APPLICATIONS OF GIS FOR MAPPING AND TRACKING UNDERGROUND INFRASTRUCTURE

by

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ABSTRACT

APPLICATIONS OF GIS FOR MAPPING AND TRACKING

UNDERGROUND INFRASTRUCTURE

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The main objective of this research is to apply Geographic Information Systems (GIS) for construction and renewal of underground infrastructures. As a first step, a suitability analysis to determine location of existing underground infrastructure is performed. Next, a GIS template is developed using a digital elevation model (DEM) to get a three dimensional visualization of the underground infrastructure. Creating a Google Map using ArcGIS is one of the key features of this research, which provides an exact location of the existing site and distances from the nearby reference points. Once the GIS data is exported to Google Map and Google Earth, it provides a wide variety of information, such as pipe parameters like diameter and length. Another important objective of this research is to develop a graphical user interface (GUI), which is an innovative technique to help in getting a walkthrough beneath the surface. Several case studies are presented that describe GIS applications for the installation and

renewal of the existing underground infrastructure. These case studies give a clear picture of the advantages of the GIS over other methods both in terms of cost and time and the least cost path analysis.

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INTRODUCTION

1.1 Background

Geographic Information Systems (GIS) is a special type of information system in which the data source is a database of spatially distributed features and procedures to collect, store, retrieve, analyze and display geographic data (Shamsi, 2002). GIS is one of the most promising and exciting technologies of the decade as it offers both geography and information systems, thus becoming an ideal solution for effective management of water industry infrastructure. Carefully designed GIS is equivalent to about one thousand words. Geography is nothing but the combination of things in spatial content. An information system is a sequence of operations including planning, storage and analysis of data. In simple terms, GIS can be defined by "GIS = Geography + Information Systems" (Shamsi, 2002).

"GIS integrates hardware, software, and data for capturing, managing, analyzing and displaying all forms of geographically referenced information" (ESRI, 2009). GIS helps to understand, question, interpret and visualize data such that it gives relationships in maps, globes, reports and charts.

Background of GIS concepts goes back 15,500 years, where on the walls of caves near Lascaux, France, Cro-Magnon hunters drew pictures of the animals they hunted. Relating the animal drawings and track lines depict migration routes. These records were similar to the modern GIS which also has attribute information (Wikipedia, 2009).

In 1854, there was a Cholera outbreak in London which was depicted by John Snow using points representing the locations of individual cases as shown in Figure 1. The outcome of his study led to the identification of the source of the disease as a contaminated water pump (Wikipedia, 2009).

The year 1962 witnessed the first development of the world's true operational GIS in Ottawa, Ontario by the federal Department of Forestry and Rural Development. It was developed by Dr. Roger Tomlinson and called the Canada Geographic Information System (CGIS) and was used to store and analyze the Canada Land Inventory (CLI), which was mainly used to determine the land capability, wildlife, waterfowl, forestry and land use at a scale of 1:50,000 (Wikipedia, 2009).

Figure 1.1: E. W. Gilbert's version (1958) of John Snow's 1855 map of the Soho cholera outbreak

The U.S. Department of Transportation (DOT) uses GIS as an asset management tool for ensuring the reliable and safe transport of hazardous liquid and gas commodities through a vast network of pipelines. The foundation of GIS for pipelines is a geospatial data repository called the National Pipeline Mapping System (NPMS), managed since 1998 by Michael Baker Jr., Inc. (ESRI, 2009). In 2002 when the Pipeline Safety Improvement Act was passed all the liquefied natural gas (LNG) plant operators and transmission pipe line operators have been required to submit their transmission pipeline and attribute data to NPMS. In 2001, the ArcIMS[1] website called Pipeline Integrity Management Mapping

[1] ArcIMS-Platform using GIS maps and dynamic data through the web

Application (PIMMA) to share NPMS data and made public. From 2001 until April 2007, PIMMA is only accessible to federal, state and local government agencies and pipeline operators (ESRI, 2009).

"Given the vast range of spatial analysis techniques that have been developed over the past half century, any summary or review can only cover the subject to a limited depth. This is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities or as optional toolsets, add-ins or analysts" (Wikipedia, 2009). Taking this factor into consideration the main focus of this research is on Spatial Analysis using ArcGIS9.2[2], which is a major tool for the suitability analysis for the distance and slope as well as ultimately projecting data onto Google Map and Google Earth or kmz files[3].

ESRI and Computer Aided Resource Information System (CARIS) were some of the important commercial vendors in early 1980s incorporating some of the CGIS features. By the end of 20th century exporting the GIS data over the internet started. There are various companies which are offering tools to GIS and some of the important companies are ESRI, Autodesk, Bentley Systems, MapInfo, Manifold System and Smallworld (Wikipedia, 2009). GIS software is not only provided by companies but also by free and open source projects. Commercial vendors focus on products for software categories but software projects on a single category. GIS software companies have a specific application domain like ESRI ArcGIS products are used for planning, business analysis and environmental applications. GIS software developed by free software projects are mainly used for server applications like Map Server, GeoServer and spatial Database Management Systems (DBMS). Free GIS software are complementing the actual software rather than competing with it (Steiniger et al., 2009). Some of the important organizations using GIS software are listed in Table 1.1.

Different types of GIS software exist with different functions. Some of the categories are Desktop GIS, WebGIS client, Mobile GIS, Libraries or extensions. Desktop GIS is used to perform GIS tasks. WebGIS clients are used for data display and access analysis and functionality from servers through

[2] One of the latest versions of ArcGIS which provides a platform for using GIS

[3] File extension of the Google Earth files

internet. Libraries and Extensions provide the functions which are not part of the basic GIS software such as network and terrain analysis. Finally Mobile GIS are used for data collection.

Table 1.1: Some of the organizations using and promoting GIS software

NAME OF ORGANIZATION	TYPE OF AGENCY
Federal Geographic Data Committee (www.fgdc.gov)	Government
Florida Department of Environmental Protection Technical Services GIS Division	Government
Office of Geographic Information Services	Government
Seminole County, FL, Geographic Information Services	Government
Southwest Florida Water Management District	Government
St.John's River Water Management Districts	Government
U.S. Geological Survey	Government
Florida Internet Center for Underground Sustainability	Non-Profit Organization
Inforain (www.inforain.org)	Non-Profit Organization
Seven Hills Regional Users Group for GIS (www.shrug-gis.info)	Non-Profit Organization
Urban and Regional Information Systems Association	Non-Profit Organization
Florida Geographic Data Library	Government
Florida Department of Transportation	Government

1.2 Research Objectives

The main objective of this research is to apply GIS technology to the maintenance and the renewal of underground infrastructure, including:

i. To conduct the suitability analysis to find an ideal location for a new site or an existing location.

ii. To develop a GIS template using a Digital Elevation Model (DEM).

iii. To create a Google Map using ArcGIS, this gives an exact location of the existing site and distances from the nearby reference points. This map would give the details of the underground infrastructure.

iv. To develop a GUI, which is the main focus of the project where an attempt is done to develop an innovative technique which helps in getting a walk through beneath the surface thus minimizing the use of the tracking tools and also manual entries into some of the intricate locations.

v. To present case studies this deals with the GIS applications for the maintenance and renewal of the existing sewers. Case studies give a clear picture of the advantages of the GIS over the ordinary conventional methods.

1.3 Scope and limitations

The scope of this research is to use the GIS tool in particular ArcGIS9.2 for the analysis of a sample model using the reference data base so as to get a faster and better path with an outstanding quality.

This research is limited only to GIS applications for underground infrastructure. It is not covering the applications of GPS. The majority of data is from the state and federal agencies. Due to security reasons, GIS data is not usually available to the public, so this research is limited to the sample databases, except to case studies obtained from several cities.

1.4 Methodology

The method used for this research is spatial analysis using GIS. The most advanced method of mapping and modeling techniques are used with ArcGIS9.2 as the platform. The basic ideas of the Arc GIS are reviewed from the web link www.esri.com (ESRI, 2009). The web link has many modules which provide a basic idea and also an introduction to the GIS.

With ArcGIS9.2 as the platform and the use of Microsoft Word and Excel, a suitable file is setup and the data sets related for the highway, land use, soil and other relevant data can be downloaded from the link http://www.glo.state.tx.us/gisdata/gisdata.html (ESRI, 2009). Dependent on the type of the project, suitable data can also be downloaded from many paid websites from state and federal departments. Once the data sets are obtained they are added into the Arc map in the form of suitable layers. When different layers are added, utmost care to be taken to ensure all the layers are in the same co-ordinate system.

Suitability analysis is then carried out once the layers are arranged. The important aspect would be conversion from vector quantities to the raster quantities by using the spatial analyst toolbar and also the arc toolbox. Finally, the classification and the reclassification of the layers are suitably calculated. Ultimately using the raster calculator the results are evaluated to get the desired output. Conversions of raster files to three dimensional images are done and also extruded using ArcGIS9.2 and ArcScene[4]. Walkthrough is also generated using the fly tool of ArcScene for a better visualization. The central idea of the research lies in the least cost path analysis done by the options of Spatial Analyst tool bar in ArcGIS. Exporting GIS files to Google Map is done using a customized tool bar from The University of Texas at Arlington to ArcGIS through ESRI. GIS maps are converted to Google Earth also by converting to kmz files.

[4]One of the applications of three dimensional Analyst toolbar for managing three dimensional GIS data

CHAPTER 2

LITERATURE REVIEW

A literature review was conducted to know the various methods involved in GIS applications, technologies used, background and the growth of the GIS application software. It also helps to know the growth involved in the GIS applications for various fields.

The research conducted by Wyngaarden and Vanderwal (2007) on managing GIS and spatial data for the pipeline lifecycle gives insight into how to properly and effectively leverage the spatial data when developing GIS throughout an enterprise. While GIS has been around as a technology for over 30 years, is only in the last several years has it started to be extensively used within the pipeline industry. In their research attention is paid to the creation of a sustained approach to data management, data acquisition, integration, retrieval and ultimately disposal. Return of Investment (ROI) technique is commonly used when implementing GIS with an enterprise view (Wynhgaarden and Vanderwal, 2007).

Research on GIS state monitoring tools for pipelines by Pallaghy and Bartos (1996) shows that GIS is an important tool which helps solve, evaluate and analyze the condition of the pipeline system and determine the expected processes. A structure is developed which aid for the collection of the GIS data, transmission of the bulky data through a network and also dispatched at low levels. It also discusses line diagrams that can assist in the engineering analysis of the condition of the pipeline. It can be inferred that development of the integrated GIS was costly and significant funding was required for the past decade. Coming to financial aspects, pipeline renewal costs are decreasing by the fact that with using GIS, maintenance can be planned on a more rational basis and timely decisions can be made on the necessary repairs (Pallaghy and Bartos, 1996).

The role of GIS in pipeline industry explains the GIS applications to produce cost-effective results. Yelakantz et al. (2003) present the integration of GIS with existing technologies for cost effective solutions in terms of the functional benefits of GIS.

Major research regarding GIS applications to buried pipelines was done in 1991, which dealt with GIS line-in polygon functions of water and sewer pipelines within a polygon area can be displayed on computer screen. The main focus of the research was to create a simplified earthquake estimation model for pipelines and depict the network features within a grid overlay and application of GIS to inventory and manipulate all pertinent graphic and descriptive information like soil conditions, earthquake intensities, pipeline properties and failure rates (Wang et al., 1991).

The *proceedings* of the conference on GIS Framework for Storm Water Asset Management by Gharaibeh et al., (2008) gave a good understanding on the effective management of drainage systems especially in critical eras of climate change and rapid urbanization. This research deals with issues in storm water drainage asset management including inventory data requirements, developing practical condition assessment methods and also showing integration of inventory and condition data and documents in a GIS framework (Gharaibeh et al., 2008).

A major research regarding 'Assessment of water loss and pipe failures in water distribution systems using GIS technology' was carried out at The University of Texas at Arlington by Moreno (2003). The main focus of this research was to use GIS technology to identify areas of high potential failure based on soil type, temperature and historical data. Methods to determine and prevent the failures are also discussed. Using GIS modeling, it was determined that the previous failures increased the future failures in the immediate vicinity (Moreno, 2003).

A case study dealing with pipe bursting method of trenchless technology for the City of Troy, Michigan, is discussed in the research dealing with the construction cost of underground infrastructure by Hashemi (2008), where GIS played a key role in collecting the sewer pipeline data. GIS also helped to get the sewer layout and the location details to perform a cost comparison between pipe bursting and open-cut method of pipeline renewal (Hashemi, 2008).

In China, Zhou et al. (2006) conducted research on the development of GIS digital mapping methods for underground space. On utilization of underground space with major projects, digital mapping of GIS was done by using software language C++ which helped in the automatic drawing of histograms and profiles. The research was mainly introduced to the underground environmental information system of water supply reconstruction projects. After implementation, the results showed that the methods have some advantages such as high accuracy, large efficiency and high automatic extent. This histogram drawing was developed in two ways with fixed table and dynamic data filling. This research is very useful in the development of design and realization of digital mapping in engineering fields (Zhou et al., 2006).

The *proceedings* of the conference on utilization of geographic information systems technology in the assessment of regional ground water quality in New York shows that GIS software was used to assemble analyze and manage the spatial and tubular environmental data. Physical processes were interpreted relative to the spatial data and an integrated database was developed to support the appraisal of regional ground water contamination. The U.S. Geological Survey (USGS) along with U.S. Environmental Protection Agency Office of Pesticide Programs and several state agencies from the State of Oregon has prepared a digital database at a scale of 1:500,000 for evaluating the ground water contamination by pesticides and other agricultural chemicals (Nebert and Anderson, 1987).

The main focus of a case study presented at the *Proceedings* of the ASCE Pipelines 2007 was enhancing pipeline management and analysis using GIS at the Tarrant Regional Water District (TRWD) (Coffey et al., 2007). The TRWD is one of the largest raw water suppliers in the state owning four reservoirs and more than 150 miles of large diameter water transmission pipeline. TRWD was interested in using GIS technology to manage their current assets with GIS technology and also utilizing the capabilities of the ESRI geodatabase. GIS staff at TRWD created a detailed geodatabase that included information on aboveground features such as land use, soil conditions, utility networks, right-of-ways, parcel ownership and aerial photography. For underground pipeline information, TRWD contracted with the Pressure Pipe Inspection Company (PPIC) to develop the water transmission pipeline and add features to the geodatabase. PPIC developed data model to track individual pipe segments from bell to spigot with inspection, integrity and repair information. Pipe segments were positioned using pipeline data from PPIC and GPS data collected from TRWD (Coffey et al., 2007).

Sewer System Evaluation Study (SSES) utilizing GIS tools by Waldron and Ratchinsky (1997) presents how GIS can be used to develop, analyze and manage the volumes of inspection and inventory data collected. A Relational Database Management System (RDMBS) was developed to link inventory and inspection data with a visual map interface. The GIS application was a main access point for managing and executing the collected data, analysis and capital improvement for SSES (Waldron and Rarchinsky, 2007).

Research from University of Florida on storm runoff modeling using remote sensing and GIS in central Florida gives an insight into how GIS can be used to store, manipulate and visualize the hydrologic data. GIS and remote sensed data tools were used to estimate the changes in land-cover and to estimate runoff responses for three watersheds in Florida. A DEM technique was developed based on travel time to watershed outlet to predict stream response to runoff events. A model was developed for predicting runoff hydrographs resulting from changes in the land-cover (Melesse, 2002).

Integration of GIS and hydrologic modeling for countrywide drainage study was carried out in 1993 by Water Resource Planning and Management in Central Florida. Early computer based application of GIS technology along with software packages was used to develop a Surface Water Management Plan (SWMP) for Polk County in Central Florida. A combination of raster based GIS package, computer-aided design (CAD) and commercial data-base management system was used to develop the model as no fully featured GIS package was available (Shea et al., 1993).

CHAPTER 3

GIS FRAMEWORK

The GIS framework has three main modules namely inventory module, condition assessment module and document module as shown in Figure 3.1 (Gharaibeh et al., 2008).

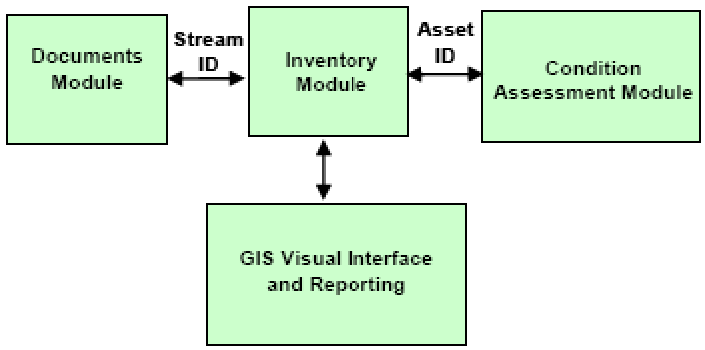


Figure 3.1: GIS framework for storm water asset management

The inventory module consists of many tables comprising of data from each asset management unit like length, material and cross section of pipelines. The document module combines both drainage infrastructure and document management capabilities. Drawings in CAD format, photos and reports are saved electronically. Lastly, the condition assessment module is based on digital photos of each unit in distressed or failed areas. Hydraulic analysis software for estimating the hydraulic capacity and analysis results are incorporated into a database.

Maintenance and repairs of the culverts can also be done and tabulated with a rating scale of excellent to satisfactory. These forms have been developed based on a thorough review of the literature particularly Ohio DOT's well developed and well documented Culvert Inspection Manual.

Hydraulic analysis software (HY-8 version 7.0) serves as an important tool along with the GIS which can evaluate the existing capacity based on the actual field conditions of drainage assets. Inputs include the dimensions of the culvert and most of the time it works on a trial and error basis.

3.1 Steps involved in GIS Applications

GIS applications require six typical steps as shown in Figure 3.2 (Shamsi, 2005):

i. Need analysis (Strategic planning)

ii. Specifications (system design)

iii. Application programming

iv. Testing (pilot project)

v. Installation (hardware, software, and data)

vi. Ongoing operation and maintenance (includes training)

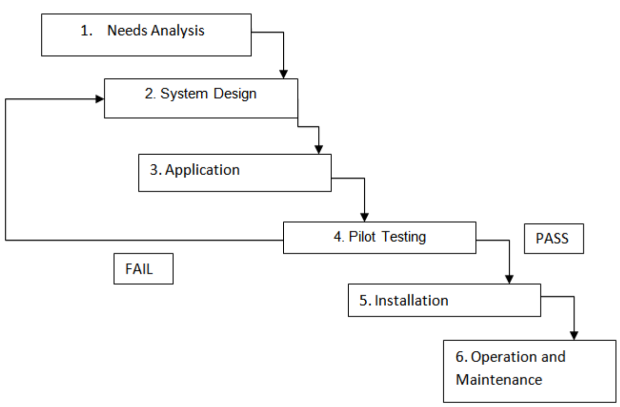


Figure 3.2: Steps required for the GIS application development

Need analysis (or needs assessment) identifies and quantifies the needs of an organization. It is similar to funding, implementing and managing. Need analysis clarifies the specific needs and defines how a GIS will benefit an organization by relating the resources and the needs to GIS capabilities. The three major goals of needs analysis are:

i. To define current work processes, date and IT resources.

ii. To determine expectations to use GIS to streamline GIS operations.

iii. To make recommendations defining the path to meet the desired output.

3.2 Augmented Reality in field work

Augmented Reality (AR) is an alternative to the two dimensional plans. AR superimposes three dimensional graphics with the real world thus giving an "X-ray vision" in order to see the underground infrastructure. AR provides faster and accurate localization of subsurface assets and thereby reducing the risks. AR is very useful in the detection of gas leaks and cable damages. AR provides planners with a graphical overlay of the planned trench and can directly modify plans and incorporate the changes with spatial interaction (Gerhard et al., 2009).

3.2.1 Geographic Data models

Geospatial data cannot be directly visualized as it is a combination of geo-referenced attributes or "features." The combination of such features mainly consists of polygons and other visual elements leads to a multi-stage pipeline as shown in Figure 3.3. An important aspect in the creation of geographic models is the geospatial data which is in various contexts such as cadastral survey or utility asset management. AR can benefit from the high degree of up-to-date data essential for different fields of application along with many useful browsers like Google Earth. Using the web feature service (WFS) the information from the production GIS is exported to the client as a document in the Geography Markup Language (GML) similar to XML (Gerhard et al., 2009).

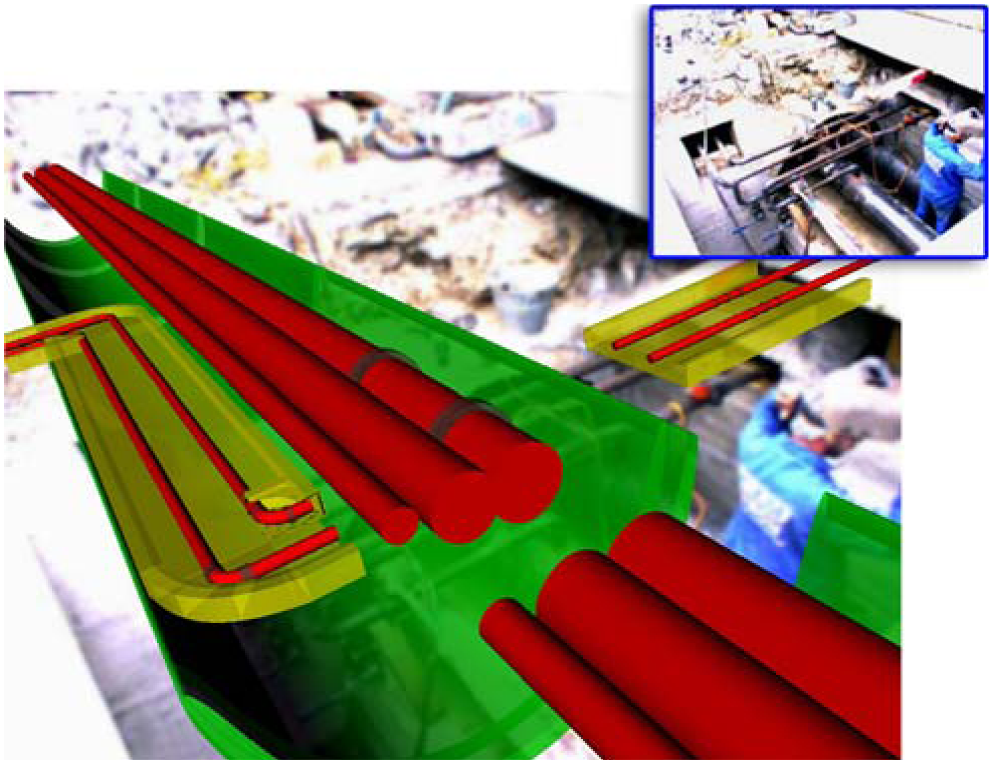


Figure 3.3: Superimposed geospatial three dimensional model on a construction site

3.2.2 Spatial Interaction tools

Various spatial interaction tools are available to make the three dimensional presentation useful. Some of these important tools are:

i. **Excavation tools** helps in the plausible interpretation of the depth through partial object occlusion and motion parallax. This tool is implemented using a magic lens technique along with attribute data from the GIS.

ii. **Labeling tools** are used to visualize the meta-information of the infrastructure. Once the user places the cross hair button on the top of an asset, information will be displayed to the right.

iii. **Filtering tools** are used for filtering and selecting information based on the attribute selection. They reduce the displayed information to a manageable amount with only minimal interaction.

iv. **Snapshot tools** are used to freeze an image at any point of time and share with others. They are always accessible with an assigned button on the AR device. It works on the principle of snapshots similar to a bitmap image which can be archived and used later.

3.3 Suitability Analysis using GIS

Suitability analysis focuses on steps required to know the suitability of a particular location. Some of the steps needed in the analysis includes (i) stating the problem; (ii) breaking down the problem; (iii) exploring the input; (iv) perform analysis-creating suitable map, classify & reclassify data, suitability scales and ranking; (v) verifying the result; (vi) implementing the result.

3.4 Material selection and estimating service life

For any pipe material, service life is dependent on the following criteria:

i. Bedding, backfill and the method of placement according to the specifications.

ii. Conditions of the foundation to confirm criteria.

iii. Dead and live loads within the permissible limits.

iv. No damage to pipe joints, gaskets or connections prior to installation.

v. Standardized conditions.

All these selection criteria must be in accordance with applicable standards (Howard, 2002). Suitable GIS model can be developed using these criteria.

