Sanitary Sewer Evaluation Surveys: Why and How

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Introduction

Out of sight out of mind has all too often become the mindset when it comes to dealing with our sanitary sewer system. American Society of Civil Engineers (ASCE) Infrastructure Report Card 2005, awarded the nation’s wastewater infrastructure a grade “D-”, lowest of all grades issued.

The U.S. Environmental Protection Agency (EPA) estimated in August 2004 that Sanitary Sewer Overflows (SSOs), result in the release of as much as 10 billion gallons of raw sewage annually. Federal funding under the Clean Water Act State Revolving Loan Fund (SRF) program has remained flat for the past decade. With one exception, Congress appropriated between $1.2 billion and $1.35 billion from 1995 to 2004. But in FY 2005, Congress cut wastewater SRF funding for the first time in eight years, reducing the total investment to $1.1 billion. The current administration has proposed further cuts for FY 2006, with a budget submittal calling for an appropriation of only $730 million, a reduction of 33% from the FY 2005-enacted level (U.S. Environmental Protection Agency, Summary of EPA's 2006 Budget, February 2005).

With shrinking budgets and continued deterioration of our aging systems, there are compelling reasons to support a proactive and intelligent approach to the Sanitary Sewer Evaluation and Management (SSEM). This article highlights how owners and engineers might proceed with collecting attribute information associated with their collection system, identifying potential problems within the system, determining capacity issues and ultimately develop effective maintenance and rehabilitation strategies to mitigate these problems in a cost-effective manner.

Why

Sewer System Evaluation Survey (SSES) is the critical first step in Sewer System Evaluation and Management (SSEM) program which includes project management/coordination of flow monitoring, sewer system evaluation, field survey, system mapping,
hydraulic modeling and analysis, best management practices, cleaning and long-term maintenance management programs. Most local agencies have laws or ordinances that require all publicly and privately owned and operated sanitary sewer collection and transmission systems to complete a Sanitary Sewer Evaluation Survey (SSES) by a stipulated time. In many cases, the SSES is conducted in compliance with guidelines based on U.S. EPA's Sewer System Infrastructure Analysis and Rehabilitation Handbook - October 1991, EPA/625/6-91/030.

In addition, recent US EPA regulations such as Capacity, Management, Operations & Maintenance (CMOM) are requiring some Publicly Owned Treatment Works (POTW) to reduce and eliminate sanitary sewer system overflows and in order to bring the POTW’s handling domestic waste water into compliance with National Pollutant Discharge Elimination System (NPDES) permits by 2011.

By directing their sewer system self-audits into a sewer system evaluation and management program (SSEM), owners of public treatment works can satisfy EPA requirements, cure sanitary sewer system overflows, consolidate existing information, modernize facilities and focus on their CMOM program.

The following are some examples of SSES programs underway or recently completed.

- **City of Atlanta, Georgia**

  The City of Atlanta’s Department of Watershed Management is currently conducting a comprehensive Sanitary Sewer Evaluation as a part of Clean Water program, a multi-billion dollar initiative encompassing sanitary sewer rehabilitation, repair, and enhancement ([http://www.cleanwateratlanta.org/SSES/default.htm](http://www.cleanwateratlanta.org/SSES/default.htm)).

  The SSES program uses various equipment and techniques to detect pipe defects, blockages, and capacity issues. The techniques include smoke tests, dye tests, closed circuit televising (CCTV), flow monitoring, rain monitoring, building services connection location/inspection, and flow isolation.

  The sewers are grouped into drainage basins. The evaluation of *Sewer Group (SG)-1*, was completed in March 2004, and work on *SG-2* commenced in late 2004. According to the final report from *SG-1*, 316 miles of sewer were inspected using CCTV and smoke testing; 146 miles of sewer cleaned; 7349 manholes inspected; 761 manholes were raised, and 119 emergency repairs completed.

- **City of Columbus, Ohio**

  A large SSES project was accomplished for the Department of Utilities, Division of Sewer and Drains (DOSD) in Columbus, OH, in the period from August 1997 to December 1999 ([http://gis.esri.com/](http://gis.esri.com/)).
Overall, the SSES investigation included: the inspection of 1184 manholes; smoke testing of 267,162 feet of sanitary sewer; 38,912 lineal feet (LF) of CCTV inspection; 32 Dye Tests; 7 temporary flow meters; 10 groundwater piezometers; and 4 rain gauges.

