IMPLEMENTING A RISK BASED GIS PRIORITIZATION MODEL TO OPTIMIZE ROUTINE MAINTENANCE OF THE SANITARY SEWER SYSTEM

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ABSTRACT

As sewer systems age it becomes increasingly important to have a routine maintenance program which cleans the system regularly. The Environmental Protection Agency and Texas Commission on Environmental Quality recognize that cleaning is the primary method to reduce sanitary sewer overflows (SSOs). High numbers of SSOs may result in enforcement actions such as Administrative Orders and Consent Decrees that require aggressive cleaning programs and schedules. Without an effective asset management system, enforcement action will normally consist of a requirement to clean 100% of the system in five to seven years. Mandated efforts to clean the entire pipe system treat all pipes equally, resulting in cleaning of clean pipe and cleaning of pipe that have no history of blockage or SSOs. The old program in the City of Bryan was reactionary - using customer identified problems along with the Compliance Infiltration/Inflow (I&I) Supervisor and the field crew's knowledge of historical problems to determine where routine maintenance should be performed.

Geographic information systems (GIS) and extensive data collection provide a solution to the selection of sewer system lines for routine maintenance. A risk based prioritization model provides an objective methodology for selecting segments of the sewer network for routine maintenance. This model is intended to augment the Compliance (I&I) Supervisor and field crew's decision making; the model is NOT intended to provide the sole means of selecting lines that should receive maintenance or determining the frequency of cleaning. By creating the model with ArcGIS and Python, the city was able to avoid additional investment in software and utilize the capabilities of the system already in place. This paper will provide a methodology that other communities could use to implement risk based sewer cleaning to reduce the occurrence of blockages and SSOs.

INTRODUCTION

Line cleaning programs maintain sewer line flow velocity, help prevent sewage from becoming septic, and reduce the number of stoppages and sanitary sewer overflows (SSO). Routine maintenance (RM) of the sewer system (SS) can reduce the number of emergency repairs to the system by as much as 85% (TEEX 2013). The City of Bryan maintains 404 miles of sewer line, 338 of which are narrow enough that they require RM to prevent buildup of solids. In fiscal year 2010, the City of Bryan increased the number of miles that they performed RM on each year and increased the number of smoke tests in an effort to decrease the number of SSOs. The department now cleans 75 to 90 miles of the SS a year. Currently the City of Bryan uses field observations, work orders (WO), and reports from citizens to determine where to perform RM. This process has been reasonably effective with a decrease in SSOs from 116 in 2010 to 55 in

2015, but leaves room for additional reductions by targeting areas that have a higher risk of SSOs and stops with RM.

THE PROBLEM

The number of miles of sewer cleaned each year suggests that the entire system is cleaned every four to five years; unfortunately, this is not the case. While it is not a problem in and of itself, it can be problematic because of the way the lines that do receive RM are selected. The RM occurs at a higher rate in neighborhoods that are perceived to be more likely to have sewer stops and SSOs and are easy for field crews to access. Of the sewer lines 12 inches or less in diameter, 147 miles of the SS have not been cleaned in the seven years that we have GIS records - this is 43% of the cleanable SS. This failure to clean segments of the SS sets the city up for failure in the future as our infrastructure continues to age. Setting up a schedule to clean the lines in a sequential order is not a realistic solution because it would not adequately address areas that have historically had problems.

SOLUTION

Geographic information systems (GIS) and extensive data collection provide a solution to the selection of SS lines for RM. The water department's GIS analyst built an SSO and sewer stop risk model using the data that was created and maintained by the GIS technician. The risk of SSOs and sewer stoppages is defined in this paper as consequence of an SSO x likelihood of an SSO or sewer stop. A Python script was written using ESRI's ArcPy module to produce PDF maps of the highest risk sewer lines. The PDF maps are printed and given to the Compliance (I&I) Supervisor to use in assigning areas for the jet and vacuum trucks to clean and have signature lines for the field crews to sign and return to the office.

The script and ArcToolbox tools can be found at: https://github.com/bryansandw/Sewer_Maintenance. There are detailed instructions on how to import the ArcToolbox script into ArcMap for others use on the git site. The tool may require the user to reformat data, but it has been designed to handle different field names, different field types, and different weighting schemes.

