Using a GIS to Predict Sanitary Sewer Overflows

Track: Water, Wastewater, and Stormwater
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Abstract

Sanitary Sewer Overflows occur throughout the country, cause severe environmental and economic damages, and can expose the public to a variety of pathogens. GIS analysis can provide a quick and inexpensive means of evaluating an area for determining the likelihood of a Sanitary Sewer Overflow occurring. Currently, efforts to predict and eliminate Sanitary Sewer Overflows have relied on the use of hydraulic modeling and extensive collection system inventories and inspections. This methodology is often expensive and can take many years to complete. Based on historical information about the causes of Sanitary Sewer Overflows and their distribution, it is possible to identify areas at greater risk of their occurrence, and direct study efforts to those regions. This paper presents an approach to using a GIS to analyze general spatial characteristics of a Texas municipality's wastewater collection system, and compare the results to known historic occurrences of Sanitary Sewer Overflows.

Section 1.0 – Introduction and Background

This project analyzes general spatial characteristics of the wastewater collection system in the City of Austin, Texas in an attempt to identify areas at greater risk of the occurance of a Sanitary Sewer Overflow (SSO). The primary project goals are to identify risk areas without requiring the collection of new data, minimize any manipulation of pre-existing data, and avoid the use of hydraulic modeling.

As with most cities in the southwestern United States, the City of Austin utilizes separate systems for sanitary sewer and storm water collection. Both rely primarily on gravity as a means of transport, but the sanitary sewer collection system also utilizes pressurized flow through numerous lift stations and associated force mains to move wastewater through the hilly terrain. Austin's sanitary sewer pipelines are accessed via wastewater manholes, which can range from 3 feet to over 100 feet in depth. The sanitary sewer lines have diameters ranging from 1-inch force mains to 96-inch gravity main interceptors.

Within the City of Austin, there are numerous small, privately owned wastewater treatment plants, with the City maintaining three large wastewater treatment plants and one bio-solids plant. These plants are the outfalls to the three primary sewersheds within the City of Austin, and are located in the eastern part of town, along the Colorado River.

Wastewater travels roughly from West to East, flowing towards the treatment plants into the Colorado River Basin, as illustrated in Figure 1.1.