- **Miami Dade County, Florida**

Since 1994 the Miami-Dade Water and Sewer Department (WASD) has been engaged in an extensive sanitary sewer system evaluation and rehabilitation program in an effort to reduce system infiltration, exfiltration and inflow (I/E/I) ([http://www.google.com/search?sourceid=navclient&ie=UTF-8&rls=RNWE,RNWE:2005-02,RNWE:en&q=miami+dade+county+SSES+results](http://www.google.com/search?sourceid=navclient&ie=UTF-8&rls=RNWE,RNWE:2005-02,RNWE:en&q=miami+dade+county+SSES+results)).

Under the I/E/I Program, the entire sanitary sewer collection system, which represents approximately 12.9 million feet of gravity sewer lines and 58,000 manholes were evaluated by July 1997. The Program sewer evaluation consisted of cleaning and televising 100 percent of the gravity lines, the visual inspection of each manhole and the smoke testing of the entire system to identify defects. A total of 32,194 defects were identified and repaired. The I/E/I Program has been highly successful with system flows to the regional treatment facilities reduced by approximately 100 mgd. Although the system-wide infiltration was greatly reduced, Rainfall Dependent Infiltration/Inflow (RDII) and the various pump station force main improvements have continued to increase the peak flows to the treatment facilities during heavy rainfall events.

**How**

SSES is a comprehensive and systematic process aimed at identifying and investigating sanitary sewer system problems (e.g. inflow/infiltration sources, structural deficiencies) and developing maintenance and rehabilitation methods to solve these problems. During the survey, the system is thoroughly inspected and data about the conditions of various system components are collected. The main field investigative procedures typically include:

- Flow Monitoring
- Smoke Testing.
- Manhole Inspections
- Dyed Water Testing.
- Close Circuit Television (CCTV) Inspection/Sewer Scanning.

With shrinking budgets and continued deterioration of our aging systems, there are compelling reasons to support a proactive and intelligent approach to the Sanitary Sewer Evaluation and Management (SSEM) program.

The following steps are recommended in a comprehensive SSES program for owners and engineers.
History
The first step in understanding a municipality’s collection system is to obtain information from its employees. Many long-term employees have an “institutional memory” that is often missing from official records. While this step appears obvious, it is far too often ignored and is detrimental to the program. The information can be obtained through interviews or questionnaires from employees from any division that has an understanding of where problems have been occurring within the system. In addition it is important to review the history of customer complaints. Both of these pieces of information provide immediate feedback on the location and magnitude of potential problems. During the question phase, information pertaining to existing maintenance procedures should be collected. Personnel responsible for these tasks should be asked to provide recommendations for changes within the current maintenance program.

Mapping
During the interview process maps are commonly used to identify problematic locations. Having detailed maps is imperative to setting up any type of proactive evaluation program. The map becomes the means to properly track what comprises the system and where and how the system changes over time. The advent of satellite systems and technology (GPS) provides the ability to obtain very accurate locations of manholes, pump stations etc., with the click of a button. Furthermore this information can be stored in Geographic Information Systems (GIS) so as to have access to specific information regarding any attribute information associated with the collection system. Placing this information in such a system allows more precise data to be stored, enabling any interested party to understand the make up and condition of its sewer system.

Flow Monitoring
Locations of possible capacity issues can be identified by tracking sanitary sewer overflows and reported basement backups or through temporary flow monitoring. Temporary flow monitoring is usually one of the first actions taken to better understand the problematic areas within a collection system. It may also be performed to verify the success of rehabilitation projects associated with inflow/infiltration (I/I) removal. Rehabilitation success verification is performed by comparing pre- and post-rehabilitation flows in a project areas as well as using a control basin which has not been rehabilitated.

Temporary flow monitoring studies generally last 60-120 days and are performed during a community’s wet season. Electronic velocity and depth recording devices (flow meters) are strategically placed (usually in the upstream pipe entering a manhole) throughout the collection system. Typically each meter might be responsible for monitoring flow from 20,000-30,000 LF of tributary sewer. The purpose of installing flow meters is to determine the quantity of flow at a particular location during both dry and wet weather conditions. Sewers having high dry weather flows typically have little capacity for future connections. Drainage areas that experience high wet weather peaking factors, are typically scheduled for more detailed inspections. Peaking factors in excess of five times dry weather flows are generally considered to have excessive wet weather flow.
Once the initial site selection for meter placement has been made, flow monitoring personnel should visit the location to determine if the site will provide good flow monitoring data. The preliminary site inspection is performed to verify that the selected location has good hydraulic conditions, there is easy access, and to determine if it is safe to physically enter the manhole. If any of these qualifications are not met, and the flow characteristics are not compromised by relocating the meter, an alternative site should be selected. Generally, a suitable replacement site can be found within one or two manholes upstream or downstream of the original site.

