Geographic Information System Applications for Water Distribution Asset Management

by

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for Water Distribution Asset Management

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ABSTRACT

Water system information has traditionally been represented on physical map sheets, map books, ledger books and index cards. Because of the level of detail required, a water system map could be hundreds or thousands of pages long. The map, ledger books and index cards can be extremely unwieldy and present difficulty in trying to find specific information.

A Geographic Information System (GIS) is a computer mapping and analysis system that allows features to be displayed graphically in layers using a coordinate system and linked to attribute data. By linking information electronically, data can be sorted, combined, and analyzed in ways that would have been impossible previously.

This thesis illustrates the potential usefulness of a GIS applied to manage the assets of a water distribution system, with specific application to the City of Youngstown Water Distribution System. The downtown area of Youngstown, Ohio was chosen for a pilot study. Geodatabase layers and attribute tables were developed for water lines and hydrants. Several applications of the GIS for distribution system maintenance were demonstrated. The ability to obtain global position system (GPS) coordinates and to incorporate into the GIS was also shown to be possible.

This study shows that, using existing personnel and available technology, a GIS can be implemented for asset management at the daily operations level and also at the budgeting and planning level. The initial cost for equipment totals $48,000 and can be implemented for daily operations immediately with no increase in personnel costs with a project payback time of 50 weeks.

DEDICATION

For Amanda, Connor and Rowdie

ACKNOWLEDGEMENTS

I would like to thank the personnel of the Youngstown Water Department and specifically Lou Joseph and Ed Tyrrell for their diligent record keeping during their careers. I would also like to thank the Mahoning County GIS Department for their help and advice in using their website to obtain the information used for the base layers of the GIS.

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CHAPTER 1

INTRODUCTION

A water distribution system is one of the most critical components of the infrastructure of a community. Whether used for drinking, sanitation or industry, flowing water is a necessity for civilization. From the aqueducts of ancient Rome to the wooden water mains of early America to the ductile iron and plastic water mains of today, each advance in technology enabled an advance in civilization.

The advancement of computer technology is providing the next step in water distribution management. Water system information has traditionally been represented on physical map sheets, map books, ledger books and index cards. Because of the level of detail required, a water system map could be hundreds or thousands of pages long. The map and ledger books can be extremely unwieldy and present difficulty in trying to find specific information. Index cards containing information can be so voluminous that whole rooms can be dedicated to their storage.

With this traditional approach, the efficient, cost-effective management of a water distribution system is very challenging. To determine the length of water mains in the system, each pipe must be measured on a map sheet and then multiplied by the map scale. Information such as installation date, number of pipe breaks, and condition of pipe must be obtained by manually searching through the paper archives. This is tedious and time consuming. Water main extensions or repairs must be drawn after the old water main has been erased. After decades of use, physical maps become worn and illegible. Finding specific information such as the number of turns on a valve also presents problems.

Some assets may not have a street address, making it difficult to locate in the Water Department filing system.

The advent of the Geographic Information System (GIS) will lead to the next step in evolution of water system management. A GIS is an electronic mapping system that allows information to be grouped graphically and displayed by using a coordinate system. By linking information electronically, data can be sorted or combined in ways that would have been impossible previously, allowing the user to make much more efficient and effective decisions based upon the data.

This thesis illustrates the potential usefulness of a GIS as applied to water distribution systems in general, and specifically to the City of Youngstown water distribution system. The objectives of this study are to show that:

1. Physical maps can be converted to an electronic format by drawing by hand or tracing over scanned images of existing maps.
2. Attributes or qualities of objects on the electronic map can be linked to a searchable database forming a GIS.
3. The GIS can be used in both day to day operations and budgeting and engineering analysis, providing cost savings.
4. Global Positioning System (GPS) coordinates can be readily obtained and incorporated into the GIS.
5. Current technology is available and affordable, replaces manual data storage and retrieval and can be implemented immediately using existing personnel.

CHAPTER 2

BACKGROUND

2-1 City of Youngstown Water Distribution System

The City of Youngstown was founded in 1796 and incorporated in 1867 (City of Youngstown, 2009). The city has grown and now maintains a water distribution system that services 175,000 people and uses 750 miles of pipelines to deliver over 18 million gallons of water each day (City of Youngstown Water Department, 2007). The water system has been an integral part of the growth of the city from the beginning, with cast iron water mains dating to 1872 (Breslin, 2006) and fire hydrants dating to 1893. These water mains and hydrants have been in constant use since the time of their installation. The water mains range in size from 4" distribution mains to 42" transmission mains. The distribution mains are used to deliver water directly to neighborhoods and the transmission mains are used to transport bulk water from pumping stations to storage tanks. The water mains are comprised of various materials that have evolved throughout the years. Wooden water mains were used at one time to transport water in Youngstown, and the remains are occasionally unearthed during construction projects in the downtown area. The piping material that is currently used is a combination of cast iron pipe, ductile iron pipe, transite (asbestos reinforced concrete), and reinforced concrete.

The system is comprised of many other individual components, including 16,036 valves to control the flow and direction of water and 7,447 fire hydrants (City of Youngstown Water Department, 2008). There are several types of valve used, including gate valves and butterfly valves. Gate valve sizes range from 4 inch to 36 inch. The four inch valves can be operated by one person and take nine turns to open or close. The 36 inch valves must be turned 288 times to operate.

The fire hydrants in the system are from six different manufacturers. The oldest hydrant still in use, a Vogt, has a manufacturing date of 1893. There have been constant improvements made in the design of fire hydrants over the years, and the Youngstown Water Department (YWD) has many different models from each manufacturer (Mueller Company Fire Hydrant shown in Figure 2-1). This can present difficulties in maintaining an adequate supply of replacement parts. Each fire hydrant has an orange barrel (main body) to increase visibility for safety forces. The caps on each hydrant are color coded to indicate the size of water main that the hydrant is connected to. Water mains six inches and smaller have orange colored caps. Yellow caps indicate water mains of eight or ten inches, and water mains twelve inch and larger are shown by white caps. The color scheme allows fire department personnel to connect to the largest possible water source if there is more than one hydrant in the vicinity of a fire. Each hydrant is operated at least once a year to ensure that it functions correctly. Record keeping for hydrant operation is a simple check list with hydrant information on it.

Figure 2-1. Mueller Company Fire Hydrant. (Mueller Company, 2009)

The YWD has a budget of $27 million for 2009. This budget includes the purchase of water, employee costs and infrastructure improvement and repair. There are 78 employees dedicated solely to the construction, repair and maintenance of the system. Heavy construction equipment plays a vital role in the daily operations of the water department. There are six backhoes, six dump trucks, a front loader and a heavy flat bed truck with a hydraulic lift used to transport water mains. There is also a fleet of service vans and meter reading trucks. The water department has a full time garage staff of five mechanics to keep all the vehicles operational.

The Water Department budgets $3.9 million each year for infrastructure improvement, maintenance and repair. Improvements include erecting new water towers, upgrading water pumps, installing new water mains to replace old ones or to increase the pipe size, and installation of backup electrical generators. Operation of mainline water valves, rebuilding water pumps and operation of fire hydrants are examples of the maintenance performed by the water department. Due to the age of the water system, the water mains experience frequent breaks that must be repaired. Fire hydrants are occasionally damaged and must be rebuilt. Water towers must be repainted every 15 to 20 years. The personnel cost totals $4.3 million. The personnel costs are negotiated with the union representing the employees and traditionally increases 3% each year.

Ductile iron pipe has an expected life of 100 years (DIPRA, 2009). The YWD has many pipes that are exceeding their life span and will need to be replaced in the near future. Water main supplies and repair materials have increased dramatically over the past several years, as indicated by the Ohio Department of Transportation (ODOT) Steel Price Index shown in Figure 2-2. This chart shows the gross index price per ton of steel on the American Metals Market. The ductile iron pipe which is used for water mains by the City of Youngstown has shown a similar increase in cost.

Efficient management of water department assets will become more critical as costs increase. A GIS enables decisions to be made quickly and efficiently optimizing the resources available to the YWD.

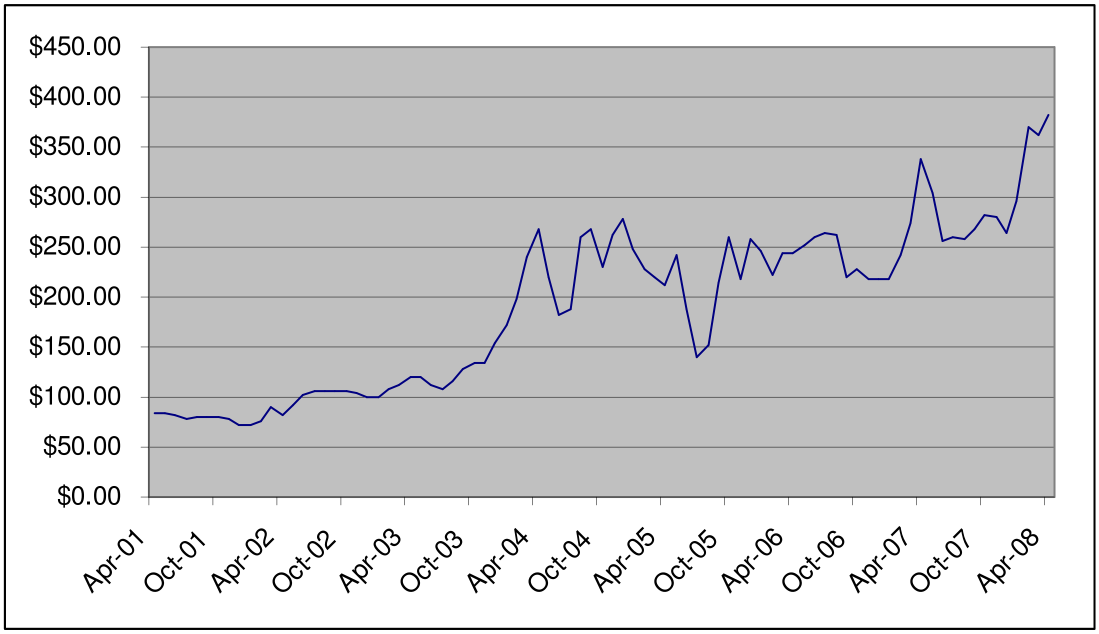


Figure 2-2. ODOT Steel Price Index (Ohio Department of Transportation, 2008)

2-2 Geographic Information Systems

GIS "integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information" (ESRI, 2009a). A GIS is a map with layers of information placed upon it. The power of a GIS is the ease with which information can be displayed, manipulated, combined and used for making decisions. For a GIS to work, each layer must use the same frame of reference or coordinate system. At the city level, there is no distortion converting the real world to a two dimensional surface. As you expand to larger distances, the curvature of the earth begins to cause errors. It is difficult to accurately portray a round three dimensional surface onto a two dimensional map. When a two dimensional map is produced, it is said to be "projected" from the three dimensional surface. Every projection has inherent inaccuracies because it "distorts the spatial properties of shape, area, distance, or direction in some combination" (Ormsby *et al*., 2004). This becomes evident in the Mercator Projection of the Earth shown in Figure 2-3 (UWSP, 2009). This common projection shows Greenland as being larger than Africa. In reality, Greenland is 836,000 square miles and Africa is 11,668,000 square miles. There are many different projections that can be used to minimize certain aspects of the map distortion, but because the surface of the Earth is not a perfect sphere it is impossible to completely eliminate all imperfections.

The sample area used in this study is small enough that these distortions will be minimal but may be of concern during full scale county wide implementation.

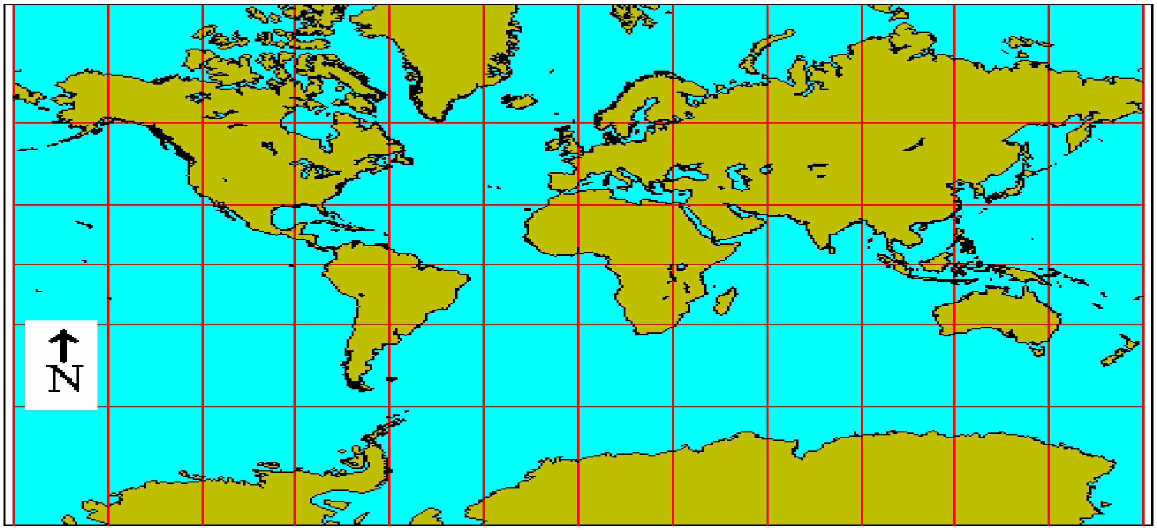


Figure 2-3. Mercator Projection of the Earth.

A coordinate system is used as a reference to determine location in any mapping system. The most widely recognized is latitude and longitude. The longitude of a position is the angle in the horizontal plane to the Prime Meridian. The Prime Meridian has been arbitrarily chosen to run through Greenwich, England. The latitude is the angle of a position in reference to the Equator. In both cases, the vertex of the angle is the center of the Earth. The Equator is the circle that splits the Earth into a north and south hemisphere. The Equator has a latitude of zero degrees and the North Pole has a latitude of ninety degrees. A mathematical correction must be used once a coordinate system is in place to relate the idealized version of the Earth as a sphere to the actual Earth. This is referred to as a datum.

Once a coordinate system and a datum have been determined, relating spatial information from the real world to mathematical or visual representations can be done with accuracy and precision. Layers of information on many different types of geographic features from many different sources can be combined on the same map. Features are geographic objects, and can be represented in vector (points, lines or polygons) or raster (pixels) format (Ormsby *et al*, 2004). Features and attributes are combined to form geodatabases. Attributes are categories of information about features (Ormsby *et al*, 2004). Attribute data are stored in tables and linked to specific features. Attribute examples may include size, average temperature, population, date created, or whatever is pertinent to the GIS users. Data can be collected and grouped according to common traits. Geodatabases are powerful because they allow data sets to be used, manipulated and referenced to other data sets by using their coordinates as the linking factor.

2-3 GIS Software

There are many vendors of GIS software. Some are tailored for specific users or computer operating systems, but the most commonly used are from Autodesk, Bentley, ESRI Inc., GE (Smallworld), Pitney Bowes (MapInfo), and Intergraph (Steniger, 2009).

Autodesk GIS is designed to run on a server platform and is designed to be compatible with the AutoCad family of software. Bentley Map provides access to Oracle database functions and is designed to be run with MicroStation software. Smallworld is compatable with the General Electric family of control systems. MapInfo is a Windows based platform and is capable of data analysis for marketing decisions.

The ESRI GIS software family is comprised of the desktop applications ArcView, ArcEditor and ArcInfo. ArcView allows for map creation and editing along with database management functions. ArcEditor permits simultaneous multi-user editing of the database and ArcInfo provides advanced modeling and analysis functions. These ESRI programs can be run on a typical office desktop computer (ESRI 2009b).

ESRI also produces ArcPad which can be used on handheld computing devices. ArcPad is compatible with the ESRI desktop applications and allows for maps and data to be transferred from one device to another, allowing data collected in the field to be easily incorporated into the desktop GIS.

2-4 Global Positioning System Data

One recurring problem that occurs in trying to locate water department infrastructure is that the surroundings change over time. Traditionally, measurements are taken from a landmark considered to be permanent. Measurements for some assets are maintained on index cards, which are filed by street address if possible. The index card in Figure 2-4 shows measurements for the curb stop valve used to shut off water serving the building at 927 Mahoning Avenue. This building is behind the building that fronts Mahoning Avenue and the water service is obtained from Rockview. Utility poles, fire hydrants, buildings, main line water valves and property lines are frequently used as landmarks. As this measurement card shows, the landmark for this property is actually the curb box for an adjacent property on the side street (66' from 21 Rockview).

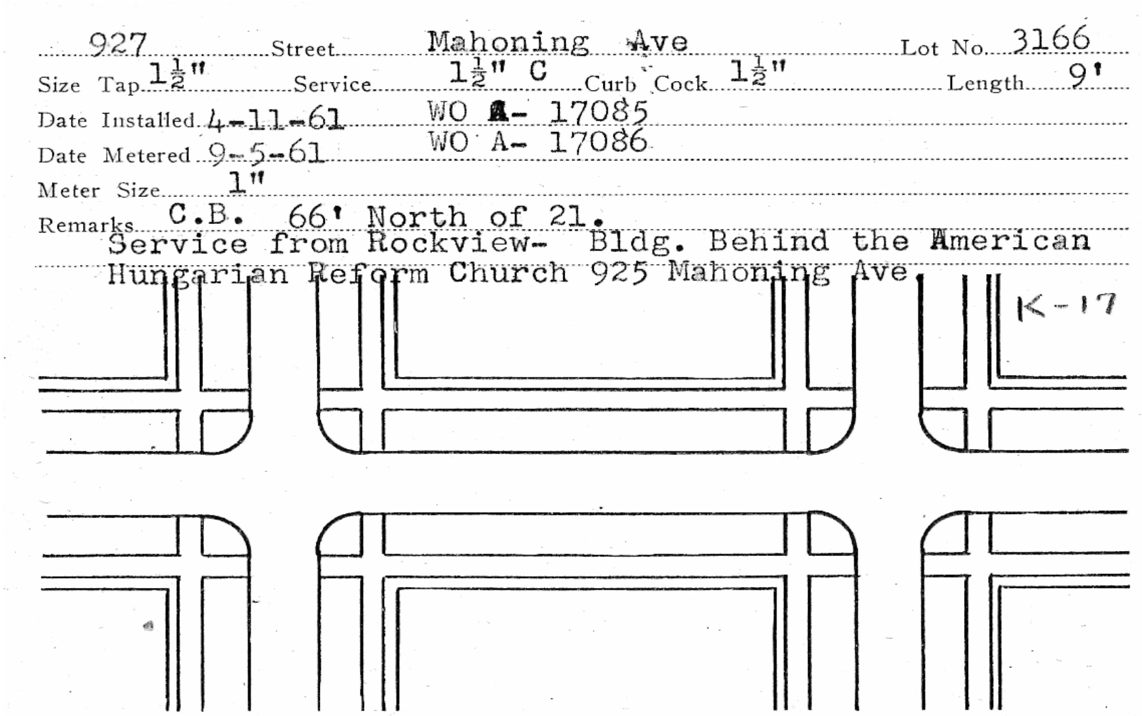

927 Street Mahoning Ave Lot No. 3166
Size Tap 1½" Service 1½" C Curb Cock 1½" Length 9'
Date Installed 4-11-61 WO A- 17085
Date Metered 9-5-61 WO A- 17086
Meter Size 1"
Remarks C.B. 66' North of 21.
Service from Rockview- Bldg. Behind the American
Hungarian Reform Church 925 Mahoning Ave.
K-17

Figure 2-4. Service Index Card.

Landmarks frequently change. Fire hydrants can be run over by vehicles and may be moved to prevent further damage. Utility poles can be replaced or eliminated as part of an upgrade program. The City of Youngstown is currently in the process of a multimillion dollar demolition program, with thousands of houses being razed in 2007 and 2008 (Schmitt, 2008). Roads are frequently repaved and widened (Franco, 2008) making measurements taken from curbs or property lines difficult to interpret. The advent of Global Positioning Systems (GPS) allows for the determination of a location without using any local landmarks. The position is determined in degrees of Latitude and Longitude.

The GPS is a "constellation of 24 operating satellites that continuously transmit one-way signals giving the current GPS satellite position and time" (National Space-Based Positioning, Navigation, and Timing Coordination Office, 2009). The predominant GPS system is owned by the United States. The satellites orbit the earth every twelve hours in a fixed pattern (United States Air Force, 2008). The satellites are arrayed at a height of 10,400 Nautical miles and spaced so that a minimum of six satellites are within line of sight of every position on the earth. The end user on the surface of the earth uses a receiver that calculates the delay in the time signal from each satellite. The delay in the time signal is then used to calculate the distance from that specific satellite. The angles between the satellites are kept constant, and once the distance is known from the location of the user to the satellite, the receiving device will calculate the position (latitude, longitude, and elevation) of the user.

The accuracy of the GPS is subject to many variables. Local terrain, foliage or buildings may obstruct or impair the GPS signal. Atmospheric conditions such as rain or snow can also impede the GPS signal. Solar activity can delay the GPS signal through the ionosphere, affecting accuracy. Because of this, night time or early morning can provide the best accuracy (Free Geography Tools, 2008).

Accuracy is also a function of the capabilities of the receiver itself. A small hand-held device used for recreational purposes is capable of accuracy within 10 meters and can be purchased for under $150.00. This is considered acceptable for hiking and recreational use. The highest degree of accuracy is obtained with GPS equipment designated "survey grade". Survey grade GPS can be accurate to the centimeter level. Survey grade GPS is also significantly more expensive, costing tens of thousands of dollars per unit. Survey grade equipment may also require post-processing of data to correct any errors that may have occurred during data collection.

2-5 Applications of GIS in Infrastructure Management

Many providers of public utilities are utilizing GIS as a tool in their asset management plans. The City of Norfolk, Virginia uses GIS to manage the 1,500 miles of pipe that comprises its water and wastewater system (Edralin, 2008). The Norfolk system is based on ESRI ArcSDE hosted on dedicated GIS servers. The City of Fontana, California is using GIS to manage the traffic signs used by its road department. The reflective qualities of signs are mapped using ArcMap (Field, 2008).

The Wilmington Delaware Public Works department began implementing an improvement project in 2003 to upgrade its water system. Wilmington created an asset management system developed on a GIS platform. Using the GIS, the most vulnerable components were identified and selected for renewal (Nayer, 2009).

The Dupage Water Commission located in Dupage, Illinois combined a GIS with water modeling software. Aerial photographs were used as a GIS layer and a water line layer was created using the photograph layer as a template. Once the water line layer was finished, the water modeling software was used to link as built drawings to individual lengths of pipe. By selecting a length of pipe the actual as built drawings would be displayed (Frelka, 2008).

CHAPTER 3

METHODS AND PROCEDURES

3-1 Selection of GIS Software

The initial step for creating a GIS for the Youngstown water distribution system was to determine a GIS software package to use. Key factors in the decision making process were:

1. Long term compatibility with other government agencies to facilitate integration if regionalization were to occur.
2. Initial cost.
3. Expandability and portability.

The Youngstown Water Department is predominantly situated within Mahoning County, Ohio. The Mahoning County Commissioners established a GIS policy board in 2001 to determine the needs of the County and create the GIS department (Mahoning County, 2009). The Mahoning County GIS uses ESRI's software to run their GIS system. The version that they use enables them to publish their maps to the Internet. The County GIS department currently has 76 layers available for use. The layers range from local interest such as property lot numbers to the national information included in the Federal Emergency Management Association flood plain data. The software enables users to select which layers are of interest and display them. It also allows for layers to be searched for specific information and have that information displayed to any internet capable device. ESRI software is also the dominant software in use worldwide with 78% of GIS professionals using it (GISJobs, 2009).

The initial cost of a single user license of ESRI ArcView was $1200 on June 5, 2008. MapInfo has a cost of $1500 (SGSI, 2009). The ESRI price included the ArcMap, ArcCatalog, ArcToolbox and Modelbuilder modules. ArcMap is used to display and manipulate maps. The interface allows the user to determine the appearance of the map and which layers of information to display. ArcCatalog is used to create and edit geodatabases. ArcToolbox allows for the analysis and combination of data in geodatabases

ESRI enables purchasers of their products to upgrade to the next levels of software ArcEditor or ArcInfo. ArcEditor allows multi user editing of geodatabases, and spatial data creation from scanned maps. ArcInfo includes all of the other options plus publication quality mapping and advanced data analysis and modeling. ESRI also produces a software program called ArcPad. ArcPad is used by field personnel to "integrate GPS, rangefinders, and digital cameras into GIS data collection"(ESRI, 2009c). This increases efficiency. A field technician can download necessary GIS information into their field equipment, collect data, make necessary changes or additions and then transfer the data back to the GIS database at the end of the workday. This replaces the traditional approach of carrying cumbersome field books and surveying equipment into the field, logging all information by hand and then manually entering the data into the central GPS system.

Because ESRI ArcView is compatible with Mahoning County GIS, costs less than other platforms and is able to be expanded if necessary it was determined to be the best solution for the initial entry into the GIS field. The software was purchased and installed on a desktop PC running Microsoft Windows Professional.

3-2 Selection of Sample Area

The Youngstown Water Department is comprised of many physical assets, including 750 miles of water mains, 7,447 fire hydrants, valves, 8 pump stations, 8 storage tanks/water towers and over 55,000 curb stops. In order to provide an effective demonstration of the capabilities of an applied GIS for a water distribution system, the scope of this project was limited to the downtown area of Youngstown, Ohio. This 1.74 square mile area provides a sample of 376 water mains and 259 fire hydrants to exhibit the capabilities of a GIS without being overly cumbersome. The area chosen is bounded by US interstate 680 to the south, US highway 62 to the east, US highway 422 to the north, and Ohio route 193 to the west, as shown in Figure 3.1.. The boundary limits are marked in green. This sample area includes a variety of water main piping materials, piping sizes, fire hydrant types and fire hydrant flow rates.

