

# Sanitary Sewer Flow Model and Storm Water Analysis for the Meadow Hills Subdivisions in Rochester, MN

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## Abstract

Data were digitally developed to determine sanitary sewer locations, elevations, flow directions and parcels' impervious areas during the summer of 2002 for the City of Rochester, Minnesota. The purpose of this project was to use these data and to develop and model a GIS template for the City of Rochester. This model was developed to model sewage flow in the event of future sanitary pipe emergencies. This model analyzes sanitary sewer pipe blockages to determine potentially impacted parcel(s) by the blockage. A second model was developed to facilitate planning in regards to storm water management. Storm water runoff was analyzed on a per parcel basis to predict rainfall runoff based on percentages of impervious surfaces. DOQQ photography was used to capture the impervious areas in parcels by onscreen digitizing. ArcMap 8.2 was used to analyze the data. The Meadow Hills subdivision was used as a pilot area for both models. An ArcIMS demo of a pilot sanitary sewer database was also created as part of this project.

## Introduction

Rochester is the third largest city in Minnesota. It is located in the Southeastern portion of Minnesota and is home of the world-renowned Mayo Clinic. The population of Rochester is approximately 90,000 people and contains an area of about forty square miles.

Sewer maps enable one to gain valuable insights into the infiltration/inflow problems of the area (Environmental Protection Agency, 1976). The City of Rochester Public Works Department (CRPWD) requested the development of a GIS model of the sanitary sewer system. This model maps

flow within the sewer system. Serious problems that can occur in sewer systems are blockages and subsequent back-ups. If a blockage occurs, what parcel(s) will be affected? This is a critical question. This model provides a system to analyze the impact of blockages so they may be mitigated.

ArcGIS 8.2 is a powerful tool that can be used to collect and analyze data. A geodatabase of sanitary sewer data in the Meadow Hills residential subdivision was created as part of this project. The geometric networking component of the geodatabase enabled the development of a flow model.

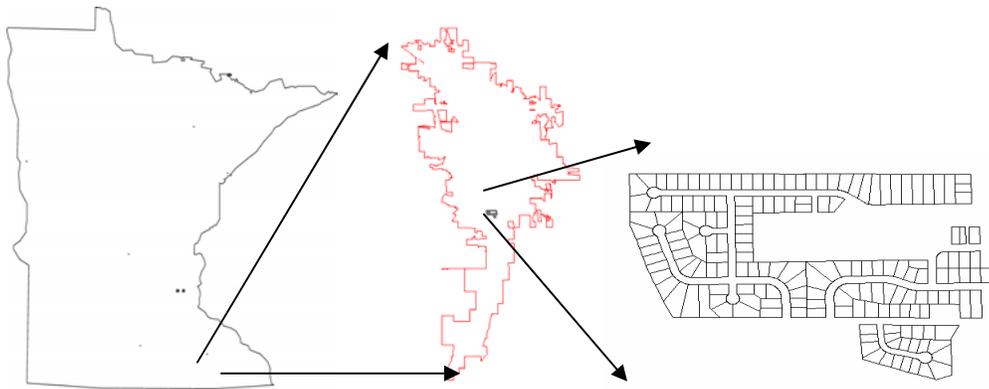


Figure 1. Meadow Hills subdivision located in the middle of Rochester, which is in Southeastern, Minnesota.

This flow model showed which direction sewage would flow, based on manhole elevations. When a blockage is identified, parcels upstream will most likely experience sewer back-ups. This model identified which parcel(s) will be affected so the problem can be fixed.

The project was tested with the Meadow Hills Subdivision template. Meadow Hills is located in the middle of the City of Rochester (Figure 1). The Meadow Hills Subdivision was chosen in order to demonstrate sewer blockages. Meadow Hills is a small enough subdivision to work with and was adequate for demonstrating some of the processes of sanitary and storm sewers.

Sanitary sewers connect to homes to remove wastewater from sinks, showers, toilets, etc. Sanitary pipe sizes range from eight to forty-eight inches in diameter, in Rochester, MN. The most common pipe size is eight inches in Meadow Hills. Smaller pipe lines connect from the house to the eight inch pipe. Street lines connect to wastewater treatment plants. Consequently, blockage of pipes may inflict plenty of damage, as homes could potentially become flooded or have sewage sludge destroy property (Figures 2 and 3).

Odors, mold, and bacteria are a risk to the health of residents and can cause significant monetary damage also.



Figure 2. Sewage back-up overflow.



Figure 3. Flooded basement.