During a preliminary inspection an accurate measurement of the pipe size is made, as well as the recommendation of the best type of flow meter to collect the information. As noted previously, flow meters record depth and velocity, but some meters are designed to perform better in different environments. The following matrix identifies some of the more prominent flow monitoring technologies and the flow parameters:

<table>
<thead>
<tr>
<th>Flow Depths (in.)</th>
<th>Flow Velocities (feet/sec)</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 in – 36 in</td>
<td>0.5 fps – 5 fps</td>
<td>ADS, Sigma 900 series, ISCO 2000 series</td>
</tr>
<tr>
<td>&gt;12 in</td>
<td>0.5 fps – 5 fps</td>
<td>MGD</td>
</tr>
<tr>
<td>Low</td>
<td>&gt; 1 fps – 1.5 fps</td>
<td>March McBirney Flow-Dar</td>
</tr>
</tbody>
</table>

It should be noted that for many years redundant depth measurements were taken with ultrasonic equipment to verify flow depths. This was done because pressure transducers had a tendency to drift, resulting in inaccurate depth readings. However, over the last three or four years, the Sigma and ISCO pressure transducers have become much more stable and reduced the need for the ultrasonic readings.

Once the site and proper meter have been selected, the time period between recording intervals needs to be determined. Flow meters are typically in a hibernation mode. They remain in the line/manhole and at established intervals the meter activates and measures depth and velocity. The most common time frame between meter readings is fifteen minutes. However, if the meter is in the vicinity of a pump station this duration may be reduced to five minutes. By reducing the time frame between readings the meter is more likely to capture the flows associated with the pump cycling on and off. Measurements are stored internally in the meter until either maintenance personnel collect the data using lap top computers, or the information is transmitted wirelessly to its desired location.

During the installation process, pictures should be taken of the sensor after it is installed in the pipe and an opening site sheet should be completed. The preferred location of the sensor (typically mounted on a steel band) is in the invert of the upstream line coming into a manhole (see Fig. 1). The opening site sheet describes the meter set up, provides a small sketch of the meter’s location within the sewer system and the sensor’s placement within the manhole. Immediately after meter installation manual measurements of the flow’s depth and velocity are taken and compared to the readings from the flow monitor.
Once meters are installed maintenance crews should service them on a weekly basis to ensure that they are operating properly. Service should include checking the battery voltage, checking the desiccant crystals (helps keep moisture out of the meter), cleaning the sensor, and comparing real-time level and velocity readings from the flow meter to readings physically measured by maintenance personnel. If these readings differ substantially, the meter should be replaced. Field crews should document the time and all information collected during their maintenance visit.

On the day that the data is collected it should be transmitted to a reviewer, for evaluation within 24 to 48 hours. The data should be reviewed to look for changes in flow patterns, and potential equipment problems. Patterns are evaluated using both hydrographs and scatter plots. Hydrographs identify the sewer’s total flow, depth and velocity of flow over some time period (see Fig. 2). Scattergraphs indicate the pipe’s flow characteristics at the depths of flow experienced by the system. These graphs quickly identify if the area being monitored has a problem with I/I and if so the magnitude. The reviewer should evaluate the data from both a weekly perspective as well as how the most recent data compares with data previously collected. This quick review will help minimize the potential for the collection of inaccurate data as a result of a malfunctioning meter. After the review is completed, any potential problems, concerns or directives should be transmitted back to the maintenance crew. Continual communication between the reviewers and the maintenance crews is critical to successfully completing a flow monitoring project.
Rain gauges are typically installed in conjunction with flow monitoring projects. These instruments should be capable of measuring rainfall in 0.01 inch increments. Rain gauges are generally comprised of a tipping bucket mechanism and a data logger. Both the flow monitor and rain gauge data should have corresponding date and time information, so as to compare rainfall events with flow readings. Rainfall data enables engineers to model a sewer's hydraulic response during different rain events.