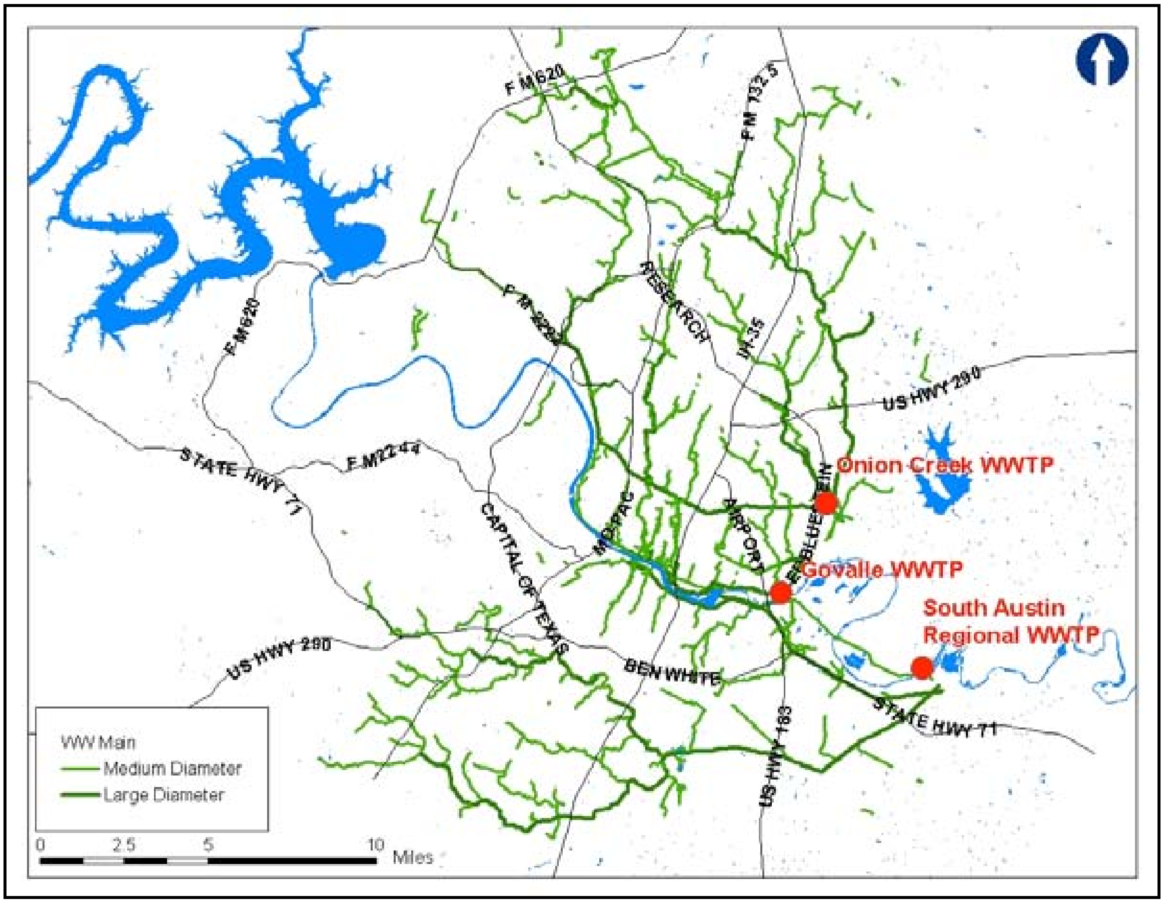

Figure 1.1 - Wastewater Collection System - City of Austin

Section 2.0 – Literature Review

Internet sites, industry-specific journals, and information from the City of Austin were the primary research sources utilized for this project. Also, abstracts from industry conferences were reviewed to gain a perspective and direction of the ongoing research and development in the field of wastewater collection systems and the control of SSOs. A list of references is provided in Section 8.0.

Section 3.0 – Relevance of Study

SSOs occur throughout the country, can cause severe environmental damage, and represent a threat to the economic investments in our infrastructure. SSOs are defined as the uncontrolled discharge of untreated sewage, and are classified as “Non-Repeat” and “Repeat” events by the City of Austin. Non-Repeat SSOs typically occur from a single event, such as the accidental damaging of a sewer line, while "Repeat" SSOs occur on a regular basis in the same general location (GSWW, 2002). These discharges often occur in populated areas or environmentally sensitive areas, such as along creek beds, over aquifers, or in streams and rivers. It is estimated by the Environmental Protection Agency (EPA) that between 23,000 and 75,000 SSO events occur every year in the United States, discharging a total volume of 3 to 10 billion gallons of raw sewage each year (Laughlin, 2004).

A well-maintained sanitary sewer collection system is an important means of controlling the spread of disease into populated areas. The uncontrolled release of raw sewage into the environment has various detrimental effects, and the potential to expose the public to many pathogens. Whenever an SSO occurs, there also lies the danger of exposing a population's water supply to numerous chemical and biological hazards.

> Because SSOs contain raw sewage they can carry bacteria, viruses, protozoa (parasitic organisms), helminthes (intestinal worms), and bioaerosols (inhalable molds and fungi). A key concern with SSOs which enter rivers, lakes, streams, or brackish waters is their effect on water quality. When bodies of water cannot be used for drinking water, fishing, or recreation, society experiences an economic loss. Tourism and water front home values may fall. Fishing and shellfish harvesting may be restricted or halted. SSOs can also close beaches. (U.S. EPA, 1996)

Wastewater collection systems represent major infrastructure capital expenditures, and the United States has over $1 trillion invested into its sewer systems (U.S. EPA, 1996). SSOs can represent a failure of some of these systems and can cause physical damage to them, if they are allowed to occur. Moreover, the presence of an SSO suggests a symptom of other potential problems within a collection system, such as issues with capacity, a sewer line collapse, a lift station malfunction, the infiltration of ground water, or the inflow of rainwater.

