GIS-BASED TOOLS TO CALCULATE CLASS LOCATION AND MAXIMUM ALLOWABLE OPERATING PRESSURE (MAOP) FOR GAS TRANSMISSION PIPELINES

by

ANNA G. LIDE

(Under the Direction of Lucy Huang, Ph.D.)

ABSTRACT

Two GIS-based analysis tools were developed for gas transmission pipelines in this project. One tool determines class location designations along a gas transmission pipeline to satisfy the U.S. Department of Transportation (DOT) regulations. The second tool calculates the maximum allowable operating pressure (MAOP) based on the structural properties of pipeline segments.

The DOT regulations in 49 CFR 192 explain the class location definitions and the operating pressure as a function of class location design factors. The DOT class locations indicate a level of the potential risk of damage to a pipeline from external activities and the potential risk to people and property near the pipeline. Class location categories set the parameters that affect the MAOP values for operating a gas pipeline. The categories are a function of population and infrastructure in proximity to the pipeline. Specifying the MAOP value reduces the risks to the pipeline and surrounding area.

INDEX WORDS: Class Location, MAOP, GIS

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CHAPTER 1

INTRODUCTION

Thousands of miles of pipelines transport natural gas and other gases throughout the United States. The pipelines traverse terrain with diverse land usage and land cover through a wide range of population densities. Numerous customers, from individual households to industrial and commercial consumers, rely on the gas pipeline products on a daily basis. Gas pipeline operators pressurize the gas to create proper flow of the product for delivery to the consumers. Although pressurizing the pipeline achieves an adequate flow rate of the gas to meet demand, pressurization also introduces a risk to the area surrounding the pipeline in the event of a structural failure of the pipe. In order to ensure public safety, the U.S. Department of Transportation (DOT) maintains and enforces the code for interstate transportation of natural and other gas documented in the 49 CFR 192. According to the DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) approximately 300,000 miles of gas transmission pipeline are regulated by 49 CFR 192 (PHMSA 2014).

Operators of gas pipelines must regularly report the established Maximum Allowable Operating Pressure (MAOP) values to PHMSA for each segment of their pipeline system. Proper reporting entails extracting the data necessary for determining the MAOP from records of pressure tests, maintenance reports, alignment drawings, mill test reports, and component specifications. Geographic Information Systems (GIS) offer a logical solution for maintaining and analyzing pipeline data because pipeline data elements have a spatial component, and the interface between public demand for the pipeline products and the prerequisite to ensure public safety resides in a geographic domain. In conjunction with GIS, accurate and up-to-date information from remote sensing of pipeline corridors may assist in determination of the population and land usage that in turn influences the MAOP by location for pipe segments.

Currently, operators of gas pipelines implement GIS at various levels and degrees to represent and analyze the vast amounts of historical and new pipeline data. In addition to MAOP reporting criteria, gas operating companies have other obligations that a GIS may support. For example, GIS aids in 1) submitting accurate location and operating status of pipeline assets to the National Pipeline Mapping System, 2) determining High Consequence Areas to support risk analysis, and 3) containing the relational database for an integrity management program. Schedule and resource constraints may lead to duplication of efforts performed both within and outside of a GIS framework. Consequently, the link between the GIS efforts and the engineering functions is often fragmented.

This GIS project demonstrates performing an engineering calculation for establishing the MAOP for pipeline segments within the GIS framework. The MAOP for a pipeline segment is the lower value determined by one of the following criteria, 1) hydrostatic pressure testing, 2) the design pressure, 3) the maximum operating pressure during the preceding five years, or 4) the maximum safe operating pressure determined by the operator (49 CFR 192.619). This project developed a GIS-based tool to calculate the MAOP value defined by the design pressure using a design factor based on the population density and infrastructure along the pipeline route. Incorporating an MAOP tool empowers the GIS to represent MAOP segments along the pipeline route as a function of location and design. As the input parameters of geographic and structural attributes change, the calculation tool within the GIS updates the results by pipe segments.

In order to evaluate current practices in calculating MAOP segments for a pipeline system and utilizing a GIS database, a literature review surveyed academic literature, industry journals, and industry conference presentations. Understanding of current industry practices assisted in defining the methods selected for developing the MAOP tool. The literature review identified challenges faced by pipeline companies in fulfilling the federal requirements and the need for developing efficient MAOP calculators.

CHAPTER 2

LITERATURE REVIEW

Review of current literature revealed that the pipeline industry encounters a substantial undertaking in order to comply with the obligations in federal reporting. The federal requirement for reporting MAOP values stipulates that the documents used in the calculation must be "verifiable, traceable, and complete" (Weise 2011). At the 2012 International Pipeline Conference (IPC) one company presentation outlined their systematic approach to assist oil and gas operators in satisfying PHMSA's requirement for "verifiable, traceable, and complete" (Lutz 2012). Satisfying the mandate would involve extensive research and cataloging of documents into a searchable database, which may strain the resources of an operating company. The necessary documents include engineering drawings, material specifications, test reports, inspection reports, and others. The methodology explained a decision making process of prioritizing the research based on document source credibility. A subsequent article to the presentation delineated the successes and recommendations of their materials verification method (Pollard 2012). It also contained the reminder that PHMSA audits would include material verification beginning in 2013. In a 2013 Pipeline & Gas Journal issue, a small capital engineering service company referenced the immense task of validating MAOP and using GIS as part of their management solution (Share 2013). At the Pipeline Open Data Standard, PODS, 2012 User Conference, a large oil and gas pipeline company presented their strategy to standardize and manage data relevant to verifying MAOP (Marx 2012). The presentation outlined an enterprise solution for collecting, certifying, storing, and retrieving MAOP data. The enterprise approach recognized the business value of the data as an asset and the interests of the multiple stakeholders regarding production levels and public safety.

In conjunction with the document research, building and improving MOAP calculators on the large pipeline data sets is a present-day endeavor. In 2008 at the International Pipeline Conference in Canada, a model was presented for a code driven comprehensive MAOP calculator that incorporated all of the nuances of 49 CFR 192 for a complete gas pipeline system (Decker 2008). The author illustrated the industry need for such a model citing the typical industry practice of isolated research to determine an MAOP rating for a specific section of pipeline prompted by isolated events. In the model, the MAOP calculator extracts the necessary data from a GIS for each pipeline record. It performs the calculations following all decision criteria specified in the 49 CFR 192 code, and returns the results to the GIS for each pipeline record. The model evaluates a complex pipeline system in a short time frame and produces a report of the MAOP rating of any GIS record with the necessary documentation of methodology and data sources.

Efficiency in validating the MAOP for pipeline systems is ongoing at numerous operating and service companies. In an October 2013 issue of Pipelines International, a large oil and gas company announced their new MAOP calculator that searches data within an existing GIS for a pipeline line or loop (GE 2013). In the calculator description, if records exist in the GIS for the line or loop then the pressures are determined, otherwise the calculator applies the most restrictive PHMSA rules in evaluating the pressure. At the 2013 PODS User Conference, a large gas utility company described their approach to MAOP validation following their 2010 pipeline failure (Harrison 2013). Building a suitable MAOP calculator led to embedding the calculations within the GIS. The calculator incorporated the logic for pressure ratings by design, test, or historical operating levels. The presenter mentioned an important consideration in reducing operating pressure; reduction in operating pressure affects the ability of the utility company to meet the public demand for the natural gas in winter months. Calculating the MAOP is critical for meeting demand as well as ensuring public safety.

CHAPTER 3

RESEARCH METHODOLOGIES AND CONCEPTS

The structural design of gas pipelines follows the American Society of Mechanical Engineers (ASME) specifications in the code for Gas Transmission and Distribution Piping Systems, B31.8 (ASME 2004). The ASME B31.8 and 49 CFR 192 code define the MAOP based on the structural design and surrounding population classification. The material specifications of the pipe limit the pipeline pressure according to the material strength, and a design factor proportionally reduces the allowable pressure. The surrounding population determines the design factor according to a schedule of class locations.

Along the many miles of a pipeline, the design requirements of the geographic environment may differ for segments of the pipe resulting in variations in the structural material specifications. Since material strength limits operating pressure, segments of the pipeline may have different MAOP values. Additionally, population densities fluctuate which means the class location and appropriate design factor also change by segments of the pipeline. After construction and startup of operations, the population density and land usage may alter necessitating modification to the MAOP.

In this project, a study area was selected in Texas where gas transmission pipelines are commonly routed. The study area includes three Texas counties: Brazoria, Galveston, and Harris Counties. Pipeline centerlines for three hypothetical pipelines traversing the counties were defined using aerial imagery in Google Earth. The analysis was conducted using ESRI software ArcMAP 10.2, and the tools were developed and scripted in Python v.2.7.5. A file geodatabase with relevant components for a pipeline system was designed. The population density along the three pipeline routes was determined using county appraisal district parcel data. The GIS tools that were developed in the project determine the class location, apply the design factor, and overlay the design factor segments with the structural properties. Linear referencing tools were used to create route events from the class locations and the calculated pressure values for a cartographic representation.

Figure 3-1 shows a flow chart with an overview of the methods employed in the project. Section 3.1 of this chapter describes the project study area and project pipelines. The codes used to assess population and the structural design criteria are explained in Section 3.2 and 3.3, respectively. Section 3.4 provides the project geodatabase design and the methods used in the processing of the data. The purpose of the project was the development of the GIS-based tools, the Class Location Tool and the MAOP Calculation Tool, which are explained in Section 3.5 and 3.6. Finally, Section 3.7 of Chapter 3 provides the method of displaying the results of the tools.

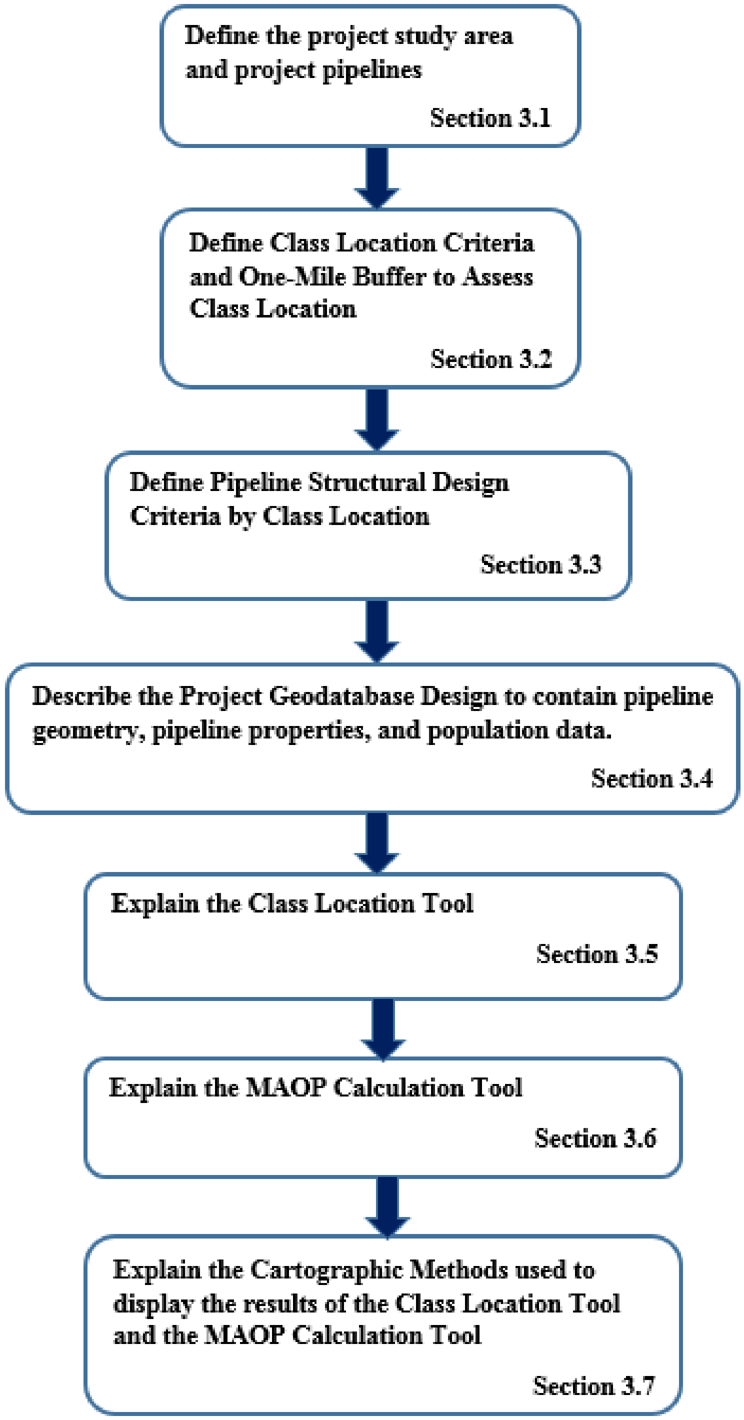


Figure 3-1 Project Methods Overview

3.1 STUDY AREA AND PIPELINES

The National Pipeline Mapping System (NPMS) Public Map Viewer shows current gas transmission pipelines by county and state. Figure 3-2 shows the location of the study area in Texas, and Figure 3-3 identifies the three counties in the project. NPMS displays the existing gas transmission pipelines for each of the project counties, Figure 3-4.

Figure 3-2 Project Study Area in Texas

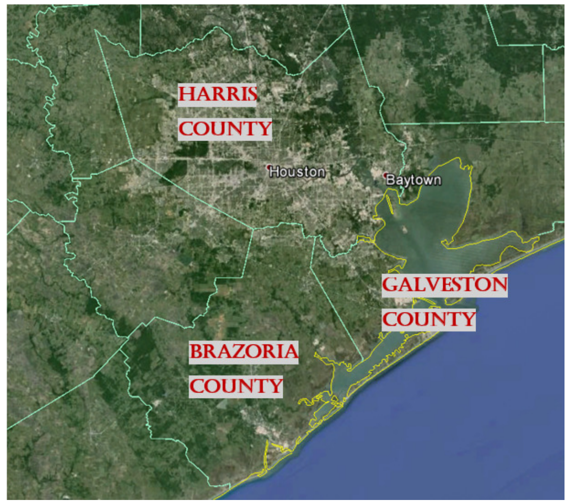
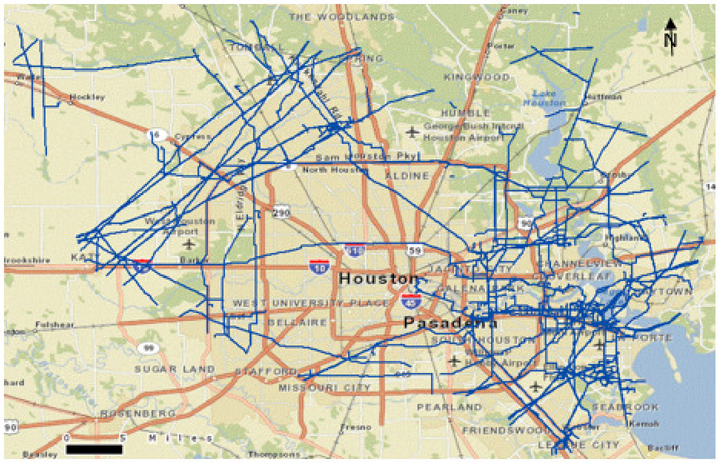
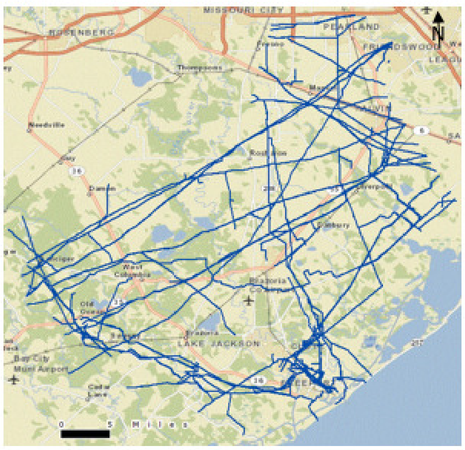


Figure 3-3 Three Counties in Project Area

Three pipeline routes were established for the study using aerial imagery. The first centerline, ID 100, runs 31.3 miles from west to east through Brazoria and Galveston County. Pipeline inflection point locations and the centerline were randomly selected without regard to existing residential and commercial property or transportation infrastructure, Figure 3-5. The paths for the second and third pipelines, ID 200 and ID 300, were directed along existing pipeline right-of-ways in the counties. Pipeline ID 200, 30.7 miles, runs north to south through Harris and Galveston County, Figure 3-6. Pipeline ID 300 begins in southern Brazoria and extends northeast for 31.9 miles into Galveston County, Figure 3-7.



a) Harris County



b) Brazoria County

c) Galveston County

Figure 3-4 NPMS Public Map Viewer of Gas Transmission Pipelines

All three pipelines were designated as natural gas transmission pipelines built from API seamless line pipe. Different segments of pipeline ID 100 have either a 20-inch or a 22-inch diameter with variation in wall thickness and material strength. Pipeline ID 200 and ID 300 have consistent material specifications for the entire length of the pipeline route. Table 3-1 gives the properties for each line in the system.