3.5 Requirements for pipeline installation

Some of the important aspects which are covered at the time of pipe installations are:

i. Trench Excavation

ii. Foundations

iii. Trench walls

iv. Bedding and Laying

v. Pipe Joining

vi. Embedment

vii. Backfill

viii. Compaction of soil

ix. Soil strength or bedding factor which also depends on

   a. Soil type

   b. Soil density

   c. Pressure distribution on the bottom of the pipe

All these pipe installation techniques should comply with the ASTM standards (Howard, 2002). These techniques are very useful for the suitability analysis using ArcGIS software.

3.5.1 Trench Width

Trench width is one of the important criteria for pipe selection then some of the specifications required for the installation are shown in Table 3.1 (Howard, 2002). Now using ArcGIS as a tool a model can be developed by using the combinations of all the requirements for the pipe installations in accordance with the specifications.

Table 3.1: Relationship of pipe diameter with minimum trench bottom width

Pipe Diameter	**Minimum Trench Bottom Width**
less than 6 in.	24 in.
6 in. to 18 in.	Outside diameter + 20 in.
More than18 in.	Outside diameter + 36 in.

3.5.2 Trench walls

The type and density of the soil in the trench walls will have a major effect on the performance of the pipe and the pipe soil system. Sheeting, bracing, shoring or trench shields are some of the various methods used in trench wall support in accordance with the operational safety and health administration (OSHA) standards. Even the federal regulations require that the contractor has to designate a “competent person” who has the knowledge of authority and to maintain a safe excavation during construction.

3.5.3 Bedding and Joining

Bedding is the material placed on the bottom of the trench for the uniform support of the pipe, which is required to support the pipe longitudinally and also to distribute the load on the bottom of the pipe. The thickness of the bedding depends on the type and size of the pipe. Typically, the bedding thickness in inches is the outside diameter of the pipe divided by 12. The soil particle use in bedding must be in accordance with the ASTM and the American Water Works Association (AWWA) standards (Howard, 2002).

3.5.4 Joining pipe

Joining of the pipe depends on the manufacturer and each time manufacturer should be consulted for skilled labor’s knowledge and experience. Details of the joining will be obtained from the manufacturer. Some of the main type of joining are casketed, welded, solvent cemented, heat fused, adhesive bonded, flanged, mechanical coupled and fiberglass overlaid (Howard,1996).

3.5.5 Embedment

The embedment is the material around the pipe. Each pipeline is designed for the specific embedment and any changes in the types of pipeline should be in accordance with the manufacturer as it can be detrimental to the trench. The embedment for rigid pipes depends on the load on top of the pipe (dead, live, weight of pipe) and spreads the load to the bottom of the pipe to the soil. This load distribution ranges from zero for a line load and 1800 for a full load. Typically embedment is specified from the bottom of the pipe to a level of 25% to 50% of the outside diameter of the pipe (Howard, 2002).

3.5.6 Backfill

Backfill is the material is placed over the embedment soil and the pipe. Backfill requirements depend on the height of the embankment and surface terrain. Usually the materials obtained from the excavation are used for the backfill. Typically the backfill should be free from construction debris, manmade waste, stumps and limbs as well as soils susceptible to potential volume change should be avoided and should include organic silts or clays, expansive soils and expansive formation materials such as siltstone, clay stone, shale and mudstone (Howard, 2002).

3.5.7 Compaction of soil

Soils are compacted depending on the type of the soil. For clay or silty soil the best method would be by impact or kneading methods. For Cohesive soils, the best method would be vibration. The amount of compaction is evaluated by measuring the density of the compacted soil and by comparing the value to a density obtained using a standard laboratory test.

Soils with 5% to 12% fines can behave either as a cohesive soil or cohesionless soil. Some of the sands with about 6% fines are not free-standing and cannot be successfully compacted. Eleven percent fines can be easily compacted with vibration (Howard, 2002).

$$\text{Degree of Conmpaction} = \frac{\text{In-Place Dry Density}}{\text{Laboratory Maximum Dry Density}} x100$$

3.6 Sample project showing the suitability analysis using ArcGIS 9.2

The main objective of the sample database developed in this thesis is to show the steps involved for the selection of a suitable site using ArcGIS as a tool. The following section shows an example for the selection of California Pizzerias based on the income, census, distance and land use. The results give the exact location of the Pizzeria depending on the selection criteria. As discussed previously, ArcGIS is the software mainly used for the analysis in this study. Figure 3.4 shows the different layers involved in the sample project, and the property table which shows the value to be assigned for the census layer and the labels for the particular layer. Formatting the label title bar shows the type of units to be used like name, color, frequency, percentage and currency which helps in classifying the census layer in terms of income level expressed in the currency unit. Once the data has been fed into the system, then the process of rasterizing is performed using the distance calculation.

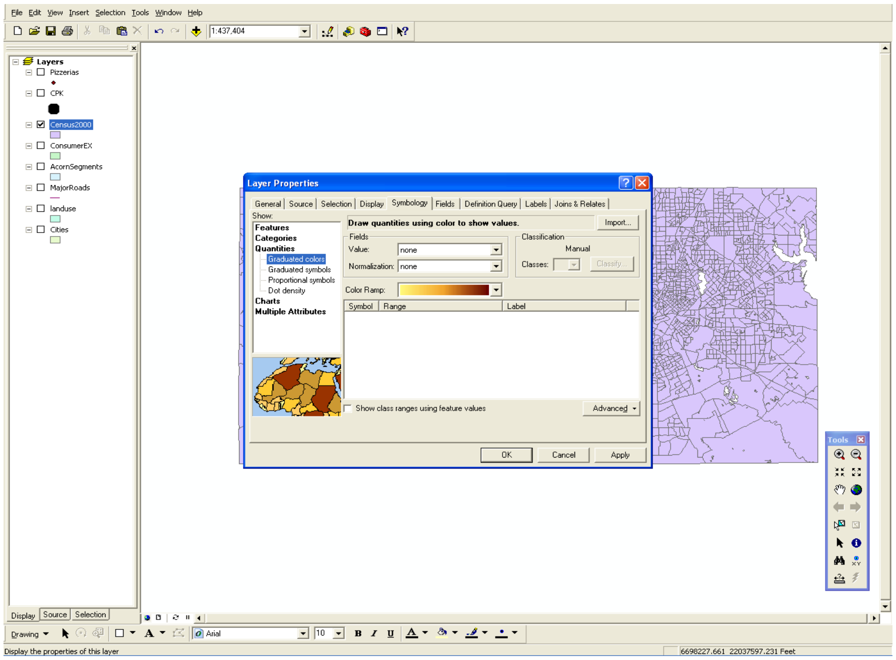


Figure 3.4: Different layers involved and the table showing categories using ArcGis9.2

Distance to the pizzerias is calculated using the three dimensional analyst tool bar and selecting distance to Pizzeria as shown in Figure 3.5. The current layer shows the distances, and it even shows the exact distances once the cursor is moved towards the locations. The next step in the suitabality analysis will be the reclassification of the existing layer giving the weightage to the individual criteria with a range of zero to one and the summation should be equal to one. This step is the critical juncture where the major decision is to be taken. Better the input suitable the results. Reclassification table is shown in Figure 3.6 and fiinally output will give a layer showing the suitable locations for the pizzerias as shown in Figure 3.7. The dotted colored portions show suitable locations for pizzerias.

3.7 Integrated GIS for site investigation

Site investigation is a vital and important step in planning and estimating construction projects. Surface and subsurface conditions influence the equipment selection and also the cost and scheduling of projects. This chapter deals with databases which help in the storage of GIS like soil data and developing

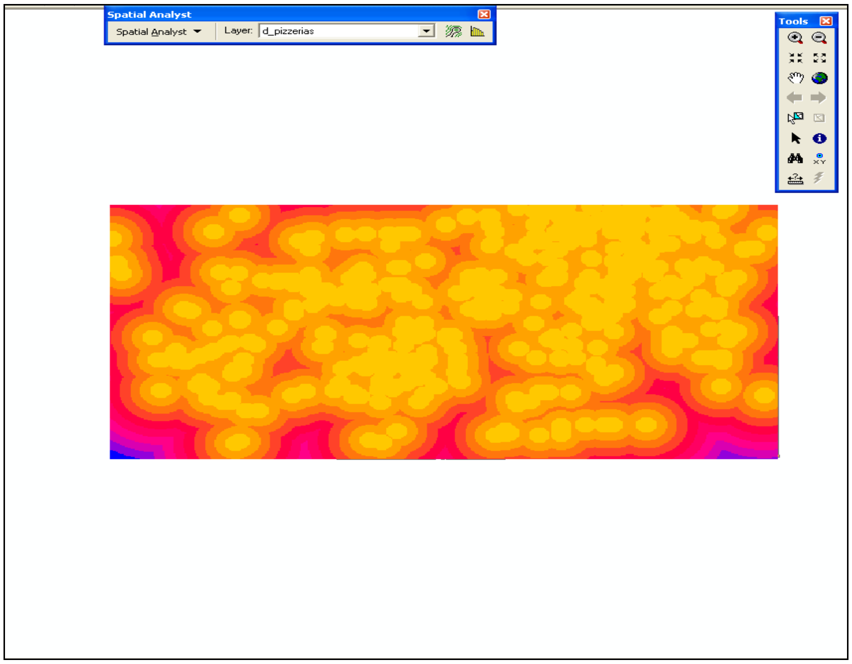


Figure 3.5: Distance to the existing Pizzerias using ArcGis9.2

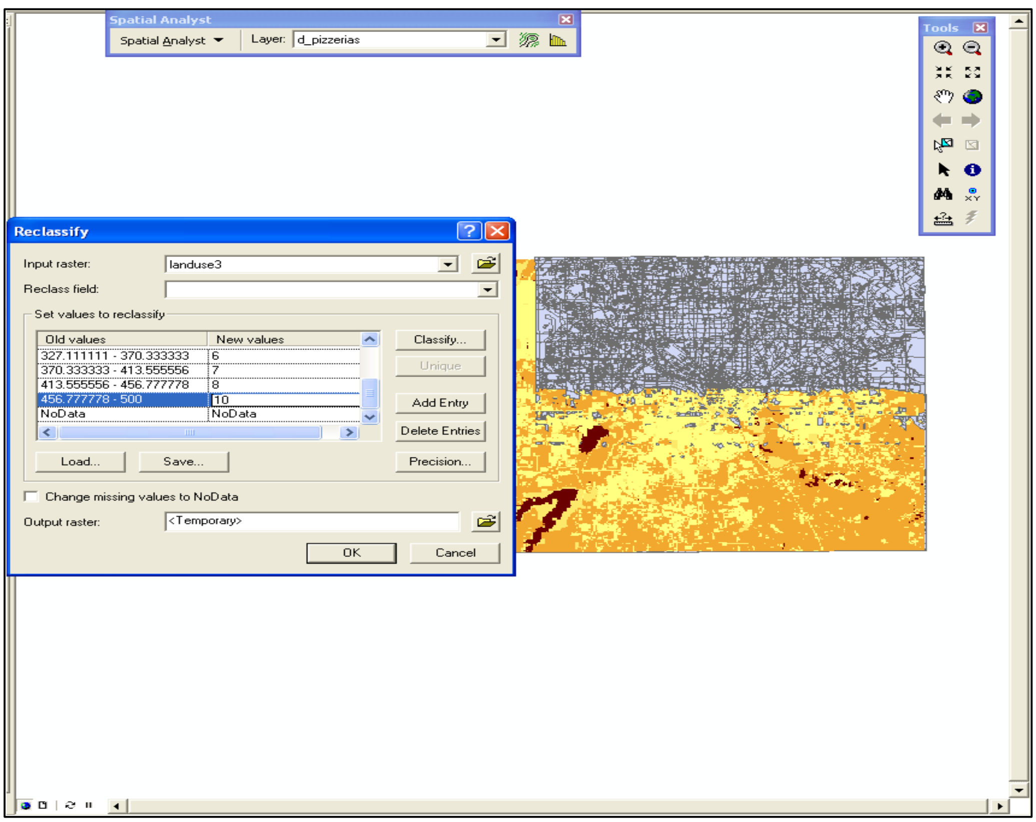


Figure 3.6: Reclassification table showing the weightage to different criteria using ArcGis9.2

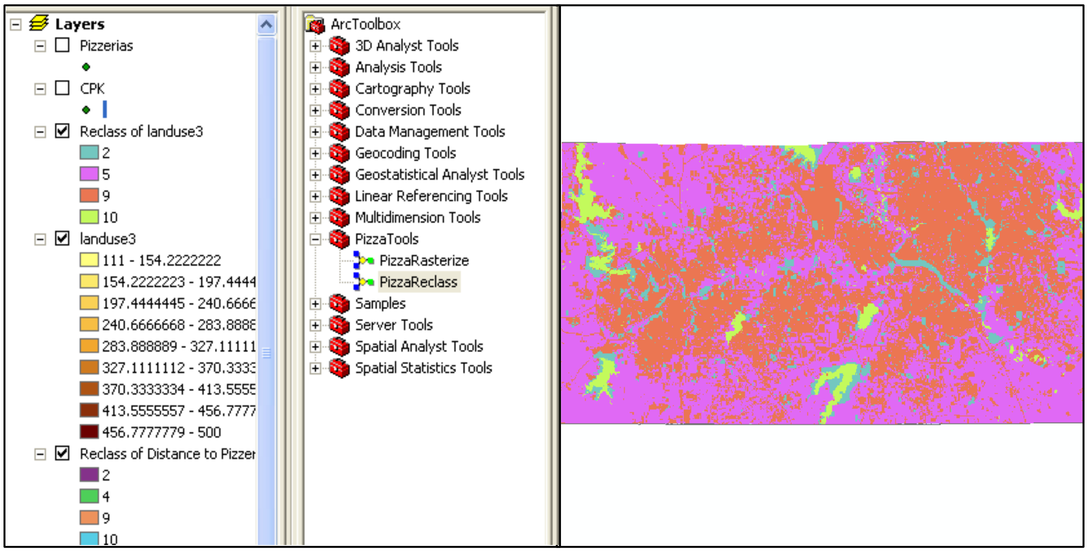


Figure 3.7: Reclassified layers and raster image using ArcGis9.2

a GUI by doing the spatial analysis.

Many software programs are developed to store and analyze subsurface soil investigations. Geotechnical Computer Applications developed a program called gINT[5] for the storage, manipulation and reporting of subsoil data (Geotechnical, 1988). The program only dealt with the descriptive aspect of subsurface soil information. There was no explicit scheme showing the geographic locations. This correlation of the data to the actual geographic locations is termed as spatial processing, which can be performed using the software like ArcGIS. GIS serves as a useful tool to analyze the logs as the format used for reporting subsurface soil conditions is in the form of boring logs.

The development of graphical operating environment allows the display of several parts of an application simultaneously on the screen which can correlate subsurface conditions to corresponding surface geographic locations. The manipulation of this data on the screen is done with the use of a pointing device like mouse but most of the work is done in the monographic-based environment, which has three limitations. First, each graphic occupies the entire screen so the log views cannot be shown

[5] Best selling software solution for geotechnical and geoenvironmental data management and reporting

side by side to the project site. Secondly, non-graphical operating environments do not support object-oriented interaction making data sharing extremely difficult and expensive.

CHAPTER 4

MAINTENANCE APPLICATIONS

4.1 Closed Circuit Television inspection of sewers

Closed Circuit Television (CCTV) inspection has been considered one of the most effective and economical method of pinpointing the internal input contribution. In the 1990s, the City of Boston, Massachusetts, had conducted 12 million ft of CCTV inspection on video tapes. Much funding has been spent on this process, but since most of inspection has been in the form conventional video tapes and paper inspection log sheets, accessing the information is difficult and time consuming (Shamsi, 2002).

Although CCTV provides valuable information, it has a cost implication and thus there is a necessity of minimizing CCTV inspection, so a selection point system is defined to allow the querying capabilities of GIS application and thus reducing further inspection with CCTV. Nowadays non-proprietary software is available to provide digital CCTV inspection in a format which is compatible with GIS applications.

4.1.1 WinCan

WinCan is software from WinCan America, Inc. (Durango, Colorado), which is another example of the video software that allows the user to capture either videos or pictures. Pictures are incorporated into different formats like JPG or BMP. Many types of equipment such as PalmPilot are used in the field to gather data with the user standing above the structure. Customized WinCan software can also be downloaded into the Personal Digital Assistant (PDA's).

WinCan interacts with GIS in two ways namely (i) Interfaces with the GIS database and (ii) Updates the GIS database. The first method interfaces the WinCan database with the GIS database using a meta-database. Database contains the unique information such as manhole identifiers, line section members, street names and pipe sizes so that when GIS tries to access a particular feature then the software searches the database to retrieve the details of the pipes. The user can display the associated pictures, videos or inspection data. In the second method an external device or utility helps the WinCan to get updated and then users can directly view the database and the graphics without the WinCan program.

4.1.2 ArcGIS pipeline data model

ArcGIS Pipeline Data Model (APDM) is mainly being used for the storage of data related to transmission pipelines, gas and liquid systems. The APDM version 4.0 has been used since 2001. The APDM is taking a new shape along with ESRI Pipe Line User Groups (PUG).

CHAPTER 5

DIGITAL ELEVATION MODELS

Digital Elevation Model (DEM) is a numerical representation of terrain elevation. It stores terrain data in a grid format for coordinates and corresponding elevation values. It also contains information of the elevation values in the form of raster**.** Cell based raster values are very much useful in the representation of geographic phenomena over space such as elevation, slope, precipitation etc. DEM is useful in modeling and spatial analysis of continuous surfaces like rainfall and stormwater runoff. DEM is stored in one of the following data structures like:

i. Grid structures

ii. Triangular irregular network (TIN) structures

iii. Contour-based structures

DEMs can be defined in the x, y and z values where x and y represent the location coordinates and z represents the elevation values. The data structure consists of a square grid matrix and the elevation of each grid labeled as a pixel, also stored in matrix format. TIN represents a set of non overlapping contiguous triangular facets of irregular size and shape. Digital terrain models (DTMs) and digital surface models (DSMs) are different varieties of DEM. DEM-based point elevations are most accurate in relatively flat areas with smooth slopes. DEMs produce low-accuracy point elevation values in areas with large and abrupt changes in elevation, such as cliffs and road cuts (ESRI, 2009).

5.1 Applications of DEM

Major DEM applications, as described in previous section, include (Shamsi, 2002):

i. Delineating watershed boundaries and streams

ii. Developing parameters for hydrologic models

iii. Modeling terrain data for energy location resources

iv. Determining reservoir volumes

v. Calculating the amount of material removed during strip mining

vi. Determining the probabilities of landslides

DEM can be used for automation delineation of watershed and sewershed boundaries and in the generation of graphics such as isometric projections displaying slope, direction of slope and terrain profiles between designated points. Raster GIS software packages convert the DEMs into image maps for visual display as layers in a GIS. DEM combined with other data types such as stream location and weather can help in fire control or combined with remote sensing can help in the classification of vegetation.

5.2 Three dimensional visualization

The three dimensional computer modeling has become a vital aspect in most of the engineering disciplines including layout, design and construction of industrial and commercial facilities. The three dimensional models are highly effective for public and town meeting presentations. GIS develops create accurate topographic elevation models and generates precise three dimensional data. DEMs are raster images, still they can be imported to the three dimensional visualization packages. Thus the software and the three dimensional data can be used to create virtual reality representations with the help of stereo imagery and automatic extraction of three dimensional information. For example Skyline software systems (www.skylinesoft.com) provide realistic, interactive, photo-based three dimensional maps of many locations and cities around the world. GIS also plays an important role in obtaining the geographic location in three dimensional space and link the location and attributes through photogrammetry and remote sensing. Sometimes three dimensional geographic imaging is used to create orthorectified imagery, DEMs, stereo models and three dimensional features.

5.3 Terrain concepts

A terrain dataset is a TIN-based dataset that uses geodatabase feature classes as data sources. A triangulated Network (TIN) is a data structure used to model surfaces such as elevation as a connected network of triangles.

These are assembled from a series of points with X, Y and Z values and partition geographic space into non-overlapping triangles and the nodes of each triangle are the elevation or surface points. Each triangle has a xy coordinate and z surface value and any surface value can be interpolated in a face or edge as shown in Figure 5.1. Terrains are also represented by the use of pyramids for multiple resolutions. First the pyramids levels are defined, working range and the level of details which are defined by the Z-resolution at that map scale as shown in Figure 5.2 (ESRI, 2009).

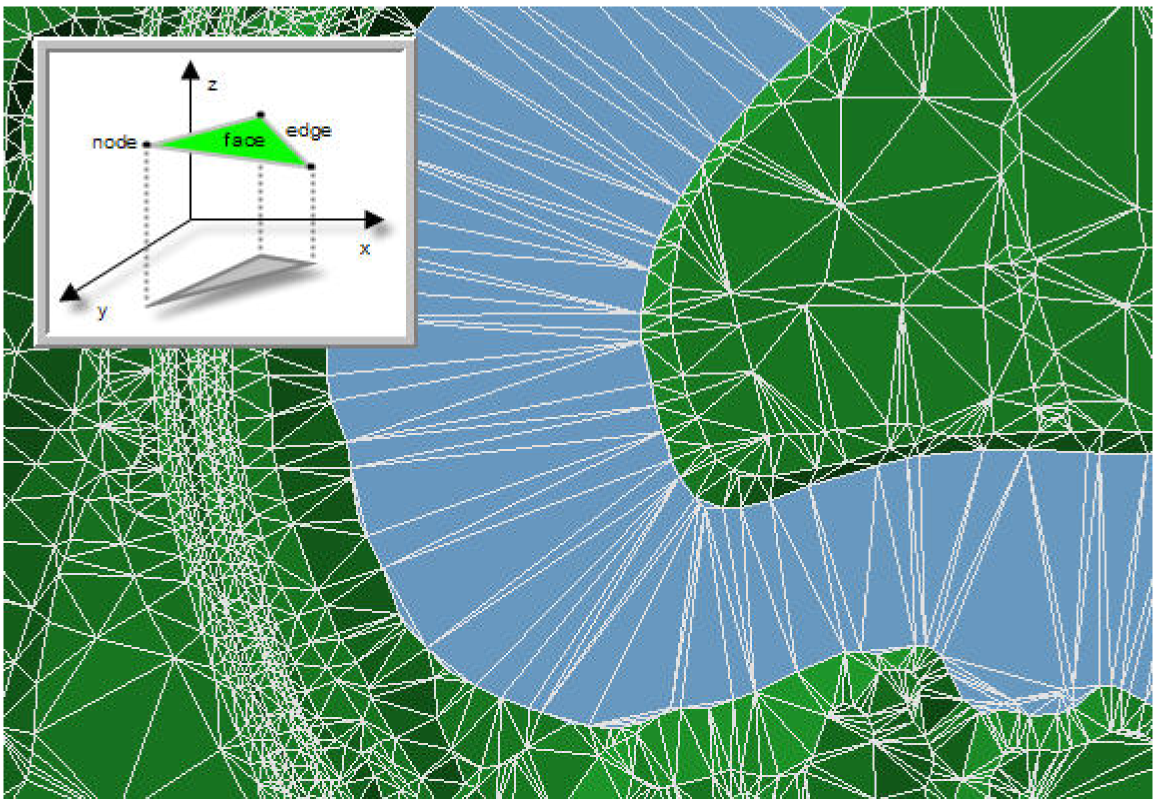


Figure 5.1: TIN data structure to represent surfaces

5.4 Developing a DEM to TIN

First the files are uploaded into ArcMap and rasterized as explained in previous chapters. One has to make sure that the three dimensional Analyst tool bar is activated. Once this is activated go to options and convert raster data to TIN as shown in Figure 5.3 and features to TIN as shown in Figure 5.10. Set the tolerance limit closer to zero to get the maximum accuracy. Make sure all the layers are in the right co-ordinate system.

