City of Houston

SWEET Roadside Ditch Evaluation

Technical Report

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EXECUTIVE SUMMARY

The Stormwater Evaluation Enhancement Tool (SWEET) is a Geographic Information System (GIS)-based computer tool developed for Public Works & Engineering (PWE) to identify and prioritize areas within the City of Houston (CoH) that have drainage and flooding issues. The SWEET evaluates drainage requirements by assessing seven primary categories of need: 1) drainage effectiveness, 2) damage costs from structural flooding, 3) impacts to emergency response and critical infrastructure, 4) impacts to traffic mobility, 5) impacts to the community, 6) impacts to environmental and historical resources, and 7) barriers to economic development. The output from the SWEET identifies and organizes data for completion of Extended Feasibility Studies (EFS) which will lead to specific scopes of work for preliminary engineering projects to be programmed into the Five-Year Capital Improvement Plan (CIP). The first phase of the project, which included the design and development of the SWEET software, has been completed.

This next phase of the SWEET project continues and builds upon the efforts developed in previous phases. As authorized by the CoH, Klotz Associates has further enhanced the SWEET toolbar data used in processing and further developed methodologies to: prioritize drainage needs; develop areas for EFSs, and categorize and rank proposed projects for programming in each year's update to the five-year CIP.

This specific technical report addresses the integration of the city-wide drainage ditch network into a data-set that can be utilized in the SWEET software. In general, Klotz Associates has utilized roadside ditch data that was gathered by a survey team and developed various algorithms and methodologies to provide the CoH with a Level of Service (LOS) for each delineated watershed area draining to a corresponding ditch. This LOS coverage includes areas draining to a roadside ditch network and identifies the adequacy of the roadside ditches to carry the 2-year, 5-year, 10-year, 25-year, and 100-year rainfall events. This technical report was not developed to present the results of the analysis, but simply to document how the analysis was performed, the assumptions that were made, and the issues and remedies that will likely surface upon any other update. The specific methodology used to determine the LOS for each area is outlined in this technical report.

SECTION 1 Introduction

1.1 Authorization

The development of this SWEET Roadside Ditch Evaluation for the CoH was authorized by agreement between the CoH and Klotz Associates.

1.2 Background

Klotz Associates created the SWEET, a GIS-based computer tool developed to assist the CoH in the identification and prioritization of areas in significant need of drainage improvements and flood reduction across the city. The SWEET is a planning tool intended to focus CoH storm water planning on areas where various reports and conditions indicate that storm water infrastructure improvements are needed to address drainage or flooding problems. The SWEET is an adaptable, updatable, objective, and dynamic tool which enhances decision making, ultimately leading to the structuring of a CIP for drainage projects across the CoH. The SWEET combines physical, historical, projected, and technical data from a variety of sources with stakeholder information to objectively develop recommendations for prioritizing drainage and flooding problems areas. These recommendations are then used to provide additional information for objective decision making by the CoH leaders.

Klotz Associates was hired to perform an engineering analysis in the form of a technical report documenting the procedural steps used to determine the LOS for each area draining to a roadside ditch. This specific technical report addresses the integration of the city-wide drainage ditch network into a data-set that can be utilized in the SWEET software. In general, Klotz Associates has utilized roadside ditch data that was gathered by a survey team (hired by the CoH) and developed various algorithms and methodologies to provide the CoH with a LOS for each delineated watershed area draining to a corresponding ditch. This LOS coverage includes areas draining to a roadside ditch network and identifies the adequacy of the roadside ditches to carry the 2-year, 5-year, 10-year, 25-year, and 100-year rainfall events.

1.3 Test Case

The CoH instructed Klotz Associates to first perform the analysis on the area named 455G. Klotz Associates developed a working methodology on this test case area. Once the code was proven to be useful in accurately determining the drainage areas, the test area was then expanded to DEM 095G32 and the process was repeated. The Figure below shows the two test case areas.

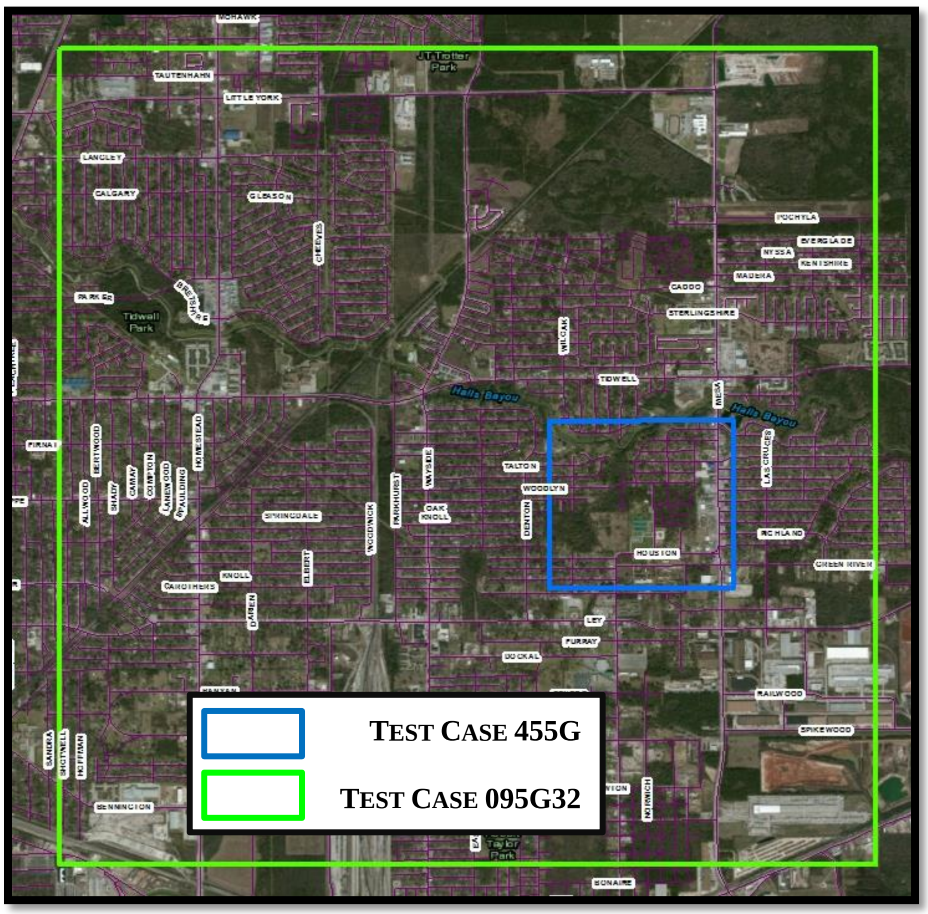


Figure 1: Test Case Areas

1.4 Project Boundary

The project limits for this analysis included all surveyed roadside ditch data provided by the CoH to Klotz Associates. The roadside ditches analyzed during this process generally included areas within the CoH city limits and some ditches within the CoH Extraterritorial Jurisdiction (ETJ) boundary. Klotz Associates performed the computations necessary to determine roadside ditch capacity for all data provided by the CoH, not only for data within the CoH and ETJ boundary. The Vicinity Map Figure below shows the surveyed roadside ditch network in relation to the CoH City Limits and the ETJ Boundary.

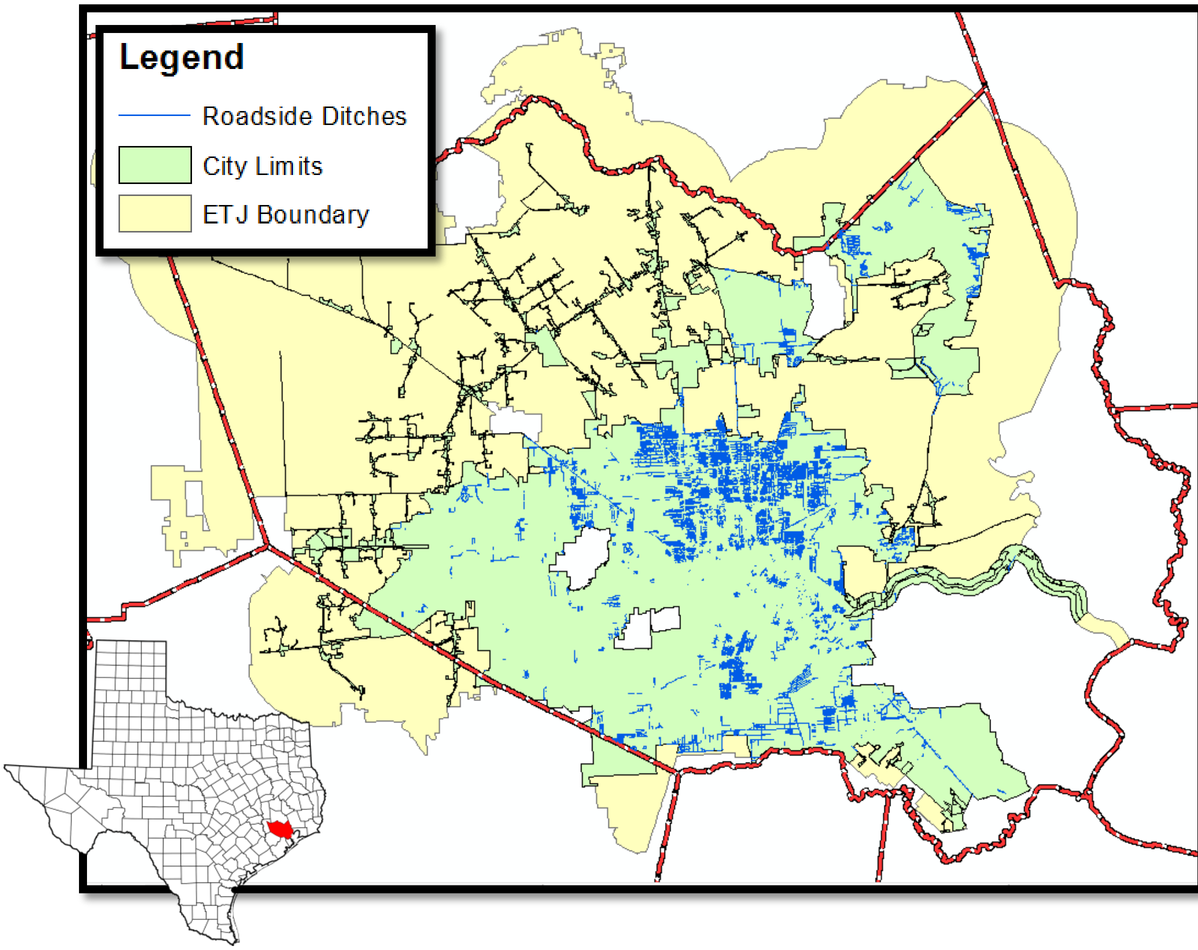


Figure 2: Vicinity Map

SECTION 2 Data Gathering

2.1 Data Acquisition

2.1.1 Survey Data

The CoH hired a surveyor to collect cross sections for the roadside ditch served areas within the CoH. In general, the surveyor collected 11 points at each cross section along the roadway. The Figure below was a schematic provided to Klotz Associates identifying each point. In addition to these 11 points, the surveyor also took survey shots at culvert flowlines (in and out), discharge points, and other necessary points that would be helpful in defining the drainage system.

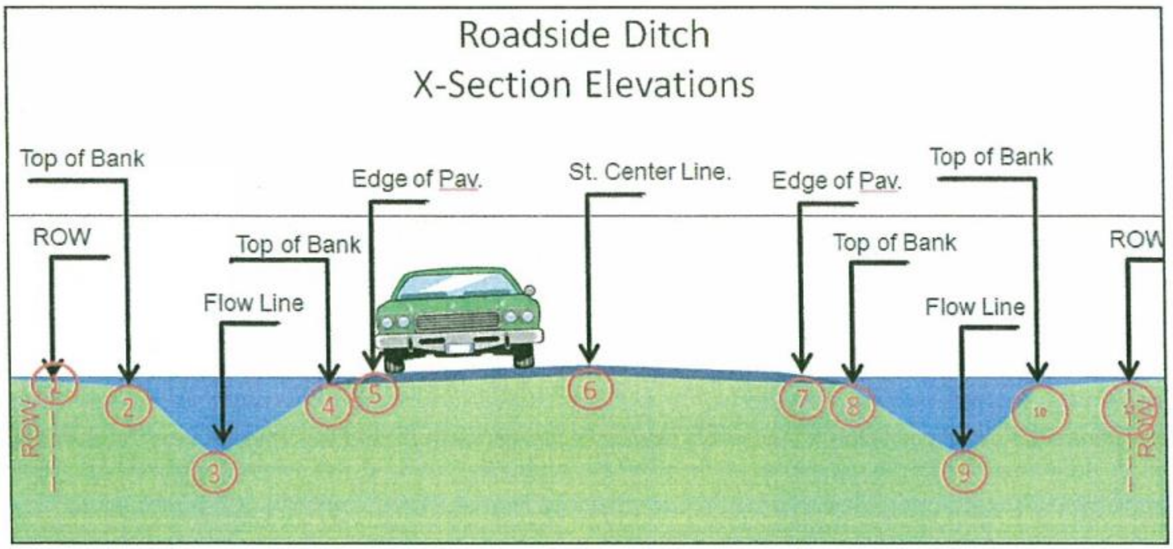


Figure 3: Cross Sectional Survey Data

2.1.2 LIDAR Data

In conjunction with the Geographic Data Committee, the Houston-Galveston Area Council (H-GAC) maintains LiDAR data flown by Merrick & Company in mid-2008 for Harris County and its watersheds. The LiDAR data provided by H-GAC (to the CoH and then to Klotz Associates) consist of five-foot pixel resolution bare-earth digital elevation model grids and surface elevation model grids, one-foot contour lines, breaklines, and bare-earth and surface hillshades. In addition, raster digital elevation model (DEM) and hillshade mosaics were included for use in ArcGIS. The Figure below represents a view of this data from within ArcGIS.

Figure 4: LiDAR Data

2.1.3 Impervious Raster Data

The CoH provided Klotz Associates with an impervious raster data set completed for the purpose of the CoH's drainage fee. This impervious raster data was a 1'X1' grid, with each cell containing a 20 or a 0 (20 for impervious and 0 for pervious). This raster data was utilized in determining the amount of impervious cover within each delineated drainage area, and consequently the amount of flows (runoff) that would be expected at each cross section. The Figure below represents a view of this data from within ArcGIS.