Figure 3-5 Pipeline ID 100

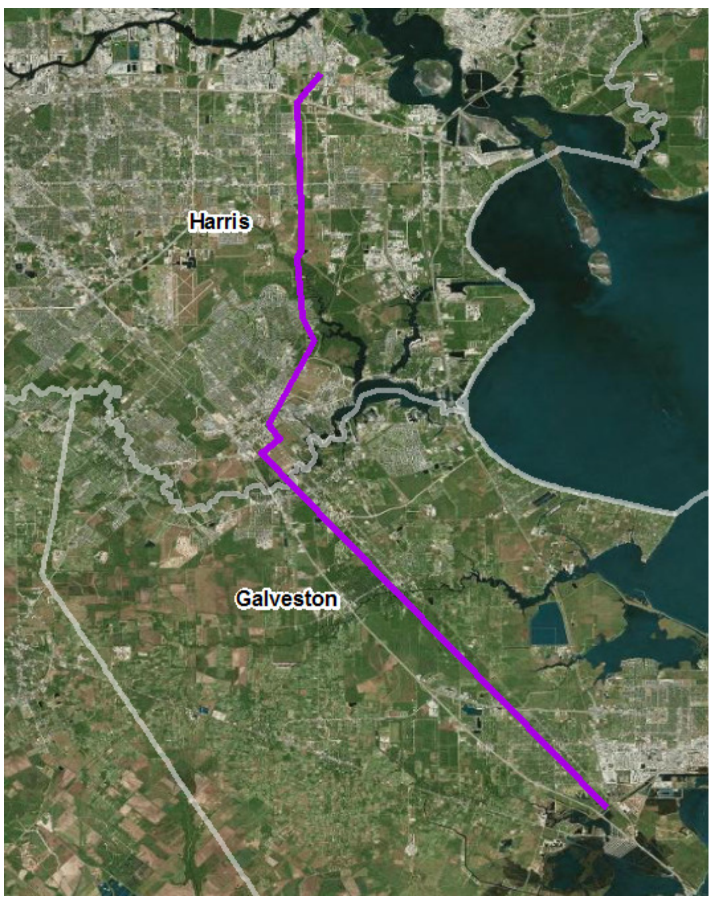


Figure 3-6 Pipeline ID 200

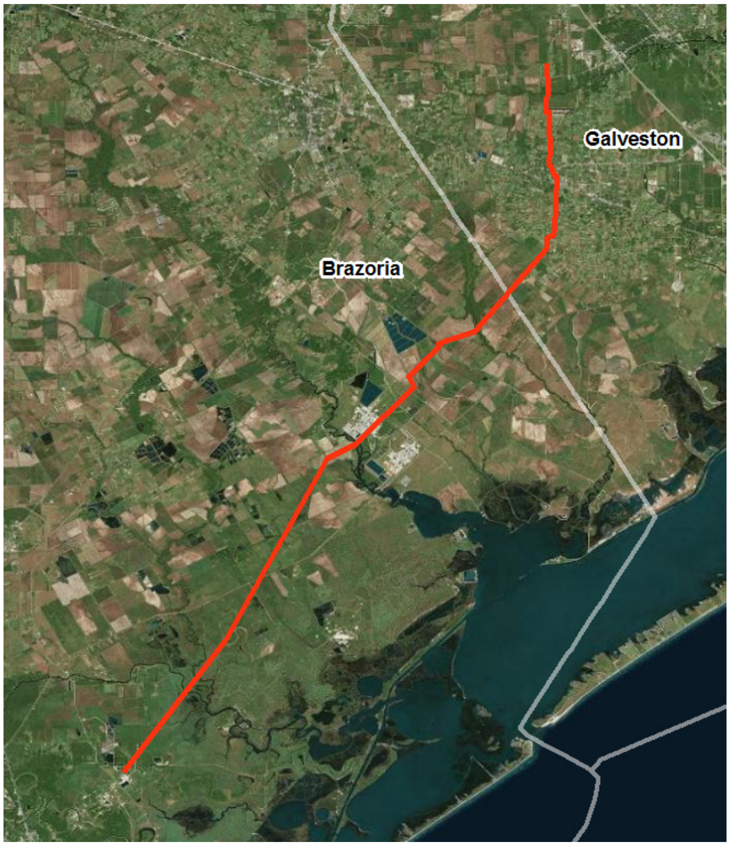


Figure 3-7 Pipeline ID 300

Table 3-1: Pipeline Material Specifications

PIPELINE ID	Diameter (inches)	Wall Thickness (inches)	Material Specification	Specified Minimum Yield Strength (PSI)
100	20	0.25	API 5L X52	52,000
	20	0.375	API 5L X42	42,000
	22	0.25	API 5L X52	52,000
200	22	0.25	API 5L X52	52,000
300	12	0.312	API 5L X52	52,000

3.2 POPULATION AND CLASS LOCATION

Public activity in proximity to the pipeline increases the possibility of damage. As neighborhoods develop, construction for homes and laying of underground utilities increase the potential for interfering with buried gas lines, and the addition of new residential dwellings increases the consequences in the event of a ruptured gas line. The class location designations for a gas transmission line represent the degree of exposure of the pipeline to activity that could lead to damage and indicates the extent of possible consequences to the public of a pipe failure.

The class location designation for a pipeline segment is based on the number of dwellings along the pipeline route within a buffer of the centerline. The locations are classified as 1 through 4 with Class 4 indicating the highest probability of possible damage and consequence to the public. The number of dwellings are assessed within the buffer of the pipeline for any one-mile segment. The 49 CFR 192.5 stipulates the buffer as 660 feet on either side of the pipeline centerline for a total width of ¼-mile. The regulation delegates any one-mile segment with 10 or fewer dwellings inside the buffer as a Class 1 location. A one-mile segment with more than 10 but less than 46 dwellings is defined as a Class 2 location. Finally, a Class 3 location refers to a one-mile segment with 46 or more dwellings. A segment with a multistory building of four or more stories or a high traffic area becomes a Class 4 location. Table 3-2 summarizes the class locations.

In order to classify segments with the greatest number of dwellings, or a Class 4 instance, i.e. multistory building or high traffic, the assessment adjusts the one-mile length buffer along the pipe centerline. By linear adjustment of the one-mile buffer along the route, the greatest clustering of dwellings and Class 4 instances are captured in the buffer.

Table 3-2: Class Locations

Class Location	Structures in a One-Mile Segment
1	Number of Dwellings ≤ 10
2	10 < Number of Dwellings < 46
3	Number of Dwellings ≥ 46
4	Building with 4 or More Stories or High Traffic Areas

In this project, the datasets of parcels from the county appraisal district for each county were used to quantify the number of dwellings within the buffer. Multistory buildings and intersections with areas of high traffic were identified manually with aerial imagery. The parcel datasets from each county are illustrated in Figures 3-8 through 3-10. The class 4 instances along the project pipelines are identified in Figure 3-11.

The land areas and estimated populations were obtained from the U.S. Census QuickFacts website. The values and population density of each of the counties in the project are listed in Table 3-3. Harris County covers the largest land area with the greatest population density. As shown in Figure 3-4, according to the NPMS, the gas transmission lines typically remain outside the area of highest population density and clustering of multistory buildings such as downtown centers or other business districts. However, population and infrastructure over time creep into the vicinity of existing transmission lines. The changes in population and infrastructure may prescribe a class location study to assess changes which may affect the operating pressure of a pipeline (49 CFR 192.609).

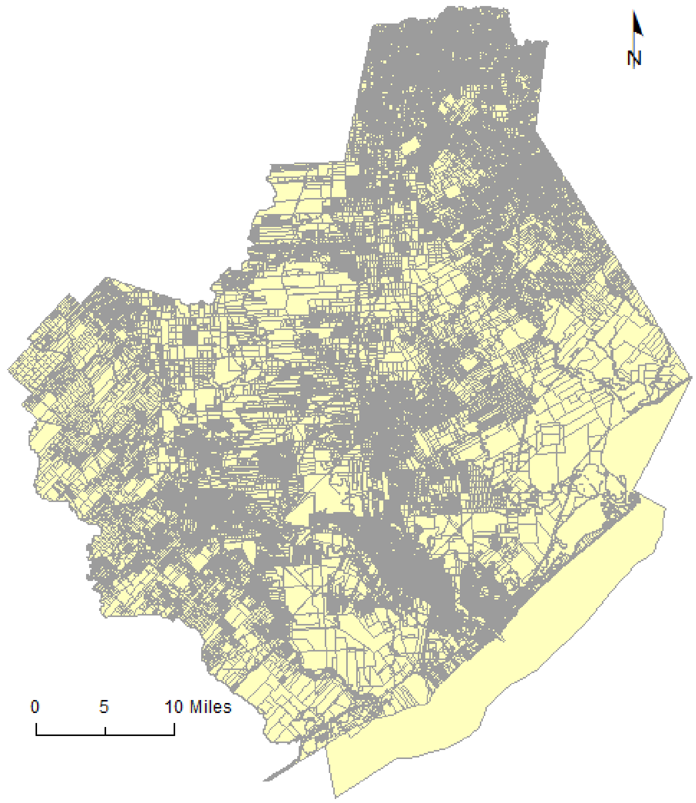


Figure 3-8 Brazoria County Appraisal District Parcel Dataset

Figure 3-9 Galveston County Appraisal District Parcel Dataset

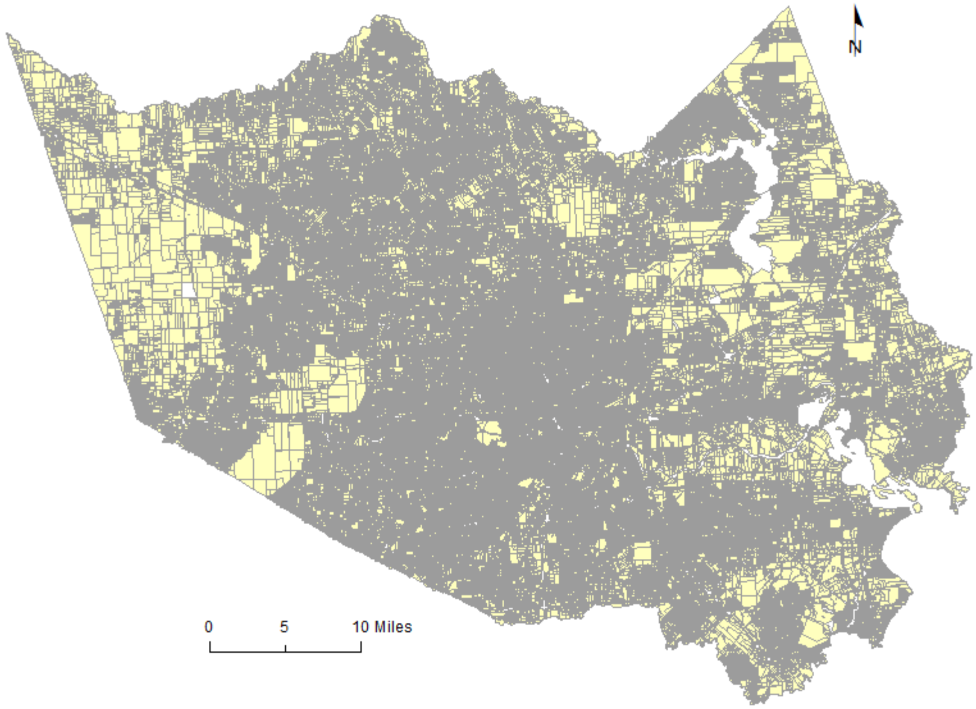


Figure 3-10 Harris County Appraisal District Parcel Dataset

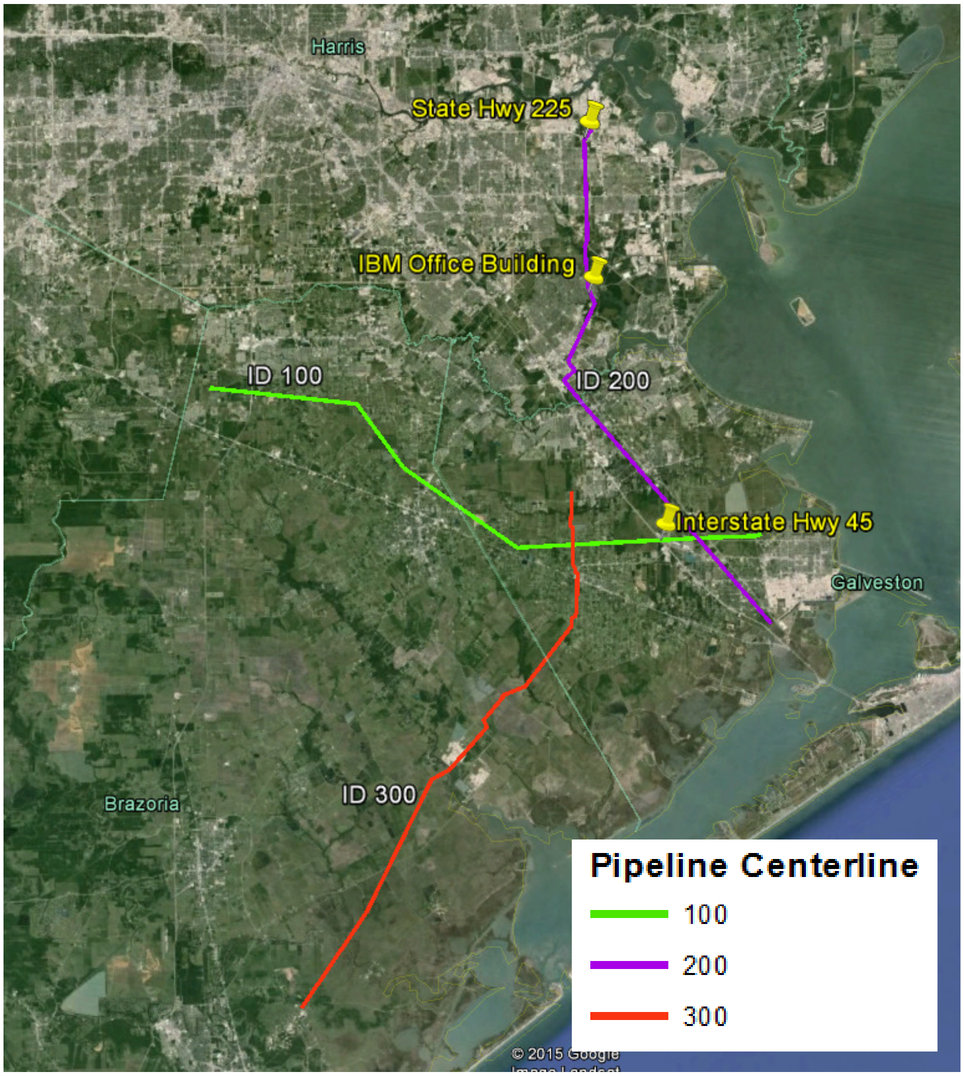


Figure 3-11 Class 4 Instances Identified by Pushpin Symbols

Table 3-3: County Population Density

County	Land Area (sq. miles)	Estimated 2013 Population	Population Density (persons/sq. miles)
Brazoria	1357.70	330,242	243
Galveston	378.36	306,782	811
Harris	1703.48	4,336,853	2546

3.3 Pipeline Structural Design

The design pressure of a pipeline is based on the formula for the circumferential strength, or hoop stress, of the pipe material determined by the following formula (ASME Code B31.8).

$$P = \frac{2St}{D} FET \tag{1}$$

where P is the design pressure in pounds per square inch (PSI)

S is the specified minimum yield strength, SMYS, of the material in PSI

t is the pipe wall thickness (inches)

D is the nominal outside pipe diameter (inches)

F is the design factor based on class location

E is a longitudinal joint factor

T is a temperature derating factor

In this project, the values for E and T were set equivalent to 1.0. CFR 49 192.111 gives the values for the design factor F as a function of class location, Table 3-4. The pipe dimensions and material strength for the project pipelines are listed above in Table 3-1.

Table 3-4: Design Factors for Steel Pipe

Class Location	**Design Factor, F**
1	0.72
2	0.60
3	0.50
4	0.40

3.4 Geodatabase Design

A geodatabase was created with a pipe segment property table and three feature datasets to contain the geometry of the pipeline system, pipe attributes, and the surrounding population datasets. The three feature datasets have a geographic coordinate system spatial reference in the North American Datum 1983. Figure 3-12 displays the geodatabase structure for the project.