METHODOLOGY

DATA ACQUISITION AND MAINTENANCE

The risk model uses data from: sewer lines, sewer manholes, RM, WO, streams, roads, and parcels. The City of Bryan has an all pipes GIS sewer model. The sewer feature class contains detailed information about the individual segments of sewer line, such as diameter, year of instillation, material, etc. When new lines are constructed this information is added to the GIS. RM is a separate feature class from the sewer lines to allow for frequency information to be collected and to account for lines that are only partially cleaned. The WO data is geocoded by the city's IT department from the SunGard HTE database that is updated through green screen by the admin staff. The stream data comes from Federal Emergency Management Agency (FEMA), the major road data comes from the city IT GIS department, and the parcel data comes from the

Brazos County Appraisal District, which includes the owner name, value of the property, and tax category.

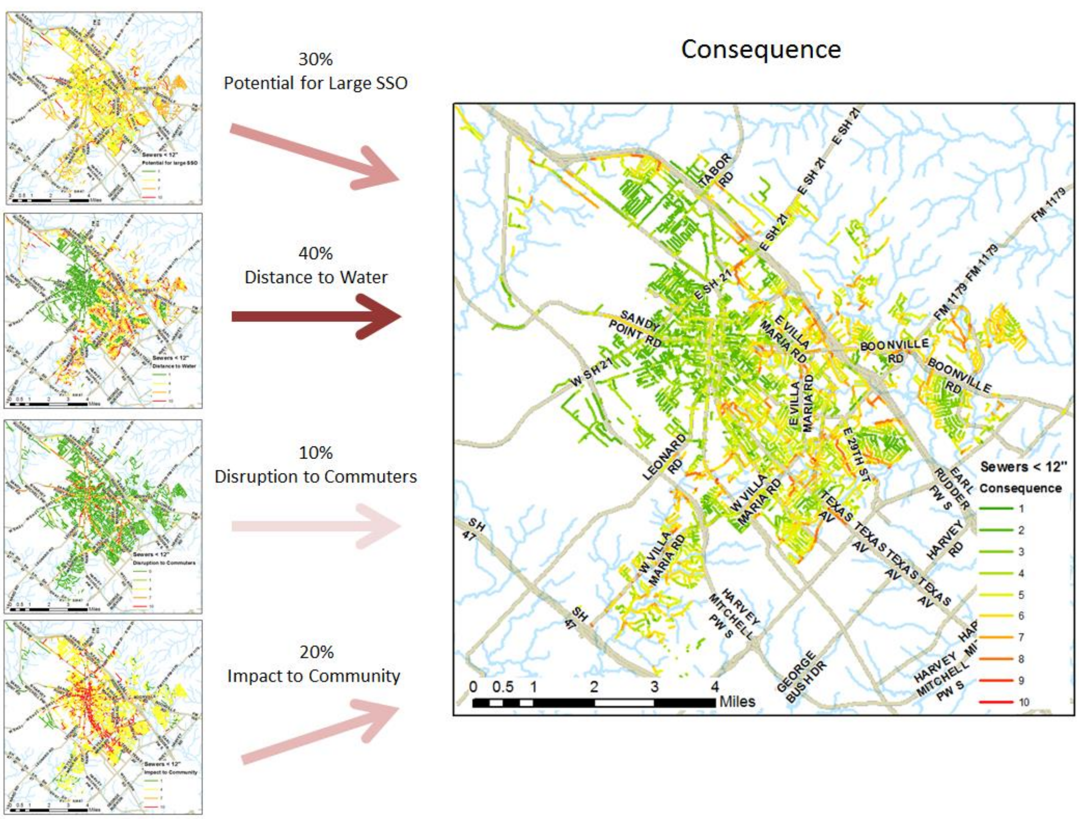
RISK MODEL

The risk model takes the existing GIS data and creates new features that provide information to create a consequence score and a likelihood score that are multiplied to create the risk score that is used to prioritize sewer line maintenance. The risk model variables and weights are based on the risk model from Flores et al. 2011, with some changes where the City of Bryan did not have the same data available, or the department believed additional information should be used in assessing the risk of SS problems.

CONSEQUENCE

The consequence score quantifies what areas a SSO would be the most detrimental to the community (Figure 1). The score is based on four categories: potential for large SSO, distance to streams, disruption to commuters, and impact to community (Table 1).

Figure 1. The potential for large SSO, distance to streams, disruption to commuters, and impact to community are shown on the left and the resulting consequence score is shown on the right. The figure shows how the weighted values from different metrics combine to show areas where the consequence of an SSO would be highest.



1. The **size of the SS lines** is used in the model as an indication of the amount of wastewater that could potentially be spilled by that line. Larger spill require more time and manpower to clean, so is given a 30% weight.

2. The **distance to streams** is given the greatest weight for the consequence score with 40%. If a SSO reaches the water ways it must be reported to the state and could increase oversight of the city by the Texas Commission of Environmental Quality.