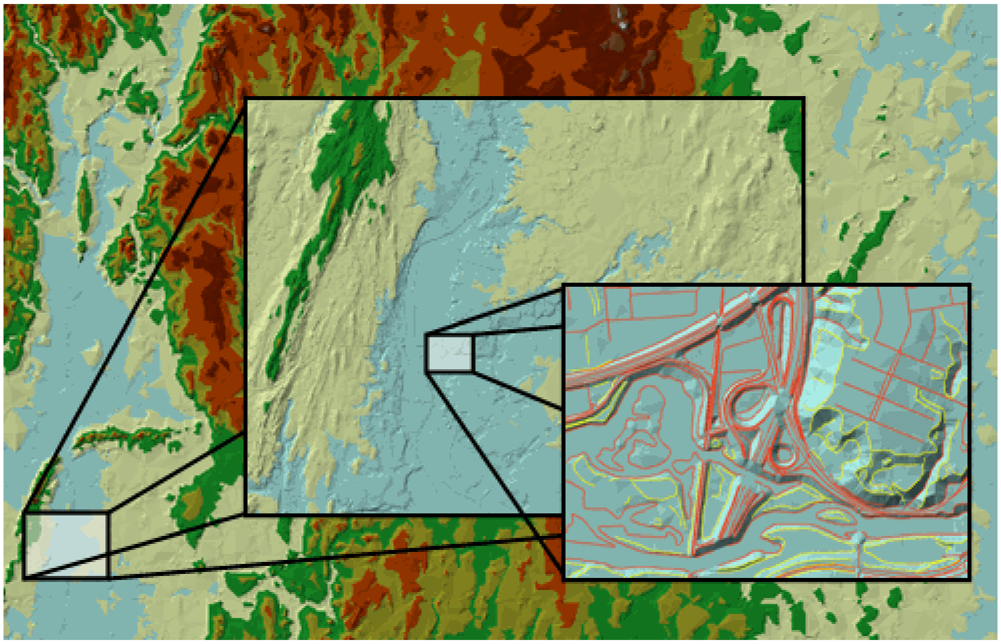


Figure 5.2: Representation of terrains using pyramids for multiple levels of resolution

Open ArcScene and using the three dimensional Analyst option and click the globe option to add 'rastin' using the symobology tab, add 4th face and go to dismiss and uncheck edge types and faces. Right click on scene layer and scene properties to make the vertical exaggeration to 5 or 10.

Figure 5.5 shows sample layers like contours and DEM are exported to ArcScene. The exported TIN data is opened in ArcScene and the three dimensional Analyst toolbar is activated as shown in Figure 5.6. The vertical exaggeration is done to 10 as shown in the dialog box mentioned in Figure 5.7Figure 5.7. Once this is done one can zoom in and zoom out the TIN image along with the walk through using the fly tool as shown in Figure 6-8. Figure 6-9 shows a sample water polygon layer in between the buildings. This is a sample data file for the city of Austin and water polygon layer. One can actually extrude the base height of the buildings by using the properties option of the layer. Ideal value used in this example is 200.

Walk through can be obtained on this data using fly through option in the tool bar. Right clicking the mouse will increase the speed and left clicking the mouse would decrease the speed. A snap shot of walk through is shown in Figure 5.10. Snap shots can also be seen in Appendix A.

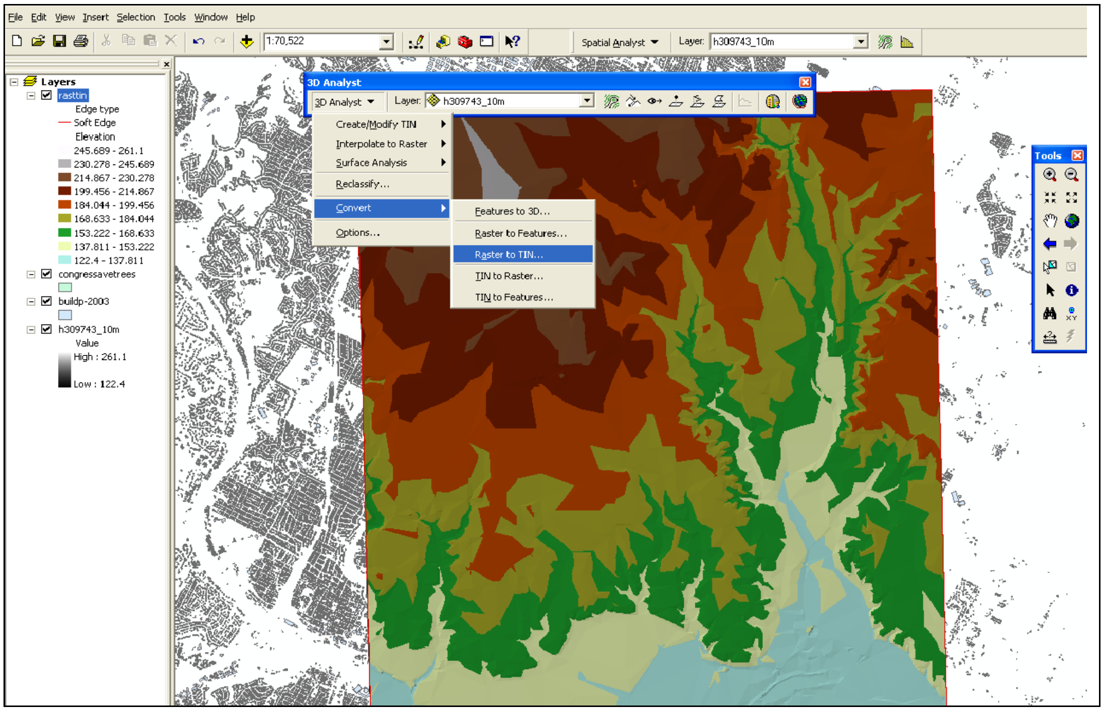


Figure 5.3: TIN images obtained from raster to TIN conversion using ArcMap

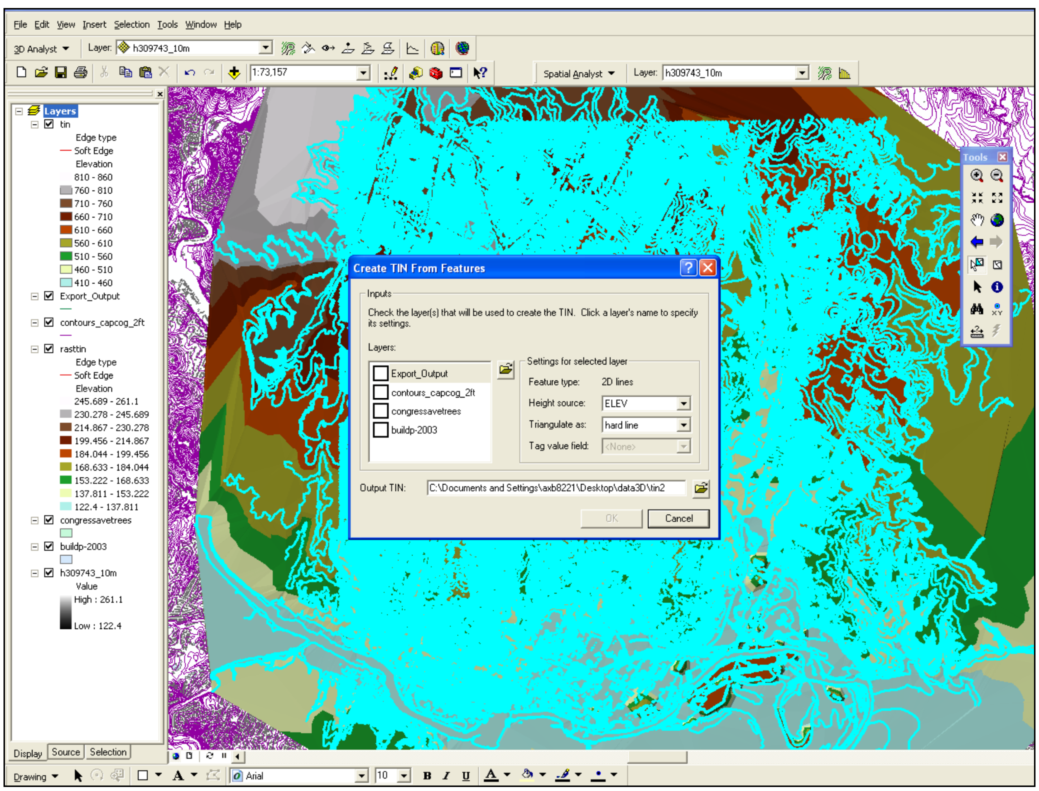


Figure 5.4: Converting features to TIN using ArcMap

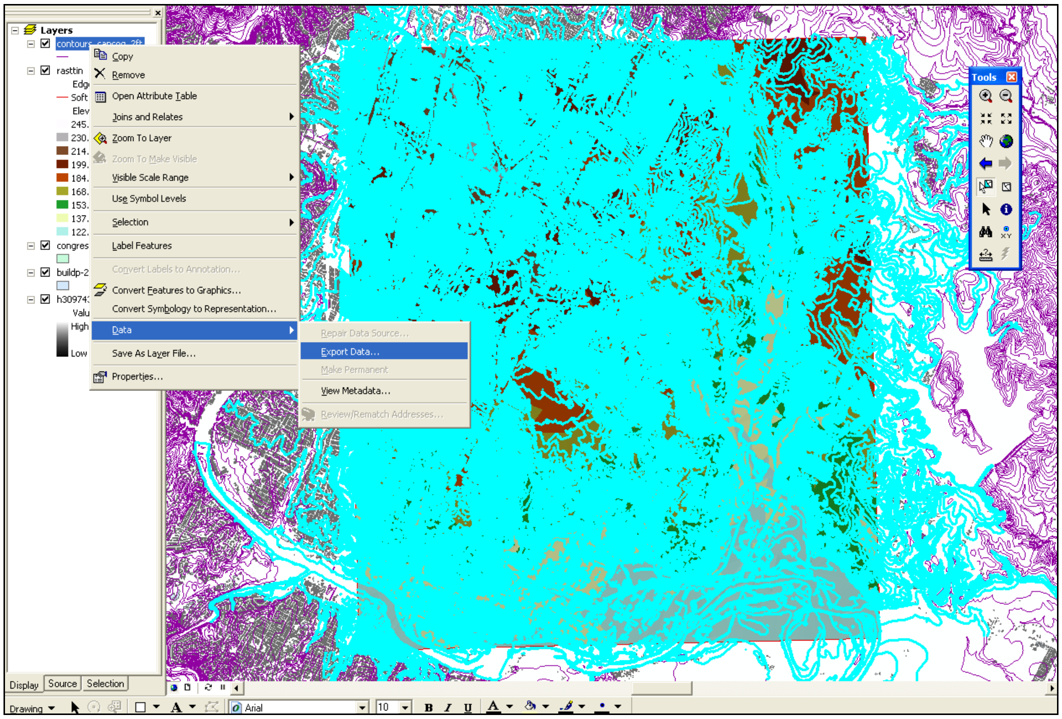


Figure 5.5: Exporting data to ArcScene

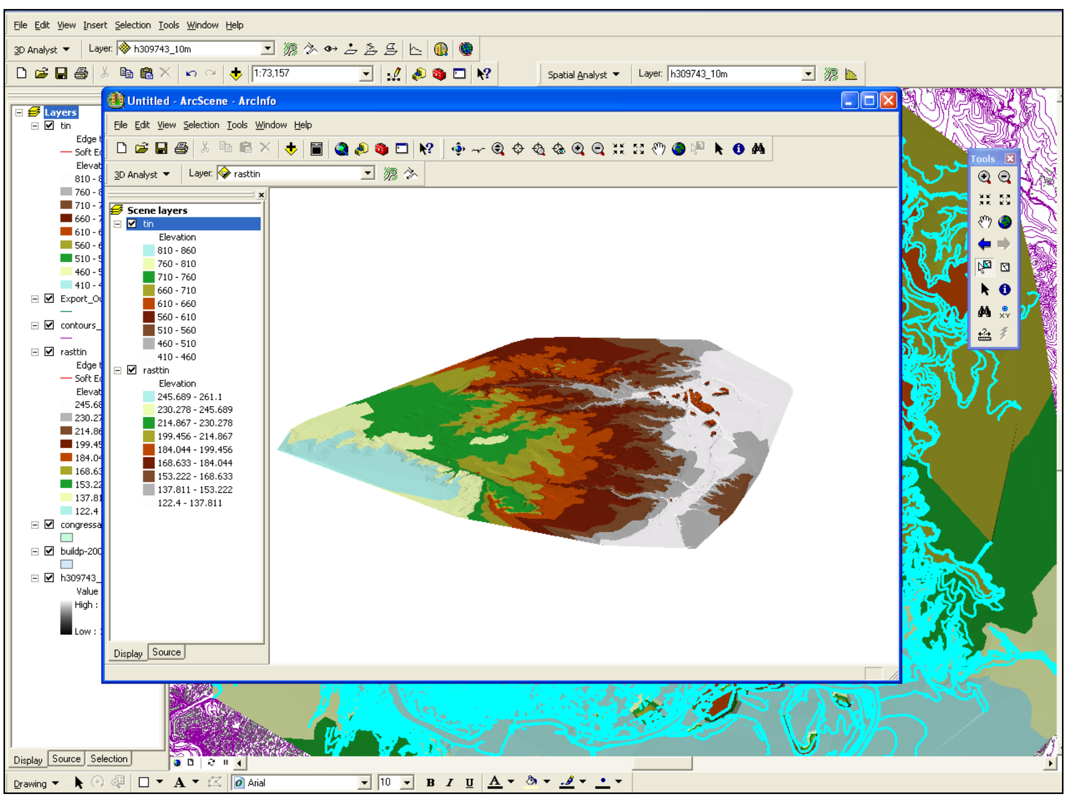


Figure 5.6: Creating TIN in ArcScene

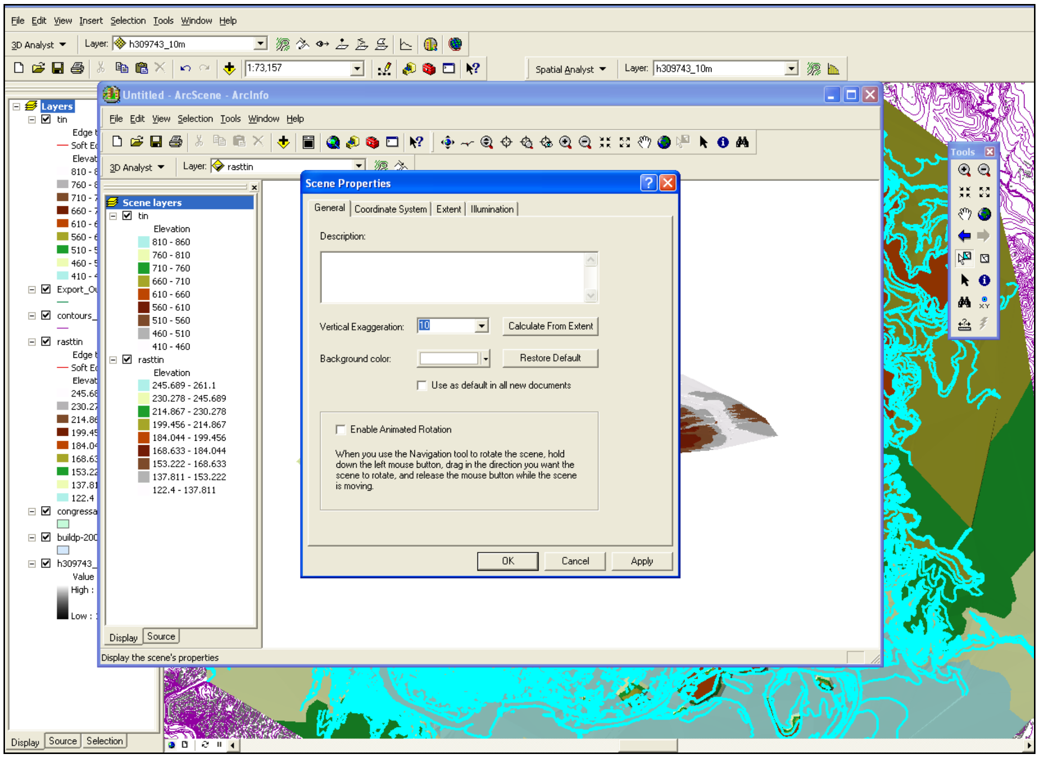


Figure 5.7: Vertical exaggeration using ArcScene

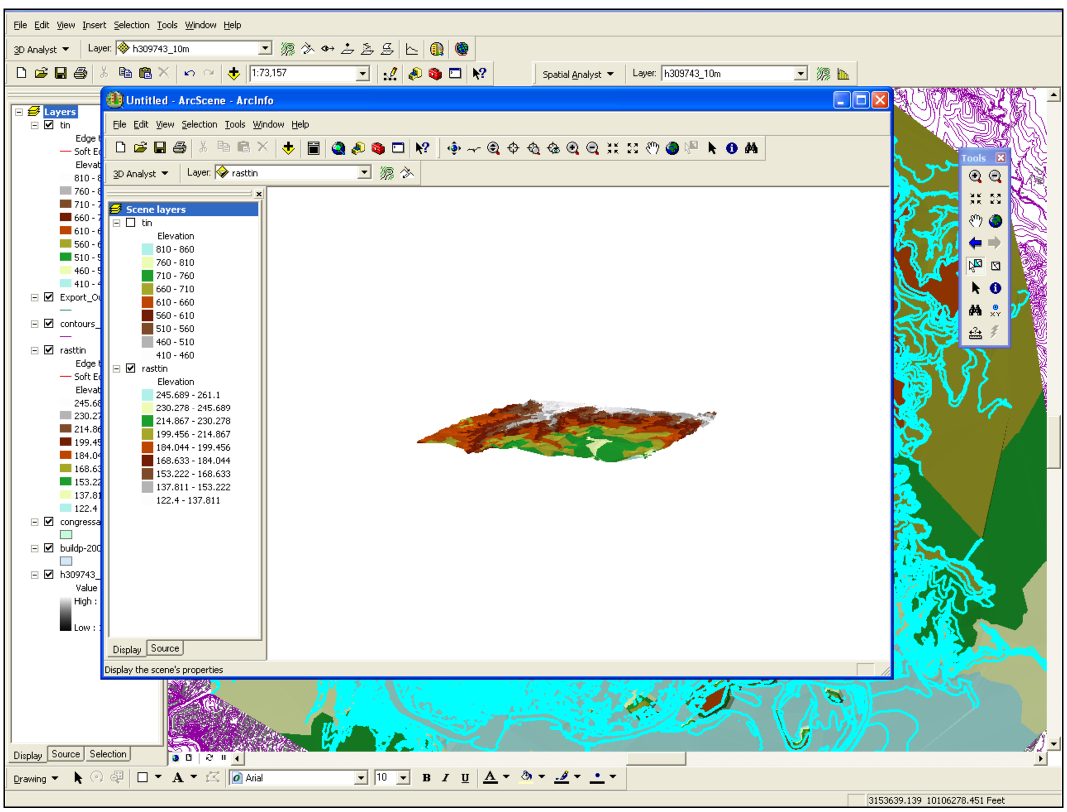


Figure 5.8: Use of fly tool in ArcScene

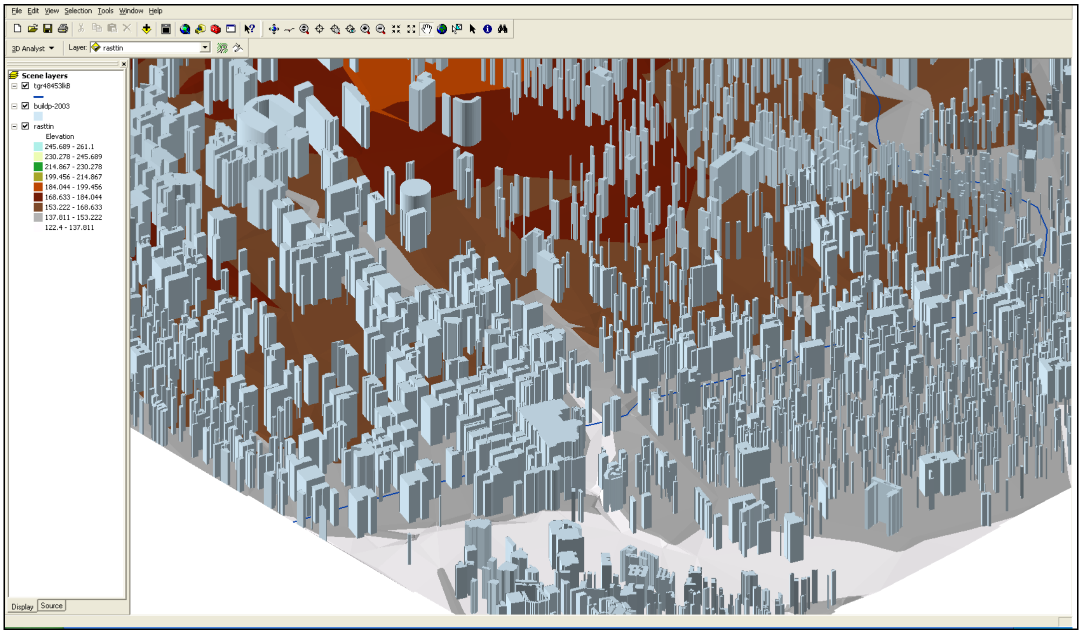


Figure 5.9: Sample of Austin, Texas data extruded with water polygon

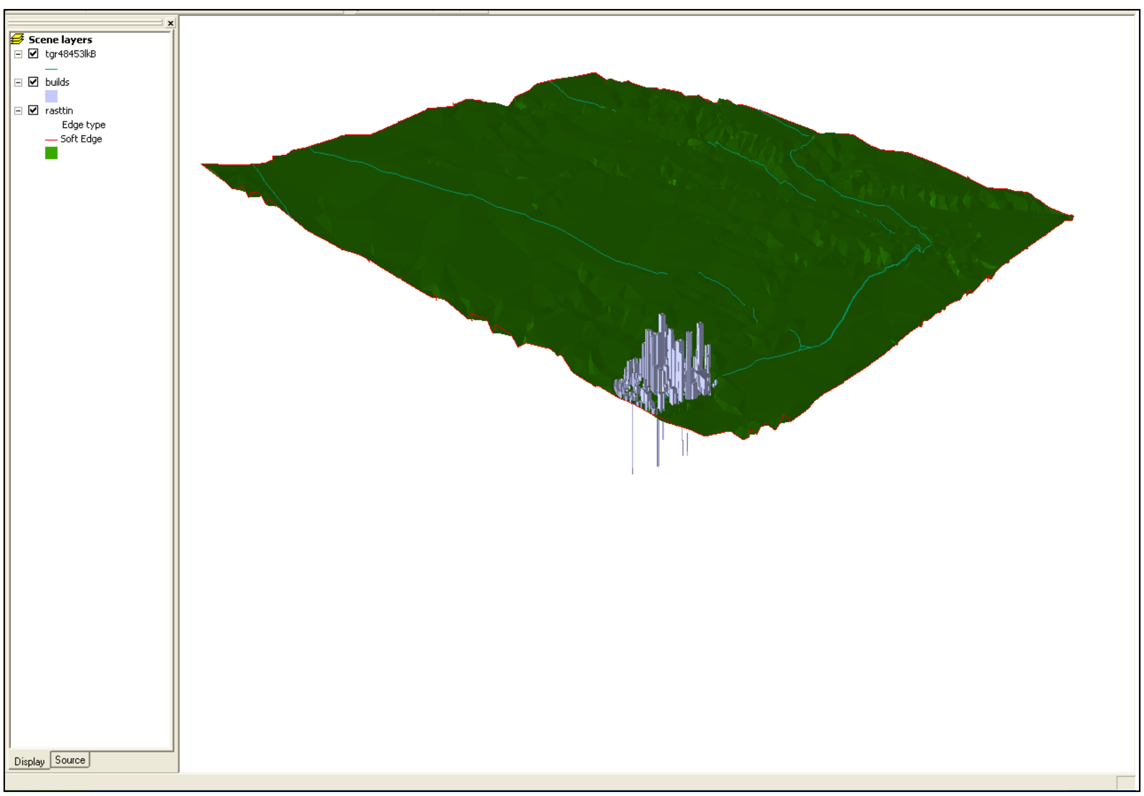


Figure 5.10: Snap shot of the fly through over the portion of Austin, Texas

CHAPTER 6

DEVELOPING GOOGLE MAP

This chapter deals with the application of ArcGis9.2 along with Google Maps to come up with a user friendly map showing the desired locations and also the driving directions of the particular location.

6.1 Developing a sample Google Map of Tarrant County

The Figure 6.1 shows education related areas of Tarrant County. The first step is to download ArcMap2GMap, one of the links http://arcscripts.esri.com/details.asp?dbid=14904 (UT Arlington GIS library, 2008) or from any of the public domains of the Environmental Systems Research Institute (ESRI) website. Software to be installed in the program file directory where all the installing directories are saved like the 'C:' drive. Navigate to the ArcMap2Gmap.mxd and run it. The most important factor is that the GIS data also to be added to the same directory and uploaded to the ArcMap. Ensure that the data is geographically referenced in terms of the latitudes and the longitudes. The style of symbology of the layers is not going to affect the Google Map.