Section 4.0 – Data Review

Understanding the underlying causes of SSOs dictates the types of data needed to complete this project. While each wastewater collection system can be regarded as unique, there are inherently common design components and limitations, and therefore the causes of SSOs are similar. Typically, SSOs are caused by anything capable of obstructing or restricting the flow of wastewater within a sewer (City of Austin, 1995). An analysis of the specific causes of overflows in the City of Austin is instrumental in creating the SSO risk estimates for the city.

Currently, the entity with jurisdiction over the City of Austin's wastewater collection system is the Austin Water Department, a City of Austin utility. Within this utility, the Collection System Services Division keeps track of reported SSOs, responds to reported overflow problems, and initiates investigational programs in an attempt to study and prevent future overflows. For this project, the City has provided a database of overflow activity ranging from 1991 to 2002, and a matching GIS shapefile with data ranging from 1995 to 2002.

The City's database was queried to eliminate any data prior to 1995, so it would be in agreement with the provided shapefile. The final result is a shapefile and database in agreement with 1,298 records of reported SSOs. Although the suspected or confirmed causes for the SSOs were reported within the database, they were not recorded in a standardized method. It was necessary to examine the database and assign categorized causes for each SSO, as guided by the literature, such as the City of Austin's SSO web page and the EPA's reports on SSOs. These causes include pipe breaks, pipe blockages, vandalism, and many others. Within the City of Austin database, eight general causes of overflows were identified, and Figure 4.1 illustrates their distribution within the database.

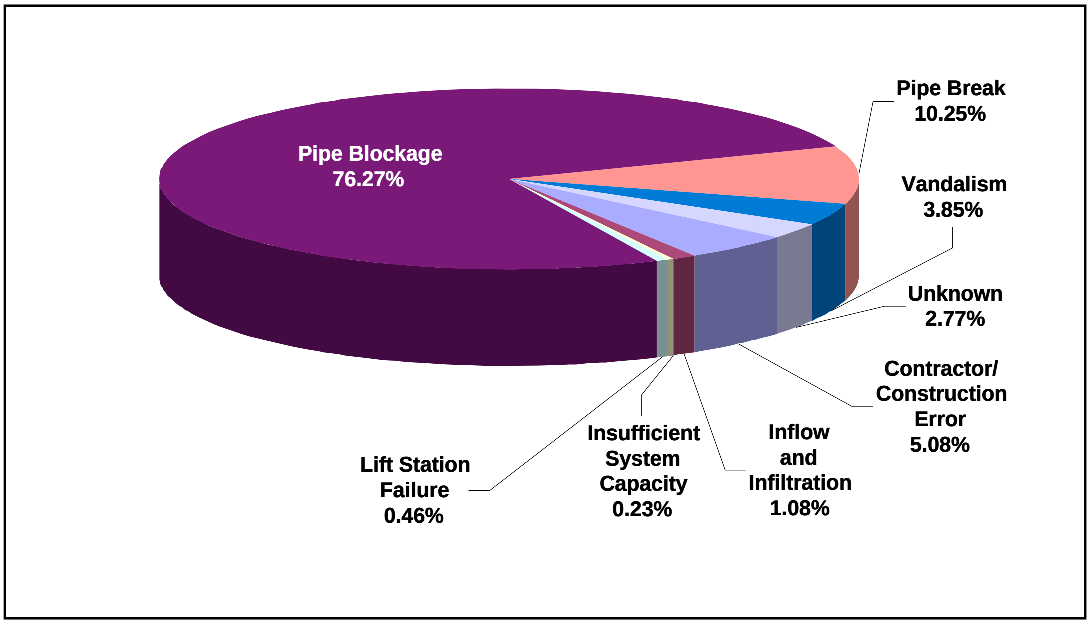

Figure 4.1 – General Causes of SSOs in the City of Austin

As illustrated by Figure 4.1, the primary cause of SSOs in the City of Austin is a pipe blockage, followed by pipe breaks and human error (construction or contractor errors) respectively. Each of these general causes was further subdivided into specific causes, in an attempt to identify any underlying patterns to the causes of SSOs.