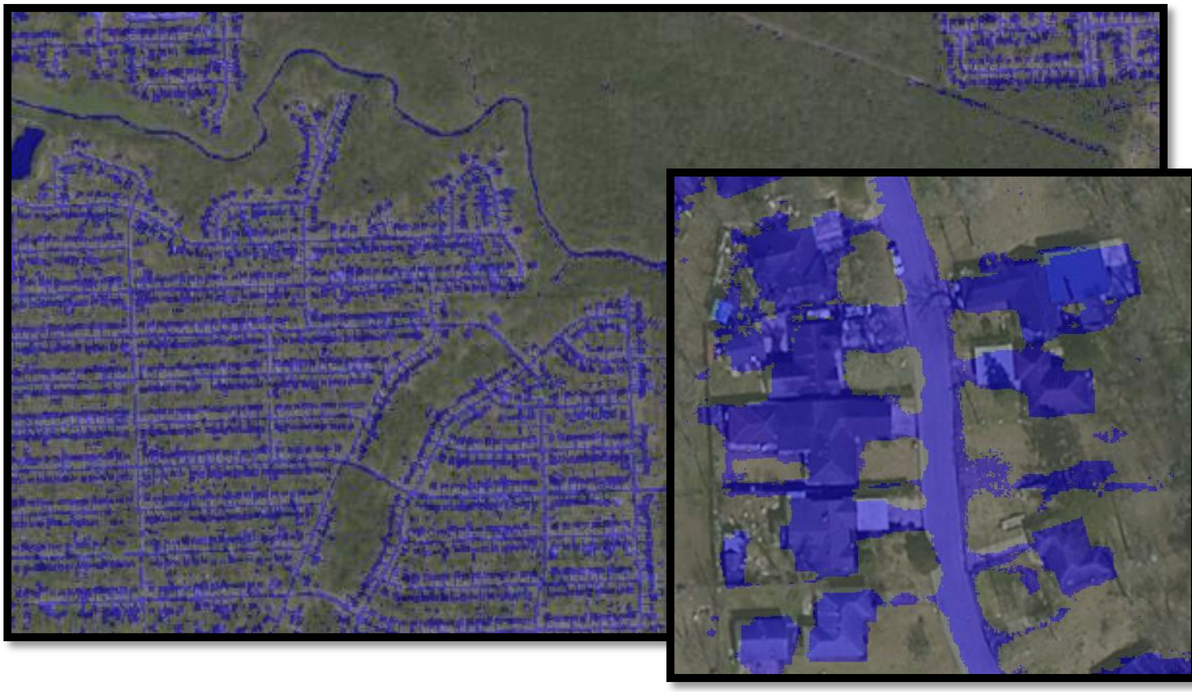


Figure 5: Impervious Raster Data

2.1.4 Other Data

2.1.4.1 Road Centerlines

The CoH provided Klotz Associates the most recent Road Centerlines shapefile. This shapefile, according to the CoH, is maintained by CoH staff and is updated frequently as new roadways are created, as areas are annexed, or as existing roadways are rehabilitated.

2.1.4.2 Stream Centerlines

The CoH provided Klotz Associates the most recent Stream Centerlines shapefile available. This shapefile is a Tropical Storm Allison Recovery Program (TSARP) stream shapefile containing all HCFCD currently named streams (ex. E200-02-00). This shapefile, according to the CoH, is updated by HCFCD staff as they update their stream database.

2.1.5 Data Limitations

2.1.5.1 Impervious Raster

The impervious raster dataset provided by the CoH contains limitations in computing the exact amount of impervious cover because of the way it was compiled. Because trees can canopy over impervious cover areas and because the coverage was based on aerial imagery, some areas of the coverage would be categorized as pervious rather than impervious. This can be particularly true in areas where trees line a CoH roadway. The determined percent-impervious for each watershed area was based (without manipulation) on the impervious raster provided by the CoH.

2.1.5.2 Survey Data

The survey data provided by the CoH can only be utilized if all points are completed for each cross section. At a minimum, 6 of the 11 points representing exactly half of a cross section must be provided by the survey, otherwise the calculation of conveyance capacity for a particular ditch is not possible. In limited cases, a surveyed cross section was identified to have a few missing data points. As such, the ditch capacity was unable to be determined.

SECTION 3 Data Pre-Processing

3.1 Data Preparation

The data that was gathered from various sources required significant manipulation and pre-processing to get it into a form that would give us the desired results. The sections below outline how the data was handled to prepare it for the next phase.

3.1.1 Determining a Line ID

The original data provided by the CoH contained a column called TMPTRANSID. This field appeared to be a unique number identifying the particular transect line the point was located on. A method was developed to determine the conveyance capacity of a ditch utilizing this field, however, when the final data was delivered to Klotz Associates, this field no-longer appeared to be unique and contained undecipherable values (i.e. 2342-A384-485Y-UD458). Klotz Associates ran an ArcGIS routine to determine a unique transect line identifier for use in determining the conveyance capacity. This new field was called LINE_ID. This data was then combined with the SORTORDER (the specific point 1 to 11) to create the COMBINED field representing a combined unique name for each point (i.e. 2342-1, 2343-2, 2342-3, etc.).

3.1.2 Impervious Raster Value

The CoH provided Klotz Associates with an impervious raster data set completed for the purpose of the CoH's drainage fee. This impervious raster data was a 1'X1' grid, with each cell containing a 20 or a 0 (20 for impervious and 0 for pervious). Klotz Associates completed raster math on the impervious raster to reclassify each cell to a 1 or a 0 (1 for impervious and 0 for pervious). By reclassifying the impervious raster, the zonal statistics routine to determine the percent impervious of a delineated drainage area would result in a correct value.

3.1.3 Flowline Weed-Out

The survey data provided by the CoH contained 11 points. Though all 11 points were utilized in determining the conveyance capacity of each cross section, the 11 points were unnecessary to determining the existing flow (or the flow that would pass through each cross section) or drainage area. To delineate on only areas necessary for determining the drainage area to the cross section (the major component to determine the flow), points "3" and "9" were pulled out of the entire dataset.

Note: each point contained 2 attributes of interest (SORTORDER and POINTTYPE). The SORTORDER contained the point value (i.e. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or 11), while the POINTTYPE contained the description of the point (i.e. Ditch Flow Line Point, ROW, etc.). In some cases a discrepancy existed (i.e. 8 – Ditch Flow Line Point). Klotz Associates utilized the POINTTYPE Ditch Flow Line Point instead of the SORTORDER "3" or "9" to locate all points necessary for delineation. By doing this, we were able to capture all flow line points regardless of their number label. The Figure below shows the "3" and "9" points.

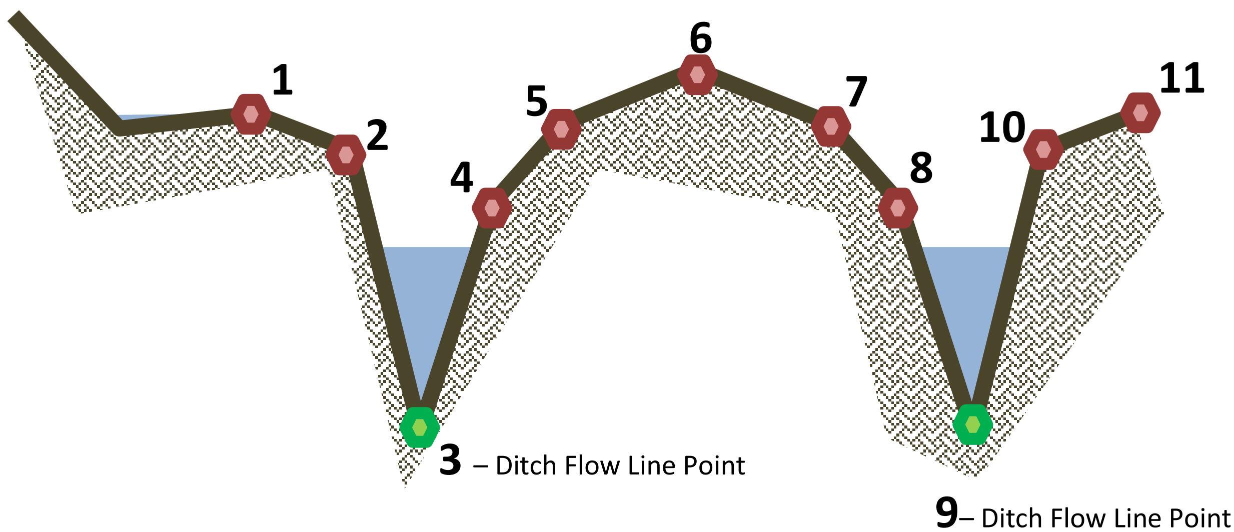


Figure 6: Schematic of Points "3" and "9"

3.1.4 Cropping Road Centerlines

The CoH provided Klotz Associates with the most recent road centerline shapefile. Because DEM reconditioning burns in culvert segments across roads and builds walls on road centerlines, the intersections of these two lines will cause issues. If the linework was not cropped, the cell containing the crossing of the two lines would experience no elevation change during the reconditioning phase because of a burn and then a build on the same cell. Because the burning of the culvert is far more important in the hydrologic reconditioning, the roadway centerline required cropping. Klotz Associates cropped out areas where the culverts and the road centerlines crossed at a radius of 25 feet prior to the DEM reconditioning process. The Figure below represents the steps used in generating the buffer and cropping out the road centerlines.

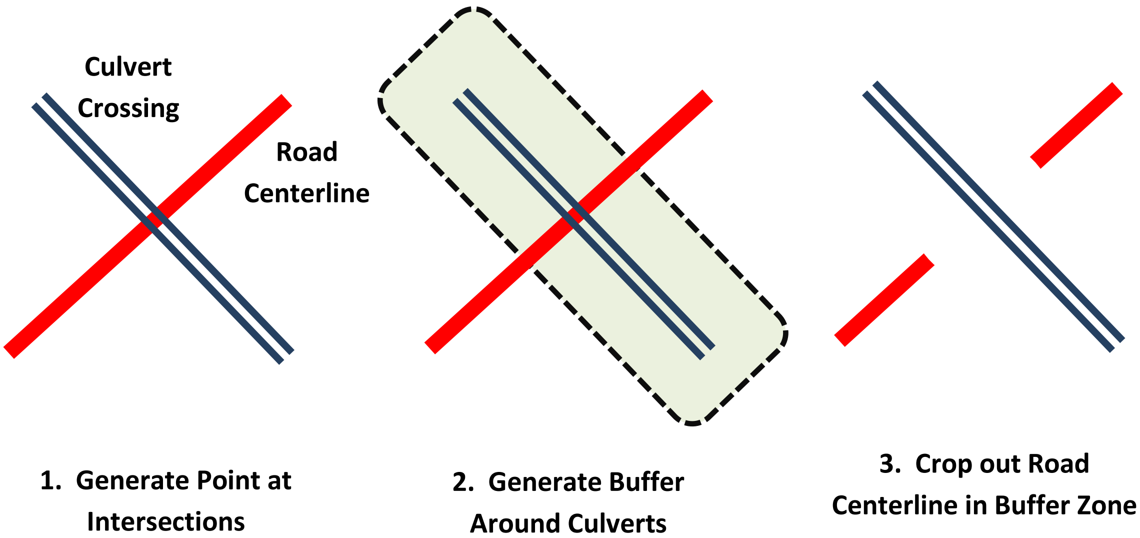


Figure 7: Road/Culvert Centerline Crop

3.1.5 Cropping Stream Centerlines for Burning TSARP Streams

Klotz Associates identified an issue with delineations that were near streams. Because the process of burning roadside ditches into the DEM resulted in roadside ditches that were lower in elevation than the nearby streams, the resulting delineations would cross streams and interfere with stream conveyance paths. This problem was remedied by completing a secondary burning of the TSARP stream linework into the DEM. The TSARP streams were prepared for burning during the DEM reconditioning – Terrain Preprocessing phase outlined below in this technical report. Figure 10 below schematically depicts the necessity of burning TSARP streams into the DEM.

The CoH provided Klotz Associates with the most recent TSARP stream shapefile and road centerline shapefile. Because DEM reconditioning burns in stream segments and builds walls on road centerlines, the intersections of these two lines will cause issues. If the linework was not cropped, the cell containing the crossing of the two lines would experience no elevation change during the reconditioning phase because of a burn and then a build on the same cell. Because the burning of the stream is more important in the hydrologic reconditioning, the roadway centerline required cropping. Klotz Associates cropped out areas where the TSARP streams and the road centerlines crossed at a radius of 25 feet prior to the DEM reconditioning process. Figure 8 below represents the steps used in generating the buffer and cropping out the road centerlines. Figure 9 below represents the completed precedent of culvers/roadside ditches, TSARP streams, and roadway centerlines.