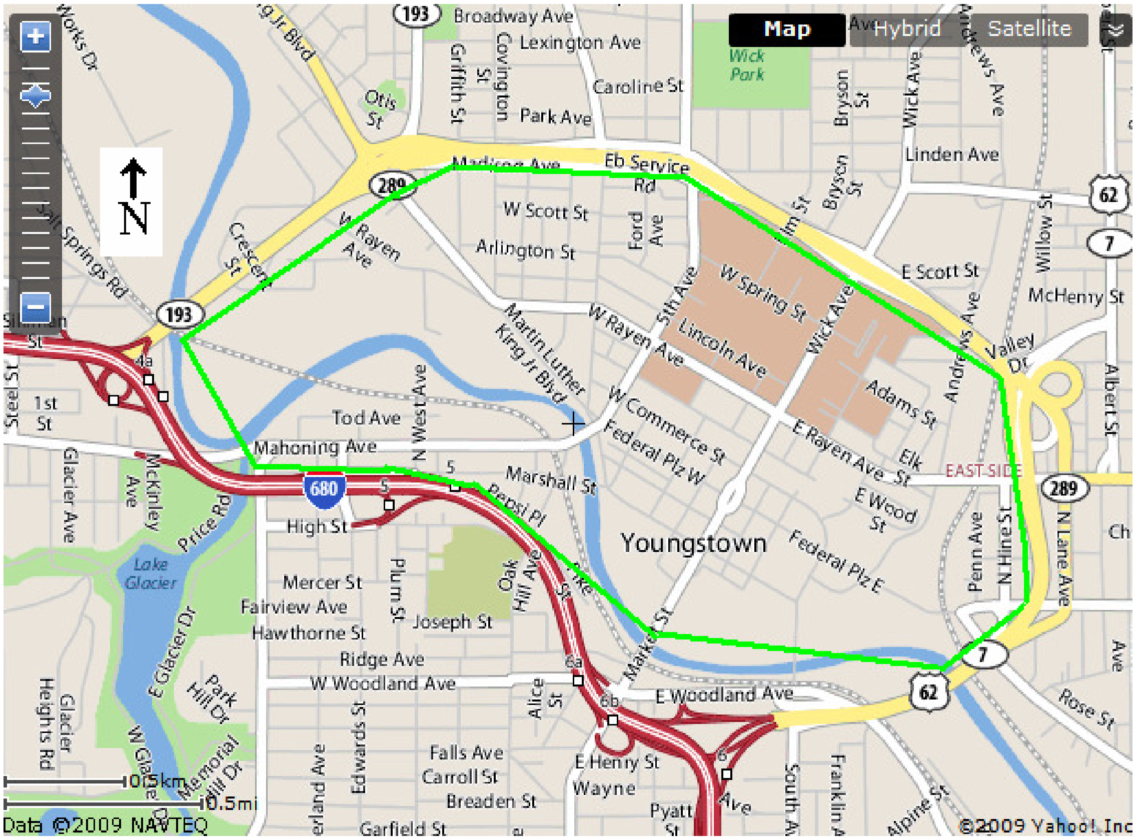


Figure 3-1. Study Boundary Map Centered on Mahoning River (Yahoo, 2009)

3-3 Base Map Development

Once the geographic scope was determined, development of the underlying map framework was necessary. In order to eliminate unnecessary work and ensure compatibility with local government agencies, the Mahoning County GIS roads, property lines and property features layers were used. These layers were downloaded using the File Transfer Protocol (FTP) system from the Mahoning County GIS website, http://gis.mahoningcountyoh.gov/PublicFT/. These layers provide maps with street names, property lines and property addresses. Each layer has many other fields that were not of direct interest to this demonstration, but have potential for future use by the Water Department, such as the owner's name and zip code. These layers use the GCS North American 1983 Geographic Coordinate System with the D North American 1983 datum. The projected coordinate system for the map is NAD_1983_StatePlane_Ohio_North_FIPS_3401_Feet. These layers provided the base map for the GIS and enabled creation of the geodatabase for the Youngstown Water Department distribution system.

The specific layer files used for this model were: Buildings_ExportCAD.DWG, Property Lines.zip, Road Centerlines.zip, Property Lots.zip and Sewer Features.zip. Creating a new GIS map and installing these layers enabled specific attributes to be displayed. By selecting the street name and the address attributes, drawing the water line and hydrant layer was made much simpler because an easy reference was visible. The step by step procedure is included in the Appendix. Figure 3-2 illustrates the GIS base map with the street name, address and building outline displayed.

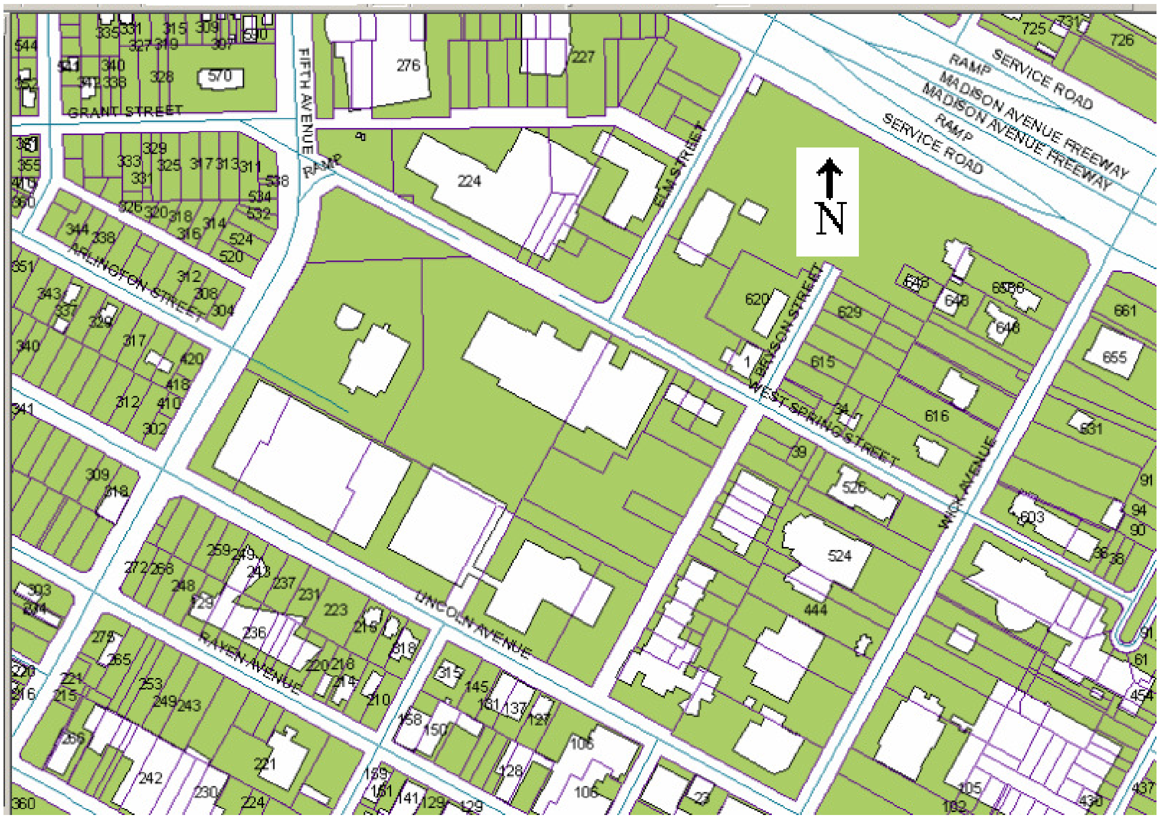


Figure 3-2. Base Map.

Legend: Road Centerline - Blue Line
Lot Boundary - Purple Line
Lot Address - Number

3-4 Development of Water Main Layer

Water main information is currently stored on maps made of linen or Mylar film. The linen map close up shown in Figure 3-3 is over 50 years old and has been repaired numerous times, as can be seen by the dark brown strips. The maps have a coordinate system developed by the YWD. The map centered on the downtown square is designated Youngstown Water Map K-19 (Figure 3-4). Figure 3-4 displays a scaled area of 26.5 in by 26.5 in. The map scale is 1 in = 100 ft and each map covers .25 square miles. The sample area used for this demonstration required 10 map sheets. The maps used as designated by the YWD are J-17, J-18, J-19, J-20, K-17, K-18, K-19, K-20, L-19, and L-20.

Figure 3-3. Linen Map Showing Repairs.

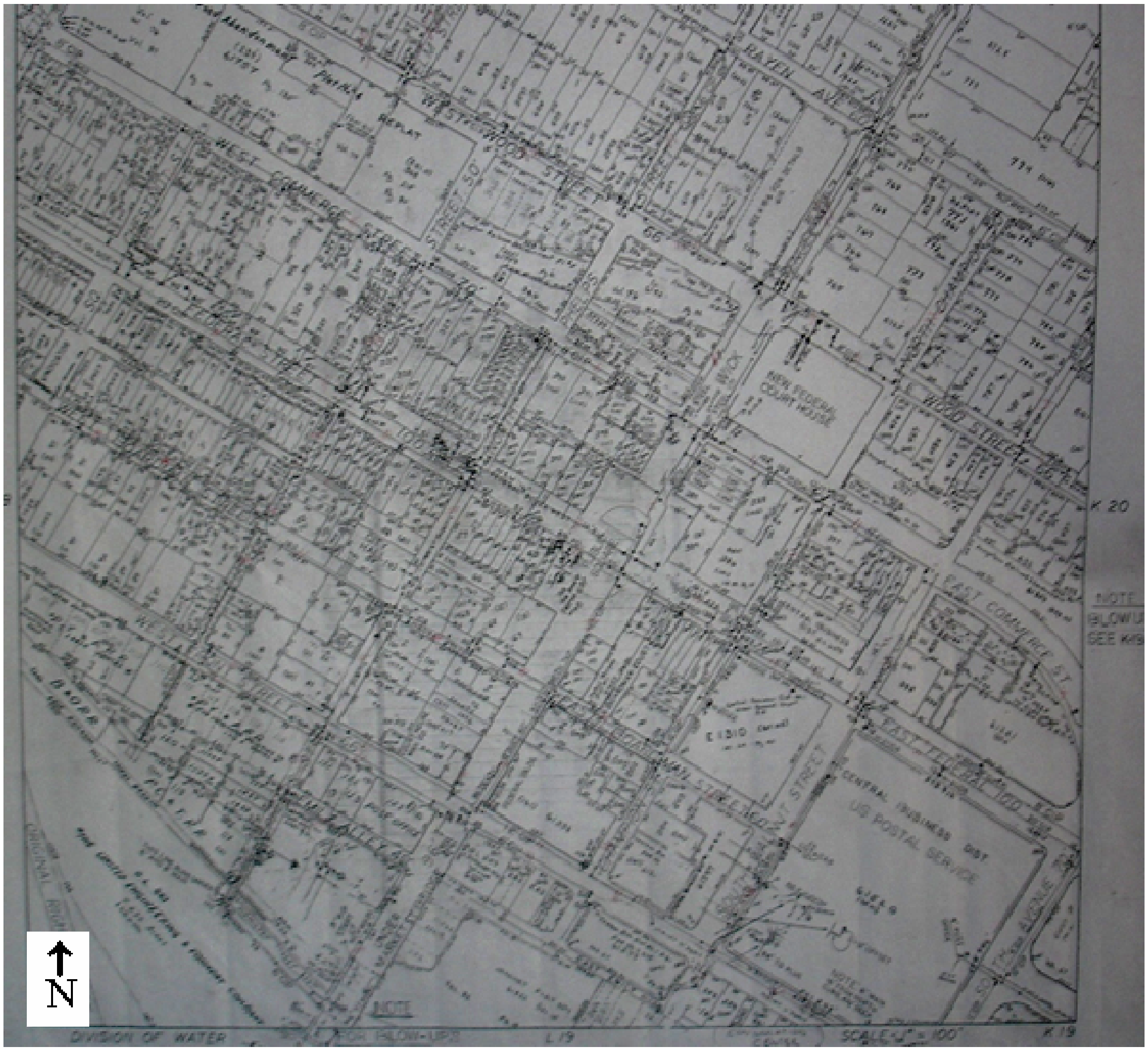


Figure 3-4. Youngstown Water Department Map K-19.

Once the limits of the GIS were established, it was decided to separate the fire hydrants into one layer (named "hydrants") and the water mains into another layer (named "waterlines"). There are several reasons this is advantageous. The first is that the fire hydrants are most easily represented as a distinct point on a map, while water mains are easily represented as a line. The second reason for splitting into two layers is that it enables the GIS user to display only the parts of the map that are relevant to the situation at hand. The third reason is that it enables the geodatabase for the specific data type to be updated without changing the whole GIS.

Each map feature is linked to a table of attributes in the geodatabase. For each water main, some of the attributes chosen were Street Name, Pipe Length, Pipe Size and Pipe Material. Street Name is the location of the water main, Pipe Length is the linear distance of pipe in feet, Pipe Size is the diameter of the pipe in inches, and Pipe Material is the composition of the pipe. The fields in the attribute table provide detailed information about the corresponding feature. The attributes are stored in the GIS database and can be accessed from the GIS map feature by selecting it. The full list of attribute fields chosen for the waterlines layer is shown in Table 3-1.

Table 3-1. Fields in Water Main Attribute Table

Field Name	Description
Street Name	Street water main is on
Street Direction	N,S,E,W ex. N. West Ave.
Pipe Length	Length of main in feet
Pipe Size	Pipe diameter in inches
Pipe Type	Pipe material, cast or ductile iron
Pipe Grade	General Condition of Pipe, 1 to 5
Pipe Year	Year Pipe was installed
Pipe Value	Cost per linear foot
Lat	Latitude for GPS coordinates
Lon	Longitude for GPS coordinates
Pipe Maintenance	Field to describe last maintenance action
Repair Cost	Cost of repairs to water main
Break Date	Date of last water break

The information for all attributes except Lat and Lon are stored in a Microsoft Excel spreadsheet at the YWD. Lat and Lon can be determined with survey grade GPS equipment.

Water line attributes were compiled in a report for the Congressional District 6 Public Works Integrating Committee to categorize the state of infrastructure assets and assign a monetary value to them. A sample is shown in Table 3-2 (City of Youngstown Water Department, 2007).

Table 3-2. Inventory Worksheet Row

Street	Year Inst.	Size Length	Value	Repairs
Armstrong	1932	16” 270 LF	$19,305.00	$3,861.00
Arrowae	1932	6” 901 LF	$24,777.50	$4,995.50
Artmar	1946	6” 862 LF	$23,705.00	$4,741.00
Ascot Ct.	1946	6” 700 LF	$19,250.00	$3,850.00

In the original spreadsheet, the Pipe Size and Pipe Length information were included in the same Excel cell. The format in the cell was with the pipe size first and then the pipe length – e.g., 16" 270 LF. To separate the information, the formula =LEFT(D105,3) was used to extract the pipe size. This operator will take the three leftmost characters in the cell. In this example, 16” was taken from cell D105. The pipe length was extracted using the formula =MID(D105,4,5). This operator will start at the fourth character in the cell and take the next 5 characters. This results in 270 linear feet. The pipe value field is calculated by dividing the pipe cost contained in the cell labeled Value by the length of pipe in that pipe segment that was previously determined. This would produce a result of cost per linear foot for that pipe segment. In this example the cost would be

$19,305 / 270 linear feet = $71.50 per linear foot.

The Repair Cost is a numeric field that will hold the cumulative repair costs for each section of water main. Break date is the date of the most recent repair on that section of water main. This only signifies the latest occurrence and does not indicate the possibility of multiple incidents or cumulative breaks over time. The break date information is currently stored separately by the YWD in an Excel spreadsheet. Using the data from the Inventory Work Sheet previously described, the data attributes for the water main just drawn are entered. The final waterlines layer included 376 lengths of pipe and is shown in Figure 3-5.

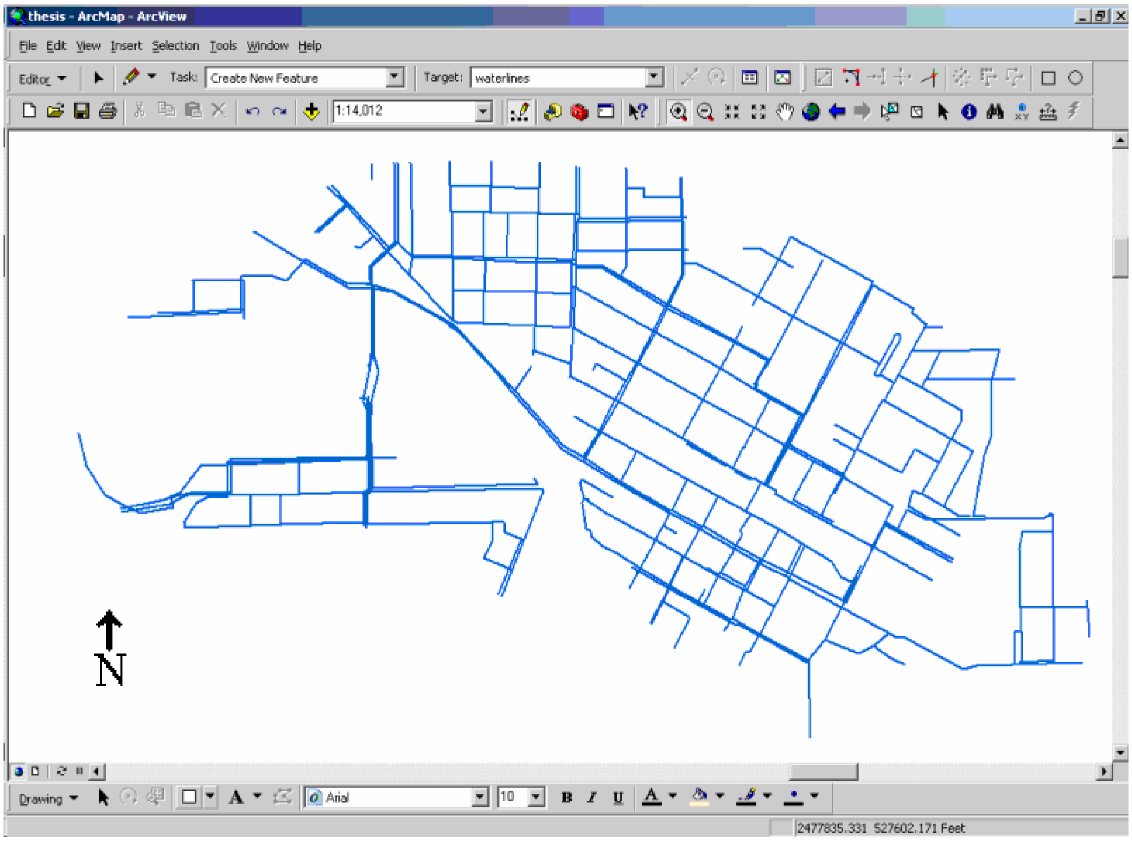


Figure 3-5. Water Main Layer.

3-5 Development of the Fire Hydrant Layer

Once the waterlines layer was complete, the hydrants layer was developed. The first step was deciding which attributes of the fire hydrant information were pertinent to this GIS application. The fields listed in Table 3-4 were chosen.

Table 3-4. Fire Hydrant Attribute Table

Field Name	Description
Hydrant Number	YWD ID Number
Make	Manufacturer and Model
Main_Size	Size of Attached Main
Addnum	Nearest Address
Adddir	Street Direction
Addstreet	Street Name
Nearstreet	Nearest Cross Street
Flow	Flowtest in GPM
Stat	Static Pressure in GPM
Resid	Residual Pressure in GPM
Lat	Latitude in Degrees
Lon	Longitude in Degrees

The YWD maintains fire hydrant information in Microsoft Word format (e.g., Table 3-5)

Table 3-5. Fire Hydrant Information

Number	Address - Valve Location - Main Size	Color - Make
A2-75	6640 Abbott Street Valve is 1 ft. in front of the Hydrant on 6 in. Main	Orange Darling B62B
A2-74	6680 Abbott Street Valve is 2 ft. in front of the Hydrant on 6 in. Main	Orange Darling B62B
Y6-215	1103 Aberdeen Avenue Valve is 7 ft. in front of the Hydrant on 6 in. Main	Orange Kennedy K10
Y6-214	1221 Aberdeen Avenue Valve is 7 ft. in front of the Hydrant on 6 in. Main	Orange Kennedy K11
Y6-213	1319 Aberdeen Avenue Valve is 9 ft. North & 4 ft. East of the Hydrant on 6 in. Main	Orange R D Wood
Y6-212	1373 Aberdeen Avenue Valve is 3 ft. in front of the Hydrant on 8 in. Main	Orange - Yellow R D Wood
L1-167	1041 Academy Drive Valve is 4 ft. South of the Hydrant on 6 in. Main	Orange R D Wood
L1-168	1169 Academy Drive Valve is 1 ft. in front of the Hydrant on 6 in. Main	Orange R D Wood

The Hydrant Number is assigned by the YWD. The Water Department has classified each hydrant based upon the district of the local fire department. Local fire departments with jurisdiction include Youngstown City, Austintown Township, Boardman Township, Liberty Township and Canfield Township. Each hydrant number begins with the letter of the department with jurisdiction. The larger districts are further divided into sections. Youngstown has 10 districts, Austintown has 4 districts, Boardman has 3 districts, while Canfield and Liberty Townships each have one. The individual hydrant number then follows. For example, the hydrant at the corner of Front and Champion is designated Y1-213. The only exception to this numbering scheme is for the fire hydrants on or directly adjacent to the Youngstown State University (YSU) campus. These fire hydrants are designated district YSU with the hydrant number following. The fire hydrant at 144 W. Wood St. is YSU-5. The YWD, with the approval of the Youngstown Fire Department, allows YSU to paint these hydrants to resemble Pete the Penguin, the YSU mascot (Figure 3-6):

Figure 3-6. Pete the Penguin Fire Hydrant.

The Make field is populated with the name of the fire hydrant manufacturer along with the model number if applicable. For instance, hydrant Y1-213 was manufactured by the Darling Company and is a model B62B. The Main_Size field is the diameter of the water main that the fire hydrant is connected to. This is in inches and can range from 4" to 42". The next three fields are interrelated and when combined give the street address for a fire hydrant. The three fields are: Addnum, Adddir and Addstreet. The address for hydrant Y1-193 is 335 E. Boardman St. The 335 would be placed in Addnum, the direction E would be placed in Adddir and Addstreet would contain Boardman St. By splitting the address into its component parts, the sort function of the GIS software can be used to organize the hydrants by street name.

Some fire hydrants are located in places without a nearby building that has a street address. To help in locating and distinguishing one hydrant from another, the Nearstreet field is used. This is a text field and may or may not have a value for a specific hydrant.

Flow, Static and Residual are determined in a field flow test for each fire hydrant. Flow is the flow rate in gallons per minute (gpm). Each hydrant will have 3 caps that allow connection to fire hoses. The largest cap on the front of the hydrant is referred to as the "steamer' cap. This name is derived from the period when steam driven fire pumps would be connected during a large fire. This nozzle is 4 ½" in diameter. The two smaller nozzles are referred to as the hose nozzles. These are 2 ½" in diameter.

Flow test information is maintained by the YWD in a Visual dBase (by Borland Software) database. The flow test is usually performed by two Water Department personnel at the request of a customer, insurance company, local fire department or engineering company doing design work for a future project. The information entered into the database includes the static and residual pressures, flow rate, water main type, location, party requesting the flow test, persons performing the flow test and any miscellaneous comments.

The Lat (latitude) and Lon (longitude) data attributes have not been determined for any YWD assets. Since fire hydrants are readily visible, it is feasible to obtain coordinates by GPS and include them in the GIS.

A list of all the hydrants in the sample area was printed out. The GIS mapping function was utilized to provide a map of all the hydrants that did not yet have a Lat and Lon entry in the data field. A route was then planned to enable all data points to be collected using a hand-held GPS device - a Magellan Explorist 300 (Figure 3-7). This device is considered an entry level GPS device and is not used in cases where extreme accuracy is required. The manufacturer lists the accuracy as less than 3 meters (Magellan, 2009). Most fire hydrants should be visible if the user is within 3 meters (about 10 feet). The unit was configured to provide location in decimal degrees of latitude and longitude. The unit was then powered up and allowed to acquire signals from the tracking satellites of the GPS network. Most hydrants were accessible by car. Some hydrants were located in positions that were previously dedicated roadways that the city has vacated. The hydrants in the core of YSU fall into this group. These hydrants had to be reached by traveling on foot.

Figure 3-7. Magellan Explorist 300. (Magellan, 2009)

Once the location of a hydrant was reached, the GPS receiver was placed either on or adjacent to the hydrant and allowed to determine the position. The position was then recorded on the hydrant printout. For example, the hydrant in front of Kilcawley Center on the Youngstown State University campus was designated YSU-72, and recorded as 41.10659 Latitude and -80.64866 Longitude.

After all the data were collected, it was necessary to verify the accuracy of the results. Google Earth was used as an external reference. Google Earth is an internet program that can be downloaded free of charge. It links aerial photographs to physical addresses or latitude and longitude coordinates. It can be run on any personal computer using a current version of Microsoft Windows. The manufacturer recommends that the personal computer have a processor speed of 4.2 GHz, free hard disk space of 2GB and an internet connection of 768 Kbits/sec. The program can be obtained from the internet site http://earth.google.com/.

Once the software is installed, a Google Earth icon appears on the computer desktop. Clicking on this icon opens Google Earth (Figure 3-8).