Once the layers are uploaded into the ArcMap, click on the 'Arcmap2Gmap' icon on the top right corner which gives a window as shown in Figure 6.2. This icon is a customized tool bar from the GIS library of The University of Texas at Arlington (UT ARLINGTON) to ArcMap of ESRI. This 'Arcmap2Gmap' toolbar can be downloaded from the ESRI website. Details of the information related to the object like field, type of the object like polyline, point or line to be entered. Opacity to be entered and it is better to keep high numbers for better quality. Select a suitable color. Click on 'submit'. Later, the required location for posting the map should be decided and selected. Finally the author name and title of the map to be entered in the box provided. Finally click on the 'lets do it' icon. Decoding of features to the desired coordinates will be done and once the operation is complete click on the Launch Google Map icon as shown in Figure 6.3, which will create a Google Map shown in Figure 6.4 which has all the education related areas in the Tarrant County. Desirable location can be obtained as shown in Figure 6.5. Distance between two desirable locations can also be obtained as shown in Figure 6.6 which is most widely used as Google directions.

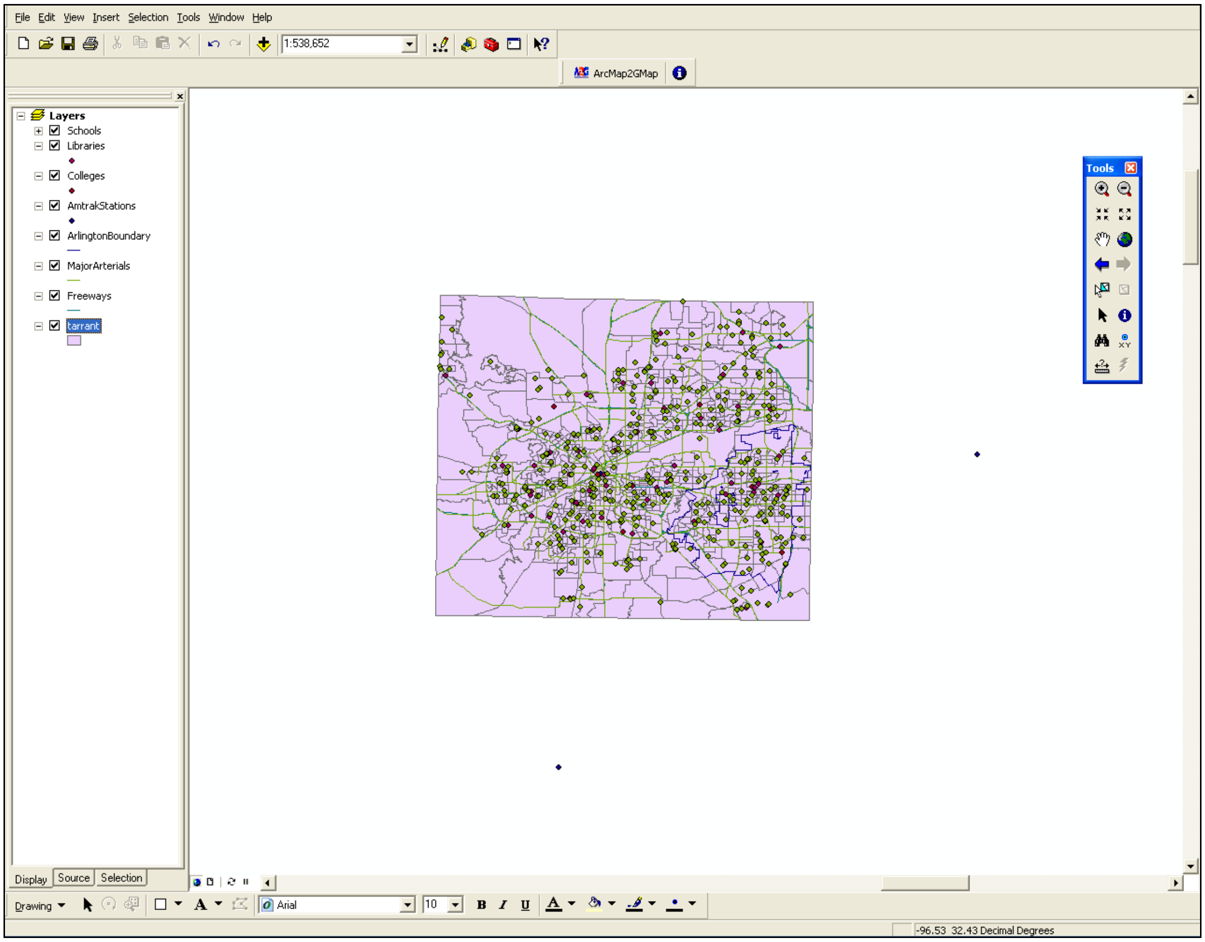


Figure 6.1: Education related areas in Tarrant County using ArcGis9.2 and Arcmap2Gmap

Ultimately this chapter helps to develop a Google Map if a suitable database is available. Thus if the data related to any pipe installation or maintenance is available then it helps us to find the length of the pipe required, distance between the two locations or distance from the manufacturing units to the construction site which serves as an important tool in the scheduling of the project. The applications are many depending on the location of the data.

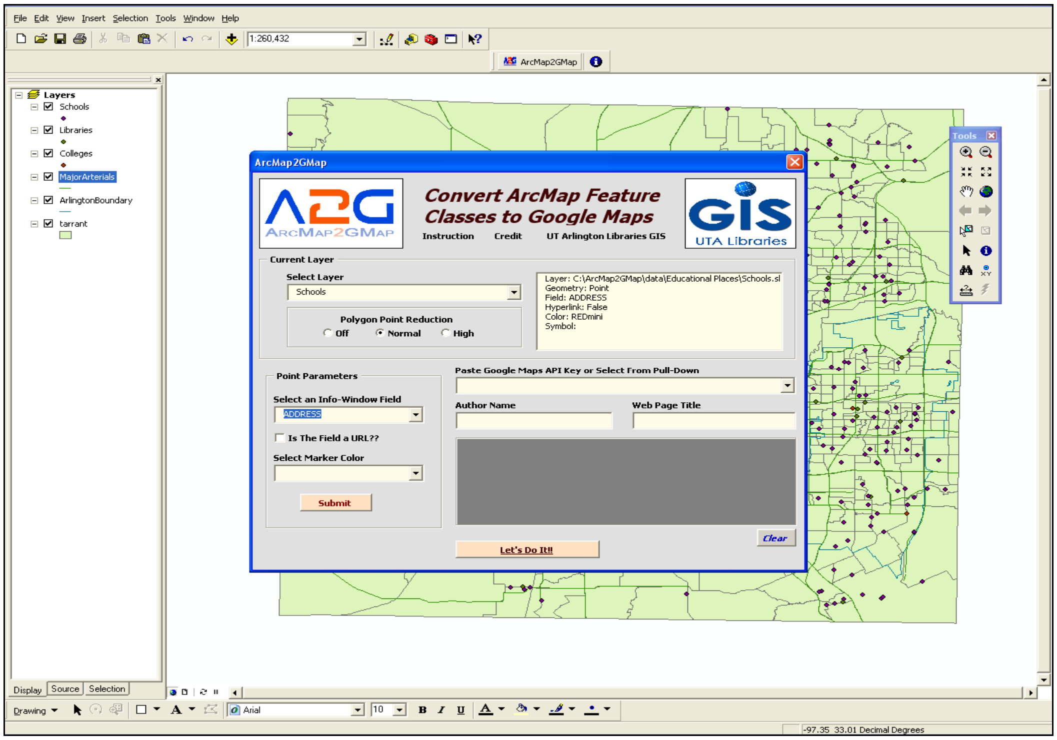


Figure 6.2: Arcmap2Gmap window showing the details to be entered

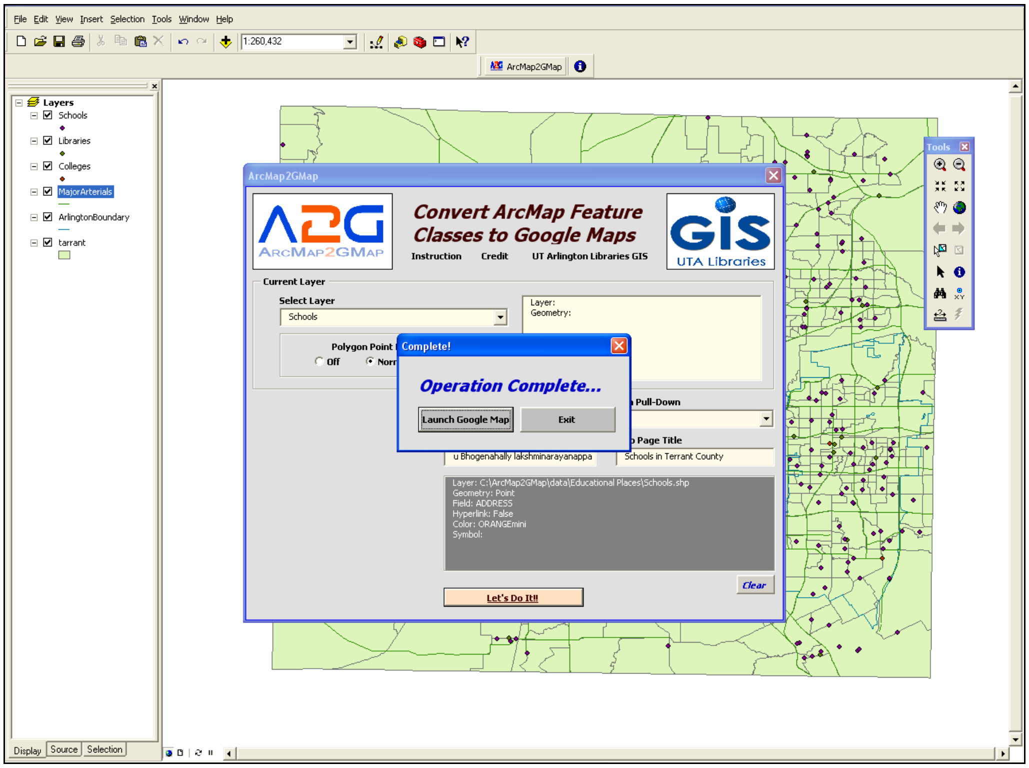


Figure 6.3: Decoding process using ArcGis9.2 and Arcmap2Gmap

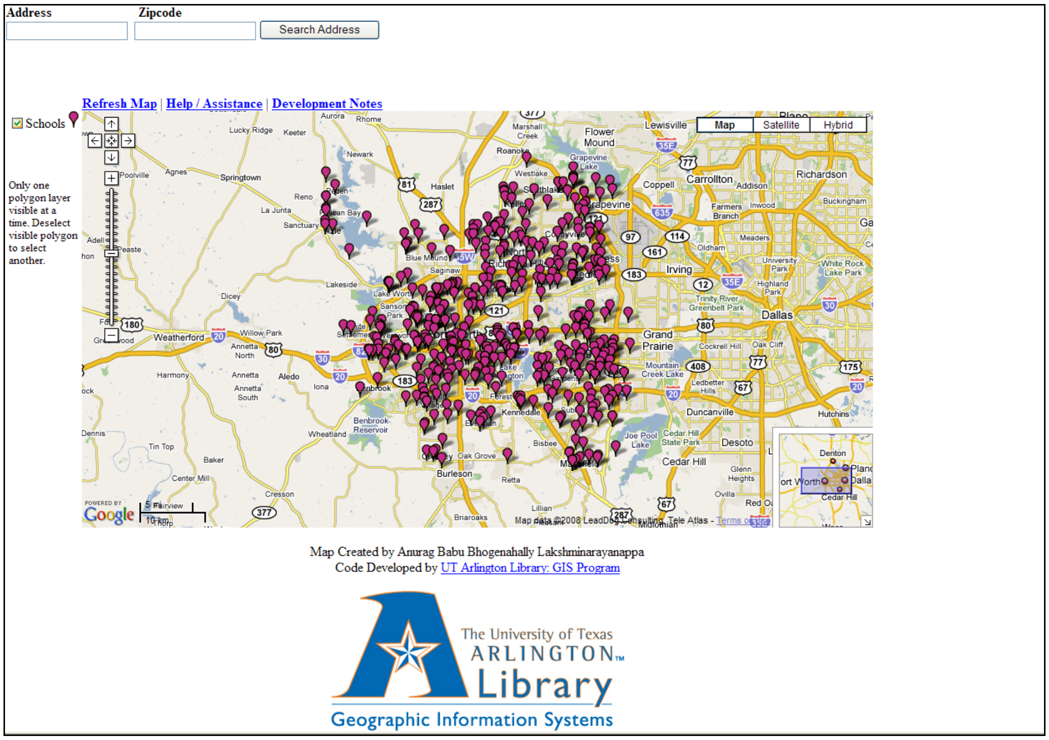


Figure 6.4: Schools in the Terrant County using ArcGis9.2 and Arcmap2Gmap on Google Map

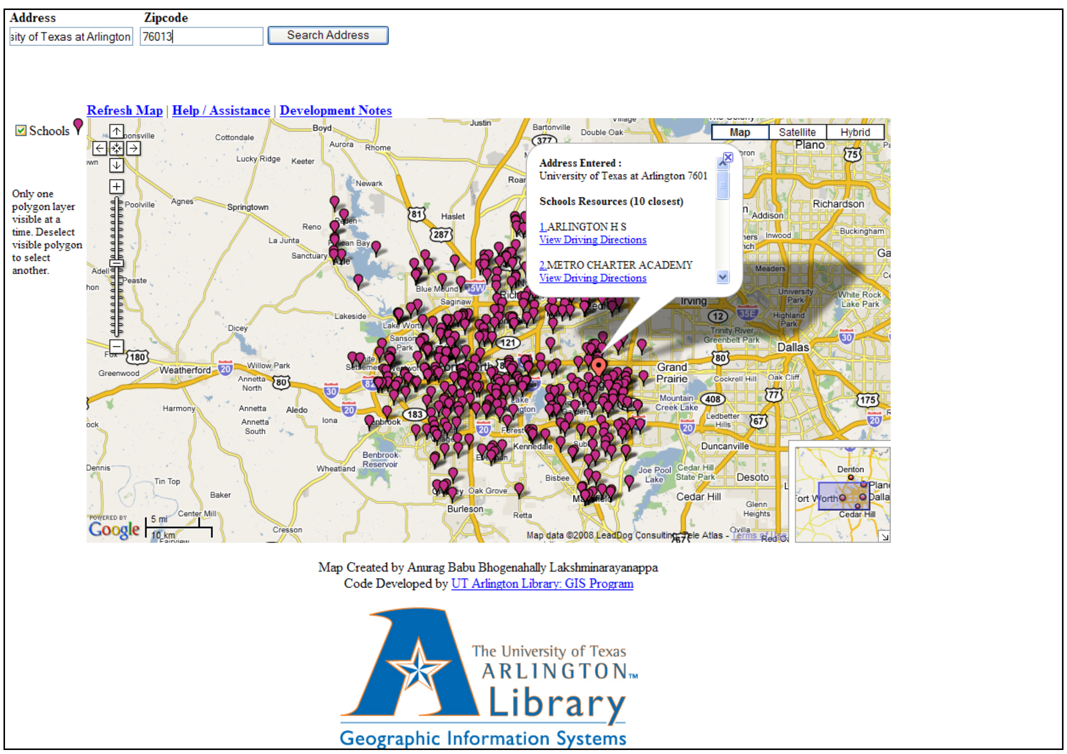


Figure 6.5: Google Map showing the desired location using ArcGis9.2 and Arcmap2Gmap

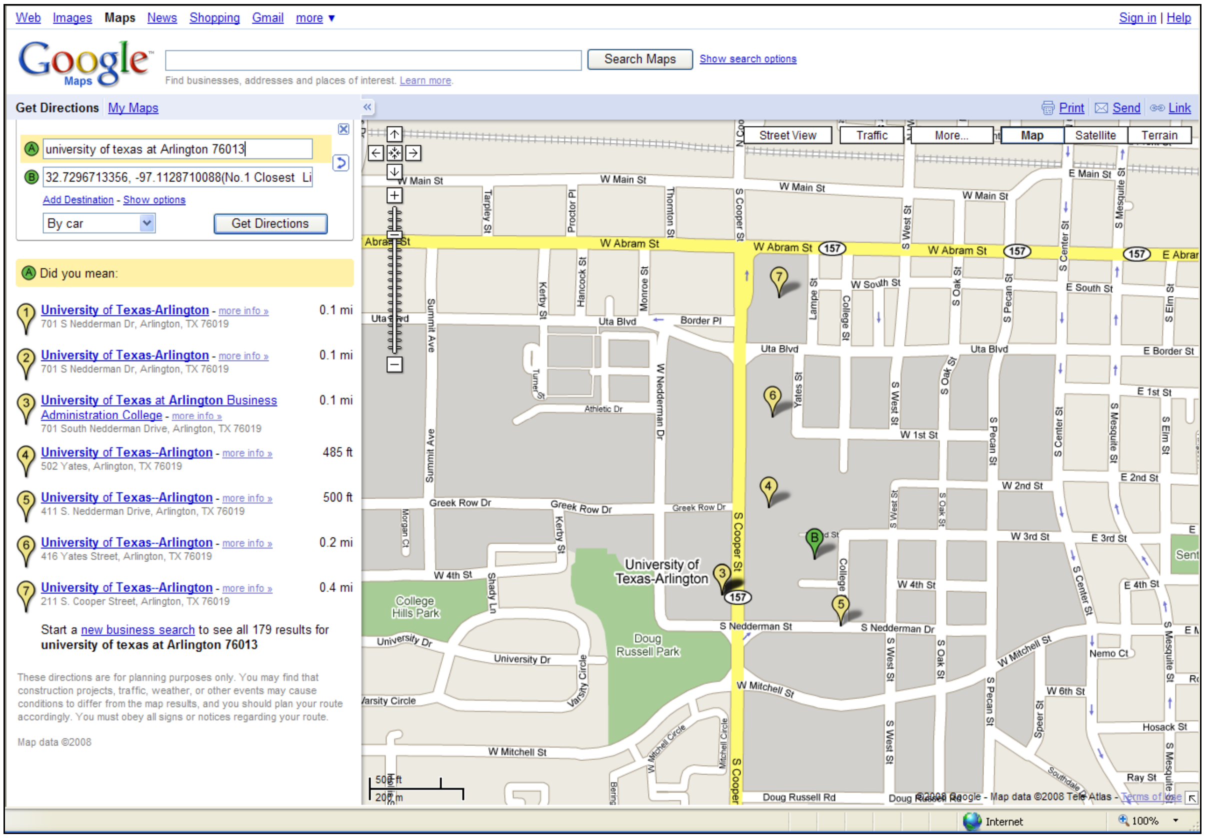


Figure 6.6: Directions between the two locations using ArcGis9.2 and Arcmap2Gmap

CHAPTER 7

CASE STUDIES

7.1 Data Extraction from the Sample Data Sheet to the ArcMap file

This chapter introduces methodology for the extraction and also incorporation of the data in the excel format to the raster data. Sample data has been chosen from Troy, Michigan with the help of Wayne State University.

7.2 Steps involved in the Data Extraction

Steps are involved in data extraction and also incorporation into the ArcMap is as follows:

i. Data source to batchgeocode

ii. Data input to batchgeocode

iii. Validate source data

iv. Address verification

v. Running Geocoder

vi. Output transfer

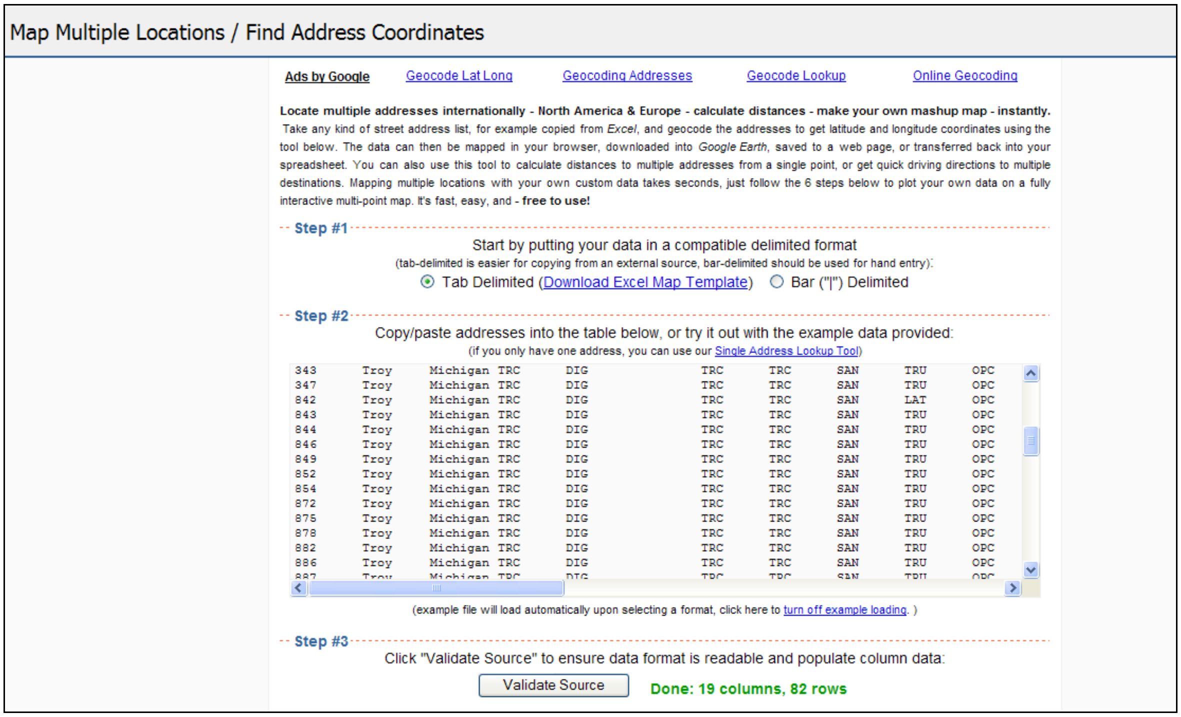
vii. Output display

7.2.1 Data source to batchgeocode

The first step towards the data extraction is the input of the given data (in this case an excel data), in which the relevant geographical data such as the County name and the State to be entered so that batchgeocode recognizes the location of the given data and processes it. Next introduce two new columns for County and State and drag these two inputs to the end of the sheet so that the all the rows have the County and the State name in it.

7.2.2 Data input to batchgeocode

Once the data is entered copy and paste the excel sheet in the batchgeocode table as shown in the Figure 7.1 using the link http://www.batchgeocode.com/.



343	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
347	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
842	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	LAT	OPC
843	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
844	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
846	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
849	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
852	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
854	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
872	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
875	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
878	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
882	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC
886	Troy	Michigan	TRC	DIG	TRC	TRC	SAN	TRU	OPC

Figure 7.1: Batchgeocode showing the input data

7.2.3 Validate Source data

The third step is to validate the source code by clicking on the validate source through which the software will validate the source and give the result in terms of the number of rows and columns as shown in Figure 7.1 in step #3.