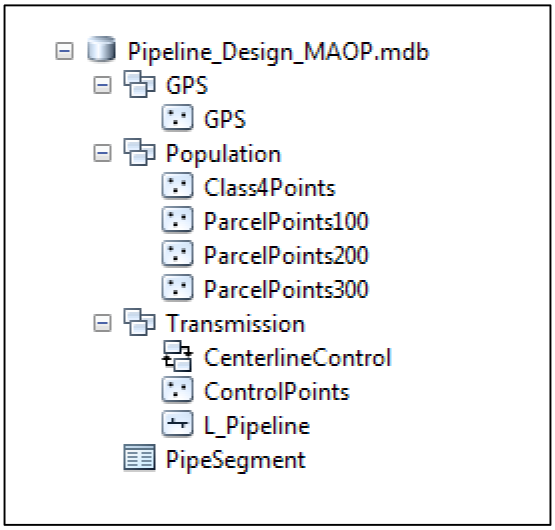


Figure 3-12 Geodatabase Structure

The first stage in developing the pipeline geometry was obtaining the point locations of the beginning point and ending point of the pipeline route and for any pipe inflection points along the route. Using aerial imagery, eight points were randomly selected for route ID 100. Fourteen and twenty-eight points for route ID 200 and 300, respectively, were intentionally selected along existing pipeline corridors. A table of latitude and longitude coordinates was created for each pipeline route in the system. In ArcMap, the data frame coordinate system was specified as a Geographic Coordinate System North American Datum 1983. The table of route points was added in ArcMap, displayed as XY data, and the XY events exported to a shapefile. In ArcCatalog, a point feature class, named GPS, was created under the GPS feature dataset. Its fields included a route identification number, RID, as a short integer data type and fields for both the latitude and longitude as double float data type. Using the simple data loader tool, the coordinates for the points and associated RID were added to the geodatabase, Figure 3-13.

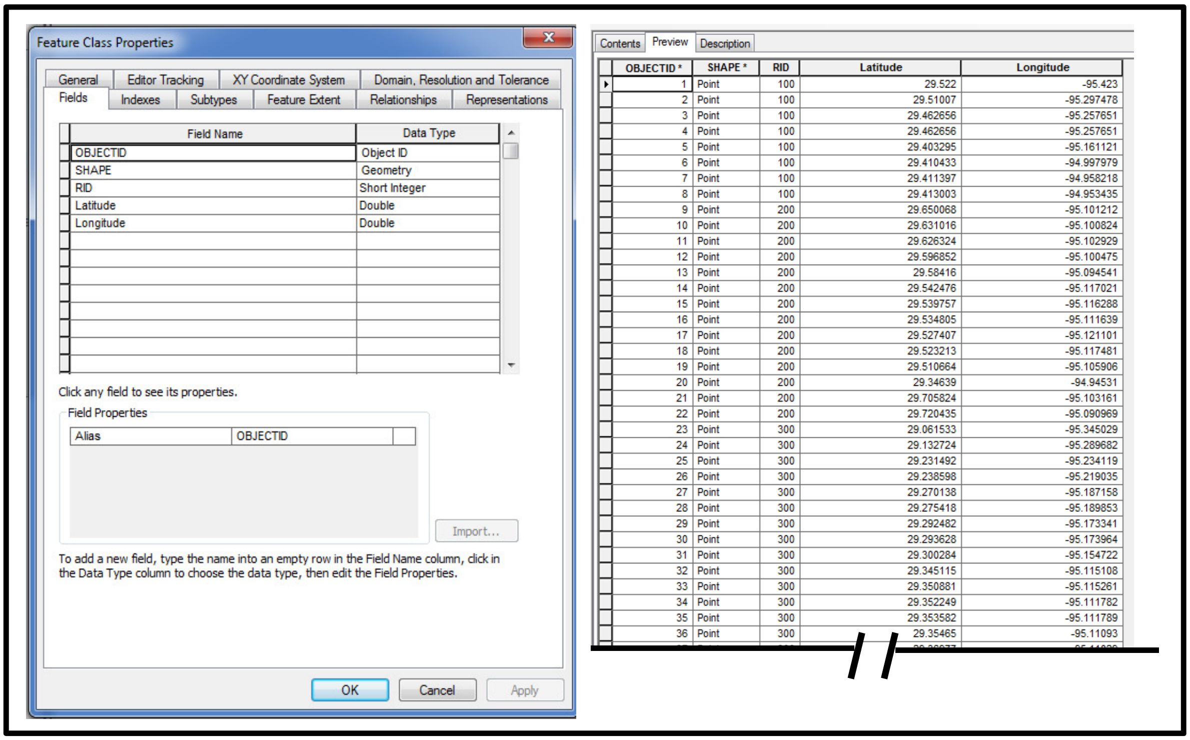
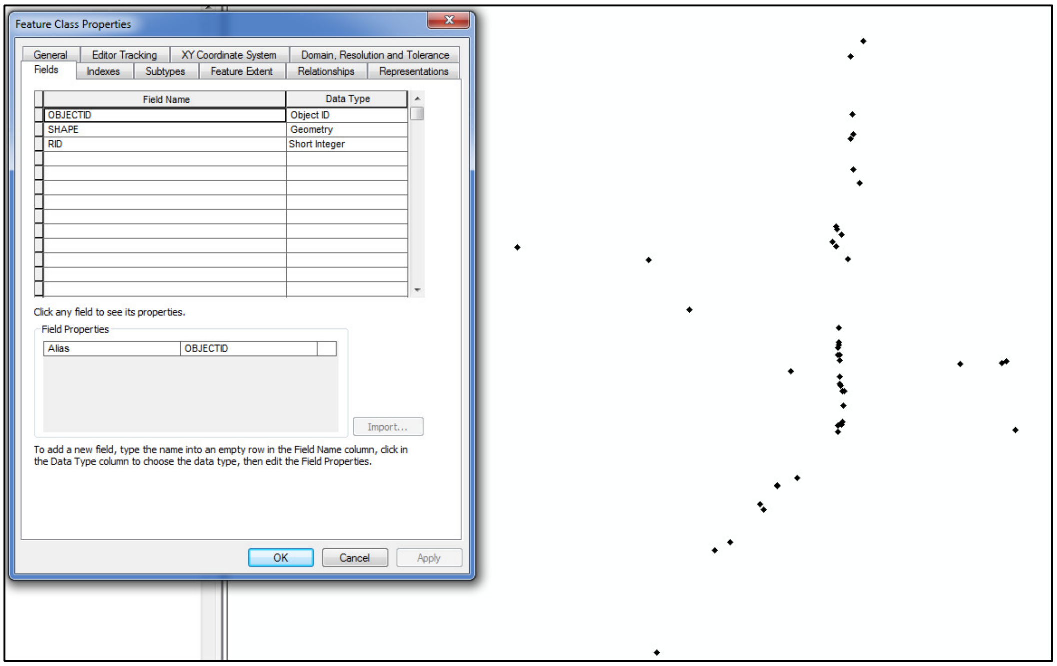
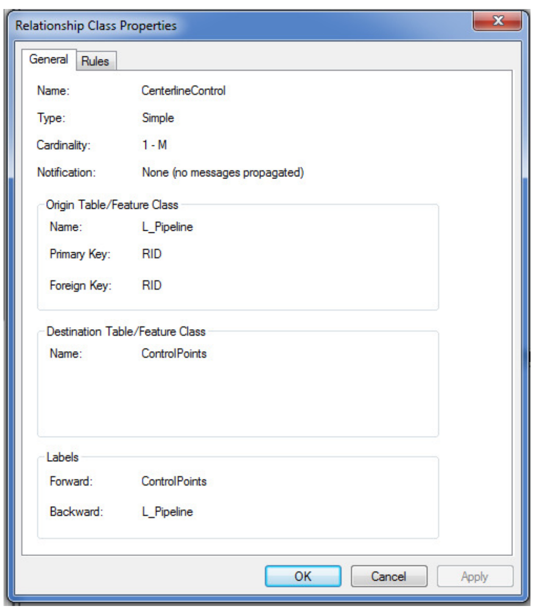


Figure 3-13: GPS Feature Class in Geodatabase GPS Feature Dataset

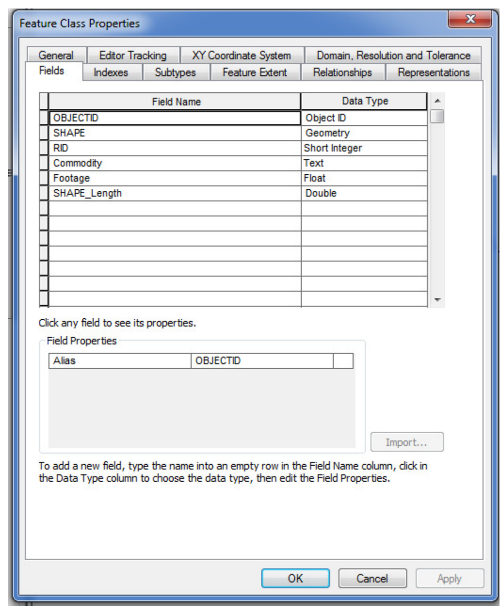
The Transmission feature dataset in the geodatabase contains control points for the route features, the linear route feature class, and a relationship class relating the control points with the linear routes. The control points contain the points from the GPS feature class and were used to create the linear routes in the L_Pipeline feature class in ArcMap. In creating the L_Pipeline feature class in ArcCatalog, coordinates to contain measure values, or M values, was specified. Figure 3-14 shows the properties of the Transmission feature dataset including the Control Point feature class, Relationship Class, and the L_Pipeline feature class properties.



a) Control Points Feature Class



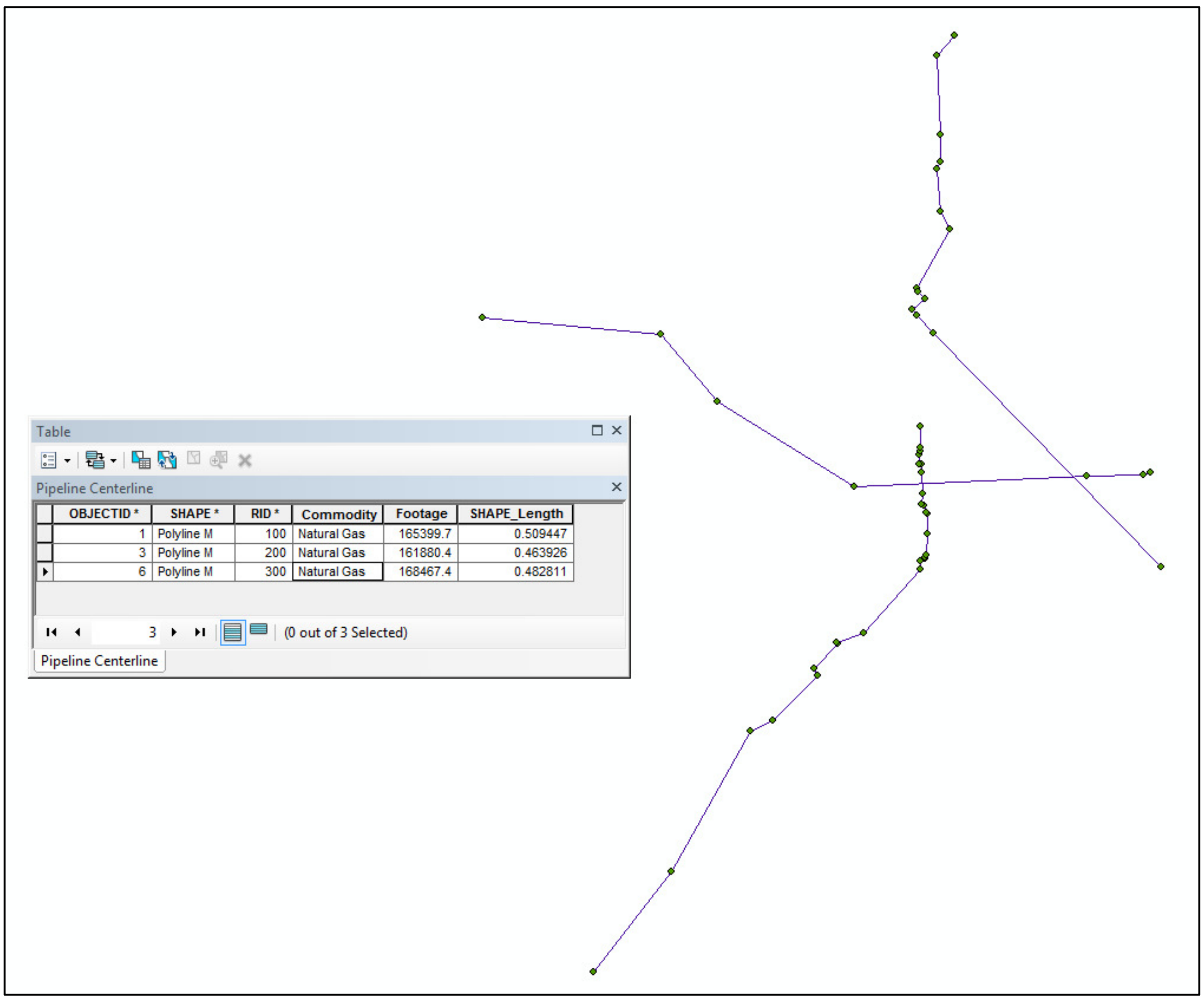
b) Relationship Class



c) L_Pipeline Properties

Figure 3-14: Transmission Feature Dataset

In ArcMap, the L_Pipeline route features were created by editing the L_Pipeline layer and snapping to the control points. The attribute table was edited to add the pipeline commodity values. After creating the route features, the L_Pipeline layer was copied into a data frame with a spatial reference of South Texas State Plane, North American Datum 1983. In the state plane projected coordinate data frame, it was possible to use the "Calculate Geometry" tool to find the length of the overall route feature measured in feet. With the "Calculate Geometry" tool, the total footage of each pipeline route was applied to the feature attributes. Figure 3-15 demonstrates the L_Pipeline features and attributes.



OBJECTID *	SHAPE *	RID *	Commodity	Footage	SHAPE_Length
1	Polyline M	100	Natural Gas	165399.7	0.509447
3	Polyline M	200	Natural Gas	161880.4	0.463926
6	Polyline M	300	Natural Gas	168467.4	0.482811

Figure 3-15: L_Pipeline Feature Class

The route measurement values were applied to the L_Pipeline features using linear referencing tools. In ArcMap, an edit session of the route feature layer was initiated. Using “Edit Sketch” and “Edit Vertices”, a measurement value of 0.00 was applied to the beginning point of the route and the total footage value was applied to the end point. In the map, “Route Measure Editing” and “Calculate NaN” was chosen in order for measurement values along the route to be evaluated and added to each vertex of the linear routes. Figure 3-16 shows the measures applied to pipeline route ID 300.