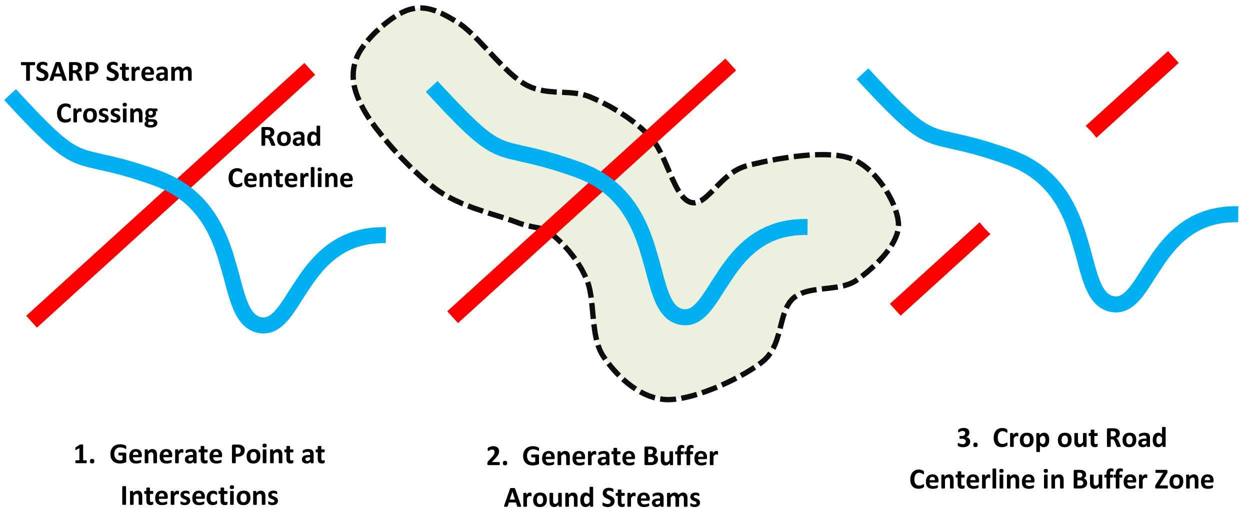


Figure 8: Road/Stream Centerline Crop

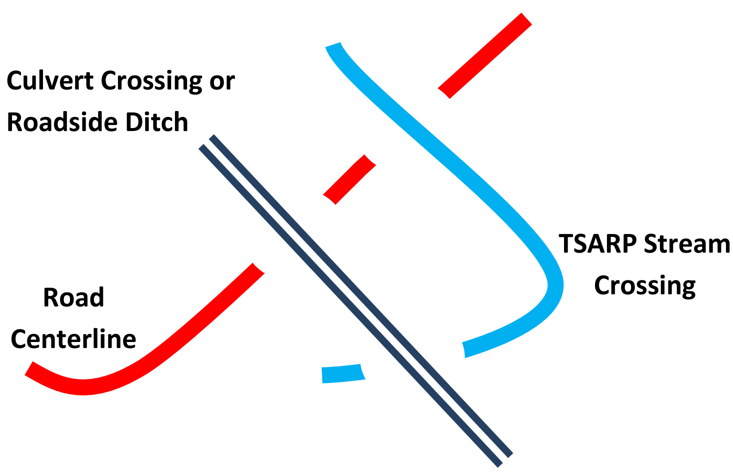


Figure 9: Linework Precedent

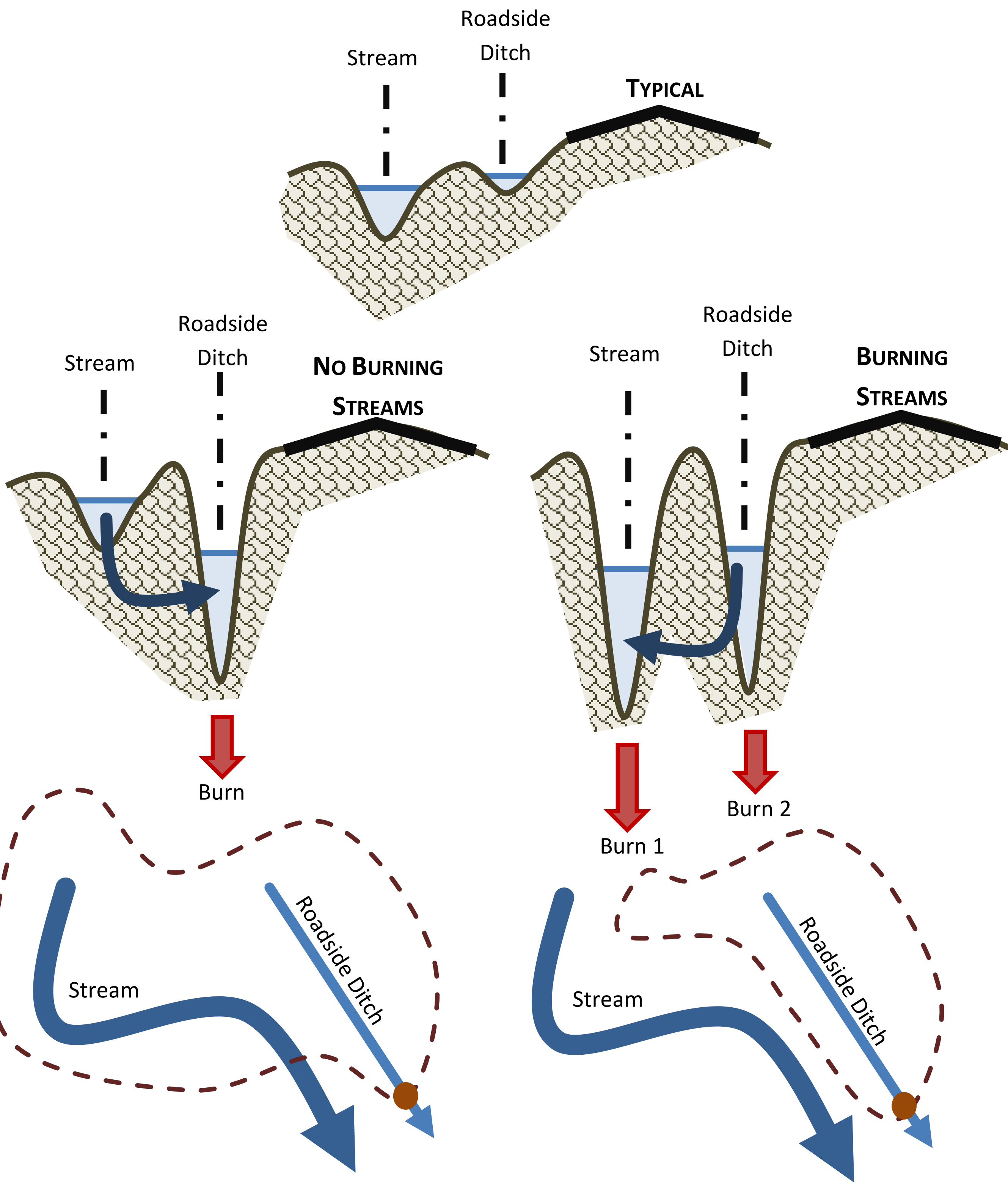


Figure 10: Burning Streams Necessity

3.1.6 Artificial Flowline Weed-out

The CoH provided Klotz Associates with an artificial flowline file that included a set of lines used in the connection of surveyed linework (roadside ditch and storm sewer), particularly linework that should be connected but was not due to survey discrepancies. Because the various roadside ditch and storm sewer surveyed linework was completed at different times and different years, the lines were not always connected. Because this linework requires connection to be hydrologically accurate, the artificial flowline file was created (by the Surveyor) as an attempt to (A) join missing roadside ditches together, (B) join the roadside ditch network to the storm sewer linework completed years prior, (C) identify flowline locations not surveyed, or (D) connect up T locations and joint locations for roadside ditches. Unfortunately, the artificial flow lines that connected the roadside ditch network to the storm sewer linework were problematic for the DEM manipulation that created a hydrologically correct DEM for watershed delineation. This was primarily caused from artificial flowlines connecting to storm sewer linework with sharp angles and overlapping connections. Through a process in ArcGIS called topology rules, Klotz Associates was able to remove "dangles," or artificial flowlines that did not have connections to the roadside ditch linework at each end of the line. The Figure below represents a schematic representation of some of the various artificial flow line types that were discovered. Through this process, the non-valuable and problematic artificial flowlines were removed from the roadside ditch linework. Approximately 70% of the artificial flow lines were removed from the processing leaving only the valuable artificial flow lines to be included in the finalized linework used in the DEM reconditioning process.

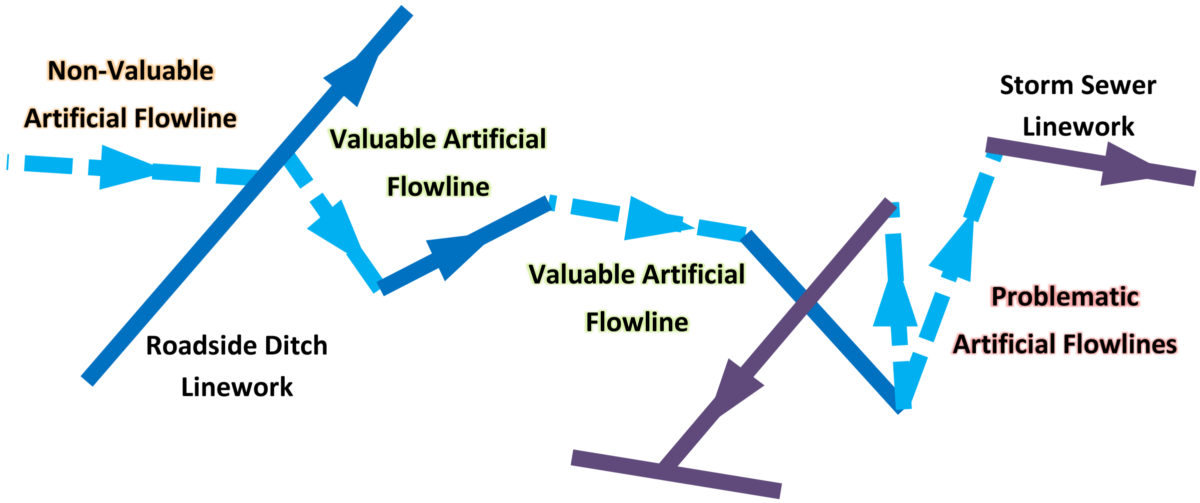


Figure 11: Artificial Flow Line Diagram

3.2 Culvert Directional Issue

The CoH provided Klotz Associates with a roadway culvert linework shapefile that was collected by the surveyor. This linework included roadside ditch cross-culverts under major roads (as opposed to driveway culverts which were not collected). The linework, at first glance, appeared to be correct because in most cases culverts run downhill with the roadside ditches. Upon further investigation, the culvert line direction was found to be dictated strictly by the upstream and downstream node elevations. In the model, the culvert would flow in the direction identified by the surveyed data (sometimes reverse grade), but in reality most culvert invert elevations were negligible in difference and the actual flow direction of the water would follow the roadside ditch. This problem created an issue with watershed delineations because the area delineation was halted by the problematic culvert drawn in a misleading direction, as can be seen in Figure 12. The solution to the problem required flipping the linework of the culverts that did not agree with the roadside ditch direction. To weed-out the necessary culverts that required flipping, a GIS process had to be performed. A representation of this process can be seen in Figure 13. Through ArcGIS processes, upstream and downstream nodes for each line were generated (red and green points). Then, only culvert lines experiencing all-red endpoints were selected for flipping (because these culverts had no outfall to a receiving stream or storm sewer system).

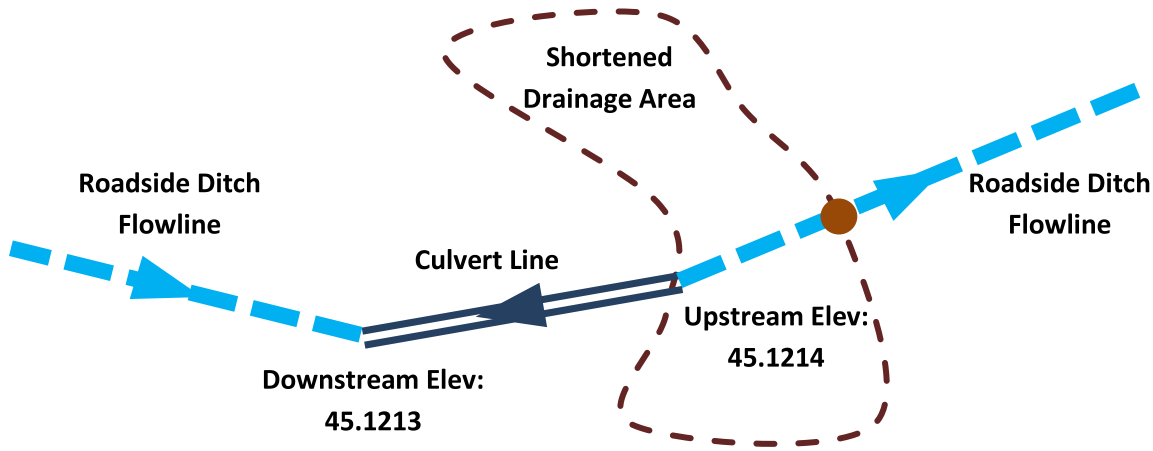


Figure 12: Culvert Directional Issue

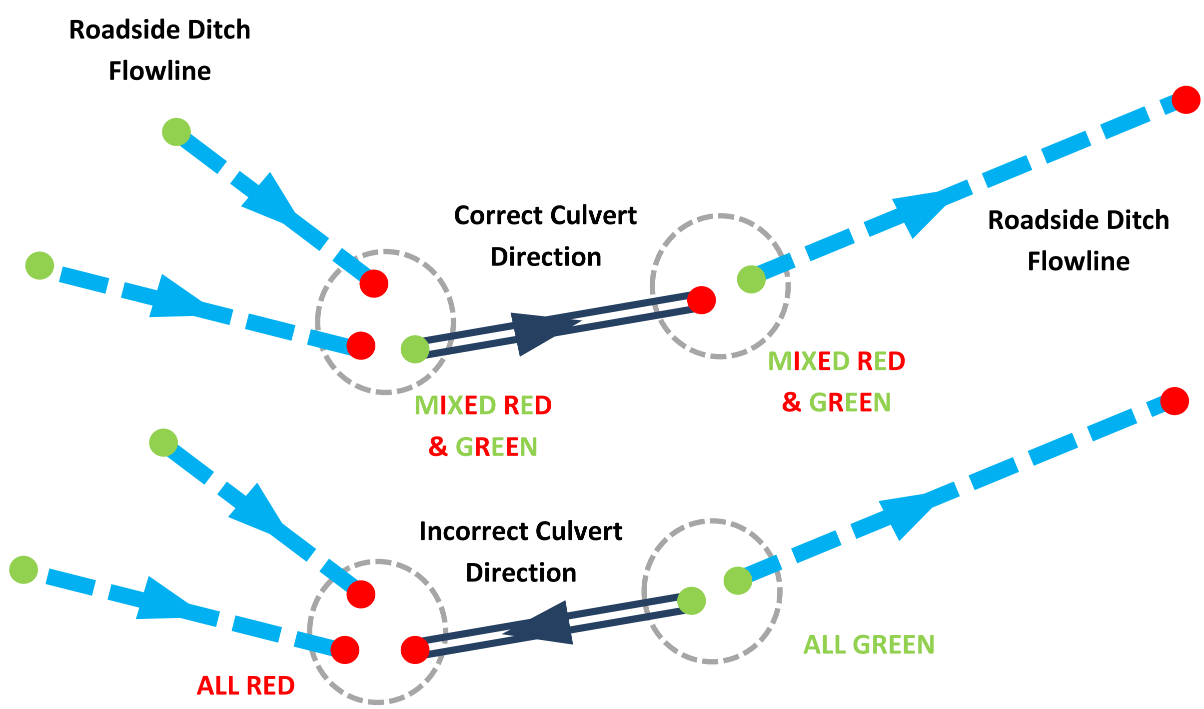


Figure 13: Determining Culvert Direction and Solution

3.3 Ditch Looping

During the final processing Klotz Associates discovered that there were instances of ditch looping (As can be shown in Figure 15 below) inside the data provided by the CoH. The ditch looping pre-process denotes the most difficult and time consuming of all the preprocessing activities Klotz Associates needed to perform to get the data ready for use in the DEM manipulation code. This problem was not evident in the smaller (455g) or larger (095g32) test case but was widespread throughout other parts of the city. Ditches that had the looping characteristic were problematic to the code because when assigning a stream slope to the linework, the lines that were looped had no calculable ending. As such, looped lines continued to "dig" themselves into the DEM and the calculations would never result in a viable solution. To make matters worse, ArcHydro does not give the user any information about the location of the loop or how many might be hidden in the linework. This meant that as Klotz Associates ran the code, full DEMs would get stuck on assigning stream slope to the linework. Some DEMs would run for days with no solution. As Klotz Associates discovered the problem, various methodologies to identify the loops were attempted with only one being an actual working solution.

Klotz Associates started with a Microsoft Excel spreadsheet containing the exported attributes of the linework. ArcHydro was used to assign a "TO" and "FROM" node to each line to give the spreadsheet a way to determine connectivity. A VLOOKUP command was utilized to determine the FROM node of each line and to jump to the next line. These VLOOKUP commands were duplicated 35 times for each line. Any connectivity that made 35 connections was flagged as a loop. The spreadsheet was tested to work for many loops, but was not flagging each loop. Klotz Associates discovered that the reason each loop was not flagged was because this methodology only allowed for a single path when in reality a loop might be hidden inside a set of links and nodes (i.e. this methodology was only foolproof if each node only had 2 lines). VLOOKUP will only identify the first link it finds and will not continue to search. Because each line could have multiple drainage paths, a random number (RAND) was generated for each line ID. This random number was used to sort the IDs (i.e. randomize their order) to "shake out" the loops. The random number was then generated repetitively to create numerous runs. Klotz Associates first ran the code 20 times, with each time taking approximately 3 minutes to complete for the entire city. The first 20 runs resulted in 761 lines containing loops (city-wide). These loops were fixed by manually removing or reversing one of the lines in the loop (at the discretion of the engineer/GIS technician) to correct the problem.

After the 761 lines containing loops were identified and fixed, the spreadsheet was again run

20 more times. The second 20 runs resulted in an additional 13 lines identified containing loops. After fixing the 13 looped lines, at this point, Klotz Associates was satisfied that all loops were removed and continued the DEM processing. A sample of this spreadsheet can be found in Figure 14 below.

Note: Ditch looping does not necessarily represent an error in the survey data. It is likely that some of the roadside ditches were "flow direction indeterminate" where the slope of the ditch was virtually zero (flat) and the direction of flow was a coin-toss. The surveyor had to assume a direction of flow. Also, the previous pre-process of culvert flipping could have added some of the loops into the system (although it also could have fixed others).

