMMENTS	Comments

Table A. 3: Data Dictionary for Conduit Attributes

Filed Name	Description
REACH	Conduit reach name
DWG_NO	Drawing number as in the map room
PHOTOS	Hyperlink to a set of digital photos for this reach
LENGTH	Length measured from the GIS
CH	Channel number as per the street department map
CHANNEL	Channel name
TYPE	Channel type
FROM_FTR	Name of the upstream feature
TO_FTR	Name of downstream feature
STRT_ST_FT	Starting station as shown on drawings in feet
END_ST_FT	Ending station as shown on drawings in feet
LENGHT	Length = End station - start station
UP_ELEV_FT	Upstream elevation in feet
DN_ELEV_FT	Downstream elevation in feet
LONG_SLOPE	Longitudinal slope
MATERIAL	Conduit material
COND_TYPE	Conduit cross section shape
NO_OPENING	Number of openings
WIDTH	Width of one opening
HEIGHT	height of one opening
CONST_DATE	Construction year
ANALYSIS	Hyperlink to run the HY-8 software for hydraulic analysis
CFS	Capacity in Cubic feet per second
COMMENTS	Comments

Table A. 4: Data Dictionary for Drop Structure Attributes

Filed Name	Description
REACH	Drop structure reach name
DWG_NO	Drawing number as in the map room
PHOTOS	Hyperlink to a set of digital photos for this reach
LENGTH	Length measured from the GIS
CH	Channel number as per the street department map
START_FTR	Name of the upstream feature
END_FTR	Name of downstream feature
START_ST	Starting station as shown on drawings in feet
END_ST	Ending station as shown on drawings in feet
CHANNEL	Channel name
UP_ELEV_FT	Upstream elevation in feet
DN_ELEV_ST	Downstream elevation in feet
LENGTH_FT	Length = End station - start station
MATERIAL	Material
CONST_DATE	Construction date
DISSIPATOR	Type of energy dissipaters
COMMENTS	Comments

Table A. 5: Data Dictionary for Pump Station Attributes

Filed Name	Description
NAME	Pump station name
DWG	Drawing number as in the map room
PHOTOS2007	Hyperlink to a set of digital photos for this reach
LOCATION	Street address of pump station
PS_NO	Pump station number as shown on the street department map
NO_MP	Number of main pumps
MP_TYPE	Type of main pumps
MP_CAP_HP	Main pump power in HP
MP_DIS_GPM	Main pump discharge in Gallon per minute
NO_SP	Number of sump pumps
SP_TYPE	Type of sump pumps
SP_CAP_HP	Sump pump power in HP
SP_DIS_GPM	Sump pump discharge in gallon per minute
IN_NO	Number of conduits discharging into the pump station
IN_TYPE	Material of conduits discharging into the pump station
IN_SHAPE	Shape of conduits discharging into the pump station
IN_W_IN	Width or diameter of conduit discharging into the pump station, in inches
IN_H_IN	Height of conduit discharging into the pump station in inches
IN_ELEV_FT	Inlet conduit elevation in feet
OU_NO	Number of outlet conduits
OU_TYPE	Material of outlet conduits
OU_SHAPE	Shape of outlet conduit
OU_W_IN	Width of outlet conduit in inches
OU_H_IN	Height of outlet conduit in inches
OU_ELEV_FT	Elevation of outlet conduit in feet
OV_NO	Number of overflow conduit
OV_TYPE	Material of overflow conduit
OV_SHAPE	Shape of overflow conduit
OV_W_IN	Width of overflow conduit in inches
OV_H_IN	Height of overflow conduit in inches
OV_ELEV_FT	Elevation of overflow conduit in feet
DATUM	Datum used for elevation measurement
REMARKS	Comments

Table A. 6: Data Dictionary for Watershed Attributes

Filed Name	Description
BASIN_ID	Basin ID
STREAM_NAM	Stream Name
CUM_SQMI	Cumulative Watershed Area, Sq. Mi
TYPE	Type of Basin
BDF	Basin Development Factor
IA_PERCENT	Impervious Surface
RQ100_CFS	100 yr Rural Expected Peak Discharge, cfs
RQ500_CFS	500 yr Rural Expected Peak Discharge, cfs
UQ100_CFS	100 yr Urban Expected Peak Discharge, cfs
UQ500_CFS	500 yr Urban Expected Peak Discharge, cfs
PERFORM100	100 yr Performance, cfs
PERFORM500	500 yr Performance, cfs
P100ZONE	100 yr Performance Class
P500ZONE	500 yr Performance Class
EVAP_IN	Mean Annual Evaporation, in
ST_PERCENT	Basin Storage %
RI2_IN	2 hr, 2 yr Rainfall Intensity, in
W_COMMENTS	Watershed Comments
SHAPE_LENGTH	Shape Length
SHAPE_AREA	Shape Area

Appendix B: Capacity of Channels

1) Open HY-8 Software
2) Fill in Name = “REACH” in GIS
3) Fill in Discharge Data
    a. Minimum = 0
    b. Design Flow = take a guess
    c. Maximum Flow = any number > Design Flow
4) Fill in Tailwater Data as shown in GIS Database
    a. Channel Type(determined by side slope; ex. Trapezoid if S1L and S1R not = 0
    b. Bottom Width= W1_FT in GIS
    c. Side Slope = lowest of S1L or S1R in GIS
    d. Channel Slope = LONG_SLOPE in GIS
    e. Manning’s n = 0.0130 for concrete, other check *Table 2. Manning’s n Roughness Coefficients*
    f. Channel Invert Elevation = DN_ELEV_FT or UP_ELEV_FT in GIS
5) Click “View…” next to “Rating Curve”
6) Determine the elevation limit by adding height (H1_FT in GIS) to the Channel Invert Elevation.
    a. In this case, H1_FT = 4 therefore limit elevation is 3702.47+4=3706.47
7) Choose different numbers for Design Flow until you get close to the limit shown as “Elevation (ft)” in the Rating Curve window.
8) The Capacity will be inserted in the GIS layer “Channels” under the field “CFS”
    a. Open ArcGIS ElPasoDrainage

b. Right-click channels layer and select Open Attribute Tables.

c. Click on the Editor Tool and Select Start Editing-Select the file which include Channels shapefiles.

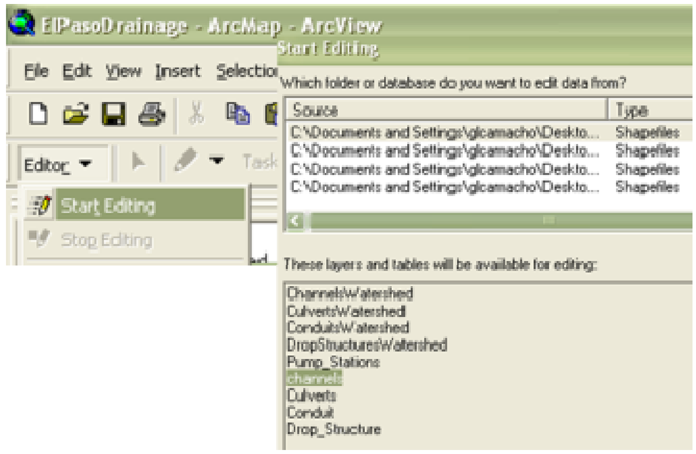


Figure B. 1: Start Editing

d. Add the new capacity to the CFS field for the channel reach.

e. BE CAREFULL NOT TO ERASE OR CHANGE ANY OTHER EXISTING DATA.

f. Save your edits in the Editor tool and select stop editing when finished.

Example:

a. Choose 3000 for design flow:

    i. The flow should be less than 300 because the elevation given for the flows are too far from the limit elevation (3706.47 in this case)

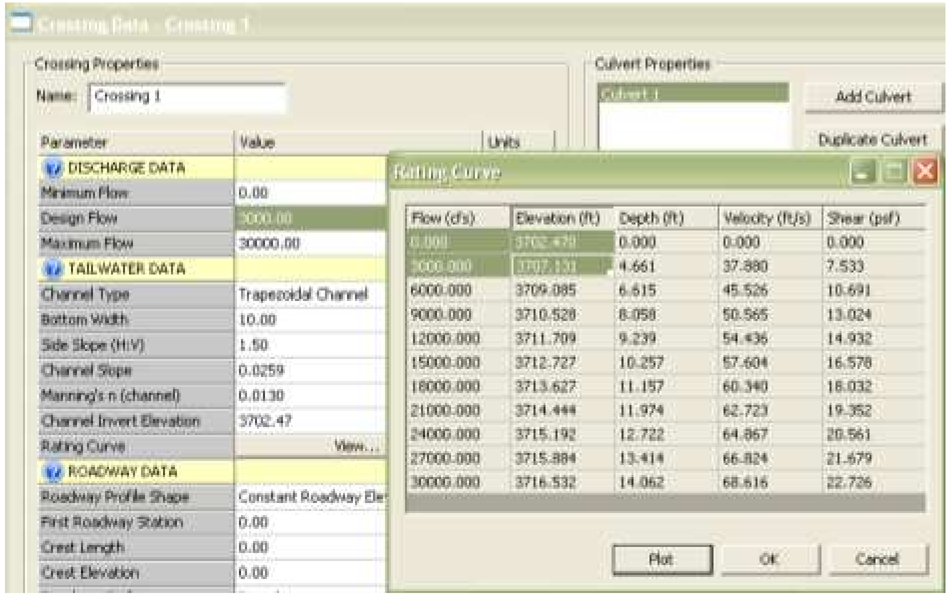


Figure B. 2: Channel Capacity Example Trial 1

b. Choose 2000 for the design flow:

    i. Try a flow between 2000 and 3000 to try to get closer to 3706.47

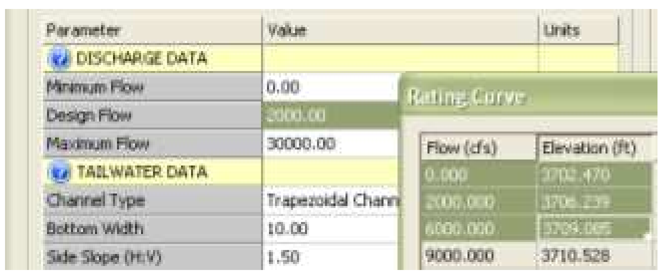


Figure B. 3: Channel Capacity Example Trial 2

c. Choose 2500 for the design flow:

    i. Try a little less.