3. **Impact to commuters** is a minor consideration. With a weight of only 10%, it is worth including because of its high visibility to the larger community.

4. **Impacts on the community** are scored 20%. Their weights are based on the proximity of the SS to different land use types. For example, lines that are close to schools and hospitals are given higher weights than SS lines near golf courses.

Table 1. Shows the four consequence categories and the breakdown of their weight assignments and percentages.

Consequence	Weight	1 Values	4 values	7 Values	10 Values
Potential for Large SSO	30%	4 in. or less	4 in. to 6 in.	6 in. to 8 in.	More than 8 in.
Distance to Streams	40%	> 1000 ft.	501 ft. to 1000 ft.	101 ft. to 500 ft.	Within 100 ft.
Disruption to Commuters	10%	50 ft. to 100 ft. from road	20 ft. to 50 ft. from road	5 ft. to 20 ft. from road	Within 5 ft.
Impact to Community	20%	Near open spaces or parks	Near residential and golf courses	Near low density commercial	Near hospitals, school, high density commercial

LIKELIHOOD

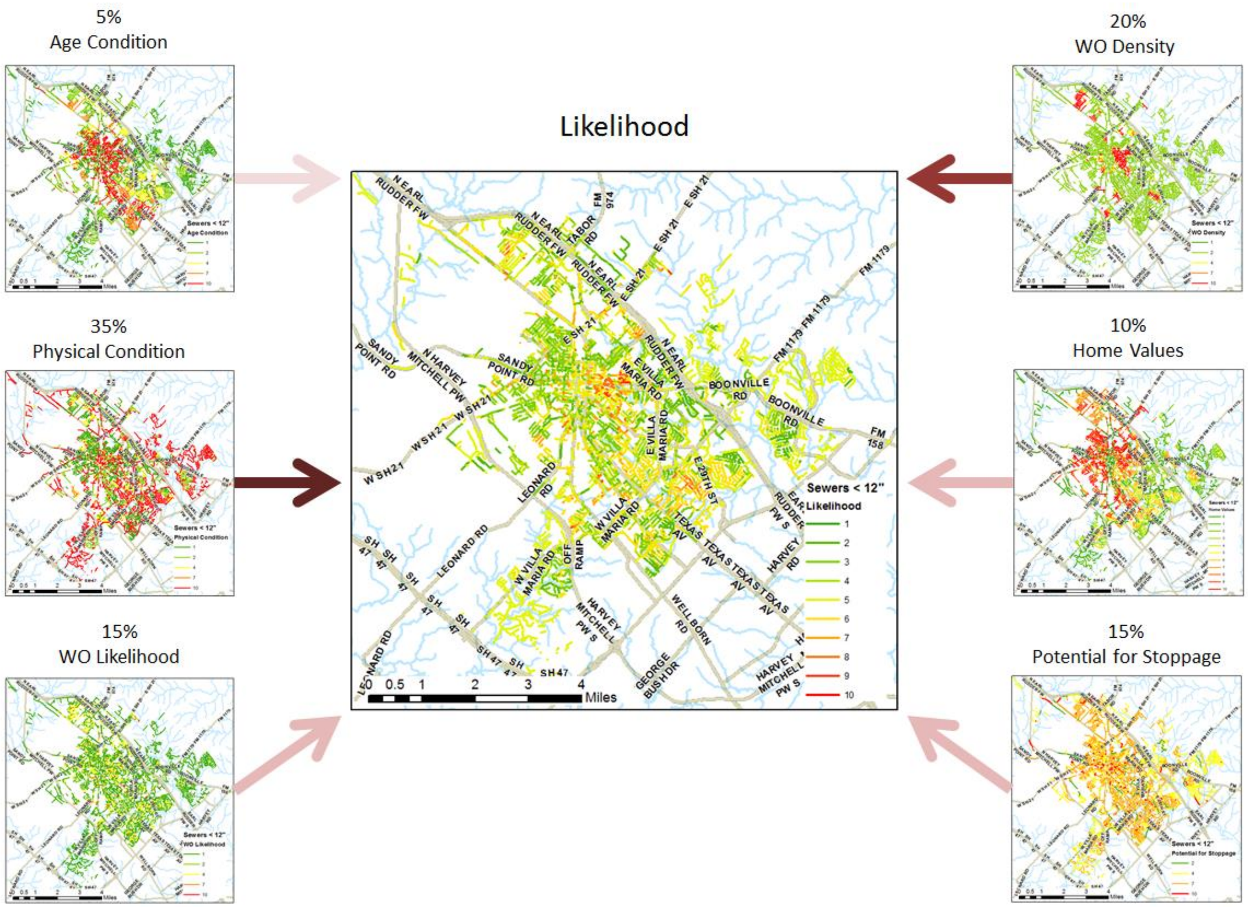
The likelihood score quantifies the lines that have a greater chance of presenting a problem. The model uses six categories: the age of the SS lines, the historic RM data, the historic WO information, the values of the homes around the SS lines, and the size of the SS lines (Figure 2). The historic WOs are used to find the WO likelihood and the WO density categories (Table 2). The not all SSO and stop WOs were used; the included types are public sewer stops as a result of debris, grease, and roots and the public SSOs as a result of capacity, pipe failure, pump station failure, debris, grease, and roots.