**Smoke Testing / Manhole Inspections**

As noted previously, during rain events sanitary sewer flows tend to increase as a result of either inflow or infiltration. Inflow is defined as rain water that can enter a sewer system directly, while infiltration percolates through the ground and then enters a sewer. See Fig. 3 for typical sources of I/I. Inflow characteristically causes rapid increases in a sewer’s flow and results in sewer overflows and or basement backups. Inflow usually recedes within four to five hours after the completion of a rain event. While infiltration is associated with slower increases in flow, and might take as long as four or five days to dissipate. When peak instantaneous flows increase in a sanitary sewer system by more than a factor of five, it is recommended to schedule more inspection activities in that basin. Since inflow usually creates more capacity problems, resulting in overflows, municipalities and engineers typically address this problem first. The two most common forms of inspection associated with locating inflow are smoke testing and manhole inspections. Each of these procedures can identify sources of inflow and assist in the development or correction of a municipality’s mapping.
Manhole inspections are typically started in the upper reaches of the problematic basin. If at all possible manhole inspections should be performed during the rainy season. Performing this task during wetter periods helps to identify I/I that might not be discovered during the dry season. The data collected during this process helps to:

- Identify sources of inflow and infiltration
- Determine structural condition of the manhole and sewer segments
- Locate and categorize structural defects
- Provide size and construction material of both the manhole and sewers
- Determine a sewer’s invert depth from top of casting
- Verify the presence of surcharging and blockages
- Verify approximate location of manhole
- Identify future television inspection locations.

In low traffic areas typically a two-person inspection crew can perform an inspection. The crew should be equipped with a truck, protective clothing, lights, digital camera, various hand tools, and other equipment necessary to conduct safe and thorough confined space investigations. Manhole entries are generally only made on manholes greater than ten feet in depth (field crews can typically see all the needed information from the ground on manholes less than eleven feet). If entry is required it must be accomplished in accordance with all OSHA, Federal and/or local laws, regulations and/or guidelines for confined space entries.

The following procedures comprise the manhole inspection sequence:
1. Erect proper traffic control measures.
2. Open manhole.
3. Inspect manhole frame and lid.
4. Descend into manhole (if greater than 10ft deep), determine the type of construction material, evaluate the structural condition of the manhole and sewers, and determine the sizes of all pertinent structures.
5. Digitally photograph any identified structural defects.
6. Measure depth of inverts from top casting.
7. Replace manhole lids and remove traffic control.

Planimetric sewer system information collected by the field inspectors should be checked against existing mapping. Any discrepancies should be marked on the mapping by the field inspectors and sent to the owner or owner’s representative for correction.

Before entering the manhole (if greater than 10ft deep), the field inspector should evaluate both the manhole lid and frame condition, and the frame connection to the manhole prior to entry. As the inspector descends into the manhole the manhole cone, barrel, trough, apron and sewer line are evaluated. Digital photographs should be taken of all manhole defects, any sources of inflow/infiltration as well as the influent and effluent lines. All of this information, including photos of any defects, should be collected in such a way to be imported into a municipalities GIS system. Pictures should also be taken in the upstream and downstream sewers and utilized to recommend locations for television/scanning inspections. Television/scanning inspections are typically recommended when significant roots, cracked pipe, slipped joints, grease, or evidence of surcharging is observed.

Smoke testing is an inexpensive technique to identify sources of I/I and improper connections to the collection system. Problems commonly identified include: storm sewer cross connections and point source inflow leaks in drainage paths or ponding areas, roof downspouts, yard and area drains, foundation drains, abandoned building sewers, faulty sewer connections, or broken clean out caps. Smoke can also escape from defects in the pipe, which are above the water table (infiltration), but the smoke must find a path to the surface in order to be observed. Smoke emerging from the ground, streets, sidewalks, etc. indicates a pipe defect, but does not indicate the exact location of the defect.

Smoke testing should only be performed when the ground is dry. Testing should be closely monitored on windy days. If the smoke coming out of the ground is blown away before it can be accurately detected by the field crew, testing needs to cease until wind and soil conditions permit favorable testing and result documentation.