Figure 4.2 is a tabular breakdown of the general causes, as well as a further breakdown of specific causes for SSOs reported to the City of Austin between 1995 and 2002. This figure illustrates that the primary cause of SSOs in the City of Austin is grease build-up within the sewer pipes, followed by unknown blockages (probably grease, as comments indicated in the SSO database) and debris.

General Cause	Specific Cause	Incidents	Total Incidents	Percent
Contractor/Construction Error	Debris	9	66	5.08%
	Faulty Design/Construction	4		
	Faulty Repair	4		
	Unintentional Structural Breach	49		
Inflow and Infiltration	Flood Damage (destroys pipes)	2	14	1.08%
	Infiltration	5		
	Inflow	7		
Insufficient System Capacity	Insufficient System Capacity	3	3	0.23%
Lift Station Failure	Equipment Failure	3	6	0.46%
	Power Failure	3		
Pipe Blockage	Debris	140	990	76.27%
	Grease	552		
	Rocks	42		
	Roots	63		
	Unknown Blockage	193		
Pipe Break	Broken Manhole/Cleanout	3	133	10.25%
	Broken Pipe	105		
	Collapsed Pipe	18		
	Missing Pipe	7		
Vandalism	Vandalism	50	50	3.85%
Unknown	Unknown	36	36	2.77%
Total Incidents of Reported SSOs from 1995 to 2002			**1298**	**100.00%**

Table 4.2 - Categorical Causes of SSOs in the City of Austin, Texas

This data indicates that human food and wastes are the primary sources of SSOs in the City of Austin, as indicated by the presence of grease in the sewer lines. While it has been previously noted that overflows can occur almost anywhere, it is important to note that SSOs can occur in parks, backyards, city streets, playgrounds, and other areas that are frequented by the public (U.S. EPA, 2004). Other SSO causes involving human intervention include Vandalism and Construction/Contractor Error.

Understanding the causes of SSOs is critical to identifying the kinds of data that will be necessary to predict their occurrence, as well as providing a means of weighting the influence of certain factors that can cause an overflow. These causes can be used to identify specific GIS data needed to complete the analysis, as shown in Table 4.3.

Data File	Source	Description
200grid	City of Austin	Divides the city into mapping grids
cenart	City of Austin	Major and minor roads in the City of Austin
creeks_network	City of Austin	Major creek systems in Travis County
hydro_p	City of Austin	Rivers, lakes, and ponds in Travis County
landuse2000	City of Austin	Land use designations for Travis County in 2000
liftstation	City of Austin	Lift stations in the City of Austin
overflow	Austin Water, CSS	Database of SSOs from 1991 – 2002 (joined with overflows_greater_95)
overflows_greater_95	Austin Water, CSS	Locations of SSOs from 1995 - 2002
tgr48000sf1blk	Census/TIGER	Table of 2000 Census Texas block group demographics (joined with block groups to form "census")
tgr48453grp00	Census/TIGER	TIGER 2000 Census block groups for Travis County
tgr48491grp00	Census/TIGER	TIGER 2000 Census block groups for Williamson County
wwfacility	City of Austin	Major facilities for wastewater treatment within the City of Austin
wwmain	City of Austin	Wastewater mains within the City of Austin

Table 4.3 - GIS Data Required

SSO contributing factors were weighted based on the percentage of their historical occurrences, and one or more feature classes were assigned to each of the potential causes, as shown in Table 4.4.

General Cause	Percent	Feature 1	Feature 2	Feature 3
Pipe Blockage	76.27%	wwmain		
Pipe Break	10.25%	wwmain		
Construction/Contractor Error	5.08%	wwmain	census	landuse200
Vandalism	3.85%	census	landuse200	
Unknown	2.77%	N/A		
Inflow and Infiltration	1.08%	creeks_network		
Lift Station Failure	0.46%	liftstation		
Insufficient System Capacity	0.23%	wwmain		

Table 4.4 - General SSO Cause Percentages

Pipe Blockage, Pipe Break, Construction/Contractor Error, and Insufficient System Capacity were all associated with the wwmain feature because they are all directly connected to the density of pipe in a given area. The more pipe in an area, the higher the probability it is to have a pipe-related SSO.