Pipe blockage is caused most commonly by tree roots seeking water, which penetrate the sanitary sewer pipe wall. Large debris like diapers, or objects accidentally flushed can also

back-up pipes (City of Camrose, Alberta, Public Works, 2000). When a blockage occurs, city officials view the sewer pipeline with a special camera (City of Rolling Meadows Public Works, 2001). Once the blockage source is located, the back-up is then removed by using specialized sewer pipe cleaning tools. Some homes in the City of Rochester only have septic tanks, which are like individual sanitary sewage treatment plants, and are not yet connected to the sanitary sewer system. The CRPWD would like everyone connected to the sanitary sewer system. Connecting to the sanitary sewer reduces the potential for ground water pollution from failing, or improperly maintained septic tanks.

Storm sewers collect water runoff from rain, snow, car washes, watering and any liquid that falls on hard, impervious surfaces. Impervious surfaces include rooftops, driveways, roads, parking lots and other hard surfaces that do not allow infiltration to occur. Alternatively, pervious surfaces allow for water infiltration. Some examples of pervious surfaces would include grass, bare soil, sand, gravel, etc. Runoff also carries many other substances with it, like car oil, fertilizers, and gasoline. Water flows into catch basins and down pipes, similar to those mentioned with sanitary sewers and into designed retention ponds along with all of the other substances it picks up on the way.

The CRPWD wants to determine a method to fairly charge each parcel in the city for its contribution to storm water runoff. The city is in the process of developing a storm water utility fee to be added to the city water bill. Based on land use factors, which are based on the percentage of impervious area in a

parcel, a storm water fee can be calculated. A resulting effect of this charge helped pay for street cleanup, storm sewer construction, cleaning and repairing as well as constructing retention ponds and wetlands to filter out pollutants as required in phase II of the National Pollution Discharge Elimination System for cities with a population of over 10,000 people (Sullivan T.F.P., 1999). Determining whether the Meadow Hills subdivision watershed has the potential to cause pollution stress on streams is important for identifying streets that need cleaning and possible new retention pond sites to reduce stream degradation.

ArcIMS demonstrated pipe blockage management for the CRPWD. ArcIMS was used to provide a quick access to the parcels that phone in with a pipe blockage. Using ArcIMS, an address was entered and the parcel was quickly located. This method provides efficient results for city officials coupled also by an informative, safe and secure map that is made available to the public.

## **Methods**

The first step in this project was to collect and create data for sanitary sewers and parcel impervious surfaces. A majority of the data was created in the summer of 2002. Engineer plans were used to find the direction of flow, length of pipeline, and manhole elevations. Aerial photography was used to capture impervious areas in parcels by onscreen digitizing. Other data that had been previously created by the City of Rochester and Olmsted County was also used. These included data on city limits, city parcels, roads, rivers, and aerial photography.

GPS points were gathered using a Trimble GPS. Many of the sewer locations had previously been recorded with GPS, but new and updated sewer locations needed to be added. Coordinates were recorded in the field, and entered into the sewer database. Sewer engineering plans provided valuable information like manhole elevations and pipe sizes and lengths that were added in ArcMap 8.2. Each manhole had its attributes updated with a coordinate location and a basin depth. Pipes were attributed with pipeline segment length, diameter, and type such as: clay, cast iron or polyvinyl chloride etc., and the direction of flow based on high to low elevation.

Sanitary sewer system data were collected in order to provide a flow model system, which could assist city engineers in case of pipe blockages. The locations of the sanitary sewers were determined by collecting Global Positioning System (GPS) points of their locations. However, in order to begin analysis of sanitary sewers, a personal geodatabase was created to help organize the geographic data and to assign hierarchical orders, which helped organize data objects. Data objects were arranged into feature datasets used to store various feature classes. Created feature classes consisted of sanitary sewer pipeline segment data along with manhole point data and parcel data. Since the study area included the Meadow Hills Subdivision, which represents only a fraction of the space within Rochester, a clip of the study area was performed from the entire Olmsted County parcel data. The study area was clipped using the Geoprocessing Wizard within ArcMap 8.2. Once the study area was clipped, clipping continued on the sanitary sewer pipe segment data;

however, a problem was encountered with this process. The problem involved clipping the sanitary pipe segment layer, which was a line feature class within the parcel data. Only polygon or point images can be clipped in that manner. The Geoprocessing Wizard would not clip the desired line segments, so the line segment along with the manhole point features were selected for the Meadow Hills Subdivision, and then the selected features were exported, and imported as a new layer. Once all the feature classes were created for the pilot area, population of the new personal geodatabase was possible. Manhole feature and sanitary sewer pipe segment feature classes were placed into the same feature dataset to prevent any networking problems that might occur. From a development standpoint, it was best to keep the two feature classes together since they shared the same spatial reference and were also designed to share a physical representation of the network connectivity. The parcel feature was kept as a stand-alone feature class. Data were established within the geodatabase model followed by the creation of geographic object types. Creating the different object types; particularly, network features, allowed the opportunity to develop connectivity between sanitary pipeline and manhole features, thus resulting in an effective sewer flow model (Environmental Systems Research Institute, ESRI INC., 2001).

