

Enhancing Wastewater Utility Mapping and Flow Line Analysis with Geographic Information Systems (GIS)

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Abstract

Wastewater treatment is a very costly and very important part of a city's day to day functions. Any instance in which a city is forced to replace a treatment plant or process more water than the plant has capacity for is extremely expensive. This study was conducted to analyze a current wastewater system to determine if it was functioning as efficiently as it should. This study also determined which specific structures in the wastewater system are problematic. This allowed for insight into a future rehabilitation plan to replace problematic structures before damage occurs that could cost a city and its citizens million of dollars.

Introduction

The purpose of a wastewater flow line analysis study is to determine how water infiltrates the current system. For example, water runoff is supposed to flow into a storm sewer inlet and then into the storm sewer system for removal. However, if there are sanitary sewer manholes that are in poor condition, or are located on very low ground, or have structural defects, rainwater can infiltrate the sanitary sewer system. This excess water then flows into the wastewater treatment plant to be processed. The cost to treat extra water runoff in the treatment plant is very expensive. The average household uses 75 to 100 gallons of water per person per day (Olson, 2002). A treatment plant is built and operated on such estimates. With excess water leaking into the wastewater system the plant could suffer inefficiencies in the processes, which could produce water that has not been

properly treated, or costly damage to the plant itself. The life cycle cost of wastewater treatment systems, which include "design, construction, operation, maintenance, repair and replacement," according to Olson, are so high that the constructions costs are "usually spread over a twenty-year period." That does not include maintenance costs or repairs. So, to add to the cost of construction, repair, and maintenance, the cost of an influx in water that was not initially calculated can reach into the millions of dollars, therefore it is imperative to keep the excess water infiltration to a minimum.

This study was designed to locate problematic structures and current areas that are in need of rehabilitation. This utility mapping study was conducted on a city located in Western Iowa that has a population of approximately 2,368 as of the 2000 census, covered 4.9 square miles (Anonymous, n.d.). The study was comprised of locating sanitary sewer

structures, surveying structures by means of GPS, and creating a geodatabase and functional map document using ESRI GIS software.

Methods

This project was completed in three separate tasks. The following tasks resulted in the completion of this project:

1. Location, survey, inspection, and data collection of the sanitary sewer structures within the study area. Simultaneously, a geodatabase containing feature datasets and feature classes for wastewater structures was created using the SDSFIE. SDSFIE stands for Spatial Data Standards for Facilities, Infrastructure and Environment. It is a method that keeps the data organized and standardized.
2. Data importation. Data was imported from DataPro into the geodatabase.
3. Map creation, manipulation, and analysis.

Location, Survey, Inspection, and Data Collection

The field survey consisted of a technician physically locating manholes within the city. Once each manhole was located, each feature was spatially recorded via GPS. The survey equipment used was sub-centimeter grade GPS, which meant that every collection shot had an accuracy that was within a centimeter of its actual location. The shot also established a unique identifier name for each specific structure. An example is “utww0016_1118070.” The beginning of the name indicates which section of the SDSFIE one is working

with. In this example, the “utww” stands for Utilities Wastewater in the SDSFIE, and the rest is the unique number identifying a specific structure. The name became the primary key, so it was very important that the name was unique.

The junction point inspection was completed using the following categories as requested by the city: condition, defects, infiltration, location, and ditch location.

Condition

Each manhole was visually assessed for cracks, leaks, broken lid, or other ways water could infiltrate the sanitary sewer system. Defects and infiltration were also key factors in determining the overall condition of a manhole. To catalog the condition of a manhole it was given a rank between one and four depending on assessment evaluations. Value rank of “one” meant the structure was in poor condition and needed to be replaced immediately (Figure 1). A rank of “two” meant the structure was in fair condition and replacement would soon be imminent. A rank of “three” meant the structure was in good condition and would not need replacement in the immediate future. A rank of “four” was given strictly to brand new structures.

Defects

Structural defects define manholes that have physical deficiencies such as a broken lid, crumbling brick, or insufficient casting (Figures 2A and 2B). Defects were not ranked; they were noted in the attribute table for repairs. These defects were specifically listed per structure in the attribute table in ArcGIS.



Figure 1. A manhole in very poor condition with a very high infiltration rate with cracks in the walls. This manhole would have been given a rank of “one” for condition due to the size of the cracks and a “five” for infiltration rate based on the amount of water potentially entering the structure. This structure would have been scheduled for replacement as soon as possible.



Figure 2A. Existing manhole with a broken lid and insufficient casting.



Figure 2B. Existing manhole with crumbling brick.

The defects were then analyzed to determine which were the most severe.

Infiltration

According to the Merriam-Webster Online Dictionary (2008), infiltrate means to “to permeate something by penetrating its pores or interstices.” For this study, the infiltration definition was interpreted as the amount of water that penetrates a structure due to cracking or other structural defects. The infiltration rate was ranked zero through five. A rank of zero meant the structure did not have any immediate infiltration potential. A rank of “one” represented little infiltration, while a rank of “two” represented little to moderate. Little to moderate infiltration was quantified as an amount that would not drastically increase the amount of water being distributed to the wastewater treatment plant. Moderate infiltration was ranked as a “three.”

