Infrastructure Rehabilitation Program

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D. Wayne Loveday — 2·19·2009

D. Wayne Loveday | Date

KUB

pace10

Partners Acting for a Cleaner Environment
A 10-year Program to Improve Our Waterways

Executive Summary

Effective management of KUB's collection system maximizes the operation and performance of wastewater assets. The Infrastructure Rehabilitation Program (IRP) plays an integral role in managing KUB's assets as a link between the Continuing Sewer System Assessment Program (CSSAP) and accomplishing necessary sewer improvements. The primary objectives of the IRP are to address infiltration and inflow (I/I) and other conditions causing sanitary sewer overflows (SSOs) by maintaining or restoring capacity and structural integrity.

The IRP uses information gathered in the CSSAP through flow monitoring and modeling to direct wastewater system rehabilitation. As KUB moves forward under the IRP, other components of the CSSAP will play an increasingly important role in supporting asset management decisions. KUB will place increasing emphasis on a variety of information sources and decision-support tools, such as televising lines and inspecting pump stations, as the CSSAP matures. Those tools will help KUB make prudent infrastructure management decisions to prevent component failure from structural deterioration or insufficient capacity.

The IRP decision process consists of five basic steps:

1. **CSSAP -** This step provides data from the flow monitoring network, rain gauges, closed-circuit television (CCTV) inspections, pump station inspections, and the hydraulic model.
2. **Correction Alternatives -** This step describes the application of evaluated and approved sanitary sewer techniques to identify system defects identified in the CSSAP.
3. **Correction Prioritization -** The next step is to determine the priority of each sanitary sewer improvement identified in the first step.
4. **Correction Implementation -** After priorities have been established, KUB groups individual improvements into projects for implementation.
5. **Continued Evaluation -** KUB assesses the completed project through the ongoing CSSAP.

The 7 Elements of a Proper MOM Program
KUB's Infrastructure Rehabilitation Program (IRP)

1. **Utility-Specific**
   Based on the needs of our service area and customer base, KUB's IRP serves as a guide to provide an efficiently maintained and operated sanitary sewer system and reduce any potential negative impact on the environment and hazards to public health.

2. **Purposeful**
   This program is designed to
   - Restore and maintain system hydraulic capacity
   - Restore and maintain structural integrity of system components
   - Reduce corrective maintenance costs associated with the wastewater collection and transmission system (WCTS)
   - Support decision-making and prioritization of system improvement projects including:
     - Sewer rehabilitation
     - Storage
     - Relief sewers
     - Pumping system improvements
     - Additional treatment capacity, if required.

3. **Goal-Oriented**
   KUB provides structured guidance for the operation, evaluation, and performance of the sanitary sewer system. It provides a systematic decision process from the evaluation of system deficiencies to the implementation of improvement projects.

4. **Uses Performance Measures**
   Reduce the risk of system failure that
   - Could cause interruption in service
   - Could result in impact to the community
   - Would increase costs as compared to scheduled maintenance and repairs.

5. **Periodically Evaluated**
   KUB will review the IRP annually and amend it as appropriate. Modifications may be made to the program based on the review and assessment of previous years' performance in the following areas:
   - Number of SSOs related to structural failures
   - Progress in achieving performance measures for each program element.

6. **Available in Writing**
   This program will be maintained and kept readily available as a reference for current staff and will be used to train new personnel to ensure program expectations and requirements are met.

7. **Implemented by Trained Personnel**
   Internal resources receive a series of training components. KUB employees are regularly introduced to new techniques designed to improve safety and efficiency.

Contractors selected to perform outsourced components of the IRP are held to the same standards as KUB's internal staff. KUB's contracts for these outsourced projects contain written standards and specifications detailing KUB's approved requirements for physical system assessment and improvements of its wastewater system. Contractors are contractually obligated to ensure the work site and the work of their employees' meet federal, state, and local laws, statutes, and regulations, specifically including, but not limited to, safety requirements mandated by the Occupational Safety and Health Administration (OSHA).

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SECTION 1: SYSTEM PERFORMANCE CRITERIA

The purpose of KUB's IRP is to restore and maintain system hydraulic capacity, restore and maintain structural integrity of system components, and to reduce corrective maintenance costs associated with the WCTS. The primary objectives of the IRP are to address I/I and other conditions causing SSOs through the following:

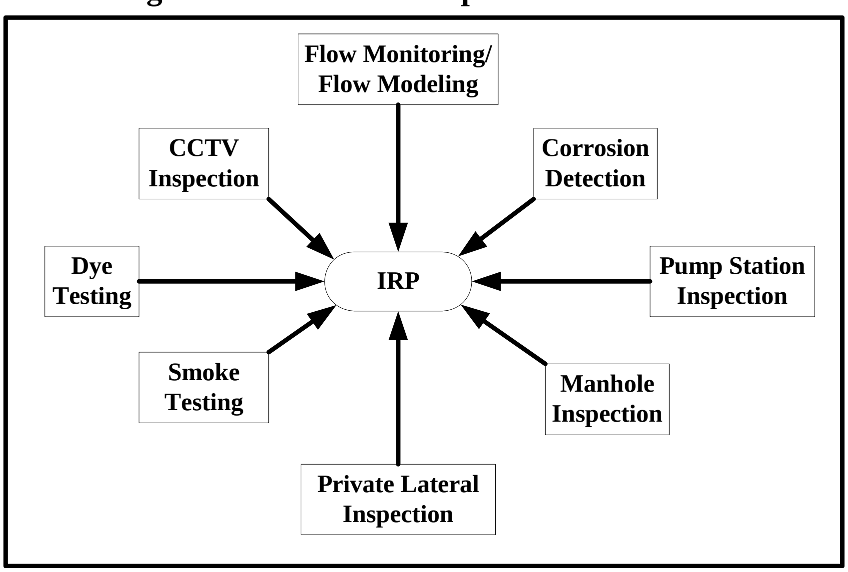
- **Capacity restoration –** The goal of this objective is to keep assets functioning at their full, original capacity. Examples are removing sediment or debris, reducing I/I, and/or repairing system defects that would limit flow capacity. In some cases, it is cost-effective and/or necessary due to growth or upstream I/I to provide increased capacity or storage to attain desired system hydraulic capacity.