Reviewed feature classes found that pipe graphics were all uniform, despite different size variations. They had the necessary attribute information, but lacked unique descriptions suitable for a viewer. Therefore, a feature-linked annotation was created, which would properly provide automated text

placement for the pipe network. The feature-linked annotation text was derived from the value of the field, pipe\_size, found within the sanitary pipe feature. The convenience of creating an annotation feature class is in the relationship it shares with the feature class that it is annotating. It takes the role as the destination class, while the origin class is given to the annotated feature. Therefore, if any changes are made to the annotated feature, the annotation feature class should change simultaneously. For example, if the origin class has changed orientation, or the value of the specified field is changed, the destination class automatically changes to satisfy those edits. Once the annotations were created using ArcCatalog, they were stored within an annotation class. This annotation class was loaded as a separate feature class into ArcMap.

A personal geodatabase was created for Meadow Hills (Figure 4). It provided organization for all of the sanitary sewer files in one place (GIS by Environmental Systems Research Institute, ESRI, 2000).

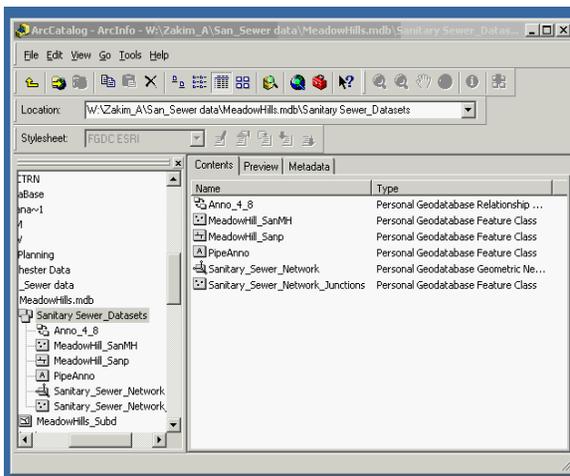


Figure 4. Personal geodatabase file created for Meadow Hills.

It also made sure data and networking remained together to insure accuracy and fast processing.

Once feature classes were developed, the next steps were to create the sanitary flow model. In order to establish the flow model, a topological relationship between the sanitary pipe segment and manhole feature classes had to be developed. Relationships were created using the geometric network option within ArcCatalog.

The network recognized the features involved, as edges and junction components. Manholes were classified as junctions, while the pipe segments represented edges. After the geometric network was developed, a field called “ancillary role” was created within the manhole attribute table. The purpose of this field was to designate whether the junction represented a sink, source, or neither. In this study, the water treatment plant was designated as the sink. This allowed for proper calculation of flow direction, leading directly to the water treatment plant. The geometric network proved to be the perfect tool for modeling the Rochester sanitary sewer network.

In order to use ArcMap to analyze the geometric network, the Utility Network Analyst toolbar was used. This toolbar calculated the flow direction by using the set flow direction button. This button recognized the designated sink and provided a determinate flow direction.

Model two, examined impervious surface data in order to help generate storm water utility fees for each parcel within the city. A compressed SID image of the city was used to digitize the pervious areas of each parcel in the city limits. Pervious areas were digitized because the digitizing process involved

less area than digitizing impervious areas, especially in commercial parcels. The impervious layer was created by clipping the pervious layer from the city parcels, which left the impervious layer. Figure 5 shows the SID image for Meadow Hills. Figure 6 illustrates the impervious area in the Meadow Hills parcels.



Figure 5. Meadow Hills Orthophoto.



Figure 6. Digitized impervious area.

Parcels were separated into three different classes: residential, commercial, and industrial. All 1,729 commercial parcels and six industrial parcels were digitized. Residential parcels were divided into classes in terms of their parcel size in acres. Six classes for residential parcels were created (Figure 7). Figure 7 depicts that most of the 24,251 total residential parcels in Rochester are in the 1/8 to 1/4 acre size class. The average size of a parcel is .235 acres for all residential parcels. The average size of a parcel in the Meadow Hills Subdivision is slightly

larger than the overall average at .307 acres.