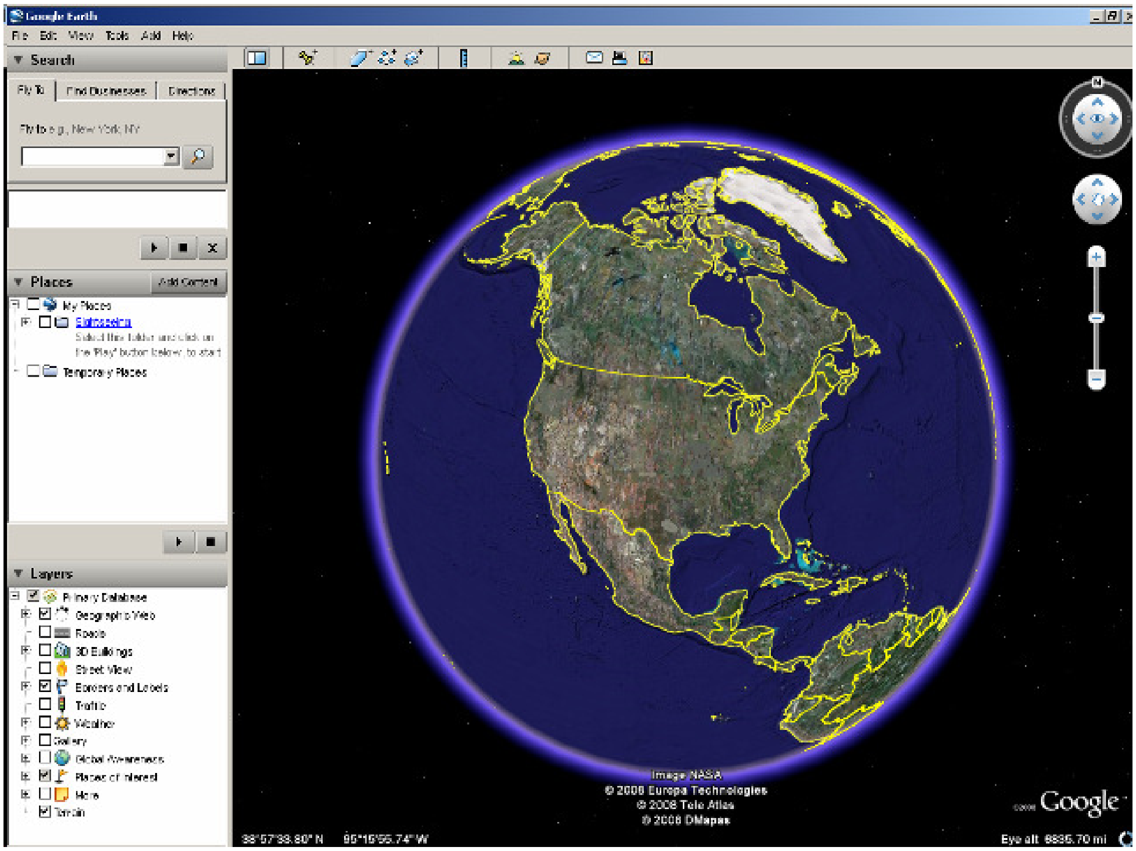


Figure 3-8. Google Earth. (Google Earth, 2008)

The top left corner of the program's main page has a tab marked Fly To. Clicking on this tab, then entering the coordinates for hydrant YSU-72 (41.10659 Latitude and -80.64866 Longitude) will cause the software to zoom in from a global perspective to a local perspective centered on these coordinates. Figure 3-9 shows the fire hydrant YSU-72 with reasonable clarity and accuracy.

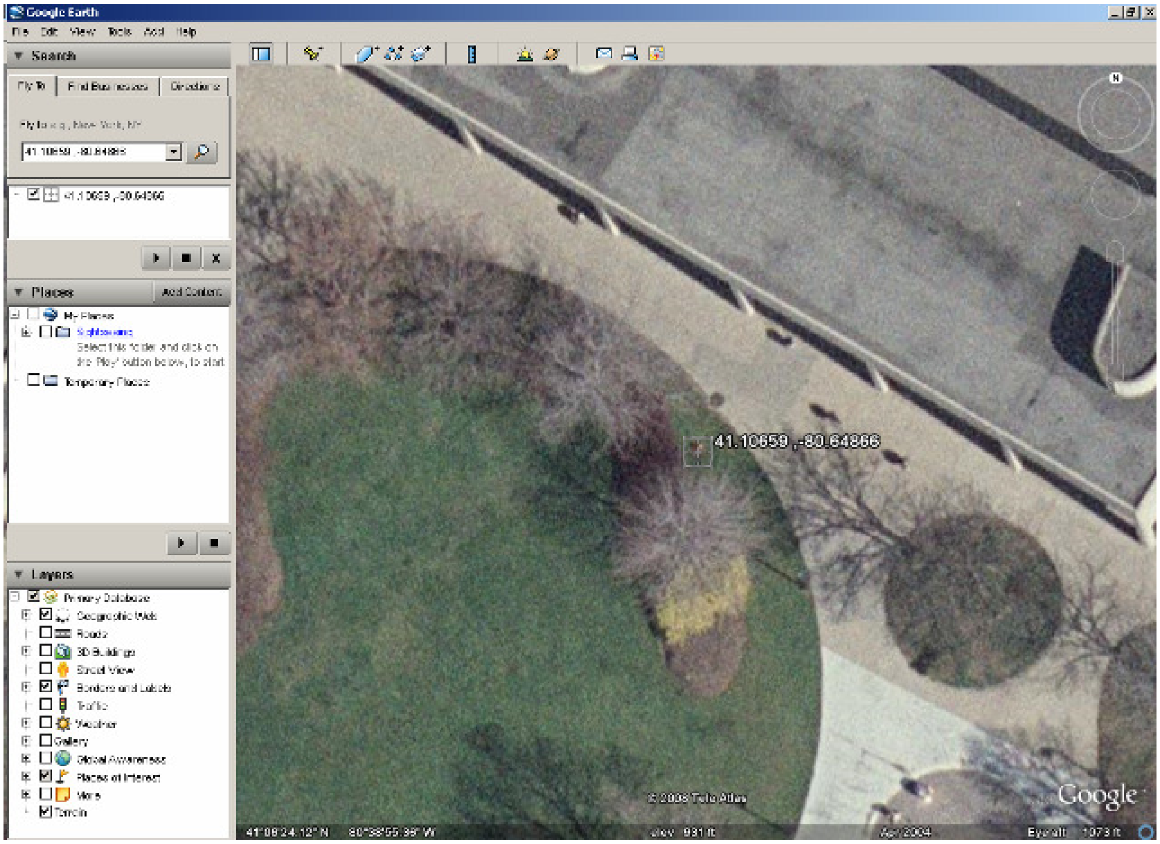


Figure 3-9. YSU Hydrant 72.

The data collected using the hand held GPS device for fire hydrant locations were then verified against the Google Earth photo imagery. Google Earth provided an external check of data. In most cases the coordinates were very similar and used as collected. If the coordinates collected from the hand-held GPS unit were noticeably inaccurate, but the fire hydrants were visible using Google Earth, the coordinates obtained from Google Earth were used. Most discrepancies are attributed to the GPS signal being blocked by nearby structures. Google Earth could not be used for all hydrants because some are not visible using Google Earth and some have been moved since photograph was taken.

Once collection of the data for the hydrant attributes was complete, the hydrant layer for the GIS could be drawn. Fire hydrants are best represented as a distinct point on a GIS map and this feature shape was chosen when drawing the map. This point is represented as an orange star to increase visibility. There are 259 fire hydrants contained within the boundaries of the sample area. All of the fire hydrants were placed on the GIS hydrants layer before proceeding to enter the hydrant attribute data. The hydrant attributes were compiled from the different sources as previously described. A section of the GIS, showing the base layers with the waterlines and hydrants layers active, is presented in Figure 3-10.

Figure 3-10. GIS for Section of Sample Area, Showing Base Map with Waterlines and Hydrants Layers.

Legend: Road Centerline - Blue Line
Lot Boundary - Purple Line
Water Main - Heavy Blue Line

CHAPTER 4

RESULTS AND DISCUSSION

4-1 Selecting Hydrants by Manufacturer

One of the key qualities of a GIS is the ability to represent data visually. Each attribute can be used to differentiate based upon the values contained in the data field. Fire hydrants were displayed using a different color for each hydrant manufacturer. ArcMap enables the user to automatically color the hydrants. This was done by clicking the hydrants layer in the Table of Contents window, selecting the Symbology tab, Categories in the Show box and then selecting the Unique values option. Make was selected from the Value Field drop down menu and then the Add all Values button was pressed. ArcView will then search all values in the Make field, group them and assign a specific color to that make. ArcView determined that there are thirteen hydrant makes and displayed each with a different color on the GIS as shown in Figure 4-1. This would be of benefit when planning routine maintenance or in the event of a manufacturer's recall. If a certain hydrant make needed to be upgraded, the location of each hydrant and the proximity to the nearest one of the same make is displayed. This makes planning work details and dispatching workers much simpler.

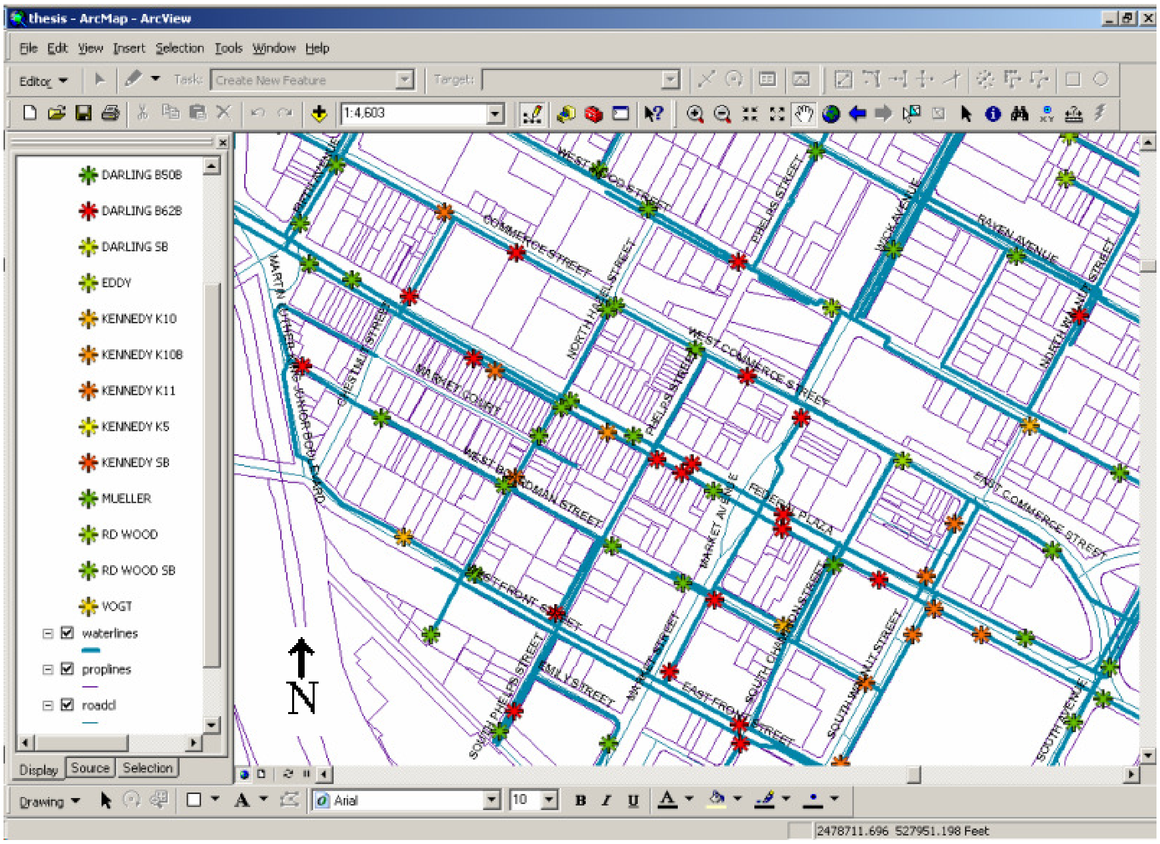


Figure 4-1. Fire Hydrants Color Coded.

4-2 Hydrant Flow Rate

The same procedure was followed to display the fire hydrants based upon their measured flowrates. From the Show box in the Symbology tab, the Graduated symbols option was selected under the Quantities heading. By setting the Classification Classes to 4, the Symbol Size displayed the fire hydrants in increasing size based upon the available flow in gallons per minute (Figure 4-2). Displaying fire flow rates in this manner enables rapid engineering assessments of the water distribution system. If adjacent hydrants show dramatic differences in the displayed size, it is possible that the hydrant is broken, or that there is a water valve partially closed or an obstruction is present. A maintenance crew could then be dispatched to determine the cause. Displaying hydrants based upon flow rates would also be beneficial to fire departments. There are areas where two different pressure zones are contiguous. The pressure available in a zone will affect the flow rate. By illustrating which hydrant would produce the most flow the fire department would be able to extinguish a blaze more quickly.

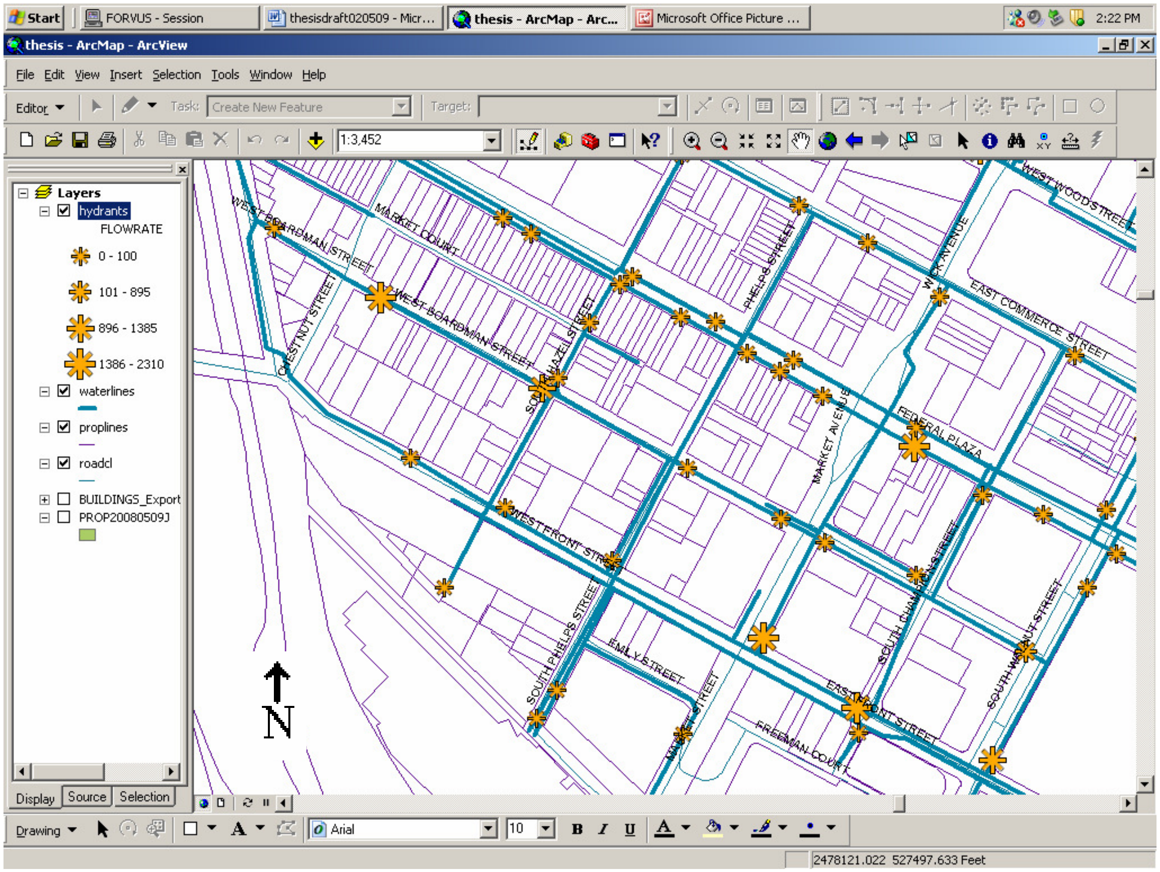


Figure 4-2. Hydrant Flow Rate in Gallons per Minute.

4-3 Water Main Size

The waterlines layer can also be used to display differences in pipe characteristics that would be useful in asset management. The waterlines can be displayed using a different color for each pipe size (Figure 4-3). This would be extremely valuable at locations such as the intersection of West Avenue and Tod Avenue where there are nine water mains of different sizes. If a leak were to occur, it would be much easier to determine on the GIS where the shut off valves are located compared to the traditional paper map.

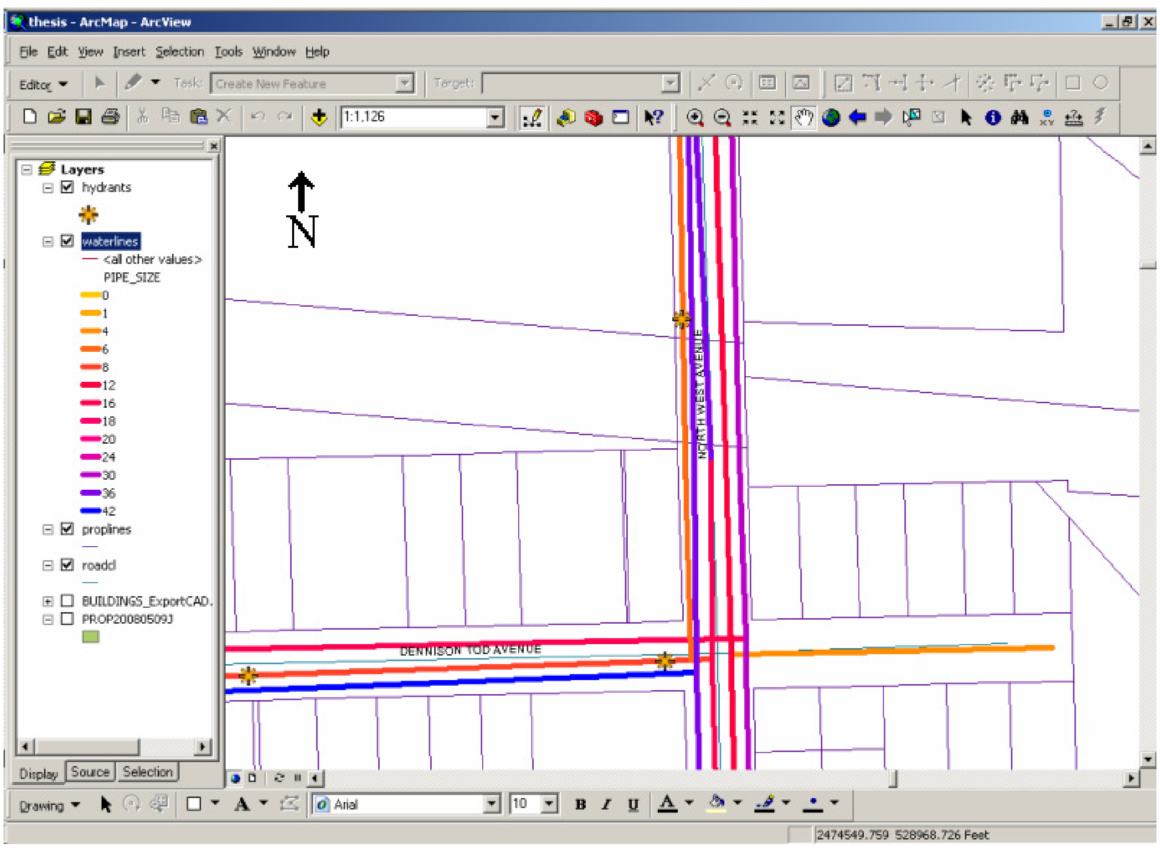


Figure 4-3. Water Main Size in Inches.

4-4 Water Main Material

The type of material that the water main is made of can be used as a determining factor for display (Figure 4-4). This can be a useful tool in day to day operations. Water mains of different materials will have different diameters. The primary types of water mains are cast iron (CIP), ductile iron (DIP), plastic (PLA) and steel (STE). This presents a need for the correct sized repair equipment to be used. Delays encountered replacing the improperly sized repair equipment may cause undue hardship to the water customer. Different tools are also required to work on different pipe materials. The cutting tools used to cut transite water pipe are different than the cutting tools used to cut ductile iron or plastic pipe. Down time can be eliminated by ensuring that the correct tools are brought to a job site by displaying the water main material before a maintenance crew is dispatched.

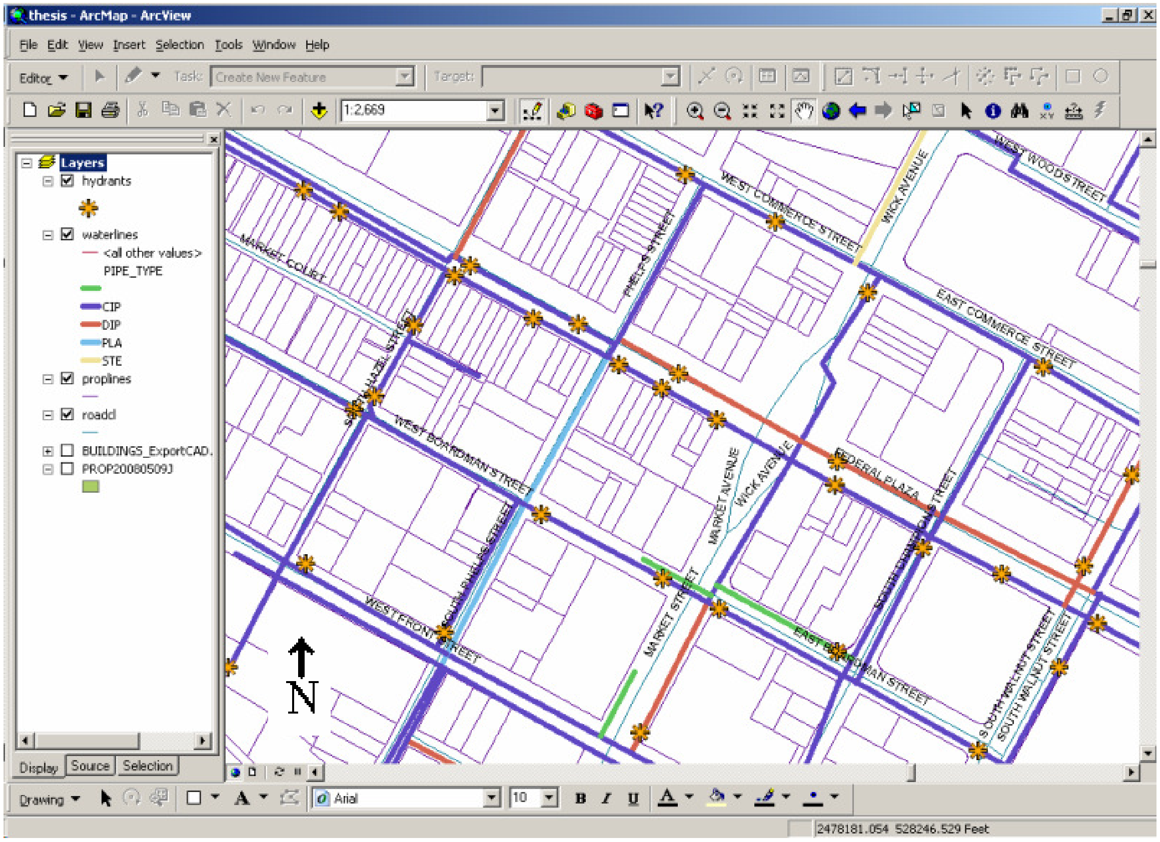


Figure 4-4. Water Main Material.

4-5 Water Main Selection Using Logical Expressions

ArcView provides the user with the option of selecting which data to display based on logical expressions. To display water mains that were installed between 1966 and 1980, the Definition Query tab was selected after left clicking on the waterlines layer in the Table of Contents window. The search expression "PIPE_YEAR" >'1966' AND "PIPE_YEAR"<'1980' was entered in the Definition Query workspace and the GIS showed only the water mains installed during that time frame (Figure 4-5).

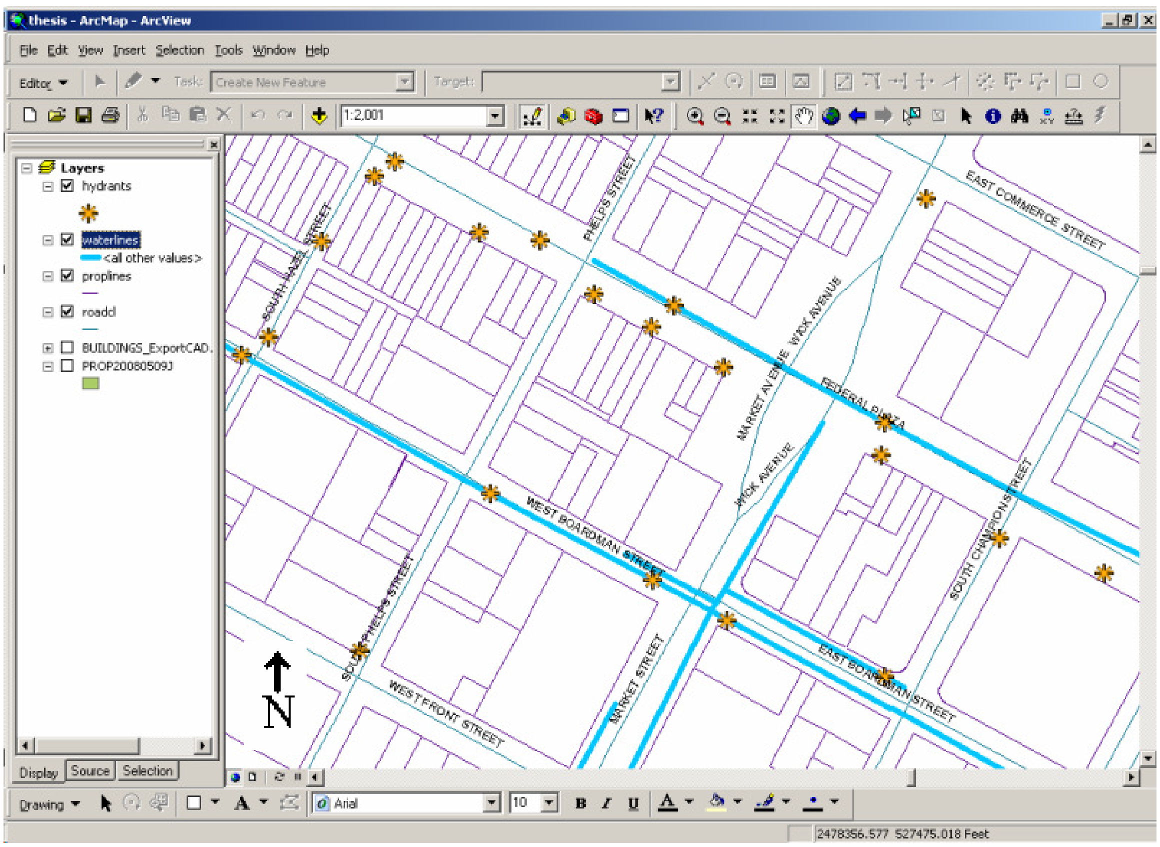


Figure 4.5. ArcMap Water Main Logical Expression Closeup Display.