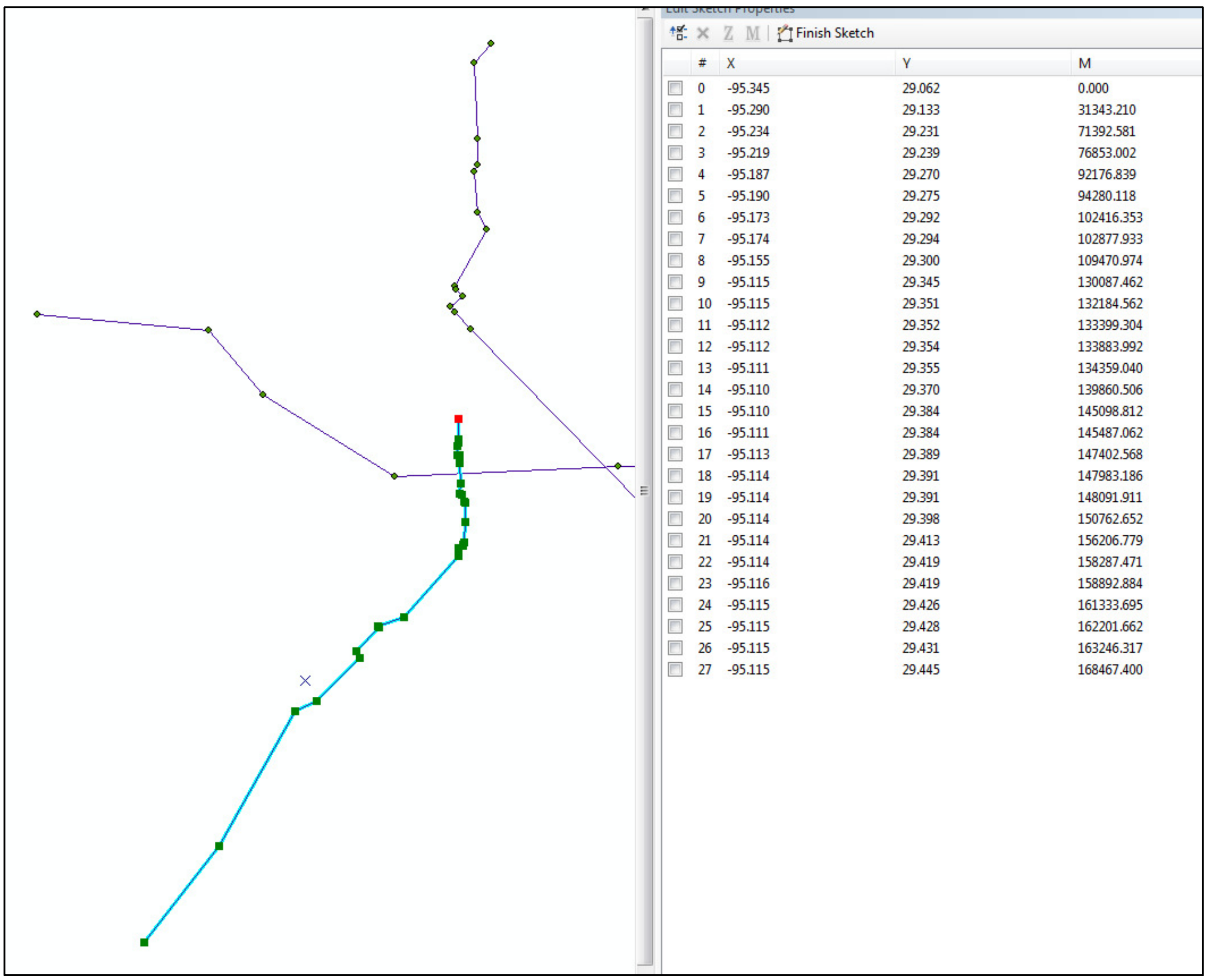


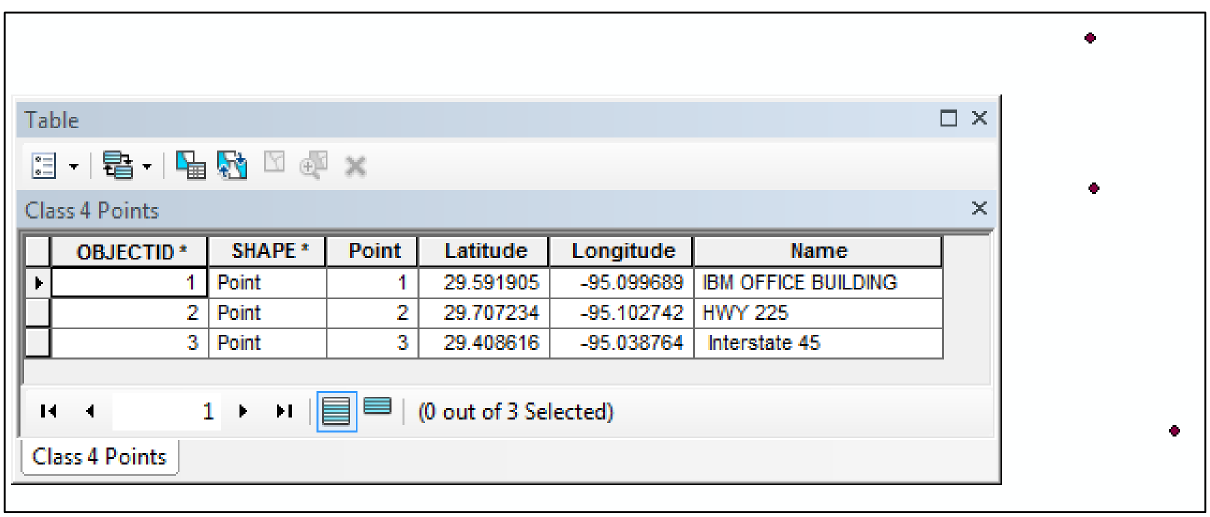
Figure 3-16: Route Measures Applied to Route ID 300 in ArcMap

The PipeSegment table in the geodatabase contains the structural properties of each route as previously listed in Table 3-1. Pipeline ID 200 and 300 maintain consistent properties for their entire routes. Pipeline ID 100 represents a pipeline with various redesign or changed pipe properties. The route measure values, BeginSta and EndSta, in the PipeSegment table indicate the measurements along the pipeline for each set of pipe segment properties, Figure 3-17.

OBJECTID *	RID	BeginSta	EndSta	Diameter	WT	Material	SMYS
1	100	0	50000	20	0.25	API 5L X52	52000
2	100	50000	75000	22	0.25	API 5L X52	52000
3	100	75000	110000	20	0.25	API 5L X52	52000
4	100	110000	145000	20	0.375	API 5L X42	42000
5	100	145000	165399.7	20	0.25	API 5L X52	52000
7	200	0	161880.4	22	0.25	API 5L X52	52000
8	300	0	168467.4	12	0.312	API 5L X52	52000

Figure 3-17: Geodatabase PipeSegment Table

The Population dataset contains point feature classes for the purpose of evaluating the class locations in the one-mile segments along each pipeline route. The Class4Points feature class has the description and spatial location of the class 4 instances as explained in Figure 3-11. The Class4Points feature class is illustrated in Figure 3-18.



OBJECTID *	SHAPE *	Point	Latitude	Longitude	Name
1	Point	1	29.591905	-95.099689	IBM OFFICE BUILDING
2	Point	2	29.707234	-95.102742	HWY 225
3	Point	3	29.408616	-95.038764	Interstate 45

Figure 3-18: Class4Points Feature Class

The county appraisal district parcel datasets, Figures 3-8, 3-9, and 3-10, were converted to point features in order to assess the number of dwellings within the ¼-mile wide buffer of the pipelines. The parcel shapefiles and L_Pipeline layer were added to ArcMap. In order to select parcels, a one-mile wide buffer was applied to each pipeline route using the "Buffer" geoprocessing tool. The parcels that intersected the buffers were selected and placed in a new layer for each route. Using the "Feature to Point" tool, the selected parcel polygon features were converted to point features where a single point was located inside each polygon. In ArcCatalog, a feature class for each route was created in the Population feature dataset. Fields and data types were imported from the appraisal district shapefiles. The feature points were added to the geodatabase using Simple Data Loader tool in ArcCatalog. The process for creating the ParcelPoints300 point feature for route ID 300 is demonstrated from Figures 3-19 through 3-23. Generating ParcelPoints100 and ParcelPoints200 followed an identical procedure.

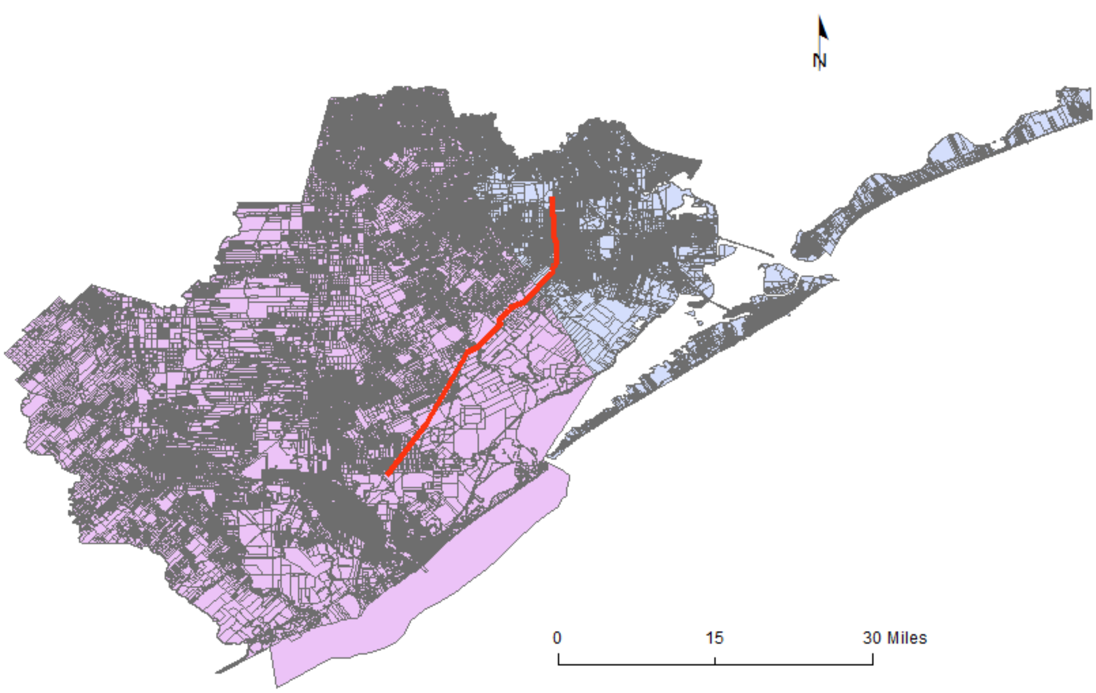


Figure 3-19: Pipeline Route ID 300 Traversing Brazoria and Galveston County Appraisal District Parcels

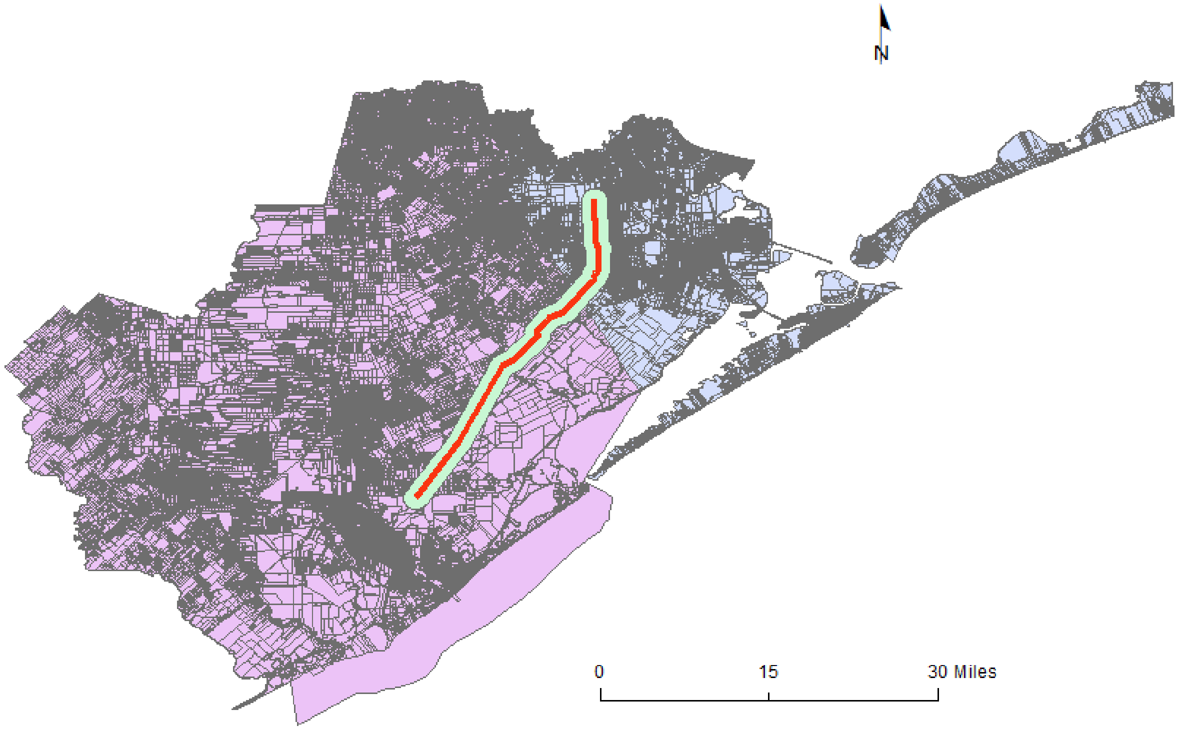


Figure 3-20: Pipeline Route ID 300 Buffer

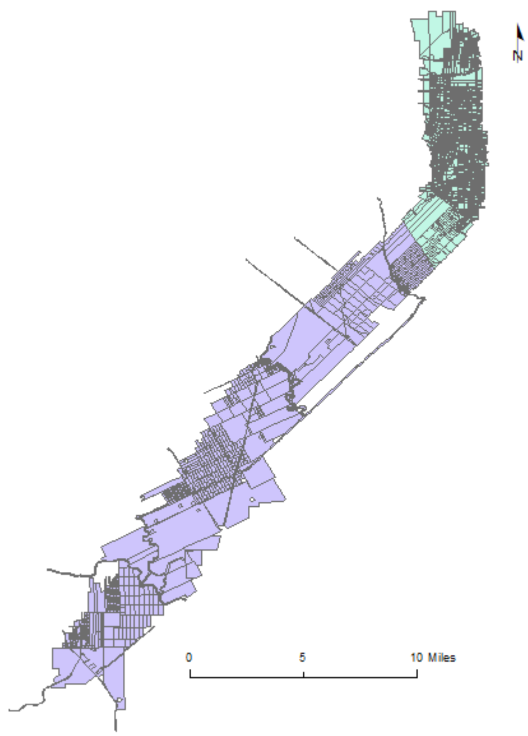


Figure 3-21: Brazoria and Galveston County Parcels Intersecting Route ID 300 Buffer

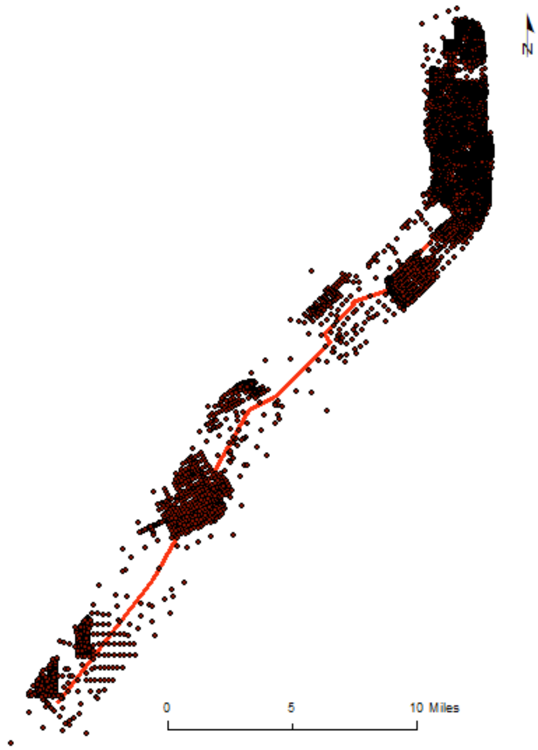


Figure 3-22: Brazoria and Galveston County Parcel Features Converted to Point Features

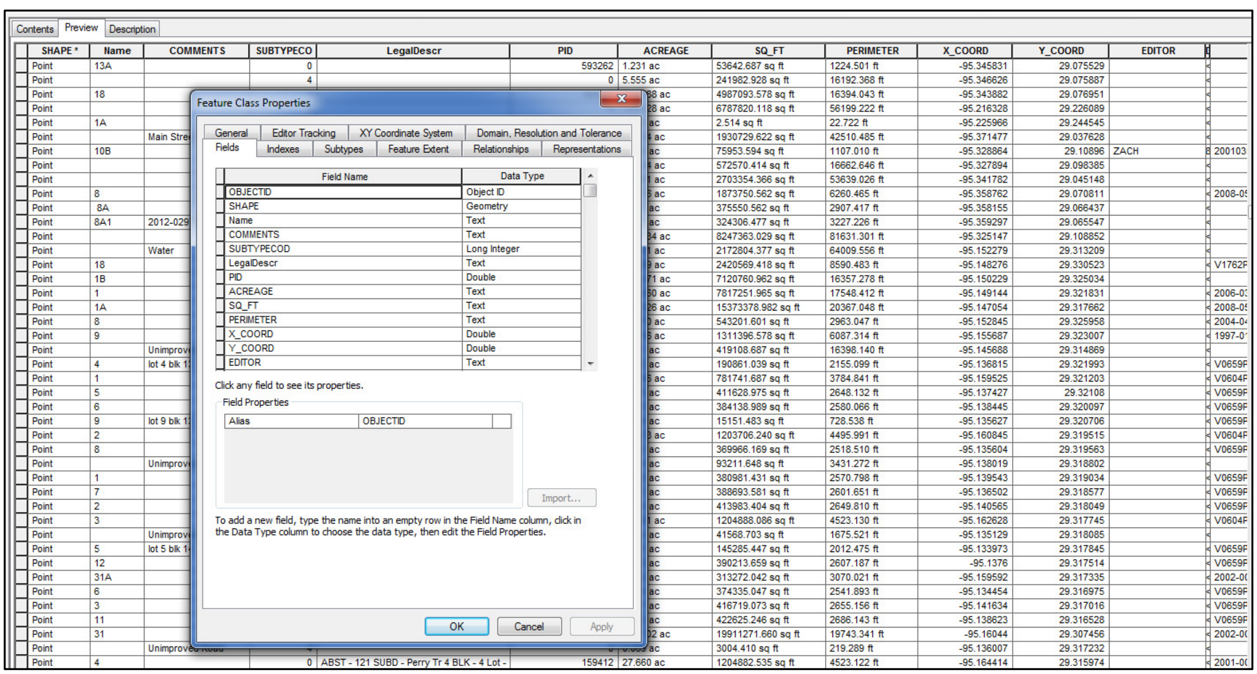


Figure 3-23: Point Features Loaded into ParcelPoints300 Feature Class in Geodatabase

All point feature classes in the Geodatabase Population dataset are represented in Figure 3-24. The yellow pushpin symbols illustrate the Class 4 instances. Each of the parcel polygon features that were converted to point features along the pipeline route are labeled in Figure 3-24.