While there are many causes of Inflow and Infiltration (the intrusion of ground and rain water into a sewer pipe), the cause has been generalized to indicate the primary source is from creeks. Census and land use data were associated with Construction/Contractor Error and Vandalism because a higher level of population in a residential or commercial area results in a higher discharge to the sewer pipes, and would be a direct contributor to the occurrence of SSOs.

Section 5.0 – GIS Analysis

A diagram was created to guide the analysis of this project, and is presented as figure 5.1.

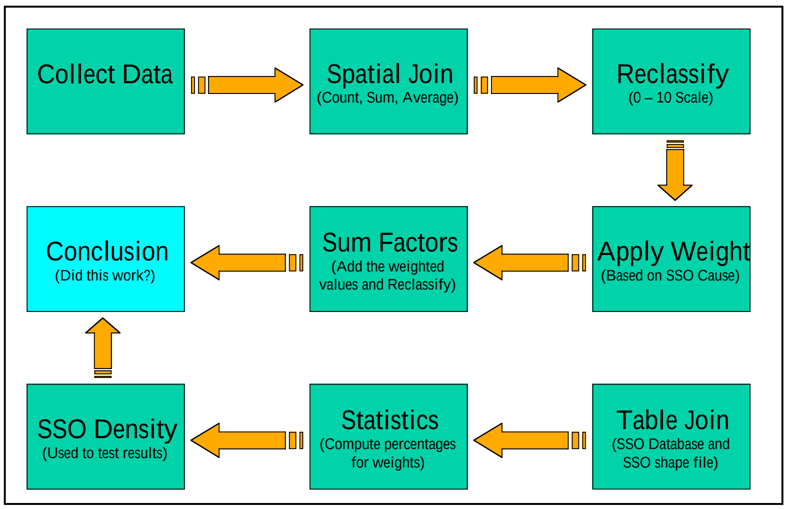

Figure 5.1 – Analysis Flow Chart

Understanding the general causes of SSOs can yield a basis to calculating the probability of occurrences in a given area. Further, it is necessary to look beyond the point at which the SSO occurred, as pipe conditions upstream or downstream of an SSO may have a significant impact on the occurrence of the SSO (URS Corporation, 2004). For this reason, it was determined to base SSO prediction analysis on an area at and around the SSO, rather than focus on the specific location of the SSO only.

Therefore, it was determined that a common area divider would be used to analyze and normalize the data. This was chosen to be the grid system developed by the City of Austin, a feature class called 200grid. This grid is the basic mapping unit for the Austin Water utility, and is often used by City personnel for their work in the office and in the field. The final analysis would be based on these grids, with the goal of being able to identify which grids were most likely to experience SSOs, and should therefore be the focus of future investigations and scheduled maintenance. Also, because the grids were of identical size and area, they acted to normalize the variables, so densities would not need to be calculated.

Each feature was spatially joined with the City's grid, and the appropriate summary values were calculated for each resultant joined feature class. Most values were summed within the grids, such as the number of lift stations or the linear footage of the sewer pipes. However, other values were averaged, such as land use and census data. Land use and census data were averaged with the classification that a particular grid would be occupied by a particular value, and a general assumption could be made about the characteristics of each grid based on this averaged value.

Because some of the SSO causes were reflected in multiple feature classes, their percentages of cause were adjusted to reflect their multiple appearances. Further, because nothing could represent an Unknown SSO cause, its category's percentage was split evenly among the other causes, based on the assumption an Unknown SSO was still caused by one of the other factors--it was just not identified or recorded in the overflow database. This final weight scale is reflected in Table 5.2.