Moderate infiltration was quantified as an amount that would not drastically increase the amount of water being distributed to the wastewater treatment plant immediately, but if it does not subside then damage could occur. A rank of “four” meant there was an infiltration rate between moderate and heavy, and a rank of “five” meant that the infiltration potential was heavy. Ranking for the upper end of moderate to heavy were quantified as an amount of water that would have an impact on the wastewater treatment process. There was not a specific numeric value set for the quantification of infiltration. The assessment was in the judgment of the survey technician based on the number and size of the cracks in the structure, and the amount of water that can be seen

entering the structure through the damaged area (Figure 1).

Location

This was in reference to manholes that could not be located. There are instances where manholes are unable to be located for a variety of reasons. The most common reasons were due to the fact that the manholes were buried, removed, or relocated, and the city records were not updated to reflect the location of each manhole structure.

Ditch Location

The reason it was essential to locate manholes located in ditches was because a manhole that is located in a ditch is prone to higher infiltration potential due to its location in a lower ground drainage area. A ditch is determined to be, according to the Merriam-Webster Dictionary on August 18, 2008, “a long narrow excavation dug in the earth (as for drainage).” Ditches are typically found in fields, right of ways, or in older parts of town where they are used for instead of a storm sewer system. Ditches, like defects, were not on a rank scale. It was simply noted in the attribute table whether or not the structure was located in a ditch (Figure 3).

Data Collection

Data Collection was a very important part of this project. Utilizing the ArcPad software and Xplore tablet made field data collection a very efficient and almost effortless process when compared to the previous methods of field data collection, which included hand written notes and manual data entry. After the survey data points were imported into the geodatabase in an ArcMap project,

the data was then exported to an ArcPad project for field editing. The geodatabase was literally “checked out” from the server like a library book and used in fieldwork. When the data was checked back into the server, the geodatabase was updated with the new information.



Figure 3. Here ditches are used for drainage along roadways.

The field data collected consisted of flow lines for analysis, overall condition of the structure, size and material of the structure and pipes, type of structure (i.e. circular), use (i.e. in service, abandoned), spacing and casting size, rim diameter, and manufacturer of structure.

The creation of the geodatabase was relatively simple. Using ArcCatalog a new personal geodatabase was created, as well as the necessary feature datasets. Using the SDSFIE geodatabase as a template, the required feature classes were imported from the SDSFIE geodatabase into the project geodatabase.

Data Imports

Imported data was used to create a new shapefile, which was then copied and pasted directly into the geodatabase.

There was an issue that arose with importation. Coordinate systems, although essential, are sometimes a hindrance when they are not used properly. For this project, the survey was completed in NAD 83 Iowa North. Occasionally, the data would be collected in the wrong coordinate system, or lacking a coordinate system altogether. When this happened the data did not overlay properly in ArcGIS since the lack of a coordinate system shifted the structures approximately six feet from their actual location. Extra steps were required to move the structures to their correct locations. However, when the data was collected properly, with the correct coordinate system attached, the software was very efficient during importation.

Data Creation and Data Manipulation

The most useful aspect of the software was its ability to create a shapefile directly from the raw data. Using the DataPro software, the imported raw GPS data was converted into a shapefile. The user flag field was populated by the name field using the Field Calculator (Figure 4). Once loaded into ArcGIS, the data in the shapefiles was directly copied and pasted into the feature class that was associated with that shapefile in the geodatabase. For example, a shapefile named UTWWMH, which is a wastewater manhole, was copied into the wastewater junction point feature class in the geodatabase. Once all the shapefiles had been copied and pasted into their respective feature classes, data manipulation began. The importance of the DataPro software lies in its ability to transform raw GPS data into shapefiles. The other option of importing data would be to use the Xcel table and add

the data based on their coordinates, create a shapefile based on the coordinate locations, then copy and paste those results into the respective feature classes. The DataPro software skips the beginning steps of adding the coordinate data by converting the raw data directly into a shapefile.

Manipulating the data consisted of joining the feature classes with the survey data. This was done based on the user_flag, formerly the it_name in the shapefile, as a primary key. After joining the geodatabase with an Xcel table that stored the coordinate information, the columns for northing, easting, elevation, latitude, and longitude were populated using the field calculator in ArcGIS. This is a major part of the usefulness of the GIS and the necessity of GPS data collection.