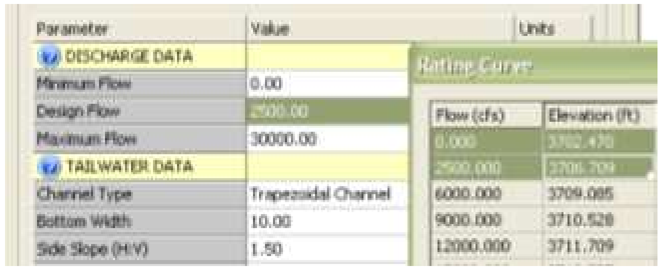


Figure B. 4: Channel Capacity Example Trial 3

d. Choose 2200 for the design flow:

   i. Close enough therefore capacity =2200

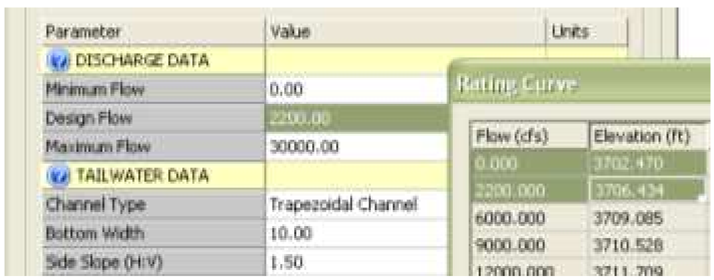


Figure B. 5: Channel Capacity Example Trial 4

Appendix C: Capacity of Conduits

1) Open Excel “Non Dummy Conduits” and/or “Non Dummy Culverts”
    a. You will fill in the capacity in the column “CFS” in the excel sheet first to keep track.
2) Open ArcGIS “ElPasoDrainage” and look for the next conduit or culvert on the excel sheet.
    a. You can do this by right-clicking on the “Conduits” layer or “Culverts” layer and selecting “Open Attribute Table”.
    b. Search for the reach by going to options and selecting “Select by Attributes”
    c. Create a formula for example, "CHNLNO" = 'CH1' or “CH”=’CH1’
    d. Right click on the highlighted records and select “zoom to selected”
    e. Use the “i” tool in GIS to select to click objects we want information on
3) Open HY-8 Software
4) Fill in Name = “REACH” in GIS
5) Fill in Discharge Data
    a. Minimum = 0
    b. Design Flow = take a guess
    c. Maximum Flow = any number > Design Flow
6) Fill in Tailwater Data as shown in GIS Database (This will be data of the channel downstream of the culvert or conduit)
    a. Channel Type(determined by side slope no.; ex. Rectangular if S1L and S1R = 0
    b. Bottom Width= W1_FT in GIS
    c. Side Slope = S1L or S1R in GIS

d. Channel Slope = (LONG_SLOPE in GIS (Longitudinal Slope)) divide by 100

e. Manning's n = 0.0130 for concrete, other check *Table 2. Manning's n Roughness Coefficients*

f. Channel Invert Elevation = UP_ELEV_FT in GIS (Upstream Elev., ft)

7) Fill in Roadway Data

a. Roadway Profile Shape = Constant Roadway Elevation

b. First Roadway Station=0

c. Crest Length = 100

d. Crest Elevation = any number > channel invert elevation about 10 to 20 feet above

e. Roadway Surface = paved

f. Top Width = 10 or 20

8) Fill in Culvert Data (This is data from culvert or conduit)

a. Name = "REACH" in GIS

b. Shape = "CU_TYPE" or "COND_TYPE" in GIS

c. Material = "MATERIAL" in GIS

d. If Box, Elliptical, or Arch;

i. span = "WIDTH" in GIS

ii. rise = "HEIGHT" in GIS

e. If Circular;

i. Diameter = "WIDTH" or "HEIGHT"

f. Manning's n = default

g. Inlet Type, Inlet Edge Condition, Inlet Depression = default

9) Fill in Site Data (this is data from culvert or conduit)
    a. Site Data Input Data = default
    b. Inlet Station = 0
    c. Inlet Elevation = “UP_ELEVE_FT” in GIS (Upstream Elev., ft)
    d. Outlet Station = “LENGTH” in GIS
    e. Outlet Elevation = “DN_ELEV_FT” in GIS (Downstream Elev.,ft)
    f. Number of Openings = “NO_OPENING” in GIS
10) Determine the elevation limit by adding height (H1_FT in GIS of upstream channel) to the Channel Invert Elevation (Invert Elevation in Site Data)
    a. In this case, H1_FT = 4 therefore limit elevation is 3679.77+=3683.77
11) Click Analyze Crossing
    a. Choose different numbers for Design Flow until you get close to the limit shown as “Headwater Elevation (ft)” in the “Summary of Flows at Crossing” window.
    b. Roadway Discharge must also = 0.

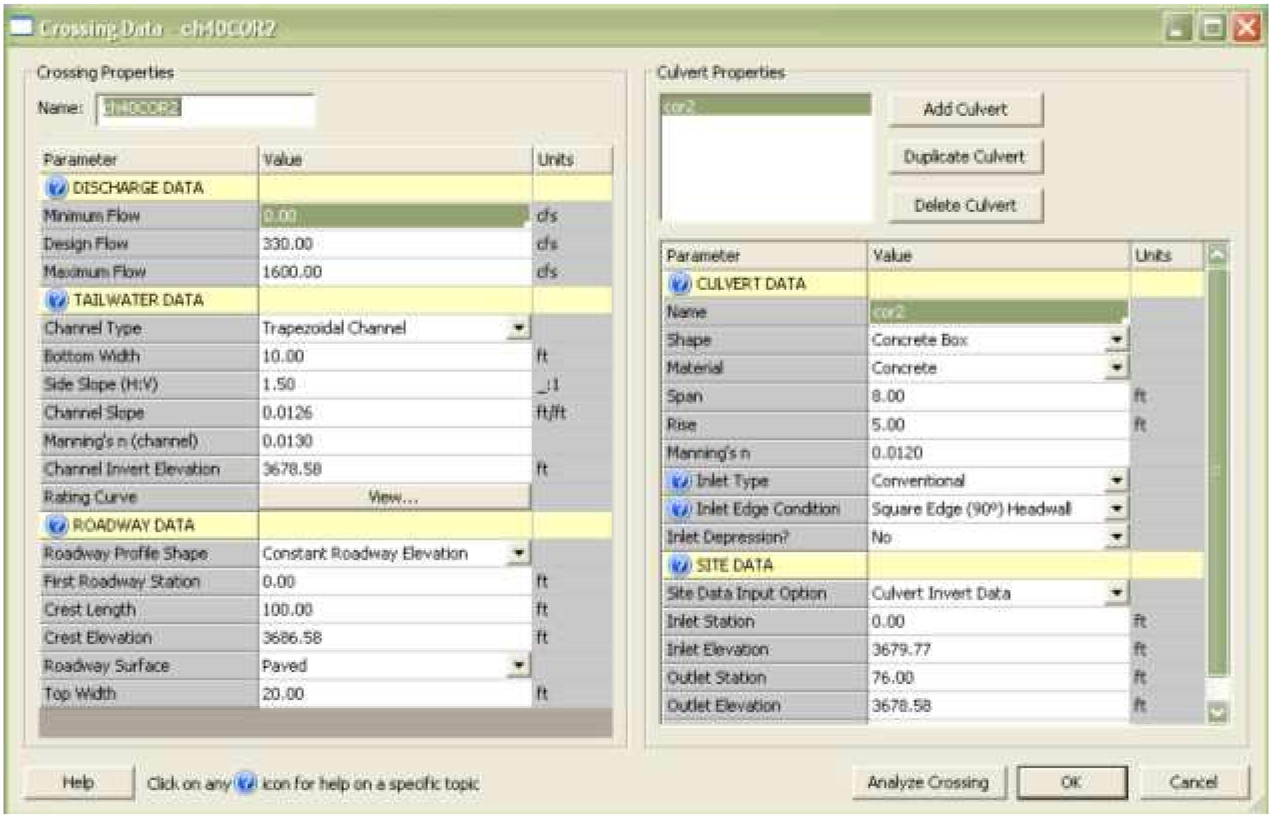


Figure C. 1: Conduit Capacity Crossing Data

12) Save the file under the culvert or conduit reach in Copy of ElpasoGIS-2\ElpasoGIS-2/Drainage\Hydraulic Analysis\CH#\REACHNAME

13) Example Copy of ElpasoGIS-2\ElpasoGIS-2/Drainage\Hydraulic Analysis\CH40\CH40-COR2

14) Type the capacity in the excel sheet and continue with the next culvert or conduit.

15) All Capacity will then be inserted in the GIS layer “Channels” under the field “CFS”

    a. Open ArcGIS ElPasoDrainage

    b. Right-click channels layer and select Open Attribute Tables.

    c. Click on the Editor Tool and Select Start Editing-Select the file which includes culverts and conduits shapefiles.

d. Fill in capacity in the column Capacity, cfs or CFS.

e. Save your edit frequently and BE CAREFUL NOT TO ERASE ANYTHING OR CHANGE ANYTHING ELSE.

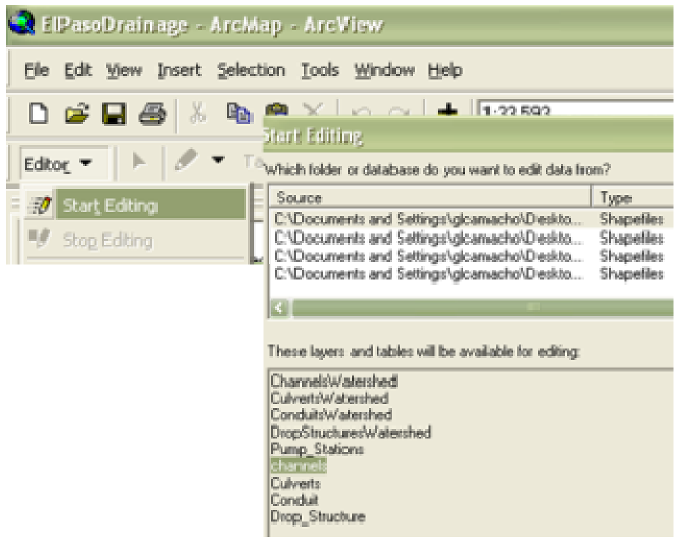


Figure C. 2: Conduit Capacity Start Editing

Example:

a. Choose 500 for design flow:

   i. The flow should be less than 500 because the elevation at 500 is too high (3685.05 in this case). Try the capacity closest to the limit elevation. i.e. 310.

Headwater Elevation (ft)	Total Discharge (cfs)	cor2 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
3679.77	0.00	0.00	0.00	1
3682.24	160.00	160.00	0.00	1
3683.65	320.00	320.00	0.00	1
3684.89	480.00	480.00	0.00	1
3685.05	500.00	500.00	0.00	1
3686.96	800.00	728.66	71.30	5
3687.32	960.00	766.22	193.34	4

Figure C. 3: Conduit Capacity Example Trial 1

b. Choose 310 for the design flow:

   i. Close enough therefore capacity = 310

Headwater Elevation (ft)	Total Discharge (cfs)	cor2 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
3679.77	0.00	0.00	0.00	1
3682.24	160.00	160.00	0.00	1
3683.57	310.00	310.00	0.00	1
3684.89	480.00	480.00	0.00	1
3686.17	640.00	640.00	0.00	1
3686.96	800.00	728.67	71.30	5

Figure C. 4: Conduit Capacity Example Trial 2

Appendix D: Performance Tool Conditions

Performance:

1. IF Performance > Capacity THEN P100ZONE or P500ZONE = 1
   a. 1 signifies a drainage structure that WILL NOT fail
2. IF Performance < Capacity THEN P100ZONE or P500ZONE = 2
   a. 2 signifies a drainage structure that WILL fail

Dummy:

3. IF Channel is Dummy THEN P100ZONE and P500ZONE = 9 AND UQ100 and UQ500 = 999999
   a. Urban Channels need Longitudinal Slope to perform peak discharge equations therefore a dummy longitudinal slope (999999) is how a dummy reach is defined.
      i. IF LONG_SLOPE = 999999 THEN
         1. P100ZONE and P500ZONE = 9
         2. (UQ100_CFS", "UQ500_CFS", "PERFORM100", "PERFORM500")= 999999
   b. Rural Channels don't need Longitudinal Slope to perform equations therefore
      i. IF H1_FT=999999" OR "WIDTH=999999" OR "HEIGHT=999999 THEN P100ZONE and P500ZONE = 9
4. IF Watershed is NA
   a. Rural: IF IA_IN=0 AND TYPE_1=RURAL THEN P500ZONE = 9
   b. Urban: IF IA_IN=0 THEN P100ZONE and P500ZONE = 9

5. IF Channel is Basin Type (Type_1) = Dam or Pond THEN
    a. P100ZONE and P500ZONE = 0
    b. (RQ100_CFS, RQ500_CFS, UQ100_CFS, UQ100_CFS, UQ100_CFS, PERFORM100, PERFORM500)= 909090
6. IF Capacity could not be calculated
    a. Capacity=0 THEN P100ZONE=9 AND P500ZONE = 9

Appendix E: El Paso GIS User Guide

1.0 Introduction

“El Paso’s GIS for Storm Water Drainage Infrastructure” (El Paso’s SWAD-GIS) was developed for the City of El Paso under the project “Enhancements to El Paso's GIS-based Infrastructure Management Systems.” SWAD-GIS integrates available data on the following storm water drainage infrastructure assets:

a. Major Concrete Lined Channels
b. Storm Water Conduits
c. Culverts
d. Drop Structures
e. Pump Station
f. Dams
g. Hydro Areas
h. Hydro Lines
i. Pond Areas
j. Manholes and Inlets
k. Watersheds

This guide is intended to facilitate the installation of files and usage of the tool by providing examples of basic capabilities of this GIS application. Special training in GIS is needed to use the full capabilities of this application.