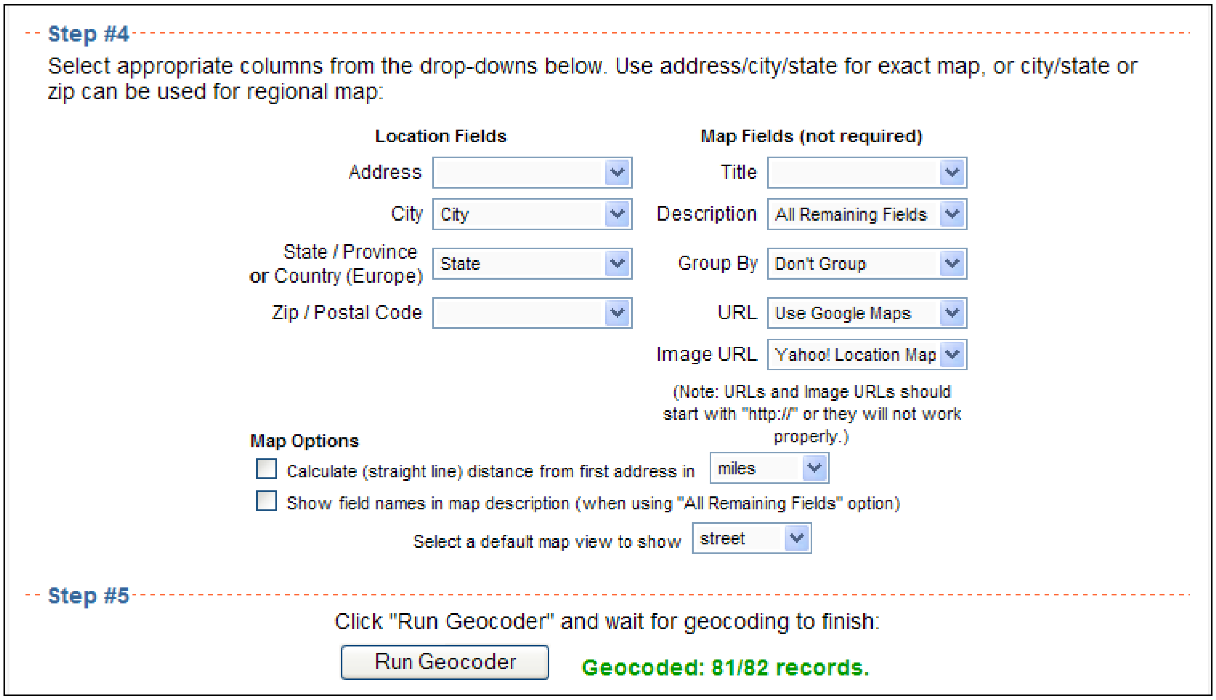


Figure 7.2: Address input to batchgeocode

7.2.4 Address verification

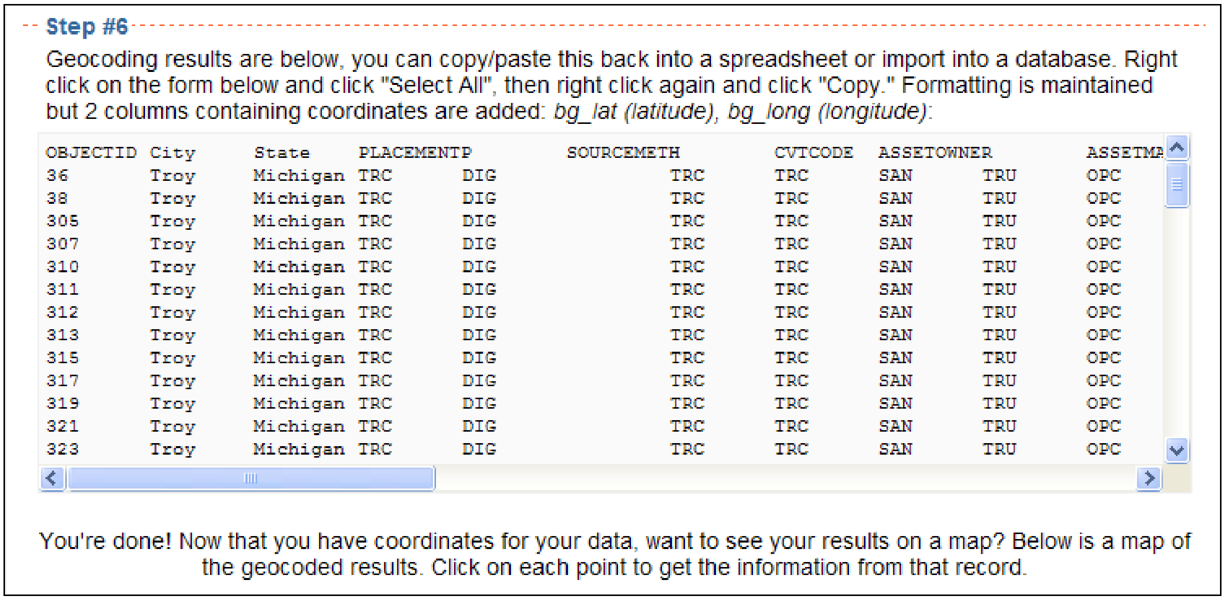
The fourth step is to enter the address into the system through various fields provided as shown in Figure 7.2. The program will still run if the address and the map remain as default or not entered at all. The Map fields are impressive if one has to customize their own maps by giving the title, description and URL. Map options are useful when the distance calculations are involved and also to get the street views.

7.2.5 Geocoder

The fifth and the final step are to run the geocoder. Batchgeocode takes some time to evaluate the data as it has to check each and every row in the input data. Ultimately it comes out with the result showing the latitude and the longitude of the given data in the excel sheet, which is the required output. One has to ensure that maximum of only 500 rows can be geocoded, which is one of the limitations of batchgeocode.

7.2.6 Output transfer

Once the batch geocoder is run, the desired output as shown in the Figure 7.3, the complete results are copied by using Cntrl and the letter A in the keyboard or using the mouse entire data can be selected. Then it should be pasted back to the excel sheet which will be the same as the earlier with two new columns namely bg_lat (latitude) and bg_lon (longitude) being added to the sheet and saved in the Comma Separated Values (CSV)[6] format as the GIS ArcMap recognizes data only in the CSV format.



Step #6

Geocoding results are below, you can copy/paste this back into a spreadsheet or import into a database. Right click on the form below and click "Select All", then right click again and click "Copy." Formatting is maintained but 2 columns containing coordinates are added: *bg_lat (latitude), bg_long (longitude)*:

OBJECTID	City	State	PLACEMENTP		SOURCEMETH		CVTCODE	ASSETOWNER		ASSETMA
36	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
38	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
305	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
307	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
310	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
311	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
312	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
313	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
315	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
317	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
319	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
321	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC
323	Troy	Michigan	TRC	DIG		TRC	TRC	SAN	TRU	OPC

You're done! Now that you have coordinates for your data, want to see your results on a map? Below is a map of the geocoded results. Click on each point to get the information from that record.

Figure 7.3: Results of the batchgeocode

7.2.7 Output display

The output will also be displayed in the map as shown in the Figure 7.4. The result gives the exact location using the co-ordinates in the form of a map which can be exported to Google Earth or can be saved to a webpage. One can also customize the output display with map options and map fields as explained in the sixth chapter.

7.3 Get the map and the shapefile

For an input into the GIS ArcMap one must have data in the '.shp' extension or shapefile. One of the weblink http://arcdata.esri.com/data/tiger2000/tiger_download.cfm gives the information related to

[6] Used for the digital storage of numbers in the form of tables

counties as shown in Figure 7.5. First input the County name and submit selection which redirects to a new webpage which gives the geographic information of the counties. Selecting any of the options shows additional options to download the shapefile.

7.4 Exporting the data

Once the shapefile is obtained, it is uploaded into the ArcMap along with the source data in the CSV format. Out of which only the shapefile related to the County is in the raster format but the CSV files

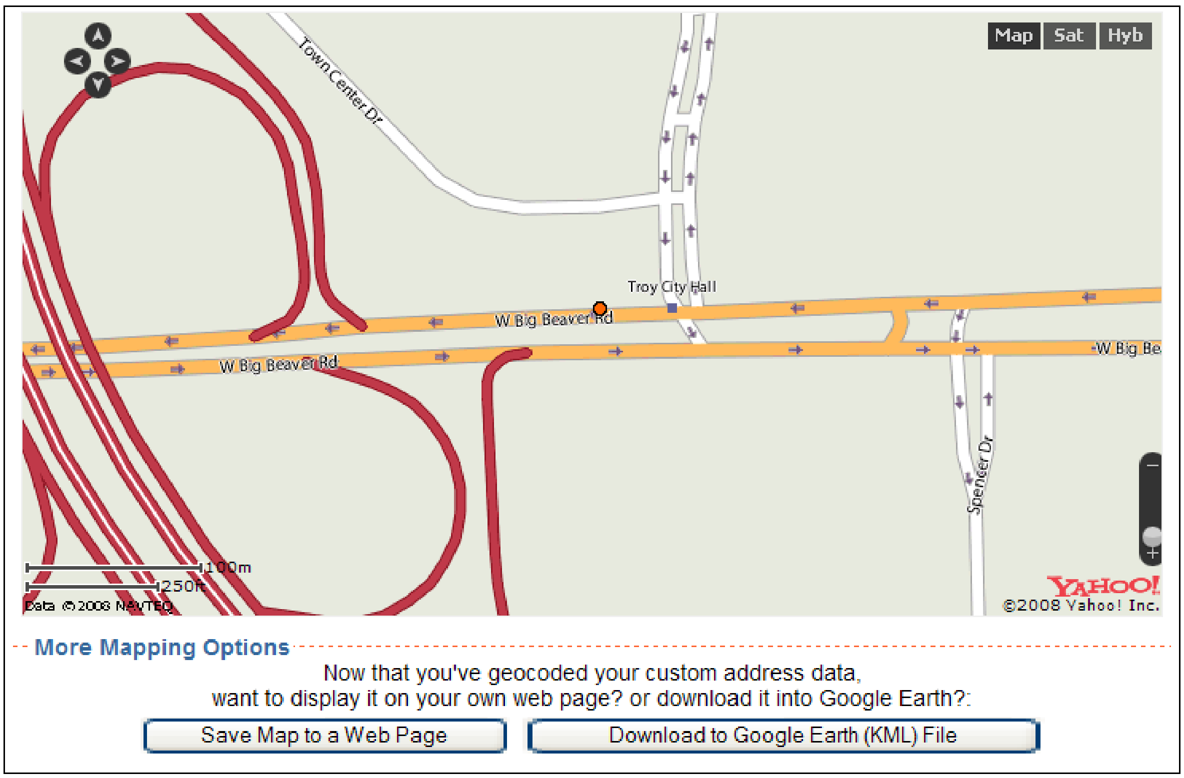


Figure 7.4: Output of the geocoder in the Google Map

are in different co-ordinate systems. So the next step would be to combine the data into single entity and converting to raster. The attribute tables are as shown in the Figure 7.7. Using the toolbox of the ArcGIS, the spatial join of the attributes are done as shown in Figure 7.8.

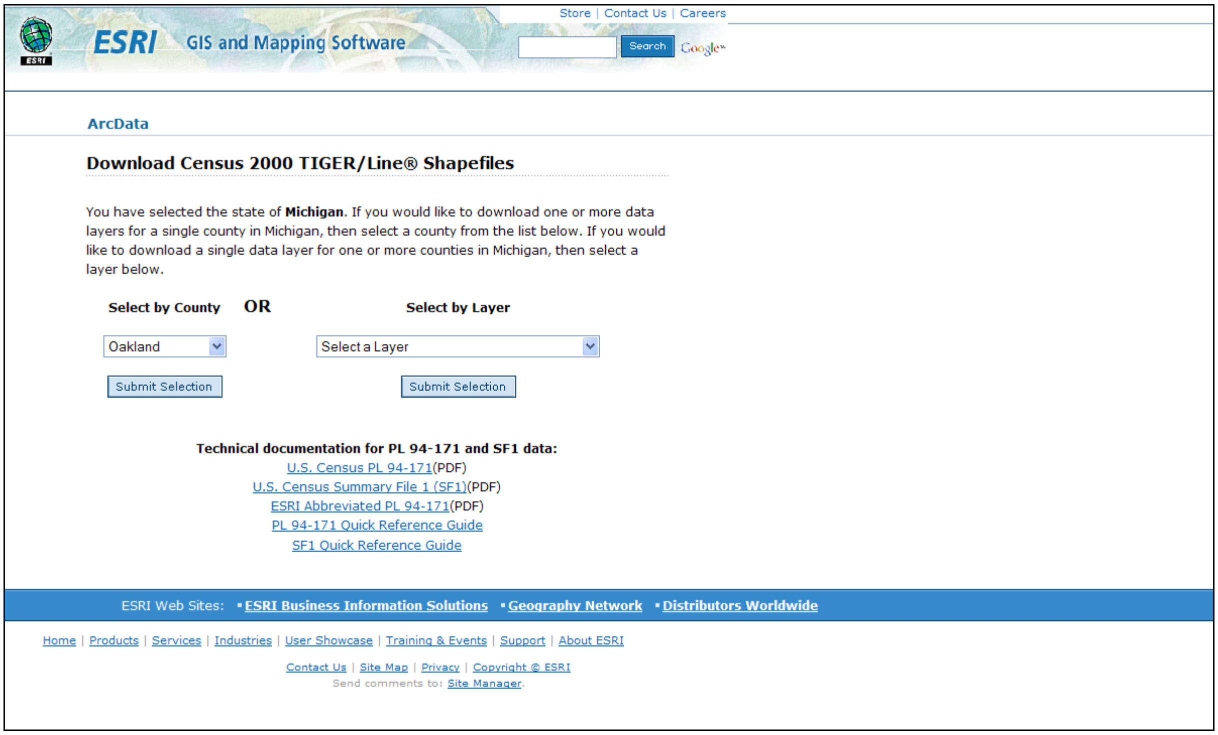


Figure 7.5: ESRI website to get the GIS data for counties

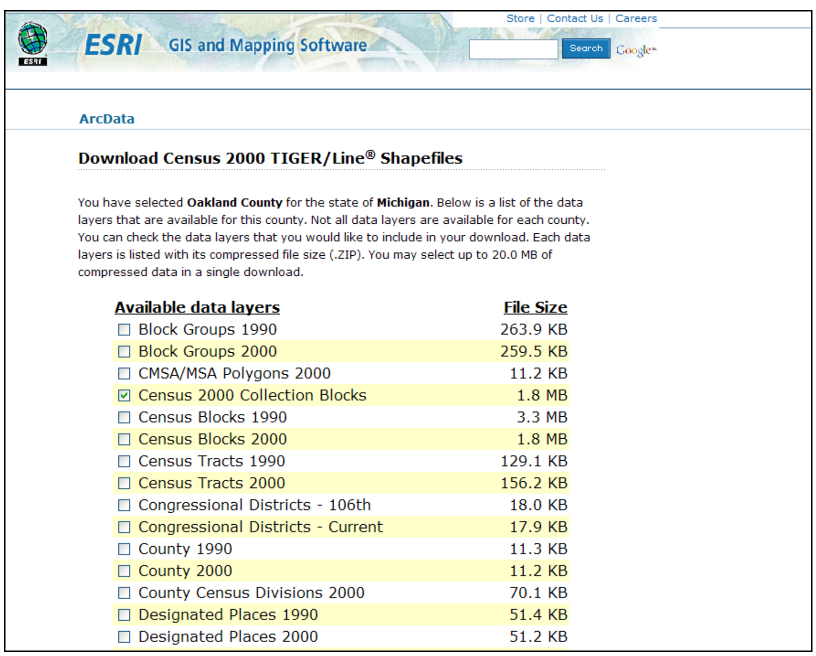


Figure 7.6: Geographic information of the counties using ESRI weblink

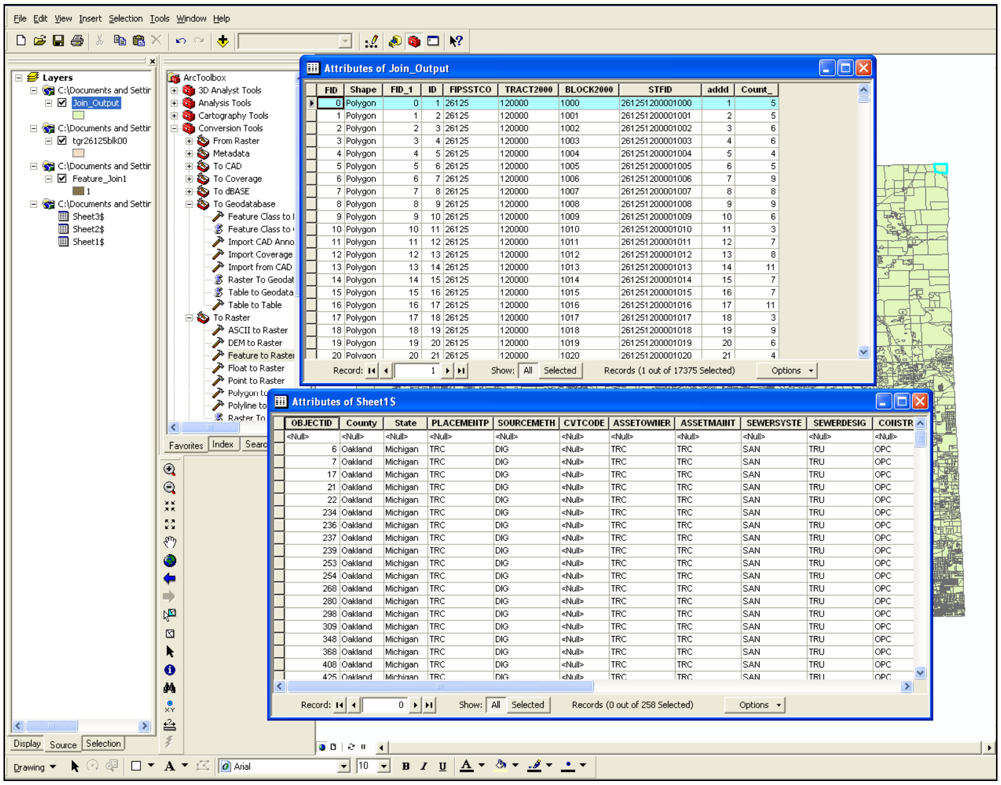


Figure 7.7: ArcMap showing the County layer, source data and the attribute file using ArcGIS9.2

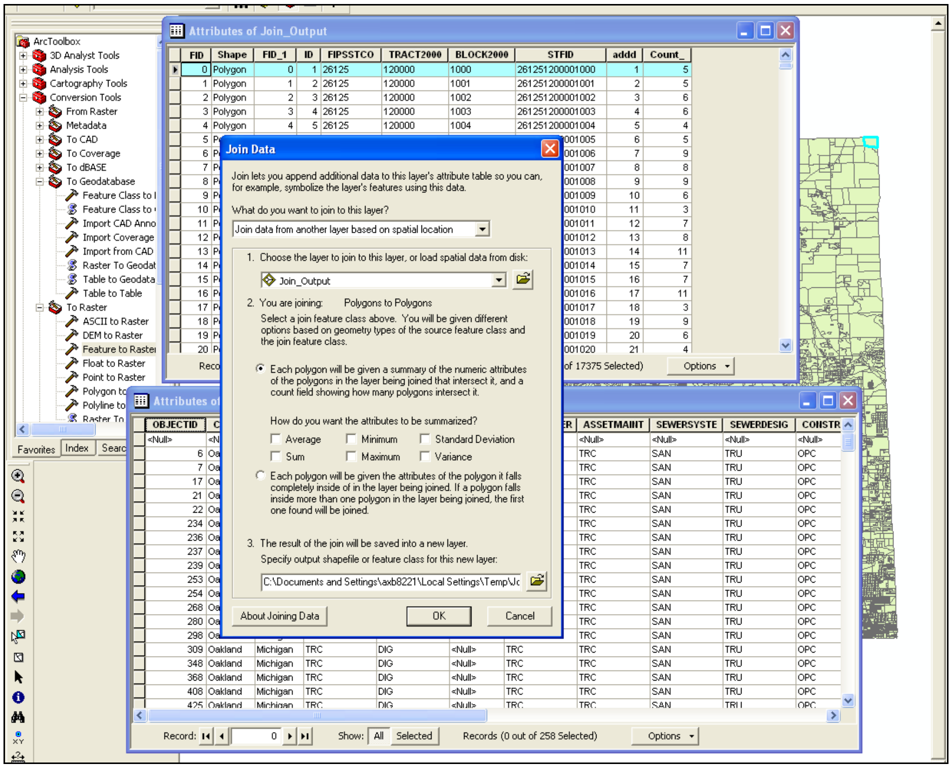


Figure 7.8: Spatial joining of the two layers using the Spatial Join option of ArcGIS9.2

7.5 Least Cost distance calculation for Allen, Texas

This section deals with the calculation of the least cost path between any two points. The principle behind this section is very helpful in the suitability analysis. There are various steps involved in the least distance and weighted average calculations.

7.5.1 Steps involved in the Least Distance Calculations

The various steps involved in the least distance calculations are:

i. Uploading the data

ii. Configuring the Spatial Analyst

iii. Slope calculation

iv. Distance calculation

v. Reclassification of the data

vi. Raster Calculation

vii. Extract by attributes

viii. Calculation of shortest path

First the data in the form of shape files or geodatabase are uploaded to the ArcMap and then Spatial Analyst tool bar is configured, the extent is set to one of the base files which are being worked. Slope is calculated depending on the suitable data and then the distance to individual layers are calculated by the use of Spatial Analyst tool bar there by the data is rasterised. Ultimately the data is reclassified using the reclassification option of the Spatial Analyst tool bar. First the raster data is obtained from the Texas Natural Resources Information System (TNRIS), and the raster images is uploaded into ArcMap as shown in Figure 7.9.

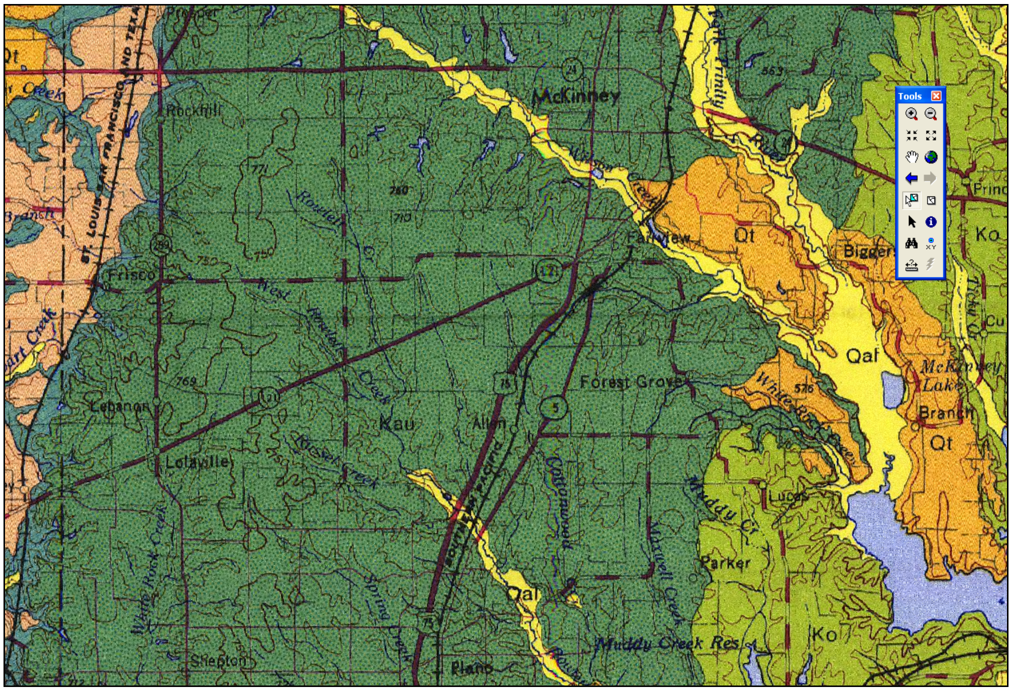


Figure 7.9: Different layers of the sewer data along with TNRIS

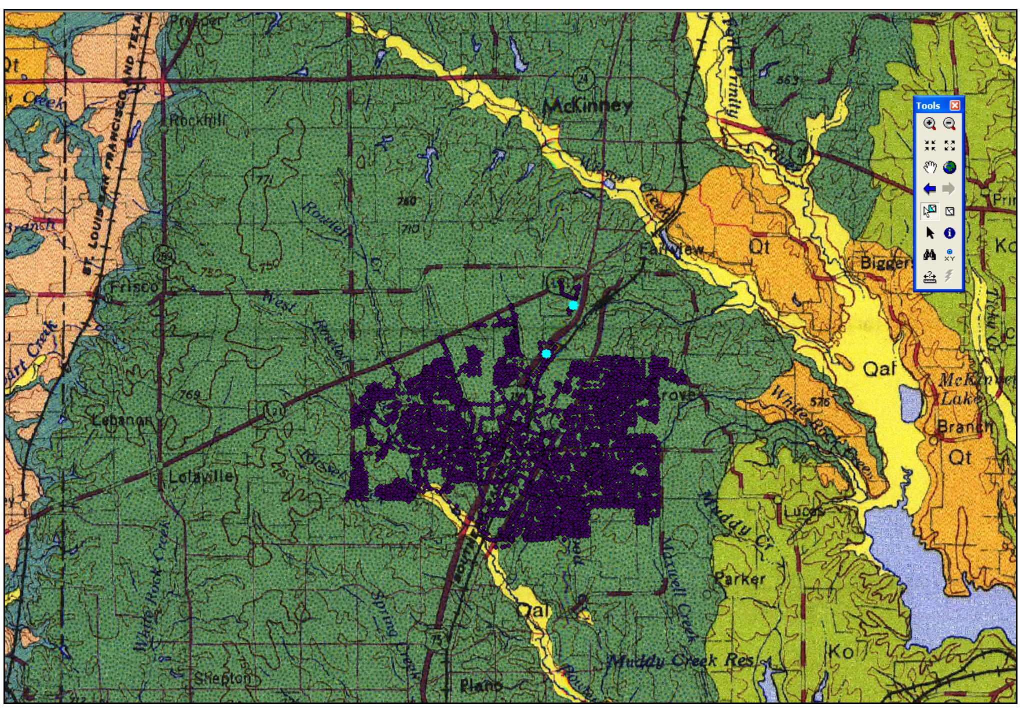


Figure 7.10: Sewer system manholes around Allen, Texas and highlighted manholes for sewer line proposal

Sewer system manholes are clearly visible in Allen city area over the raster image as shown in Figure 7.10. It also shows highlighted manholes between which a new sewer line is proposed. Then the distance calculation is done using the spatial analyst toolbar which also rasterizes the images and the data obtained is the gdb or geodatabase format. Next the data is reclassified using the reclassification tool. In this case study just an approximate interval of 200 as the minimum and the maximum is kept the default value. Using a raster calculator all the raster files are multiplied to get a calculation image in a range of zero and one. Using the reclassification tool the value of one is given a priority of one and the value of zero a priority of 10 which can be seen as one of the layers in Figure 7.11.