This can be a powerful tool in deciding which water mains to replace when using limited capital improvement funds. When the search criteria was set to show all water mains installed before 1934 ("PIPE_YEAR" >'1'and "PIPE_YEAR"<'1935'), it becomes evident that the majority of the water mains in the downtown Youngstown area are over 75 years old (Figure 4.6).

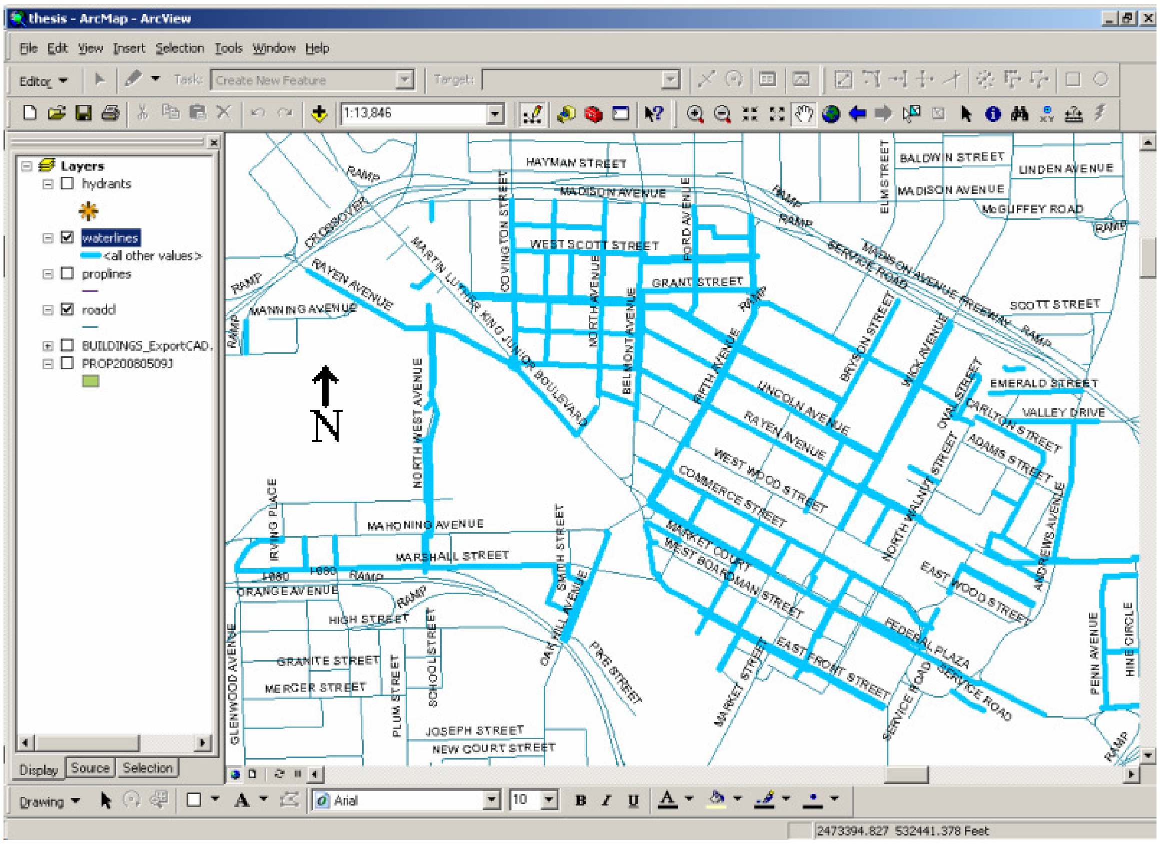


Figure 4-6. ArcMap 75 Year Old Water Main Display.

4-6 Water Main Selection Using Multiple Criteria

Multiple selection criteria can also be used to identify specific water department assets. For instance, setting the Definition Query to "BREAKDATE" > date '2007-09-01' AND "BREAKDATE" < date '2008-04-01' AND "PIPE_YEAR"<'1935' displayed all water mains over 75 years old that experienced a main line break during the winter of 2007-08 as shown in Figure 4-7.

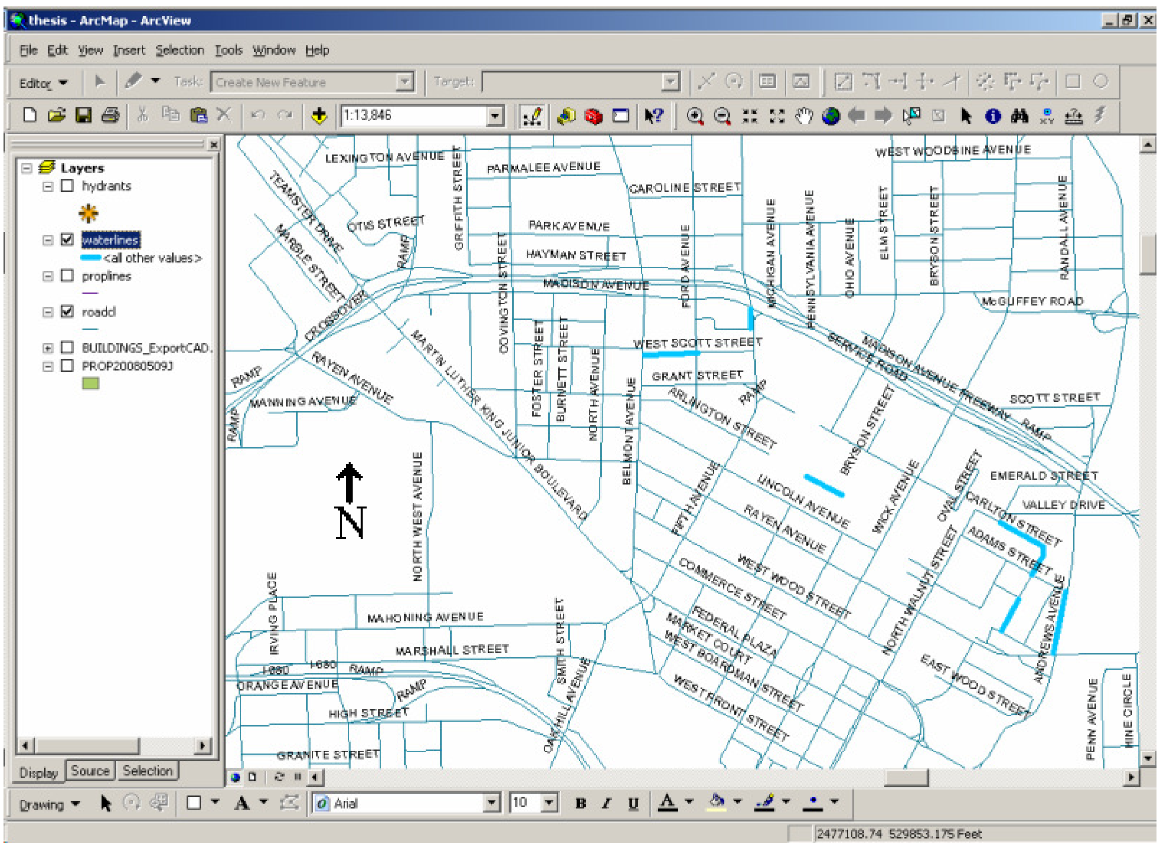


Figure 4-7. ArcMap Display of Main Breaks in 2007-08 that were on Mains Older than 75 Years.

4-7 Generating Reports Based on Selection Criteria

A visual display is a helpful tool, but can lack detail when specific information is required. ArcView has a Tool available that provides data processing functions based upon the displayed information. As an example, this can be of use when calculating water main replacement costs. To determine the total length of 24" water main in the downtown Youngstown area, the waterlines layer was selected and the Definition Query tab of the Layer Properties was selected. The Definition Query was then specified as "PIPE_SIZE" = 24 and then the Apply button was selected, presenting the screen display shown in Figure 4-8.

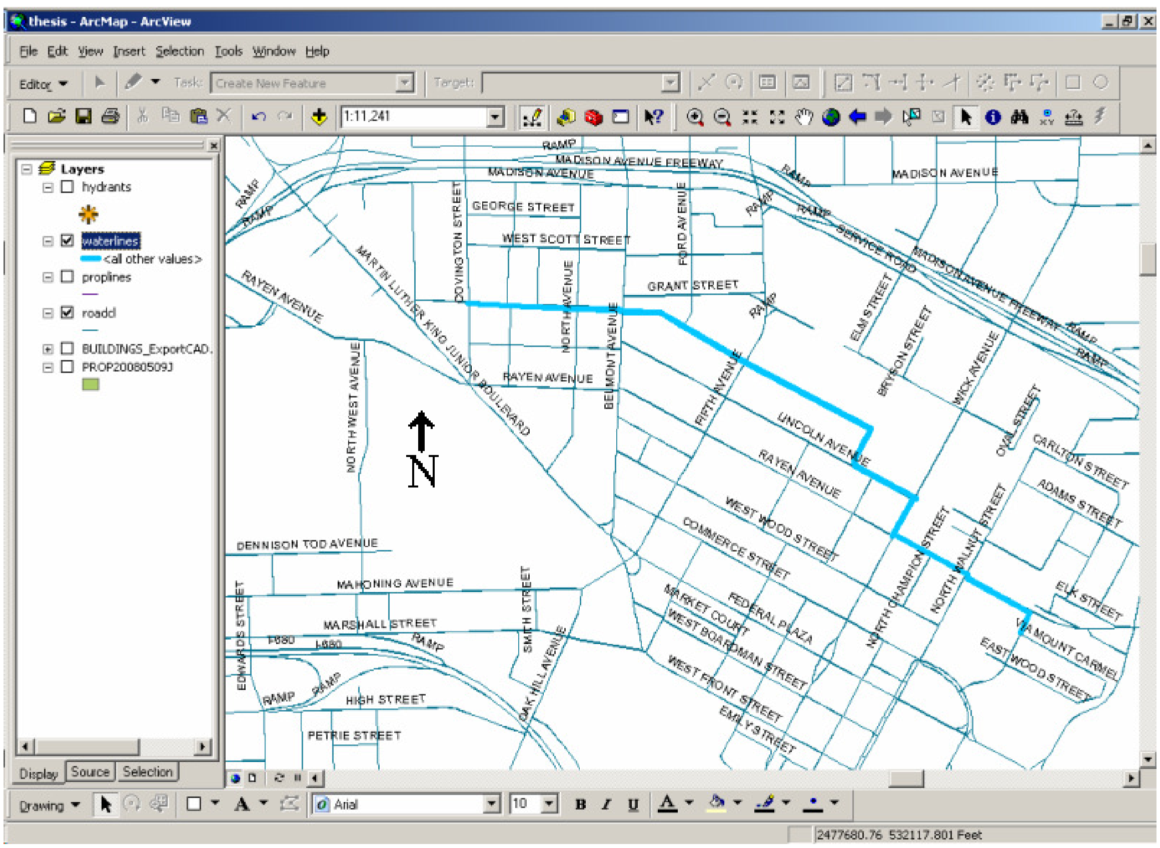


Figure 4-8. ArcMap 24" Mains Display.

A customized print out of this map can be obtained. A title was added by selecting Insert from the toolbar and then selecting the Title option. This opened an entry box on the map. "Youngstown Water Department" and "24" Water Mains in Downtown District" were entered. Selecting File from the menu bar and then Print produced the map shown in Figure 4-9.

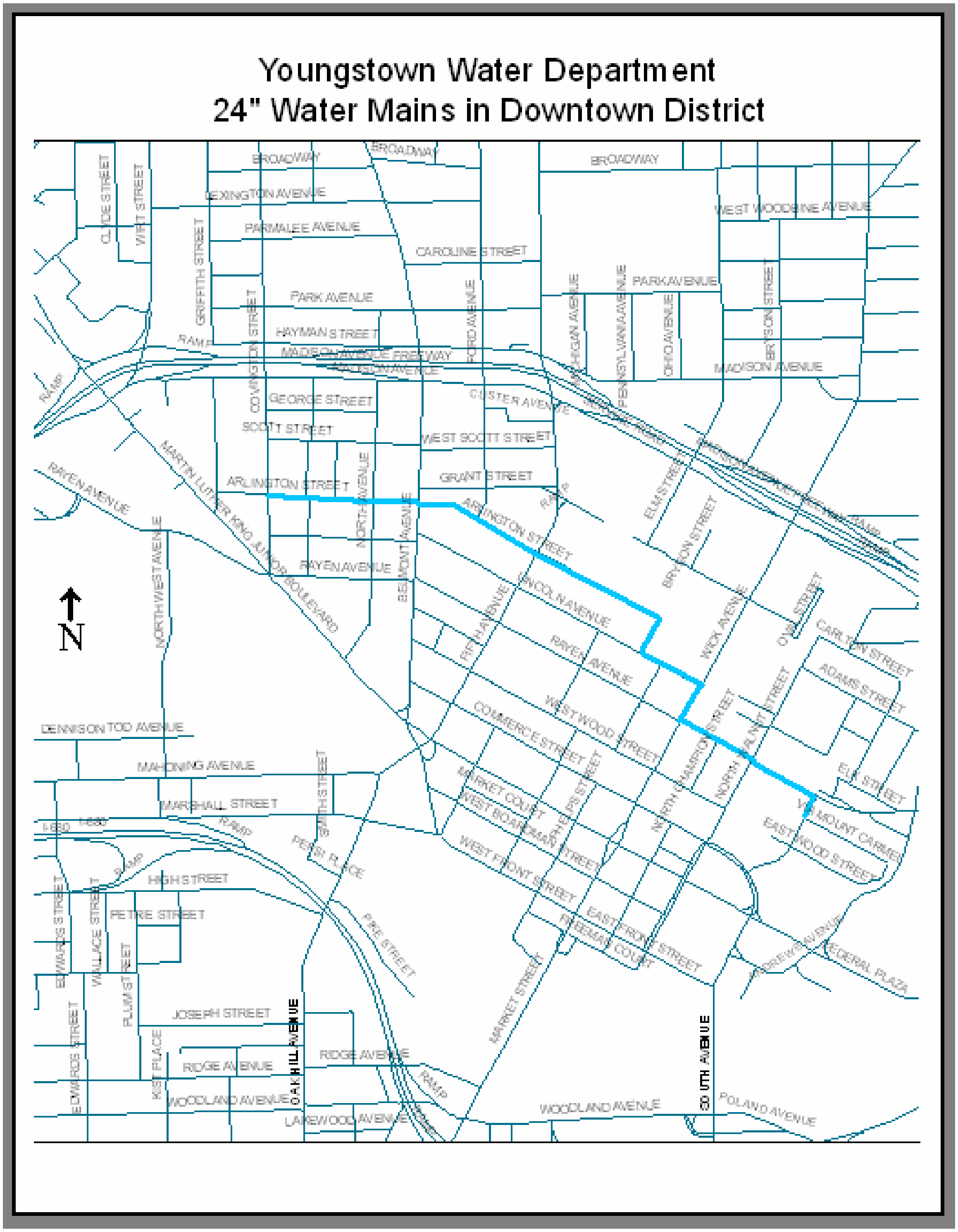
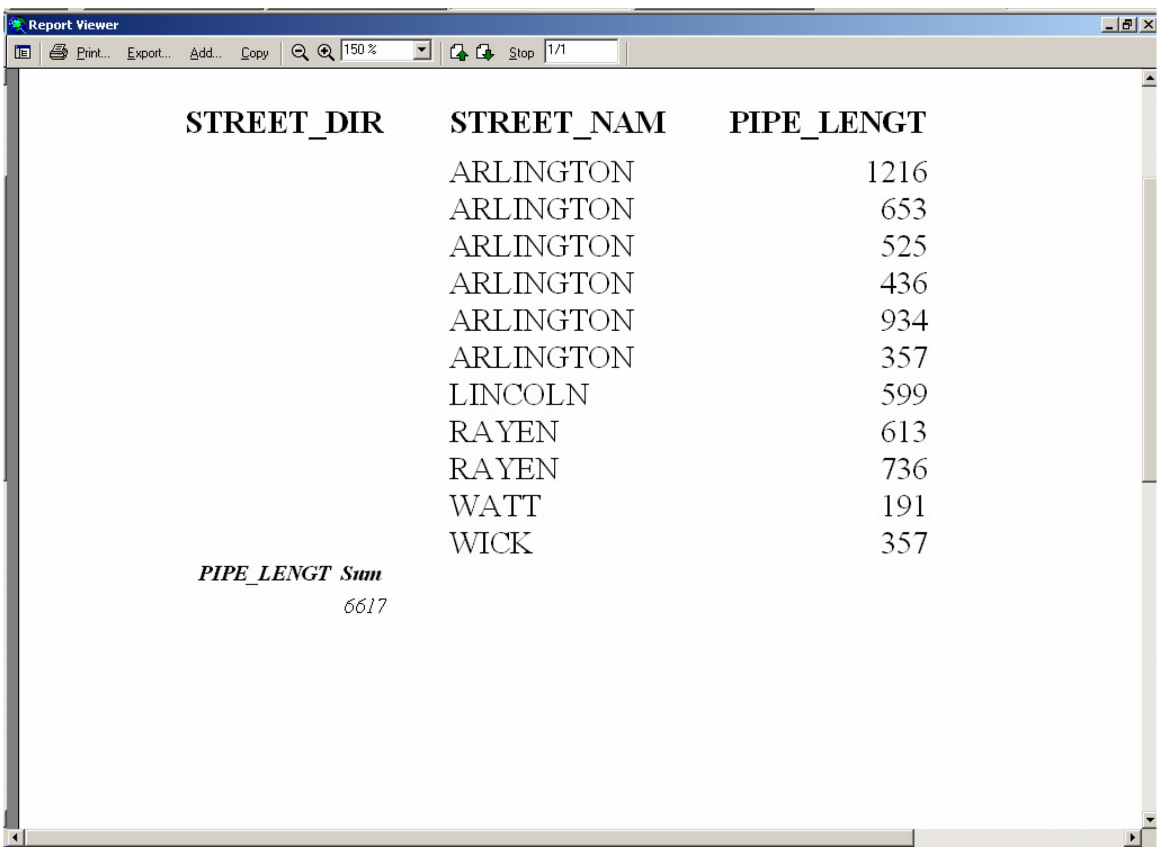


Figure 4-9. ArcMap Print Layout for 24" Water Main Map.

This map presents the route the 24" water main follows through downtown Youngstown, but it would be difficult to determine the exact length of pipe involved. A report can be created by determining the exact pipe length. The report can be customized to have as much or as little detail as needed. In this case, the street direction, street name and pipe length were selected. The street names were sorted by alphabetical order and the pipe lengths summed. The report summarizing the 24" water main pipe length produced a sum of 6617 feet as shown in Figure 4-10.



STREET_DIR	STREET_NAM	PIPE_LENGT
	ARLINGTON	1216
	ARLINGTON	653
	ARLINGTON	525
	ARLINGTON	436
	ARLINGTON	934
	ARLINGTON	357
	LINCOLN	599
	RAYEN	613
	RAYEN	736
	WATT	191
	WICK	357
PIPE_LENGT Sum		
6617		

Figure 4-10. Water Main Length Report.

Another factor that could be used for asset management is the age of the infrastructure in question. To produce a map of all water mains over 75 years old, the expression "PIPE_YEAR" <'1934' AND "PIPE_YEAR" >'0' was used, resulting in Figure 4-11.

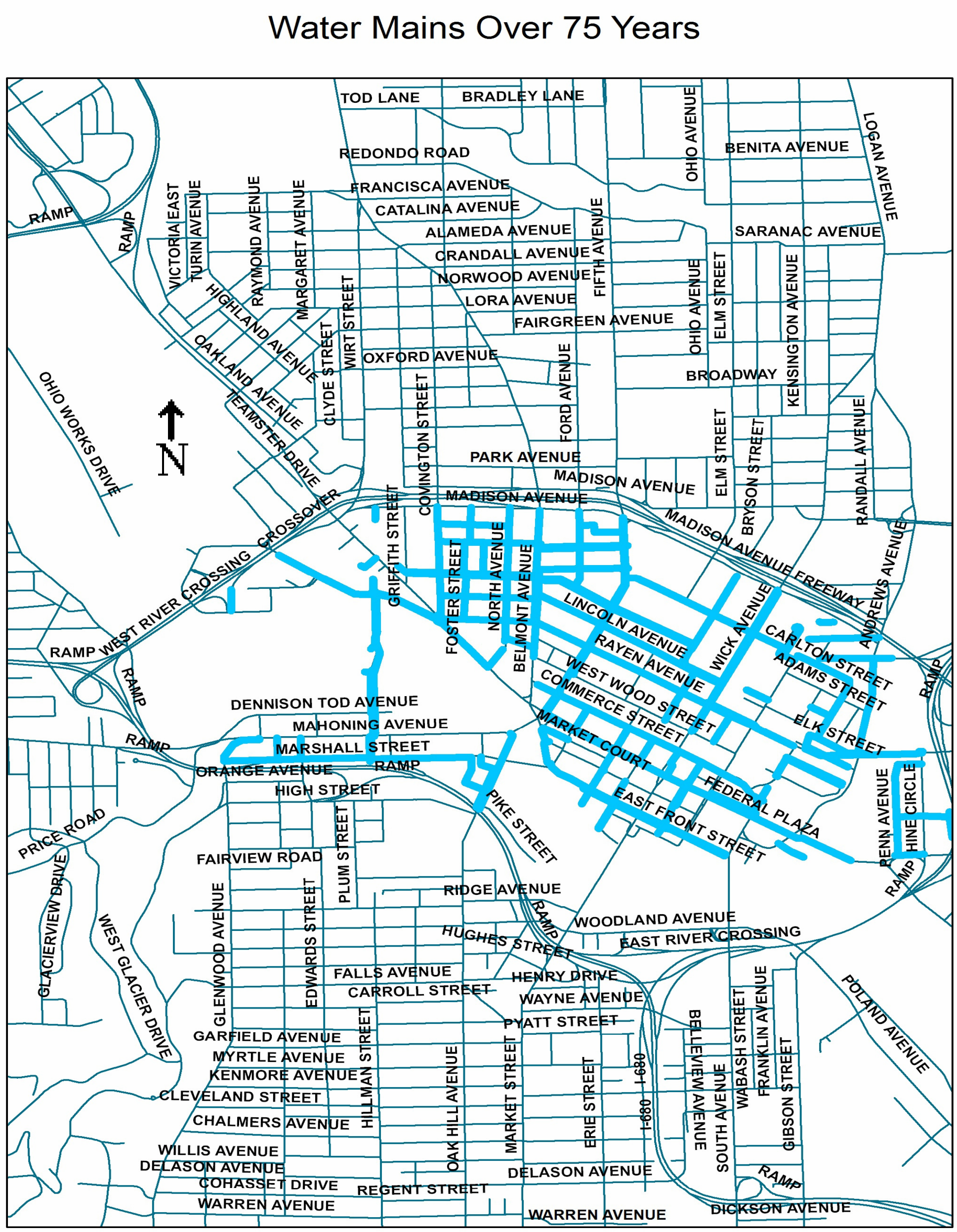


Figure 4-11. Water Mains Over 75 Years Map.

The “PIPE_YEAR”>’0’ is required in the logical expression to include water mains that do not have an installation year entry in the PIPE_YEAR field. A report was produced providing an exact total length of pipe greater than 75 years old in the downtown sample area. The report was eight pages long, with the final page of the report showing the cumulative pipe length in feet (Table 4-1). This would be useful in providing preliminary cost estimates or for infrastructure replacement.

Table 4-1. Water Mains Over 75 Years Report

STREET_NAM	PIPE_SIZE	PIPE_LENGT	PIPE_YEAR
HIMROD	8	399	1926
RAYEN	8	33	1926
PIPE_LENGT Sum			
114224			

Units: PIPE_SIZE-in; PIPE_LENGT-ft

4-8 Report Generation Producing Exact Results

For planning or estimating construction costs, exact numbers are necessary. To obtain specific results, any combination of pipe attributes can be combined using the logical expressions provided in the Query Builder. To determine the exact length of 8" cast iron pipe that is over 75 years old, the expression "PIPE_YEAR" <'1934' AND "PIPE_YEAR" >'0' AND "PIPE_TYPE"= 'CIP' AND "PIPE_SIZE" = 8 was entered, producing the GIS map shown in Figure 4-12.