Shape File	Occurrences	Divide the Unknown	Adjusted Percentage
census	2	0.55%	4.17%
creeks_network	1	0.55%	1.63%
landuse200	2	0.55%	4.17%
liftstation	1	0.55%	1.01%
wwmain	4	0.55%	89.00%

Table 5.2 - Final Weighted Variable Values

Each feature's summary attribute was then reclassified to a 10-point scale, and then multiplied by a weight based on its percentage of cause, as illustrated in Table 5.2. The resulting features were joined to create a grid, where each cell contained the attributes of the contributing causes. The final weights for each grid consisted of the sum of the individual contributing causes weighted to a 100-point scale. These total values were then grouped into levels of prediction ranging from "Less Likely" to "Highly Likely" that an SSO would occur in each grid.

As a check on the veracity of the resulting grid values, the original SSO shapefile provided by the City of Austin (the physical locations of the entries in the SSO database) were plotted. A density calculation was performed to identify regions with high SSO concentrations, and is illustrated in Figure 5.3.

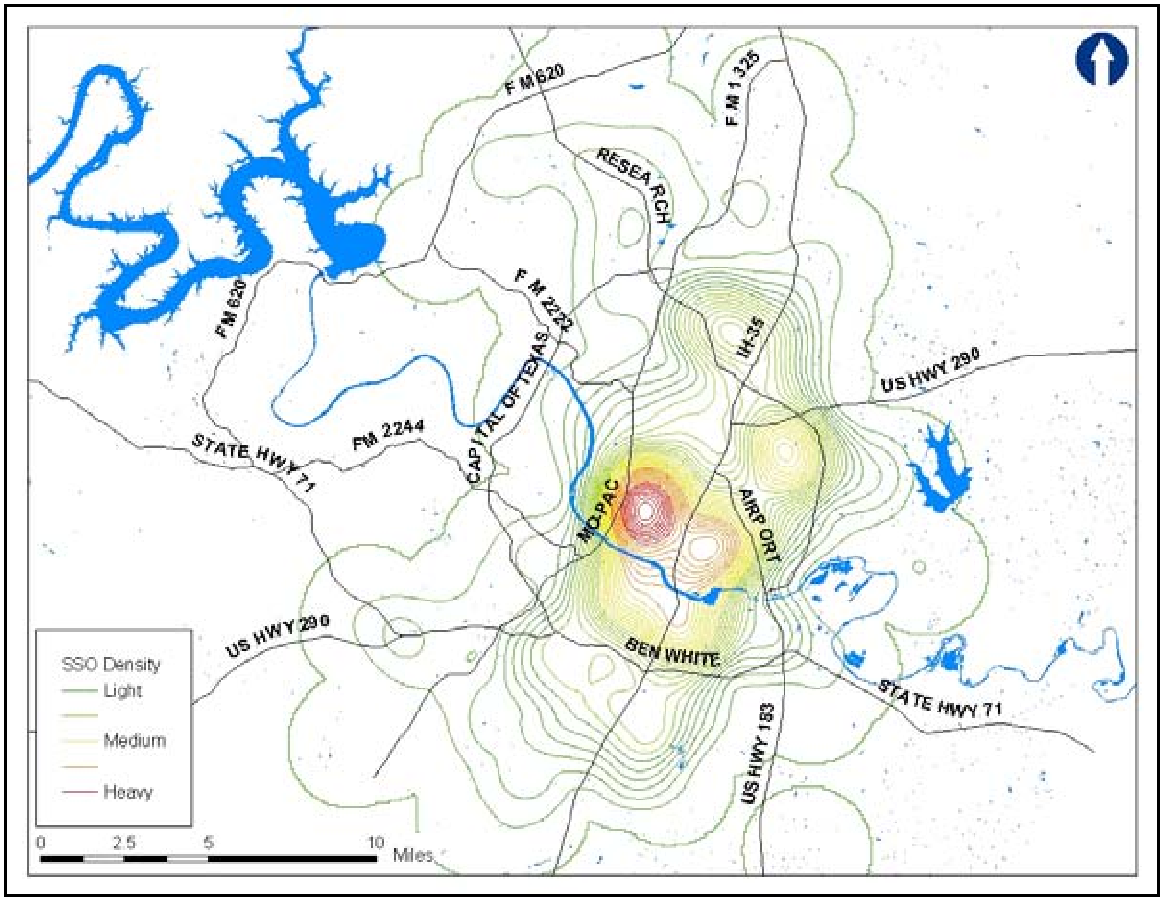

Figure 5.3 – SSO Density, City of Austin 1995 – 2002

Section 6.0 – Results and Conclusions

The resulting map, Figure 6.1, represents the weighted and ranked grids.