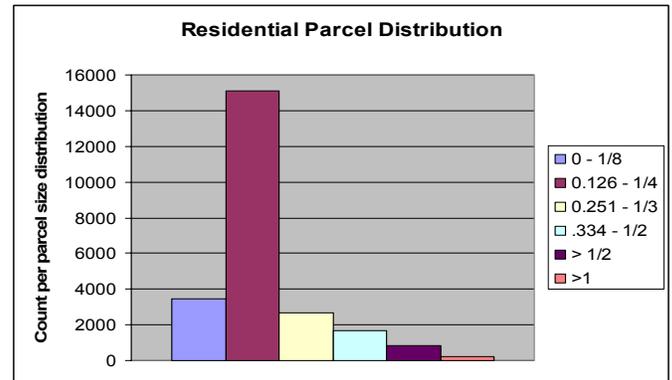


Figure 7. Residential size class divisions.

One percent of the total residential parcels are an adequate sample size for determining impervious area (University of Connecticut College of Agriculture and Natural Resources, 1999). A random sample was created on the parcel identification number in Microsoft Excel for the whole city. The first one percent in each class was chosen for digitizing. This approach was conducted to save time in having to digitize all residential parcels. Having accurate data in a quick manner was very important for determining if this method would produce desired results for the project. All of the pervious areas in these parcels were digitized. In ArcMap's geoprocessing wizard, the parcel layer was joined to the pervious surface layer to create a layer with combined data. An impervious layer was created by using 'select by location' to select all the pervious parts of the combination. Those selected parts were deleted, leaving just impervious areas in the parcel layer. Impervious surfaces were then dissolved for the area attribute to have impervious area for each parcel instead of each digitized polygon.

The goal of digitizing was to help the CRPWD create a system to help pay the \$2.5 million needed to comply with NPDES Phase II. These funds will help pay for street cleaning and management of storm water. An extra charge will be added to the water/sewer/electric bill of residents and commercial users within the city limits to recover these funds. This charge is calculated using a Land Use Factor (LUF). LUFs are factors that are based on the amount of impervious surface in a parcel and are created by city engineers using a special formula. An LUF was calculated for one to one hundred percent imperviousness of a parcel, which went from a low of .37 to a high of 5.0 for one hundred percent imperviousness (Bonestroo et. al., 1997) (Figure 8). The LUFs were multiplied by the number of acres per parcel and \$190.52 amount to calculate the storm utility charge. The \$190.52 figure is the necessary fee per acre and year to cover the \$2.5 million cost.

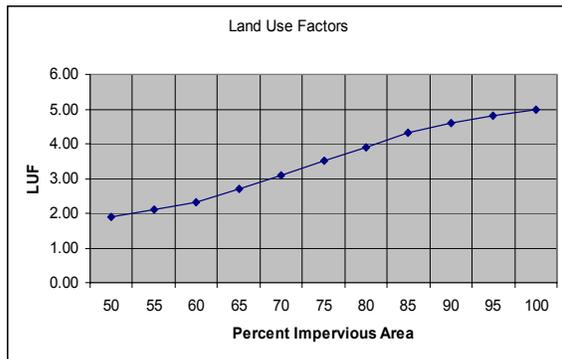


Figure 8. LUF values as calculated for different percentages of impervious area in parcels.

Storm water was also analyzed for areas of high runoff. When a watershed is over thirty percent impervious, streams are likely to be degraded (University of Connecticut College of Agriculture and Natural Resources, 1999). Xtools, an ArcView

3.3 extension, was used to calculate area, perimeter and acreage for the impervious surfaces in each parcel. A query was conducted to select the parcels with over thirty percent impervious area of total area. The selected parcels were made into a new shapefile called high runoff. This was done to identify parcels contributing the most to degradation of streams through pollution runoff.

An ArcIMS project was setup to display Meadow Hills sanitary sewer system using ArcIMS Author. This was done to show a quick demonstration of ArcIMS functionality. City parcel data for the entire city was added, Meadow Hills Subdivision parcel data, and manhole and pipe data were also added. Scale dependant rendering was set so that shapefiles only become visible when zoomed into different perspective scale sizes.

## Results and Discussion

A sanitary sewer system geodatabase was created and modeled using ArcGIS 8.2. The Public Works Department had to search through files and retrieve paper subdivision plans and city engineer plans every time they wanted to understand how and where a sewer flowed. Now, they have all the information they need for working on sewers in an easy-to-use project in ArcMap. The data is organized to ensure accuracy and completeness in the sanitary sewer system.