8" Cast Iron Water Mains Over 75 Years

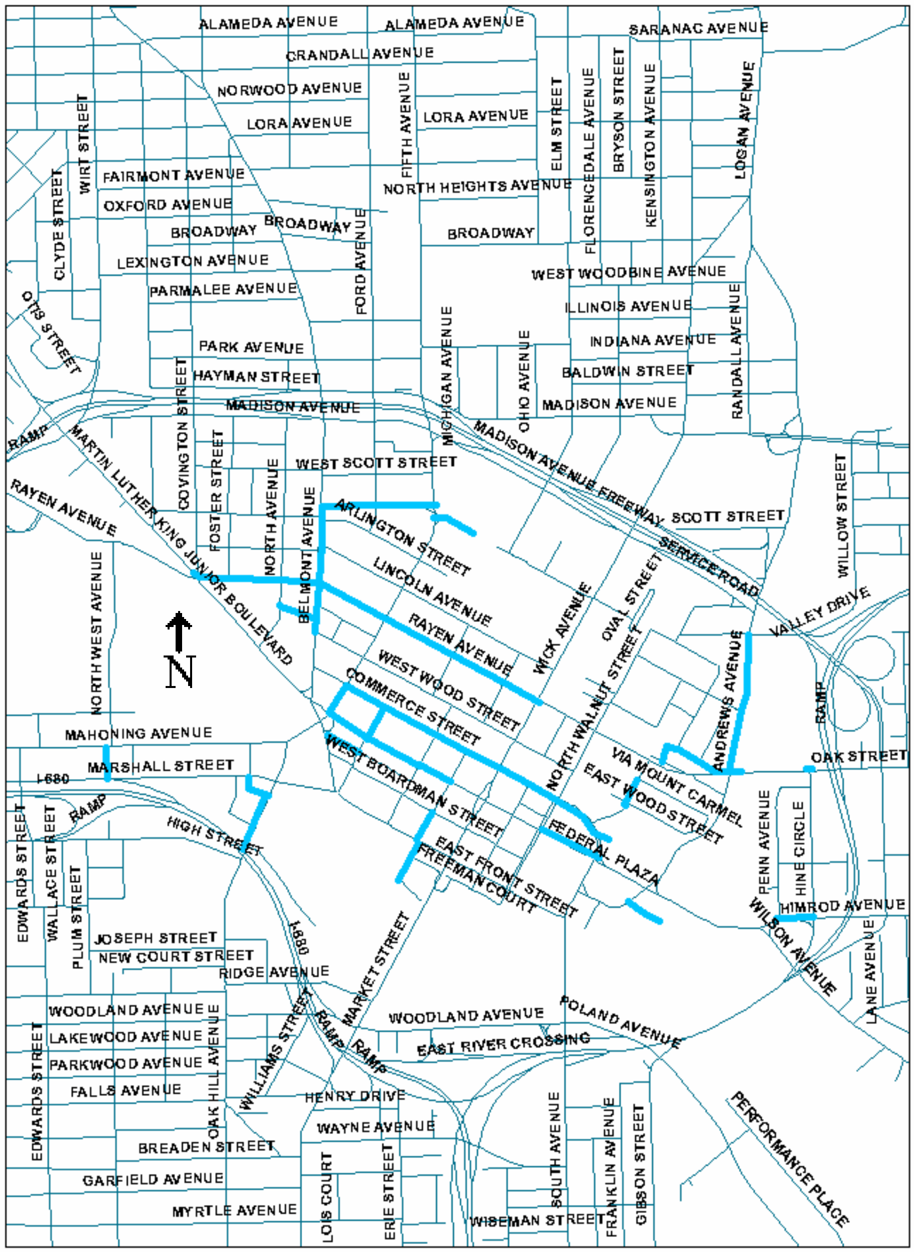


Figure 4-12. Eight Inch, 75 Year Old Cast Iron Mains Map.

Generating a report with the street name and length of pipe selected produced the results shown in Table 4-2. This listing shows that there are 45 sections of 8 inch pipe totaling 19,966 feet. This is detailed enough information that specific plans could be developed with accurate construction cost estimates.

Table 4-2. 8" Cast Iron Mains Over 75 Years Old.

STREET_NAM	PIPE_LENGT
FEDERAL	690
COMMERCE	306
COMMERCE	346
COMMERCE	408
PHELPS	444
FEDERAL	383
FEDERAL	649
COMMERCE	380
COMMERCE	639
CHESTNUT	400
ELK	110
ELK	258
WATT	183
ANDREWS	666
OAK	139
RAYEN	317
OAK	49
SPRING	469
GRANT	644
GRANT	581
RAYEN	802
RAYEN	834
BELMONT	175
BELMONT	218
BELMONT	433
BELMONT	537

BELMONT	428
RAYEN	388
RAYEN	579
RAYEN	379
FEDERAL	498
COMMERCE	478
FIFTH	343
DUTTON	388
VANS	352
WEST	328
RAYEN	422
RAYEN	650
WATT	318
COMMERCE	750
ANDREWS	404
OAK HILL	642
PHELPS	347
ANDREWS	813
HIMROD	399

PIPE_LENGT Count	***PIPE_LENGT Sum***
45	*19966*

Units: PIPE_LENGT-ft

4-9 Assessment Using Seasonal Differences

An end of year or season assessment can be performed using the GIS. To determine the effects of weather or temperature on the water distribution system, the number of water main breaks was compared for the winter versus the summer. The Definition Query was specified as "BREAKDATE" > date '2006-10-31' AND "BREAKDATE" < date '2007-04-01' to limit the search to the water main breaks between November, 2006 and March, 2007. This produced the GIS map shown in Figure 4-13.

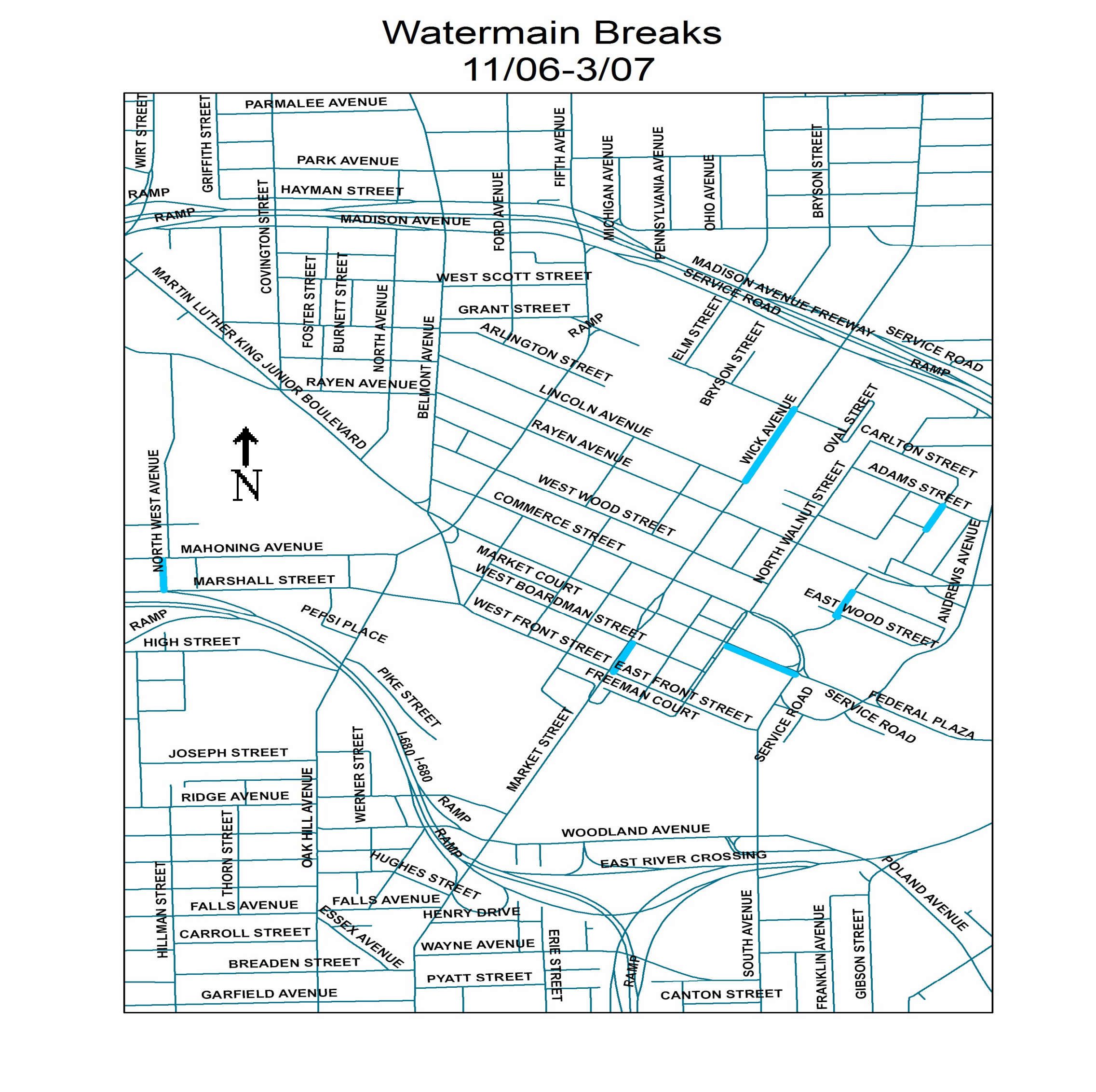


Figure 4-13. Winter Water Main Breaks Map.

The associated report containing the street name, the material the main is composed of, the size of the main, and the year installed, is shown in Table 4-3.

Table 4-3. Winter Water Main Breaks Report

STREET_NAM	PIPE_TYPE	PIPE_SIZE	PIPE_YEAR
MARKET	DIP	12	1967
FEDERAL	CIP	20	1926
WATT	CIP	6	1926
WICK	CIP	12	1926
WEST	CIP	8	1925
WATT	CIP	8	1926

Units: PIPE_SIZE-in

To determine the water main breaks during the warm weather months, the Definition Query was specified as "BREAKDATE" > date '2007-03-31' AND "BREAKDATE" < date '2007-11-01', producing the GIS map shown in Figure 4-14.

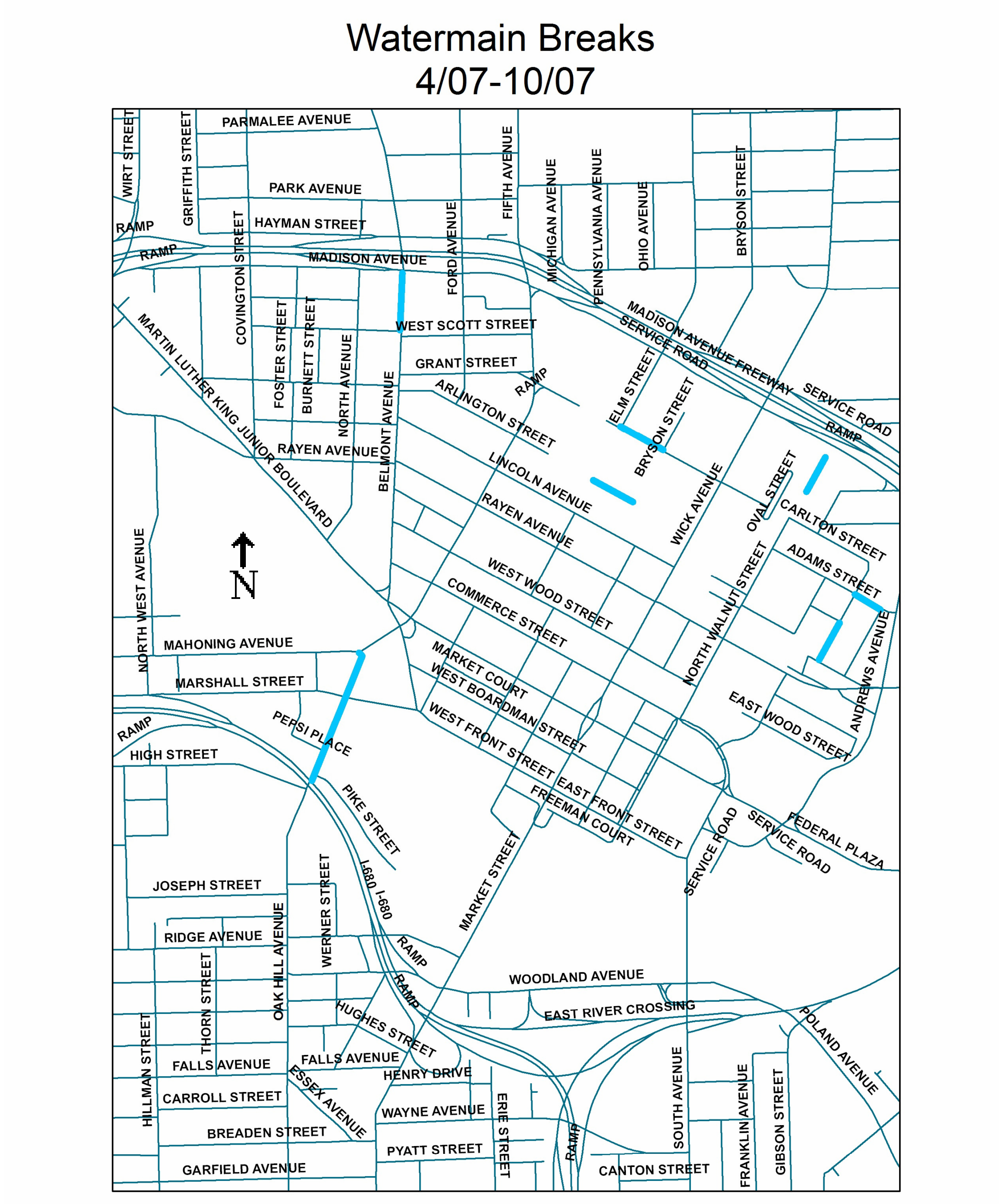


Figure 4-14. Summer Water Main Breaks Map.

Generating the report to show the street name, water main material, size, and the year installed, produced Table 4-4.

Table 4-4. Summer Main Breaks.

STREET_NAM	PIPE_TYPE	PIPE_SIZE	PIPE_YEAR
WATT	CIP	6	1926
ADAMS	CIP	6	1955
WALNUT	CIP	6	1967
SPRING	CIP	6	1926
ARLINGTON	CIP	6	1926
BELMONT	CIP	4	1932
OAK HILL	CIP	6	1926
MAHONING	CIP	6	

Units: PIPE_SIZE-in

The length of pipe on Mahoning Avenue did not have an installation year provided in the original data. Comparing the results, the winter months had 6 breaks and the summer months had 8 breaks. The age of pipe appears similar for both reports. The majority of the pipe in the study is cast iron and both reports reflect this. The key difference between the two time frames is the pipe size involved in the water breaks. During the winter, 50% of the breaks occurred on 12 inch or larger water mains while during the summer no large mains ruptured. This is not conclusive because of the limited sample size, but illustrates the comparative capabilities possible using the GIS.

4-10 GIS for Daily Operation

The GIS can also be used for day to day operations. For instance, if a fire hydrant manufacturer stops production of replacement parts or issues a safety recall on certain parts, it would be prudent to determine the number of hydrants in the system that may be affected and their location. Traditionally, this search would be done by an employee paging through the two binders that comprise the hydrant information. This is a tedious procedure and subjects the results to the potential for human error. It is also difficult to repeat searches with changes in the search parameters.

To search for a specific make of hydrant, the hydrants layer was selected and the Query Builder used to select the manufacturee Vogt. According to the GIS there are two Vogt hydrants in the study area, one on Bryson and one on East Wood St. (Figure 4-15 Vogt Hydrant Map). The report was generated with the fields HYDRANTNUM, ADDSTREET, LAT and LON selected. The finished report is displayed in Table 4-5.

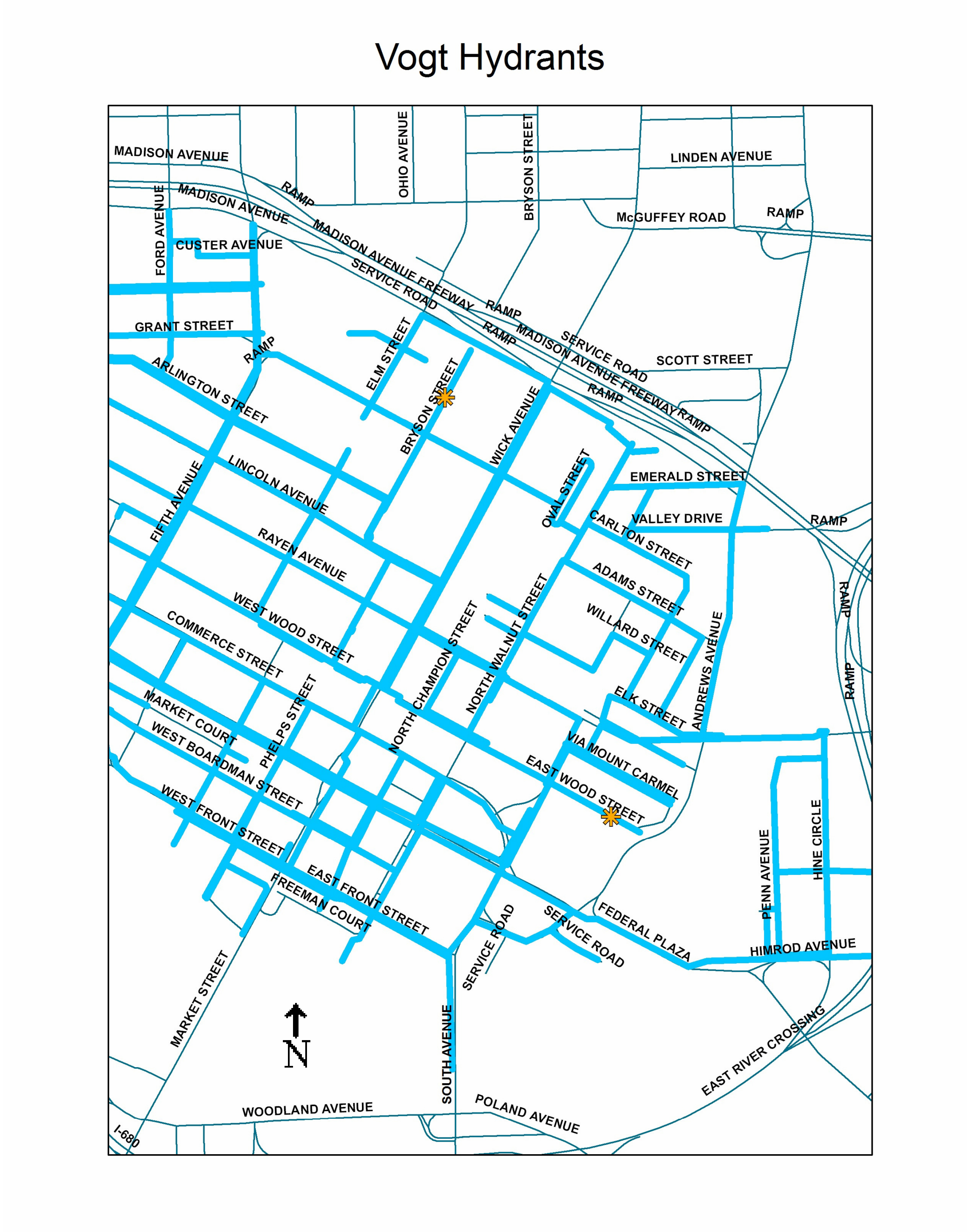


Figure 4-15. Vogt Hydrant Map.

Table 4-5. Vogt Hydrant Locations

HYDR	ADDSTREET	LAT	LONG
YSU90	BRYSON	41.107498	80.646202
Y1266	WOOD	41.0994	80.644997

4-11 Combining GPS with GIS

Combining the GPS coordinates with the GIS allows for an asset to be specifically identified during an event or planning session. Because many fire hydrants are located in areas without a street address, it is often difficult to determine which fire hydrant is being referred to. Often times, repeated trips are made by workers trying to respond to a complaint or incident before the location of the problem can be determined. By providing GPS receivers to work force personnel, ambiguity and repeated trips can be eliminated. Currently, a worker would report a fire hydrant out of service along the freeway using nearby streets and intersections. The aerial photo shown in Figure 4-16 illustrates that, in some cases, there are no convenient landmarks.

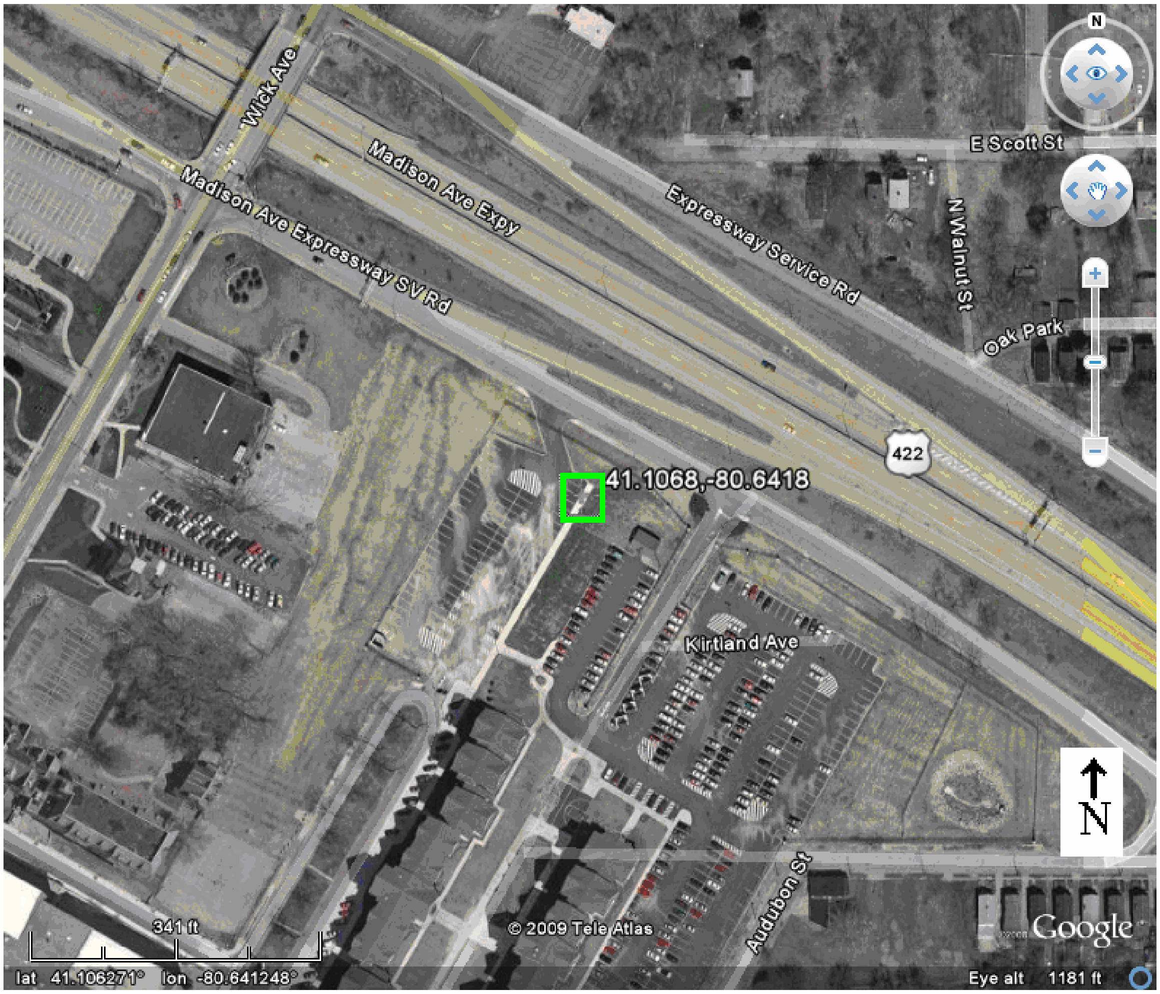


Figure 4-16. Remote Hydrant Aerial Photo. (Google Earth, 2009)

By specifying the GPS coordinates of the hydrant as 41.1068, -80.6418 the specific hydrant can be selected immediately from the GPS. Selecting the Hydrants layer and setting the Definition Query to "LAT" >41.1068 AND "LAT"<41.1069 AND "LONG" >80.6413 AND "LONG"<80.6420 displayed the hydrant that is bracketed by these coordinates (Figure 4.17). A bracket slightly larger than the exact coordinates allows for inaccuracies in the GPS equipment.