ID	FROM	TO	RAND		1	2	3		34	35	LOOP
27074	29243	29238	0.136		29237	29123	29228				NO
15234	48562	42132	0.741		42512	42563					NO
12130	13386	13387	0.844		25321	25327	25323		25327	25323	**YES**
12561	12563	15632	0.261		956	952	978		12564		NO

Figure 14: Looping Table Example

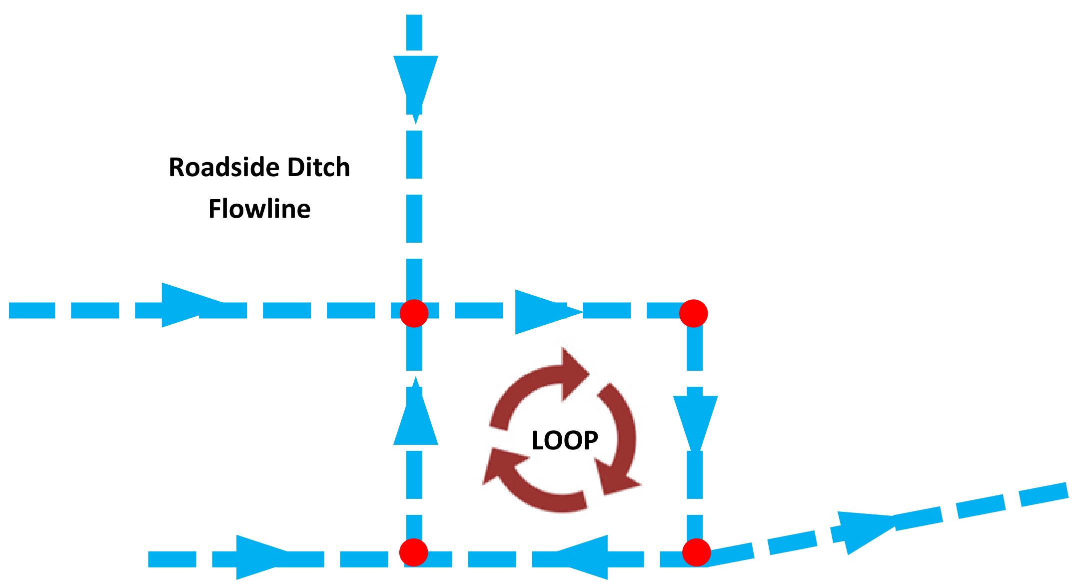


Figure 15: Looping Schematic Example

3.4 Database File Structure

In order to manage the data and keep redundancy to a minimum, a standardized file structure was used for each DEM. First, a parent folder was created for each of the DEMs and named using the name from the quarter-quad (i.e. dem_29095g32). Each of these folders was filled with the necessary pre-processed data to be used by the Python code (discussed later in this report). This data included the buffered DEM, buffered impervious raster, transect points (3s & 9s), ditch centerlines, stream centerlines, and road centerlines. Each folder was then modified by the Python code to include the processed data as the code during the analysis. An example (dem_29095g32) of the DEM Pre-Analysis and DEM Post-Analysis file structures can be found in the Figure below.

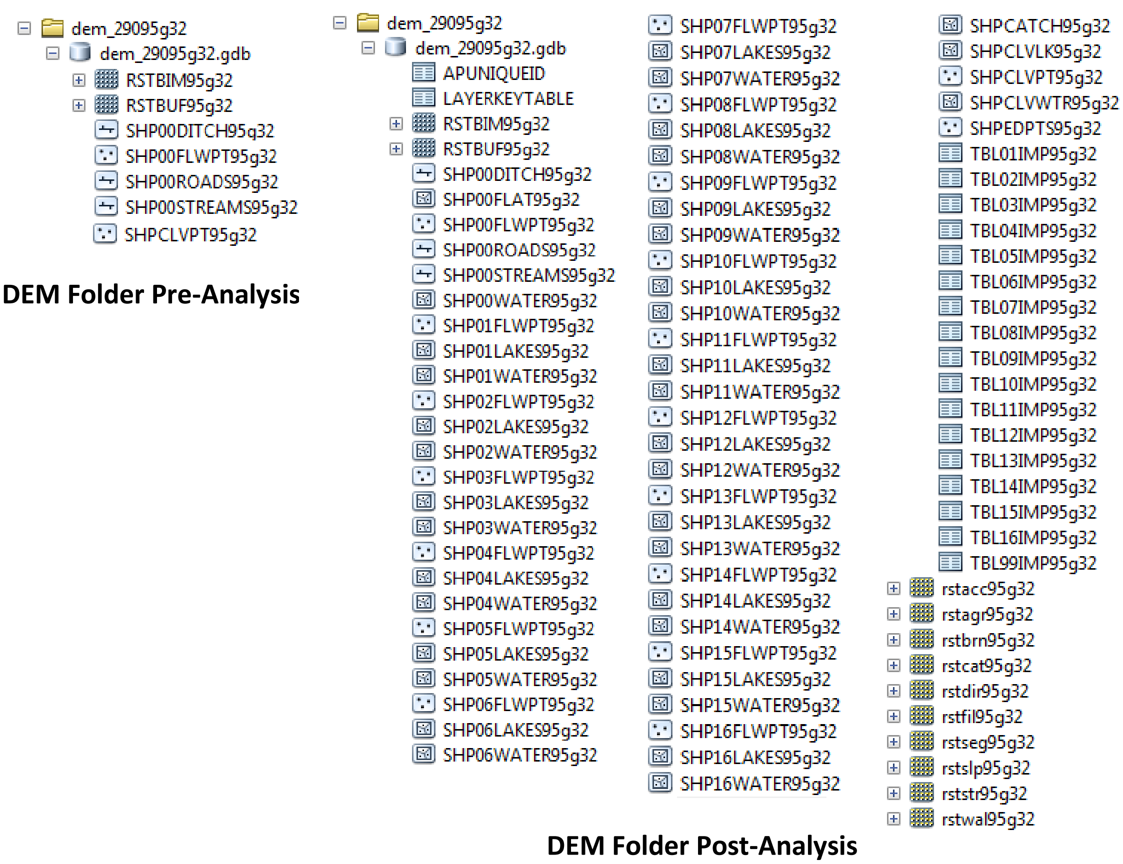


Figure 16: File Structure

You will notice in the file-structure Figure above that the SHPXXFLWPT, SHPXXLAKES, and SHPXXWATER shapefiles are divided into 16ths. This is because each of the DEMs was divided into 16 different areas. In order to address issues arising during the processing and minimize processing time due to data error crashes, the code was written to divide the SHP00FLWPT shapefile into quarter-quads (16 sub-areas) inside each DEM and process the 16 areas separately. This would allow the code to restart at a specified 16th area if the script crashed. The Figure below shows how each DEM was divided into 16 different areas.

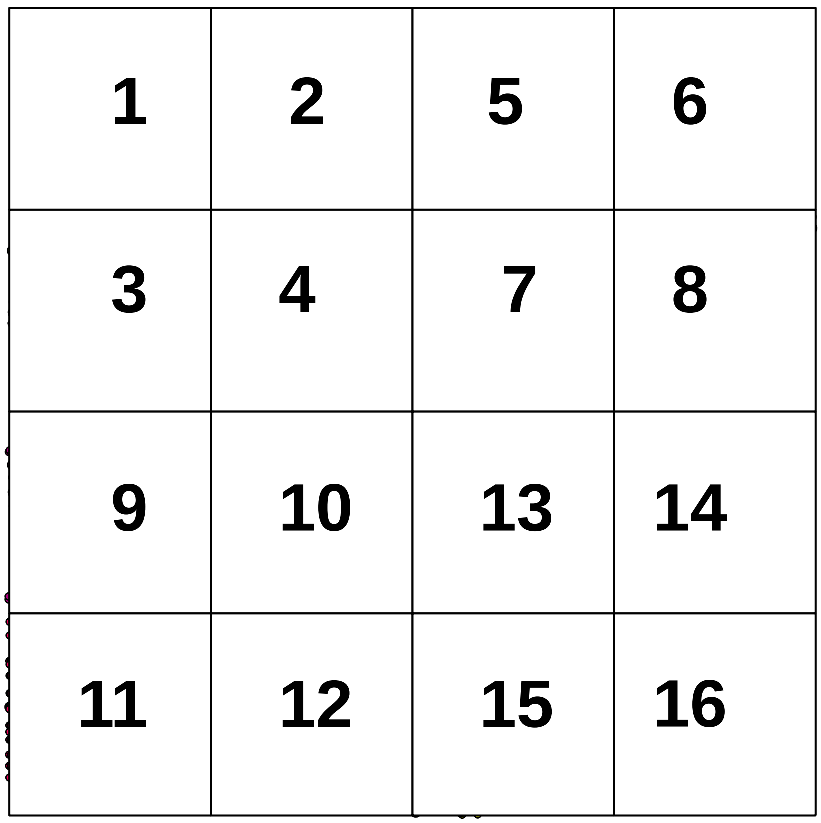


Figure 17: DEM Division to 16ths

3.5 Naming Convention

The naming convention for each of the shapefiles works in conjunction with database file structure and allows for data to be easily accessed by location. Each data file contains the name of the DEM to-which it was derived at the end of the name. The tables below outline the description of the various names.

Table 1: Geodatabase

Name	Description
DEM29095g32	Geodatabase 1
DEM29095g45	Geodatabase 2 etc.

Table 2 DEMs / Rasters

Name	Description
RSTDEM95g32	Original DEM
RSTBUF95g32	Buffered original DEM (1 Mile Buffer)
RSTIMP95g32	Impervious Raster (preprocessed with 0s and 1s… not the 0s and 20s)
RSTBIM95g32	Buffered Impervious Raster (1 Mile Buffer)
RSTFIL95g32	Fill Raster – Fill Routine
RSTAGR95g32	Agree Raster – Roadside Ditch Burning Routine
RSTBRN95g32	Burn Raster – Stream Burning Routine
RSTSLP95g32	Slope Raster – Assign Stream Slope and Burn Stream Slope Routine
RSTWAL95g32	Walled Raster – Build Walls Routine
RSTDIR95g32	Flow Direction Raster – Flow Direction Routine
RSTACC95g32	Flow Accumulation Raster – Flow Accumulation Routine
RSTSTR95g32	Stream Definition Raster – Stream Definition Routine
RSTSEG95g32	Stream Segmentation Raster – Stream Segmentation Routine
RSTCAT95g32	Catchment Raster – Catchment Routine

Table 3: Shapefiles

Name	Description
SHP00DITCH95g32	Roadside Ditches Shapefile (cut at 5000 foot buffer)
SHP00FLAT95g32	Flattened Polygons
SHP00FLWPT95g32	Transect Points 3s & 9s Shapefile for all tiles
SHP00ROADS95g32	Roads Shapefile (cut to 5000 foot buffer)
SHP00STREAMS95g32	Stream Centerline Shapefile (cut to 5000 foot buffer)
SHP00WATER95g32	Merged Watershed Delineations for all tiles
SHP01FLWPTS95g32	Transect Points 3s & 9s Shapefile 1
SHP01LAKES95g32	Lakes shapefile
SHP01WATER95g32	Batch Watershed Delineations Shapefile 1
SHP02FLWPT95g32	Transect Points 3s & 9s Shapefile 2
SHP02LAKES95g32	Lakes shapefile
SHP02WATER95g32	Batch Watershed Delineations Shapefile 2
SHP03FLWPT95g32	Transect Points 3s & 9s Shapefile 3
SHP03LAKES95g32	Lakes shapefile
SHP03WATER95g32	Batch Watershed Delineations Shapefile 3
SHPCATCH95g32	Catchments Shapefile
SHPEDPTS95g32	Edit Points Shapefile created in ArcHydro Processing

Table 4: Tables

Name	Description
TBL1IMP95g32	Impervious Table 1 - Zonal Statistics results.
TBL2IMP95g32	Impervious Table 2 - Zonal Statistics results.
TBL3IMP95g32	Impervious Table 3 etc.

SECTION 4 Existing Flow Determination

The existing flow for each roadside ditch must be determined to compare the actual flow with the calculated capacity. This section outlines, primarily, the watershed delineation process to determine the drainage area used in the existing flow computation.

4.1 DEM Manipulation

4.1.1 DEM Buffering

Each of the Digital Elevation Models (DEMs) were buffered to a one-mile radius; this is done to ensure that the delineated watersheds within each quarter-quad were complete and not prematurely sliced at the edge of a quad. The DEM buffering process is completed in the Slice Script. A schematic representation of the buffering routine is shown in the Figure below.

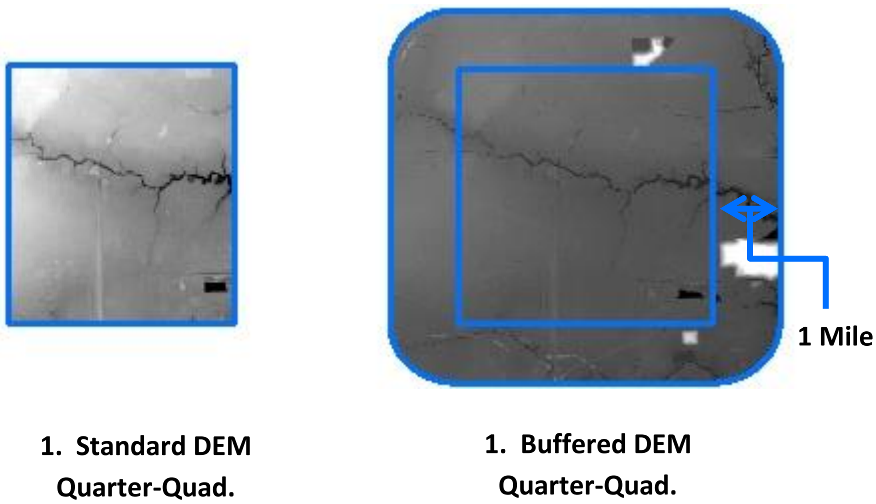


Figure 18: Buffered DEM Quarter-Quad

4.1.2 Impervious Raster Buffering

In order to minimize processing and to ensure that watersheds delineated beyond the DEM boundary had an impervious value, the impervious raster was also buffered by one mile. Because the impervious raster only covers areas within the CoH Limits, some of the buffered rasters have irregular boundaries that don't match the buffered DEM. These irregularities did not affect the impervious calculations. A schematic representation of the impervious raster buffering routine is shown in the Figure below.

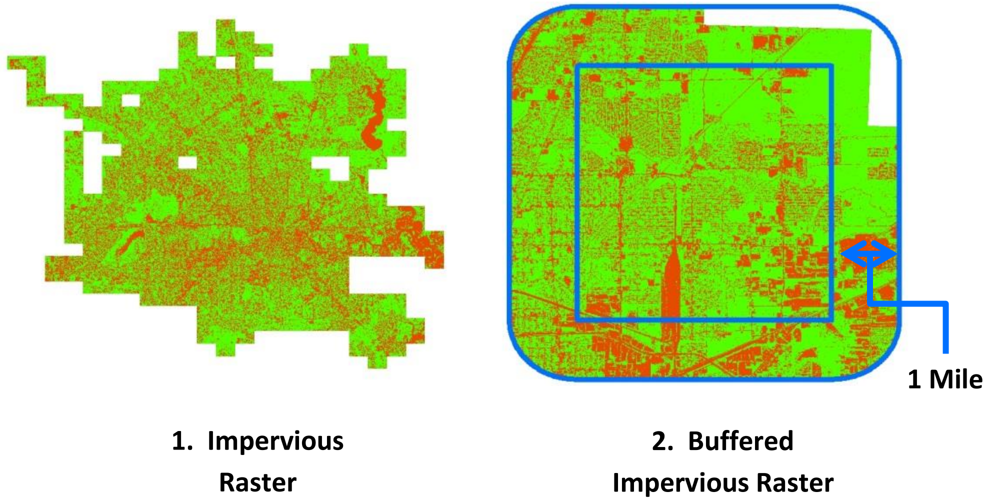


Figure 19: Buffered Impervious Raster

4.1.3 Cropping Data

Vector data (Ditch Centerlines, Road Centerlines, and Stream Centerlines) was cropped to the buffered DEM boundary to ensure that watersheds could "run" onto the buffered zone. The 3s & 9s transect points, however, were cropped to the DEM quarter-quad boundary (not the buffer) in order to systematically control the processing. The ditch centerlines and road centerlines were cropped to 5000' beyond the DEM quarter-quad boundary (just shy of 1 mile) because ArcHydro will not process lines with edges that are coincide with the DEM boundary. A schematic representation of the cropped data is shown in the Figure below.

Figure 20: Cropping Data

4.2 DEM Reconditioning - Terrain Preprocessing

DEM Reconditioning is required for the watershed delineation processing. In general, terrain preprocessing is used to vertically exaggerate hydraulic features to allow for correct hydrologic processing. This process takes a DEM that is topographically correct and reconditions it to be hydrologically correct. This process is shown in the Figure below.