- **Structural integrity restoration –** The goal of this objective is to repair structural damage and failures from wear, corrosion, age, and/or construction-related damage to extend the useful life of the component. This function reduces the risk of system failure that
  - Could cause interruption in service
  - Could result in impacts to the community
  - Would increase costs as compared to scheduled maintenance and repairs.

- **Maintenance optimization –** The goal of this objective is to repair portions of the system that are subject to known, repeated maintenance problems that increase maintenance costs and keep crews from conducting more productive preventive maintenance. Examples are root intrusion, offset joints, pipe sags, improper service connections, and other system deficiencies that typically lead to recurring problems including dry and wet weather SSOs.

KUB's CSSAP will provide the information needed to implement IRP and Corrective Action Plan/Engineering Report (CAP/ER) projects. Figure 1-1 illustrates the information obtained in CSSAP and used in the IRP. As KUB moves forward, components of the CSSAP will play an increasingly important role in supporting asset management decision-making under the IRP. As the CSSAP matures, more and more emphasis will be placed on a variety of information sources and decision support tools to make prudent infrastructure management decisions before components fail.

Figure 1-1: CSSAP Components Used in IRP



The IRP will address both the gravity portion of the WCTS (gravity lines and related appurtenances including manholes) and the transmission components of the WCTS (pump stations and force mains).

1.1 Gravity System Performance

Hydraulic capacity and structural integrity are the key performance criteria for the gravity system. The CAP/ER component of the IRP is focused on capacity-related performance, with the goal of restoring or increasing system capacity to address SSOs reported in the SSOER and its updates. Specifically, gravity sewer and manhole rehabilitation along with pipe upgrades (replacements and parallel relief sewers) and storage will be designed to contain, at a minimum, flow conditions based on predicted Rainfall Dependant Inflow and Infiltration (RD I/I) into the system for a pre-determined peak flow that includes growth. KUB's ultimate goal is to upgrade the system component capacities as necessary to be able to certify capacity for new connections in accordance with the requirements of the Capacity Assurance Program (CAP).

A critical component of the gravity system rehabilitation effort is the evaluation of rehabilitation effectiveness in reducing RD I/I. This is addressed in Section 5 of this IRP. When sufficient data is available on rehabilitation effectiveness, it will be analyzed in an effort to develop a decision support process to target areas for rehabilitation, and identify appropriate rehabilitation techniques. Additional information on initial selection and prioritization of areas for sewer and manhole rehabilitation will be provided in the Phase 1 CAP/ER.

In parallel with the CAP/ER, CSSAP activities including manhole inspections and CCTV work will provide information that will be used to prioritize component rehabilitation and/or replacement to restore structural integrity and optimize maintenance activities. The information to be obtained and stored in an Information Management System (IMS) is further described in the CSSAP. The effectiveness of structural integrity restoration efforts will be measured by trending structural failures and SSOs related to structural failures.

1.2 Wastewater Transmission System Performance

Key performance criteria for wastewater transmission system components (pump stations and force mains) are hydraulic capacity and structural integrity. Key performance criteria for pump stations are mechanical and electrical reliability. Under the CAP/ER component of the IRP, pump station hydraulic capacities will be upgraded if necessary to address SSOs contained in the SSOERs. Specifically, pump stations (and force mains and downstream sewers, if necessary) will be upgraded as needed to address SSOER events to convey, at a minimum, peak flows from a pre-determined peak flow that includes growth of the system and RD I/I without causing additional SSOs. KUB's ultimate goal is to upgrade pump station capacities as necessary to be able to certify capacity for new connections in accordance with the requirements of the CAP.

In parallel with the CAP/ER, CSSAP activities, including the corrosion defect identification and pump station performance and adequacy elements, will provide information to prioritize component rehabilitation or replacement to restore structural integrity and mechanical and electrical reliability and optimize maintenance activities. The information to be obtained and stored in an IMS is further described in the CSSAP. The effectiveness of these efforts will be measured by trending failures in each category (structural, mechanical, electrical) and related SSOs.

1.3 Resources

The Collection System Improvement (CSI) Team will have the primary responsibility of implementing the IRP. The members of the CSI Team manage, direct, and monitor the IRP. They work closely with a combination of internal and external resources such as KUB Underground Construction (UGC), other KUB departments, and consultants to implement this program.

SECTION 2: INFORMATION MANAGEMENT SYSTEMS (IMS)

KUB will develop and implement an IMS to manage, track, and measure progress toward the IRP goals. In the previous sections, references have been made to several applications to address this need. In this section, the key IMS programs are highlighted to illustrate their support of the IRP. They include

- The Stormwater Management Model (SWMM) used for modeling the sewer system
- The Collection System Maintenance (CSM) Program used to record field information
- The CCTV software for recording findings of CCTV inspections
- The Geographic Information System (GIS) used as a centralized database for system attribute data and collected information.

2.1 SWMM Model

KUB has developed and continues to refine a hydraulic model of the WCTS to support development of the CAP/ER and the CAP. The model has been developed using physical attributes of the WCTS (sewer size, slope, roughness, elevations relative to grade, pump station capacities) along with dry and wet weather flow conditions developed through analysis of flow monitoring information. The model is calibrated and updated as new flow monitoring data is collected. This practice ensures the model is an accurate reflection of the actual system.

The objectives of this hydraulic model development effort are to

- Provide a calibrated system-wide hydraulic model
- Diagnose dry and wet weather capacity problems
- Develop improvement alternatives for each basin in the system.

2.1.1 Hydraulic Model Development

KUB developed hydraulic models of the trunk sewer in each basin using the EXTRAN block of EPA's SWMM. Data furnished by KUB staff, review of available GIS information, and record drawings were used to create each model. The models include all major trunk sewers greater than 10-inches in diameter and approximately 56 pump stations within the WCTS. Smaller pump stations, typically around the periphery of the WCTS, are used as load points for entering hydrographs to the model. After the physical attributes of the system were entered into the models (pipe inverts, diameters, manhole rim elevations, and other system characteristics), the models were used to route predicted sewer flows through the system to determine downstream flows and water surface elevations for a range of different flow conditions in the system. Different flow conditions are estimated based on future growth projections in the study area as well as estimated quantities of RD I/I entering the system during wet-weather conditions, as determined from flow monitoring data.