A case study is shown to demonstrate the tools and system of the GIS file. Copper Field Industrial Center, located near the Hawkins I-10 exit and north of North Loop. Chapter 5 focuses on features and the use of tools in Copper Field Industrial Center.

Data

A CD-Rom and a DVD contains the data files for installation. The CD-Rom contains the files need to run ElpasoGIS-2 including photographs and HY-8 results. The DVD contains the aerial photos that form a GIS layer. The data include inventory (asset ID, name, drawing number (as defined in the City's map room), length, etc.), design and construction parameters (e.g., dimensions, shape, construction year, material type, etc.), digital photos (taken in October-November 2007), and links to the HY8 hydraulic analysis software. The case study, Copper Field Industrial Center, features are also located in the CD in the same manner as other channels. Features in Copper Field Industrial Center are numbered starting at 1000. These include channels, conduits, drop structures, inlets, manholes, and ponds. Additional tools were added to analyze drainage performance and to synch layers to facilitate editing. These additional tools are:

Update Layers Tool (when editing)

Hydraulic Performance Assessment Tool

Data fields were added to the Watershed layer as part of the hydraulic performance assessment tool. These fields include performance and performance class for the 100 and 500 year storms. Watershed data and drainage data were combined into ChannelsWatershed, ConduitsWatershed (includes conduits and culverts), and DropStructuresWatershed layers. Performance results are run and saved in these layers.

A data dictionary describing data fields of the Attribute Tables is available in Appendix A and is also provided in the Excel file “Data Dictionary for Attribute Tables.xls”. The file is available in electronic form in the folder “ElpasoGIS-2\Drainage\”.

Software Requirements

Windows XP

ArcGIS 9.2 or higher

C Drive with a minimum disk space of 4.7 GB

Software Setup

1. Copy all folders from the installation CD-ROM to Desktop or other location.
2. Copy all folders from the DVD to ElpasoGIS-2\Aerials\image catalogs or to another location such as an external hard drive. (Aerials are 4.0 GB).
3. To install the HY-8 hydraulic analysis software, double click on the file “setup.exe” in the folder “ElPasoGIS-2\Drainage\HY-8 7.1.0” Follow the HY-8 installation instructions. HY-8 is public-domain software developed by the Federal Highway Administration (FHWA). Further information on HY-8 can be found at www.fhwa.dot.gov/engineering/hydraulics/software/hy8/.

2.0 **Running SWAD-GIS**

To run SWAD-GIS, ArcMap 9.2 should be installed on your computer. Double-click on the file "ElPasoDrainage.mxd" in the folder "ElpasoGIS-2" or open it from the File menu of ArcMap as shown in *Figure E.* 1.

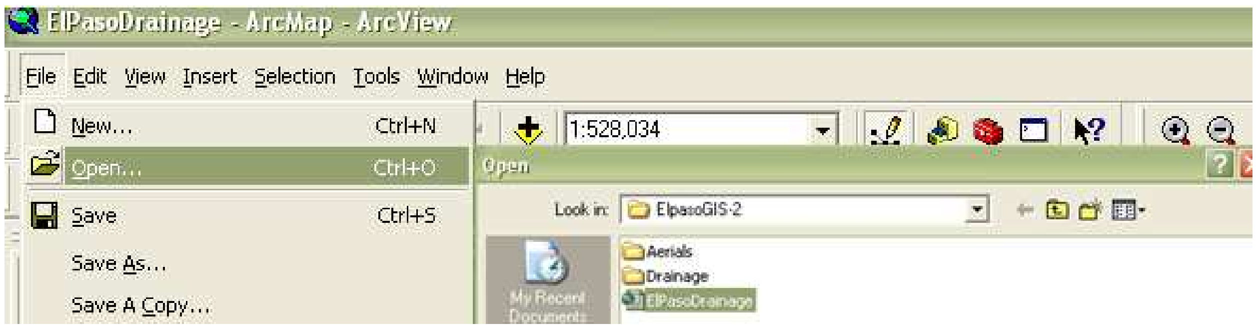


Figure E. 1: Opening ElPasoDrainage GIS File

If the aerial layer is not shown on the GIS map, the layer will have a red exclamation point next to the name of the layer as shown in *Figure E.* 2. Clicking on the red exclamation mark will open a new window to choose the location or source of the layer. This will be the location where the aerial data was saved on the computer.

Figure E. 2: Repairing Data Layers

Correcting libraries for GIS

After the ElpasoGIS-2 file is copied from CD to Desktop. Open "ElPasoDrainage File and click on Tools/Macros/Visual Basic Editor as shown below in *Figure E. 3*.

Figure E. 3: Selecting Tools/Macros for correcting libraries for GIS

From the Macro Editor Window shown in *Figure E.* 4 a) click on the Tools/Reference, b) remove the checkmarks for any references whose name contains "MISSING", and c) click on OK and close the Visual Basic Editor Window.

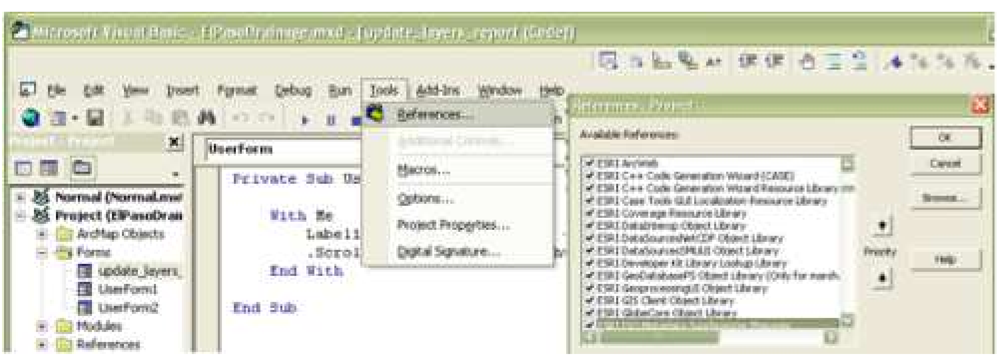
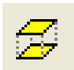


Figure E. 4: Selecting References from Visual Basic Program and Unchecking "Missing" Titles

3.0 **Tools**



Updating Layers Tool

The Updating Layers Tool is used to update changes to drainage layers such as Channels, Culverts, Conduits and Drop Structures. Any changes should be done in those layers. The "Update Layers Tool" will update "ChannelsWatershed", "ConduitsWatershed" and "DropstructuresWatershed" to match the changes. Either single layers or all layers can be chosen for updating as shown in *Figure E. 5*.

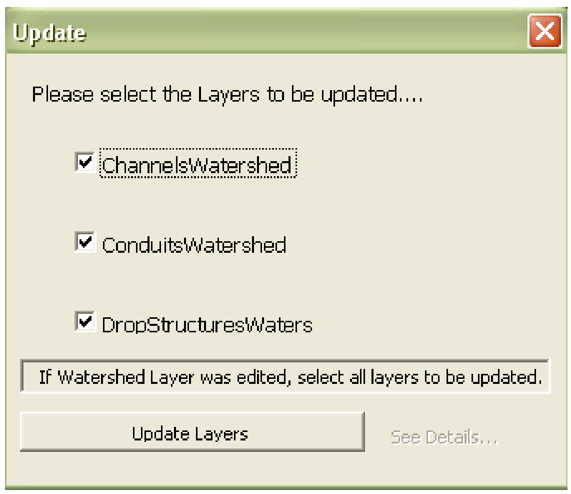


Figure E. 5: Updating Layers Tool

Performance Tool

The Performance tool will first ask for the Area to be used in the calculations, either cumulative area or individual area as shown in Figure E.6. The individual area is the watershed area directly intersecting the drainage. Cumulative area is the summation of upstream watershed areas and is manually added by the user into the watershed database under "Cumulative Area" to include upstream channels that may drain into the channel. The Performance tool, shown in Figure E.7, will then color code the "ChannelsWatershed", "ConduitsWatershed" and "DropstructuresWatershed" according to the failure possibility for a of 2-hour, 2-year rainfall.

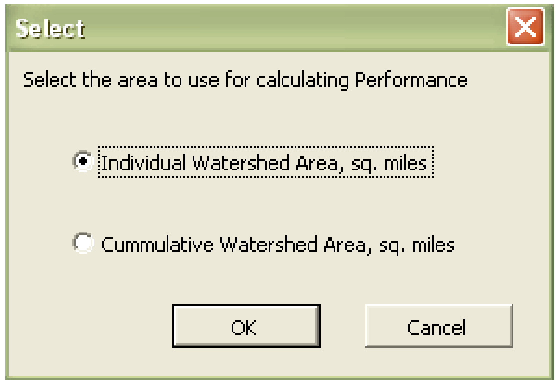


Figure E. 6: Performance Tool (Area)

Figure E. 7: Performance Tool

4.0 Examples for Displaying Data and Performing Queries

The layers are combined into group layers such as Inlets and Manholes, Drainage Assets, Pond Areas, Watershed, Street Map, and Aerials. This section provides examples for displaying data and performing queries.

Viewing Attribute Tables

To view all the layers in the group click on the plus sign next to the layer. Check the box to the left of each layer to view or uncheck to turn off the layer. To view an attribute table, a) select one of the drainage asset layers, b) right-click, and c) select "Open Attribute Table". An example is shown below in *Figure E. 8*.

Figure E. 8: Viewing an Attribute Table

Running Queries

To run a query click on "Options" from the Attribute Table and click on "Select By Attributes" as shown in *Figure E.9*. As an example shown also in *Figure E.* 10, [CHNLNO] = 'CH28a' selects and highlights Channel 28a.