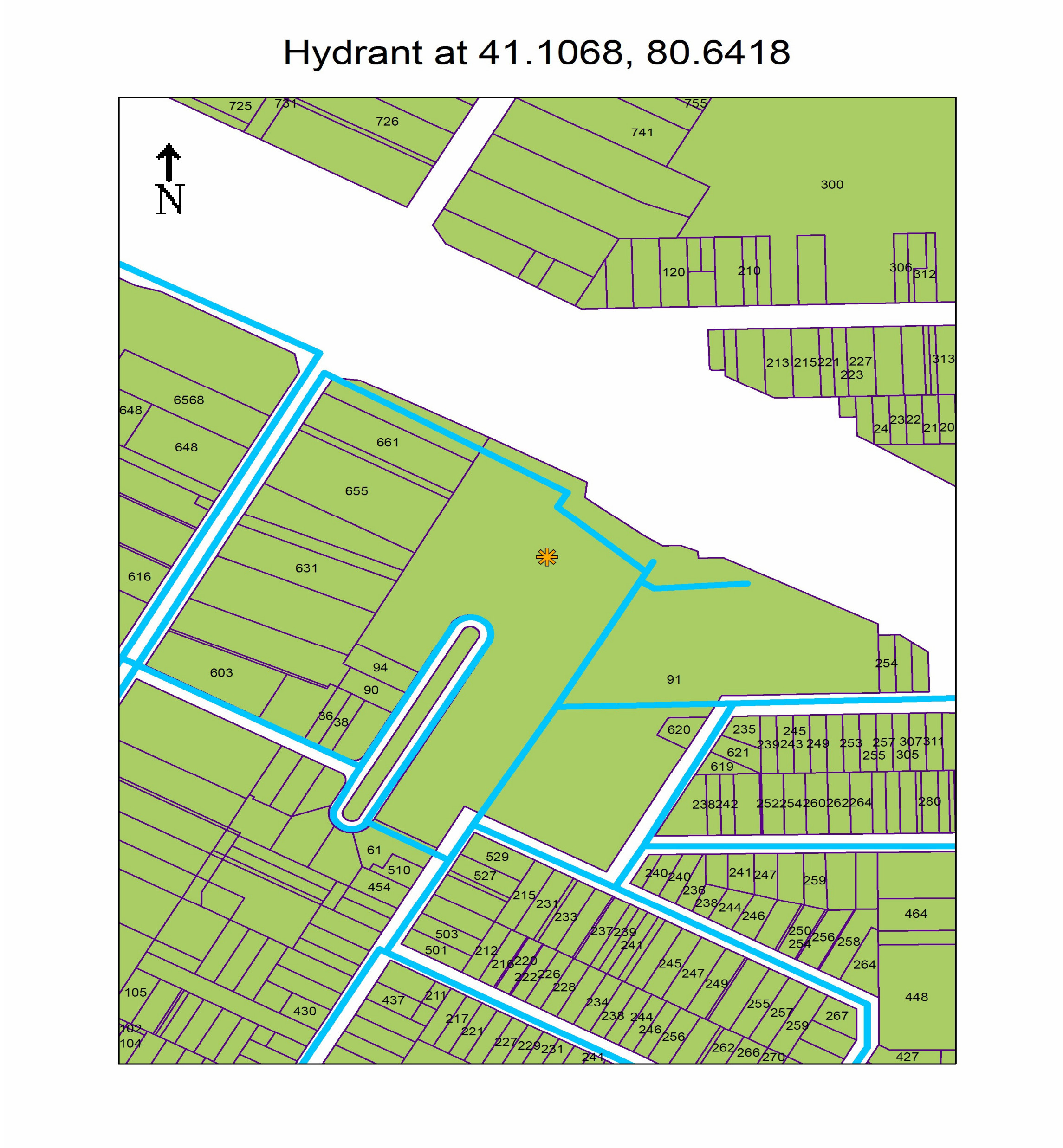


Figure 4-17. GPS Query Display.

By clicking the identify button on the toolbar and then selecting the hydrant, all information pertaining to that specific hydrant was displayed (Figure 4-18). This would allow a work crew to be dispatched directly to the job site with the correct parts required for that specific model of fire hydrant, minimizing down time searching for the proper location.

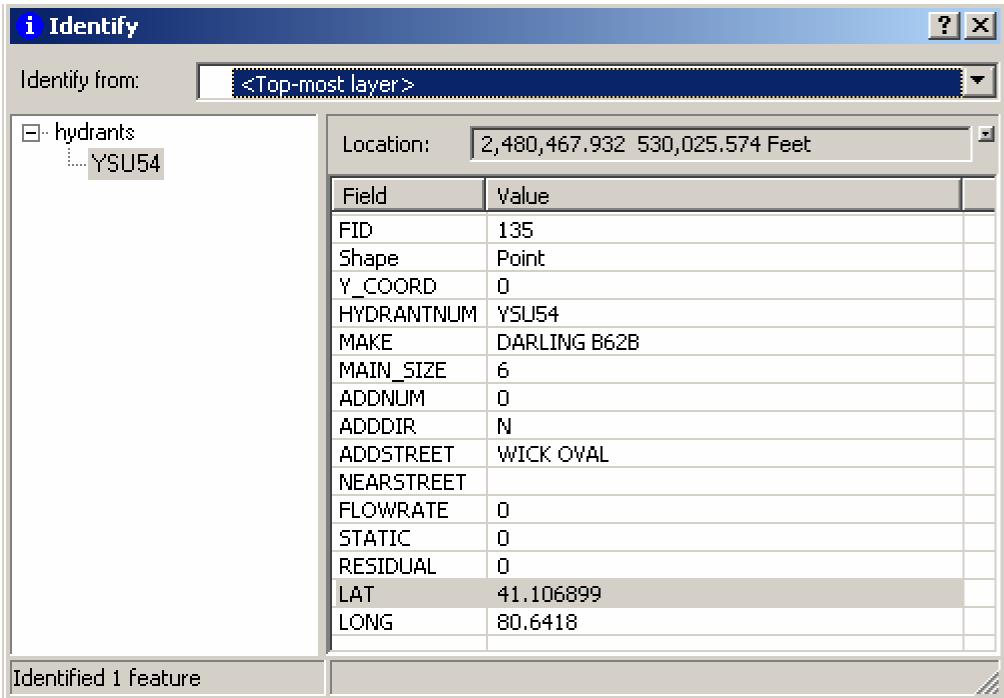


Figure 4-18. Hydrant Identify Display.

4-12 Feasibility

The Youngstown Water Department currently has a single user license for ESRI ArcMap software and a personal computer capable of running it. The position of Engineers Aide / Draftsman is currently filled by a full time employee of the YWD. This employee is responsible for field inspections, assisting work crews in locating department assets and maintaining the map documents currently utilized by the Water Department. This includes the full size maps and the office field book. There are approximately 17 field books in daily use by the department personnel. Any changes, additions or corrections are maintained in the office field book. Approximately every 10 years, the office field book is copied and distributed to the necessary employees. The Draftsman has recently begun to make small revisions using AutoCAD and has been distributing each critical update as an addendum before the complete field book is reprinted.

The YWD has three full time Engineer Aides. The Engineer Aides are responsible for locating assets during the daily field operations of the Water Department. The Engineer Aide will respond to locating requests from work crews, other utilities or the Ohio Utility Protection Service. These employees use the field book extensively throughout the day. After adequate training, replacing the field book with a hand held GIS device incorporating current Water Department data would be a seamless transition for the field employees. Once the GIS is established, the Engineer Aides would be able to make immediate updates and corrections to data in the field. This would reduce the time the Draftsman would dedicate to day to day operations and allow focus to be directed to expanding the functionality of the GIS.

Mobile GIS units would be required for YWD personnel that currently use a Field Book in day to day operations. These include the three Engineer Aides, the Draftsman, six Maintenance Men, three Foreman and four members of the Supervisory staff. One possible option that bundles GIS and submeter GPS functions into one handheld unit is the Magellan MobileMapper CX (Figure 4-19).

Figure 4-19. Magellan Mobile Mapper. (Magellan, 2009)

This unit provides submeter accuracy and compatibility with ArcMap using ArcPad, the ESRI software for mobile computing devices. The current package price per unit is $2,795. Total hardware and software implementation cost for the seventeen construction yard personnel would be 17 X $2,795 = $47,515.

Incorporating current Water Department data presents the largest obstacle. The maps used are large linen or Mylar sheets. The maps have been scanned and saved as digital picture files but have not been put to use. Fire hydrant data are stored as

Microsoft Word documents. Fire hydrant flow test information is stored as a Visual dBase data file. Water tap locations are maintained on index cards. Service account billing information and customer records are housed on a mainframe computer using a COBOL database program.

The maps can be imported into the GIS directly and combined to form their own layer. This can be used as a reference tool as a direct replacement for the Field Book. It can also be used as a template for a full function GIS layer to be drawn over or traced (digitized), dramatically speeding data entry of YWD assets. There are 385 map pages for the YWD system. The sample area was covered with 10 map pages. Data entry of these 10 maps took 20 hours (2 hours per map). The draftsman can reallocate 2 hours per day from physical map maintenance to GIS conversion, allowing full conversion in 385 workdays, or 1.5 years.

The fire hydrant data can be imported with some operator manipulation into a data base format that will allow easy addition to the GIS. The index cards containing water tap and service information present the largest conversion problem. A brute force approach would involve an operator manually entering each card into a database. Another option would be to have the index cards scanned and have the image linked to a database using the address as the common field. The billing account information is currently in a digital format. The City of Youngstown is currently exploring software options to perform billing functions on a Microsoft Windows platform. If this were to be done, inclusion of customer information in the GIS would be straightforward.

Collection of GPS data could be done by water department personnel during their normal work day. The fire hydrant coordinates could be obtained by the three Engineer

Aides during the occasional down time they encounter. Each Aide obtaining 10 hydrant coordinates a day will complete data collection in less than one year (7447 hydrants / 3 aides / 10 hydrants a day / 260 workdays in a year = .95 years).

Assuming the 17 field personnel save one half hour per day and using the base rate of the Engineer Aide ($22.59/hr.), the $47,515 equipment cost will be recovered in 50 weeks ($47,515 / 17 employees per day / .5 hrs per employee / $22.59 per hour / 8 hrs. per day = 50 weeks) . This is a conservative estimate. There are times where a construction crew will sit idle waiting for the correct information to be found regarding a water main or valve. Significant time is frequently lost trying to determine the exact location of water main valves during water main breaks. Reducing search time will reduce the amount of damage caused by main breaks and save the associated repair costs for streets and sidewalks.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

A Geographic Information System (GIS) was developed for a portion of the Youngstown Water Department (YWD) distribution system. Several sample applications of the GIS were performed to evaluate the benefits of the GIS. Based on this work, the following conclusions were drawn:

1. The current system of maps, index cards, notebooks and field books the YWD uses for record keeping can be converted to an electronically accessible form.
2. Converting to an electronic form enables assets of the YWD represented on a map to be linked to a searchable database forming a GIS. The GIS can be used to find general or specific information which can then be displayed on a map or in a table.
3. The GIS can be used in day to day operations by field personnel for repairs, replacement and maintenance of existing assets.
4. The GIS can be used for engineering analysis of the status of the YWD, troubleshooting the existing system and design of replacement water mains.
5. Current technology is available and affordable with a startup cost of $47,515.00 and can be implemented immediately.
6. The GIS can be created and maintained using the existing workforce with no additional labor costs.
7. Using the time of only the field personnel, payback time is 50 weeks. The YWD will then save $48,000 per year by using the GIS.

To maximize the benefits of GIS to the YWD, it is recommended that the YWD:

1. Require plans for all future projects to be submitted in an electronic format. GPS coordinates for all assets should also be field verified and included in an electronic format submitted with the as built drawings.
2. Draftsman should immediately begin conversion of the physical maps. Averaging 2 hours per map conversion will enable completion in less than 2 years.
3. Purchase of handheld computing devices should be done immediately. Data collection can be performed by field personnel as part of their daily routine. The data collected can then be incorporated into the GIS by the Draftsman the following day.
4. Once established, the GIS should be expanded to include customer information such as owner's name and curb box location. YWD collection employees could then utilize the GIS in revenue generating efforts.
5. Coordination with Mahoning County and the Mahoning County Sanitary Engineer's (MCSE) offices should be attempted to allow joint data collection efforts.
6. Take digital photographs of every job site before, during and after any work is performed. The photographs can then be linked to the GIS providing the YWD proof of damage or conflicts with other utilities.

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APPENDIX

This Appendix contains detailed descriptions of the procedures used to create various components of the water distribution system GIS. These details are provided to assist any individuals who might continue or expand upon the work reported in this thesis.

GIS Base Layers

To create the GIS map, the base layers from the Mahoning County GIS department are obtained using the File Transfer Protocol (FTP). Using an internet browser, the Mahoning County website at http://gis.mahoningcountyoh.gov/PublicFT/ is navigated to. There are numerous layers available for downloading including orthographic photos, topographic maps, zip codes and school districts. The specific layers used for this model are: Buildings_ExportCAD.DWG, Property Lines.zip, Road Centerlines.zip, Property Lots.zip and Sewer Features.zip. The Buildings_ExportCAD.DWG file is located in the root of the directory. The other files are located in the Shape_Files directory.

The Road Centerlines.zip file contains the shape file roadcl.shp. The roadcl.shp file will display the centerline of any dedicated roadway in Mahoning County. The Road Centerlines.zip file also contains the roadcl DBF file. The DBF file contains the specific data attributes for the road information. The primary attribute used for this model is STNAME. This field contains the street name, and by including it allows the street name to be displayed on the model.

The Property Lines.zip file contains the shape file proplines.shp. The proplines.shp shapefile will display the property lines of a parcel. This file only displays the perimeter of a parcel. The Property Lots.zip file contains the shapefile PROP20080509J.shp. This file will display the property lot of a parcel as polygon. The Property Lots.zip file also contains the file PROP20080509J.DBF. This file contains the attributes for each parcel. These attributes include the parcel area in square feet, the perimeter in feet, the county property identification number, the deeded owner, the street name, the street address, the school district, and the mailing address.

The Buildings_ExportCAD.DWG contains an outline of each permanent structure located on a property. This is a computer aided drafting (CAD) drawing. This file does not contain any information or data attributes for each structure. It is only a line drawing of the perimeter of each building.

The files must be downloaded to the user's computer. For portability reasons, an external hard drive was used as the main storage device. The hard drive used is a Western Digital 5000AAV 500 gigabyte drive. A directory is created to store the GIS files from the county. The file directory is titled County GIS. Inside the County GIS folder is created a separate folder for each file to be downloaded. These folders are named Buildings, Property Features, Property Lines and Roads.

To download the files from the Mahoning County GIS FTP site, http://gis.mahoningcountyoh.gov/PublicFT/, click on the file name with the mouse using the right button. This will open a dialog box. One of the choices is to Save Target As. Clicking on this choice using the left mouse button will open a popup window allowing the user to determine the location of the file directory. Click on the appropriate folder name, then click Save. The correct files are shown in Figure A-1. A download progress window will open and show the percent completion. Some of the files are very large and may take several hours to download. Once the download is complete, a dialog box will appear giving the options to Open, Open File, or Close the box. Clicking on Open will open the file and extract any compressed files if they are included in the file as shown in Figure A-1.

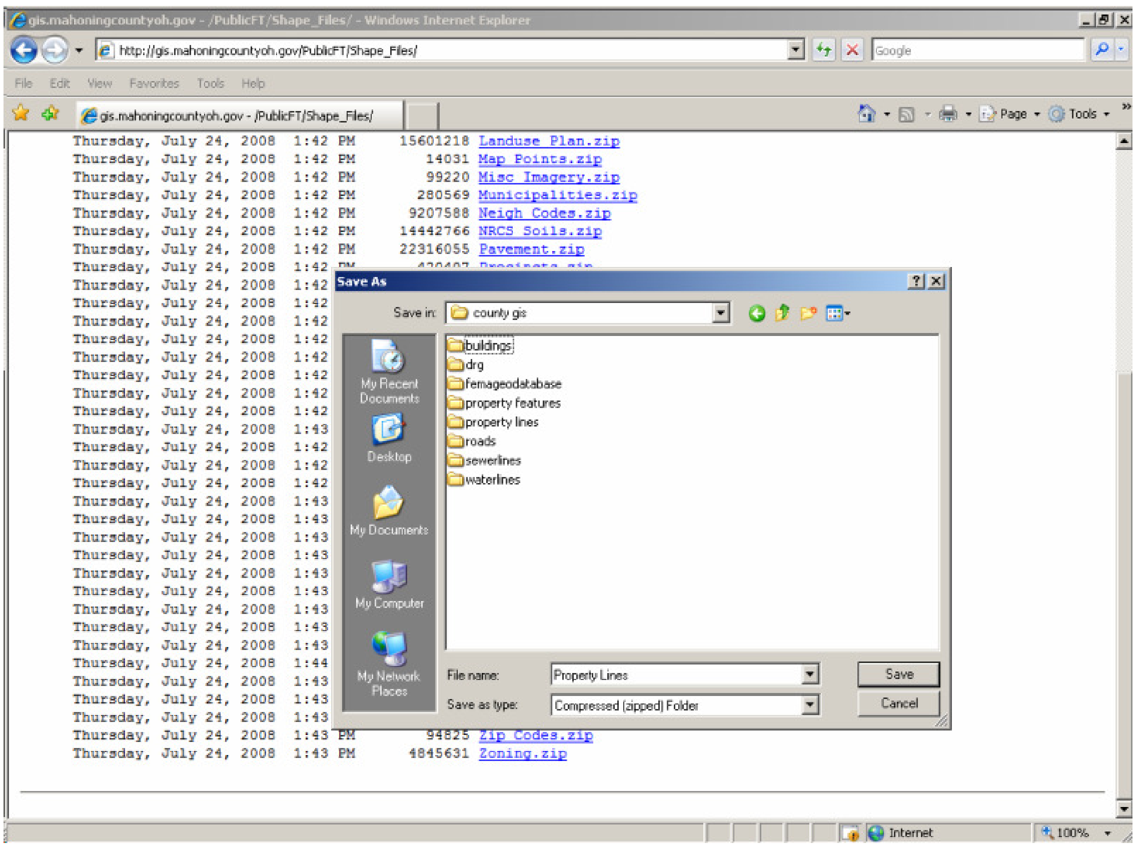


Figure A-1. Download Screenshot.

ArcGIS must be installed on the computer. This is done by following the instructions provided by the manufacturer. Once ArcGIS is installed and the GIS layers are downloaded and saved to the appropriate folder, ArcMap can be started by clicking on the ArcMap icon on the computer desktop. Alternately, ArcMap can be started by clicking the Windows Start button, sliding to Programs, sliding to ArcGIS, sliding to ArcMap, then left clicking on the ArcMap icon. ArcMap will open and query the user to open an existing map or create a new empty map. Clicking a new empty map, then the OK button will open a blank ArcMap workspace. Using the mouse and right clicking will open a menu box as shown in Figure A-2.

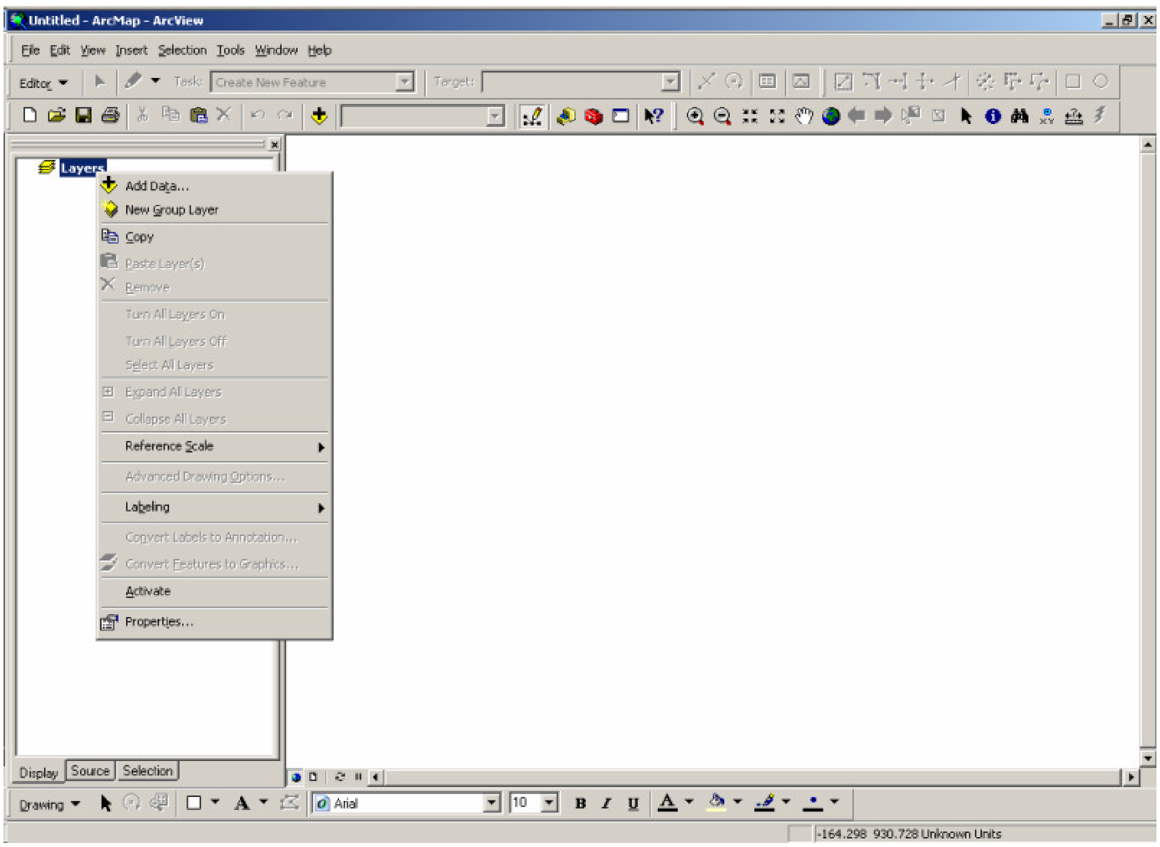


Figure A-2. ArcView New Map Screen.

Clicking on Add Data will open a window allowing navigation to the file to be added. Figure A-3 shows the roadcl.shp file inside the roads folder.

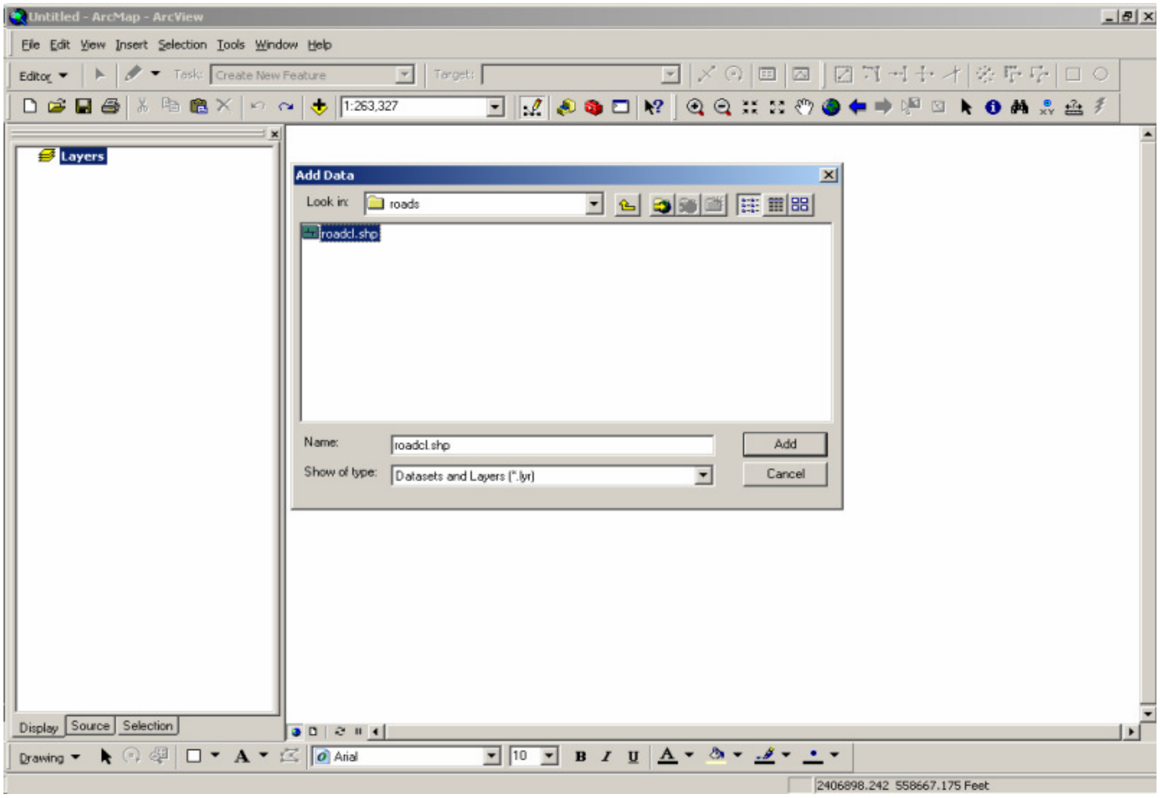


Figure A-3. Roadcl.Shp Screen.

Clicking the Add button will add the road centerlines for Mahoning County to the map (Figure A-4). This procedure is duplicated for the property line file – proplines.shp, the property lots file – PROP20080509J.shp, and the building outlines file – Buildings_ExportCAD.DWG.

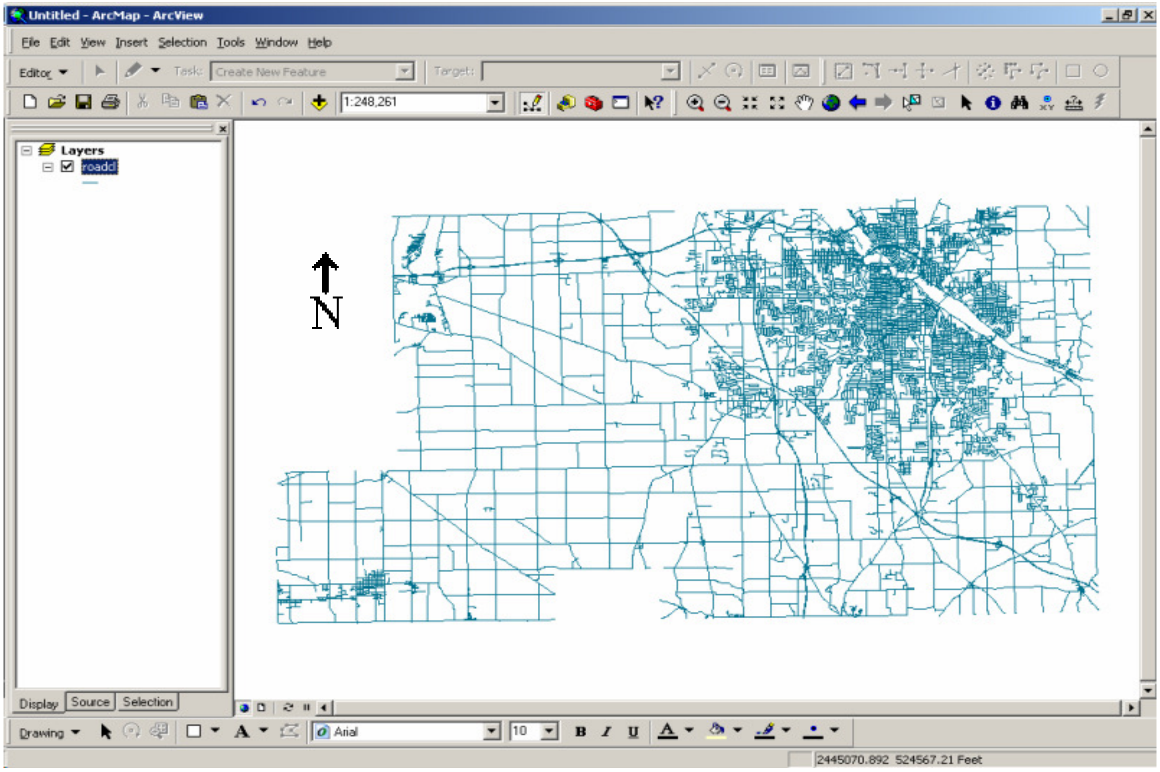


Figure A-4. Mahoning County Roads.