2.1.2 Estimating Sanitary Sewer Flows

KUB calculated existing and future wastewater flows to analyze the performance of the WCTS. Since only limited current flow monitoring data was available from a 1991-1992 CSSAP, the program employed systemwide temporary flow monitoring (2003-2005), population and employment projections, land use, and known industrial and commercial discharge patterns to predict wastewater flows under current and future dry-weather conditions. Dry-weather flows were developed for 2002 (existing), and in 10-year future increments from 20 to 40 years in the future. Future wet-weather conditions were based on predicted RD I/I into the system for a pre-determined peak flow that includes growth of the system. The RD I/I hydrographs were simulated using a unit hydrograph technique. One of the key hydrograph parameters is the R-value, or the fraction of rainfall from a storm event that enters the sewer system as RD I/I. Unit hydrograph parameters for each sub-basin were calibrated to an actual storm event recorded during the flow-monitoring program. The calibrated parameters were then applied to a simulated pre-determined peak flow that includes growth of the system. Resulting RD I/I hydrographs were added to the 2002 (existing) and future dry-weather flows. The predicted flows are then used to evaluate future capacity needs in the system and to develop alternative sewer system improvements that address those needs.

2.1.3 Hydraulic Model Calibration

Dry-weather hydraulic analysis is performed by routing the diurnal base flow hydrographs through the trunk sewer system using the EXTRAN hydraulic model. To calibrate the models to dry weather conditions, the output flows produced by the simulation were matched against the flows measured by the monitors. Where necessary, adjustments were made to the model to calibrate it to observed conditions. Wet-weather calibration is performed in the same manner as the dry weather calibration. Wet-weather flows are calibrated to a real storm event observed during the flow monitoring programs.

2.1.4 Hydraulic Model Use

KUB will continue to maintain the hydraulic model by

- Periodic updates to the sewer attribute database as projects are completed or as discrepancies are identified
- Periodic recalibration using permanent flow monitoring data
- Periodic revisions to wet weather RD I/I input hydrographs using temporary flow monitoring studies to determine the effectiveness of system rehabilitation and deterioration in unimproved basins
- Periodic updating of projected future dry weather flows using updated population and employment data.

KUB will continue to rely on the hydraulic model to support CAP/ER and other capital improvements including the IRP and to support the CAP.

2.2 Collection System Maintenance (CSM) Program

The CSM Program is the electronic record-keeping tool used by investigation crews. This program collects information for the proactive cleaning and assessment of the collection system and also records the activities of crews that respond to trouble calls in the system.

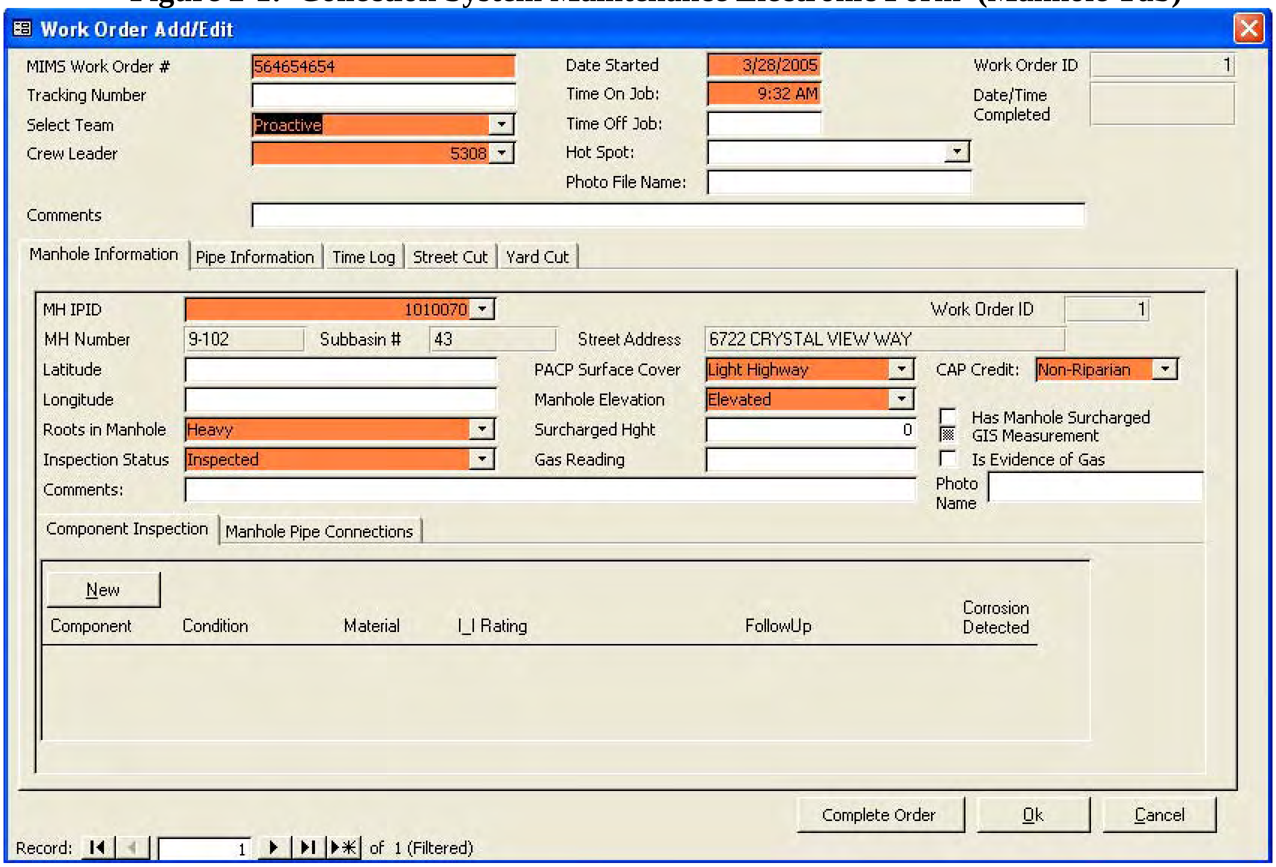
As illustrated in Figure 2-1, the typical information collected in this program includes

- Tracking numbers
- Team performing work
- Date and time
- Manhole information
- Pipe information
- Production numbers

- Follow-up street or landscaping repairs.

Manhole Inspection Data
The manhole information section of this program records the assessment during manhole inspections. Figure 2-1 illustrates the electronic format for recording manhole information.

