GIS Based Collection System Modeling

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Abstract

The City of Abilene, Texas is evaluating their water and sewer infrastructure. The consulting team of enprotec/Hibbs&Todd, HDR Engineering and Pipeline Analysis performed a Wastewater System Master Plan as an important part of this evaluation. This team brought together invaluable local knowledge, full GIS capabilities, modeling experience and flow monitoring expertise to deliver a complete solution to the City of Abilene. As part of this project, a detailed hydraulic model of the City's wastewater collection system was developed to help identify locations of capacity restrictions (bottlenecks) and to size the system improvements needed for future development.

The hydraulic model was developed using MWH Soft's H2OMap SWMM software in a GIS based environment. The model layout was based on existing collection system maps. However, much of the physical data necessary to construct the model had to be surveyed to fill in gaps in the existing system database. Contributing wastewater flows from residential and commercial users were developed by geo-coding water billing data and converting the demands into wastewater flows. Also, flow meters were installed to collect data for model calibration and for estimating inflow and infiltration (I&I) contributions across the system.

Once the model was developed, bottlenecks in collection system capacity were located and improvements to alleviate these restrictions were defined. Additional improvements were identified in areas of anticipated growth. The model was also used to identify the best locations for a potential satellite treatment facility that could be located near reuse water customers so that collection system capacity could be maximized while conserving potable water use. The identified collection system improvements will provide the most capacity expansion possible with the fewest feet of new pipe installed.

Introduction and Background

The City of Abilene is conducting a Wastewater Master Plan study. The consulting team of enprotec/Hibbs&Todd, HDR Engineering and Pipeline Analysis was hired to perform the study. The team performed flow monitoring, developed population and land use projections, developed a hydraulic model of the collection system, and identified existing and future constraints within the collections system. A list of projects were identified that will be required to meet the future development conditions within the City of Abilene.

The drivers for the wastewater planning study were:

- Inadequate Existing Capacity
- Population Growth
- Changes in Service Area (Annexation)
- Potential Reuse Projects

Existing capacity issues in the collection system have caused some sanitary sewer overflows (SSO's). The city is primarily interested in eliminating the occurrence of SSO's. Limited capacity in portions of the collection system was identified through interviews with city staff and by running the hydraulic model. The model helped to confirm some problem areas and to uncover others.

Population growth is not a big driver for the City of Abilene. However, steady increases in population are projected over the next 30 years. The total projected population growth over the next 30 years is approximately 10% of the current population. Growth is some areas will, of course, be greater than others especially in areas planned to be annexed by the city. It is in these projected growth and annexation areas that particular attention was given to ensure adequate capacity for the future.

The City of Abilene was also interested in exploring possible locations for a satellite wastewater treatment facility. The plan was to find a location where a satellite plant might scalp flows from the collection system, treat to reuse levels and then pump into the reuse distribution system. The idea had particular merit because the largest reuse customers in the city are located on the west side of town. The current wastewater treatment facility is located on the northeast edge of the city.

Because of the existing capacity problems across the system and the need for planned expansion, a hydraulic model of the system was needed. Selection of a predictive hydrologic and hydraulic model for the sewer system is a key element of the master planning process. The selected model must be capable of analyzing current loads, determining theoretical hydraulic and hydrologic capacity, and identifying and locating deficiencies in the existing systems. The selected model must also be able to analyze future growth loads imposed on the existing systems and evaluate scenarios for handling these loads.

The selected model should serve as a tool to provide reasonable results for planning efforts and be easily updated to reflect ongoing land use changes and development. The model should be user friendly and allow for import and export of data for utilization and maintenance by City staff. Key points of evaluation included:

- Integration/interface with GIS software
- Single software vendor for both water and sewer models
- Cost
- Interface with City data
- User friendliness

A survey was conducted of commercially available sanitary sewer collection computer models. The vendors and programs listed in Table 1 were compared based on the criteria listed above. After comparison, the MWH Soft product H2OMap SWMM was selected as the best modeling software for the City of Abilene.