The “ancillary role” field was created during the development of the geometric network. Its primary purpose was to provide the option of designating whether a created junction took the role as a sink, source, or neither. The water treatment plant was given the role of a sink, which meant that all sewage flows

directly to its facilities (Figure 9). By assigning a role to this particular junction, the utility network analyst tool, of ArcGIS 8.2, was able to develop flow direction models (Figure 10).

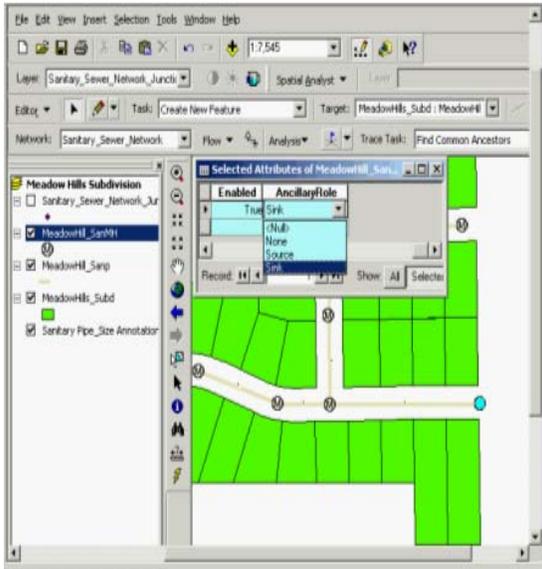


Figure 9. Ancillary Role attributes the highlighted junction.

Network analysis provided an efficient solution for modeling sanitary sewer flow, instead of looking at many paper maps (Environmental Systems Research Institute (ESRI) INC., 1996). Overall, geometric networking within ArcCatalog, along with the utility network tool bar from ArcMap, provided the necessary tools to accomplish flow direction calculation, automated text placement, and connectivity. Those tools allowed for proper analysis of the sanitary sewer flow model (Figure 10).

To identify the water treatment plant properly, symbology was given to “ancillary role” field based upon unique values. Those values were categorized to represent whether the junction was a sink, source, or neither (Figure 11).

During the analysis, the pipe segments provided the viewer with

limited information. As a result the feature linked annotation layer was created. Using ArcCatalog, the annotation was created by building a relationship with the pipe segment feature class. The feature-linked annotation layer was capable of providing valuable information, but also proved convenient for labeling pipe segments (Figure 12).

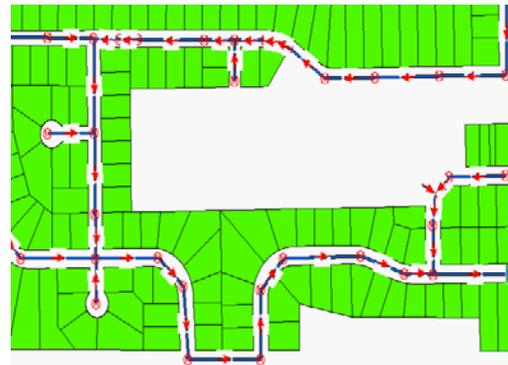


Figure 10. Identifies the direction of flow based on location of sink or treatment plant.

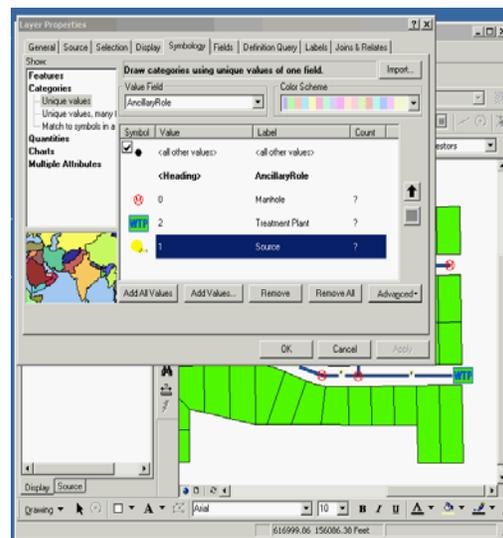


Figure 11. Symbolizes the network features for the sink, sources and water treatment plant.

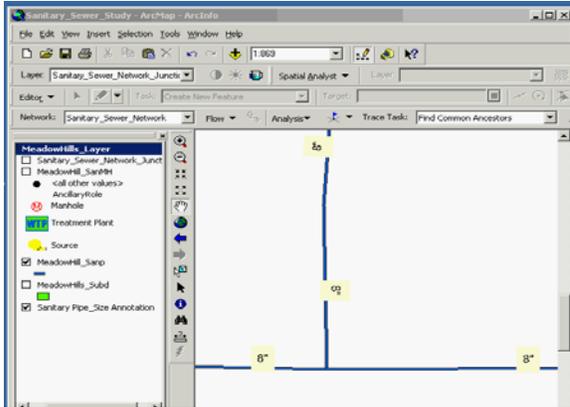


Figure 12. Feature-Linked Annotation layer for particular pipe segments.