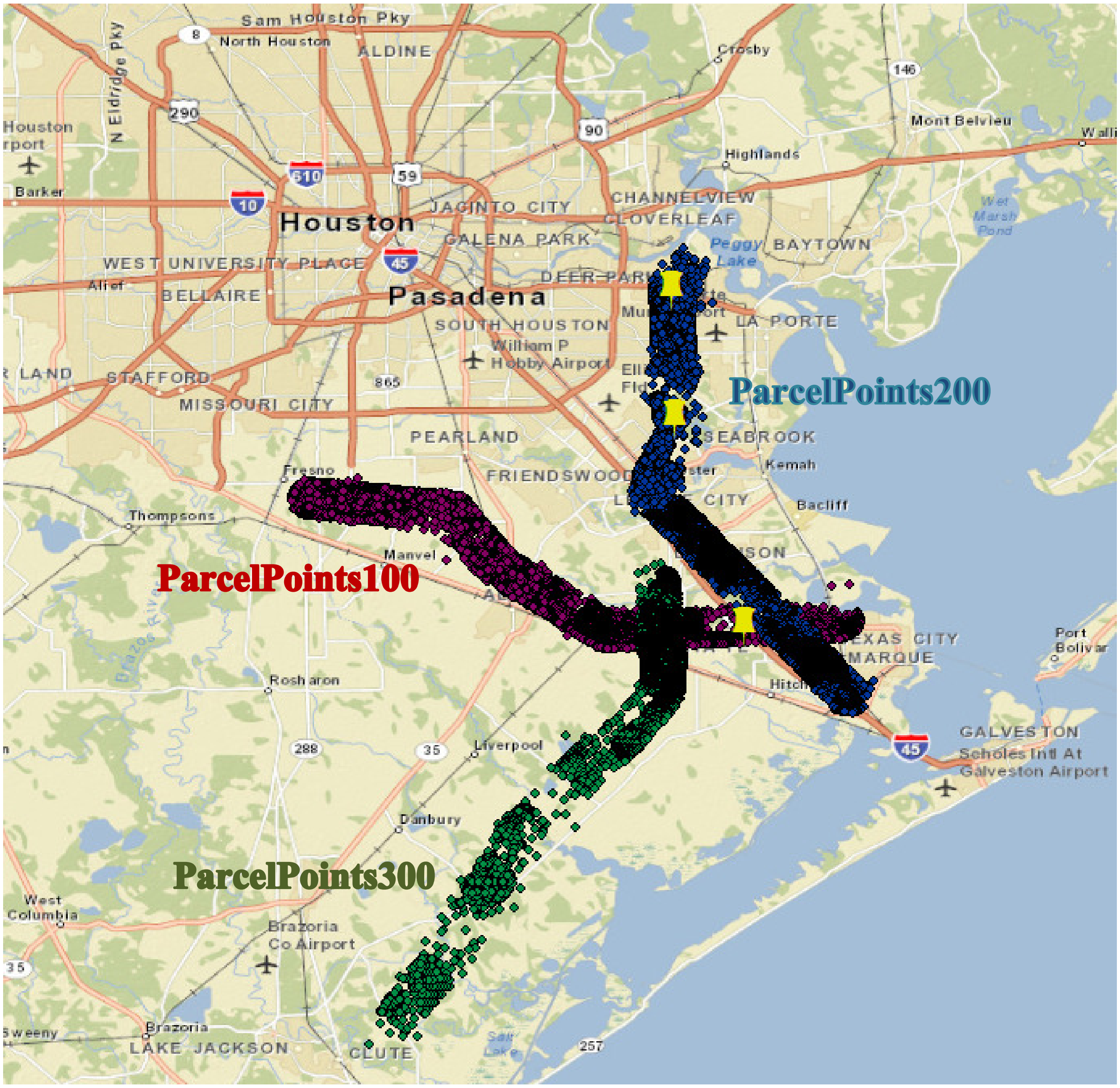


Figure 3-24: Population Dataset in Geodatabase

3.5 Class Location Tool

The class location tools were scripted in Python v.2.7.5 and added to a toolbox in ArcMap. Three scripts comprise the class location tools. The first two scripts use the "LocateFeaturesAlongRoutes_lr" command. The class 4 instances are applied to the route under analysis in the script "Locate Class4 Points Along Pipeline", and the second script "Locate Houses Along Pipeline Route" locates the dwellings. In both scripts, the point features within 660 feet of the route centerline are located. Both scripts result in an output table of route events. The route event tables are used as input tables in the "Pipeline Rt Class Locations" script. Figure 3-25 shows the toolbox containing the three scripts.

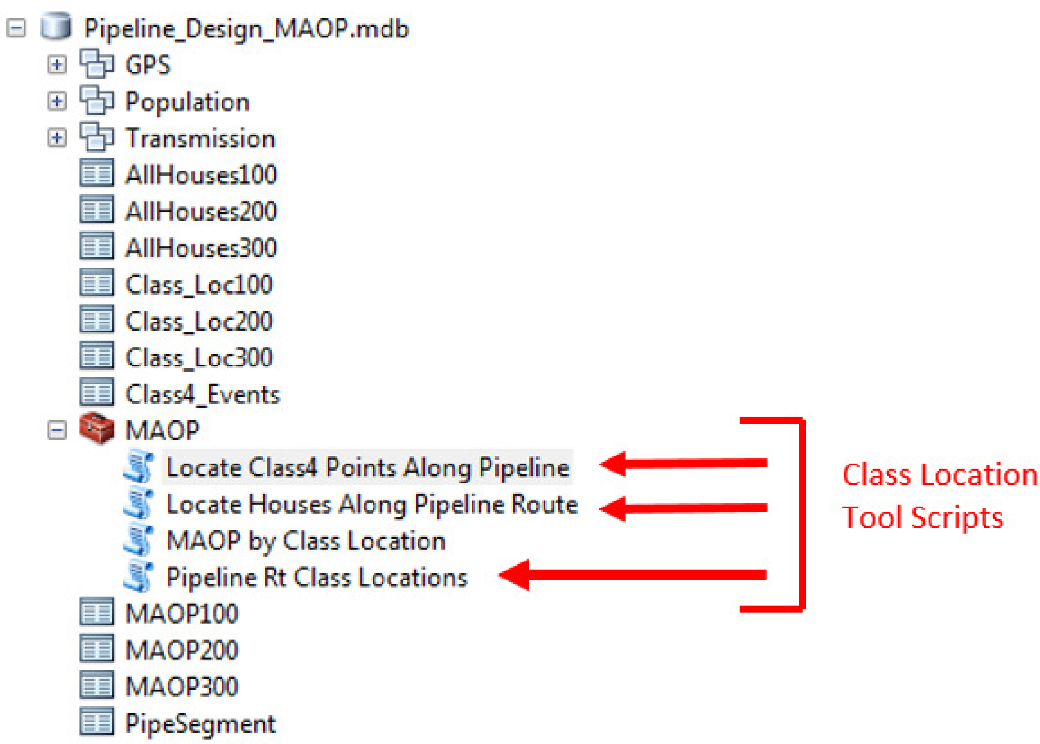


Figure 3-25: Geodatabase Toolbox with Class Location Tool Scripts

All of the scripts for the Class Location analysis are provided in the Appendix A. The logic for the location of class 4 instances and dwellings is explained with the flow chart in Figure 3-26. The difference in the “Locate Class4 Points Along Pipeline” and “Locate Houses Along Pipeline Route” script is the input point feature class and the user specified output table. Figure 3-25 shows the output event tables for the class 4 events, “Class4_Events”. Also shown in Figure 3-25 are the output event tables for dwellings along each route: “AllHouses100”, “AllHouses200”, and “AllHouses300”. Accessing the class 4 instances and the dwelling location scripts in ArcMap is show Figure 3-27a and 3-27b.

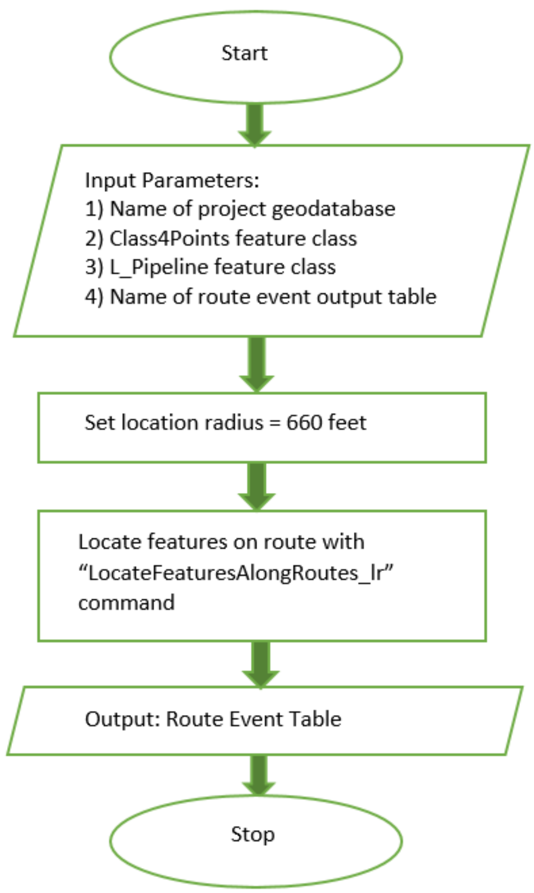
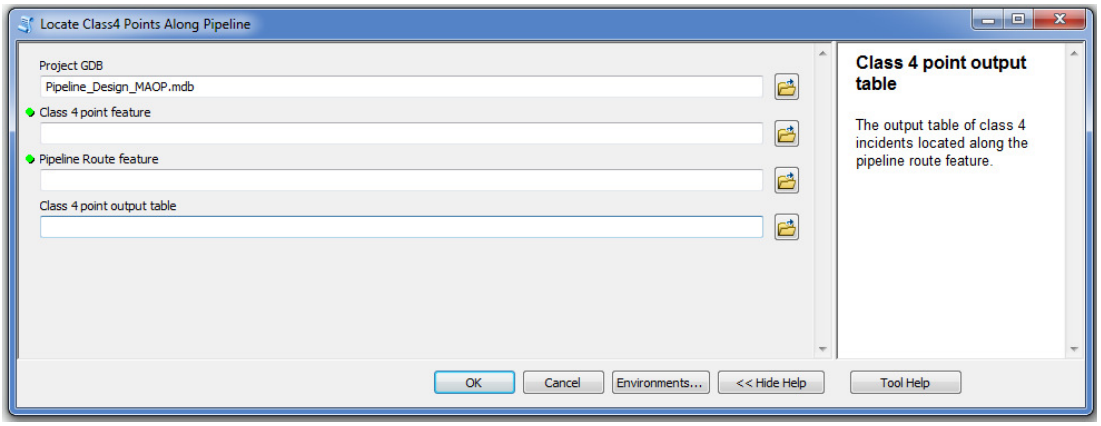
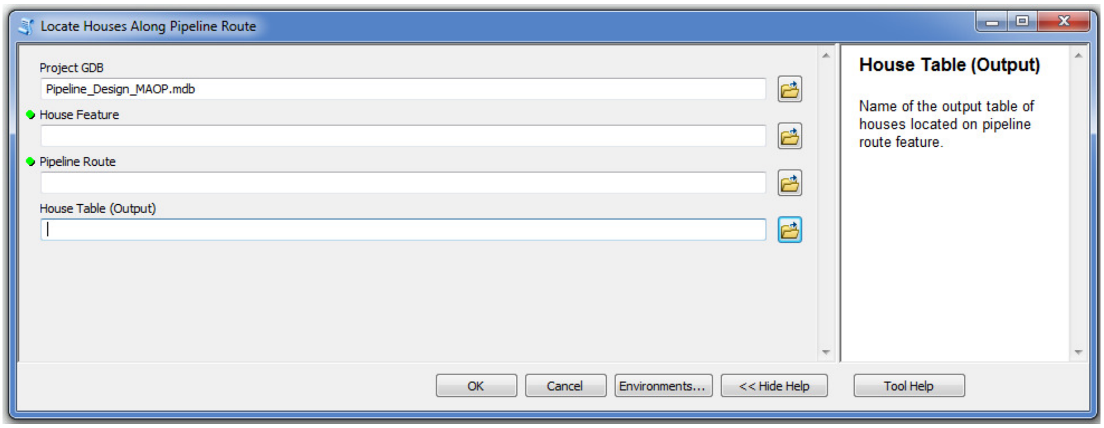


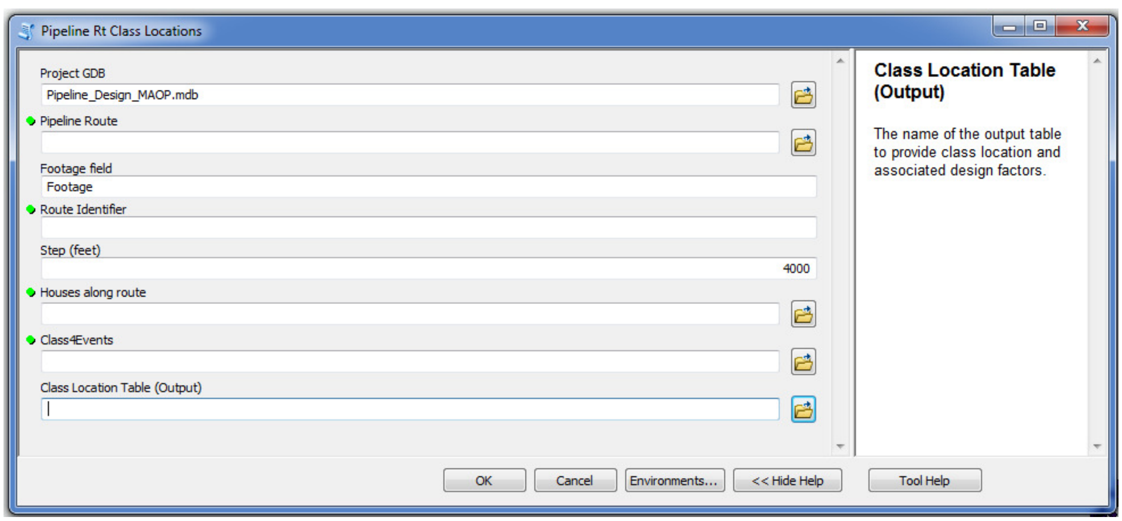
Figure 3-26: “Locate Class4 Points Along Pipeline” Script Logic



a) Locate Class 4 Points Along Pipeline



b) Locate Houses Along Pipeline Route



c) Pipeline Rt Class Locations

Figure 3-27: Accessing the Class Location Tool in ArcMap

Once output event tables for dwellings and class 4 instance points are created, the "Pipeline Rt Class Location" script creates a table of class locations measured along the feature route. Accessing the tool in ArcMap is shown in Figure 3-27c above. The class locations are assigned according to the schedule listed in Table 3-2. The one-mile segment buffer used to quantify the number of dwellings and the class 4 points must be adjusted forward or backward on the route to determine the maximum clustering of events. Figure 3-28 below demonstrates different positions of the One-Mile buffer, dashed line, leading to different Class Location specifications. Position 1 captures nine houses, which represents a Class 1 Location. Position 2 captures twelve dwellings, a Class 2 Location. When the one-mile buffer moves to position 3, only three houses reside in the buffer, a Class 1 Location. Position 4 contains two dwellings and a multistory building leading to a Class 4 designation.