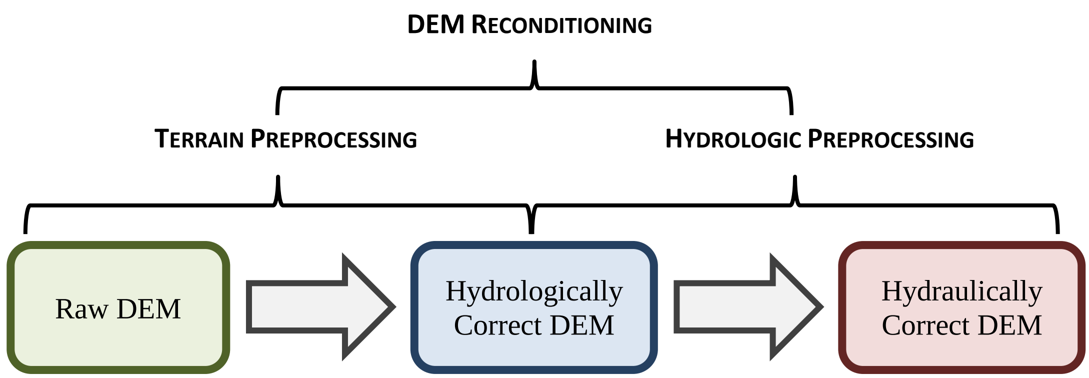


Figure 21: DEM Reconditioning Diagram

Terrain preprocessing is the process by-which the computer (namely ArcGIS) alters the DEM elevational data to manipulate the DEM into a resultant hydrologically correct DEM. By altering the elevational units of a DEM to be hydrologically correct (as opposed to typographically correct), the Hydrologic Preprocessing (the next step) can determine where flow would accumulate and how much area would drain to each cross section. The blue box below indicates the steps needed for Terrain Preprocessing. Figure 22 below represents (schematically) what will happen to a cross section during this process.

DEM Reconditioning Steps - Terrain Preprocessing

1. ***Terrain Preprocessing***
   a. *Create RSTFil - Terrain Preprocessing > DEM Manipulation > Fill Sinks*
   b. *Create RSTAgr - Terrain Preprocessing > DEM Manipulation > DEM Reconditioning*
   c. *Create RSTBrn - Terrain Preprocessing > DEM Manipulation > DEM Reconditioning*
   d. *Create RSTSlp - Terrain Preprocessing > DEM Manipulation > Assign Stream Slope*
   e. *Create RSTSlp - Terrain Preprocessing > DEM Manipulation > Burn Stream Slope*
   f. *Create RSTWal - Terrain Preprocessing > DEM Manipulation > Build Walls*

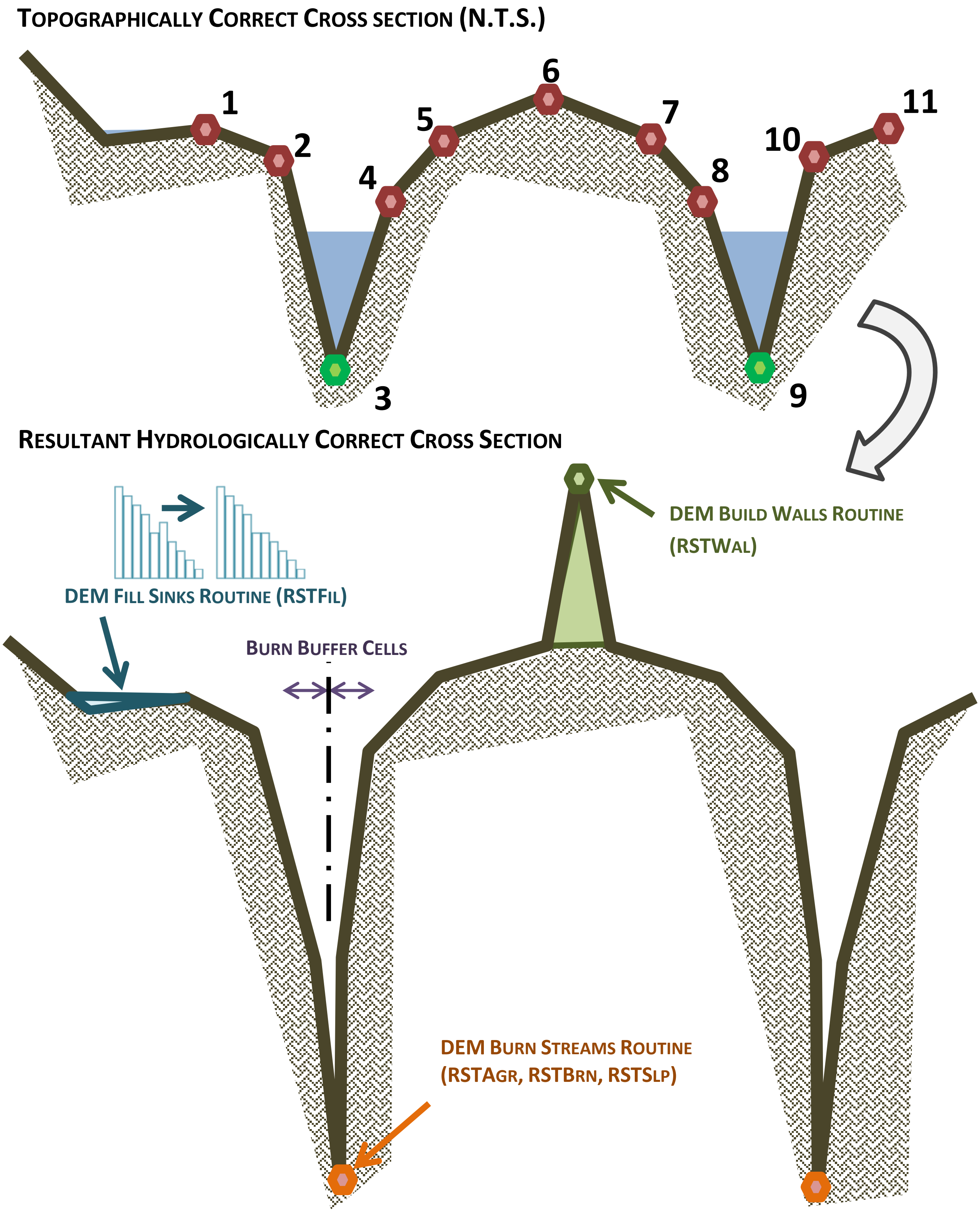
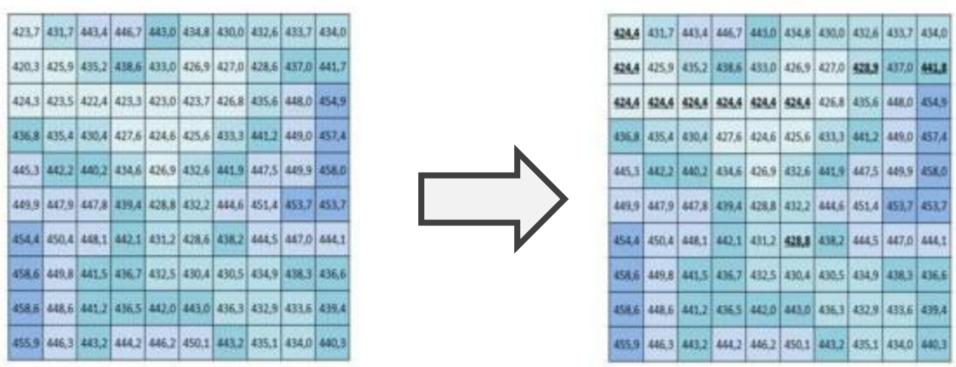


Figure 22: Terrain Preprocessing Methodology

4.2.1 Fill Sinks (RSTFil)

Sinks are areas that hydrologically present processing problems. Sinks can be artificial and artifacts of DEM construction. Sinks can also be real, where low-flow conditions might not yield discharge to the drainage infrastructure while high-flow conditions could contribute downstream. Unfortunately, the software doesn't have the ability to "overtop" a low-lying cell. If a cell is surrounded by higher elevation cells, the water is trapped in that cell and cannot flow out. The Fill Sinks function modifies the elevation value to eliminate these problems. Because terrain processing for watershed delineation is a mathematical process by-which all elements in the DEM must flow downstream with no sink ponding, a fill sinks routine was performed to fill these shallow ponding areas in the DEM. A schematic representation of the fill sinks routine is shown in the Figure below.



RAW DEM FILL SINKS

Figure 23: DEM Fill Sinks Routine (RSTFil)

4.2.2 Agree Stream Creation (RSTAgr & RSTBrn)

One of the most critical aspects to creating a reconditioned DEM is imposing (or burning) the known and surveyed drainage patterns onto the DEM. In this case, the survey provided to Klotz Associates by the CoH provided the first step to creating a "Roadside Ditch Feature Class." This feature class was comprised of roadside ditch flowline features for all areas of study. This feature class was burned in the known drainage patterns and helped to accomplish a reliable delineation. The Agree Stream routine "drags" the elevation of the streams down to a constant elevation. Figure 22 above graphically shows how the stream elevation is vertically pulled down to a constant elevation, thus burning in the streams. A second "burn" was also completed to impose the TSARP Streams as shown in Figure 10 in the pre-processing portion of this technical report.

4.2.3 Assign and Burn Stream Slope (RSTSlp)

The Assign Stream Slope routine assigns a relative stream slopes to the input Roadside Ditch Feature Class. Note that this relative slope is not the actual 3-dimensional slope of the roadside ditch, but simply a relative slope increased by a constant amount at each upstream node. The function will generate the fields FROM_NODE and TO_NODE to be populated (which were discussed earlier in this technical report and were used to rid the Roadside Ditch Feature Class of looping errors). Assign Stream Slope will also populate the FROM_ELEV and TO_ELEV fields for each stream feature with relative elevations. Similarly note that this is a relative elevation and not an actual 3-dimensional elevation. Figure 22 above graphically shows how the slopes and assigned elevations are simply relative to their next connection upstream/downstream.

Burn Stream slope is simply the process that burns the Roadside Ditch Feature Class elevations with slopes built based on FROM_ELEV and TO_ELEV into the DEM. This process results in a series of Edit Points Feature Class which represent points generated along the Roadside Ditch Feature Class at the intersection of the feature class and the center of each DEM cell. The Edit Points contain the interpolated elevation data along each ditch derived from the TO_ELEV and FROM_ELEV fields. These Edit Points are the elevations that are then burned into the DEM at each cell.

4.2.4 Build Walls (RSTWal)

The Building Walls routine was used on the Roads Feature Class to raise the center of the roads to not allow for cross flow over a road. It was assumed, for this analysis, that the roads acted as dams and that water was restricted from crossing the roads. Water could only cross the roads at burned culvert locations.

4.3 DEM Reconditioning - Hydrologic Preprocessing

Hydrologic preprocessing is the process by-which the computer (namely ArcGIS) utilizes the terrain preprocessed DEM (from the previous steps) to determine hydraulic features of the surface, and ultimately delineate a watershed for cross section location. The process applies specific methods to a raster file by utilizing the elevational data from the terrain processed

DEM to determine the direction of flow, how flows would accumulate, when to define a stream, and how each point will form a delineated area. The blue box below indicates the steps needed for Hydrologic Preprocessing.

> **DEM Reconditioning Steps – Hydrologic Preprocessing**
>
> ***2. Hydrologic Preprocessing***
>
> *a. Create RSTDir - Terrain Preprocessing > Flow Direction*
> *b. Create RSTAcc - Terrain Preprocessing > Flow Accumulation*
> *c. Create RSTStr - Terrain Preprocessing > Stream Definition*
> *d. Create RSTSeg - Terrain Preprocessing > Stream Segmentation*
> *e. Create RSTCat - Terrain Preprocessing > Catchment Grid*
> *f. Terrain Preprocessing > Catchment Polygon Processing*
> *g. Set up points for individual delineation.*
> *h. Watershed Processing > Batch Watershed Delineation*

4.3.1 Flow Direction (RSTDir)

The flow direction routine computes the flow direction for each grid cell in the DEM. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. A schematic representation of the flow direction routine is shown in the Figure below.

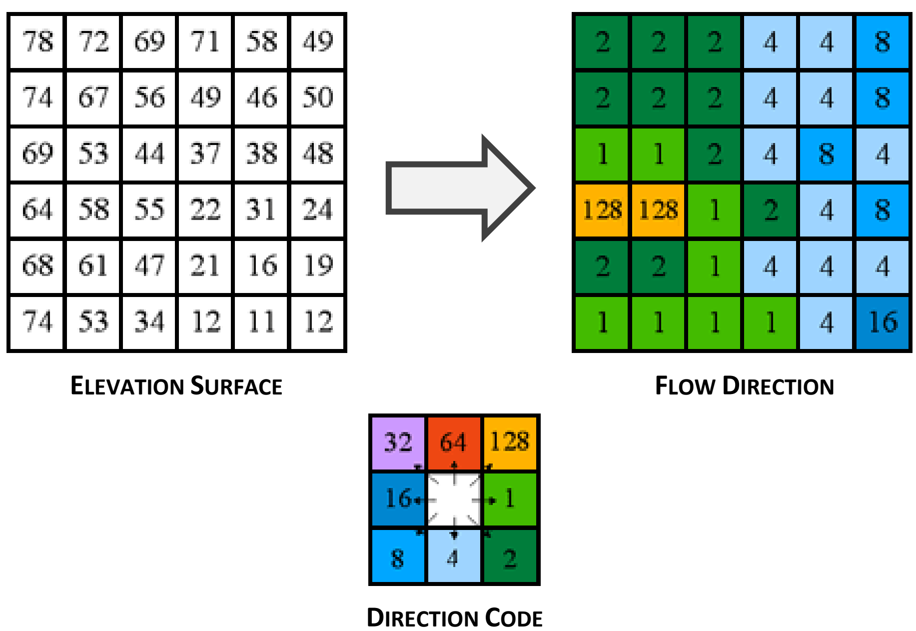
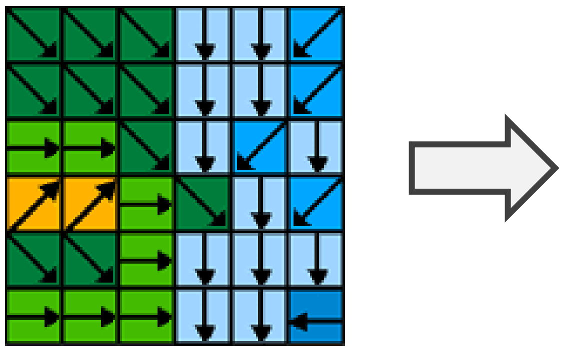


Figure 24: DEM Flow Direction Routine (RSTDir)

4.3.2 Flow Accumulation (RSTAcc)

The flow accumulation routine will determine the cumulate amount of grid cells that flow to each DEM grid cell by utilizing the flow direction DEM created in the above step. The number in each cell represents the count of cells that will drain to that location. A schematic representation of the flow accumulation routine is shown in the Figure below.



FLOW DIRECTION

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

FLOW ACCUMULATION

Figure 25: DEM Flow Accumulation Routine (RSTAcc)

4.3.3 Stream Definition (RSTStr & RSTSeg)

This Stream Definition routine creates a stream definition grid that is based on a given threshold. The grid contains a value of "1" for all the cells in the input flow accumulation grid that have a value greater than the supplied threshold value. All other cells in the DEM will contain no data. A schematic representation of the stream definition routine is shown in the Figure below.