Table 1
Sewer Modeling Software Packages

Vendor	GIS Integrated	GIS Interface
MWH Soft, Inc.	InfoSWMM/ InfoSewer	H20Map Sewer/ H20Map SWMM
Haestad Methods/Bentley	SewerGEMS	SewerCAD
Wallingford Software	--	InfoWorks CS
Danish Hydraulics Institute (DHI)	--	MikeURBAN CS

Model Development

As part of the Wastewater Master Plan project for the City of Abilene, the project team of Enprotec/Hibbs & Todd (e/HT) and HDR Engineering (HDR) has:

- Collected existing CAD and GIS based maps for the wastewater collection system
- Inventoried the existing data to determine information needs
- Formatted and geo-processed the existing maps and databases for use in the hydraulic model, H2OMap SWMM

The City of Abilene's existing wastewater system data, as provided to e/HT and HDR, consisted primarily of two GIS files: SANMHS (sanitary sewer manhole data) and SANLINE (sanitary sewer line data). Additional data including GIS files containing parcel information, roads and railroads was also provided to the project team by the City. A CAD map of the sanitary sewer system was provided as a supplement to the GIS files.

The SANMHS file included 9,727 features representing manholes within the City of Abilene's Wastewater Collection System. Of these manhole features, 3,088 were missing rim elevation and/or manhole depth information. A list of approximately 200 manholes was created for field verification of the missing data. These manholes were associated with larger diameter collection system pipe and other critical model elements.

The SANLINE file contained 15,883 line features, representing the city's wastewater collection lines. Of the 15,883 line features, 4,722 were missing diameter data. Of those 4,722 features, 4,533 represented service laterals to individual properties. These features were left without diameter attribute data and were not utilized in the model. Diameters for the remaining 189 features were either surveyed or estimated as accurately as possible, or determined not to be critical components of the model and left unchanged.

In the SANMHS file provided, manholes were represented by polyline features. The modeling software required that the manholes be represented as point features. First the polyline features were converted to polygons. For most of the manhole features, this process was automated by a script. A script is a set of instructions, written in a script language like VBScript, which can be used to automate tasks such as data conversion within the GIS environment. However, for many of the features, the polyline start and end points did not match and hand editing was required for conversion of the complete set of manhole data.

After all of the manhole features had been converted to polygons, a point feature was assigned to the centroid of each of the converted polygon features. The new point features were updated with their associated identification numbers, rim elevations, invert depths and other attribute data using a spatial join process. The features were also updated with northing and easting information, based on the Texas State Plane Coordinate System, NAD 27, Central Zone.

Formatting of the data is an important factor to consider when developing a GIS based map of any infrastructure system. Of particular importance for pipe networks, the pipes must meet at points for most modeling packages to represent the system correctly. Much of the model construction time for this project was spent formatting the data the city thought was already in the correct format. Developing the maps in the correct format from the beginning may save considerable time and effort when the maps are subsequently used for model development.

During the month of May, 2006, Pipeline Analysis, LLC conducted flow monitoring for the purposes of this study. Results of the flow monitoring were used in the determination of flow composition in the City of Abilene. Flow is generally comprised of three key elements: base wastewater flow, groundwater infiltration and rainfall-dependent infiltration/inflows. The hydrographs generated from the flow monitoring can be used to estimate these three components for each sub-basin.

Base dry weather flow (BWF) is the flow contributed to the system directly from customers. Flows are generally diurnal, which means they follow patterns throughout the day with peaks generally occurring during the morning between 7:00 am and 9:00 am and again in the evening from 6:00 pm to 10:00 pm. Commercial and industrial flows diurnal patterns stay more constant during the work day. Weekdays and weekends typically exhibit different flow patterns, therefore we used weekday average flows. Base dry weather flows can be broken down further into three basic components: residential, commercial and industrial flows.