Next step is to use the cost weighted tool of the spatial analyst tool bar to find the cost direction and cost distance to the path required. First the required initial point is selected either by the attribute table or by the selection tool from the tool box until it is highlighted. In the cost weighted table, create direction is highlighted and always make sure that default temporary path is selected to save the file. Cost direction and cost distance layers will be created. The color coding shows that the color pink is of the least priority and the color green is of the highest priority.

Next the target point is selected using the selection tool or by using the attribute table. Using spatial analyst tool bar the shortest path is selected and the details such as cost weighted, cost direction and cost distance are entered in the table. Again the default temporary path or any suitable path can be given to save the file. Results are shown in Figure 7.12 and Figure 7.13 with base map.

7.6 Sample sewer line proposal for Troy, Michigan

Similar to Allen, Texas and Fort Worth, Texas a shortest path and least cost analysis was done to find the best path for three different input locations namely one, two and three to the final target point zero. Ultimate target is to have three multiple inlets intersect and later exit to a common single exit. Finally a final merged least path is obtained on the ArcMap. Some of the steps involved in the analysis are:

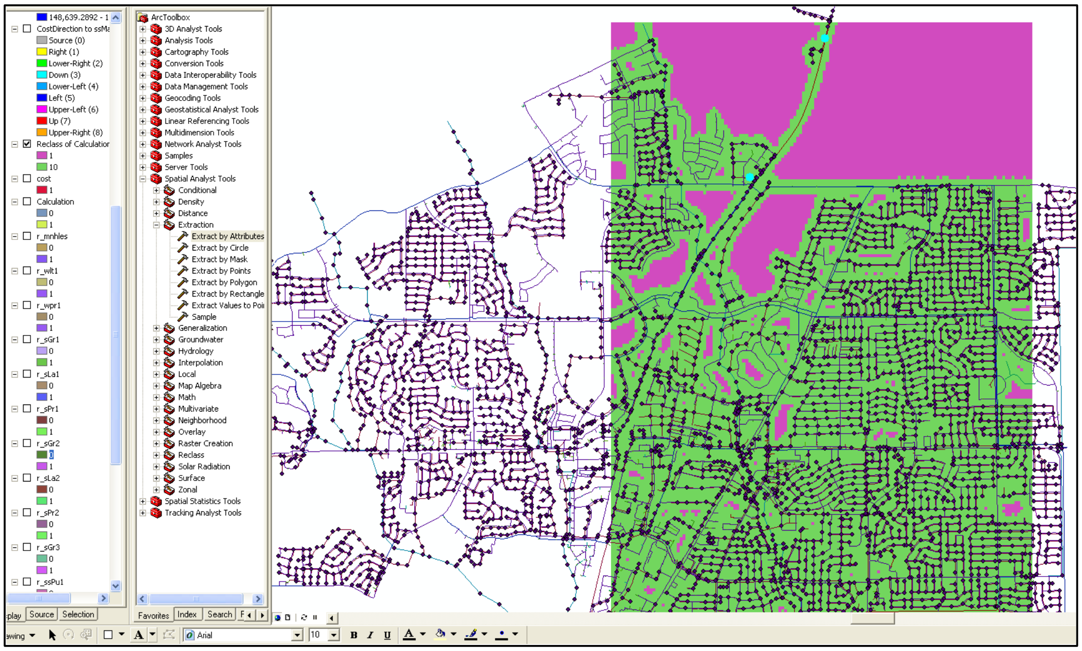


Figure 7.11: Raster Calculation using raster calculator showing a range of priorities one and 10

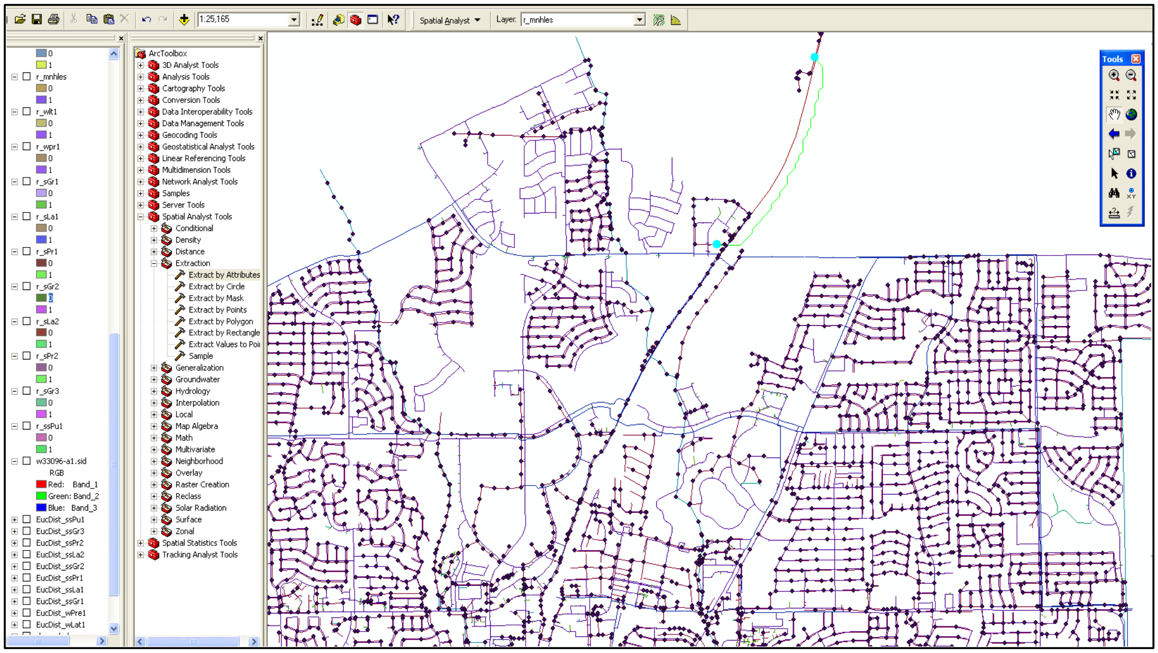


Figure 7.12: Least cost path for new sewer line using ArcMap

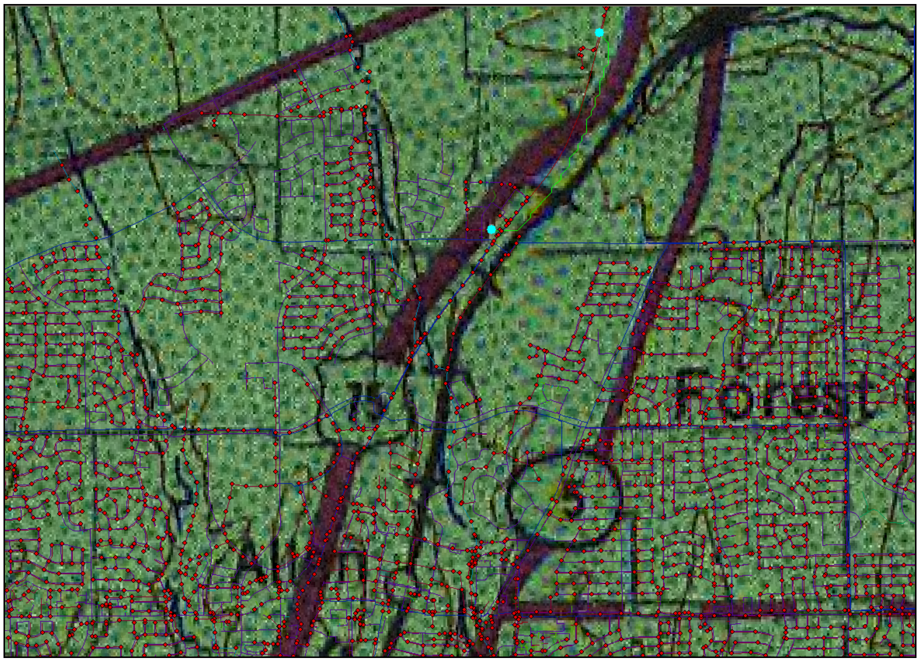


Figure 7.13: Final least cost path overlayed on the base map

i. GIS excel data obtained from Wayne State University is converted to CSV format which has both the latitude and longitude by batchgeocoding using the weblink www.batchgeocode.com.

ii. CSV files are exported to ArcMap and then to Google Map to know the exact CSV of the points in the Michigan state and vicinity to highways and waterways as shown in Figure 7.4.

iii. Base raster file of the Oakland County and the hydrological units are obtained from the Texas Natural Resources Information System (TNRIS) website gateway and uploaded into the ArcMap and a suitable slope is calculated as shown in Figure 7.14.

iv. Shortest path and least cost analysis are done similar to the case study discussed for Allen, Texas to find the best path for three different input locations and the target is to have three multiple inlets intersect at a common point and later exit to common exit point.

v. Finally a merged least path is obtained on the ArcMap as shown in Figure 7.14.

vi. Using three dimensional analyst tool bar DEM features of the Oakland County are converted to TIN as shown in Figure 7.15.

vii. ArcScene is opened and the converted TIN file, final path and target points are uploaded and also extruded to a suitable number from base height as shown in Figure 7.16. In this case study base height is extruded to -200 from the base, so proposed path is significant as shown in Figure 7.18.

viii. Final map is also exported to kmz or Google Map format to open in Google Earth and a snap shot of which is shown in Figure 7.18

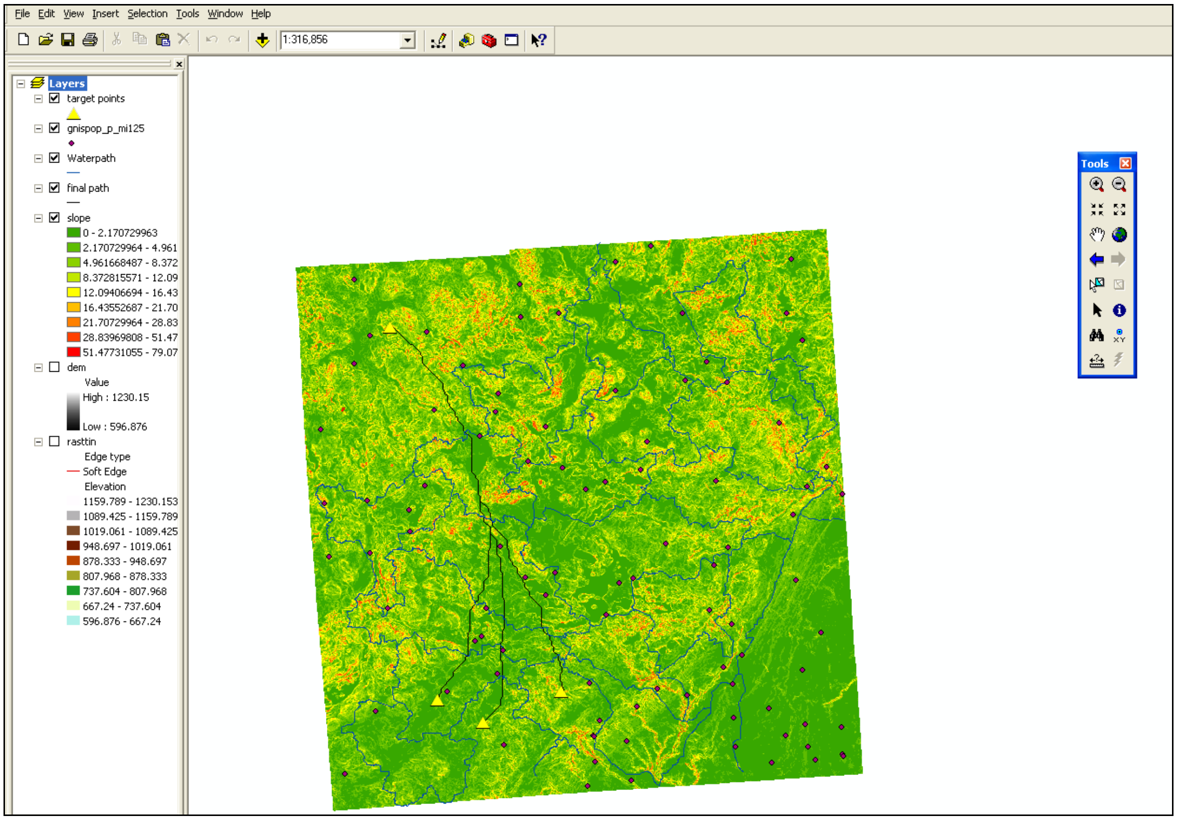


Figure 7.14: ArcMap showing the target points and the hydrological units

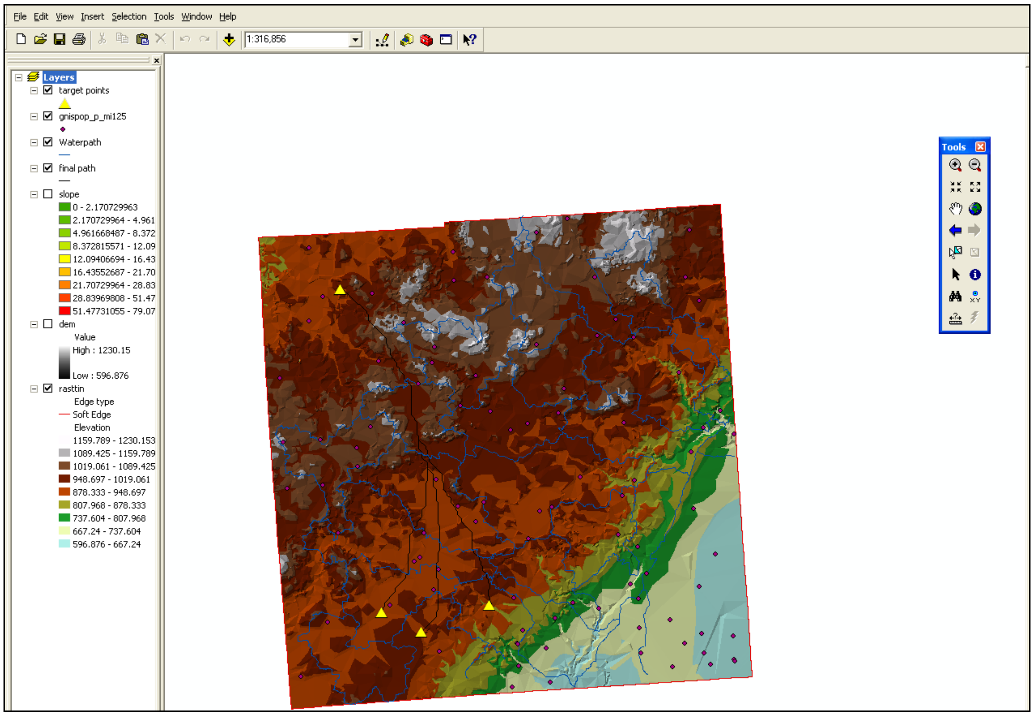


Figure 7.15: ArcMap showing the TIN image of the Oakland country and target points

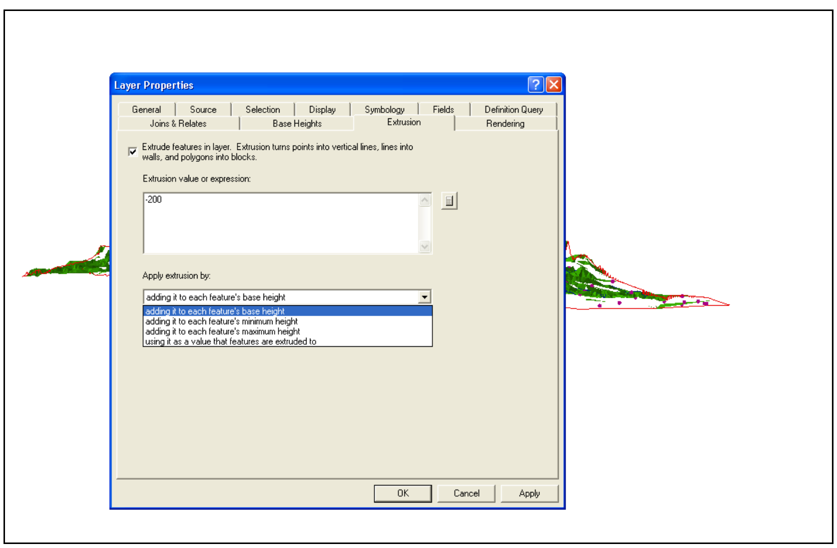


Figure 7.16: ArcScene showing the TIN features and extrusion properties

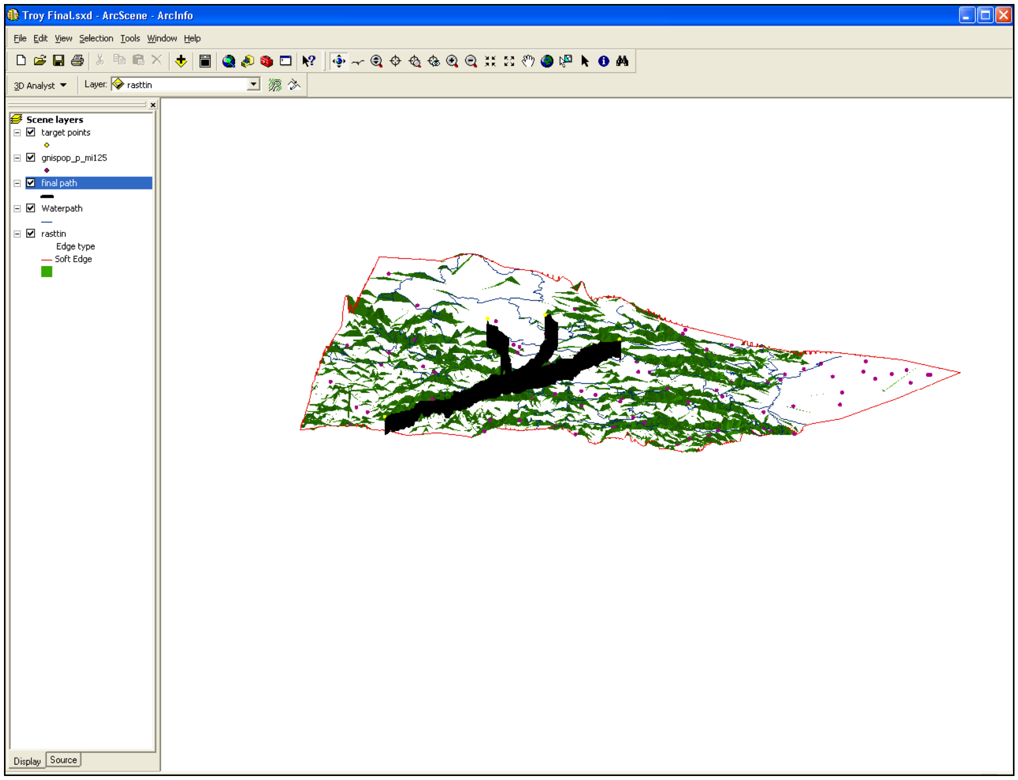


Figure 7.17: ArcScene snapshot of a fly through showing the subsurface features

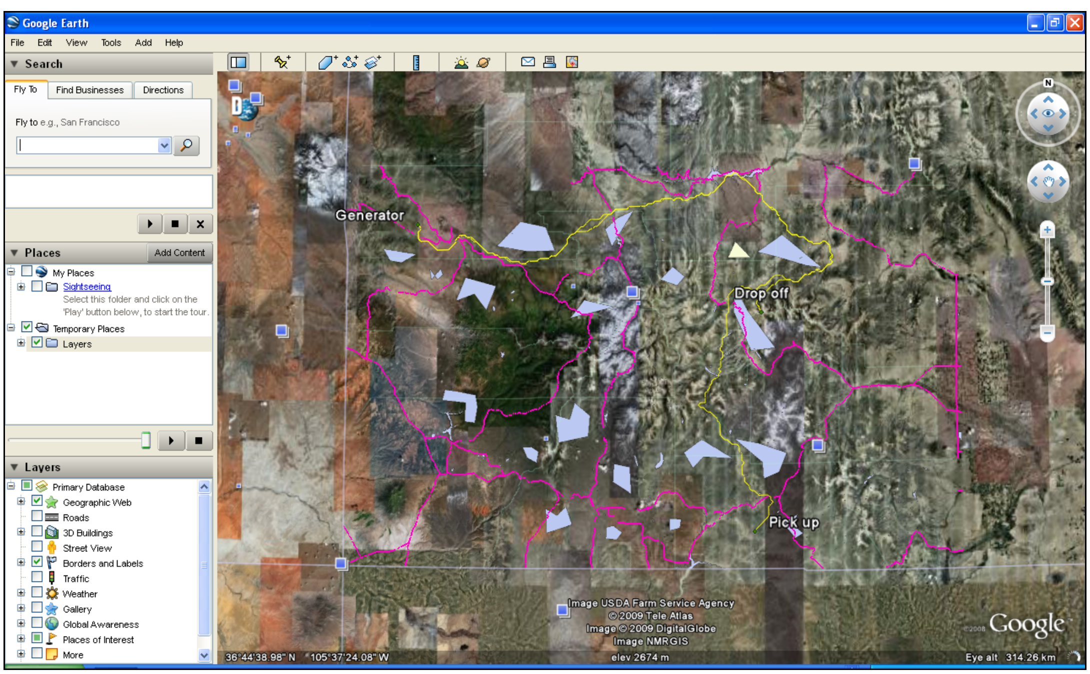


Figure 7.18: Sample project showing the conversion of GIS map to kmz or Google Earth file

7.7 Case study for Fort Worth, Texas

Similar to the case study done with Allen, Texas the analysis is carried out for Fort Worth, Texas but in this analysis the only extra data is the railroads and the water stream. The analysis is performed on the same lines and a least cost path is obtained. The Figure 7.19 shows some of the layers used for the analysis. The overlay image is obtained using the remote GIS servers like ArcGIS servers, where one of the shape files namely Census_Tiger2000 is uploaded as shown in Figure 7.20, which is basically a Google Map overlay. The other file basically called USGS_EDC_Ortho_Urban which is a Google Earth overlay showing the residential areas in Fort Worth, Texas area. Many overlays can also be obtained for free from Texas Natural Resources Information System (TNRIS). Various raster data are also available depending on the location and types like transportation, political boundaries, hydrology, elevation, soil survey and data imagery.