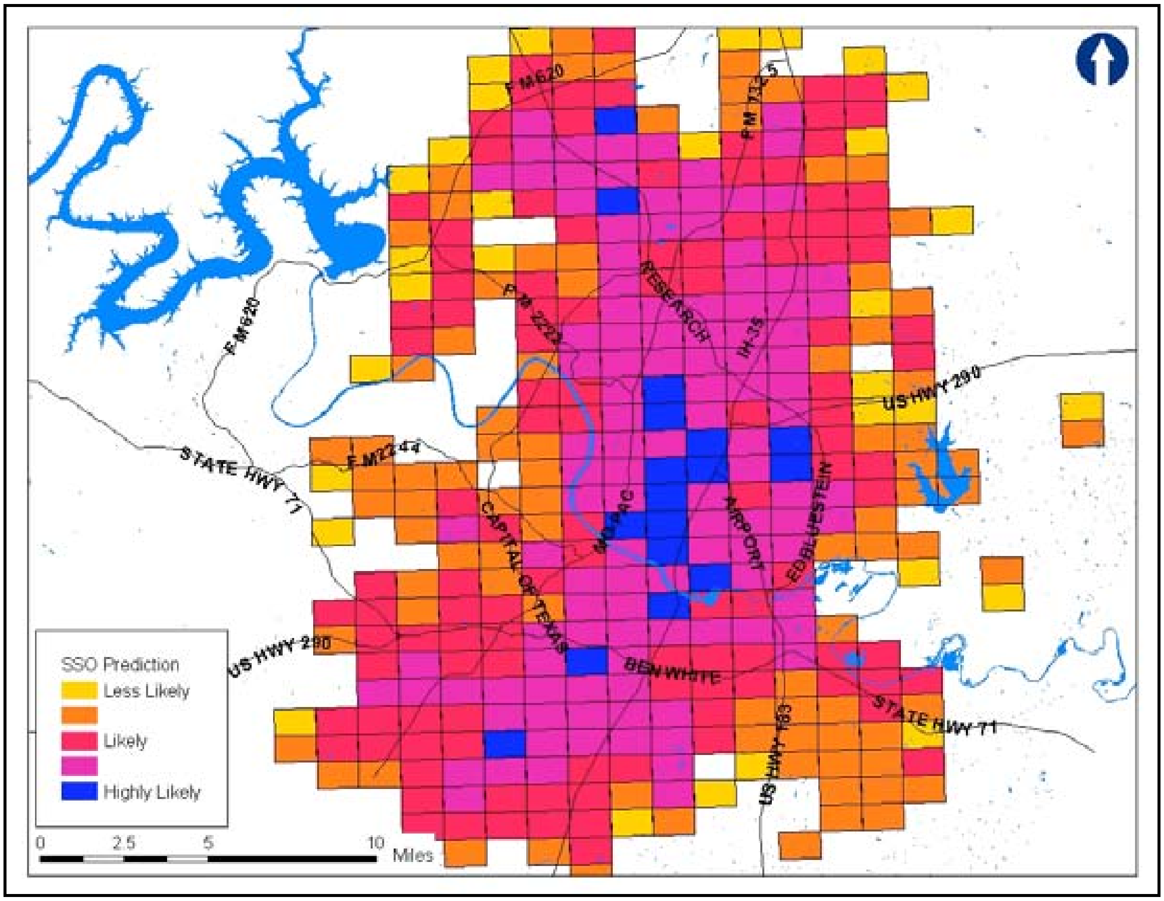

Figure 6.1 – SSO Prediction Grid

As Figure 6.1 illustrates, there is similitude between the SSO Prediction Grid and the SSO Density of Figure 5.3, which is based on historical SSO activity in the City of Austin. However, many areas were designated as "Highly Likely", but did not have a corresponding level of SSO Density. These areas are in the southwest portion of the city, and one possible explanation might be that Austin's growth is focused in the southwest region. These sewer pipes are among the newest, and they have not had a chance to build up grease and debris, or allow any of the other factors that cause SSOs to occur. Also, there are many tracts of undeveloped land in this region, and SSOs may be occurring, but are not reported.