Figure 2-1: Collection System Maintenance Electronic Form (Manhole Tab)



The information collected for each manhole during the routine manhole inspection process includes the following general information:

- Manhole Item of Plant Identification (IPID) number (KUB's internal numbering system for manholes)
- Latitude and longitude
- Pipeline Assessment and Certification Program (PACP) surface cover
- Manhole elevation (flush, above, or below the surrounding area)
- CAP credit (located in riparian, non-riparian, or paved area)
- Roots in manhole (severity of roots in manhole, if present)
- Inspection status (inspection completed, unable to locate manhole, etc.)
- Evidence that manhole has surcharge, and if so, to what height in manhole
- Evidence of gas in the manhole, and if so, what is the gas reading.

Specific information will be documented for each component of the manhole as illustrated in Figure 2-2. The manhole components to be inspected include

- Lid

- Ring
- Chimney
- Steps
- Cone
- Riser
- Bench
- Trough.

Figure 2-2: CSM Manhole Component Assessment

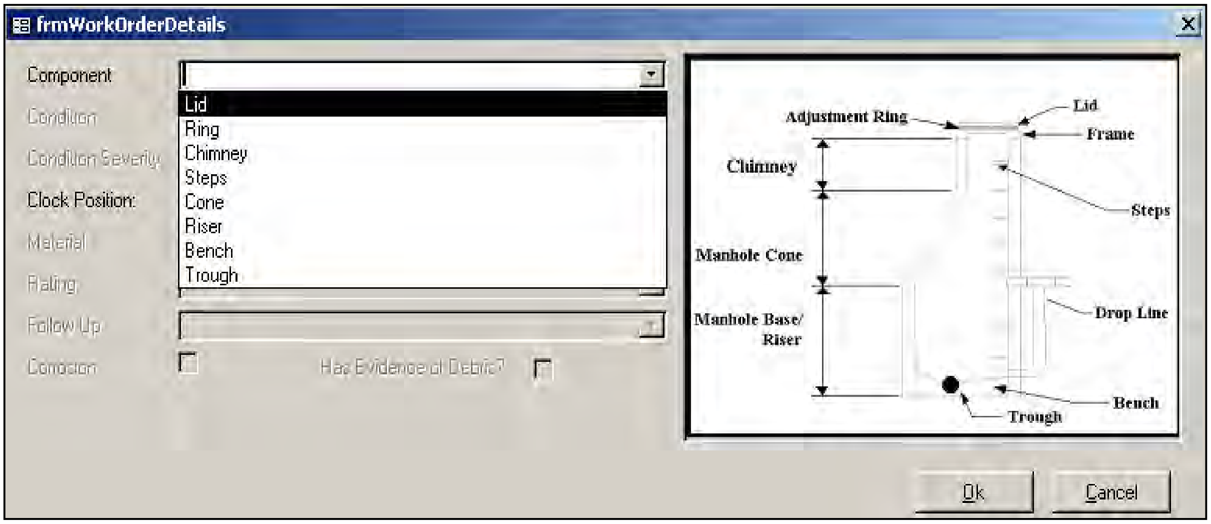
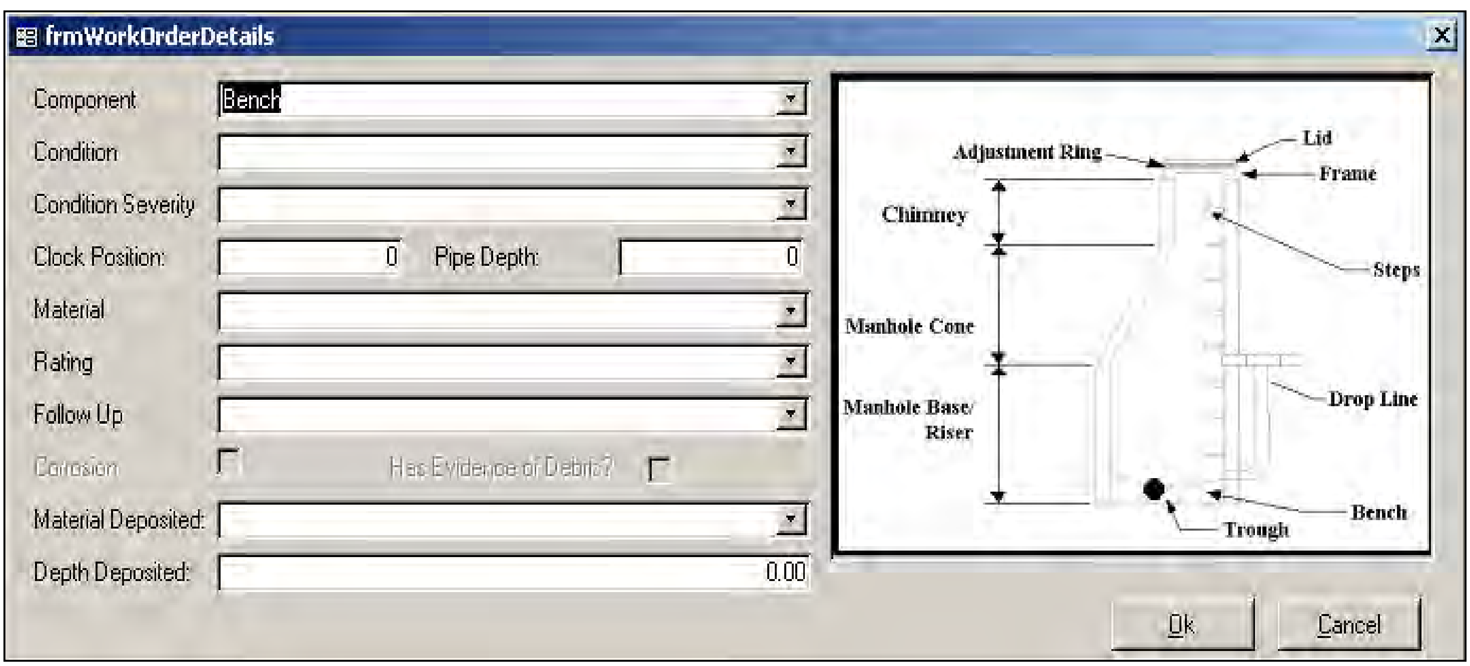


Figure 2-3



As shown in Figure 2-3, each component possesses its own characteristics, so each component will be evaluated with different criteria:

- Condition (cracked, debris, etc.)
- Condition severity
- Position and location of defect with respect to discharge pipe
- Depth (vertical location of defect from invert)
- Material (concrete, brick, etc.)
- Rating (CAP rating or severity of I/I, if present)
- Material deposited (type of material deposited, if present)
- Depth deposited (if material is deposited, what is the depth of the deposit)

Pipe Maintenance and Assessment Data

The CSM Program collects general information pertaining to the sewer line as shown in Figure 2-1 in Section 2.1.3. The general information collected for sewer lines include

- Pipe IPID (IPID is the unique GIS numbering system for assets)
- PACP surface cover
- Confirmed pipe size (diameter of pipe)
- CAP credit (infiltration sources and severity, if present)
- Pipe material
- Pipe follow-up (other maintenance or inspection activities recommended)
- Confirmed pipe length
- System disruption (broken pipe, debris, roots, grease, etc.)
- Evidence of gas in the manhole, and if so, the gas reading.