Prior to beginning smoke testing, colored notification flyers should be placed on all residential and business locations explaining that smoke testing will be occurring in the area during the next few days. The notice should include a phone number that the occupant can call to have any questions answered. Additionally, each morning before smoke testing begins, field crews should contact the appropriate fire department, other potential emergency respondents and the municipality’s customer service center, to report where smoke testing activities will be occurring that day. Maintaining good
communications with all these different groups will help to minimize the confusion that can occur when people see smoke coming from unusual locations.

Smoke, typically generated using liquid smoke canisters, is forced through the sewer system using gasoline powered smoke blowers. Smoke blowers having a capacity to generate at least 3000 cubic feet per minute is preferred. Typically, two or three sections of sewer can be tested at each setup (700-900 LF). As the smoke is being blown through the pipe, field inspectors walk around and document any observed leak on a smoke test form. Digital pictures should also be taken of all substantial leaks. Leaks should be referenced by distances from at least two permanent locations. One way this is done is by measuring a distance from one of the manholes along the sewer line that is leaking and also measuring the perpendicular distance, left or right, to the sewer line from the leak. It is also common to reference leaks from building corners or trees.

The information collected from smoke testing can often find sources that contribute large sources of inflow, such as cross-connected storm grates or downspouts. Fig. 4 shows smoke emerging from both a rain downspout and a crack between the asphalt and the sidewalk. It can also lead to recommendations for additional field inspections.

![Fig. 4 – Smoke Test Photo](image)

**Television Inspection/Sewer Scanning**

Internal television is typically performed as a result of information collected during manhole inspections and smoke testing, customer complaints, excessive infiltration, or in
association with a preventative maintenance program. The purpose of this type of inspection is to determine:

- Structural condition
- Location of structural defects
- Identify size and material of construction
- Locate service laterals
- Locate obstructions and sources of infiltration

CCTV uses a television camera mounted on a remote controlled, self-propelled robotic device that is connected to a video monitor typically located in a van. The robotic system is inserted in a manhole and placed in the sewer to be inspected. Once inside the sewer, the remote control device moves through the pipe. As it moves, an operator watching the video monitor stops the camera at any type of defect or pipe condition change to get a more detailed inspection. The inspector typically uses the camera’s 360 degree articulating lens to get detailed information at all points of concern. This information is electronically recorded on VCR tapes, CDs or DVDs, however CDs and DVDs are becoming more prominent because of their ease of use. An electronic footage counter is connected to the camera and enables the operator, and engineers reviewing the data, to know where the problems are located within the sewer.

Historically, individual cities, television companies and engineering companies have had their own protocols for coding defects identified during television inspections. This lack of uniformity in coding preferences lead to problems when comparing collected video information. However, recently the PACP coding system has been established to help bring uniformity to the process and remove subjectiveness currently inherent to the diverse guidelines.

Until recently traditional CCTV (on a crawler) was the best way to evaluate sewers from 6-72 inches in diameter (where flow depths are less than 30% of the pipes diameter). However, there is a new technology that can provide more complete, accurate and easily understandable data for sewers from 6 to 30 inches in diameter. The Sewer Scanning Evaluation Technology (SSET) is an alternative technology to CCTV that takes the responsibility of rating the structural integrity of the sewer away from the camera operator and places it into the engineer’s hands. The SSET provides the frontal image that CCTV provides, but it also provides a 360 degree scanned visual image of the interior surface of the pipe wall. The data can then be subsequently analyzed in the office with the assurance that no important defect is overlooked. The system also records inclination, thus providing sag locations and potential locations for sedimentation buildup. The 360-degree scan enables the entire surface of the pipe wall to be observed in plan view, giving the engineer the capability to measure the opening of the joint. In addition this view enables the engineer and owner to develop a baseline condition of the sewer, and the ability to compare the degradation of the pipe wall over a period of time. The side scan also permits a much faster review of the information. For example, 300 feet of sewer might take five minutes to review as opposed to the fifteen or twenty minutes it would take to review the same line of traditional televised information.
The sewer scanning system allows the entire surface of the pipe wall, from manhole to manhole, to be viewed on one screen!

Figure 5 shows approximately 100 LF of sewer on one screen. The information is reviewed similar to reading a sentence or a paragraph. The upstream portion of the sewer is located on the left side of the first line. The data is reviewed from left to right. The data from the right side of the first line matches up to the left side of the second line. This process continues until you reach the bottom of the screen. Red lines are overlaying cracks. Light blue circles identify locations of good laterals, dark blue indicates a problem with the lateral. The pink line identifies root intrusion. Finally, the gold lines identify joints that have excessive separation. Using the cursor to click anywhere on the screen will provide either a closer side scan view at that location and/or the traditional CCTV frontal looking view. Both the CCTV-type view and side scan view can also be reviewed concurrently. Pricing for SSET is competitive with traditional CCTV, and can be imported into most GIS Data Bases.