The importance of the study of SSOs and the ability to predict their occurrences is evident in the publications referenced in this paper, as well as countless others. Identification of probable locations of SSOs and the evaluation of their causes should be a part of any comprehensive preventive maintenance program (Black & Veach Corporation, 2000). By assigning a priority to a particular grid, a municipality can better focus its resources and more efficiently target problem areas.

Finally, it is important to note SSO prevention needs to take a temporal dimension. SSOs in the city of Austin have pattern of occurrence, as shown in Figure 6.2.

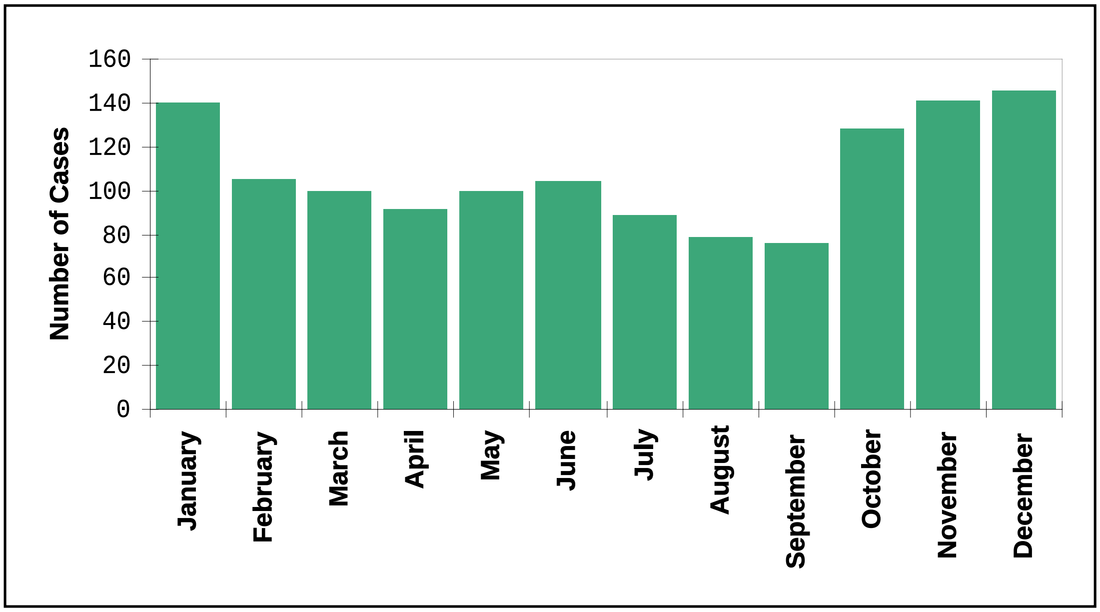

Figure 6.2 – Monthly Occurrences of SSOs: 1995 – 2002

SSOs appear to be more prevalent in the Fall and Winter months, possibly because of the increased system demand. This time of the year signifies more food preparation and consumption, as well as a higher volume of use of the wastewater collection system (visitors and people staying at home). Higher system demands can lead to the increased build-up of grease and debris in the sewer lines, which can lead to heavy SSO activity. Perhaps routine wastewater line cleaning and maintenance could be performed during this time of year as a preemptive measure.

Section 7.0 – Areas of Further Study

Further analysis of SSO activity is recommended as a result of this project. A more precise means of identifying trouble areas could be developed by adding additional criteria and data to this model. For instance, knowing the locations of high grease-producing areas could aid in locating probable areas in which blockages could occur. Also, factoring the diameter and age of the pipes will further define the selection of areas of probable SSO occurrences. Finally, the use of a smaller grid size would allow for a more precise level of determination of an area's susceptibility to SSOs.

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