The specific activities pertaining to cleaning and inspecting the sewer mains are also recorded in this program.

- Job Code (records the specific work done to the asset)
- Work Code (records the asset receiving the work)
- Unit of measure (unit of work, such as linear feet or cubic yard)
- Amount of feet/cubic yards
- Truck number
- Amount of water used
- Number of passes (number of times that the line was either flushed or televised).

Other Data

The CSM collects other information relating to maintenance and assessment including the following:

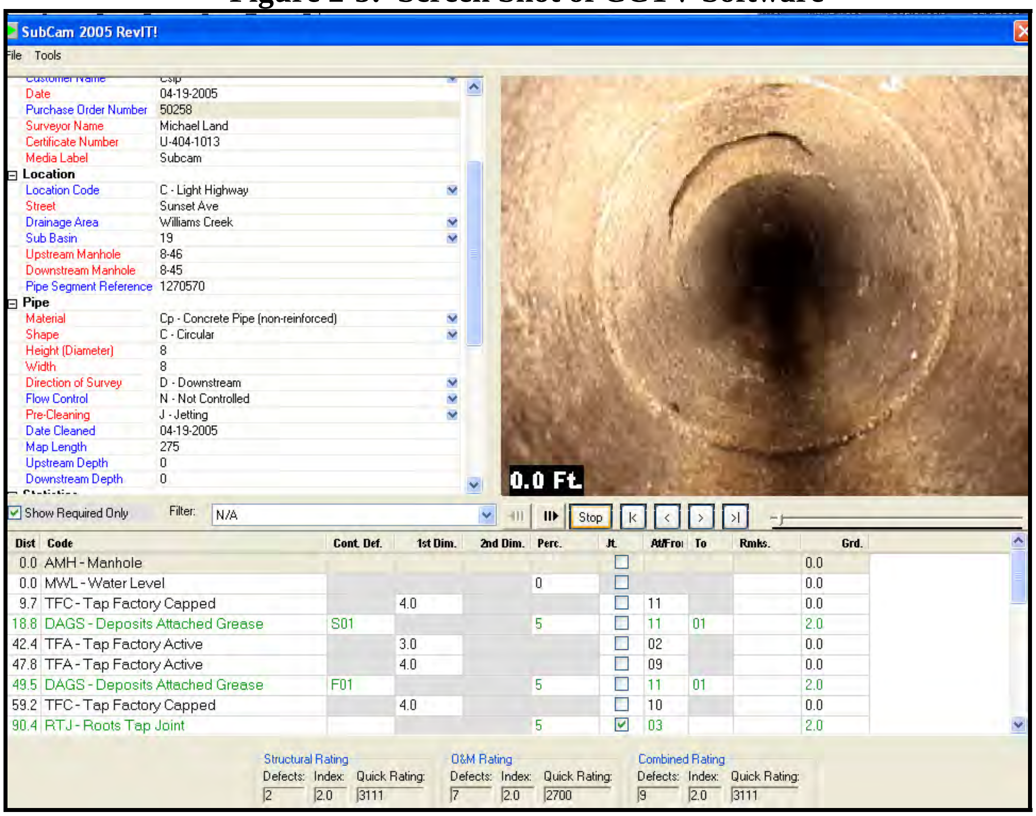
- Team leader (name of lead person)
- Crew members (names of KUB personnel performing work)
- Equipment number
- Number of employee and equipment hours (regular and overtime)
- Street and yard cut information (street repair required due to activities).

2.3 CCTV Software

KUB has incorporated information management software to record condition assessment of the WCTS. The CCTV software provides structured data input while ensuring a uniform standard to facilitate office review. Each individual CCTV inspection consists of tabular inspection data, linked still photos, and digital videos. The PACP-certified software fully supports and conforms to PACP Standard Data Format export and/or import guidelines.

A screen shot of the software used for CCTV inspections is illustrated in Figure 2-5.

Figure 2-5: Screen Shot of CCTV Software



Line segments are inspected using a computer screen displaying observations from a CCTV camera and footage readings from a properly calibrated footage counter. Footage readings are automatically displayed on the screen, and the Survey Log includes footage readings that directly correspond to the location of each coded defect. The same footage readings are consistently displayed in graphic and tabular reports subsequently generated.

In addition to video and footage readings, windows of the display screen displays a blank inspection log, an assortment of data entry tools consisting of user-defined single-stroke hot-keys, drop-down code-selection menus, and other on-screen tools to record additional data required by PACP. After completion of each coded entry, the "entered" data is displayed in PACP tabular log format with additional column(s) displaying PACP Condition Grades associated with individual coded entries. For example, a special key, "S," is available to designate and automatically number entries for continuous defects. There is also a means provided to automatically close those entries ("F" entries) when termination points are noted and to prevent inspection termination until all continuous defects are "closed." Built-in audit capability limits the array of data entry fields to only those associated with the PACP codes selected.

After the user exits from data entry mode, completed inspections are automatically stored on hard drives in a truck-mounted computer-data logger. Inspections are stored during the inspection and the reports are stored automatically after the inspection. The CCTV data on each of the camera trucks will be downloaded onto the CSI server using a direct network connection.

Office technicians have the option to conduct an Intermediate Review of field inspections directly from "transport" media or to copy the data to a selected office computer hard drive or server.

1. **Intermediate Review:**
   The office system recognizes transport media based on path data stored in the set-up file and generates an index from which reviewers select individual inspections for review. Data from the selected inspection is displayed in an edit screen consisting of windows to display the tabular observation log, listing of associated header information, and a window in which to display still photos (jpegs) associated with each coded observation. Using forward/reverse tabs or selecting individual coded entries allows a quick review of coded entries and associated still photos.