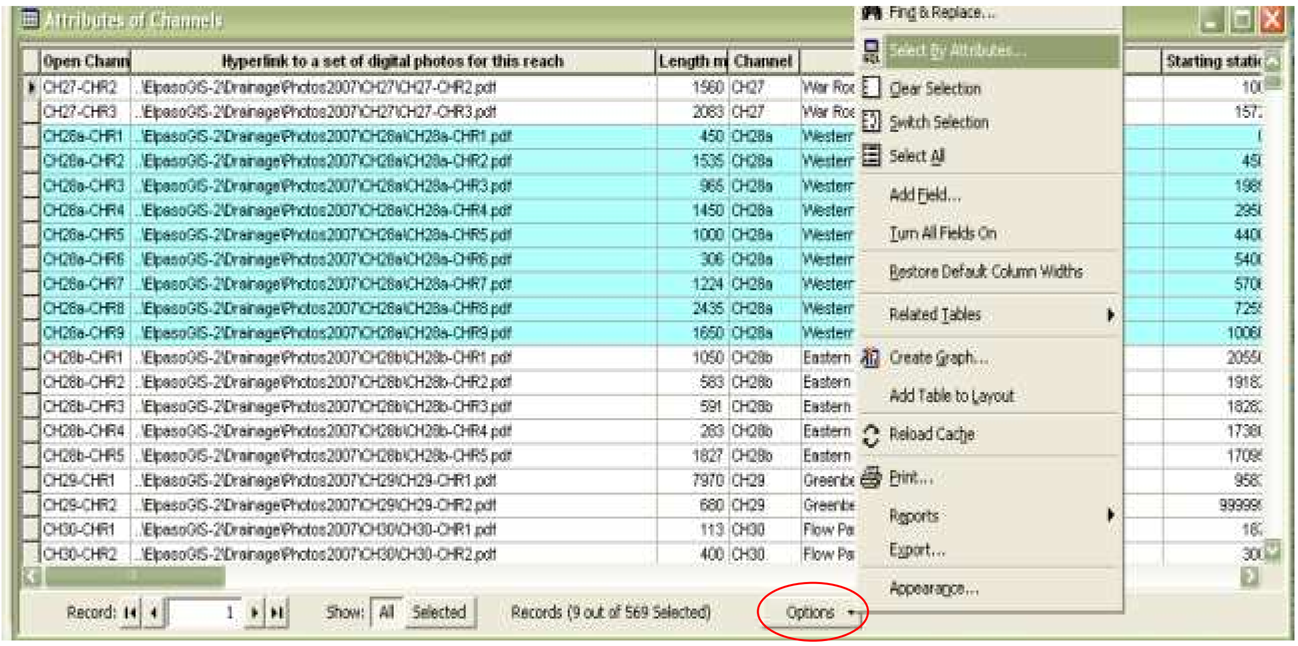


Figure E.9: "Select by Attributes" from Attribute Table for Queries

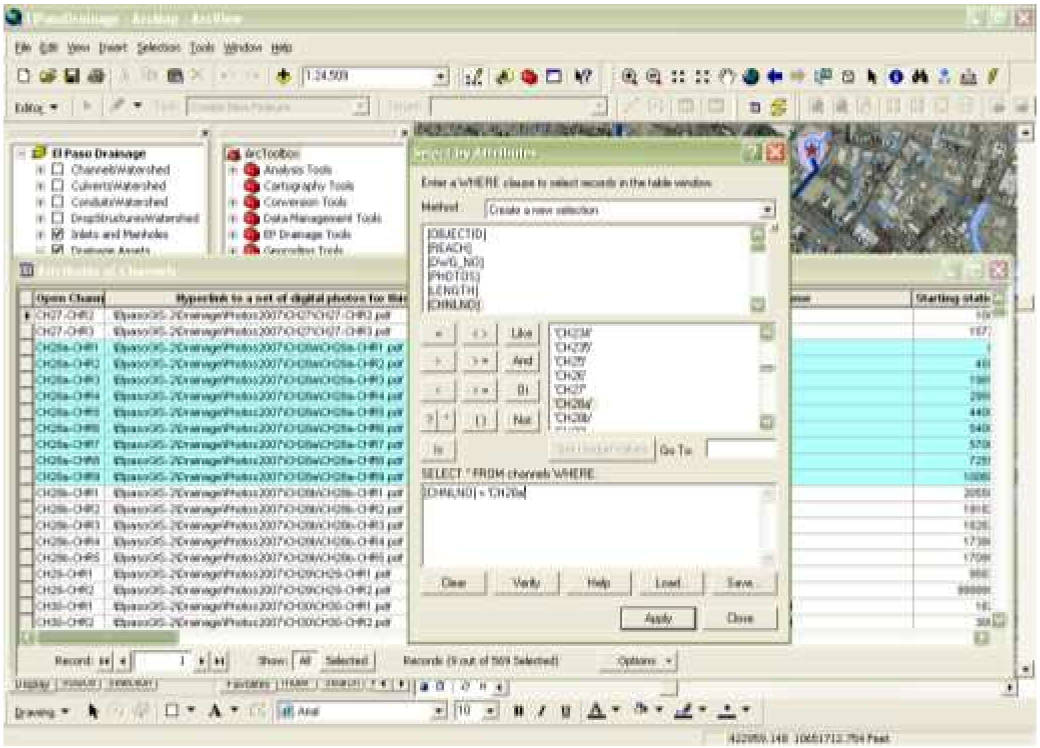


Figure E. 10: Query Search

To zoom to a certain set of records in the attribute table, a) highlight the desired records, b) right-click, c) position the mouse on the left edge of the table, d) select “Zoom to Selected”, and e) minimize or close the Attribute Table. An example is shown below in *Figure E.* 11.

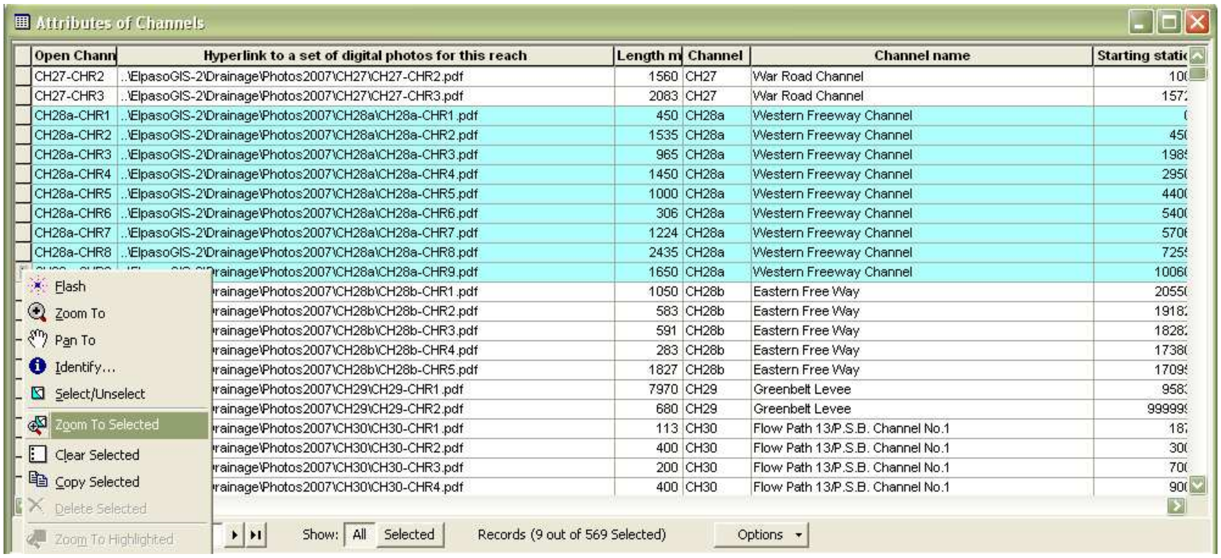


Figure E. 11: Zooming into the highlighted query search on the GIS map

Viewing Existing Data

To view existing data on an asset (channel reach, pump station, culvert, etc.), a) click on the Identify button  and b) point to the desired asset on the map and then click. An example is shown in *Figure E. 12.*

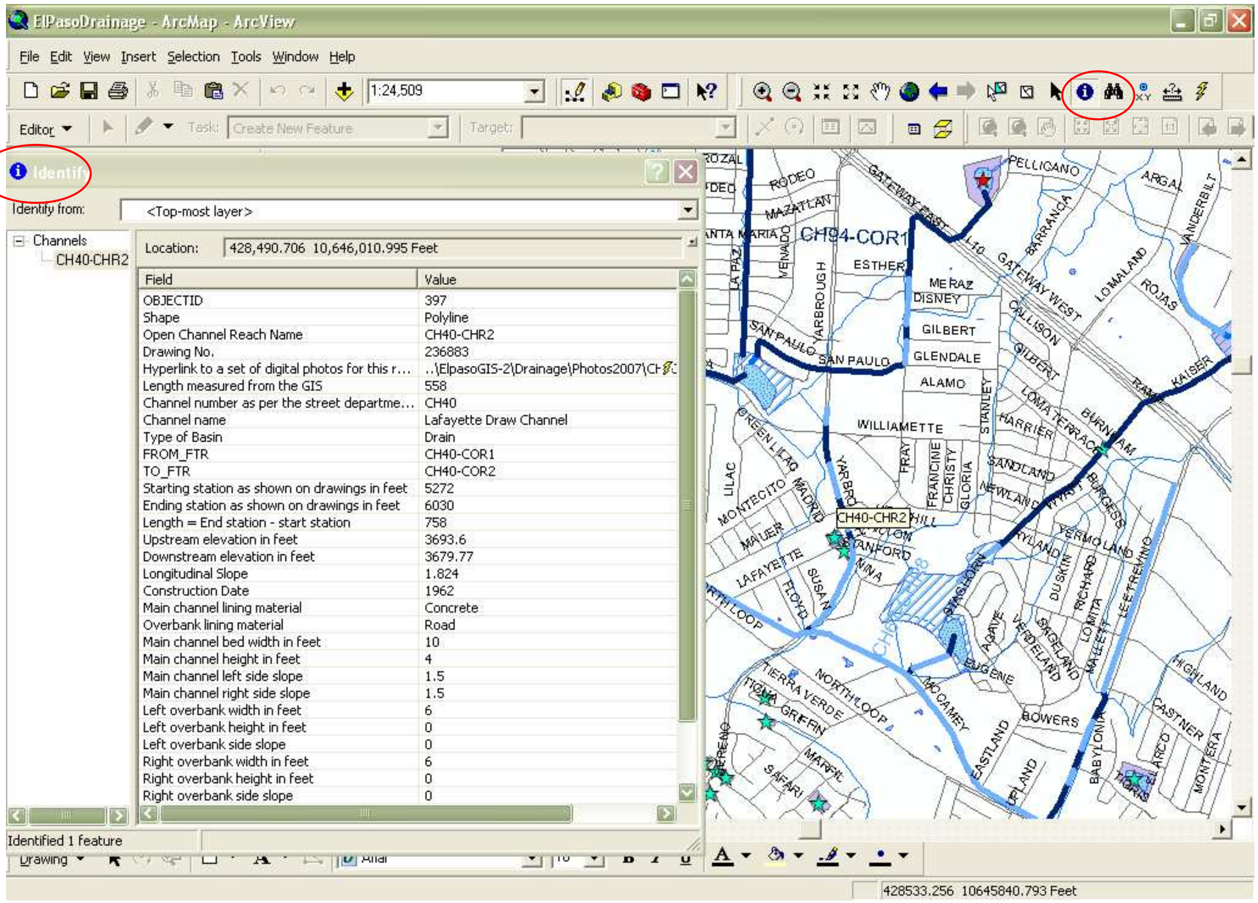


Figure E. 12: Viewing Existing Data Using the Identify Function

To view current photos of the selected asset, click on the “Photo” record in the Identify Table. An example is shown in *Figure E.* 13.

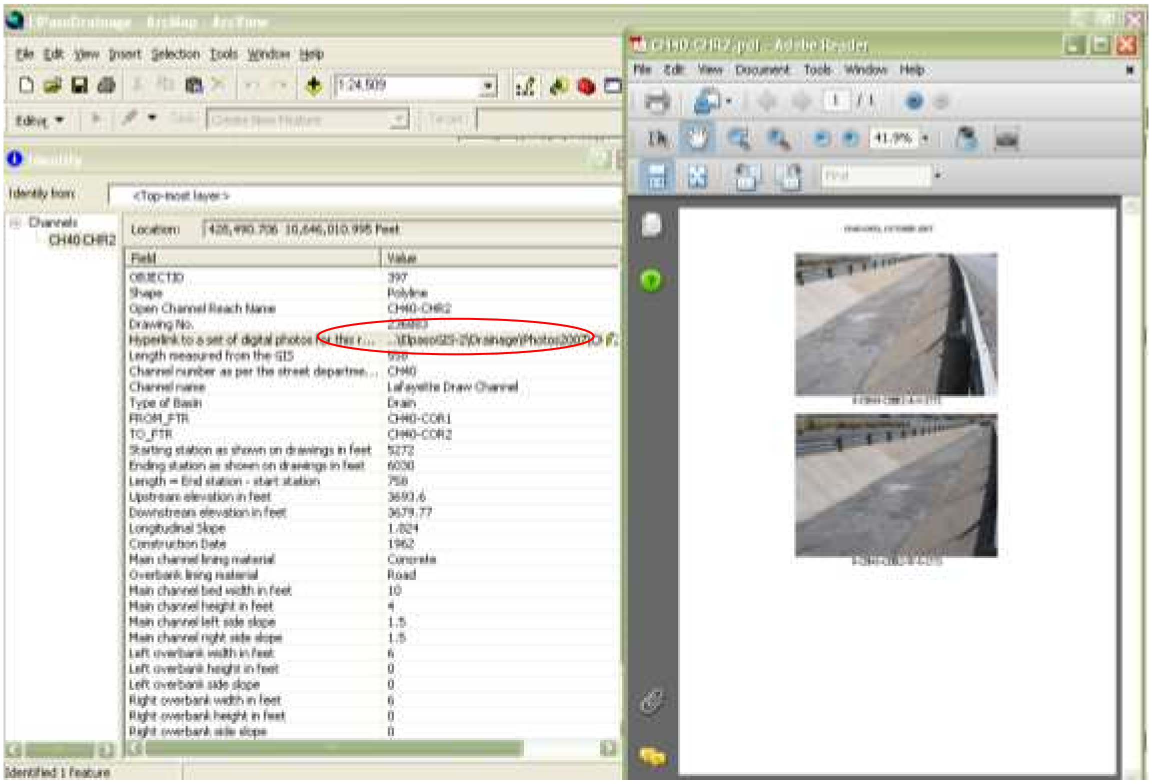


Figure E. 13: Viewing Photographs in the Identify Table

Viewing the Hy8 hydraulic analysis software, click on the "Analysis" record in the Identify Table. An example is shown in *Figure E.14*.