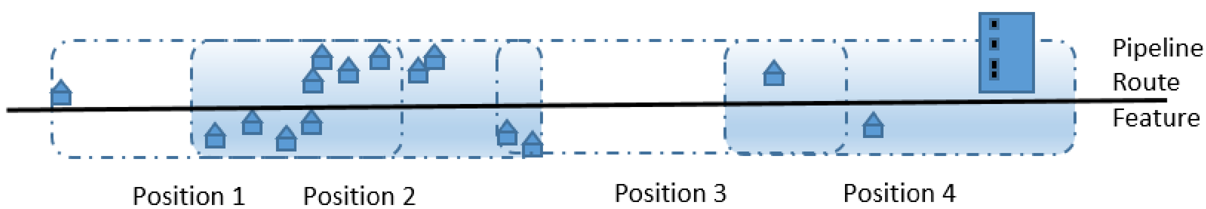


Figure 3-28: Sliding One-Mile Buffer. Position 2 Includes the Largest Cluster of Dwellings for a Class Location of 2. Position 4 Contains a Class 4 Instance

The class location script has three parts indicated in Figure 3-29. Part 1 of the script determines the positions of the one-mile buffer segments and the degree of overlap. The step interval for sliding the buffer along the route feature is an input at the initiation of the class location tool. Figure 3-30 demonstrates the user defined step interval value. Part 1 creates a temporary table of BeginSta and EndSta measurements for the one-mile buffer segments.

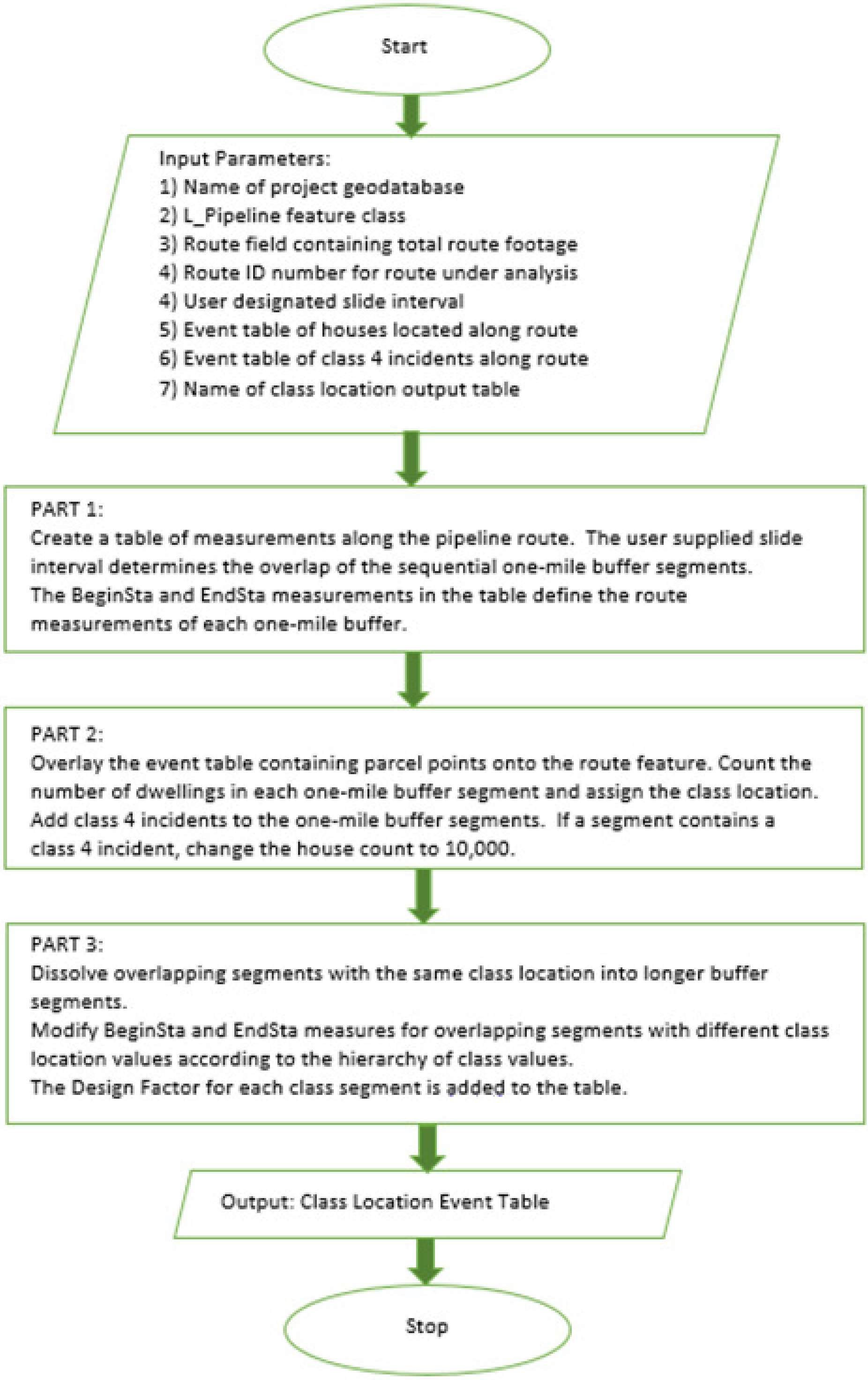


Figure 3-29: "Pipeline Rt Class Location" Script Logic

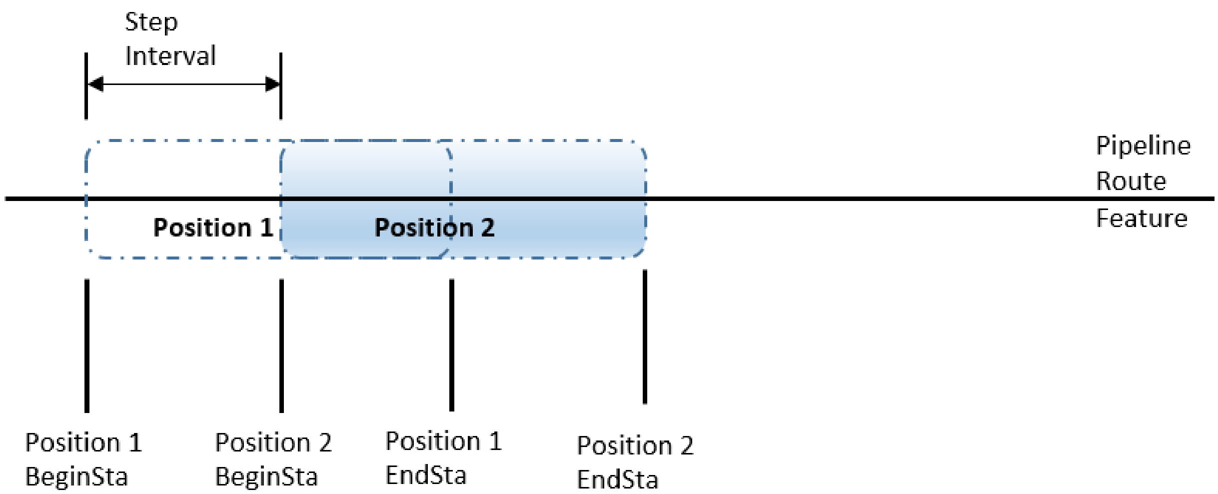


Figure 3-30: User Defined Step Interval for Sliding One-Mile Buffer

Part 2 uses the “OverlayRouteEvents_lr” command to assess the number of dwellings captured in each one-mile buffer segment. The class 4 instance points are included in the one-mile buffer segments, and the housing count for segments containing a class 4 instance is changed to 10,000 to ensure class 4 designation. The script sets the class location values in the table by the dwelling count for each segment.

Part 3 of the script dissolves the overlapping segments with identical class location assignments. The BeginSta and EndSta measurements of the dissolved segments are modified to remove overlap according to the hierarchy of class locations as shown in Figure 3-31. The script adds the Design Factors defined by class location as listed in Table 3-4 to the output table. The final event table is added to the geodatabase for each route feature. Figure 3-25 shows the project class location tables for routes 100, 200, and 300 as “Class_Loc100”, “Class_Loc200”, and “Class_Loc300”, respectively. The “Class_Loc300” table is shown in Figure 3-32.

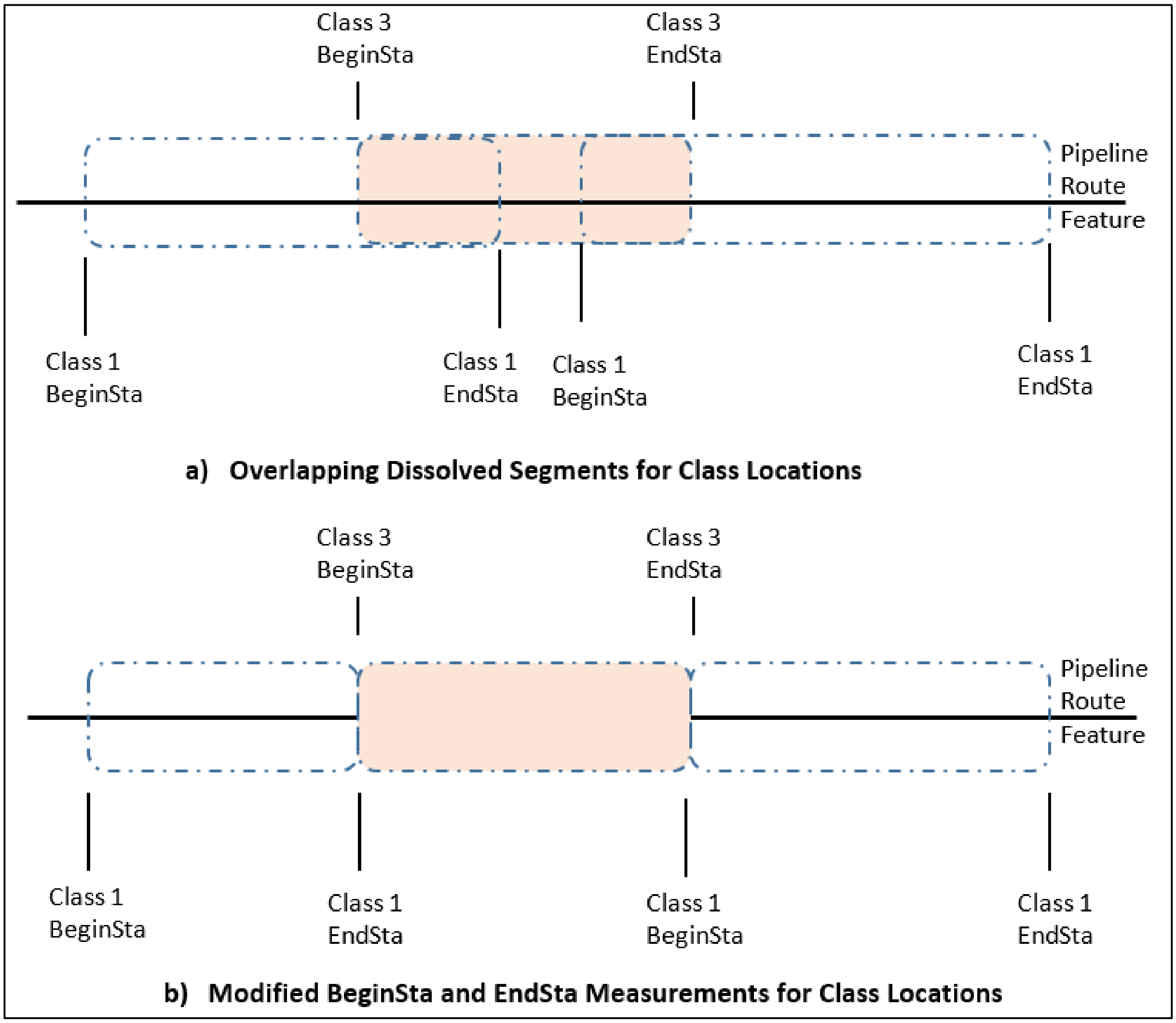


Figure 3-31: Class Location Segments in Final Output Event Table

Contents | Preview | Description

OBJECTID *	RID	BeginSta	EndSta	ClassLoc	DesignF
1	300	0	44000	1	0.72
2	300	44000	57280	2	0.6
3	300	57280	108000	1	0.72
4	300	108000	121280	2	0.6
5	300	121280	124000	1	0.72
6	300	124000	136000	2	0.6
7	300	136000	161280	3	0.5
8	300	161280	163187.4	2	0.6
9	300	163187.4	168467.4	3	0.5

Figure 3-32: Class Location Output Event Table for Route ID 300

3.6 MAOP Calculation Tool

Once the Class Location output table from the Class Location Script is added to the geodatabase, the MAOP values for the pipeline may be evaluated. The script "MAOP by Class Location", Figure 3-25, performs an intersection of the PipeSegment table and the Class Location table with the "OverlayRouteEvents_lr" command. The MAOP Calculation Tool script is found in Appendix A. Figure 3-33 describes the script logic. Figure 3-34 shows access to the tool in ArcMap.

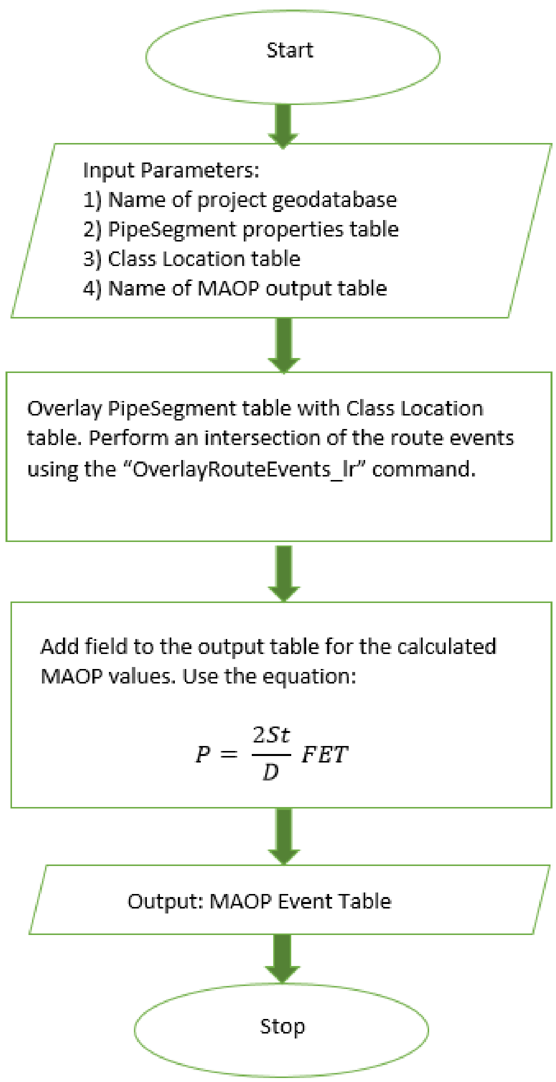


Figure 3-33: "MAOP by Class Location" Script Logic

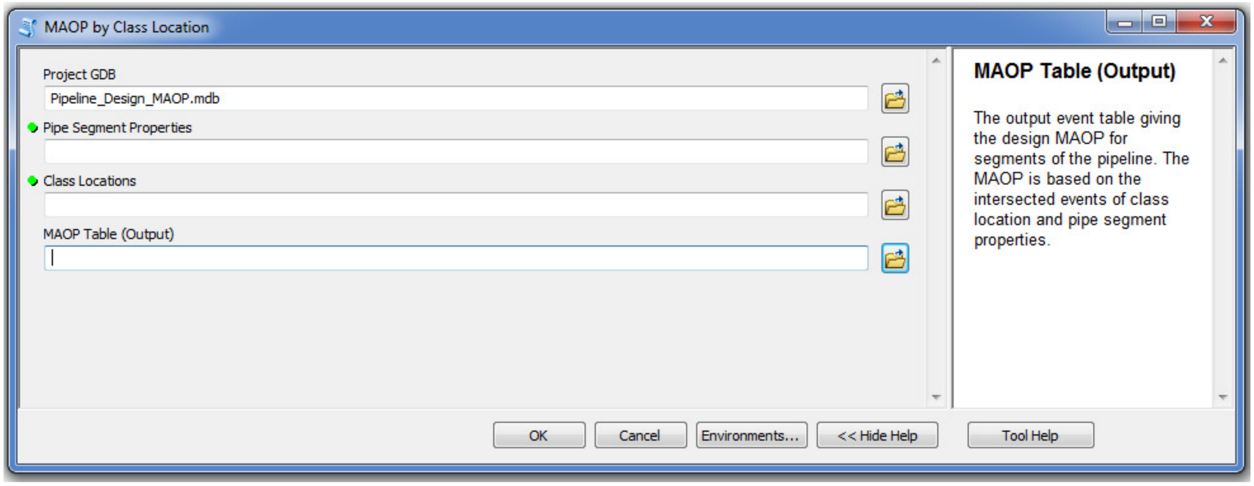


Figure 3-34: Accessing the MAOP Calculation Tool in ArcMap

Intersecting the overlay of route events allows the correct pipe segment structural properties to be matched with the appropriate class location and design factor value. In the case of Route ID 100 where the pipe segment properties change, intersecting the overlaid structural properties with the class location segments is critical.