   Additional menu options permit a shift from "quick review" mode to the original data entry screen format that includes the associated video.

   At either review level, edit capability enables reviewers to make corrections to tabular data and delete entries. When viewing full screen with video, additional defects are added to the inspection log.

2. **Review From Office Computer Hard Drive or Server:**
   Procedures for review and edit from the office hard drive or server are identical to those for Intermediate Review.

   The CSI Team reviews the results of the inspections. When the data has been verified, the information will be available to other KUB users and can be shared with KUB consultants to program system improvements. Refer to Section 3 for more detail on the IRP Decision Process.

   Office and Field Reports are generated in the same manner through selection from menus. Report generation is initiated by selecting individual inspections from the Inspection Index or Find Inspection screens and may be printed individually or in batch mode. Standard reports are available in the following formats:
   1. Header Report - PACP Header information and custom fields
   2. Defect Listing – PACP log format
   3. Defect Listing – Plot format; horizontal or vertical plot displaying all recorded observations in relation to footage locations and color-coded to reflect Condition

Grade

4. Defect Listing – Plot with Small photos; same as Defect Listing – Plot format above, but including thumbnail photos of each coded observation
5. Defect Listing – Small Image; report sheets displaying Header information and four photos (with tabular data) per page
6. Defect Listing – Large Image; same as Defect Listing – Small Image above, but only 1 image per page
7. Condition Grades – Tabular listing of PACP Condition Grades listed separately by "Structural," "O&M," and "Combined" categories, with a separate listing of each Continuous Defect and its length; and calculations displayed (by category) for PACP Pipe Rating, Structural Index, and Quick Rating.

A default selection of reports and output/export format may be made for each customer when the Customer File is established, but that selection may be changed at any time. Report output types are selected from PDF, Excel, HTML, Text, or TIFF formats, and options are provided to "save" reports after edit changes, view the report on-screen, or to print it. Through an "Auto-Save" feature, reports may be automatically saved after completion of each field inspection and the saved report stored with tabular, jpeg, and video data for each inspection.

2.4 GIS Integration

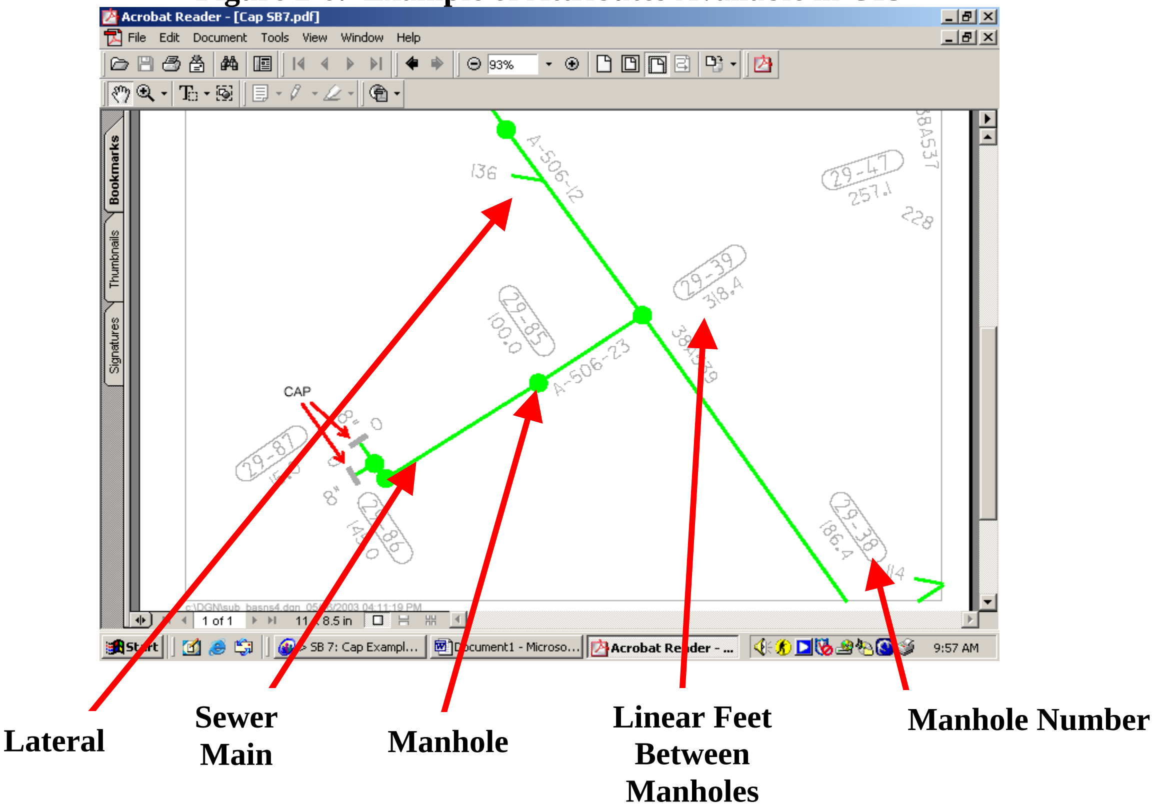
The Knoxville-Knox County-Knoxville Utilities Board Geographic Information System (KGIS) was established in 1985 by a charter agreement between the City of Knoxville, Knox County, and KUB. KGIS is unique in that it was the nation's first major multi-participant municipal GIS.

The KGIS Office administers the common portions of KGIS and its computer system. It also provides GIS and computer technical support and serves as a clearinghouse of GIS information and products. The KGIS Office is also responsible for updating a common set of computer-based maps (for all Knox County) that are used by all of its users. This base map data includes planimetric maps, topographic maps, digital terrain models, and digital ortho aerial photography. KGIS is also responsible for selling hardcopy map products and for all licensing of digital map products to the general public or to groups providing services to one of the KGIS users.

The roughly 526 square miles of Knox County have been mapped at scales of one inch = 100 feet (1:1200) for highly urbanized areas or at one inch = 200 feet (1:2400) for lesser-developed areas. In addition to mapping the photo-identifiable features, the various agencies in KGIS have mapped other related information, including property and jurisdictional boundaries, road and address locations, utilities, and facilities.

From a technical standpoint, the GIS displays the graphic (map) data as layers of information; that is, streets on one layer, parcels on another, houses on another, etc. That allows an almost unlimited flexibility for viewing only the desired features and area. Non-graphic information is also associated with many map features and is stored in databases for immediate retrieval (Figure 2-6).