A demonstration of ArcIMS was produced in Author (Figure 13). The project was started with all of the parcels inside of the City of Rochester’s limits set to visible. When a scale is set at 1:25,000 or larger, the Meadow Hills parcels appear with the manholes and sewer piping (Figure 14). Figure 14 also diagrams the “Find dialog box” that is used to search and zoom to queried parcels. For example, if the CRPWD receives a call from a resident with a sewer blockage issue, they can simply enter in the person’s name and the problem parcel can be found immediately. Figure 15 shows the potential blocked sewer of ‘Jane Doe.’ Once zoomed to a scale of 1:3,500 or greater the labels for the manholes and parcel taxpayers appear. The label for the pipe also becomes visible. The pipe’s label is which manhole it is flowing towards. When a blockage is called in by a person, one also knows the direction the blockage may impact on other parcels.

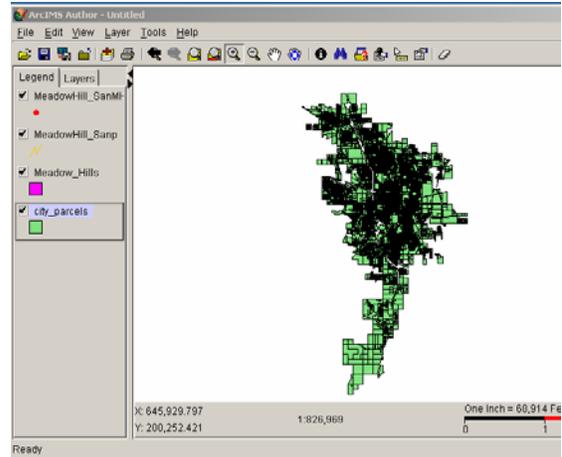


Figure 13. ArcIMS project developed for the City of Rochester.

The CRPWD also received a demonstration of the qualities of ArcIMS before a potential purchase. ArcIMS provides a method of sharing information with the residents of Rochester with a published website

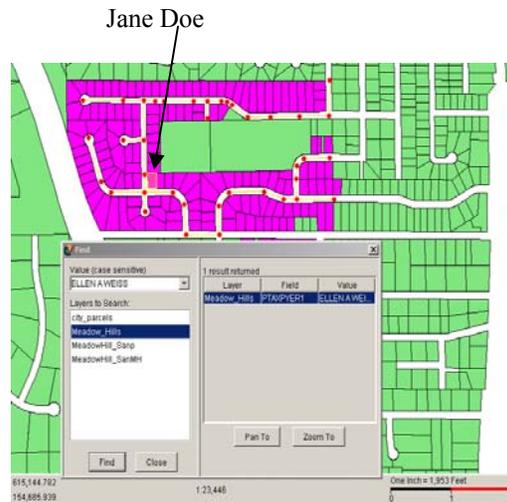


Figure 14. Meadow Hills Subdivision with a Find dialog to locate and zoom in on a problem parcel.

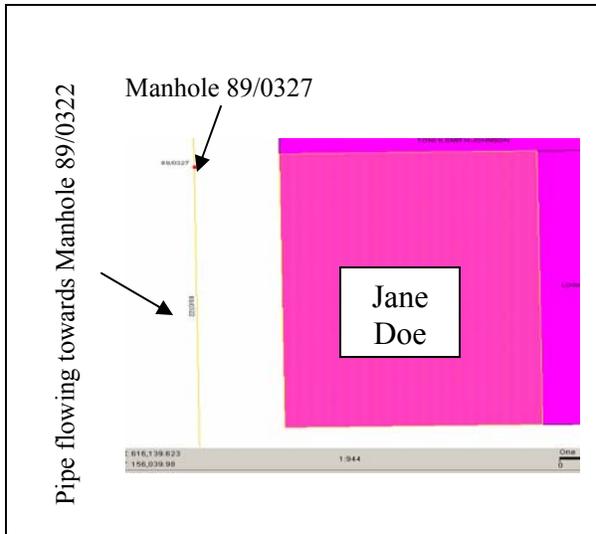


Figure 15. Parcel zoomed into shows labels and direction of flow.

instead of residents coming in and requesting information. This saves employees time by not having to print maps and figures and residents from having to come to city hall to pick materials up. ArcIMS is a safe way of distributing the information. Information placed online is whatever one feels comfortable sharing. The data can not be downloaded from the website, it is only observed. The detail of analysis tools and buttons can also be limited.