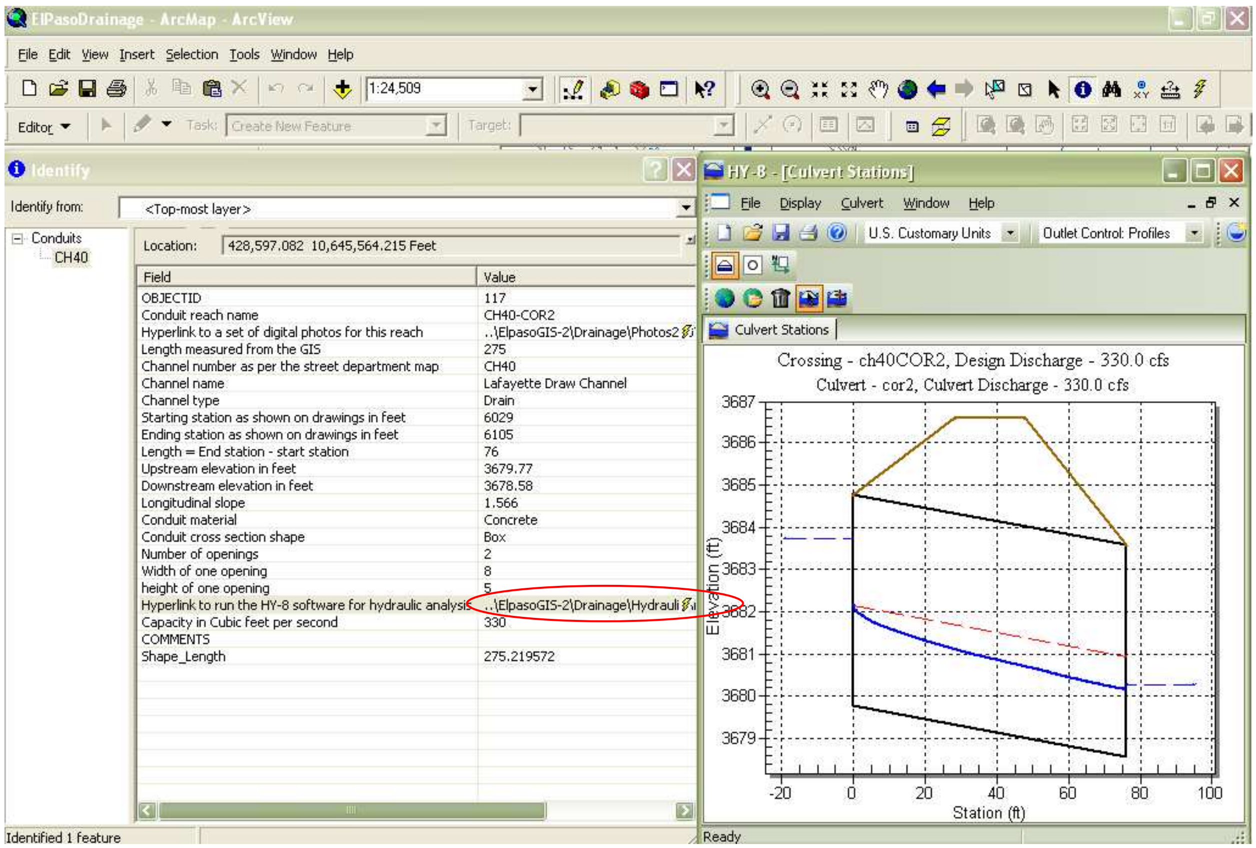


Figure E.14: Viewing HY-8 capacity results

5.0 **Copper Field Industrial Center Example**

Copper Field Industrial Center was chosen by the City of El Paso as an example area that contained all features such as channels, conduits, drop structures, inlets, and manholes. Data for this area was obtained from map drawings 600268 and 238189 from the City of El Paso. Features from these recent maps were added to the ElPasoDrainage GIS file with the Editor tool by drawing the line and point features and adding the data available in the Attribute Table. This section shows how to add new features to ElPasoDrainage GIS file and the use the Performance and Update Layers tools.

Start Editing

Editing is performed using the “Start Editing” function in the “Editor” tool, as follows:

1. Select the personal geodatabase containing all the layers and click “OK” and “Start Editing” as shown in Figure E.15.
2. The task for editing should be selected as “Create New Feature” and select the “Target” as the type of feature that will be added such as “Channels,” as shown in *Figure E.16*.
3. The pencil tool is then selected to begin drawing the feature. At the end of the segment the right mouse button is clicked and “Finish Sketch” chosen. In this case we are adding the channel circled in red in Figure E.16.
4. The database table can be entered by right-clicking on the new layer, in this case “Channels” and selecting “Open Attribute Table,” as shown in *Figure E. 17*.
5. When editing is finished, save and stop editing from the “Editor” tool.
6. The “Updating Layers” tool should then be used to reflect these changes in the Performance group of layers, “ChannelsWatershed”, “ConduitsWatershed”,

“DropStructuresWatershed”. When the new features have been reflected in these layers then the “Performance” tool can be run to determine the performance of the system with the new structures included.