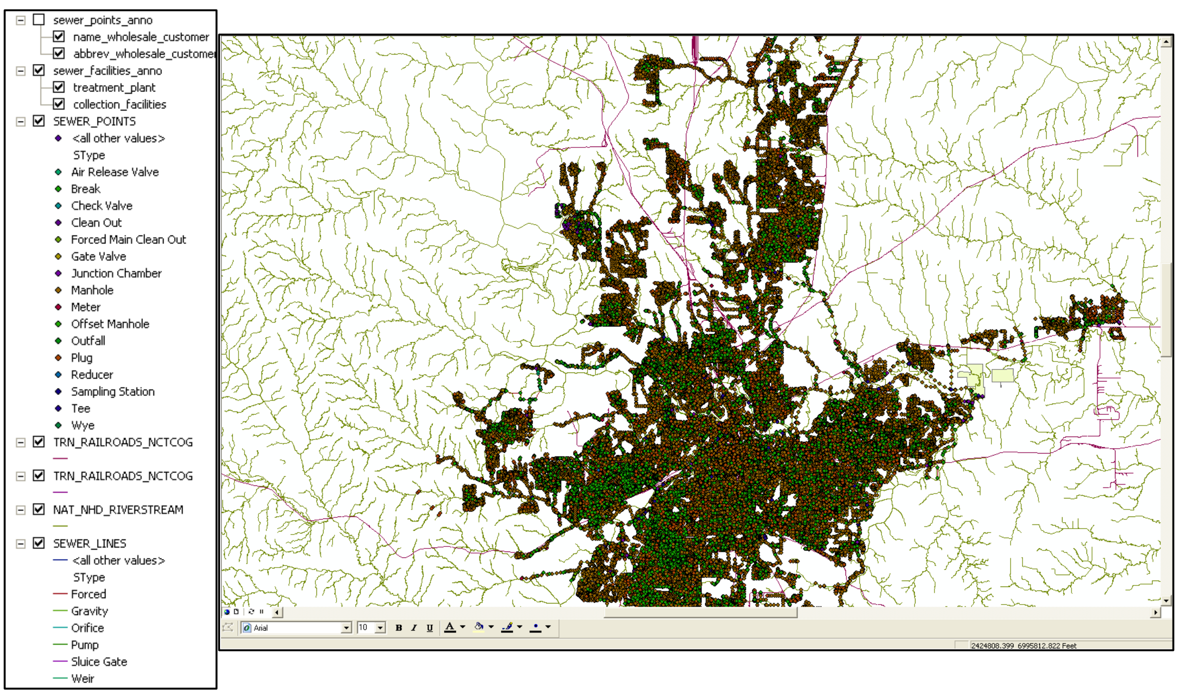


Figure 7.19: Different layers from Fort Worth, Texas

The Figure 7.20 shows highlighted manholes between which a sewer line is proposed. The criteria are based on avoiding the existing sewer lines, gravity flow lines but very near to sewer stations.

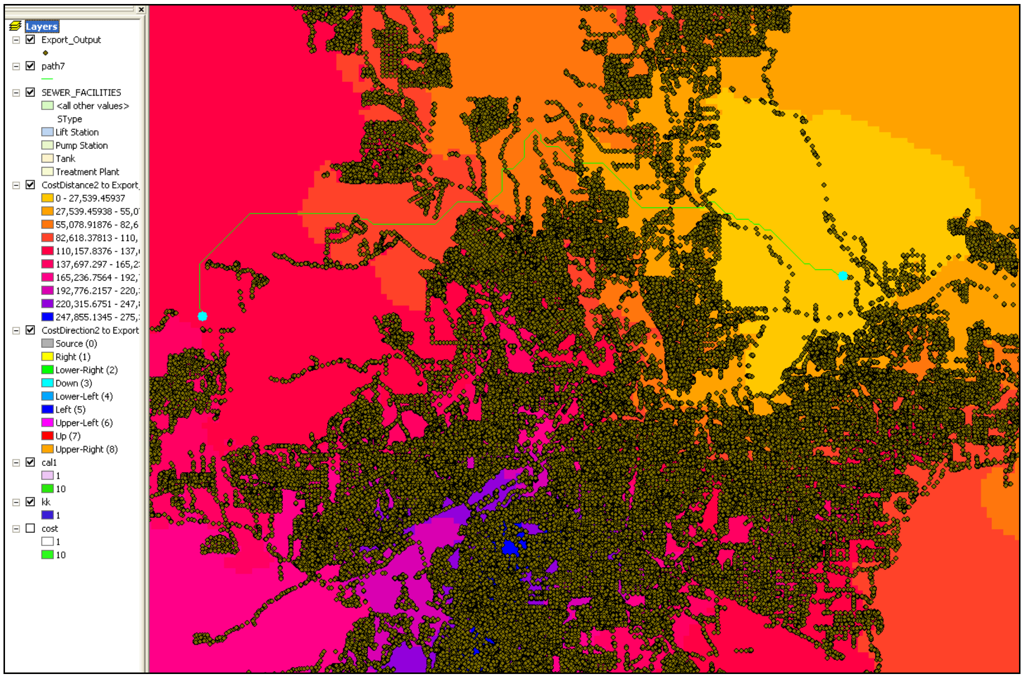


Figure 7.20: Raster images of cost distance, cost direction and final proposed path

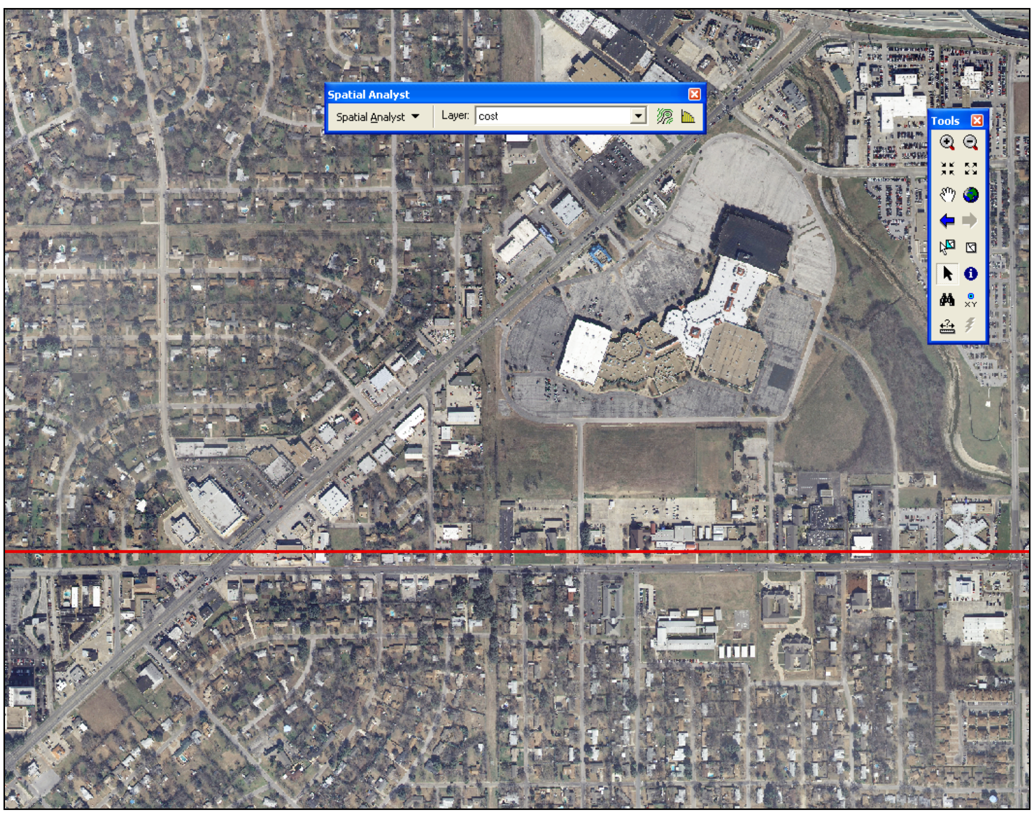


Figure 7.21: Final path on Google Earth image overlay using ArcGIS servers

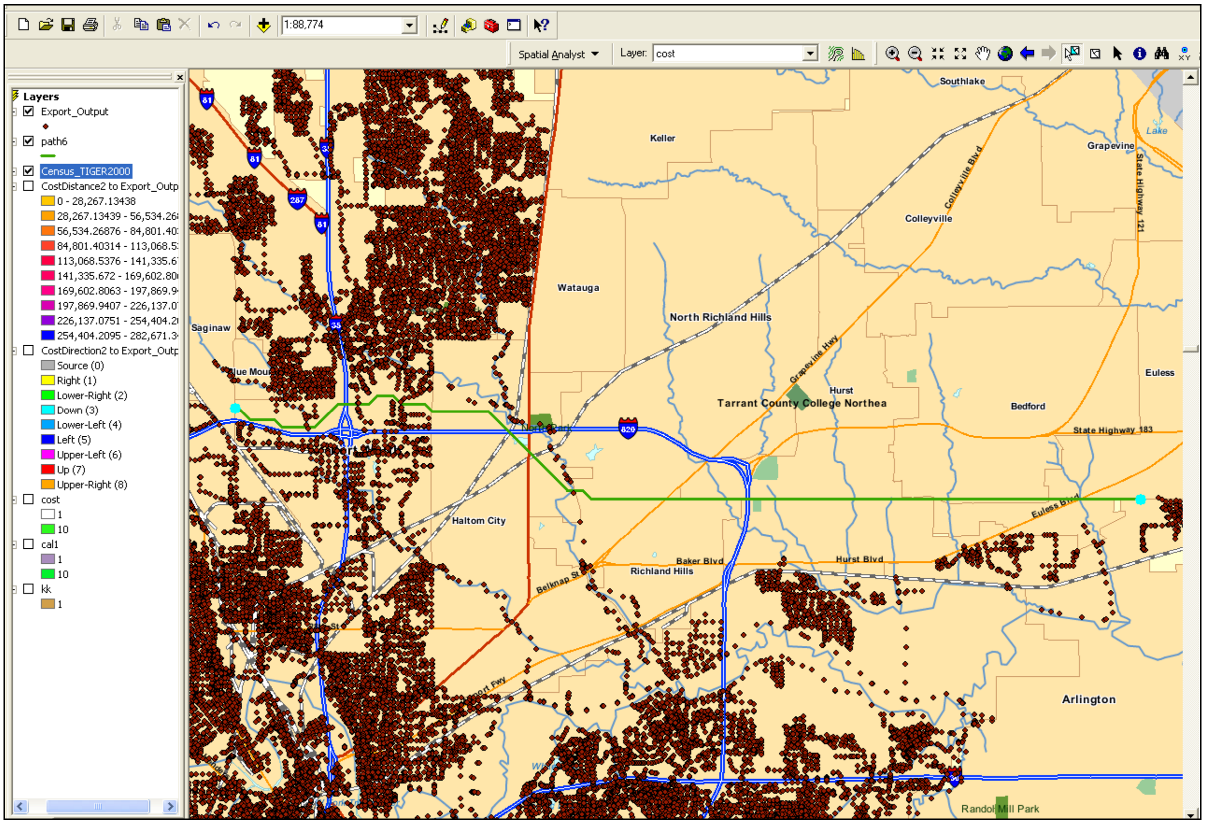


Figure 7.22: Final path with Google Earth image overlay using ArcGIS servers

Then the distance calculation is done using the spatial analyst toolbar which also rasterizes the images. Next the data is reclassified using the reclassification tool. In this case study just an approximate interval of 25 ft as the minimum and the maximum as the default value is used. Using raster calculator all the raster files are multiplied to get a calculation image in a range of zero and one. Using the reclassification tool the value of one is given a priority of one and the value of zero a priority of 10.

Next step is to use the cost weighted tool of the spatial analyst tool bar to find the cost direction and cost distance to the path required. First the required initial point is selected either by the attribute table or by the selection tool from the tool box until it is highlighted. In the cost weighted table, create direction is highlighted and always make sure that default temporary path is selected to save the file. Cost direction and Cost distance layers will be created which are raster images.

Next the target point is selected using the selection tool or by using the attribute table. Using spatial analyst tool bar the shortest path is selected and the details such as cost weighted, cost direction and cost distance are entered in the table. Again the default temporary path or any suitable path can be given to save the file. Results are shown in Figure 7.20, where a highlighted path is the least cost path based on the given criteria. ArcGIS server overlay images are shown in Figure 7.21 and Figure 7.22 which gives the exact location of the proposed sewer line in the Tarrant County on Google Map and Google Earth.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 Conclusions

The main focus of this research deals with spatial analysis using ArcGIS9.2 to perform the suitability analysis. The outcome was to calculate the distance, slope and direction using the sample datasets and later implementing the technique in the case studies. Classification and reclassification were some of the important concepts which help to customize and meet the desired outputs.

One of the key accomplishments of this research was to develop a Google Map from ArcMap using a customized tool bar from UT Arlington to the ArcMap through the ESRI website. This was the first approach done through UT Arlington's GIS library. Using this toolbar many Google Map images were developed using the sample files and also actual datasets from the case studies. Similar to Google Map, Google Earth files were also created which shows the effective utilization of the ArcMap toolboxes. Once the map or the layer is exported to kmz files the applications are enormous as it is a GUI.

A major attempt was the three dimensional visualization of the data through the concept of DEM and TIN. ArcGIS desktop auxiliary software like ArcScene played a key role in developing a three dimensional visualization of the data sets. Eventually careful use of the software helped to develop a GUI and ultimately enabled a walkthrough above and beneath the surface, thus playing a key role in tracking and mapping the underground infrastructure.

A very key concept of the research was implemented through case studies, although there was a struggle in the actual data collection at the start of the research. For case studies, a least cost path was developed depending on the criteria and type of input. In the start, an analysis was done to propose a sample sewer line between three target points and later least cost path was drawn between the points and extruded for a better visualization using the ArcScene software as a tool. Similar analysis was carried out for the cities of Allen and Fort Worth which resulted in a least cost path between two manhole points. The best part of this least path analysis was maneuvering the hurdles like the already existing sewerlines, gravitylines, streamlines and railroads. The final path was later overlaid with Google Map and Google Earth to get a better visualization.

8.2 Recommendations for future research

This research was based on the GIS Spatial Analysis to focus the applications of GIS for Underground Infrastructure. Further research is recommended to implement spatial analysis to actual pipeline construction and renewal projects to better understand the advantages and limitations of this technology. Various upcoming technologies in underground infrastructure like trenchless technologies (TT) need a good tracking and mapping tool like GIS. Although GIS utilization in trenchless technologies has been started, an in-depth research is required for implementing the spatial analysis. Some of the new emerging techniques such as underground freight transportation using pipelines and tubes would need GIS spatial analysis for a faster and better framework in the near future.

GIS is a very good platform for tracking underground infrastructure also but once coordinated with other tracking tools like GPS it would be of great advantage. The research is only limited to GIS so future recommendation would be to implement GIS with GPS in order to come up with a sample model which could be of great help in the underground infrastructure.

It would be beneficial to implement this spatial analysis of GIS to various other civil engineering fields, especially to the fields of renewal and asset management of infrastructure systems. This research was conducted using only the spatial analysis of ArcGIS9.2. There are various methods involved in the ArcGIS software for the aspects of mapping and tracking. Careful and effective utilization of these methods for analysis would generate outstanding results for different fields. ArcGIS desktop has variety of application software which are very useful tools for three dimensional visualization of GIS data.

APPENDIX A

ADDITIONAL ILLUSTRATIONS

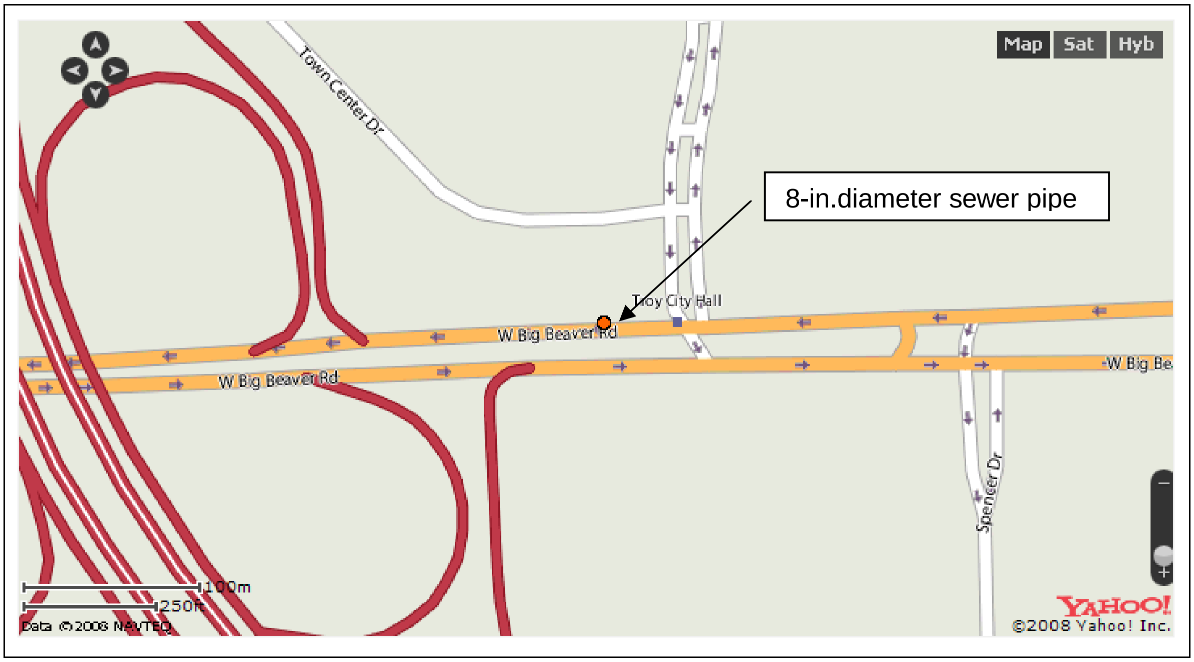


Figure A.1: Location of an 8-in. diameter sewer pipe in Troy, Michigan

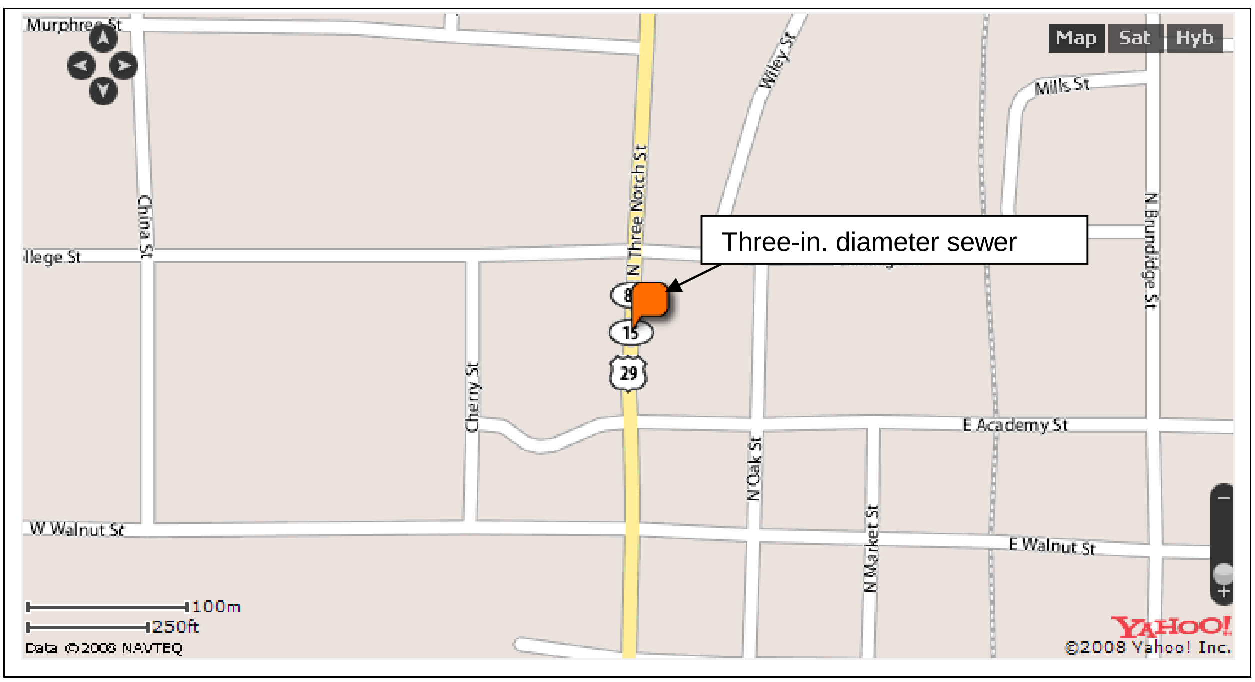


Figure A.2: Location of the three-in. diameter sewer of Troy, Michigan

Figure A.3: Raster calculator values showing range of one for highest priority and 10 for lowest priority for Allen, Texas