Model two, involved digitizing parcels in order to find the percentages that were impervious. First the total acreage had to be found. Figure 16 graphs how many total acres are in each residential parcel size class. Size divisions that have the most acres also have the most parcels. Even though there were bigger sized parcels, they were so few in number that all the proportions primarily remained the same. Only the smallest and largest parcels differed in proportion.

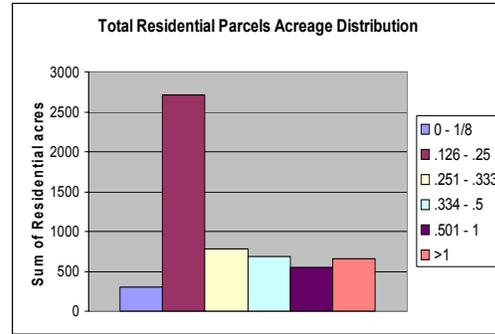


Figure 16. Total residential parcel acreage distribution.

The impervious acreage then had to be digitized and totaled. Figure 17 shows another similar distribution of the size classes in terms of impervious acreage. This was done for all of the residential parcels by using assigned estimations of percentage impervious area. Residential parcels were estimated at 35.6 percent and commercial and industrial parcels at 85 percent impervious (University of Connecticut College of Agriculture and Natural Resources, 1999). The total acres in each category could then be multiplied by the estimated percent impervious to calculate the estimated impervious area. When done by digitizing one percent of the total residential parcels, very similar results were found as compared with the assigned estimate figures.



Figure 17. Total residential impervious acreage.

Using the total acreage and impervious acreage, the percentage of impervious area can be calculated. Figure 18 shows the distribution of the percentage of impervious area to total area. This conveyed that the smaller a parcel was, the greater the impervious area. A smaller parcel did not have more impervious area compared with larger parcels, but more of its content was impervious, which was more important than total acres impervious. This was more important because the percentage impervious was the factor used in calculating the storm water charge.

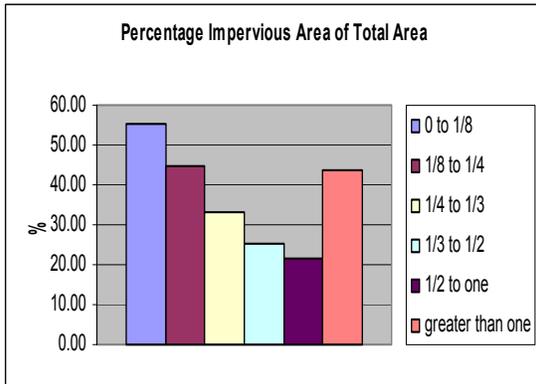


Figure 18. Residential percentage of impervious area to total area.

All commercial and industrial parcels were also digitized. Figure 19 shows the total amount of impervious acreage digitized for commercial and industrial parcels. Figures 20 and 21 plotted the percent of each parcel that is impervious to runoff. The majority of commercial and industrial parcels were greater than forty percent impervious (Figures 20, 21), while residential parcels were mostly less than fifty percent impervious (Figure 18). Meadow Hills had no commercial or industrial parcels.

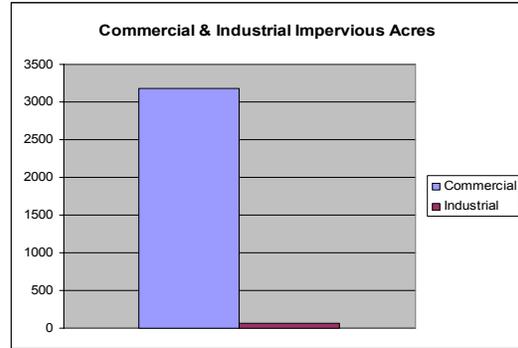


Figure 19. Total impervious acreage from commercial and industrial parcels.

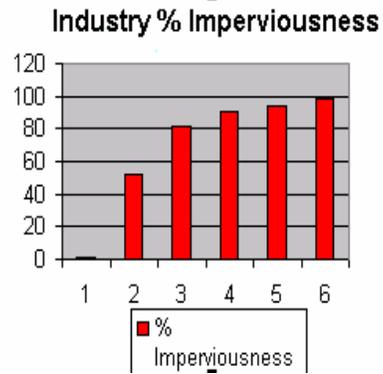


Figure 20. Six industrial parcels impervious area percentages.