Figure 2-6: Example of Attributes Available in GIS



The information gathered from the IRP is stored in GIS tables to provide easily assessable information to Basin Owners, UGC field crews, consultants, etc. The viewing capability offered by GIS provides a visual representation of the data collected in the field. For example, manholes that have been recently inspected in an area can be isolated for system improvement planning. GIS will allow the information collected from IRP activities to be viewed graphically while providing a centralized database accessible for review by KUB and contractors.

2.5 Supervisory Control and Data Acquisition System (SCADA)

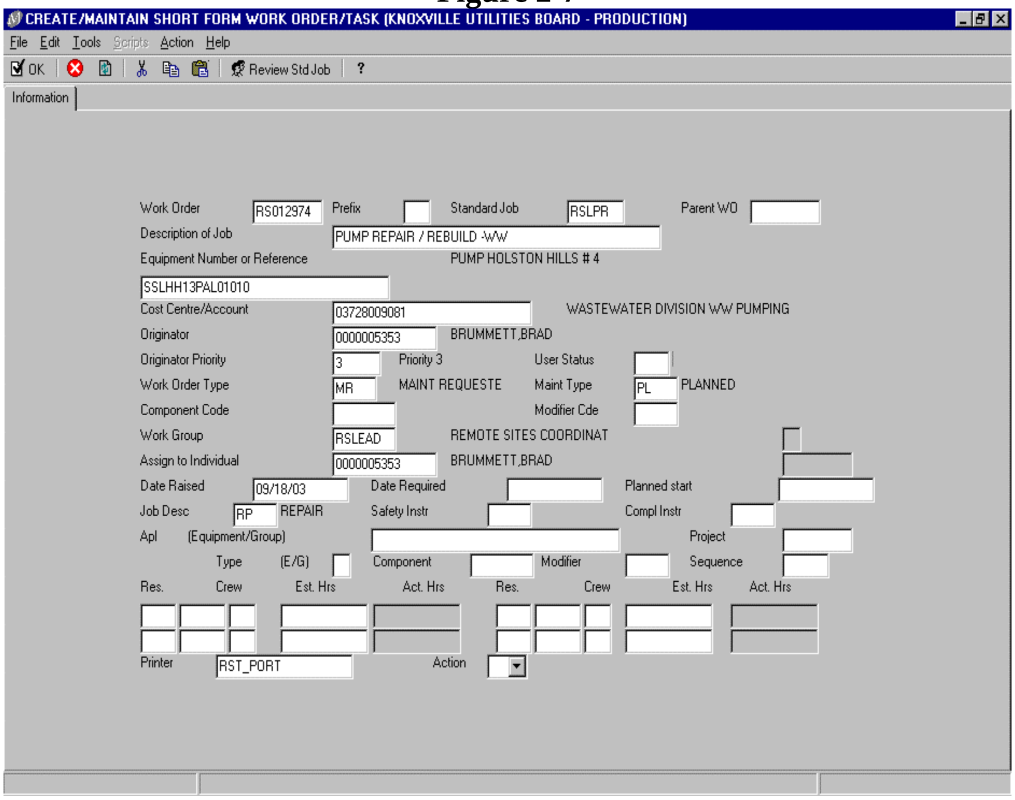
The automated SCADA system may also initiate a field order through System Operations. SCADA notifies System Operations if there is a system failure in any of KUB's pump stations. That prompts System Operations to contact Station Management Services (SMS), which investigates the event and remediates the problem. The possible overflow has then either been prevented or cleaned up. SCADA gives valuable information on the duration and volume of the overflow and tracks the pump operating time. SCADA is also used to identify system improvements and the operability of the station and to identify potential SSO events so that measures can be taken to prevent a discharge.

2.6 Asset Management System

The goal for implementing the asset management system was to capture and report business information and support well-defined corporate metrics and strategy for doing business and the use of established best-practice work methods.

The Operations Center uses the asset management system to generate work orders and standard jobs and to track equipment and work orders (Figure 2-7). Damage claims can be tracked for costing purposes. Engineering work orders can be tracked for time purposes.

Figure 2-7



The SMS group uses the asset management system extensively for maintenance equipment tracking. Larger equipment groups (large breakers, relays, pumps, etc.) are tracked for time purposes and job packaging. Entering a maintenance code and searching for the identified asset can query repair data. Job Packaging is used to create the hierarchy of a project area.

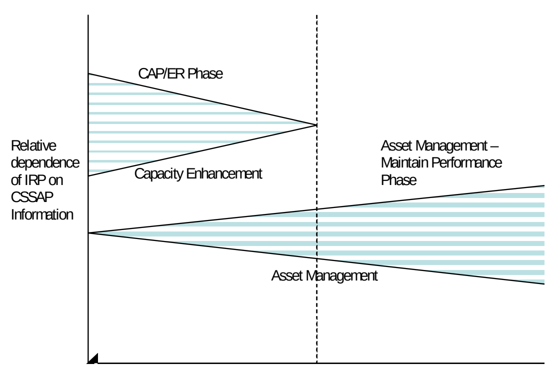
SECTION 3: DECISION MODEL

Effective management of KUB's collection system maximizes the operation and performance of wastewater assets. KUB's asset management plan contains long-range planning, life-cycle costing, proactive operations and maintenance, and capital replacement plans based on cost-benefit analyses. This plan ensures that KUB is improving its wastewater system and optimizing its financial resources in the following ways:

- Making sure components are protected from premature failure through proper operations and maintenance
- Facilitating proactive capital improvement planning and implementation to reduce annual overall costs
- Reducing the need for expansions and additions of wet-weather capacity through I/I reduction
- Reducing the cost of new or planned investments through economic evaluation of options using life-cycle costing and value engineering
- Focusing attention on results such as reducing wet-weather flows and SSOs by clearly defining responsibility, accountability, and reporting requirements within the organization.

The IRP plays an integral role in KUB's asset management of its wastewater system by providing the link between the CSSAP and accomplishing necessary sewer improvements. Section 2 presented KUB's process for gathering and organizing information on its sewer assets using the CSSAP program. This IRP decision model will illustrate the progression from condition assessment data obtained in the CSSAP to the development of the sanitary sewer project. This model not only defines project scope but also evaluates and prioritizes scheduling of these projects. Figure 3-1 illustrates the relationship between the CAP/ER and the IRP.