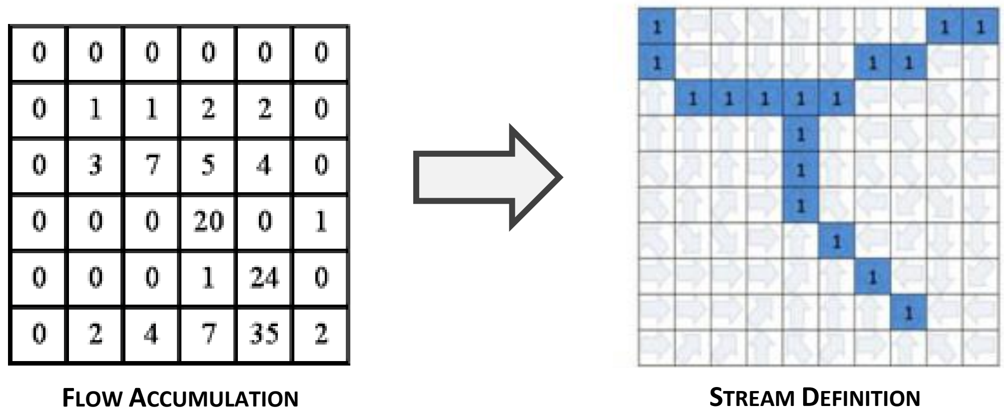


Figure 26: DEM Stream Definition Routine (RSTStr)

4.3.4 Stream Segmentation (RSTSeg)

The Stream Segmentation routine creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is assigned to that segment. A schematic representation of the stream segmentation routine is shown in the Figure below.

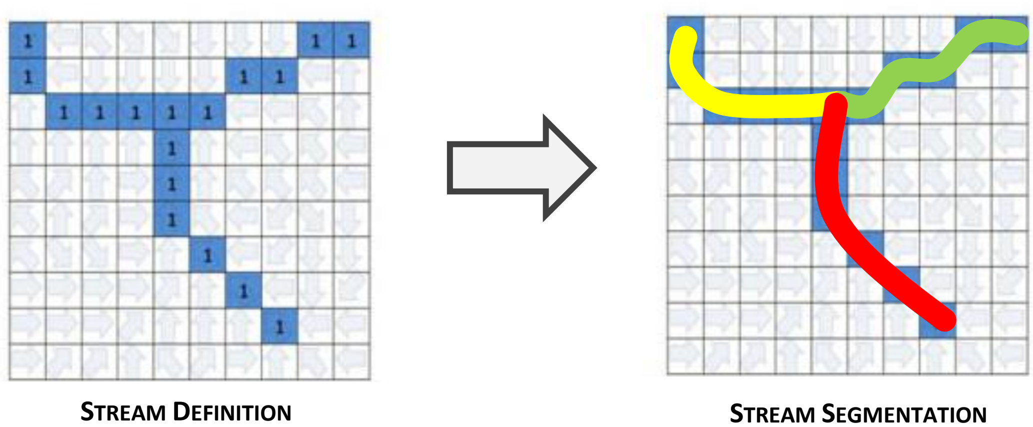


Figure 27: DEM Stream Segmentation Routine (RSTSeg)

4.3.5 Catchment Grid Delineation and Polygon Processing (RSTCat)

The Catchment Gird Delineation routine creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value within the DEM corresponds to the value carried by the stream segment determined in the Stream

Segmentation routine. A Catchment Polygon Processing method is also completed to simply convert each catchment into a catchment polygon feature class. A schematic representation of the catchment definition routine is shown in the Figure below.

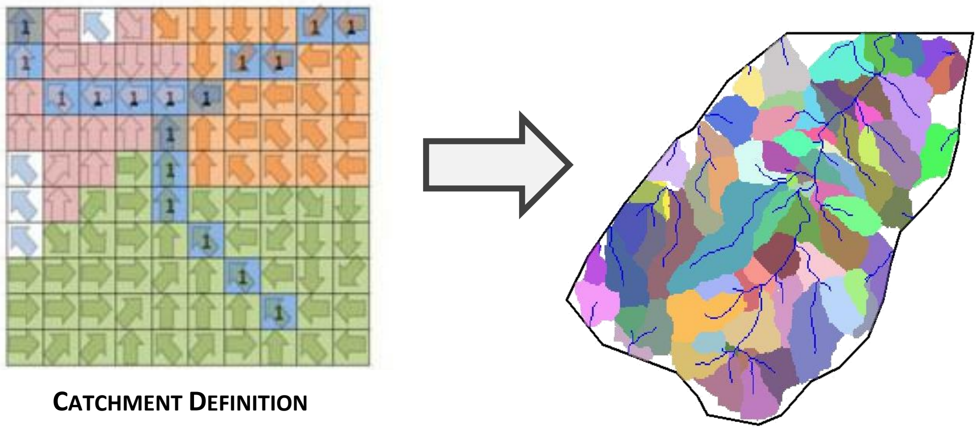


Figure 28: DEM Catchment Grid Routine (RSTCat) and Watershed Delineation

4.4 Individual and Overlapping Drainage Areas

The Rational Method (used in calculating a point flow) primarily requires only one single element to determine flows: the drainage area contributing to the flow-point. The other components to the Rational Method (intensity, time of concentration, and imperviousness) can all be derived from standard constants or can be computed with the area boundary. Because the prime parameter needed to approximate flow at a cross section is the contributing area, drainage area delineations were completed at each sample point (or each point located at the flowline of each cross section 3s & 9s). By completing a delineation on the cumulative total area upstream of each sample point, a connection of nodes and links "following" drainage patterns was not required. Simply put, each cross section would have its own corresponding and cumulative drainage area. This overlapping drainage area methodology results in a feature class of polygons that are all overlapping. Because the watersheds are cumulative at each sample point moving downstream, the area and percent impervious values are computed for each area regardless of the overlap and evaluates each drainage area individually.

The overlapping drainage area methodology is a very important key to this analysis. The typical method for determining a point flow at an outfall is to first delineate a series of watersheds and then to connect the watersheds using a link-node system. This method requires a very detailed link-node networking system through a complicated water-tracking spreadsheet. The overlapping drainage area methodology solves this issue by, instead, delineating cumulative drainage areas at specific points and determining the flow at each point. This results in a series of overlapping drainage areas that are then flattened during the post processing.

4.5 Resolved Issues

4.5.1 Multiple Drainage Path Delineation Issue

There were a number of issues that were resolved during the test case methodology discovery phase of this project. Most of the issues were resolved through the above-mentioned pre-processing methods. This issue, however, was resolved in the code. The issue was identified by the discovery that some of the drainage area delineations were being cut-off even when the delineation point was located directly on the line. This was found to be caused by the DEM flow direction grid. Because the flow direction grid allows for diagonal flow directions, a drainage area can become detached from the total delineation. Figure 29 below shows how a delineation area can become unconnected due to split flow paths at a diagonal down the roadside ditch. The solution to this problem was the Mini-Lakes Methodology. ArcHydro has tools that allow for the determination of flow to a polygon. This is typically used to determine the amount of area that would drain to a lake. Instead, Klotz Associates utilized this methodology to delineate a "mini-lake" at each flow-point. A X' diameter circular polygon was generated at each flow-point, and then the delineations from the point were completed on the circular polygon instead of the point. This gave the delineation point a buffer zone that would correct the flow path problem. Figure 29 below shows how this Mini-Lakes methodology corrected the problem shown in Figure 30.

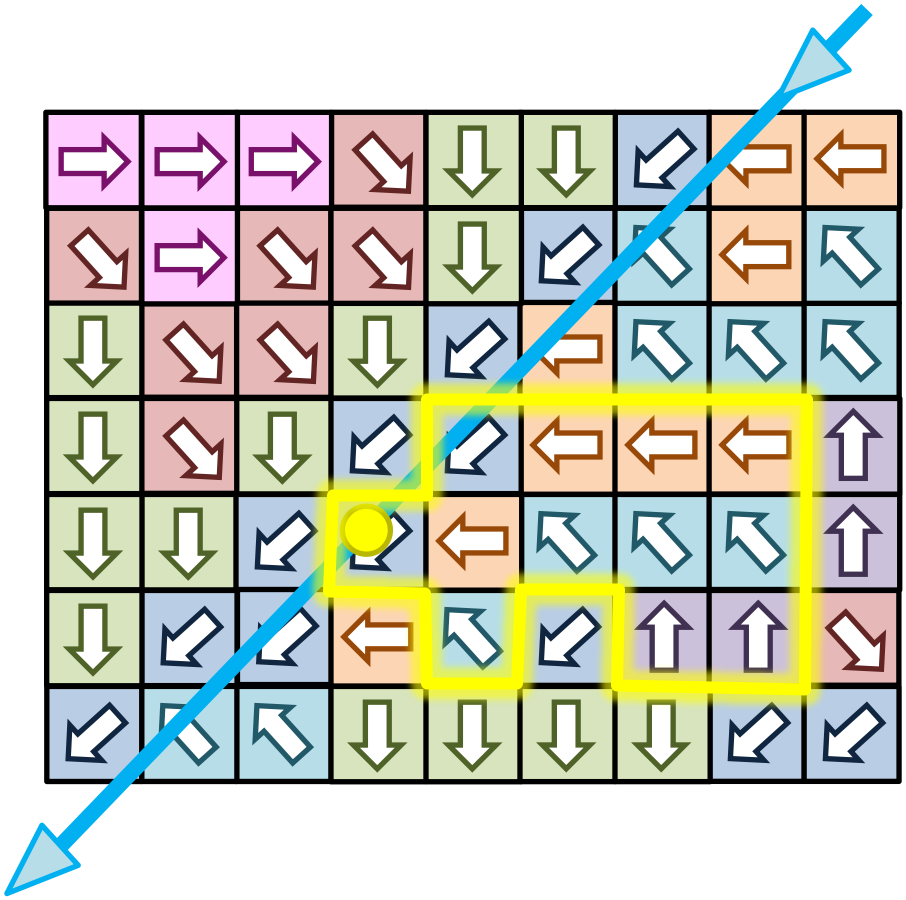


Figure 29: Multiple Drainage Path Delineation Problem

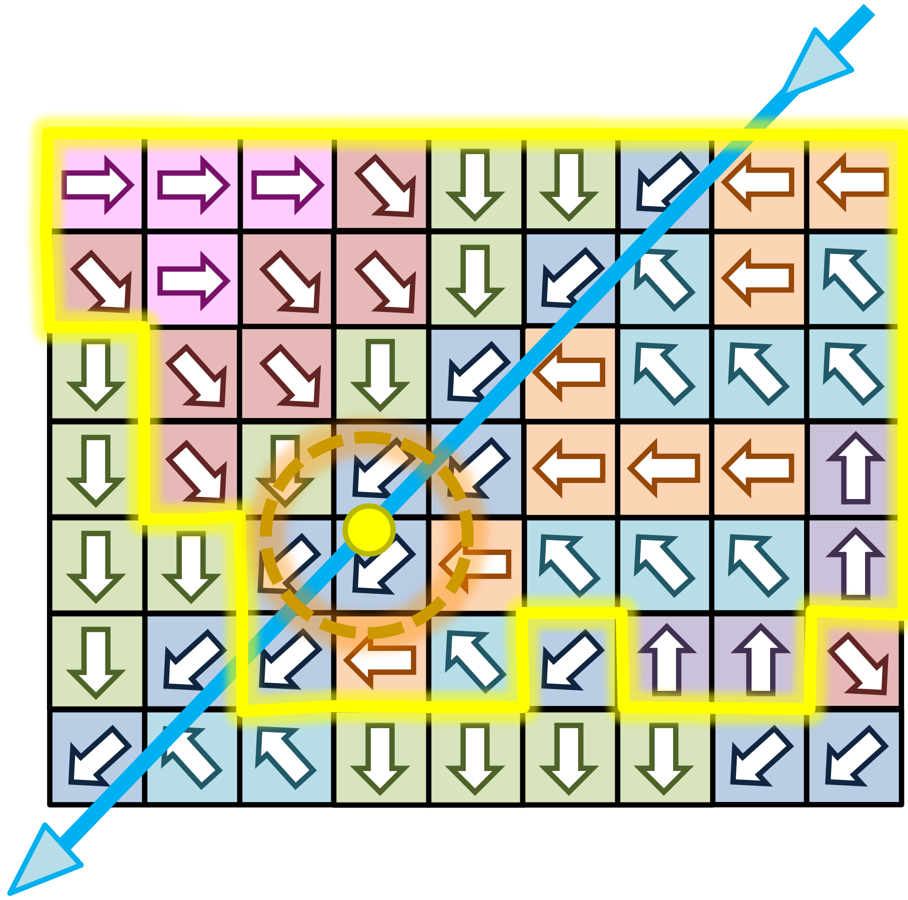


Figure 30: Multiple Drainage Path Delineation Solution

SECTION 5 Conveyance Capacity

5.1 Survey Data

5.1.1 Raw Data Used

Using the data explained in Sections 2.1.1 (Survey Data) and 2.1.2 (LIDAR Data), the conveyance capacity was determined for each cross section of the roadside ditches. Conveyance capacity is best defined as the maximum amount of water flow that can be conveyed from one roadside ditch cross section to the next roadside ditch cross section. These flows vary from cross section to cross section, depending on the width and side-slopes found in each roadside ditch.

The first step in determining the conveyance capacity of each of the roadside ditch cross sections was to export the data to Microsoft Excel. These tables were called "RAW" in the spreadsheet and were the result of exporting the data directly from ArcGIS shapefiles to an Excel format. The benefit to using a "raw" data table is that when data changes (for example as the city provided updated information) the raw table can be copied back into the spreadsheet and the calculations will be updated. There were three Microsoft Excel spreadsheets of raw data that were used in the conveyance capacity calculations:

1. The first spreadsheets was the transect point data provided by the City (labeled "Raw SHPTRANS"). This data contained a record for each point that was surveyed (points 1 to 11). The fields used in determining conveyance capacity from this spreadsheet included the ID, Station, and Elevation of each point.

2. The second spreadsheet exported to Excel was the ditch linework data provided by the City (labeled "Raw SHPDITCH"). This data contained only one field that was utilized in Excel: Avg_Slope containing the traverse slope of the ditch.

3. The last spreadsheet exported to Excel was the flowpoint spreadsheet queried from the transect point data but only containing the flowpoints (i.e. point 3s & 9s). This spreadsheet was labeled "Raw SHPFLWPT" in the Excel Workbook. The data in this spreadsheet was post-processed and contained the contributing acreage and percent-impervious cover for each of the delineations.

The survey information that was provided contained a large amount of fields that were not needed to determine the conveyance capacity of a ditch. As such, Klotz Associates created a "GRAB" table that was paired with each of the "raw" tables. The "grab" tables were used to grab only the fields that were needed in the analysis. The "grab" tables also provided a way for Klotz to easily update the spreadsheet should survey column information change from one deliverable to the other (i.e. as the survey data was finalized and delivered to Klotz).

5.1.2 Raw Data Tables

For all three spreadsheets, a "Combined Name" column was added to identify and combine the Line ID with the Point and POINTTYPE (i.e. Line ID "2", Point "11" and POINTTYPE "Right of Way Point" would be displayed as "2-11 Right of Way Point" under the "Combined Name" column).

In addition to the Combined Name column, a column labeled "AVG_Slope_Adjusted" was added to the SHPDITCH Grab spreadsheet. This was done because some of the Avg_Slope data points would either display a "<Null>" value or equal 0, which would mean that the traverse slope was incalculable from the survey data. Since a flow rate was desired at each cross section, Klotz Associates assumed a 0.01% slope as a default value for incalculable slopes.