Figure A-5 shows the GIS centered on the Youngstown State University Campus with all four layers installed and active.

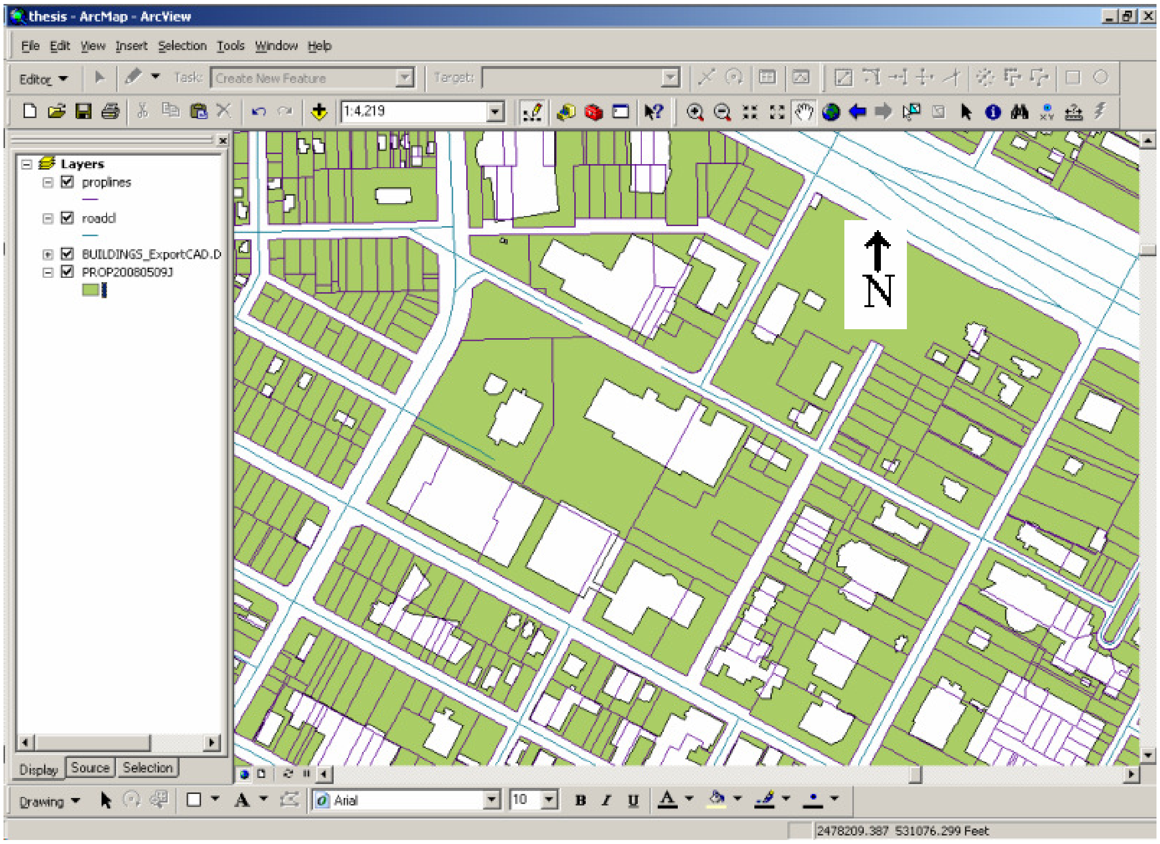


Figure A-5. YSU Layers.

To aid in recognition of streets and buildings, the street names and the building addresses are displayed. To do this, right click on the roadcl layer. This opens a drop down box. The bottom option is Properties. Left clicking with the mouse will open a box with tabs showing options for the specific layer properties. Clicking the Labels tab will show a box enabling options for Label Fields. Scrolling through the fields will show STNAME. This is the field in the database that contains the name associated with that section of roadway. Click on the check box to Label features in this layer, and then click the Apply button on the bottom right. Click the OK button and the street names will appear on the GIS (Figure A-6).

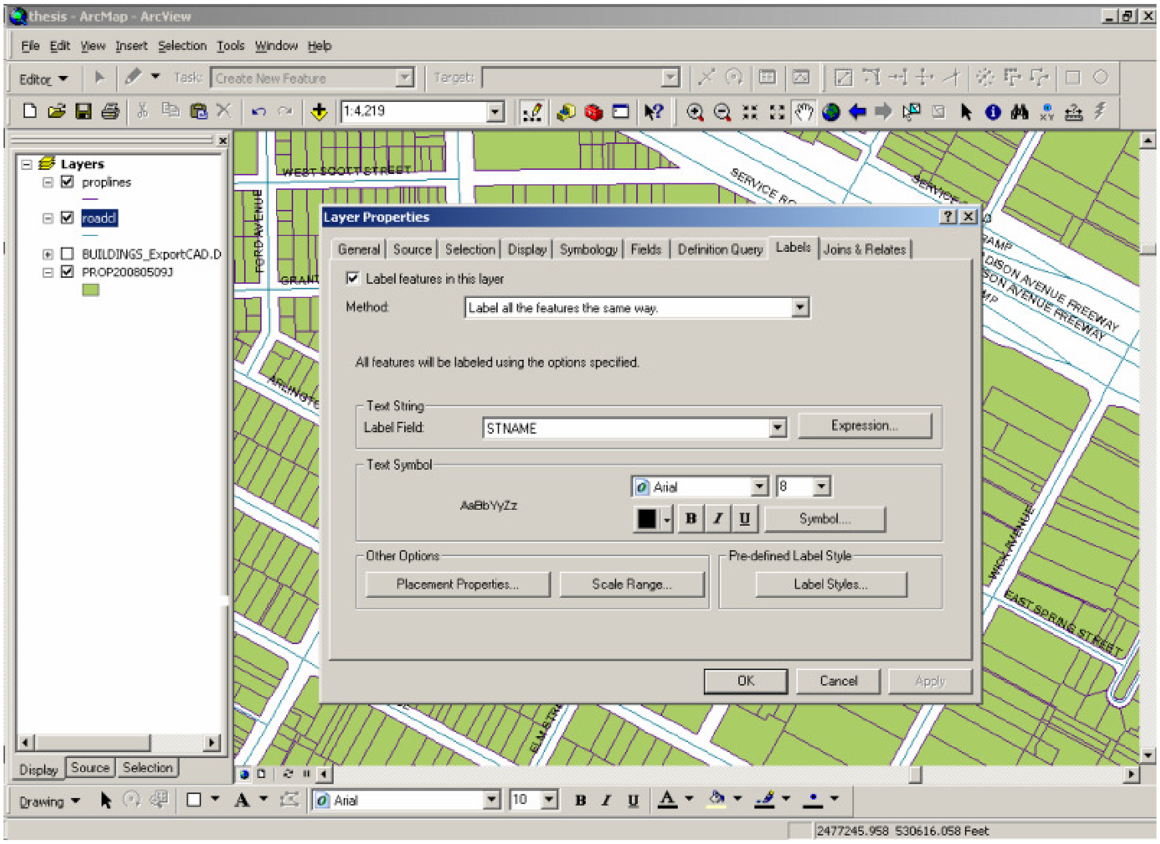


Figure A-6. Address Display.

The same procedure is used to display the addresses for each lot. The addresses are an attribute of the PROP20080509J.DBF layer. Right clicking on this layer name, then clicking on Properties and setting the Label Field to LOCNUM will select the address. Left clicking the Label features in this layer, the Apply button and then the OK button will turn on the addresses. Figure A-7 shows the GIS with all layers active and the street name and building addresses displayed.

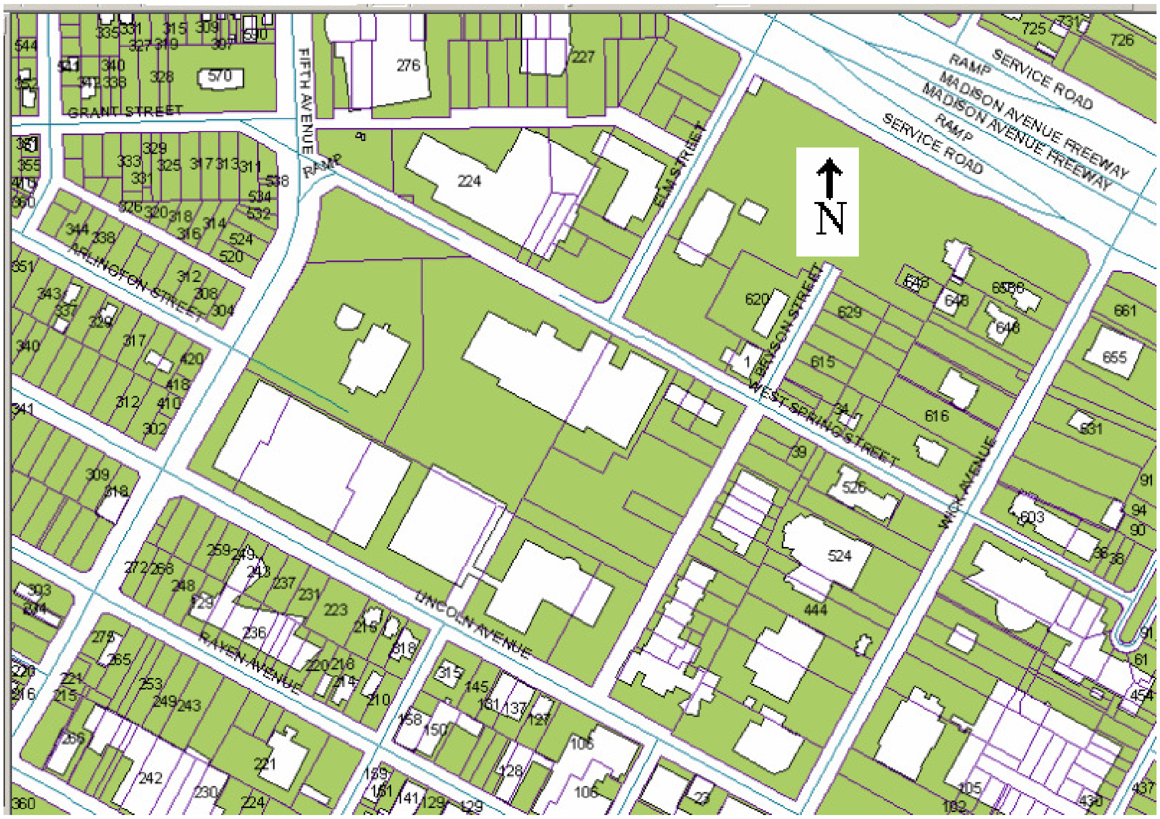


Figure A-7. Base Layers Closeup.

This procedure establishes the basic framework for the GIS project. Selecting File, then Save As will present the option of saving the GIS framework at this point. The filename used for this model is Thesis. For other applications or full-scale development of this GIS, an appropriate file name should be selected.

Waterline Layer Creation

To ensure compatibility of the new "waterlines" layer with all layers of the existing Mahoning County GIS, a similar GIS layer was used as a template. In this project, the file Sewer Features.zip was used from the Mahoning County GIS website. The procedure to download it is identical to the base map layers. Once the file is downloaded, the data attributes must be changed from sewerlines to the waterlines attributes. ArcView has a data editor component called ArcCatalog that facilitates data management. To open ArcCatalog from within ArcMap, the Tools heading on the menu bar is clicked. The ArcCatalog icon is then clicked on the drop down box. This opens ArcCatalog. The file structure is shown on the left side of the workspace. In this case, the files are located on the E: drive. Left clicking the E: drive icon, the county gis icon and then the sewerlines icon will show the two data sets available in this folder as shown in Figure A-8.

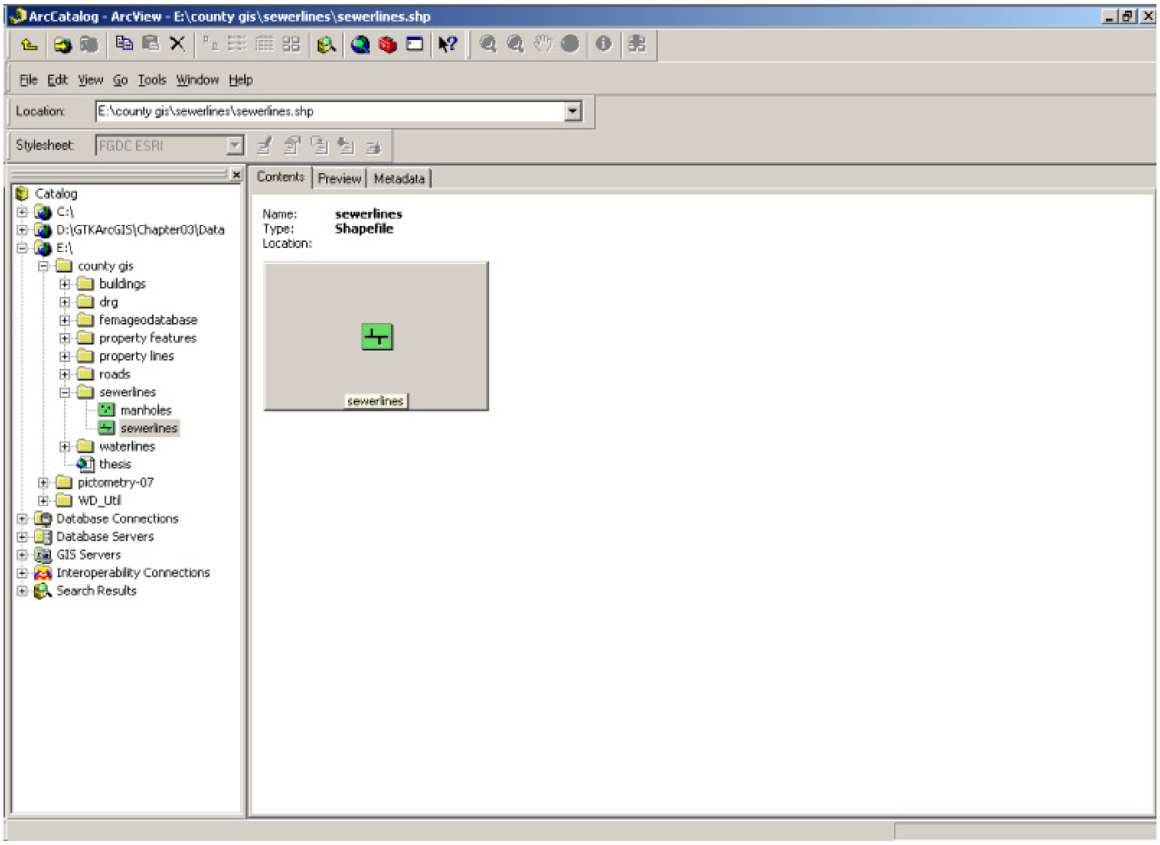


Figure A-8. Sewerline Layer Screen.

Right clicking on the sewerlines file name opens a menu box with Properties as the bottom option. Left clicking on Properties will open the Shapefiles Properties window. This window has four tabs: General, XY Coordinate System, Fields and Indexes. The General tab will show the file name. The XY Coordinate System will show the map Projection, map Datum and the Geographic Coordinate System used. The Fields tab will show the data fields for this layer and the type of data contained. The data type may be: short or long integer, float, double, text or date. The Index tab gives the option of creating a database index based on a specific data field. An index will increase the speed with which database searches can be performed.

Clicking on the Fields tab displays the data fields. These will be deleted and the waterline fields will be created. To delete the data fields, the field name is clicked on using the left mouse button. This will highlight the name as shown in Figure A-9.

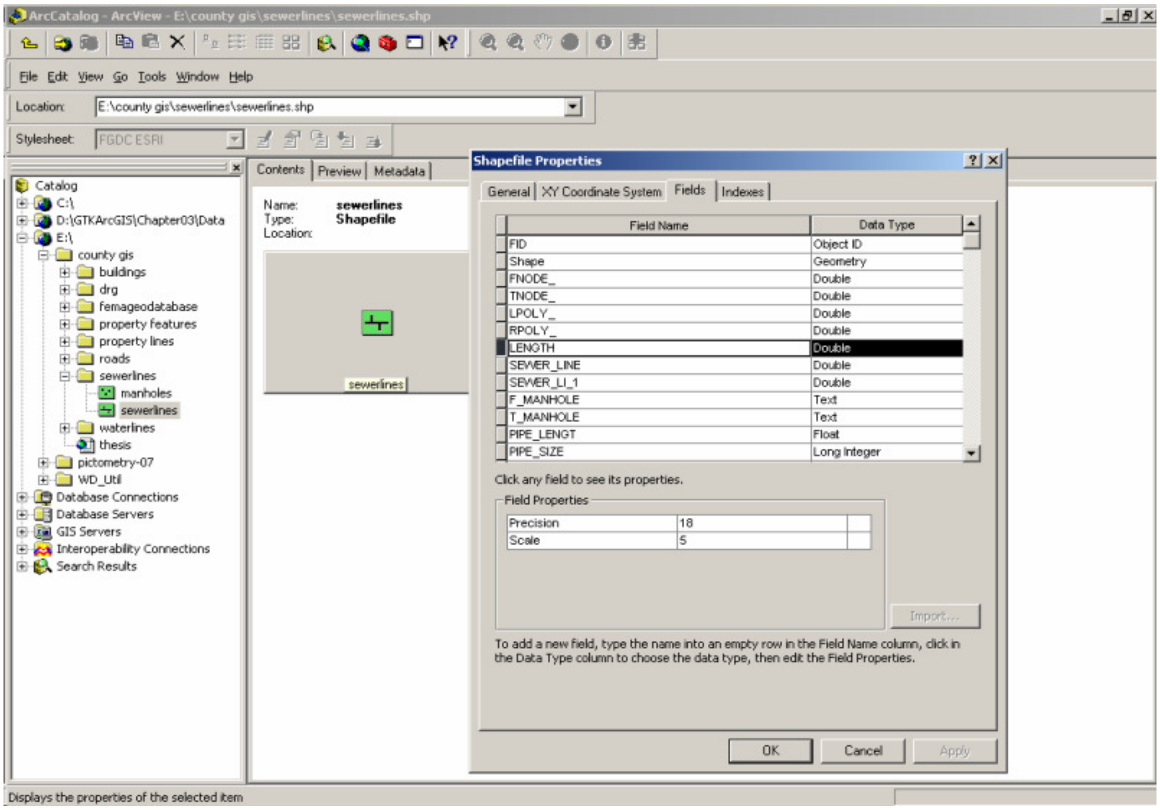


Figure A-9. Sewerline Delete Screen.

Hitting the delete button and then clicking on the Apply button will remove the data field from the file structure. This is performed repeatedly for all fields except FID, Shape, Fnode_, Tnode_, Lpoly_ and Rpoly_. The FID and Shape fields are default fields. The FID is an identification number used to "uniquely identify each object, or feature while the Shape field stores each feature's geometry (the coordinates) (ESRI, 2006). The attribute fields Fnode_, Tnode_, Lpoly_ and Rpoly_ are kept to allow for potential future use in water modeling software.

Once all of the data fields are removed except for those mentioned, the Apply button and then the OK button are clicked using the left button of the mouse. The sewerline name is clicked using the right button of the mouse. This opens a pop up menu with a Rename option. This is left clicked and the sewerline name is changed to waterlines. Left clicking the county gis folder, then left clicking the File heading, then New Folder will create a new folder in the county gis directory. Typing waterlines in the box provided for the folder name, then hitting enter will finalize the new water lines directory. To copy the waterlines data file from the sewerline folder to the waterlines folder, the waterlines name is then right clicked opening a pop up menu. Left click with the mouse on the Copy button, then left clicking on the waterline folder, right click and select Paste.

Right clicking on the waterlines file in the water lines folder will open a pop up menu. Left clicking on Properties in this menu will open the Shapefile Properties window. Clicking on the Fields tab will present the Field Name and Data Type entry fields. Left clicking on the blank Field Name will allow entry of the first data attribute field for the water lines. PIPE_LENGT is typed in and the Enter key is pressed. This will move to the Data Type scroll down menu. This allows for determination of the kind of information that this field will contain. The options are: short and long integer, float, double, text and date. Long integer and double are used for numbers above 32,767. For PIPE_LENGT, the Float Data Type is chosen. The Field Name and Data Type are then entered for each waterlines attribute as shown in Table A-1. The Apply button and then the OK button are then clicked with the left mouse button.

Table A-1. Water Main Attribute Data Types

Field Name	Description
PIPE_LENGT	Float
PIPE_SIZE	Long Integer
PIPE_GRADE	Text
PIPE_YEAR	Float
PIPE_VALUE	Text
PIPE_MAINT	Float
SYMBOL	Double
LAT	Float
LON	Float
STREET_NAM	Text
STREET_DIR	Text
REPAIRCOST	Long Integer
BREAKDATE	Date

The next task is to add water lines to the GIS. Left clicking the ArcMap icon on the menu bar will open ArcMap. Selecting File, Open, and then Thesis (or whatever the geodatabase is named) will open the GIS framework previously saved.

To add the waterlines layer to the GIS map, right click the Layers icon, then left click on Add Data. This will open the Add Data window as shown in Figure A-10.

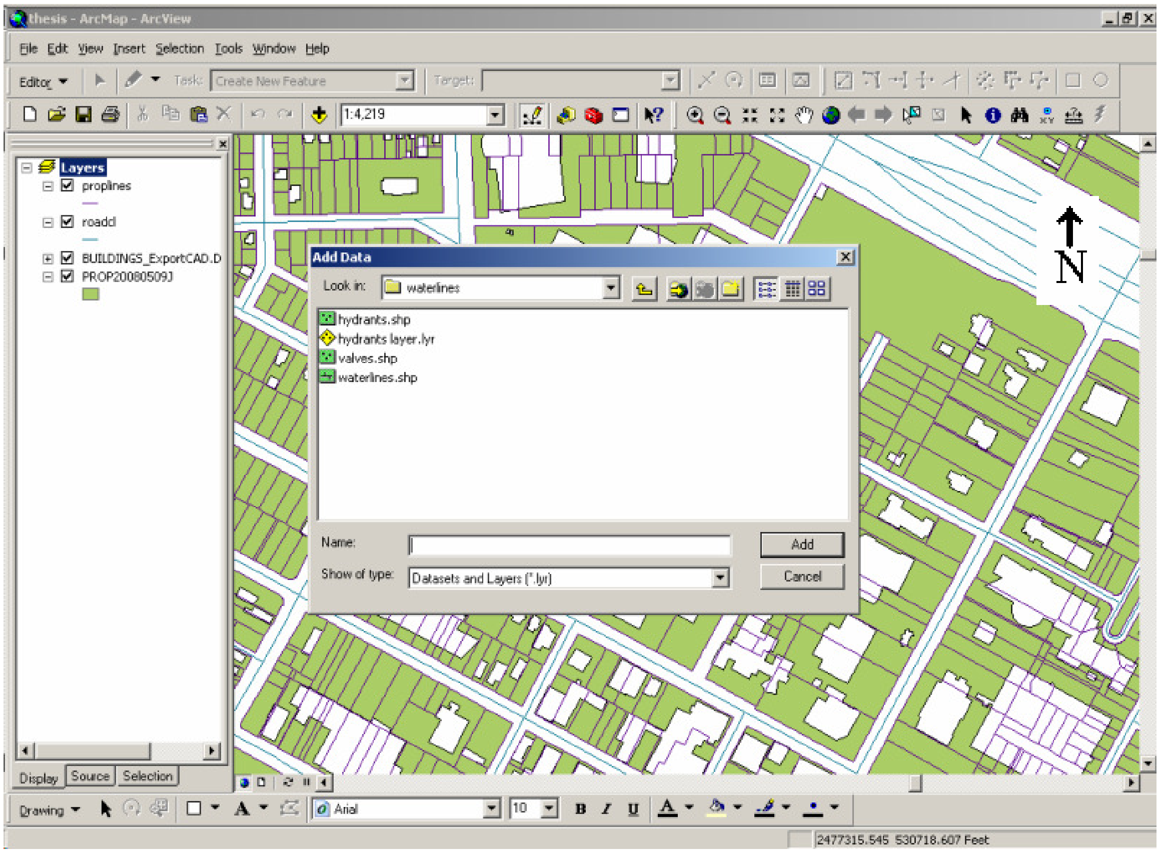


Figure A-10. Waterline Layer Additions.

The waterlines.shp file name is left clicked, then the Add button is left clicked. The waterlines layer is now ready to be populated with data.

To add data to the waterline layer, the Editor button on the menu bar is left clicked, then left click the Start Editing button that appears. This will open a window that presents all of the layers of the GIS that are possible for editing, shown in Figure A-11.