Figure 3-35 illustrates the MAOP route events created in the intersect operation. The "F" values in Figure 3-35 represent the design factor provided in Table 3-4. "Properties" refers to material strength, diameter, and wall thickness used in the design pressure calculation. The "MAOP by Class Location" script calculates the design pressure, P, using equation (1) above, (Section 3.3). The MAOP value is set equal to the calculated design pressure, P. The MAOP event table produced by the tool is added to the geodatabase. Figure 3-36 gives the output table for route ID 100, "MAOP100".

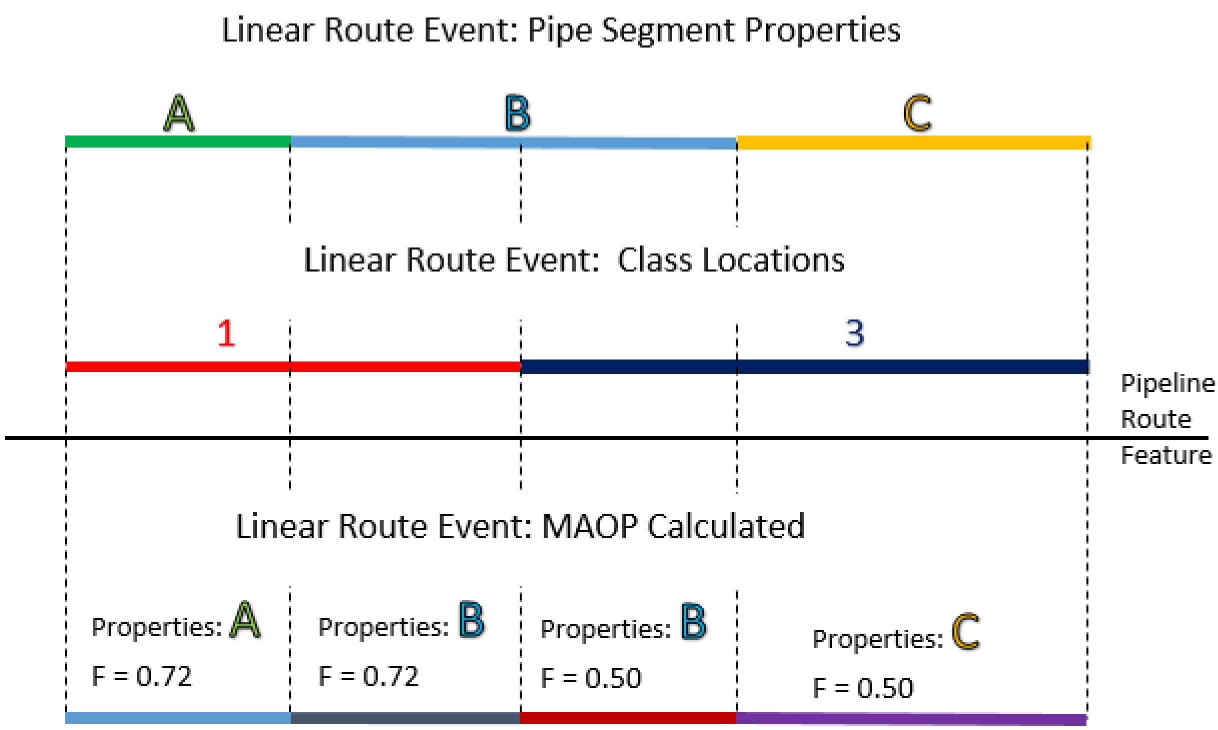


Figure 3-35: Intersection of Pipe Segment Properties and Class Location Linear Route Events

OBJECTID *	RID	BeginSta	EndSta	Diameter	WT	Material	SMYS	ClassLoc	DesignF	MAOP_DF
1	100	0	20000	20	0.25	API 5L X52	52000	2	0.6	780.0001
2	100	20000	25280	20	0.25	API 5L X52	52000	3	0.5	650
3	100	25280	37280	20	0.25	API 5L X52	52000	2	0.6	780.0001
4	100	37280	40000	20	0.25	API 5L X52	52000	1	0.72	936.0001
5	100	40000	49280	20	0.25	API 5L X52	52000	3	0.5	650
6	100	49280	50000	20	0.25	API 5L X52	52000	1	0.72	936.0001
7	100	50000	52000	22	0.25	API 5L X52	52000	1	0.72	850.9091
8	100	52000	61280	22	0.25	API 5L X52	52000	3	0.5	590.9091
9	100	61280	64000	22	0.25	API 5L X52	52000	1	0.72	850.9091
10	100	64000	75000	22	0.25	API 5L X52	52000	3	0.5	590.9091
11	100	75000	81280	20	0.25	API 5L X52	52000	3	0.5	650
12	100	81280	88000	20	0.25	API 5L X52	52000	2	0.6	780.0001
13	100	88000	93280	20	0.25	API 5L X52	52000	3	0.5	650
14	100	93280	108000	20	0.25	API 5L X52	52000	2	0.6	780.0001
15	100	108000	110000	20	0.25	API 5L X52	52000	3	0.5	650
16	100	110000	113280	20	0.375	API 5L X42	42000	3	0.5	787.5
17	100	113280	120000	20	0.375	API 5L X42	42000	2	0.6	945.0001
18	100	120000	125280	20	0.375	API 5L X42	42000	3	0.5	787.5
19	100	125280	129280	20	0.375	API 5L X42	42000	2	0.6	945.0001
20	100	129280	136000	20	0.375	API 5L X42	42000	1	0.72	1134
21	100	136000	141280	20	0.375	API 5L X42	42000	4	0.4	630
22	100	141280	144000	20	0.375	API 5L X42	42000	2	0.6	945.0001
23	100	144000	145000	20	0.375	API 5L X42	42000	3	0.5	787.5
24	100	145000	149280	20	0.25	API 5L X52	52000	3	0.5	650
25	100	149280	156000	20	0.25	API 5L X52	52000	1	0.72	936.0001
26	100	156000	165399.6875	20	0.25	API 5L X52	52000	2	0.6	780.0001

Figure 3-36: MAOP Output Event Table for Route ID 100

3.7 CARTOGRAPHIC REPRESENTATION

The Class Location Tool, “Pipeline Rt Class Location” script, produces the class location event table for the pipeline route under analysis. In ArcMap, the “Make Route Event Layer” geoprocessing tool produces a layer that was symbolized by category using the “ClassLoc” field as shown in Figure 3-37. The symbology shows the pipeline centerline in segments according to the class locations determined by the population along the linear route.

The MAOP Calculation Tool, “MAOP by Class Location” script, generates the MAOP event table. An event layer was created in ArcMap with the linear referencing geoprocessing tools. Symbolizing the MAOP event layer with the “MAOP_DF” field as graduated symbols allows the magnitude of the design pressure values to be represented by the relative width of the pipeline segments, Figure 3-38.

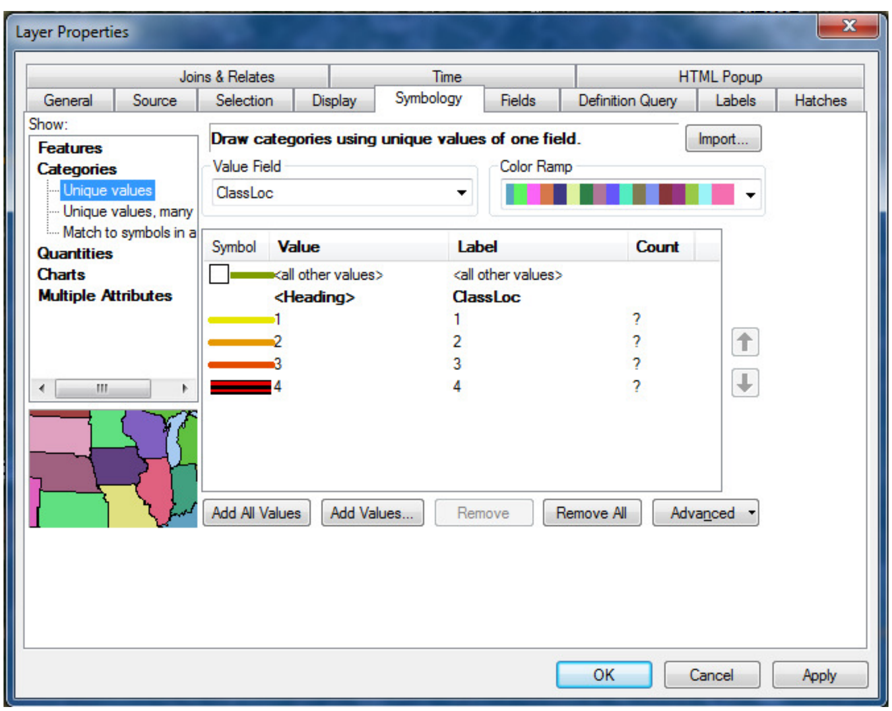


Figure 3-37: Class Location Event Layer Symbology

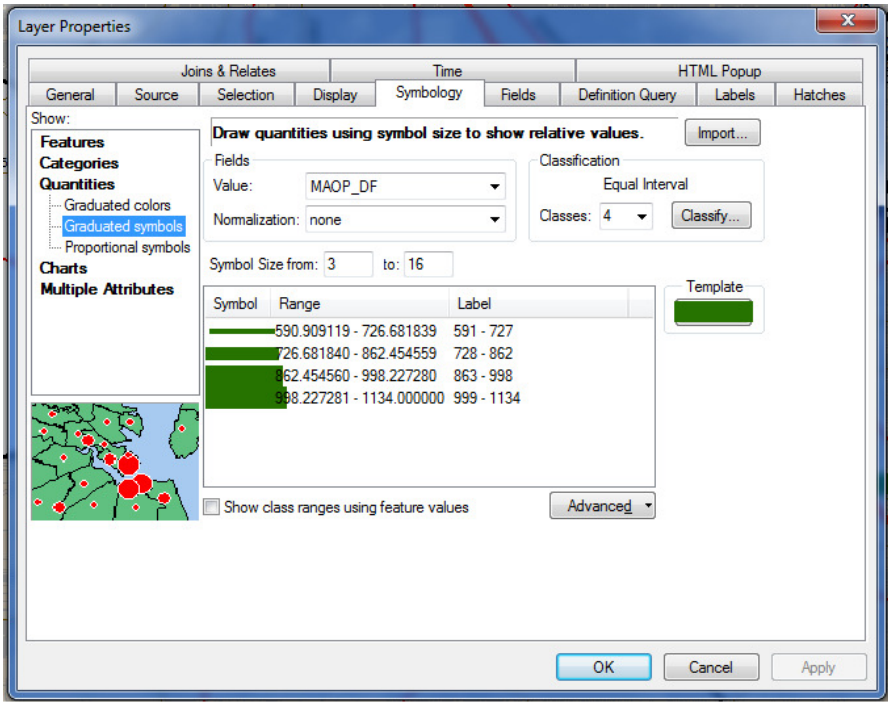


Figure 3-38: MAOP Event Layer Symbology

CHAPTER 4

DISCUSSION AND RESULTS

The Class Location Tool produced the event tables necessary to display the class locations along the pipeline routes, and the MAOP Calculation Tool produced the event tables able to identify the maximum design pressures calculated within each class location.

The tools demonstrated that the population along a pipeline route may be evaluated using linear referencing methods. This project used the county appraisal district datasets to analyze the number of dwellings. The parcel datasets were converted to point data to be evaluated as point events on the linear route features. The population data was enhanced with identification of elements that necessitate the Class 4 location category. The user of the tool may increase the accuracy of the population datasets with immediate knowledge of dwellings and structures along a pipeline right-of-way. Additionally, the Class Location Tool allowed for a user input of the step interval in the sliding one-mile buffer. Selection of the step interval may be based on user discretion and knowledge of the right-of-way. The tool processing time was tested with different step intervals as shown in Figure 4-1. The processing time of the script was tested on a 64-bit, Intel Core i7 processor with 8 GB of RAM. The graph implies an exponential relationship where the smaller step interval increases the software processing time.

The project validated the use of a GIS system in performing engineering calculations such as the design pressure for a pipeline with the MAOP Calculation Tool. The use of graduated symbols in GIS permits the maximum design pressures to be represented in a flow map. In the cartographic representation, the width of the linear symbol is proportional to the magnitude of the pressure value. The maps developed for this project are included in Appendix B.

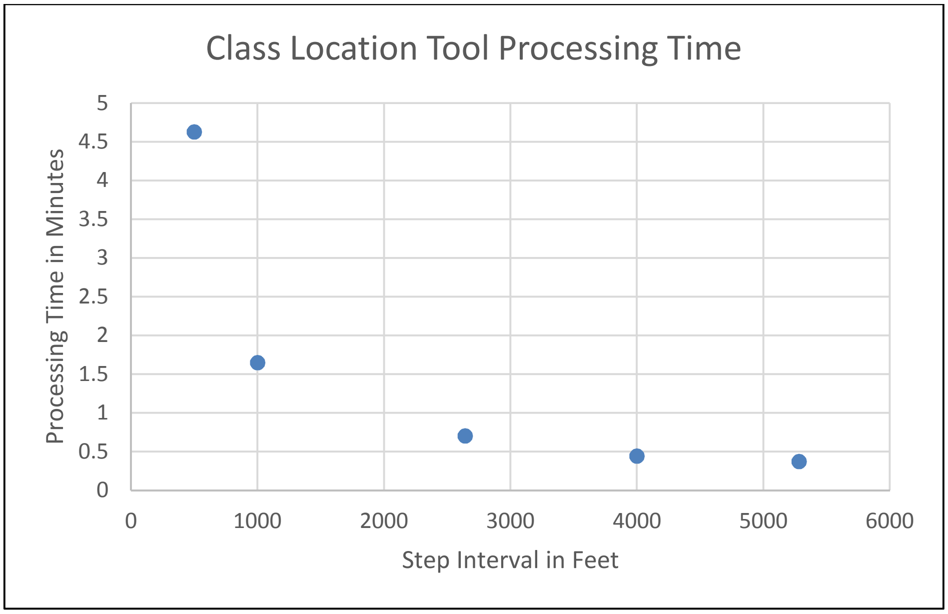


Figure 4-1: Class Location Tool Processing

Figure 4-2 indicates the method of symbolizing the class location linear events, which allows the results of the class location tool to be geographically visualized. Figure 4-3 illustrates the method of displaying the maximum design pressures as a flow map. By comparing the class location segments and design pressure segments, it is evident that the lower class values coincide with higher design pressures. In the case of pipeline route ID 100, the variation in pipe segment structural properties also contributed to the design pressure values by intersecting the linear events of material properties and class location design factors. The class location values determined the design factor used in the pressure calculation. In Appendix B, the results of the analysis using the Class Location Tool and MAOP Calculation Tool are exhibited for each pipeline ID 100, 200, and 300.

Figure 4-2: Class Location Linear Events

The MAOP value calculated in the project and displayed in the project maps was based solely on the design pressure calculated with a design factor according to the class location. The actual operating pressure depends on additional design considerations. In reality, the operating pressure would not change by each class location. However, the operating pressure would not exceed the calculated MAOP value. The location of compressor stations and pressure let down stations on the pipeline route determines the length of pipeline segments operating at certain pressure level. Within a given segment of the pipeline, the lowest MAOP value would be the upper limit on operating pressure. The flow maps developed in the project allows the operator to visualize the geographic implications of population density and class 4 instances along the route.