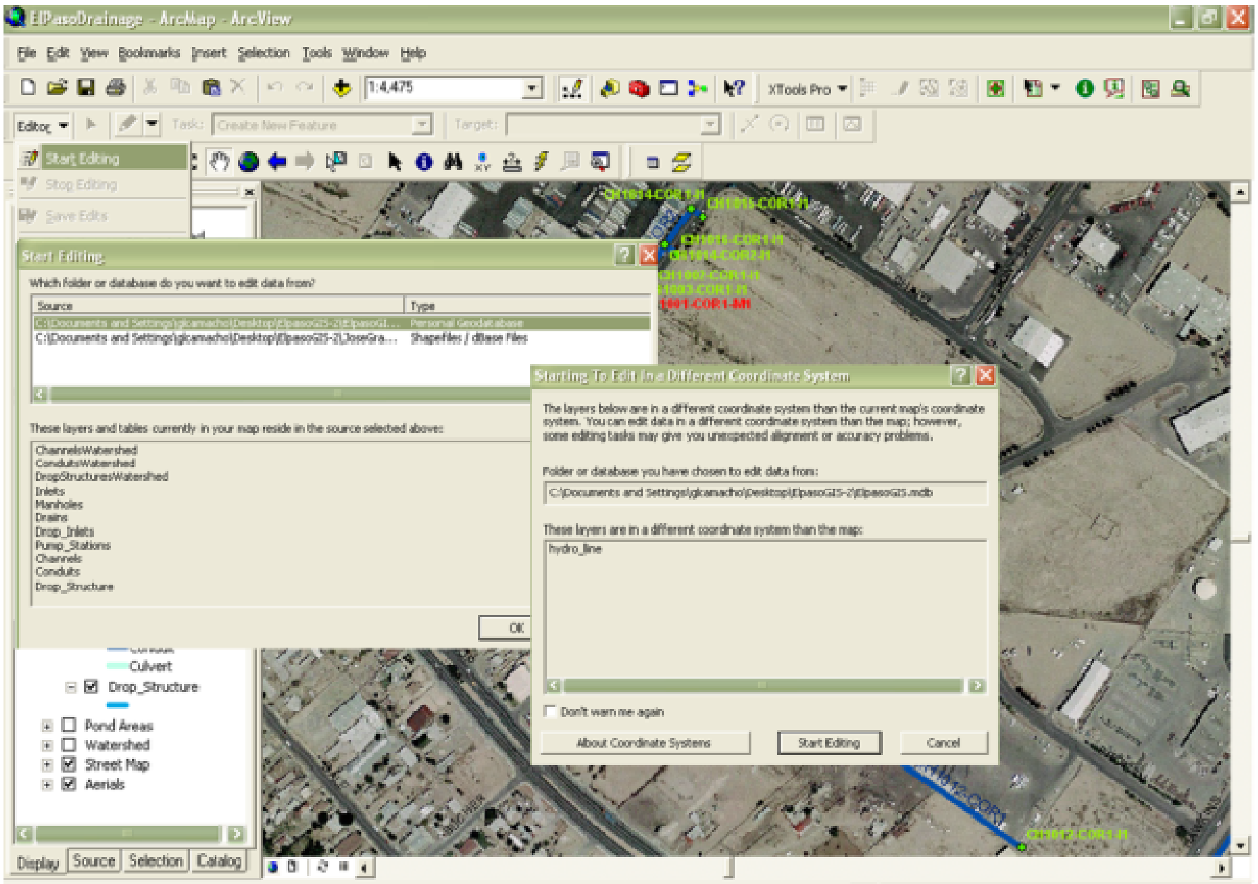


Figure E.15: Editing Tool

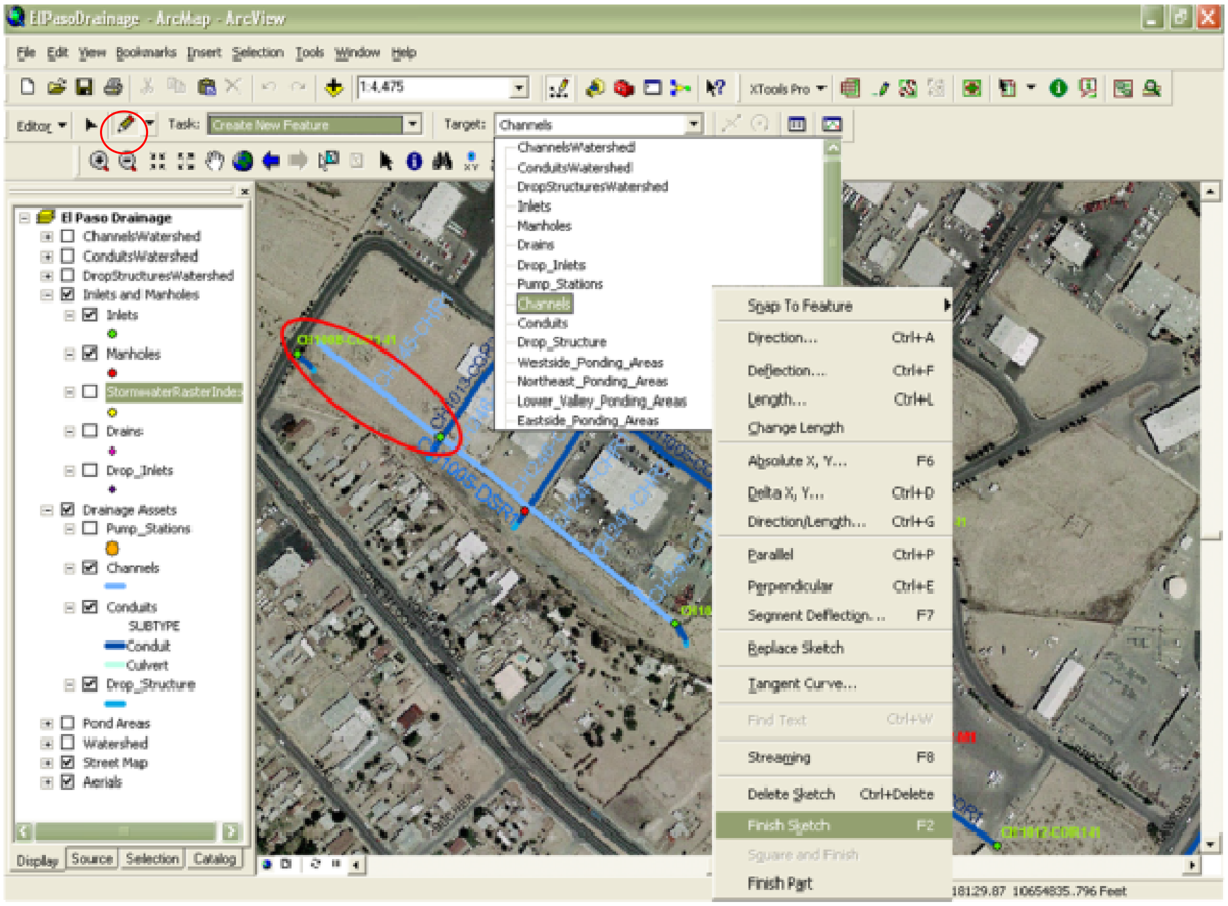


Figure E.16: Creating New Feature

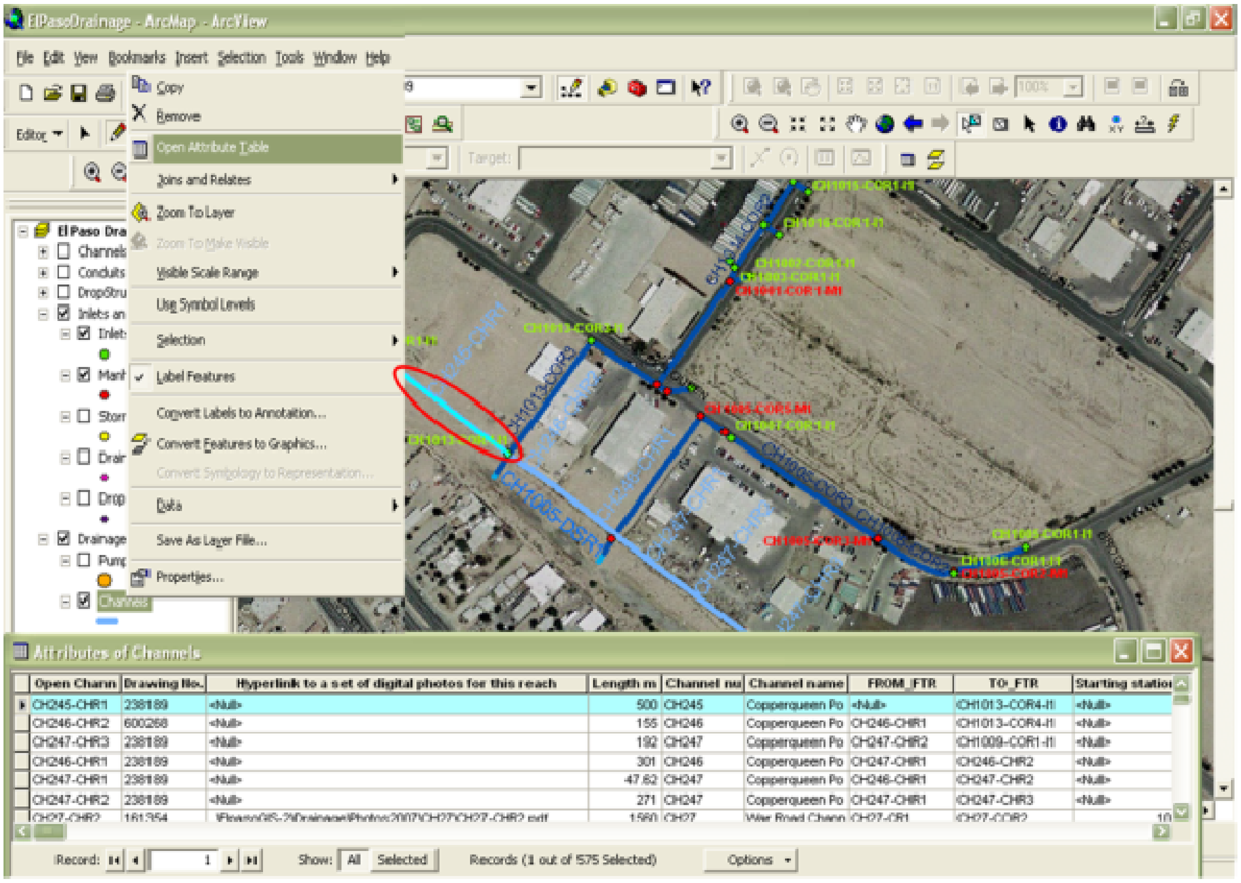


Figure E. 17: Adding data to the Attribute Table

Preparing and Adding Photos

A very simple process to generate the PDF Image Files (PIF) is explained thoroughly in Appendix B. The PDF's are to be included into the ArcGIS database with the editor tool in the same manner explained previously. A hyperlink to the photo will be added to the database as follows.

In the "Attribute Table" the user should edit the content on the "Photo Hyperlink" column and then click "Save Edits" as explained before. It is important to enter the route correctly; otherwise the platform (GIS) will not be able to find the resource. The template for the route that should be

entered is "..\ElpasoGIS-2\Drainage*Photosfolder\Channelnumber\PDFfilename*". An example for "Inlets" is portrayed in Figure 5.4. The exact "Photo Hyperlink" for the selected inlet is "..\ElpasoGIS-2\Drainage\Photos2007\CH1000\CH1000-COR1-I1".

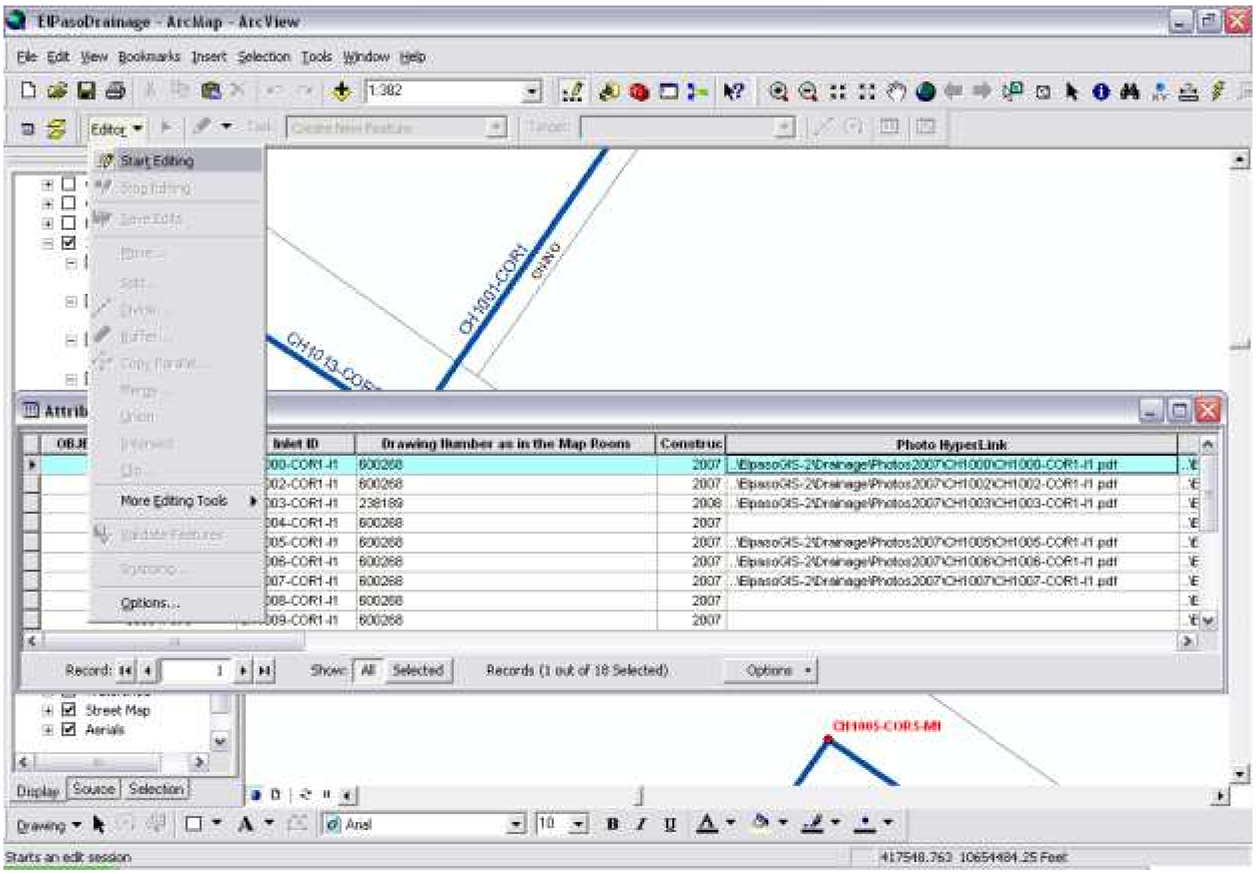


Figure E. 18: Editing and Saving Changes to Copper Field Industrial Center

Finally if the process was carried out correctly, the user should be able to see the lightning symbol in the right-most side of the "Photo Hyperlink" value box in the "Identify" window as shown in Figure 5.5.