Advanced Technologies for Sewer Survey

As advances in electronics continue to improve, so will the techniques used to collect information on the condition of sanitary sewers. Two of the lesser known technologies include sonar and laser scanning. Sonar is used to identify problems below the flow line of a sewer and lasers are used to evaluate sewers above the flow line of a sewer. Sonar
units emit a sound wave that travels until it hits a solid object (pipe wall or debris line) and returns back to the unit. The sound wave outlines the shape of whatever it bounces off. The information can be used to identify things like the level of debris in a siphon (Fig. 6) or if the invert of a pipe is loosing structural integrity.

Currently most the sonar units generate two-dimensional information. However, new technology is coming out that can actually generate three dimensional drawings of the sewer. By moving to the third dimension engineers can generate a three dimensional model of the entire pipe and get a better and easier understanding of the pipe’s condition.

Laser scanning is a relatively new technique used to evaluate sewers. The technology has only been applied to sewers for the last two years and works by emitting up to a million points at a time. These laser points enable the pipe and any other attribute within the pipe to be outlined, and a three dimensional model constructed. The advantage of this technology is that very accurate measurements are generated without the presence of light. While this technology is beneficial for all pipe sizes, it is probably the most beneficial for the evaluation of large diameter sewers. On a twelve foot diameter pipe a change of less than $\frac{1}{8}$ of an inch can be seen. This is important because currently the primary way to inspect large diameter pipe is by having personnel walk in the sewers. Evaluating the condition of a large diameter sewer by walking poses many challenges. These challenges include: the need for a large amount of manpower, safety concerns for people walking in the sewer as well as the traffic safety personnel on the top of the manholes, the need for extensive lighting, and the inability to identify if the pipe is changing shape. In general when walking a sewer there is no chance for developing
baseline information on the shape and condition of the pipe, unless some gross defect is observed. By having this type of baseline information and watching how or if a large diameter pipe changes over time, municipalities can potentially predict impending failure before it happens. Knowing and addressing a possible large diameter sewer collapse before it happens, could save sewer districts tens of millions of dollars. Figure 7 is one example of how laser information can be presented to a municipality. A wire mesh grid shape. In this particular example the blue indicates where the pipe is in its original shape and the pipe changes color as it moves out of its designed shape. Red indicates where the pipe is most out of round.

Fig. 7 – Laser diagram of pipe (Courtesy: Colmatc, Inc., Laval, Quebec, Canada)

Note that many of the capabilities discussed in this article are relatively new. There are also a number of other technologies that are in the design and developmental stages. While the older methodologies used to collect information regarding sewer infrastructure still provide accurate data, there are many new and exciting ways to provide the engineers and owners with information that will enable them to make not only easier but better decisions with regards to the condition and repair of their wastewater infrastructure.

Field Data Management

Field investigation produces enormous amounts of data. Moderate to larger scale SSES projects are capable of generating data at a rate that can quickly overwhelm even the most experienced project manager. The ability to rapidly input data, conduct ongoing quality assurance checks, and publish final forms, tables and reports from a single set of data and a single program was the prime driving force in development of the SSES
database. The key to any sewer system evaluation and management (SSEM) program is “Data Management”.

An excellent paper on the topic has been presented by authors Halfaway, Pyzoha, et. al. (http://gis.esri.com/library/userconf/proc00/professional/papers/PAP158/p158.htm) based on the work done for City of Columbus, Department of Public Utilities, Division of Sewerage and Drainage (DOSD) as part of Engineering Agreement No. CT-16376 A.

Approximately 70 MB of SSES data for the project was stored as a collection of tables (or relations), where each table contains a set of records. The SSES database was developed using MS-Access® Relational Database Management System (RDBMS).

Two primary keys are employed within the database to link the numerous tables and queries associated with Manhole and TV inspection work:

- **MH ID** – a unique number assigned to each manhole structure during initial data entry;
- **Line ID** – a unique number assigned to each main line and lateral connected to a manhole structure.