5.2 Point Layout

5.2.1 VLOOKUP

A "Point Layout" spreadsheet was created to organize the data from the SHPTRANS Grab spreadsheet in a way where the surveyed points can be viewed from left to right (i.e. Point 1 to Point 11). The VLOOKUP command in Microsoft Excel identified the Line ID, Point, and POINTTYPE from the SHPTRANS Grab spreadsheet and the Station and Elevation associated with that particular point. If no station or elevation data was found with a particular point, or there was another type of error, the IFERROR command in Microsoft Excel was used to produce a blank cell so that Klotz Associates could determine which Line ID's had erroneous data and would not be used in conveyance capacity calculations.

5.2.2 Station and Elevation

By using the values of the station and elevation data point, the distance and the percent slope between each point could be determined. As mentioned in section 5.1.1, the cross section stationing was calculated using the longitude and latitude coordinates from ArcGIS. The distance between each point was obtained by taking the difference of the station values from point to point; the absolute value command (a.k.a. "ABS") was applied in case a distance calculation resulted in a negative value. The difference of the elevation values between two points, divided by the distance between those points, then multiplied by 100, provided the percent slope between the points. A negative value meant the elevation slanted downward, left to right; a positive percentage meant the elevation slanted upward, right to left.

5.3 Cross Sectional Area

5.3.1 Control Point (CP) Elevation

Two types of points were used to determine the conveyance capacity exceedance: control points and acting control points. A control point, or CP, is the maximum elevation between two adjacent points in each ditch (i.e. Points 1 & 2, Points 4 & 5), and controls whether the flow capacity will remain in the ditch or spill off the side of the ditch/onto the road. Figure 28 depicts the control point between a pair of points.

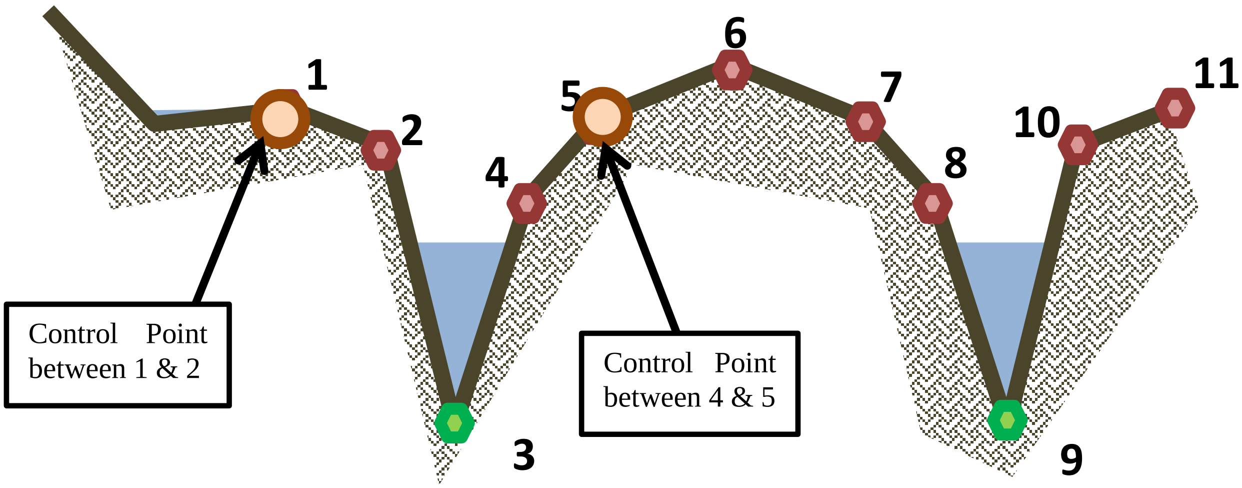


Figure 31: Control Point Determination

An acting CP is the lesser of the two maximum elevation points in each ditch (i.e. the maximum of Points 1 & 2 and Points 4 & 5). This lower elevation determines where the flow will spill (off the road or onto the road) when the capacity of the ditch has been exceeded. Figure 29 depicts the acting CP of a roadside ditch and the water surface elevation, or WSE, of that ditch. The WSE is the projected elevation for the ditch capacity.

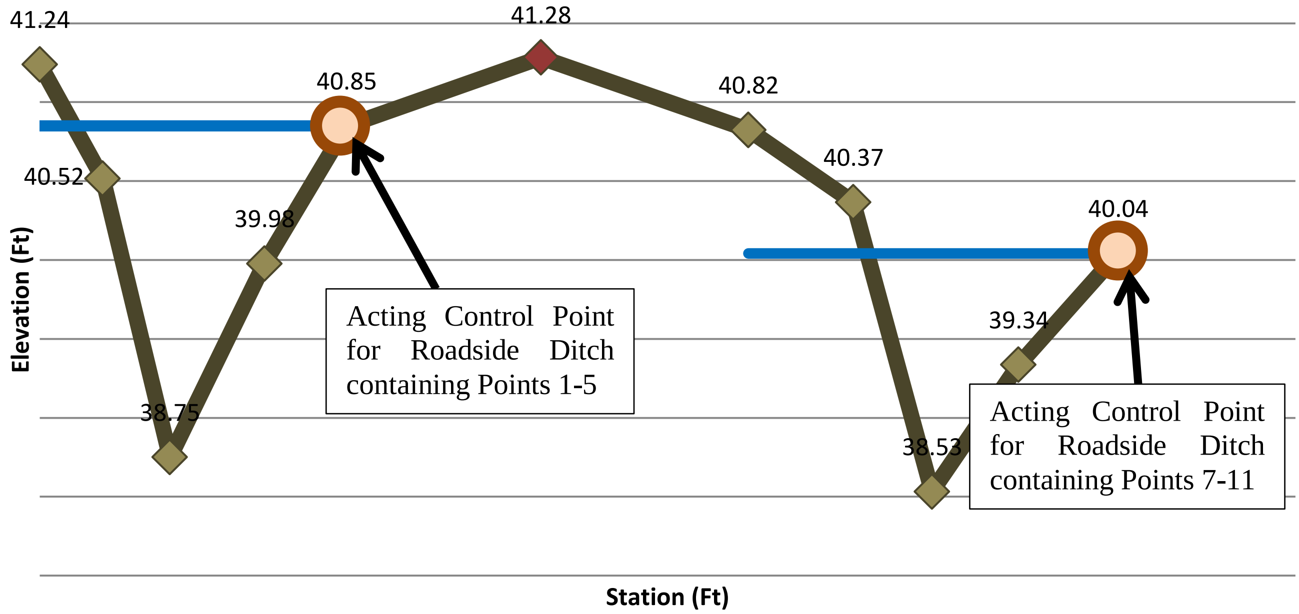


Figure 32: Acting Control Point Determination (Blue Line Indicates WSE)

5.3.2 TRUE-FALSE Scenarios

After the acting CP was found for each ditch, Klotz Associates determined whether the other points in the respective ditch were below the CP. If a point was below the acting CP, it was marked "TRUE"; if it was above the CP, it was marked "FALSE."

There were four scenarios used to calculate the cross sectional areas of each ditch: FALSE-FALSE, TRUE-TRUE, FALSE-TRUE, & TRUE-FALSE.

1. FALSE-FALSE meant both points were above the acting CP, and the area would not be taken into consideration when calculating the conveyance capacity. The value for FALSE-FALSE always equals 0.
2. TRUE-TRUE meant both points were below the acting CP, and the entire area would be taken into consideration when calculating the conveyance capacity. The value for TRUE-TRUE never equals 0.
3. FALSE-TRUE meant the first point was above the acting CP, but the second point was below the acting CP. The area below the acting CP in this scenario would be used to calculate conveyance capacity, while the area above the acting CP would be neglected.

4. TRUE-FALSE was the mirrored version of the FALSE-TRUE scenario, but the area calculations remained the same.

The area for each pair of points was determined based on the scenario for each pair of points (i.e. if Point 1 was TRUE and Point 2 was FALSE, the area calculation for a TRUE-FALSE scenario would be used).

5.3.3 Special Scenarios

Four pairs of points had unique scenarios that affected the area calculations: 1 & 2, 4 & 5, 7 & 8, and 10 & 11. If the right-of-way or pavement points were less than the top of bank points, the area of that particular pair was not used in the cross sectional area calculations (i.e. if Point 2 was greater than Point 1, then the area between 1 & 2 was removed from the total area calculations).

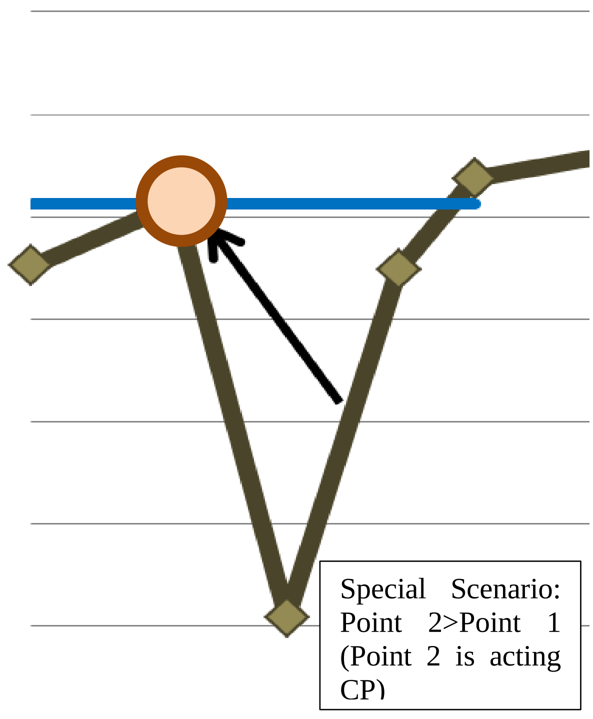


Figure 33: Special Scenarios (Blue Line Indicates WSE)

After the scenarios were determined and areas for each pair of points were computed, Klotz Associates found the cross sectional areas of the road side ditches containing Points 1-5 and

Points 7-11. The cross sectional areas were then organized into columns in a new spreadsheet labeled "Mannings" using the VLOOKUP command as explained in Section 5.2.1.

5.4 Wetted Perimeter

5.4.1 Definition of Wetted Perimeter

The wetted perimeter of a cross sectional area is the perimeter that will be "wet." For an open ditch, the wetted perimeter would be the bottom of the ditch and the side-slope lengths of that ditch below the WSE. Figure 31 indicates the wetted perimeter and cross sectional area relationship.

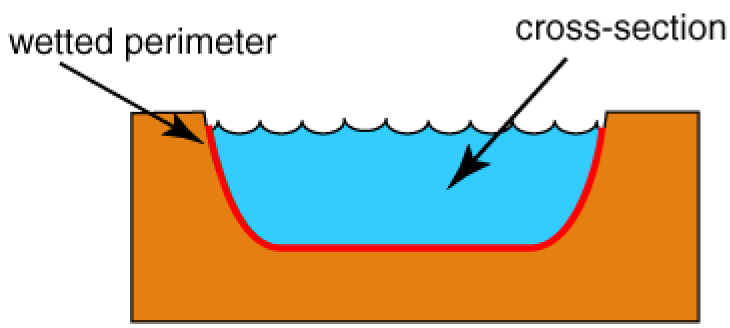


Figure 34: Wetted Perimeter of a Ditch

5.4.2 Control Point (CP) Elevation

The acting CP used to determine the cross sectional area in Section 5.3.1 was also used to determine the wetted perimeter.

5.4.3 TRUE-FALSE Scenarios

Using the acting CP, Klotz Associates used the same TRUE-FALSE scenarios from Section 5.3.2 to determine the lengths from point-to-point. The Pythagorean theorem was used for the TRUE-FALSE scenarios to calculate the length of the two points.

5.4.4 Special Scenarios

The four points mentioned in Section 5.3.3 were evaluated in the special scenario section of the capacity calculations. If the right-of-way or pavement points were less than the top of bank points (i.e. Point 2 greater than Point 1), the length of that pair of points was subtracted from the wetted perimeter calculations.

After the scenarios were determined and the length of each pair of points were computed, Klotz Associates found the wetted perimeter of each road side ditch containing Points 1-5 or Points 7-11 in feet. The wetted perimeters were then organized into the "Mannings" spreadsheet using the VLOOKUP command as explained in Section 5.2.1.

5.5 Channel Slopes

A channel slope (longitudinal slope) is the change in elevation from one flowline point to a connecting flowline point downstream. This is not to be confused with the side-slope (transverse slope) of the ditch, which is the change in elevation from one cross section point to an adjacent cross section point.

The AVG_Slope_Adjusted column created in Section 5.1.2 includes the channel slopes for both ditches on every Line ID. They were organized into the "Mannings" spreadsheet using the VLOOKUP command as explained in Section 5.2.1.

5.6 Flow Rate Determination (Q)

The flow rate of each Line ID was calculated using Manning's equation. This equation uses the cross sectional area of a Line ID, the hydraulic radius, Manning's roughness coefficient, and the slopes of the channels. Manning's equation was written as followed:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Where:

- Q=flow rate (cubic feet per second)
- 1.49=conversion factor in U.S customary unitsn=Manning's roughness coefficient
- A=Cross sectional area (square feet)
- R=Hydraulic radius (R=A/WP)
- WP=Wetted Perimeter (feet)

- S=Channel slope

5.7 Quality Assurance / Quality Control

5.7.1 Error Flag Identification

The survey data contained a few errors. Data was either incorrectly input (i.e. survey points were not organized in ascending/descending order, a sign change from negative to positive from one station elevation to the next) or no data was available for a few or all of the survey points for a particular Line_ID. A column was created in the Point Layout spreadsheet (labeled "ERROR FLAGGER") to determine which Line IDs had bad distance data, bad slope data, or no data at all.

5.8 Comparison

5.8.1 Hydrology

The runoff was calculated using the Rational Method provided in Chapter 9 of the City of Houston Infrastructure Design Criteria Manual, Ver 2012. The Rational Method is comprised of three variables as shown in the equation below:

$$Q = C * i * A$$

Where:

- Q= Runoff flow rate (cubic feet / second)
- C= Rational/Runoff Coefficient
- i= Intensity (in / hr)
- A= Area (acres)

The Rational Coefficient was calculated using the percentage impervious cover value, estimated from watershed delineation processing, the CoH formula:

$$C = (0.6 * Impervious) + 0.2$$

Intensity was calculated using the intensity-duration-frequency formula shown below that can also be found in the Design Criteria Manual. Intensities were calculated for the 2-year, 5-year, 10-year, 25-year, and 100-year precipitation events.

$$i = \frac{b}{(d + Tc)^e}$$

Where:

- i= Intensity (in/hr)
- b, d, e= IDF coefficients
- Tc= Time of Concentration, (minutes)

5.8.2 Comparison

The Rational Method calculation provides a runoff flow rate estimate. This estimated runoff is calculated for each precipitation event and compared with the capacity of its respective ditch. A section in the spreadsheet labeled as Comparison compares these two values. Ditches with capacity exceeding a particular an event runoff flow rate are labeled as Adequate. If the capacity is less than the event runoff flow rate, it is labeled as Inadequate. Ditches with errors that prevent the calculation of the capacity are labeled as "Error". This tab summarizes the relationship between the capacity and hydrology calculations and identifies the level of service provided for each ditch.

SECTION 6 Data Post-Processing

6.1 Level Of Service (LOS) Data

Once the LOS data was completed in the Microsoft Excel form, the data was transferred back into the attributes of the flowpoints by joining on the Combined Name.

6.2 Flattening Polygons

Because the goal in this data exercise was to determine the adequacy of a service area (and not only at a specific point), the LOS attributes had to be moved from the points to the polygons. As described in the sections above, the overlapping drainage area methodology resulted in a dataset of overlapping polygons. The polygons were flattened in ArcGIS by using the Feature to Polygon toolbox to flatten the polygons and move attributes from the points to the polygons.