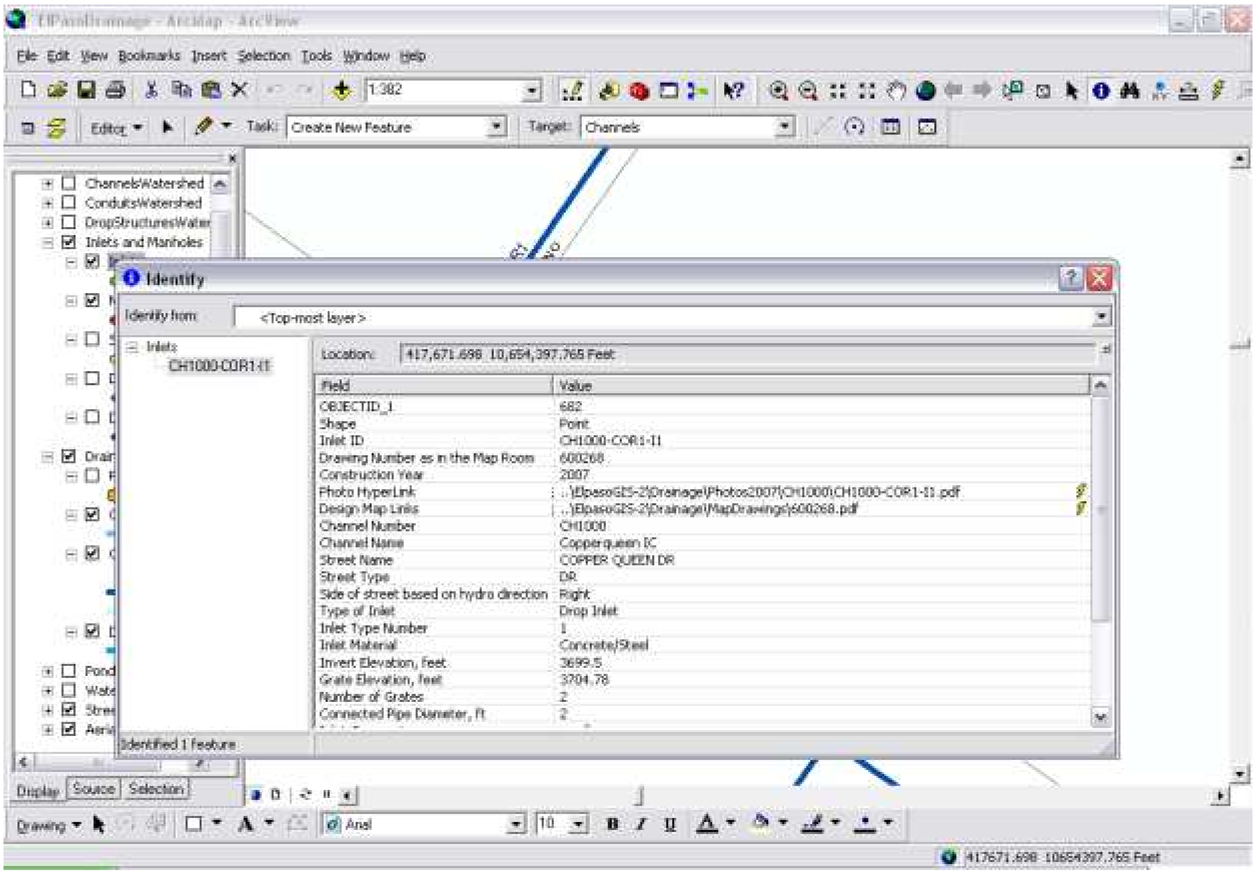


Figure E. 19: Copper Field Industrial Center Final Check

Editing the Watershed Layer

The Watershed Layer may need to be modified to determine the correct area for performance calculations. The watershed layer is formed of polygons and has topology rules so the method to edit is slightly different than for the drainage layers. Editing can be completed by "Cutting Polygons" and "Modifying the Polygon Edge". Figure E. 20 shows a watershed area in Copperfield Industrial Center that needs to be divided into smaller watershed areas as shown in the design map in *Figure E. 21*. The following sections will show the steps to forming a new smaller watershed area as circled in red.

Figure E. 20: Industrial Center Watershed Area to be Edited

Figure E. 21: Design Drawings for Copperfield Industrial Center Watershed Area

Cutting Watershed Polygons

While in editing mode, be sure to select “Cut Polygon Features” for the “Task” and “S_HydroBasin_CoEP” as the “Target” layer as shown in *Figure E. 22*.

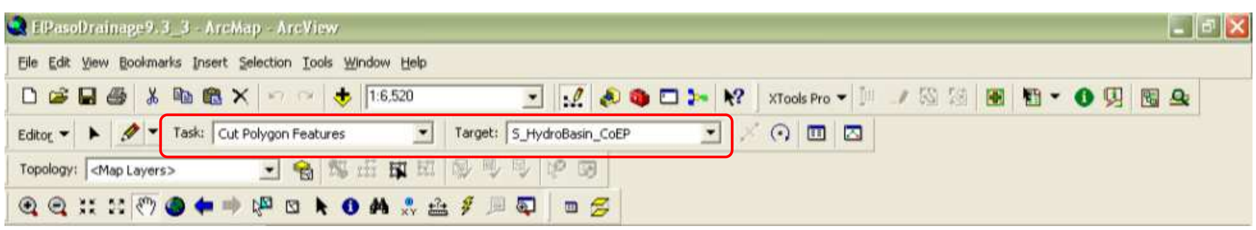


Figure E. 22: Tasks to be selected for Cutting Copperfield Industrial Center Watershed Polygons

Select the “Edit Tool” arrow next to the “Editor” drop down menu and click inside of the watershed polygon that is to be cut. The watershed polygon will be highlighted in cyan as shown in *Figure E. 20*. Next select the “Sketch Tool” Pencil to draw a line segment where the polygon will be divided as shown in *Figure E. 23*. When the sketch line closes into a polygon again, the

sketch is finished by right-clicking and selecting “Finish Sketch”. The bigger polygon is now divided into two sections as shown in *Figure E. 24*. The database will add duplicate record with the same data of the cut polygon but with the appropriate shape area.

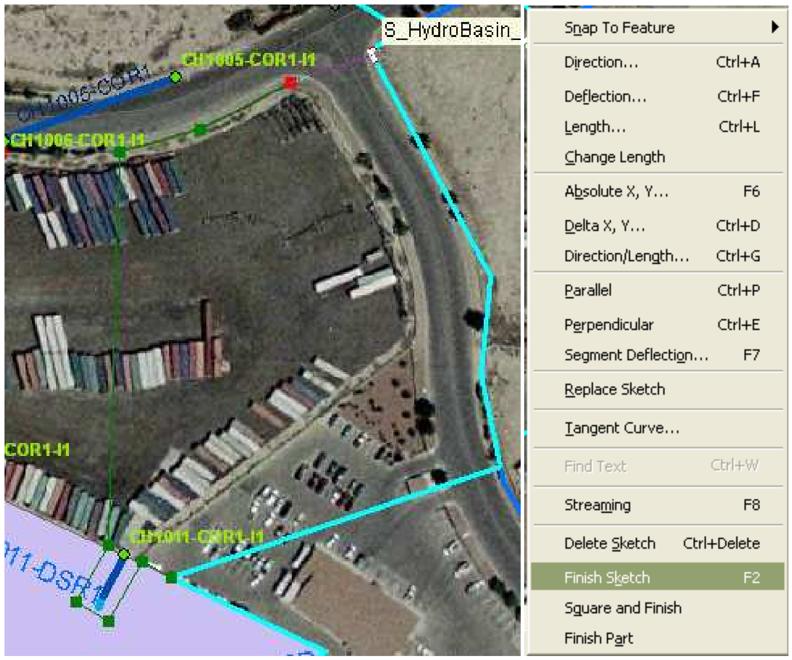


Figure E. 23: Using the Sketch Tool to Cut Copperfield Industrial Center Watershed Polygon

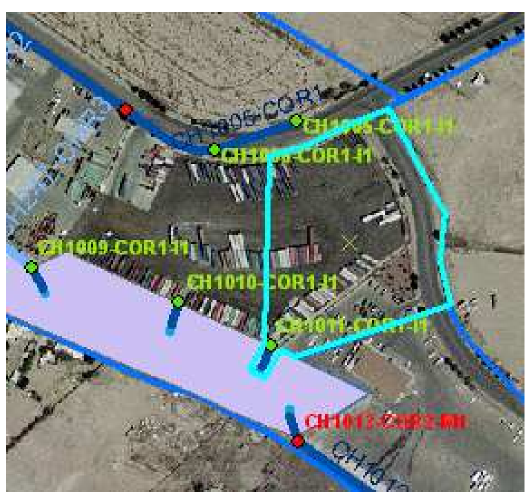


Figure E. 24: Cutting Copperfield Industrial Center Watershed Area Result

Merging Watershed Polygons

The watershed polygon areas can also be merged together to join two watershed areas as one. In editing mode, select "Create New Feature" for the "Task" and "S_HydroBasin_CoEP" as the "Target" layer shown in *Figure E. 25*. Using the "Edit Tool" and using the shift key, click in the center of each polygon that is to be merged. Under the Editor drop down menu, select "Merge" and click "OK" as shown in *Figure E. 26*. Stop and Save Edits.

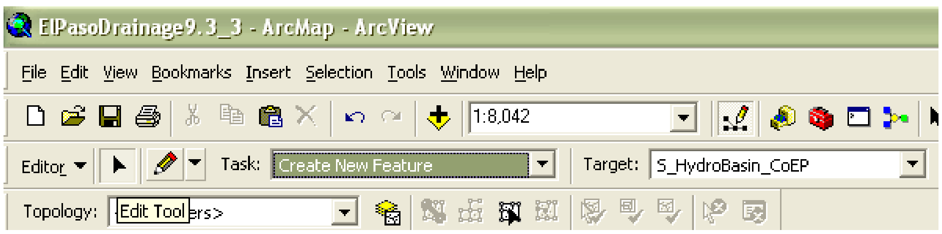


Figure E. 25: Tools for Merging Watershed Polygons in Copperfield Industrial Center

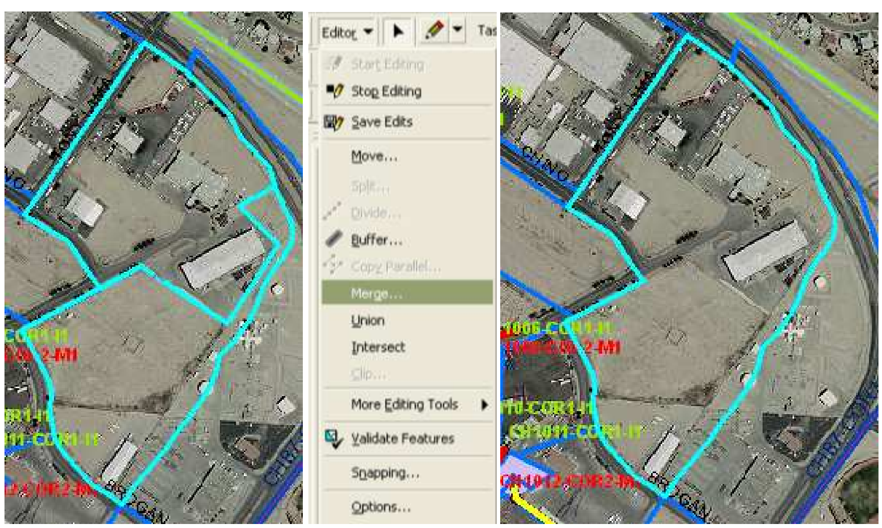


Figure E. 26: Merging Watershed Polygons in Copperfield Industrial Center

Modifying Polygon Edges

The watershed polygon can be modified when an edge needs to be slightly modified by using the topology tool. The "Topology" tool can be added to the toolbars by selecting "View/Toolbars/Topology" as shown in *Figure E. 27*. Once the Topology tool is visible, be sure to select "S_HydroBasin_CoEP" as the "Map Topology" as shown in Figure E. 29. Select the "Topology Edit" tool and select "Modify Edge" as the "Task" in the Editor tool as shown in Figure E. 28. Double-click an edge. The edge will turn purple with green vertices. These vertices can be moved to modify the line as shown in *Figure E. 30*. If a new vertex is desired, right-click on the line and select "Insert Vertex". Stop and Save Edits when finished.