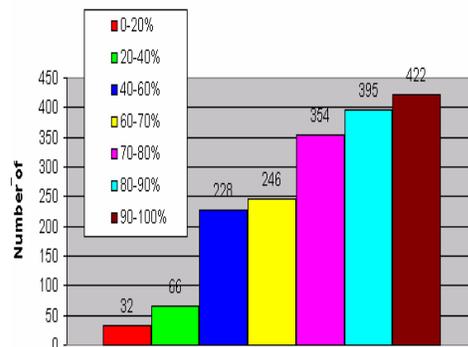


Figure 21. Groupings of commercial parcels percent impervious area.

The storm water utility fee was compiled in order to pay the \$2.5 million in NPDES Phase II budget. All parcels will be charged \$190.52 times the number of acres and times the LUF, which was based on the percent

impervious area in a parcel each year. All residential parcels will be charged the same. The average parcel size of .235 acres was used along with an LUF of 1.0 for all residential parcels. All the residential parcels would be charged  $\$190.52 * 1.0 \text{ LUF} * 0.235 \text{ acres}$ , which equals  $\$44.76$  a year or  $\$3.73$  on each monthly bill. The commercial and industrial parcels are being charged with individual bills based on the impervious area. An example is the Apache Mall parcel (Figure 22). It has 50.5 total acres and is ninety percent impervious. Ninety percent impervious coincides with an LUF of 4.5 (Figure 8). The yearly charges would be  $\$190.52 * 4.5 \text{ LUF} * 50.5 \text{ acres}$ , which equals  $\$43,295.62$ .

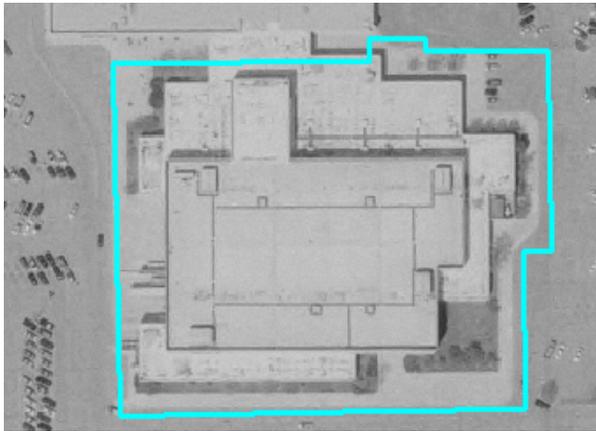


Figure 22. Apache Mall parcel.

Analysis revealed that one hundred twenty parcels out of the total one hundred seventy-three parcels in Meadow Hills were over thirty percent impervious, potentially causing a significant pollution problem (Figure 23). As a total watershed, Meadow Hills has 571 acres. Impervious acreage accounts for 173 acres of the total or 31 percent imperviousness for the total subdivision. The Meadow Hills



Figure 23. Shaded parcels with high runoff (over 30%) in Meadow Hills.

Subdivision would therefore be more likely contribute to the degradation of streams from the pollution carried away in the runoff. A range of 20 to 30 percent impervious in a watershed, is considered a medium degradation to streams and over 30 percent is considered high (University of Connecticut College of Agriculture and Natural Resources, 1999).

The total percent imperviousness for the Meadow Hills Subdivision suggested that these parcels could very well affect water and stream quality with polluted runoff. Creating retention ponds and street cleaning programs are valuable in preventing polluted runoff reaching highly sensitive streams in the area (University of Connecticut College of Agriculture and Natural Resources, 1999).

## Conclusion

Through this project, data and quality products were provided for the CRPWD. The City of Rochester requested the development of a demonstration subdivision that could be used to model the flow of the sanitary sewer system for quick access in case of a pipe blockage emergency and to develop a storm utility

charge example. Through this demonstration they also wanted a pilot geodatabase that combined all the sewer data into one large database and a demonstration of a use of ArcIMS they could use to access data fast and also distribute information to the public. This project accomplished these tasks.

It was recommend that the CRPWD take a close look at all of the models that were generated for the sewer systems, the geodatabase, and the ArcIMS demonstration to see the benefits of each. Benefits included that as soon as a pipe emergency is received, it can be located on a map and potential future emergencies can be identified immediately. The pilot geodatabase was invaluable along with a networked system to eliminate error. It allowed all information to be accessed with speed and accuracy.

Future studies could be done to look at the storm water runoff to see its environmental effects on water bodies. There are about 5,000 city parcels that were not classified as residential, industrial or commercial that need to be studied for charging information. Future sewer studies should work with a larger area and take into account the individual parcel sanitary pipe connected to the building instead of just the main line.

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