Groundwater infiltration (GWI) is defined as the constant inflow of groundwater into the collection system. This value is determined by several factors including the location of the groundwater table and the physical condition of the collection system. Flow monitoring evaluated during the late night and early morning hours is generally characteristic of GWI in systems that do not have substantial industrial and/or commercial flows that enter the system throughout the 24-hour period. GWI can also be impacted by dry and wet periods.

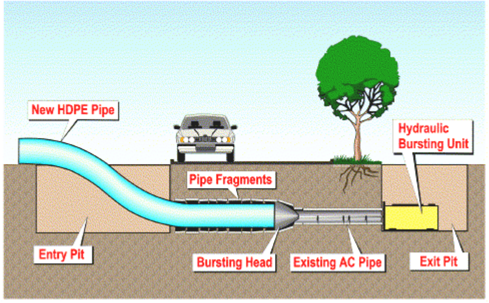
Rainfall-Dependent Infiltration/Inflow (RDII) is that portion of flow that enters the collection system during a rainfall event. The methodology used to generate the RDII hydrograph was based on a unit hydrograph approach where the characteristics were derived from the flow monitoring data, and are defined as R, T, and K. The R was originally defined for each sub-basin in the flow monitoring report as average leakiness factor. This is percentage of rainfall that entered the system within each sub-basin. T is the time of concentration, or the time difference between when the rainfall started and when the peak flow hydrograph was observed at the monitoring locations. K is the recession coefficient, or the ratio between the peak of the flow hydrograph and the point at which the RDII receded.

RDII was found to be a significant portion of total wet weather flows in the system. Infiltration may be the result of many varying issues, including but not limited to poor construction in high groundwater, root intrusion, offset joints, or broken or crushed pipe. Many of the issues addressed can be remedied through trenchless solutions. The following gives a brief description of some of the available rehabilitation techniques the City of Abilene could use to address deficiencies.

<u>Main Replacement by Pipe Bursting</u> –

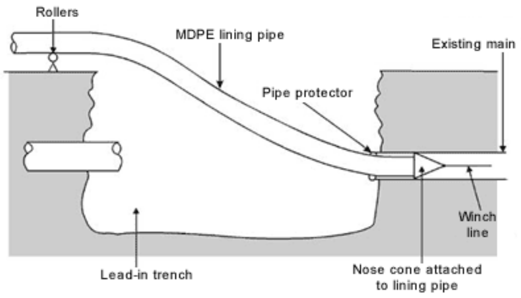
This has become a frequently used technology to replace aging sewer main that may also be experiencing capacity issues. A “bursting head” is routed through existing pipe, and a flexible new pipe is pulled from behind. In sewer projects, this can be done from manhole to manhole.

However, it should be noted that services will then need to be handled individually. This is an effective means of replacing sewer main without causing major surface impacts, but will require trenching and replacing of the sewer service. Pipe bursting is particularly effective with vitrified clay pipe. However, low areas or sags can not be addressed with this method.



Pipe Bursting Schematic

Slip Lining – Slip lining a sewer main includes installing a rigid sleeve inside the existing sewer main. This is installed from an access point at one end of the main to be rehabilitated. If the main is CCTV'ed with stationing first, the services can be robot-cut back into the trunk. Although this can be a very effective means of eliminating infiltration, it can reduce the capacity of the system and in some areas is not a viable option due to existing pipe conditions. While an effective solution in high root growth areas, deficiencies involving wide, offset joints should not be slip-lined. Additionally, low areas are not addressed with this method.



Slip Lining Schematic

Cure-In-Place – Similarly to slip lining techniques, deficiencies involving wide, offset joints should not be slip-lined and low areas are not addressed with this method.

Main and Service Line Replacement - By replacing both the main and service lines that are within the area of the sewer main trench, infiltration can be substantially reduced if proper construction practices are used. The service lines tend to be shallow and not affected by groundwater until they get close to the mains in areas where basements do not exist. Replacing the portion of the service line within the main trench should target the majority of the service line impacted by groundwater. The disadvantage to this method is the high cost and disturbance of improved areas. This method is estimated to remove approximately 90-percent of infiltration from the sewer main that is rehabilitated. Table 2 lists advantages and disadvantages of these various rehabilitation techniques.