The assignment of the identifiers generated an early coordination effort for the Project Team. The final product needed to have the key identifiers to be the assigned manhole and pipe segment numbers created by the DOSD system of identification. A link created between the database assigned identifier and the City numbering system. Links to digital photo files are maintained by automatic “update queries” in the database and photo files are assigned proper names either on the local hard drive, CD, or server being employed for file storage. CAD drawings of manholes (corbel/frame cross-section and plan view drawings) are stored directly in the database for viewing or report generation purposes. Smoke test drawings are generated directly from the map of the sewer system, including a “smoke leak” layer, and are copied directly into the database.

The ability to manage, manipulate and correlate a 70 MB database, which expands to a 500 MB file when nearly 7,600 digital photos, reports, and other images are included would be virtually impossible without the use of a database management system. In addition, the open architecture and design of the database allowed the SSES information to be readily referenced, queried, updated and manipulated as the larger GIS project began to be undertaken.
The SSES database enables users to query and view data in three categories: 1) Manhole inspection; 2) TV inspection; and 3) Smoke testing. Figure 8 shows the main database interface form. Using pre-defined queries and reports, users can quickly and easily create and print SSES reports for many topics. The user can navigate through the SSES data using various queries and forms implemented within the database environment. The following list represents a sample of the reports available from the SSES database:

Reports based on general inspections:

- Detailed inventories of main lines and laterals
- Collection system summaries
- Repair reports--including manhole walls, manhole frames, and capped / inactive lines
- Manhole cover inflow reports

Reports based on TV-inspections:

- Defect reports--including leaking mains, leaking manholes, roots, broken pipes, and cracked pipes
- Technical review
The GIS interface is used to present the SSES data in its spatial context and to present the spatial relationships among various map features. The GIS interface was developed using ArcView® and Avenue® programming language. The main function of the GIS interface is to enable the user to visualize the sewer system characteristics on the map and to query the system. The GIS interface allows users to point at map features (e.g. manholes or sewer lines) and retrieve SSES information from the database. It also allows users to run a set of pre-defined queries or build their own queries and to display query results or reports.

A useful feature of the GIS interface is to present and analyze the spatial relationships among map features. Examples of these relationships include adjacency (i.e. manholes in a specific area), connectivity (e.g. sewer lines connected to specific manholes), and containment (e.g. manholes or sewer lines contained in a specific area). An important function of the GIS interface is to produce graphics on the screen or on paper that convey the results of analysis to engineers who make decisions about maintenance and improvement work. Graphical representation of the sewer system characteristics (e.g. I/I sources) can be generated and thus allowing system users to visualize and understand the SSES data and the analysis of potential events.

Each sub-sewershed is represented as a separate view (Fig. 9). Each view contains a number of map themes that the user can choose to display or hide. A sub-sewershed view contains themes for the base map, manholes, sanitary sewer lines, storm sewer lines, street names, right of way, positive smoke testing results, and TV inspected lines, among others. The map interface retains all the standard functionality provided by ArcView. In addition, customized tools provide quick access to key information like manhole depth, images of manholes and sewer lines, inspection reports, and links to orthophotos.

The GIS interface communicates with the SSES database via the Open Database Connectivity (ODBC) standard. An important step during system configuration is to create an ODBC connection to enable communication between the SSES database and the ArcView project. The use of the ODBC standard enables databases developed using other ODBC-compliant RDBMSs to be incorporated into the system in the future. The GIS interface serves as the link between the SSES database and the project area maps. Early versions of the GIS were designed to permit the constant, ongoing editing of SSES database and AutoCAD map files that is necessary during data collection and review procedures. Design of the ArcView Views, collection of field data, review and processing of field data, and quality control checks all occurred simultaneously, thereby limiting the ability to plan each step in advance. The design of the initial GIS interface was based on using the SSES database and AutoCAD mapping procedures already in place for non-GIS related work on SSES projects.
Figure 9: Detailed Map of a Sub-Sewershed

Conclusions

With aging infrastructure and shrinking budgets owners and engineers need to advocate and support a proactive and cost-effective approach to the Sanitary Sewer Evaluation and Management (SSEM). Fortunately, with the advances in computer technology, more accurate means of collecting and storing sewer system information are available. By having better information readily available, engineers and owners have the capability to make better design and fiscal decisions which ultimately would help lift the sanitary sewer system infrastructure from the bottom of the heap, from existing D-grade to one that is hopefully an A+.