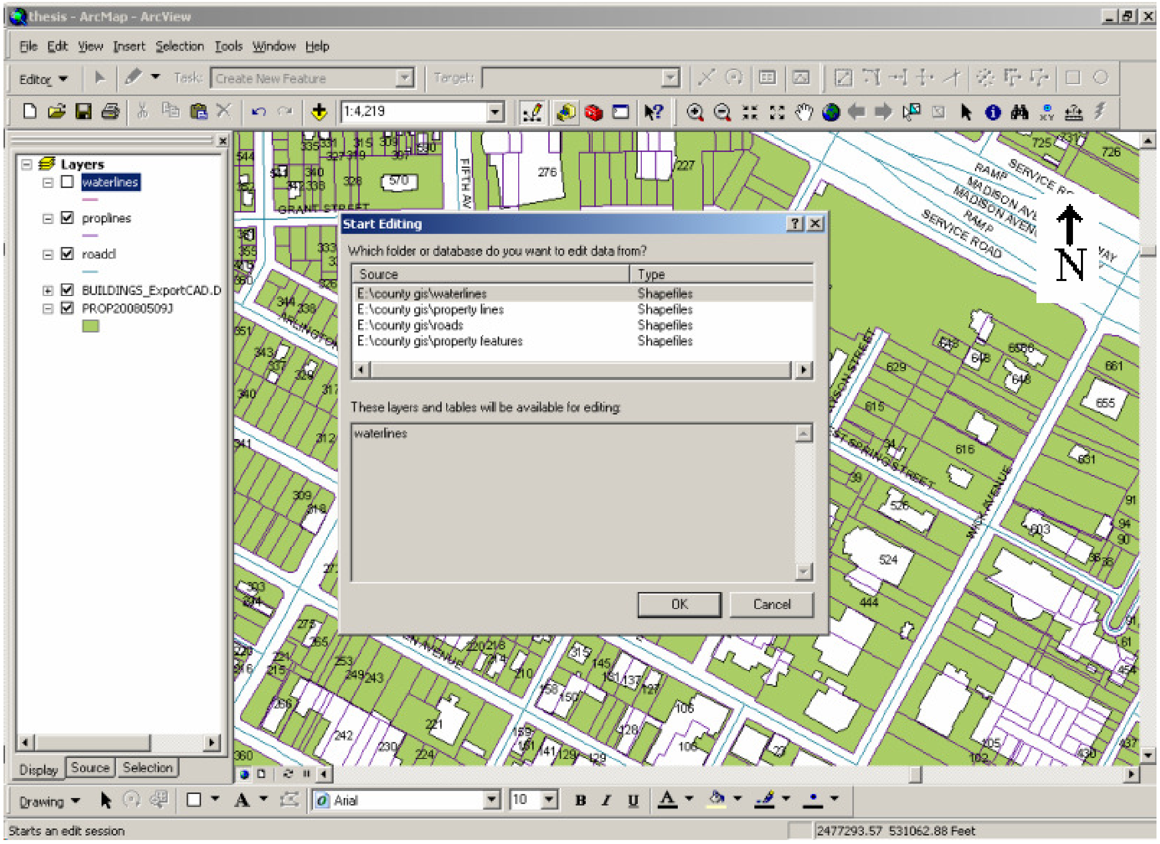


Figure A-11. Layers Available for Editing.

The waterlines layer is selected, and then the OK button is clicked. The map is panned using the hand symbol from the tool bar to center on the location of interest.

To draw a waterline, the pencil icon on the menu bar is selected. This will change the mouse pointer to a cross hair. The cross hair pointer is placed at the starting location of the water main and. The left button is clicked. The mouse is then moved to position the cross hair at the ending location of the water main and the left mouse button is clicked to anchor the water main at this point. The right mouse button is then clicked while the cross hair is still located over the end point. This will produce a menu box. Selecting the option Trim to Length will open an entry box allowing the exact length of the water main to be entered if known. Some measurements may be available from the original map. As the scale of the original map is 1" to 100', one other option is to calculate the length by measuring the length in inches on the map and then multiplying by 100. Once the length of the water line is determined, pressing the F2 button will finish drawing that segment. Using the mouse to right click the waterlines layer in the Table of Contents window will allow the Open Attribute Table option to be selected (Figure A-12).

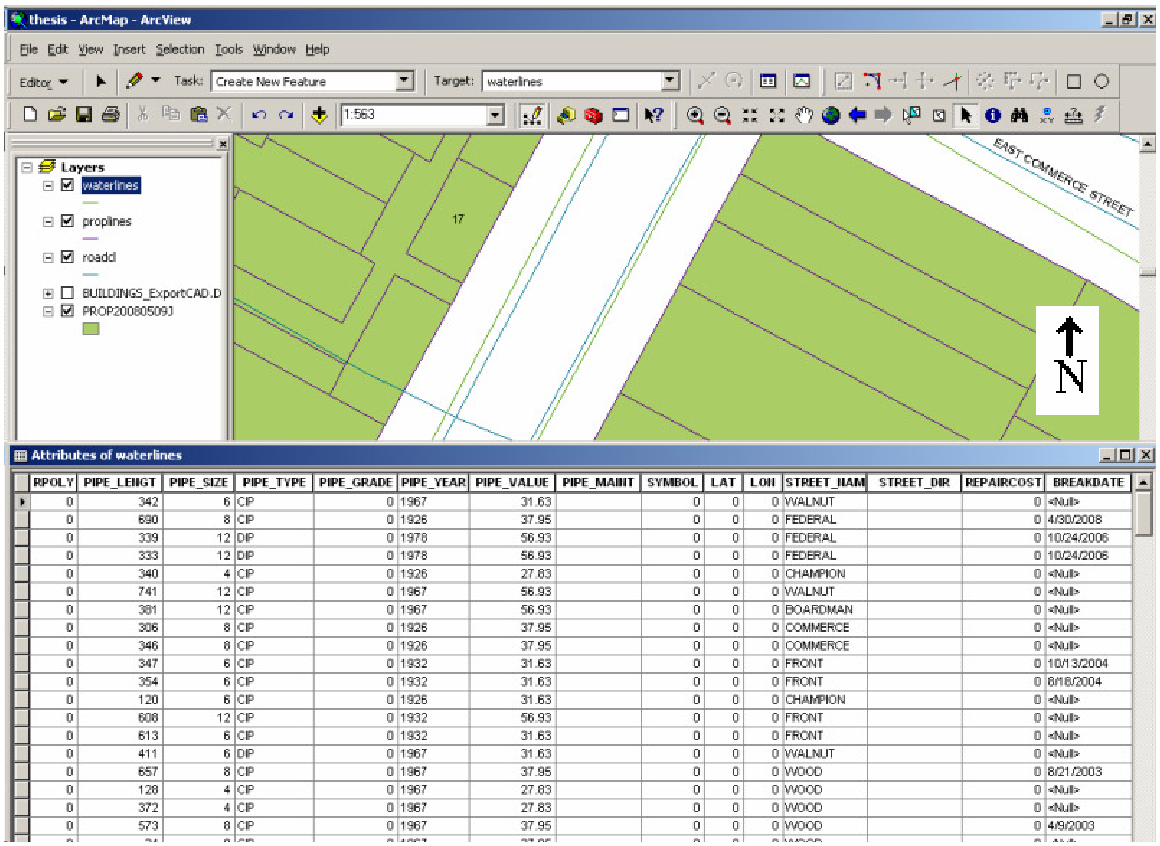


Figure A-12. Waterline Creation.

Using the data from the YWD Inventory Work Sheet, the attributes for the water main just drawn are entered. This procedure is then repeated until all of the water mains in the predefined area are drawn and all of the available attributes are entered. The Editor button is then clicked using the left mouse button, followed by the Save Edits button and then the Stop Editing button. At this point it is prudent to save the complete GIS map. This is done by left clicking the File button, the Save As option, then entering the name of the GIS and specifying the location to be saved.

Fire Hydrant Layer Creation

ArcCatalog was used to create the fire hydrants layer. The manholes layer was copied from the sewerlines folder to the waterlines folder and renamed as "hydrants". Right clicking on the hydrants layer in the Catalog tree opens a pop up menu. Left clicking Properties opens the Shapefile Properties window (Figure A-13).

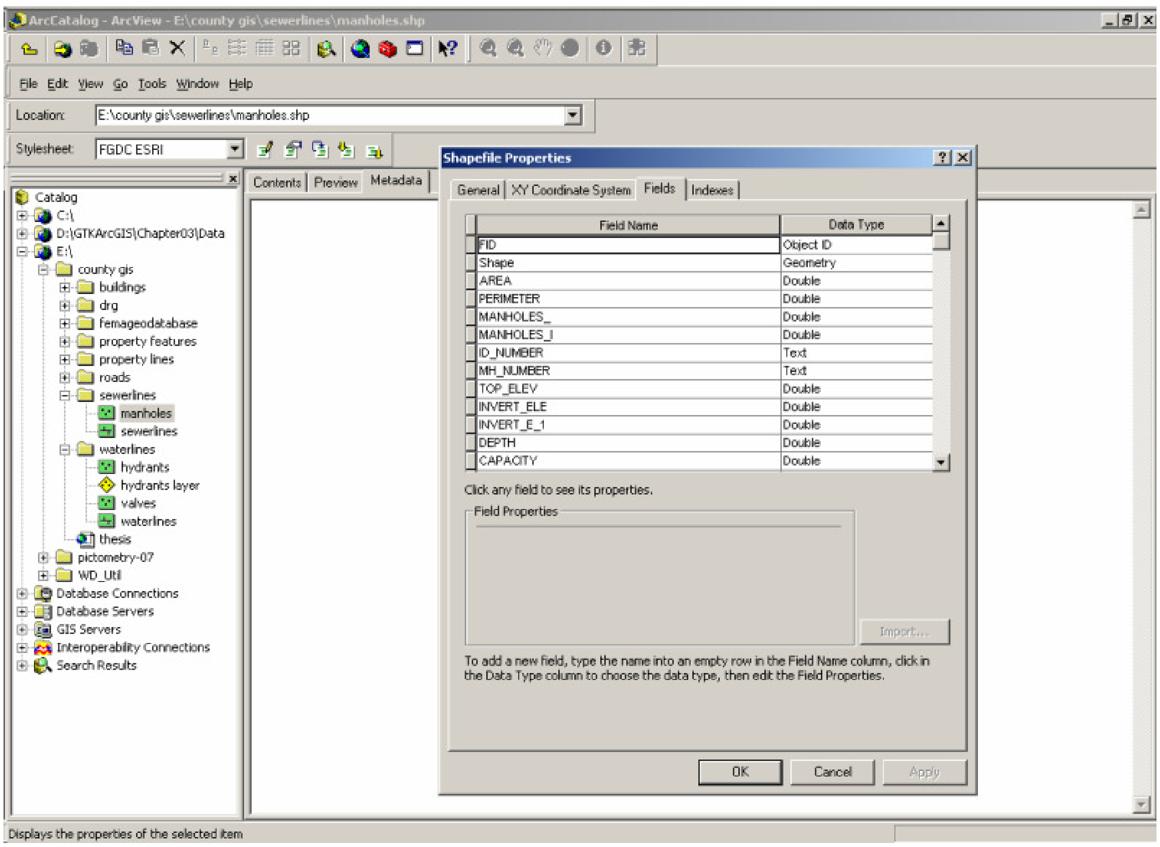


Figure A-13. Manhole Layer.

It was necessary to delete all of the fields used to hold the attributes for the manholes and replace them with the Field Names and Data Types for the fire hydrant attributes.   HYDRANTNUM, MAKE, ADDDIR, ADDSTREET and NEARSTREET are Text fields. The MAIN_SIZE, ADDNUM, FLOWRATE, STATIC and RESIDUAL fields are all Short Integer numerical fields. The LAT and LONG fields are Float numerical fields, as shown in Figure A-14. Once entry of this information was complete, the Apply button and OK buttons were clicked and ArcCatalog was closed.

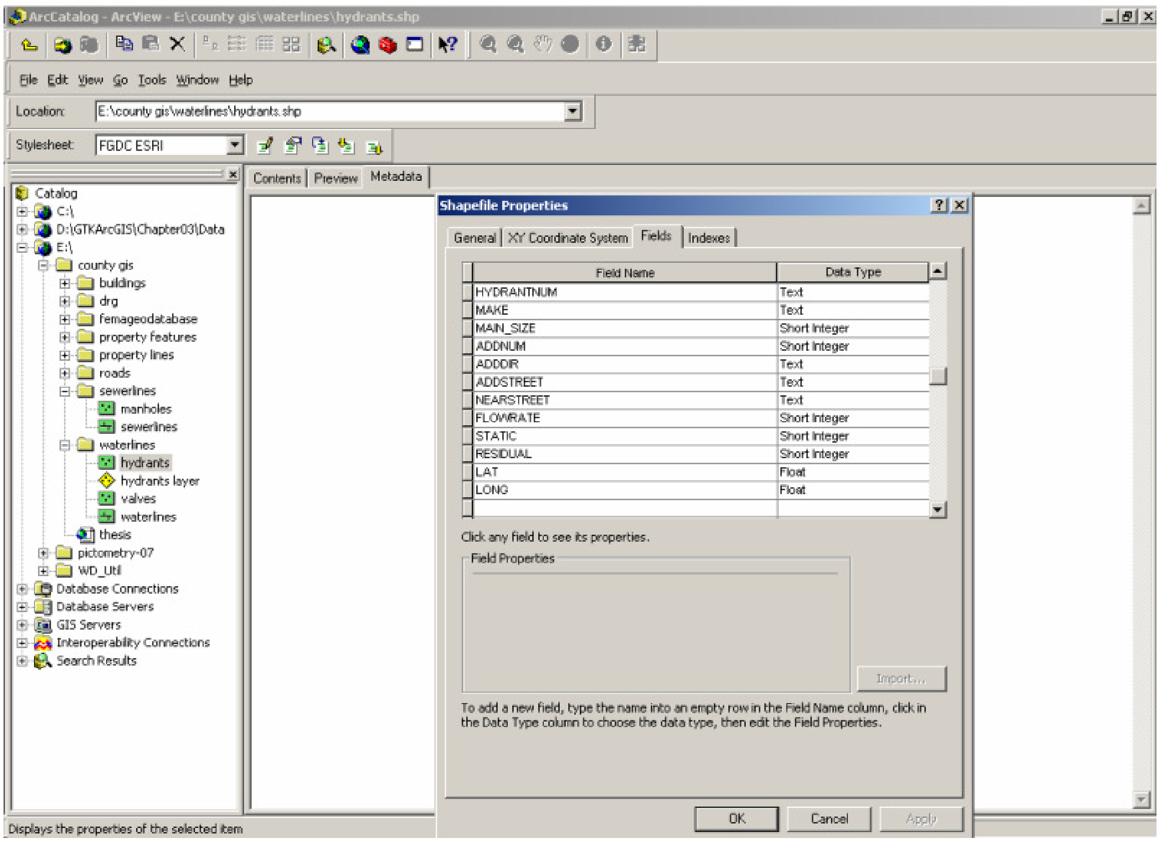


Figure A-14. Creating Hydrant Fields.

To draw the hydrants on the GIS, ArcMap is opened, and the following procedure applied:

1. Right click the Layers icon to open a pop up menu presenting the Add Data option.
2. Left click Add Data to open a window allowing the hydrants layer to be selected.

3. Left click the hydrants.shp file then the Add button to insert the hydrants layer into the GIS.
4. Left click the Editor button on the menu bar, then Start Editing to open a window allowing selection of the folder that the hydrant layer is in. The hydrants layer is located in the waterlines folder.
5. Once the hydrants layer is selected, the Task pull down menu will present several options. Select Create New Feature and set the Target option to hydrants to permit entry of new fire hydrants.
6. Click on the Ruler button on the toolbar to activate the Measure function. This enables placement of the hydrant on the GIS to duplicate the accuracy of the existing paper map (Figure A-15).
7. Once the correct location of the hydrant is determined, the pencil icon on the Editor bar is selected, enabling the Sketch tool. The cursor is placed at the location of the hydrant and the left mouse button clicked to add a hydrant symbol.

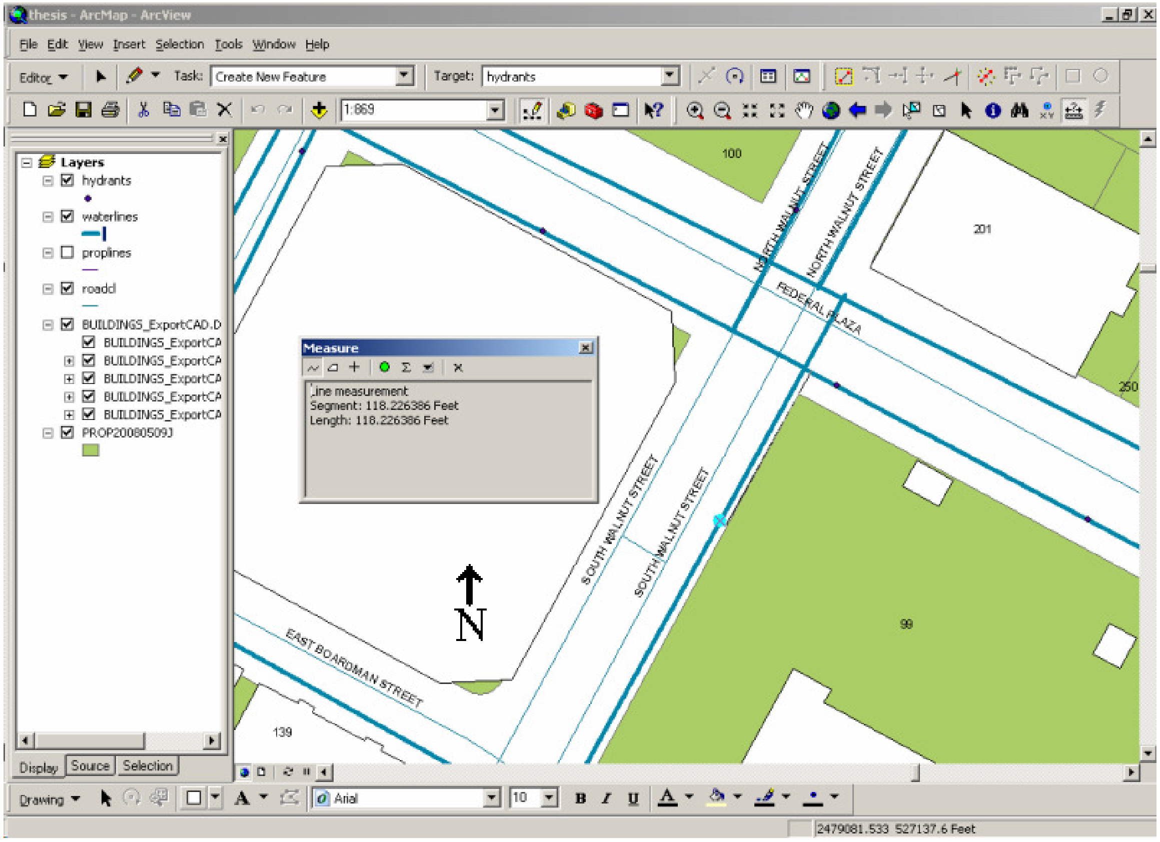
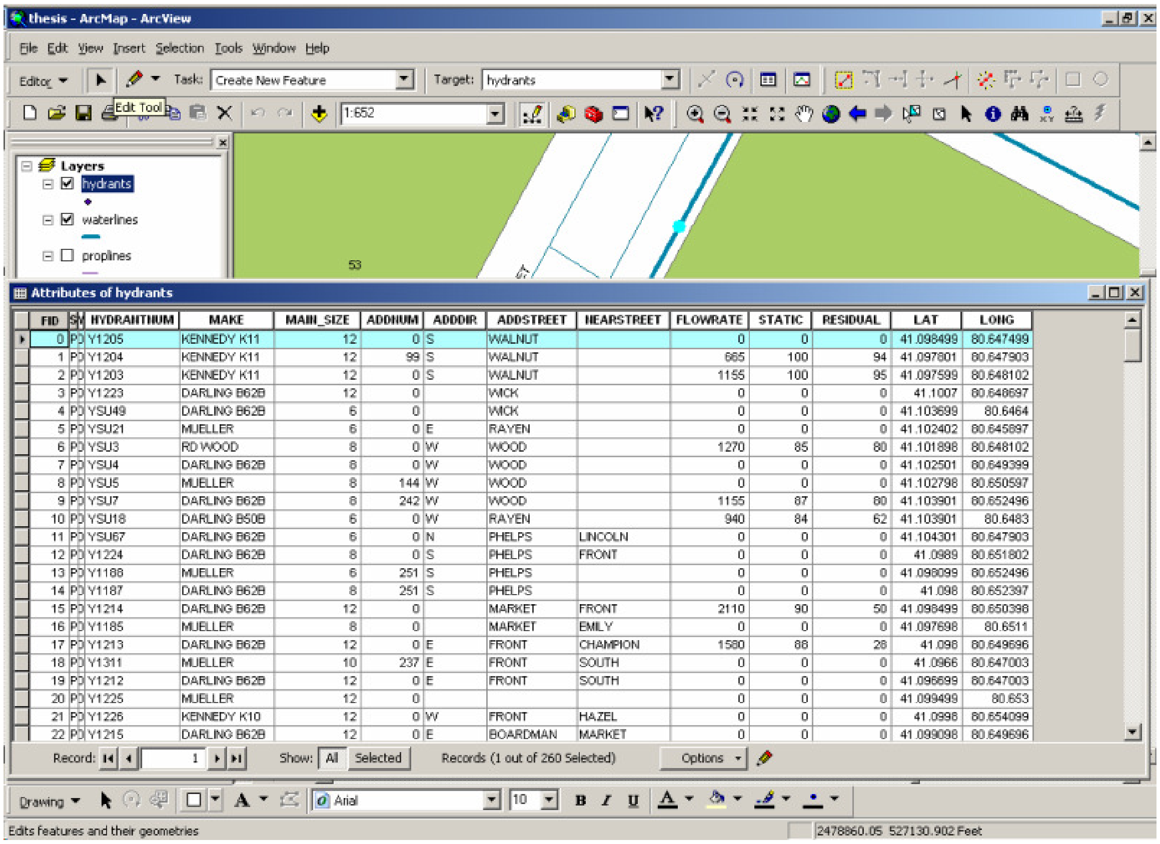


Figure A-15. Hydrant Placement.

To improve visibility of the fire hydrants on the GIS, the symbol used to represent the fire hydrants is changed from a black dot to an orange asterisk. This is done by right clicking the hydrant layer in the Table of Contents window, selecting Properties and then selecting the Symbology tab. Clicking the Symbol icon will present the options available in the Symbol library. The Asterisk 2 symbol is selected. The Color is changed to orange by selecting the Color icon in the Options frame. The OK button is clicked using the left mouse button, enacting the changes with the result shown in Figure A-16.

Figure A-16. GIS Layers.

It is recommended that all of the fire hydrants in a section of the distribution system be placed on the GIS hydrants layer before proceeding to entry of the hydrant data attributes. The hydrant attributes are compiled from various YWD sources and field data as described in the body of this thesis. To enter the data, the Editor button is left clicked, followed by the Start Editing command. The waterlines folder is specified and the hydrants layer right clicked, allowing the Open Attribute Table option to be selected. A specific hydrant is selected by left clicking on that row. This causes the hydrant to be highlighted making it easier to determine it’s location on the map. The data attributes for that specific hydrant are then entered into the Attributes table, as shown in Figure A-17.



FID	SH	HYDRANTNUM	MAKE	MAIN_SIZE	ADDNUM	ADDDIR	ADDSTREET	NEARSTREET	FLOWRATE	STATIC	RESIDUAL	LAT	LONG
0	PO	Y1205	KENNEDY K11	12	0	S	WALNUT		0	0	0	41.098499	80.647499
1	PO	Y1204	KENNEDY K11	12	99	S	WALNUT		665	100	94	41.097801	80.647903
2	PO	Y1203	KENNEDY K11	12	0	S	WALNUT		1155	100	95	41.097599	80.648102
3	PO	Y1223	DARLING B62B	12	0		WICK		0	0	0	41.1007	80.648697
4	PO	YSU49	DARLING B62B	6	0		WICK		0	0	0	41.103699	80.6464
5	PO	YSU21	MUELLER	6	0	E	RAYEN		0	0	0	41.102402	80.645897
6	PO	YSU3	RD WOOD	8	0	W	WOOD		1270	85	80	41.101898	80.648102
7	PO	YSU4	DARLING B62B	8	0	W	WOOD		0	0	0	41.102501	80.649399
8	PO	YSU5	MUELLER	8	144	W	WOOD		0	0	0	41.102798	80.650597
9	PO	YSU7	DARLING B62B	8	242	W	WOOD		1155	87	80	41.103901	80.652496
10	PO	YSU18	DARLING B50B	6	0	W	RAYEN		940	84	62	41.103901	80.6483
11	PO	YSU67	DARLING B62B	6	0	N	PHELPS	LINCOLN	0	0	0	41.104301	80.647903
12	PO	Y1224	DARLING B62B	8	0	S	PHELPS	FRONT	0	0	0	41.0989	80.651802
13	PO	Y1188	MUELLER	6	251	S	PHELPS		0	0	0	41.098099	80.652496
14	PO	Y1187	DARLING B62B	8	251	S	PHELPS		0	0	0	41.098	80.652397
15	PO	Y1214	DARLING B62B	12	0		MARKET	FRONT	2110	90	50	41.098499	80.650398
16	PO	Y1185	MUELLER	8	0		MARKET	EMILY	0	0	0	41.097698	80.6511
17	PO	Y1213	DARLING B62B	12	0	E	FRONT	CHAMPION	1580	88	28	41.098	80.649696
18	PO	Y1311	MUELLER	10	237	E	FRONT	SOUTH	0	0	0	41.0966	80.647003
19	PO	Y1212	DARLING B62B	12	0	E	FRONT	SOUTH	0	0	0	41.096699	80.647003
20	PO	Y1225	MUELLER	12	0				0	0	0	41.099499	80.653
21	PO	Y1226	KENNEDY K10	12	0	W	FRONT	HAZEL	0	0	0	41.0998	80.654099
22	PO	Y1215	DARLING B62B	12	0	E	BOARDMAN	MARKET	0	0	0	41.099098	80.649696

Figure A-17. Hydrant Attribute Table.