Open Cut Replacement is the Most Disruptive Method

Table 2
Common Rehabilitation Techniques and Advantages/Disadvantages

Method	*Applications*	*Advantages / Disadvantages*	*Comments*
Sliplining	Continuous or segmented pipe with flush joints	Generally cost-effective and timely. Requires excavation for insertion pits and lateral connections, can reduce hydraulic capacity, and usually requires bypass pumping.	Widely used and economical; however can cause disruptions and applications for severely damaged or deteriorated conduits are limited.
Cured-in-Place Pipe (CIPP)	Continuous or segmented pipe with flush joints	Generally cost-effective and timely. Can be installed from existing structures – no excavation required. Very little reduction in hydraulic capacity. No resulting annular space to be grouted. Requires bypass pumping. Applications limited by steep grades.	CIPP uses a flexible fabric liner saturated with a thermosetting resin forced into position with water or air. Applications for severely damaged or deteriorated conduits are somewhat limited.
Pipe-Bursting Replacement	Most pipe materials for which diameter for diameter or upsizing by one to two diameters is desired	Advantageous when open cut is difficult. Can correct most pipe defects. Improved hydraulic capacity. Typically requires excavation for insertion pits and service connections. More costly than "liner" methods. Requires full or partial bypass pumping.	Process breaks the old pipe outward and pulls in replacement pipe. Can be cost-effective when excavation is difficult and density of service laterals is low.
Open Cut Replacement	All applications	Repairs all defects and provides longest service life. Most expensive and disruptive. Requires bypass pumping, traffic control, excavation, backfilling, surface restoration, etc.	Traditional pipe rehabilitation method.
Point Repairs	Small, localized problems	Cost-effective and timely. Limited applications.	Accessed from pipe interior or from open cut. Used typically for isolated "spot" repairs only.
Red text indicates disadvantages.			

Model Results and Recommendations

One of the most important steps in developing recommendations for collection system improvements is the selection of appropriate design criteria for system sizing. In many cases, a utility may not have a set of pipe sizing design criteria on which to base the proposed system improvements. If that is the case, a set of criteria to be used for system layout for future conditions must be agreed upon by the city staff before the system improvements can be effectively sized.

For this project the following design criteria were used for sizing system improvements.

- Size pipes for 75% of full flow capacity at the design flows
- Design flows are based on the measured average residential flow contribution of 78 gal/capita/day
- Diurnal patterns for future flows are based on the measured flows
- Design flows for RDII are based on calculated hydrologic values, rather than a fixed input per area served
- Design flows are based on 2030 wet weather flows developed from a 10-yr, 3-hr storm event

The design flows were projected out to the 2030 planning horizon using projected population data and the measured average residential wastewater contribution of 78 gal/capita/day. This was the measured system wide average dry weather residential flow component and was the most accurate number available. The daily peaks in the 2030 system were generated by using the same diurnal flow pattern that was observed during the flow monitoring period.

The RDII contribution to the 2030 wet weather flow design condition was based on hydrologic simulation of a 10-year rainfall event in the model. The leakiness of the system (as determined during the flow monitoring and discussed above) was used to estimate the amount of RDII generated by the design storm event. This method of estimation of the amount of RDII is more accurate than using a fixed area contribution factor. Some limited reduction in RDII may be assumed to occur as portions of the collection system are replaced or slip lined, but additional leaks will develop to offset these improvements. Therefore, the total RDII contribution for each sub-basin is assumed to remain relatively constant.

Finally, the decision was made to size pipes to accommodate the projected 2030 peak hours wet weather flows with a maximum flow to full pipe capacity ratio of 75%. This value allows for some additional flow to be added to the system due to unforeseen development, additional RDII or greater than expected population increase. This design capacity ratio also allows for some additional pipe conveyance capacity to conservatively design the system since much of the design flow determination is based on estimated values.