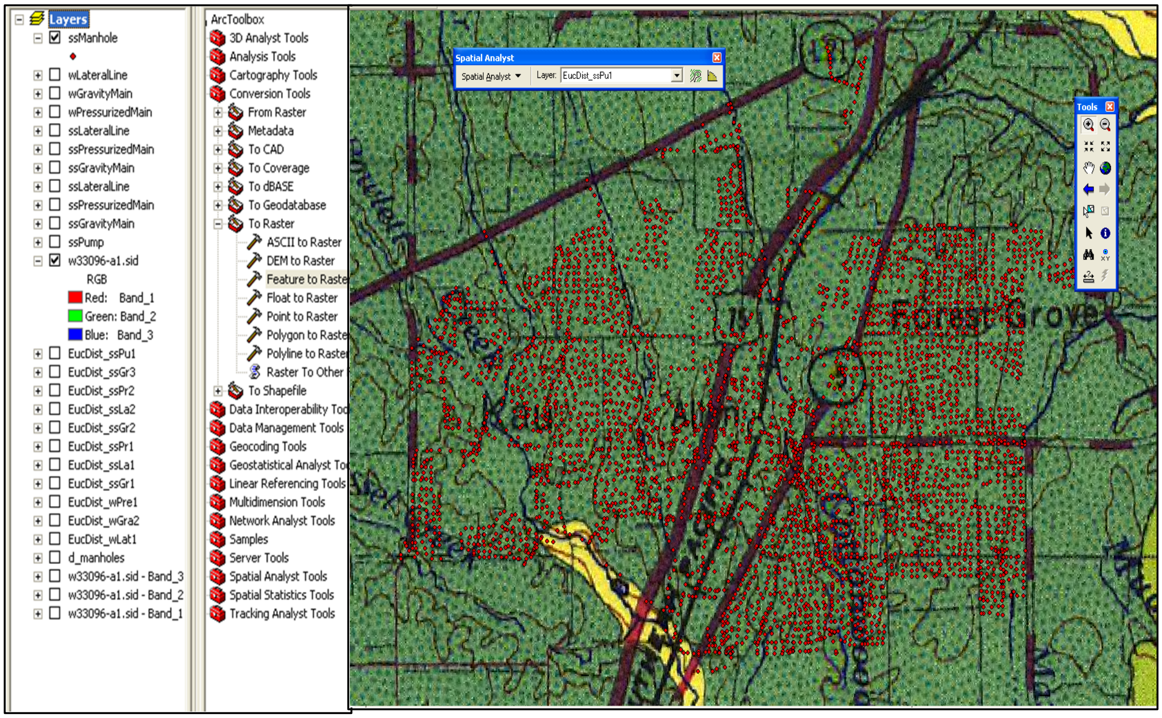


Figure A.4: Final overlay of Allen, Texas

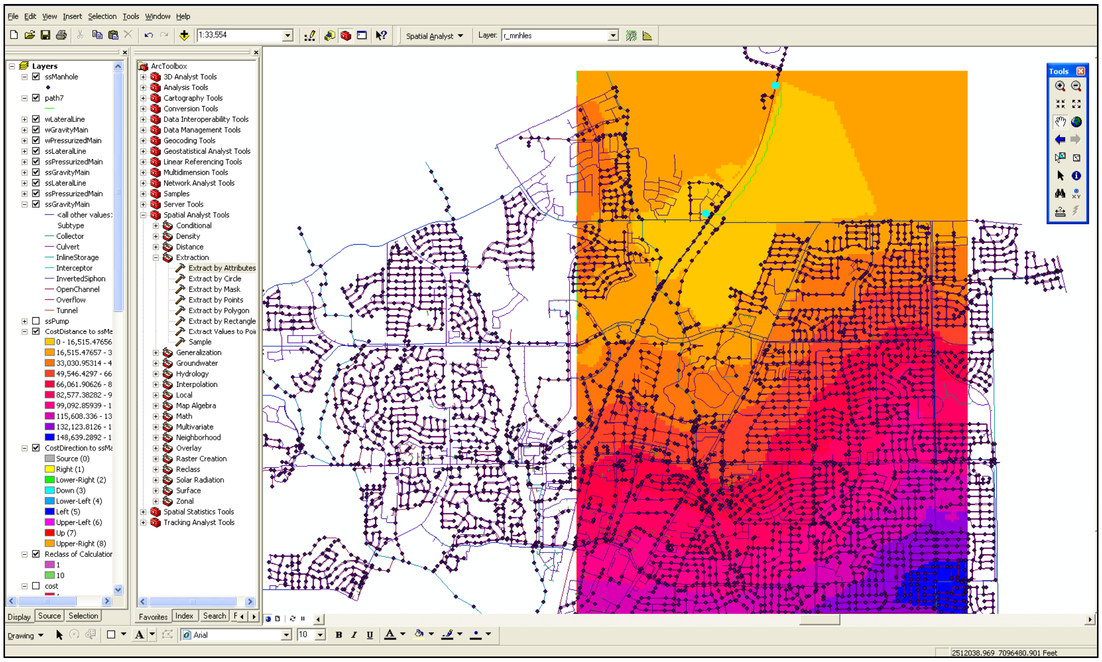


Figure A.5: Distance and reclassified layers of Allen, Texas

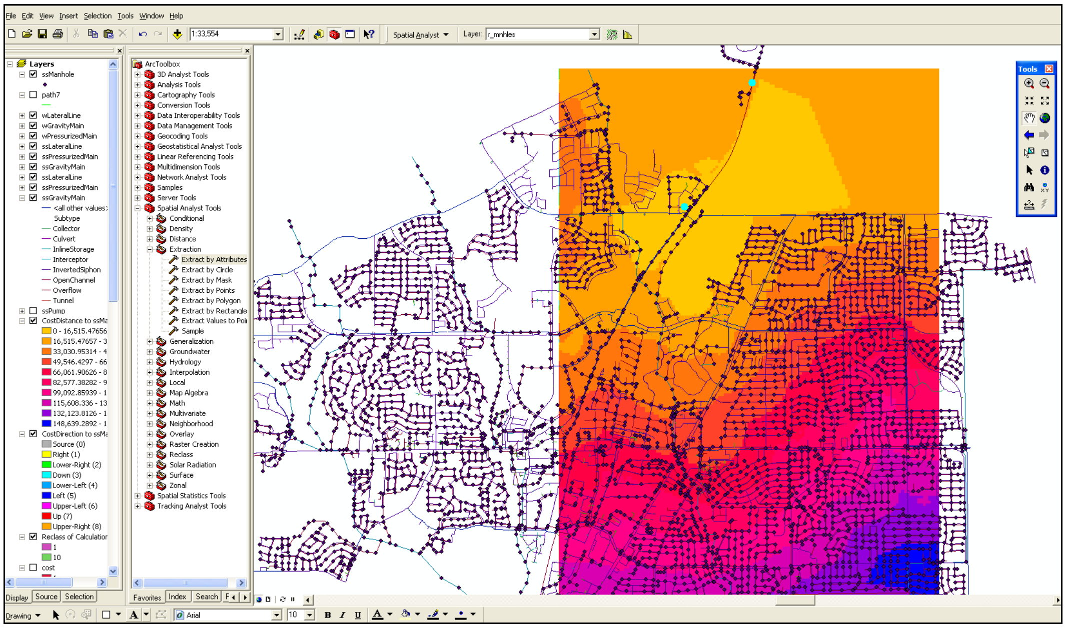


Figure A.6: Reclassified and raster calculation data of Allen, Texas

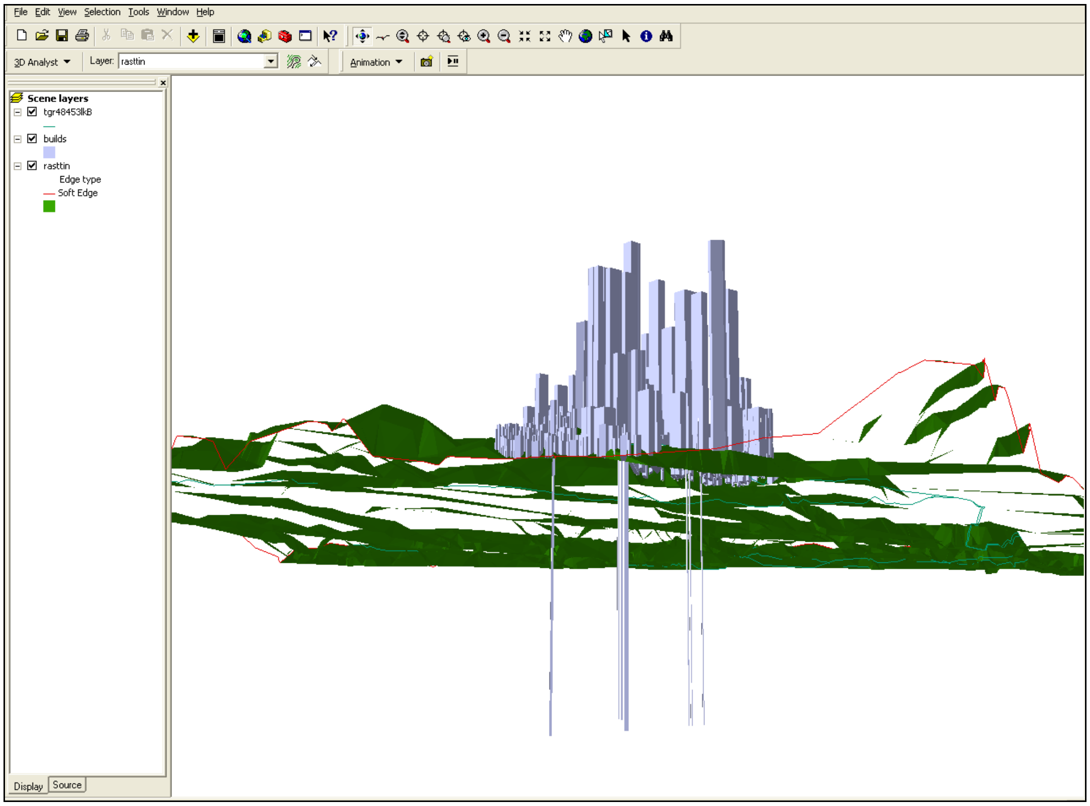


Figure A.7: Snap shot of the walkthrogh for a portion of Austin, Texas

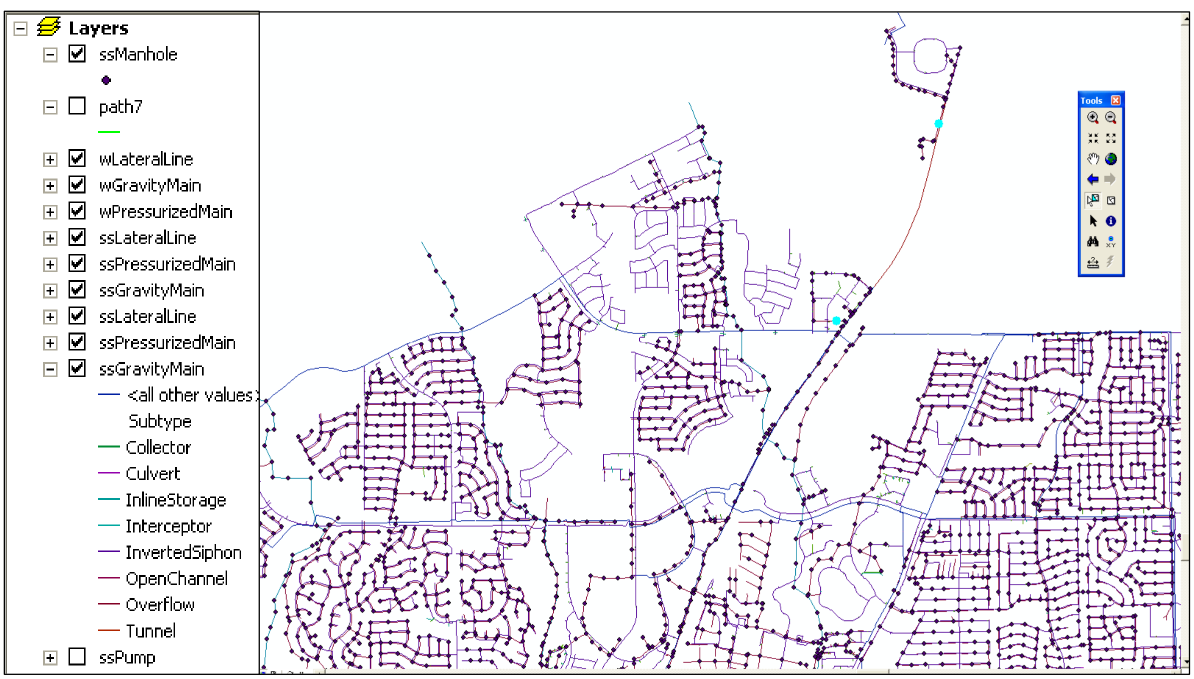


Figure A.8: Pipeline network layers for Allen, Texas

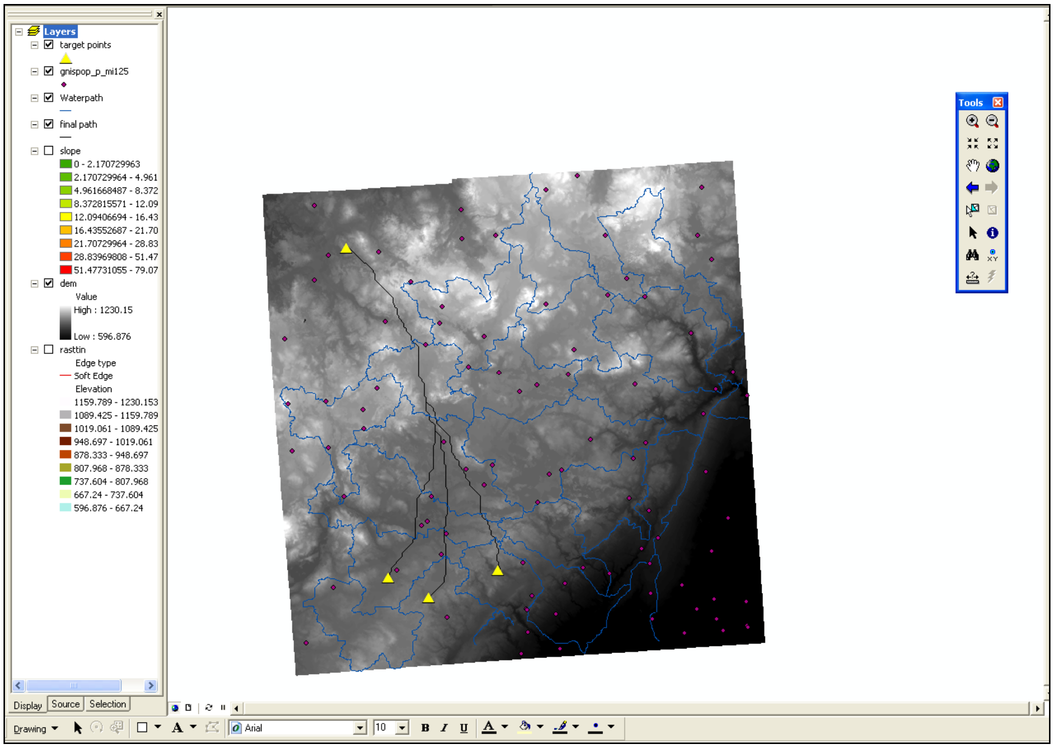


Figure A.9: Target points and the proposed sewer line for Troy, Michigan

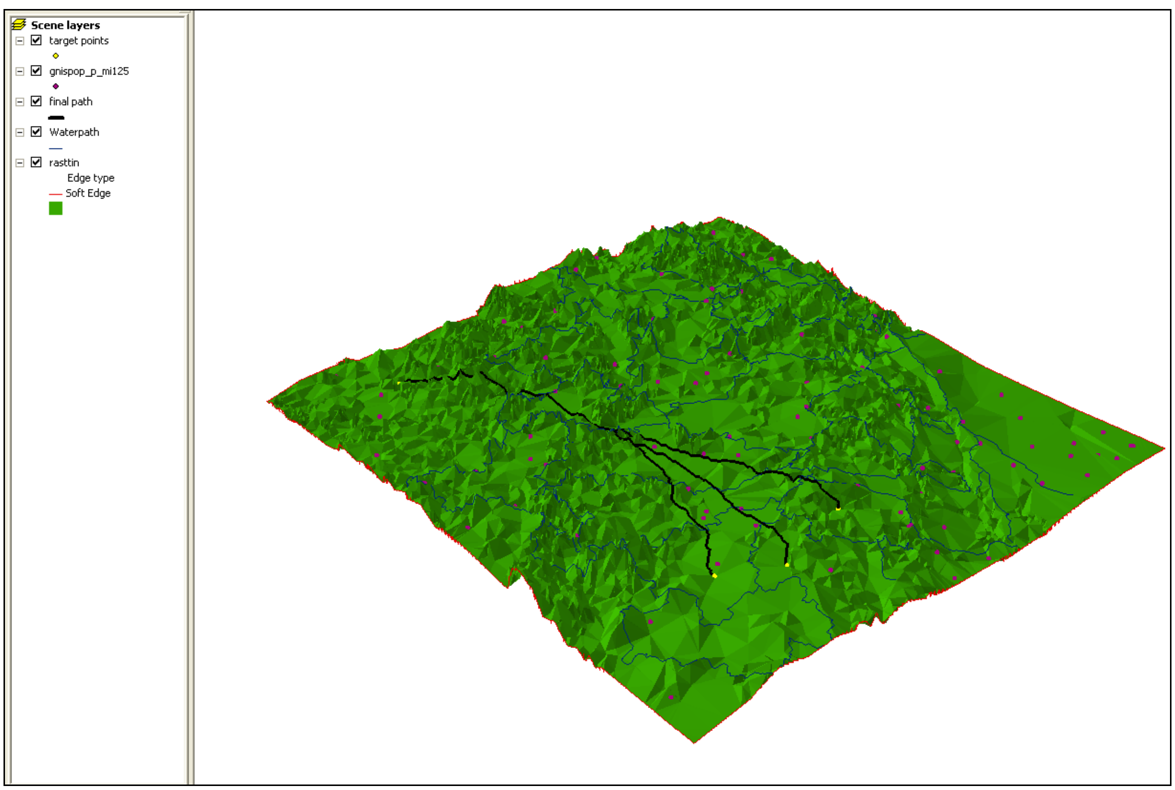


Figure A.10: TIN image for Troy, Michigan with the proposed sewer line and target points

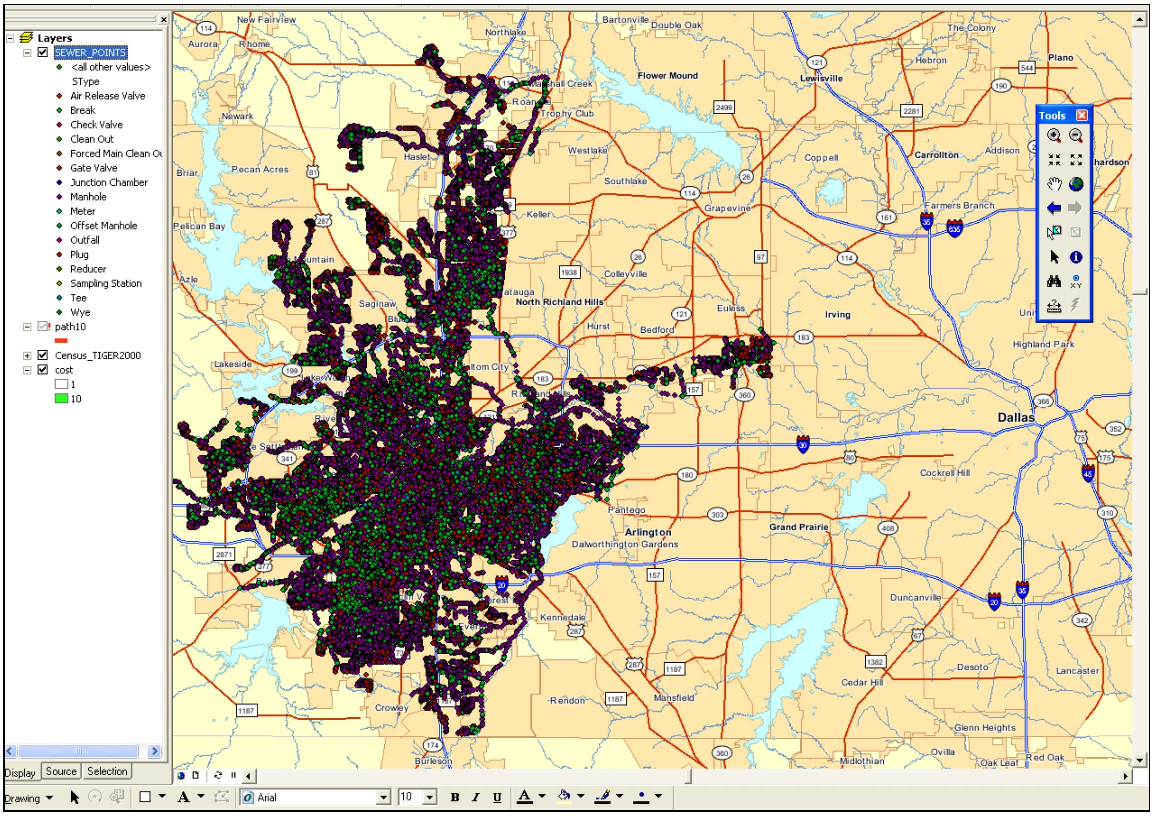


Figure A.11: Google image overlay using ArcGIS server for Fort Worth, Texas

Figure A.12: Google image overlay using ArcGIS server for Fort Worth, Texas

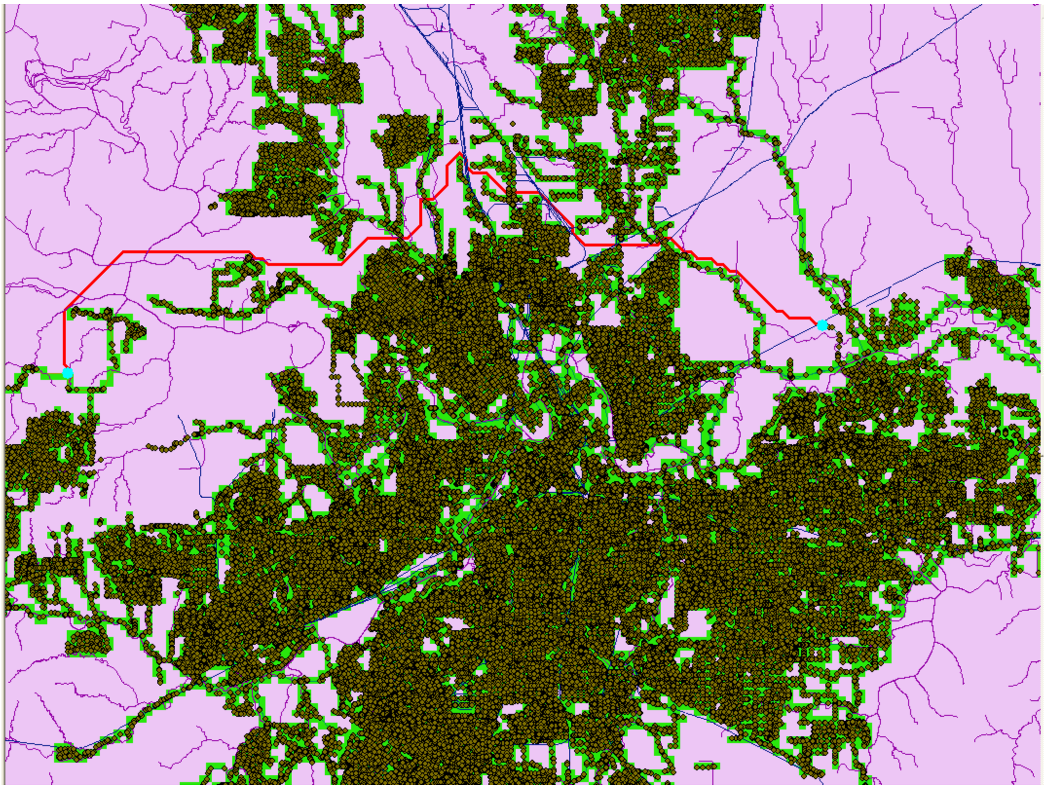


Figure A.13: Final proposed path with hydrological layers for Fort Worth, Texas

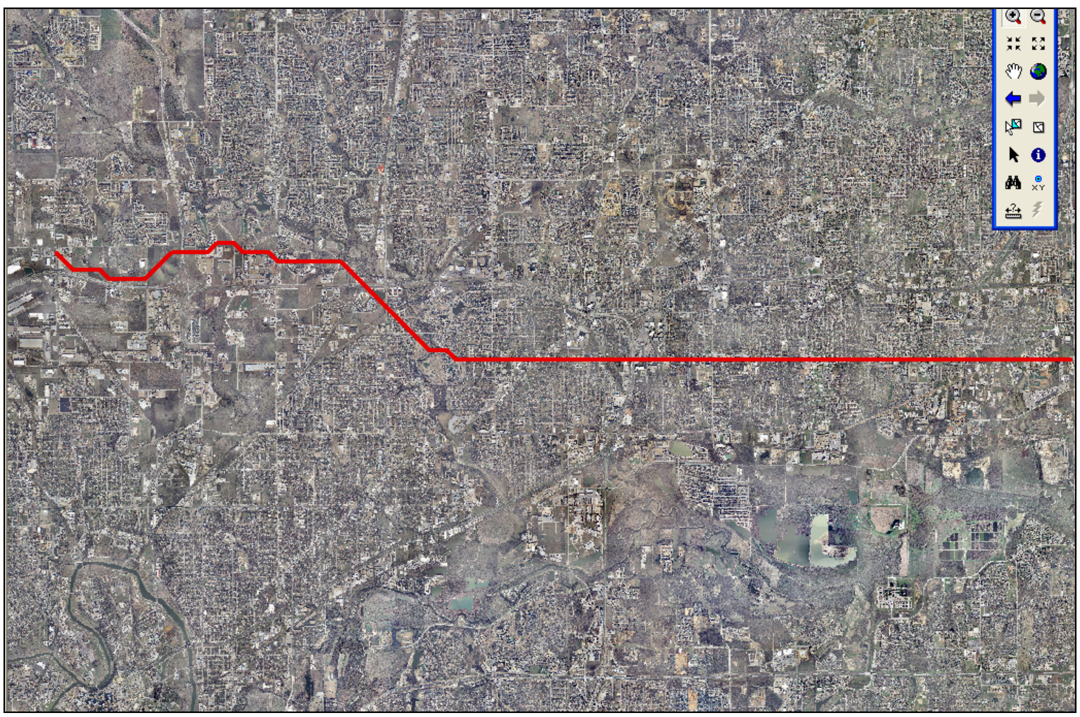


Figure A.14: Proposed path with overlay of Google image using ArcGIS

APPENDX B

ACRONYMS AND ABBREVIATIONS

ACRONYM	ABBREVIATION
AR:	Augmented Reality
ASTM:	American Society for Testing and Materials (www.astm.org)
AWWA:	American Water Works Association
CAD:	Computer-Aided Design
CCTV:	Closed Circuit Television
CGIS:	Canada Geographic Information System
CLI:	Canada Land Inventory
DEM:	Digital Elevation Model
DOT:	Department of Transportation
DSM:	Digital Surface Model
DTM:	Digital Terrain Model
ESRI:	Environmental Systems Research Institute
GIS:	Geographic Information System
GML:	Geography Markup Language
GPS:	Global Positioning System
GUI:	Graphical User Interface
LNG:	Liquefied Natural Gas
NPMS:	National Pipeline Mapping System
OSHA:	Operational Safety and Health Administration

PDA: Personal Digital Assistant

PPIC: Pressure Pipe Inspection Company

PUG: Pipe Line User Groups

PUG: Pipe Line User Groups

RDMBS: Relational Database Management System

ROI: Return of Investment

SSES: Sanitary Sewer Evaluation Studies

SWMP: Surface Water Management Plan

TIN: Triangular Irregular Network

TNRIS: Texas Natural Resources Information System

TRWD: Tarrant Regional Water District

USGS: U.S. Geological Survey

UT ARLINGTON: The University of Texas at Arlington

WFS: Web Feature Service

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BIOGRAPHICAL INFORMATION

Anurag Babu Bhogenahally Lakshminarayanappa completed his B.E. degree in Civil Engineering from the R.V. College of Engineering, Bangalore, India in 2003. After his graduation he worked in construction industry as an Assistant Project Manager performing construction management activities. He completed several residential and commercial projects representing the general contractor and project management consultants. One of his projects was awarded the nation's second best construction project from the Building Association of India.

In the Fall semester of 2008, he came to the United States to continue his studies through the Masters Program in Construction Management from The University of Texas at Arlington. He was awarded two Departmental Scholarships in 2007 and 2008. During his studies, he worked as a Graduate Teaching Assistant for Dr. Mohammad Najafi, his graduate advisor. He attended several international conferences with Dr. Najafi as part of the programs of the Center for Underground Infrastructure Research and Education (CUIRE). This organization mainly deals with trenchless technology and all innovative technologies in underground infrastructure.

Upon graduation, Anurag received an offer from the reputed construction company Landmark Structures for the position of Project Manager. He has plans to work and gain field experience in U.S.A. and possibly continuing his studies towards a Ph.D. in the field of construction management.