Table 2 shows the breakdown of the six likelihood categories and the weight assignments and percentages.

Likelihood	**Weight**	**1 Value**	**2 Value**	**4 Value**	**7 Value**	**10 Value**
Age Condition	5%	Age < 30 yr.	30 to 39 yr.	40 to 49 yr.	50 to 59 yr.	Age > 60 yr.
Physical Condition	35%	< 366 days since RM	366 - 731 days since RM	731 - 1097 days since RM	1097 - 1460 days since RM	1460+ days since RM
WO Likelihood	15%	None	1 Stop	≥ 2 Stops	1 SSO	≥ 2 SSOs
WO Density*	20%	Cold Spots	Neither	90% significant cluster	95% significant cluster	99% significant cluster
Home Values	10%	Market ≥ $230,000	Market < $230,000	Market < $165,000	Market < $130,000	Market < $75,000
Potential for Stoppage	15%	None	Main size > 8 in. and main size ≤ 12 in.	Main size > 6 in. and main size ≤ 8 in.	Main size > 4 in. and main size ≤ 6 in.	Main size ≤ 4 in.

*WO Density is based on a count of WO occurring on SS lines where STOPs are worth 1 point and SSOs are worth 3 point with a “Hot Spot” analysis run on the WO_weights.

Figure 2. The Age Condition, Physical Condition, and WO likelihood are shown on the left hand side, the WO Density, Home Values, and Potential for Stoppage are shown on the right hand side, and the resulting combined likelihood score is shown in the middle. The figure shows how the weighted values from different metrics combine to show areas where the likelihood of an SSO or stop would be highest.



1. The **ages of the SS lines** are determined by the difference between the current year and the year that the line was installed. The majority of pipe is expected to have a 50 year useful life expectancy and for this reason, pipes 50 years or older are given higher weights than younger pipes. The Compliance (I&I) Supervisor did not deem the age as a major factor in stoppages or SSOs, so it was given a low percentage of the likelihood score at 5% of the total.

2. The historic RM data is used to gauge the **physical condition** of the pipes. The lines that have been cleaned in the last three years are given low values, and the lines that have not been cleaned more than three years are given high values. Because one of the main objectives of this project is to decrease the time between line cleanings, physical condition is given a high weight, 35%, in determining the likelihood score.

3. The **WO likelihood** category is simply the location of historic WOs. Stoppages are assigned low values, and lines that have had SSOs are assigned high values. This is a

simple metric that ignores relationships between segments of sewer line, so it is assigned a low weight in determining the likelihood score, 15% of the total.

4. The **WO density** category is based on a “Hot Spot” analysis run on a count of the number of WOs that are associated with each line. SSOs were worth three points and stops were worth a single point. The areas WOs are clustered are given higher values and areas with no clustering are given lower values. This is a more complex metric that takes the sewer lines spatial relationships into account, so it is assigned a higher weight than the WO likelihood score in determining the likelihood score, 20% of the total.

5. The **values of the homes** are used as a proxy for the relative flow rate of the sewer lines in the area and for the amount of grease that is being washed down the drains. Because this is not a direct measurement of either of these factors this category is given a low weight of 10% of the likelihood score.