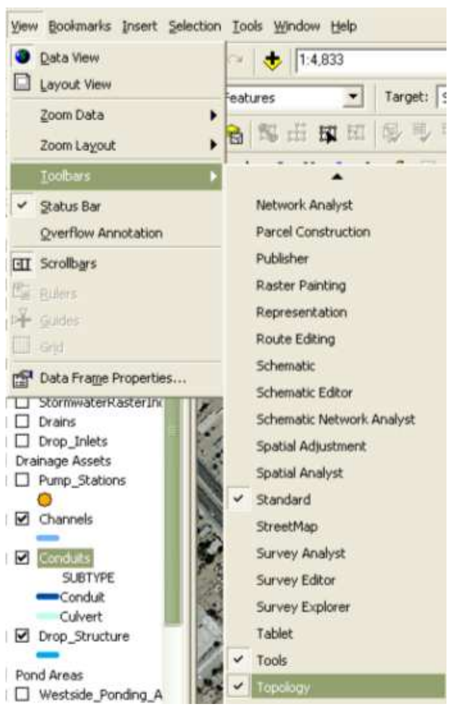


Figure E. 27: Selecting Topology Tool for Modifying Copperfield Industrial Center Watershed Layer

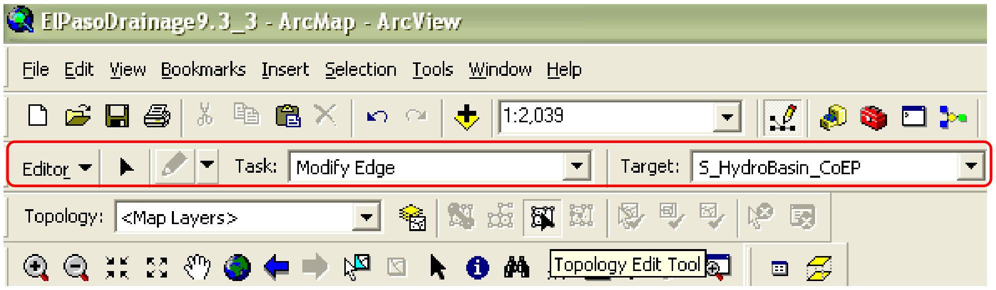


Figure E. 28: Selecting "Topology Edit Tool"

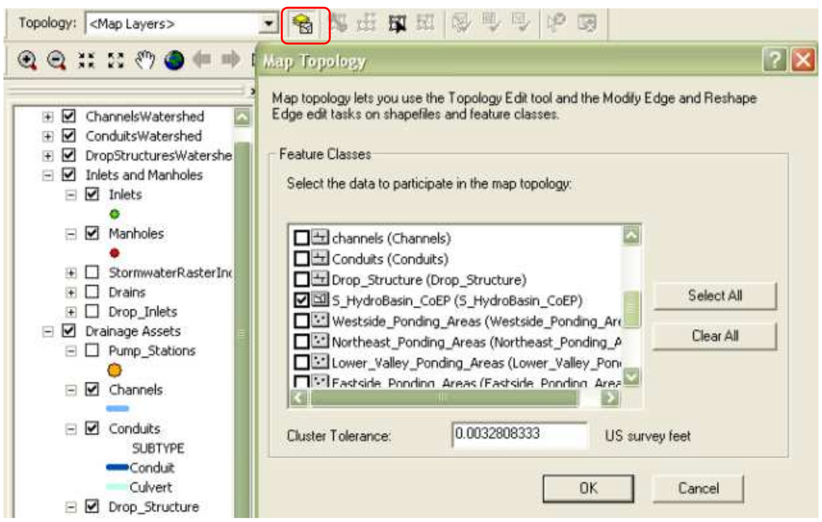


Figure E. 29: Selecting S_HydroBasin_CoEP as "Map Topology" Layer

Figure E. 30: Using Topology Edit Tool to Modify Copperfield Industrial Center Watershed

Viewing Results

To view the results of the “Performance” tool, “ChannelsWatershed”, “ConduitsWatershed”, and “DropStructuresWatershed” layers need to be checked to appear on the map. The capacities for these features were available in the design maps so no HY-8 analysis was performed to determine capacity. The results for the 1 inch 2-hr, 2-yr rainfall event for the Copper Field Industrial Center are shown in *Figure E. 31*. Specific data for each feature can be seen as explained above with the GIS “identify” tool or by viewing the attribute table of each layer. As an example, *Figure E. 32* shows the data of CH1005-COR1-I1 obtained with the “identify tool” and the links available for the design maps and photos which can be opened by clicking on the links.

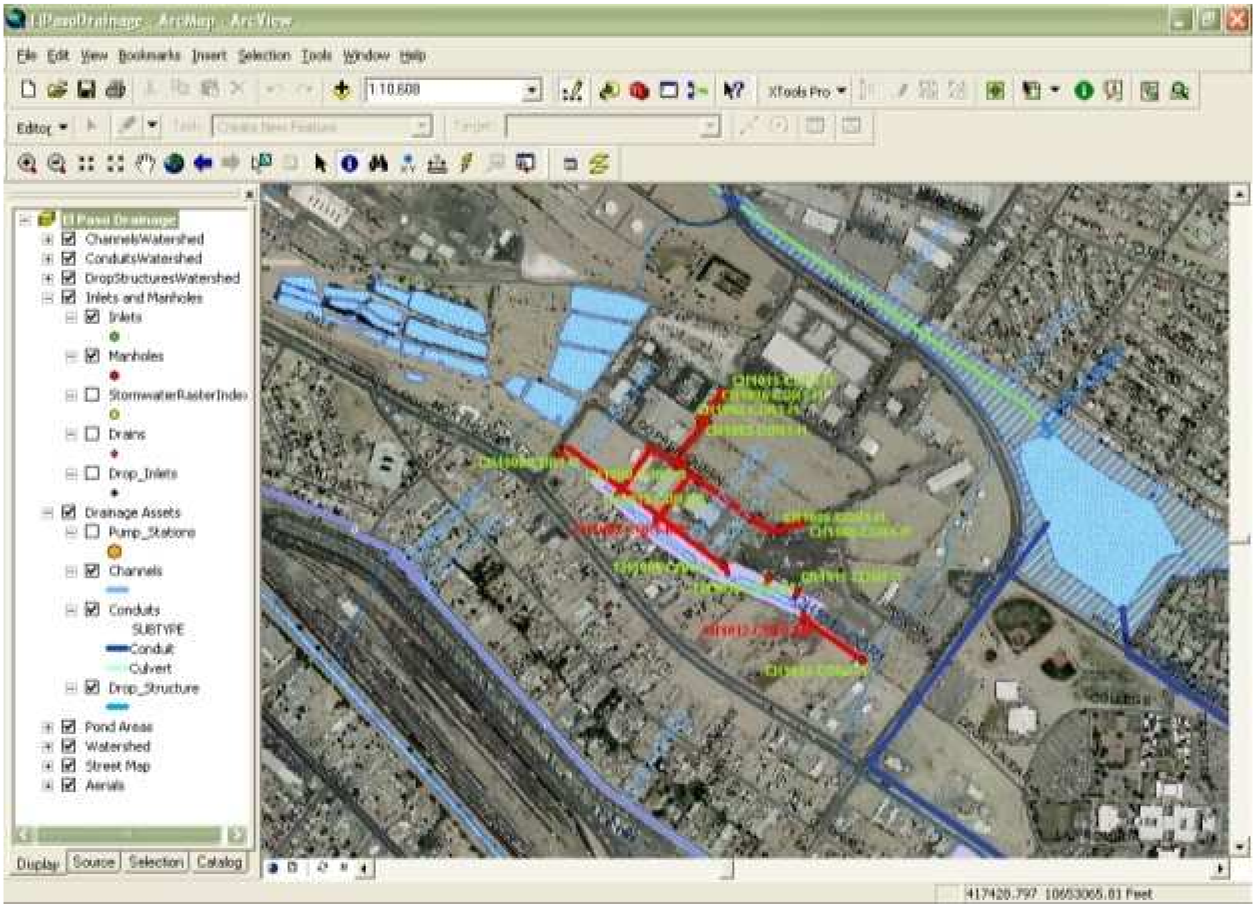


Figure E. 31: Copper Field Industrial Center Performance Result with 1 inch RI2

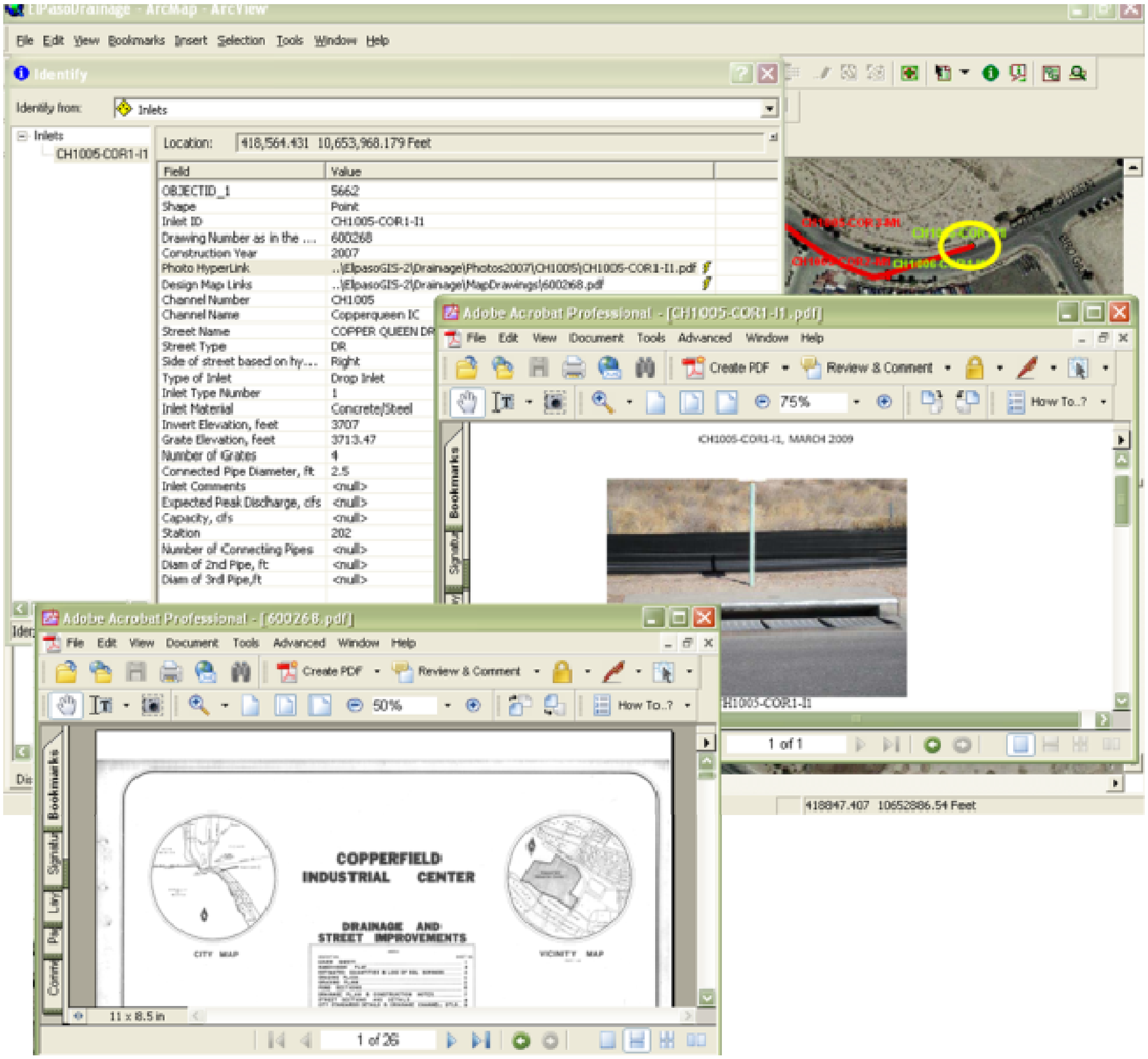


Figure E. 32: Viewing Copper Field Industrial Center Result

Vita

Gema L. Camacho was born in Chihuahua, Mexico to Josefina Lechuga de Camacho and Jose Francisco Camacho Chavez to complete the family of six. When she was four years old the family moved to El Paso, Texas, where she started her education and continued her higher education at the University of Texas at El Paso (UTEP). Ms. Camacho completed her Bachelor's Degree in Civil Engineering in 2007 and achieved a Masters Degree in General civil Engineering from UTEP in May 2009. During her studies, Ms. Camacho worked at UTEP as a Research Assistant to various professors. Her most recent project was the development of a GIS storm water drainage asset management system for the City of El Paso working under supervision of Dr. Carlos M. Chang and Dr. Nasir Gharaibeh. Ms. Camacho also had a research internship in Drexel University and worked on "Evaluating in home water purification methods for communities in Texas on the border with Mexico". Her research work has been published in the Pan American Health Organization (PAHO) Journal and the Transportation Research Board (TRB).

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