6.3 Removing Duplicate Drainage Areas

In some cases, surveyed cross sections were located very close to one-another. Because the cross sections were located very close, the delineations from each of these cross section resulted in the exact same delineated area. When flattening the polygons, there resulted in only a single polygon for two points. In this rare case, the point no longer containing a matching watershed pair was removed from the dataset.

6.4 Removing Overly Large Drainage Areas

The drainage area delineation methodology requires that the DEM be in good hydrologic standing to accurately delineate watersheds. In other words, the DEM must direct flows on the DEM surface in a direction that is hydraulically correct. Because the DEM has been manipulated to allow for the surveyed and traced hydraulic features to be prominent (i.e. roadside ditches, roads, streams, etc.), other hydraulic features that are present on the DEM may be concealed. Because of this simple fact, areas that are far from major roadways, surveyed roadside ditches, streams, etc. will have a tendency to "run" or extend beyond a reasonable boundary.

In this case, Klotz Associates used a 10-acre maximum when considering if a drainage area was correct. We assumed that no roadside ditch was designed to convey an area greater than 10 acres, and drainage areas greater than 10 acres were removed. This resulted in 753 of 62,083 drainage areas were removed from the final drainage area deliverable.

6.5 Removing Tiny Drainage Areas

The drainage area delineation methodology requires that flowpoints (3s & 9s) be located on top of a roadside ditch feature line to accurately delineate watersheds. In other words, without an underlying roadside ditch line, the flowpoint might not direct flows on the DEM surface in a direction that is hydraulically correct. Delineations from points not located on roadside ditch lines typically resulted in single-cell or much smaller drainage area delineations than accurate. In this case, Klotz Associates determined the points that were not located within 5 feet of a roadside ditch line (i.e. one DEM cell) and selected their corresponding drainage area. Then, with that selection, for the drainage areas less than 0.5 acres, the drainage area was removed. This resulted in 3,965 of 61,330 drainage areas removed from the final drainage area deliverable.

SECTION 7 Programmatic Automation

7.1 PYTHON Programming Script

Python is a free, cross-platform open-source programming language that was incorporated into ArcGIS since its 9.0 release and has become an integral part of the ArcGIS platform. Due to the large amount of processing time and consistency needed for the ditch evaluation, the process was coded in Python and made into a tool accessed in ArcMap and ArcCatalog. An effort was initially made to create the automated process in Model Builder, but due to Model Builder's limitations and the size of the data, the automation was carried into Python.

7.2 DEM Slice Script

In order to consistently recreate the base data to be processed for each DEM Quarter-Quad and because of the large amounts of data; a slice script was written to divide and sort everything systematically. The slice script creates a parent folder that will contain the File Geodatabase and all the processed rasters created from the delineation script. Within the File Geodatabase that is created, the base data is subdivided into 16 tiles within the Quarter-Quad to further break up the data.

7.3 Drainage Area Delineation Script

With over 62,000 points to delineate watersheds on, it was necessary to create an automated process to ensure consistency, timeliness, and accuracy. Python allowed the various ArcGIS Geoprocessing tools and ArcHydro tools to be used and run with minimal user interaction. The script begins by using various ArcHydro tools to process the DEM and produce a hydraulically correct raster and catchments. Then the script uses the catchments produced along with the transect points (3s & 9s) to delineate the watersheds. Once the watersheds are delineated, a special form of the Zonal Statistics tool is used to calculate the percent imperviousness using the buffered impervious raster. This whole process varies time-wise depending on the number of transect points within each DEM quarter-quad area; for the more densely accumulated transect points, it can take between 6-18 hours of processing per DEM.

SECTION 8 Known Issues

The GIS processing and spreadsheet results were inspected for errors and irregularities. A review of the outputs indicated errors caused by the raw data and processed data. Errors associated to the raw data were found after the spreadsheet analysis. The raw data issues are a result of differing Points and Point Type labeling. The spreadsheet was developed to import point data described in section 2. When the Points sequence differed from the typical 1 to 11 order, an "ERROR FLAGGER", described in section 5.7.1, was initiated. "ERROR FLAGGER" was started if the Point Type name did not follow the ROW to ROW labeling described in section 2. Figure 35 shows a cross-section that did not have 11 survey points and the labeling differed from the typical cross-section. This type of error voided the capacity calculation, so a Level of Service was not provided.

Line ID	Points	Point Type	Combined Name	Station	Elevation
253	1	TOPB	253-1 TOPB	0.00	42.87
253	2	FLOW	253-2 FLOW	5.08	43.24
253	3	TOPB	253-3 TOPB	7.75	42.63
253	4	PAVE	253-4 PAVE	17.69	43.92
253	5	CENT	253-5 CENT	24.96	44.46
253	6	PAVE	253-6 PAVE	36.80	44.02
253	7	TOPB	253-7 TOPB	42.61	43.43
253	8	FLOW	253-8 FLOW	48.83	41.02
253	9	TOPB	253-9 TOPB	51.72	43.07
253	10	ROW	253-10 ROW	55.59	43.50

Figure 35: Sample of Raw Data Irregularity

Processed data errors were realized when the data was exported to GIS. Several known areas with roadside ditch cross-sections were used to review the processed data. Errors caused by processing include flow points with no elevations and lengths and limiting cumulative drainage areas. A portion of the flow points did not align with the roadside ditch shapefile. Figure 36 shows a flow point that does not align with the ditch shapefile. As a result, the spatial join did not add the ditch attributes to these flow points.

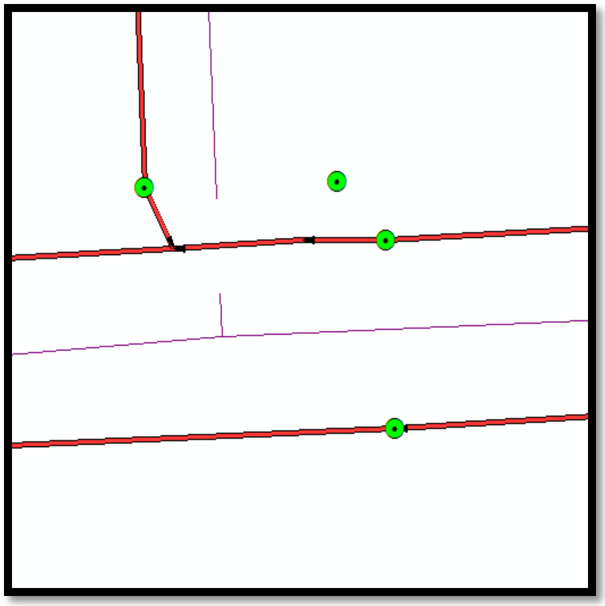


Figure 36: Intersection with Flow Point Error

Another error resulting from the processing split cumulative drainage areas. As shown in Figure 37, some roadside ditch shapefile end at intersections. Flow paths ending at intersections may not accurately reflect the overall drainage pattern. Essentially, this overestimates the Level of Service provided by ditches, because the runoff flows from cumulative drainage areas is separated downstream.

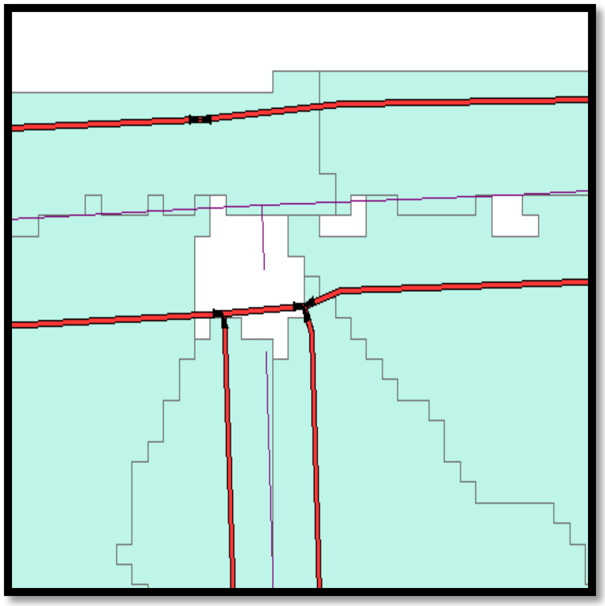


Figure 37: Roadside Ditches without Outfalls

SECTION 9 Concluding Remarks

The completed processing resulted in a final product of 57,365 total delineations. The Python code was run on two computers with each computer processing a DEM between 6 and 18 hours, with the average time being approximately 8 hours. There were a total of 67 DEMs processed. Each delineated area contained a Level of Service (LOS) value of:

- INADEQUATE
- 2
- 5
- 10
- 25
- 100
- ERROR

The drainage areas that were identified with an INADEQUATE identifier were unable to convey the 2-year storm event. The drainage areas that were identified with a 2-year identifier were able to convey the 2-year event but were unable to convey the 5-year event (and-so-on). The drainage areas that were identified with ERROR contained an error in survey data. This was primarily due to a missing point (i.e. point 4 was missing in points 1-6) in a surveyed transect.

The data quality appears to be rather accurate. The data was overlaid with 311 flooding related calls including structural flooding and impassible street complaints. The data appears to correlate rather well with this data. In areas where there are many flooding related calls, there appear to be many more inadequacies in the LOS. The Figure below shows a small example of inadequate areas overlaid with 311 calls.

Figure 38: Data Check

9.1 Statistical Summary

Klotz Associates completed a basic statistical analysis on the finalized data to better-understand the results. Below is the statistical table that calculates a percentage for each LOS on a various set of parameters. Overall, on a count basis, approximately 19% of the city did not meet adequacy for a 2-year storm event, 16% did not meet adequacy for a storm event between 2 and 100-year, and approximately 59% were adequate during the 100-year storm. Approximately 6% of the data was errors, which are further discussed in the section below. Klotz Associates also performed these same statistical calculations on a weighted (by area) basis. The area-weighted percentages are quite different than the count percentages. Overall, on an area-weighted basis, approximately 44% of the city did not meet adequacy for a 2-year storm event, 24% did not meet adequacy for a storm event between 2 and 100-year, and approximately 26% were adequate during the 100-year storm. This indicates that as the drainage areas became larger, they were much less likely to be able to convey a 2-year event (which appears to be sound logic). Klotz Associates also completed the statistical anlaysis on only data in the County, only data in the ETJ, and only data in the City to give a good comparision. You will notice that the approximately 70% of the roadside ditches in the ETJ did not meet the 2-year design adequacy. This is most-likely due to the fact that ETJ roadside ditch areas are much more rural and have much more offsite flows going to them.

Table 5: LOS Statistics

Level of Service (LOS)	COUNT	STATISTICS				
		COUNT PERCENT	AREA WEIGHTED PERCENTAGE	AREA WEIGHTED PERCENTAGE COUNTY	AREA WEIGHTED PERCENTAGE ETJ (NO CITY)	AREA WEIGHTED PERCENTAGE CITY
	#	%	%	%	%	%
ERROR	3,406	5.94%	5.37%	5.37%	6.13%	5.36%
2	2,910	5.07%	8.53%	8.53%	7.35%	8.54%
5	1,753	3.06%	4.50%	4.50%	2.06%	4.56%
10	2,072	3.61%	5.03%	5.03%	2.68%	5.09%
25	2,618	4.56%	5.82%	5.82%	2.50%	5.90%
100	33,722	58.78%	26.62%	26.62%	10.01%	27.02%
INADEQUATE	**10,884**	**18.97%**	**44.14%**	**44.14%**	**69.27%**	**43.54%**

TOTAL:	**57,365**

The table below is another form of statistics that was completed on the data. This simply shows that approximately 40% of the drainage infrastructure within the CoH is roadside ditch.

Table 6: Linework Statistics

LINEWORK	LENGTH	PERCENTAGE
	ft	%
Storm Sewer Length:	20,196,321.77	**61.19%**
Ditch Length:	12,808,628.88	**38.81%**

TOTALS:	**33,004,950.65**

9.2 Gradual Inadequacy

The Figure below shows a sample of the LOS data for a portion of the City where "Gradual Inadequacy" is evident. When designing a subdivision with roadside ditch drainage, engineers do not typically decrease the conveyance ability (i.e. depth) of the ditch as it travels upstream. Instead, in most cases, a typical cross section is used for long portions of the neighborhood streets with a constant geometry. Because of this fact, there are many evident cases where the roadside ditch is able to convey almost any storm event toward the upstream end of the drainage ditch area. As the ditch traverses downstream, the cross sectional area of the ditch remains the same but the contributing drainage area gets much larger. This results in a gradual inadequacy of many ditches. Although many of the drainage areas are adequate, the Figure below represents a general area where the roadside ditches are unable to convey the flows.

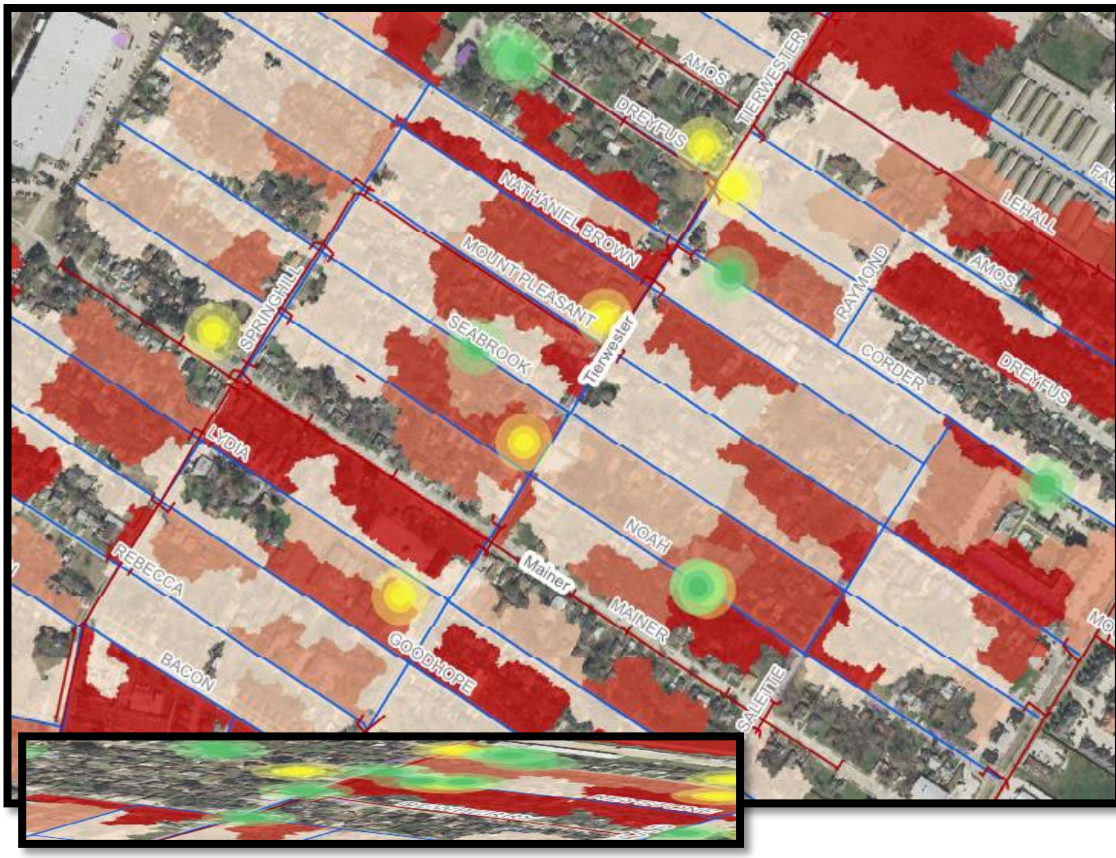


Figure 39: Gradual Inadequacy Example

Exhibits

Appendix A

PYTHON Programming Scripts

Appendix B

Standard Nomenclature and Abbreviations

Appendix C

2012 Drainage Criteria from the CoH Design Criteria Manual