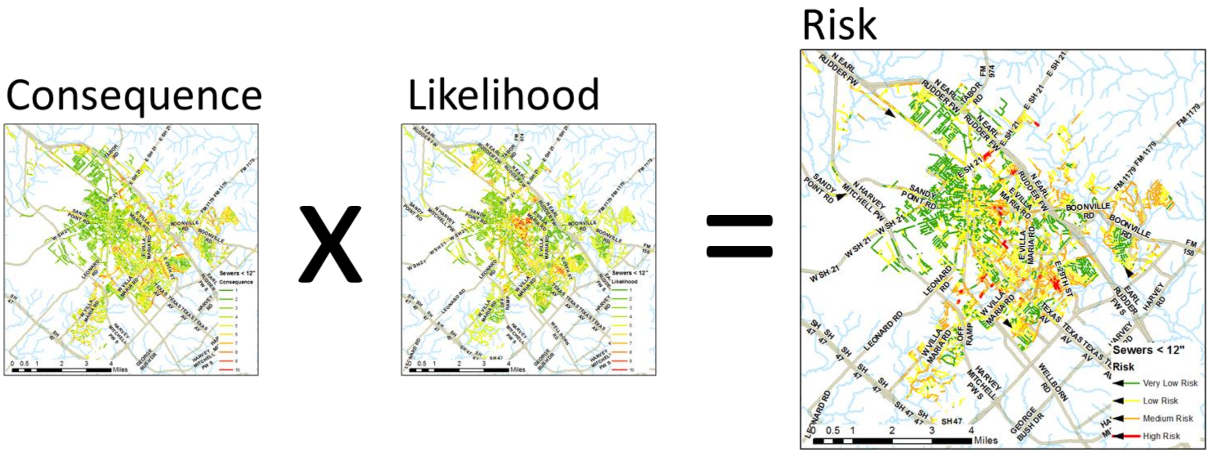
6. The **size of the SS line** is related to the likelihood of the line becoming stopped. Smaller lines are usually near the ends of the SS so have less regular flow; this increases the chance that solids will become lodged in the line creating stoppages so they are given greater weights in determining the size score. The size score makes up 15% of the likelihood score.

MAP AUTOMATION

The risk model provides a large amount of information to GIS users with an intermediate skill level with the software, but it requires time to look at and interpret the data produced (Figure 3). To cut down on the amount of time the Compliance (I&I) Supervisor would need to spend examining the data produced by the model, the highest risk lines are output as PDF maps. There is an ArcMap MXD file that holds the layers symbology and map layout. The script alters this MXD to create new maps that are exported to a folder. The scale adjusts based on the size of the sewer line that is being singled out for RM.

The output maps highlight the segment of the SS that needs to be cleaned and show the manholes that are connected to the pipe segment. This helps prevent any confusion that the user might have about what sewer line on the map needs cleaning. The upper right hand corner of the map displays the maintenance district and quadrant and the date on which the map was produced. The district and quadrant are only used for the SS maintenance district and represent ten districts separated into four quarters each with about eight miles of line. These districts and quadrants help the Compliance (I&I) Supervisor group the maps into geographic groups without requiring visual inspection of the manholes on the map.

Figure 3. Shows the result of multiplying the consequence score and the likelihood score as the risk score. The figure shows how the weighted values from consequence and likelihood combine to show areas where the risk of an SSO or stop would be highest.



FUTURE DIRECTION

The GIS analyst has begun running the Python script to identify and map the highest risk lines and prints each PDF map. The Compliance (I&I) Supervisor is presented with the PDF maps every other Monday morning, to allow for enough time for the lines to be cleaned and returned to the office staff to be processed before the next set of maps was produced. Before the success of the risk model can be assessed, the water department will need to gather more data.

Potential improvements to the model include better assessment of the SS line physical condition than the time since the last RM. This could be done by incorporating the pipe's material type and the age with RM history, or by collecting additional data on the pipe, such as Pipeline Assessment and Certification Program index score during CCTVing.

In order to test, validate, and improve the risk model the department would need to have a control area where the water department continues to select lines in the same way and a study area where the risk model would be used to select lines to clean. It would require a large level of origination and manpower. Most likely the department will substitute data from 2010 to the beginning of the pilot for the control data and compare the rate of SSOs and stops during the pilot to the rate before the pilot began.

SUMMARY

In this paper, we describe the methodology used to build a model to examine the risk of SS lines to have SSOs or stops. We use weighted consequence and likelihood factors to assign risks to each line. The consequence factors were the size of the SS lines, the distance to streams, the impact to commuters, and the impact on the community. The likelihood factors were the ages of the SS lines, the physical condition of the line, WO history, WO cluster density, values of the homes, and size of the SS lines.

CITATIONS

Texas A&M Engineering Extension Service [TEEX] (2013). "Module 6: Maintenance and Operation." *Wastewater Collection*. Print. Infrastructure Training & Safety Institute.

Flores, Michael, Joanne Siew, and Jonathan Lee (2011). "RISK-BASED PRIORITIZATION FOR SEWER MAINTENANCE AND CAPITAL IMPROVEMENTS." *19th Annual Sharing Technologies Seminar*. *The Northern California Pipe User's Group*. The Northern California Pipe User's Group.