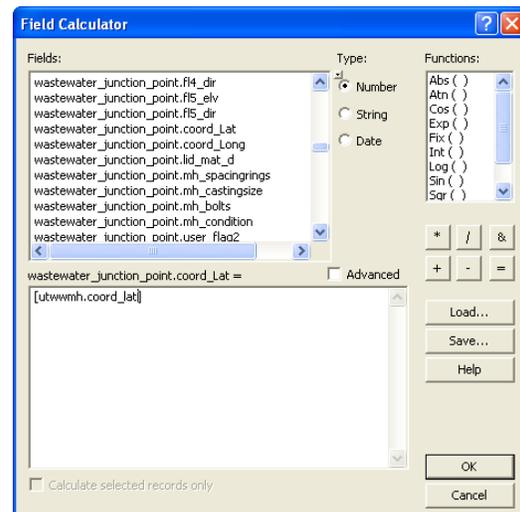


Figure 4. Field Calculator in ArcGIS. This is the tool used to populate the northing, easting, elevation, latitude, and longitude in the attribute table when manipulating the data.

Analysis

Subsequent to creation and manipulation, analysis was performed. The flow lines were diligently inspected

inside of the attribute table to highlight problem areas. Problem areas consisted of those areas with blockages, low or negative pipe slope, or standing water. Blockages were determined to be sticks, leaves, crumbling brick or concrete etc. that would prevent water from flowing freely.

A negative pipe slope occurs when the pipe is sending water flow the wrong direction. This can happen over time from soil shifting or construction. Standing water is any water that is inactive in the bottom of a manhole from either a blockage, back up, or negative pipe slope. This is water that is not currently flowing anywhere. The field data was analyzed to determine which structures need immediate attention. Any structures that had the previously mentioned problem areas and/or were deemed of high importance by their categorical rankings were in need of immediate attention. The overall manhole condition was assessed on site, as previously stated, on a scale from one to five.

Manholes with high amounts of infiltration, major structural damage, or serious flow problems were determined to need immediate attention because it is vital for sanitary sewer systems to flow without restraint to prevent backup. Backups can cause sinkholes, flooding, (Figures 5A and 5B), and infiltration of sewage into ground water and other bodies of water before treatment. These occurrences are very costly to repair, not only for clean up, but also for the other utilities harmed.

Results

The results of the analysis, which consisted of combining the categorical data with the flow line data. The

individual flow lines were analyzed in the attribute to determine which lines were not flowing properly. The analysis also analyzed the onsite data collected to determine which structures were in need of replacement or immediate attention. It was determined that there were forty structures in need of immediate replacement (Figure 6).



Figure 5A. Sanitary sewer backup can result in a sinkhole. These cause the most monetary damage because roads and utilities need to be replaced.



Figure 5B. The manhole is overflowing and flooding because of a system that was over capacity.

Flow line analysis provided information that 29 pipes had a negative slope (Figure 6). The arrows on the pipes in Figure 6 indicate direction of flow. The pipes were then color coded for clear detection of the area and its overall requirements. The red pipes represent negative slope. The red manholes have a condition of one and require replacement. The green manholes and green pipes are structurally sound with positive flow. The tan and orange manholes and pipes range from two to four, with moderate to low slope. These areas will need to be addressed in the future, but immediate attention is not required the red pipes should be inspected and replaced first. Figure 7 depicts the replacement phase plan. On average, a manhole costs approximately \$500.00 to replace. That does not include cost of construction. The cost to replace 40 manholes for would be approximately \$20,000 plus construction fees. Compared to the million-dollar amount to replace the treatment facility, replacing the manholes is the most cost effective option to keep the wastewater system operating.

Recommendations

As a result of the analysis, a six-phase plan has been completed to cover all repairs deemed necessary from this study. This six phase plan addressed the issues in a timeline that was relevant to the overall condition of the sanitary sewer. Those in need immediate repair were included in the first phase of the plan, while those repairs that were considered a low priority were pushed back until later phases (Figure 7).



Figure 6. Zoomed in portion of the final GIS. Green pipes and manholes are structurally sound with positive flow. Orange and yellow manholes are not in immediate need attention, but should be considered in the long run of replacements. The red pipes have a negative slope and need immediate attention. The red manholes are structurally poor and require replacement.

The pipes were color coded to make identifying the phase straightforward. The yellow pipes indicate those pipes which are in dier need of replacement. The pipes with a negative slope, blockage, or other factor that hinders flow will be the pipes that are replaced in the first year phase. The orange and pink colored pipes are those that are deemed for phases 2 and 3, respectively. These pipes will require replacement, but the severity of their problems is less than those of phase 1. Phase 4 is depicted by the purple colored pipes. These, again, are pipes that will need replacement, but attention is not immediately required. Phases 5 and 6 are colored light blue and dark blue, respectively. These pipes are in relatively good condition for the pipes that require replacement. These pipes are not up to grade as a normal pipe would

be, but they are not an immediate threat to the system.



Figure 7. Zoomed in portion of the six-phase recommendation plan to televise and replace pipes. The yellow colored pipes signify the first year televising and replacement plan. The orange and pink colored pipes indicate phases 2 and 3, respectively. Phase 4 is depicted by the purple pipes, while the light blue and dark blue pipes represent phase 5 and 6.

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