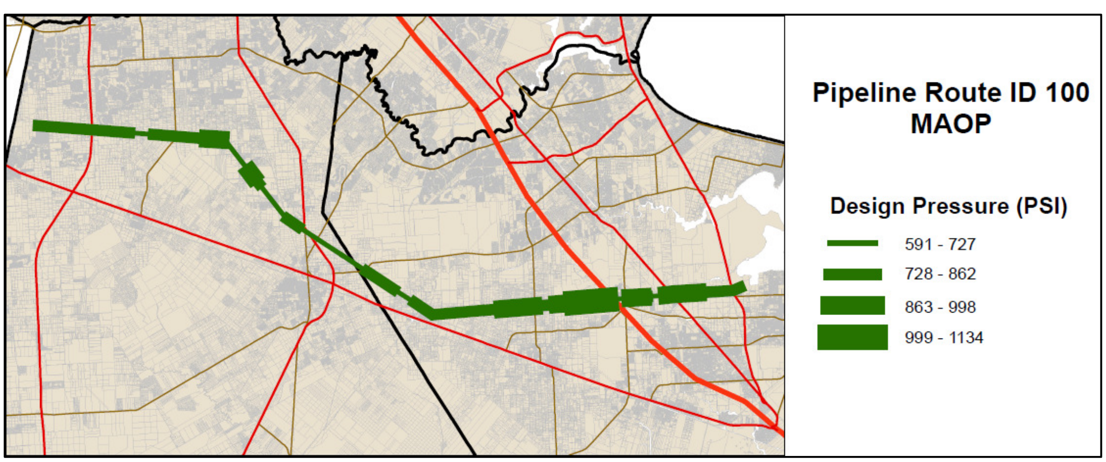


Figure 4-3: MAOP by Class Location Linear Events

CHAPTER 5

CONCLUSIONS

The project confirmed the utilization of a GIS system containing pipeline system data in performing engineering calculations. The advantage of the GIS system in conducting the calculations is two-part. The first advantage is in the benefit of employing the pipeline system geodatabase developed by many companies to manage their pipeline data. Data concerning the pipeline structural properties, pipeline components, and repairs reside and are maintained in GIS systems; therefore, conducting engineering calculations within the same framework may reduce redundancy in compiling data for different purposes in the organization. The second advantage is evident in the visual display capabilities of the geographic information. Both data and calculated results may be presented, and the intersection and coincidence of multiple layers of data may be observed and evaluated.

This project only addressed the structural integrity of the pipe as determined in the hoop stress calculation, Equation 1. According to the DOT regulation as described in CFR 192.5 and 192.111, the class location defined by dwellings, multistory structures, and high traffic area assigns the design factor employed in the hoop stress assessment. Additional criteria described in ASME B31.8 revises the design factors used in Equation 1 for a class location 1 based on the pipeline crossing different road types, such as private, unimproved roads, or hard surface public roads and railroads. The design factors used with the different road type crossing depend on the existence or lack of casings under the road or railroad. The DOT regulation also stipulates additional class 3 location instances to include areas of outdoor assembly such as playgrounds or recreational areas. Further enhancement of the Class Location Tool would include variations due to road type crossings or class 3 instances of outdoor areas. The MAOP Calculation Tool may also be extended to consider segments of the pipeline subjected to hydrostatic testing and consideration of individual pipeline components with limiting pressure ratings.

Incorporation of engineering calculations within a pipeline system GIS would improve efficiency in reducing duplication of efforts within an organizations. GIS pipeline systems are being developed and maintained with all geographic and structural properties and components of pipeline systems. Schedule and resource constraints often lead to parallel efforts performed both within and outside of a GIS framework. The GIS systems may be extended to incorporate many of the calculations currently performed outside of the GIS framework.

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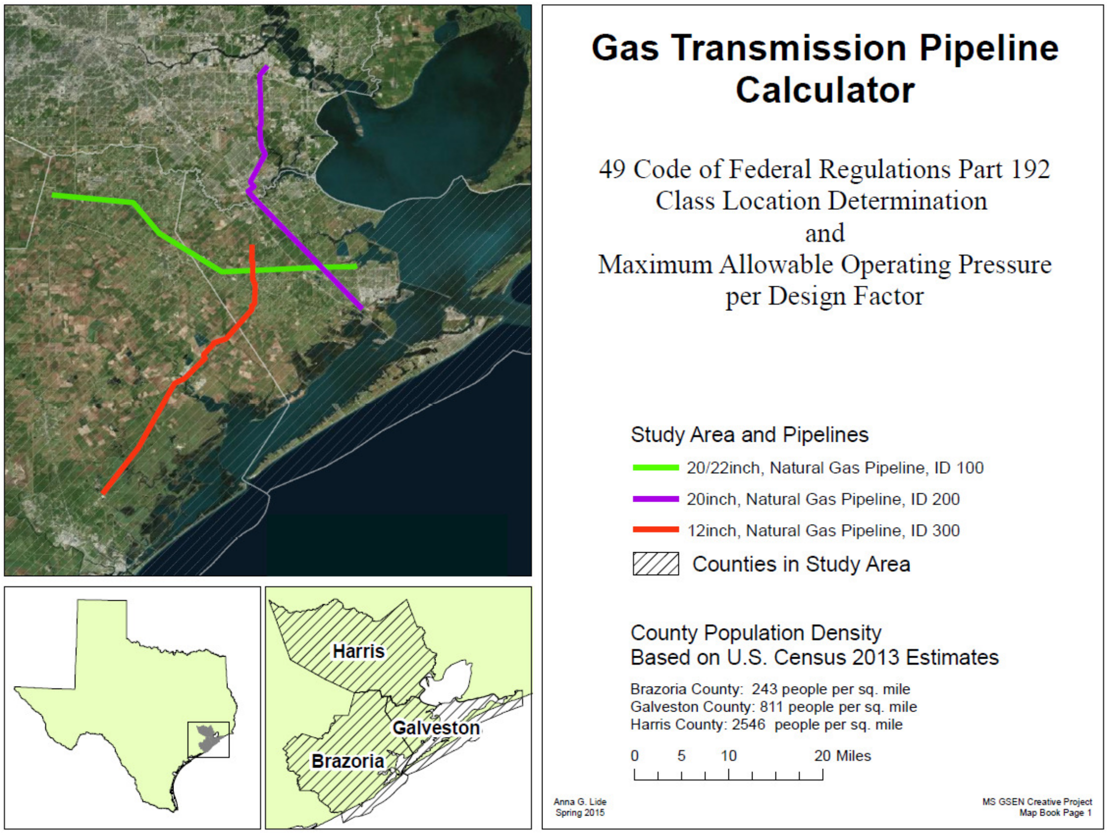
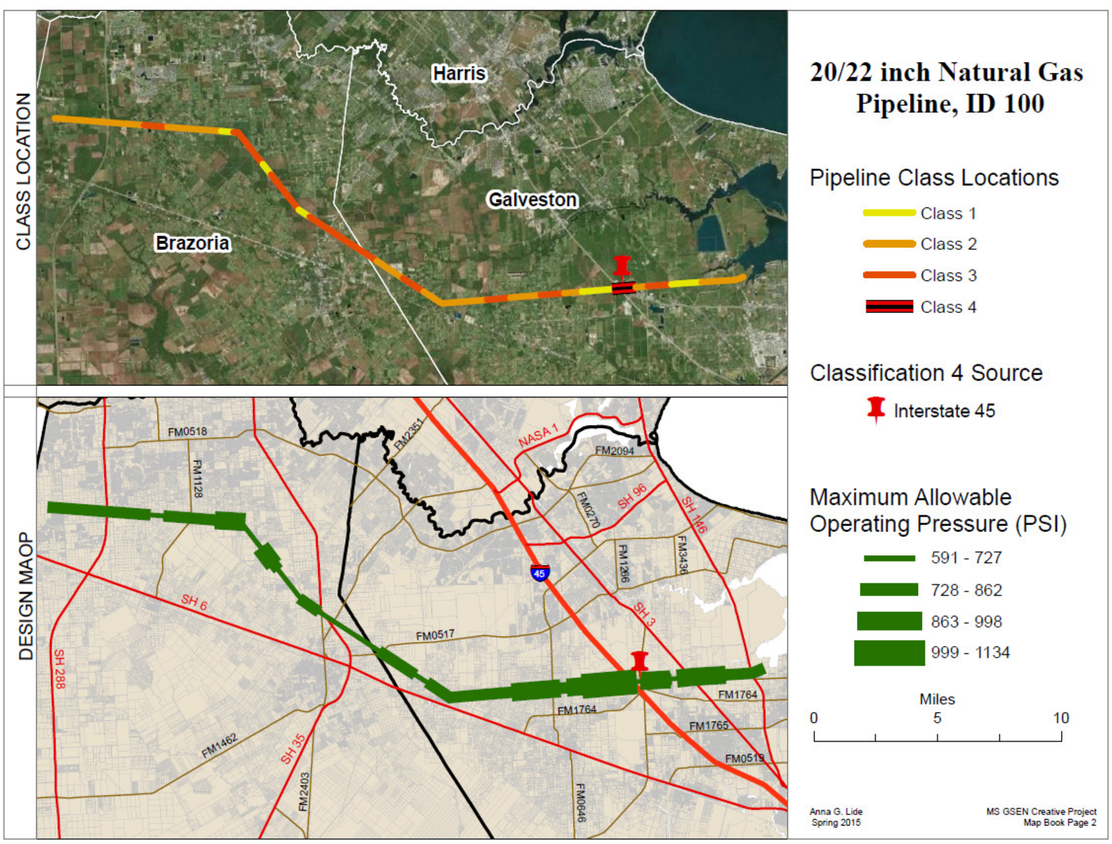
APPENDICES

A GIS Tool Scripts

(The tool scripts may be requested from the author.)

B Project Map Book


Gas Transmission Pipeline Calculator
49 Code of Federal Regulations Part 192
Class Location Determination
and
Maximum Allowable Operating Pressure
per Design Factor
Study Area and Pipelines
20/22inch, Natural Gas Pipeline, ID 100
20inch, Natural Gas Pipeline, ID 200
12inch, Natural Gas Pipeline, ID 300
Counties in Study Area
County Population Density
Based on U.S. Census 2013 Estimates
Brazoria County: 243 people per sq. mile
Galveston County: 811 people per sq. mile
Harris County: 2546 people per sq. mile
0 5 10 20 Miles
Harris
Galveston
Brazoria
Anna G. Lide
Spring 2015
MS GSEN Creative Project
Map Book Page 1


CLASS LOCATION
DESIGN MAOP
20/22 inch Natural Gas Pipeline, ID 100
Harris
Galveston
Brazoria
Pipeline Class Locations
Class 1
Class 2
Class 3
Class 4
Classification 4 Source
Interstate 45
Maximum Allowable Operating Pressure (PSI)
591 - 727
728 - 862
863 - 998
999 - 1134
Miles
0 5 10
FM0518
FM1128
FM2351
NASA 1
FM2094
SH 96
FM0270
SH 146
FM1266
FM3436
SH 3
SH 6
FM0517
SH 288
FM1764
FM1765
FM0519
FM1462
SH 35
FM2403
FM0646
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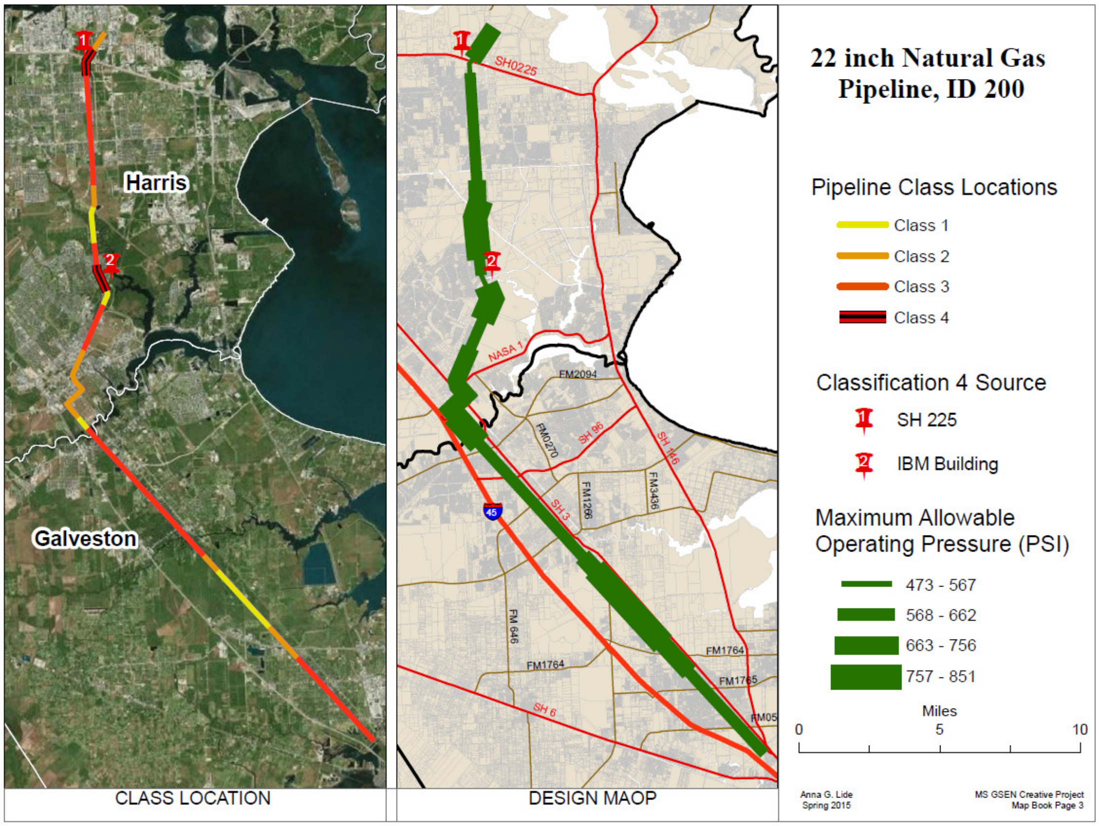

22 inch Natural Gas Pipeline, ID 200
Pipeline Class Locations
Class 1
Class 2
Class 3
Class 4
Classification 4 Source
SH 225
IBM Building
Maximum Allowable Operating Pressure (PSI)
473 - 567
568 - 662
663 - 756
757 - 851
Miles
0
5
10
Harris
Galveston
SH0225
NASA 1
FM2094
FM0270
SH 96
SH 146
FM1266
FM3436
SH 3
45
FM 646
FM1764
FM1765
SH 6
CLASS LOCATION
DESIGN MAOP
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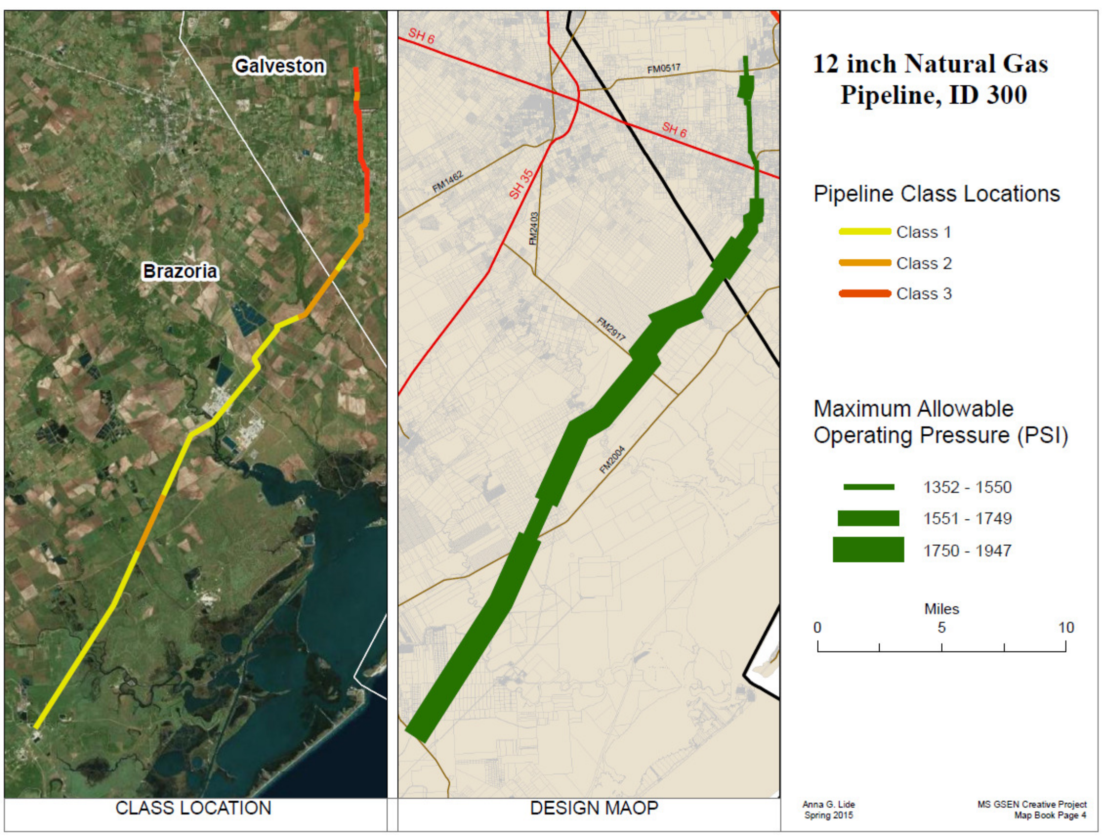

12 inch Natural Gas Pipeline, ID 300
Pipeline Class Locations
Class 1
Class 2
Class 3
Maximum Allowable Operating Pressure (PSI)
1352 - 1550
1551 - 1749
1750 - 1947
Miles
0
5
10
Galveston
Brazoria
SH 6
FM0517
FM1462
SH 35
FM2403
FM2917
FM2004
CLASS LOCATION
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