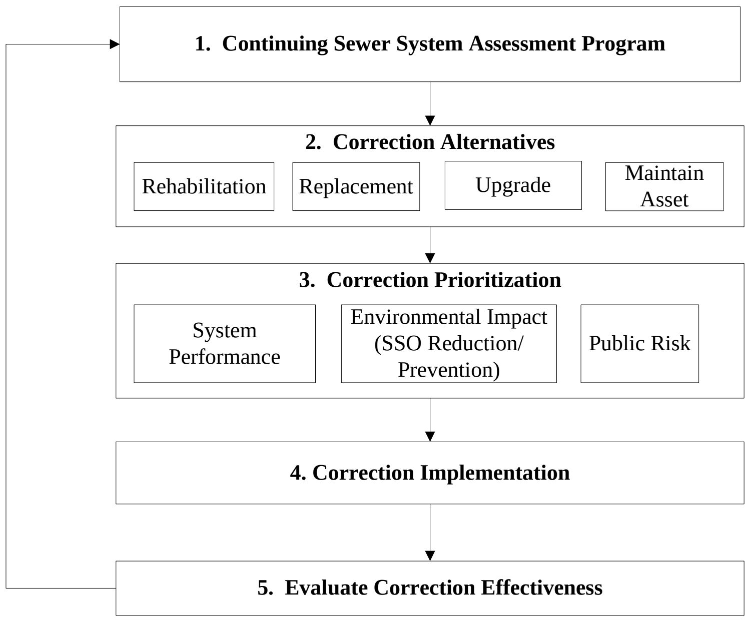
Figure 3-1
Relationship of CAP/ER and IRP



In the beginning of this program, the CAP/ER will direct most of KUB's capital improvement program. The CAP/ER is a capital improvement program focused on achieving a targeted level of performance (i.e., addressing the capacity related SSOs that have occurred in KUB's wastewater system). It consists of both capacity improvements (relief sewers, sewer replacement with larger sewers, pump station expansion and storage facilities) and existing system rehabilitation to reduce flows and minimize structural failures and root intrusions. Flow monitoring data and the hydraulic models are the primary tools for providing and analyzing system information to support decision-making for the CAP/ER. Follow-up smoke testing and CCTV are also used in areas targeted for sewer rehabilitation.

As KUB moves forward, components of the CSSAP will play an increasingly important role in supporting asset management decision-making under the IRP. As the IRP progresses, the number of projects to address SSOs or capacity issues will decrease as the proactive assessment and prioritization driven projects increase. This process is illustrated in Figure 3-2.

Figue 3-2 Infrastructure Rehabilitation Program (IRP) Process Flow Diagram



The IRP decision process consists of five basic steps:

1. **CSSAP**
   This step provides data from the flow monitoring network, rain gauges, CCTV inspections, pump station inspections, and hydraulic model.
2. **Correction Alternatives**
   This step describes the application of evaluated and approved sanitary sewer techniques to identify system defects identified in the CSSAP.
3. **Correction Prioritization**
   The next step is to determine the priority of each sanitary sewer improvement identified in the first step.
4. **Correction Implementation**
   After the priorities have been established, then the individual improvements will be grouped into projects and implemented.
5. **Continued Evaluation**
   The completed project will be assessed through the CSSAP.

3.1 Correction Alternatives

The correction alternatives describe KUB's approach for addressing the identified sewer defects in the CSSAP. The initial phase of the IRP is the CAP/ER. The CAP/ER uses rehabilitation, replacement, and capacity projects to address SSO related issues. KUB will incorporate capacity projects to ensure system performance under a pre-determined peak flow. The projects that will be implemented will include trunk sewer upgrades, storage tank installations, and sub-basin rehabilitation.

The four basic correction approaches are as follows:

- Rehabilitate the asset
- Replace the asset
- Upgrade the asset
- Continue to maintain and evaluate the asset through the Gravity Line Preventive Maintenance (GLPM) and CSSAP programs.

The first two correction approaches will use the methods described in Section 5: Sewer System Improvement Techniques. As described in Section 5, various methods were evaluated and approved for addressing the system deficiencies. These techniques have been grouped into five improvement technique categories. Sanitary sewer improvement technique categories approved in the IRP include the following:

- Pipe Rehabilitation
- Pipe Replacement
- Manhole Rehabilitation
- Manhole Replacement
- Pump Station Rehabilitation.

Pipe improvements include gravity main line, laterals, and force mains, since the same type of improvements can be made on all three asset types. The last category describes the continued maintenance and evaluation of the asset. This issue is discussed in more detail in Section 3.1.4 Maintain Asset.

3.1.1 Rehabilitation

Rehabilitation is a corrective approach that improves the existing pipe, manhole, and pump station equipment with an applied technology such as liners and spray coatings. Rehabilitation lowers the impact on the surrounding area by using the existing asset as a host.

Sewer rehabilitation efforts are described in more detail in Section 5. Rehabilitation of sewer components will improve the operability of the system.

Assets that are improved or rehabilitated can be removed from the aggressive maintenance programs such as Blockage Abatement. For example, the GLPM Program consists of a Blockage Abatement (BA) Program to provide additional cleaning of line segments. Line segments are in the BA Program as a result of roots, debris, or grease. After a line segment has been rehabilitated, the line segment may be removed from the BA Program, since the initial cause for its inclusion in the BA Program has been remediated. In this example, the line segment would remain on the Hydraulic Cleaning Program.

Typical deficiencies that are good candidates for rehabilitation include but are not limited to the following:

- Separated Joints
- Root Intrusions
- Inoperable Circuit Board (Pump Station)
- Inoperable Air Relief Valves (Force Mains).

3.1.2 Replacement

The CSSAP program provides system information to determine the need to replace the asset. A replacement will improve the operability of the system when rehabilitation of the component is not applicable. For example, a line segment that has collapsed due to structural failure will require a point repair. This line would not be a candidate for rehabilitation only.

As the CSSAP matures, the significance and influence of replacements and life-cycle replacements on the IRP will also develop. KUB will use multiple tools and data, as presented in Section 2 of this document and in the CSSAP, to evaluate system assets that need to be repaired. By using all of the CSSAP tools, KUB will perform a condition assessment evaluation to determine if an asset needs to be rehabilitated, replaced, upgraded, or maintained.

3.1.3 Upgraded

The third correction approach is to upgrade the capacity of the asset. This approach addresses asset enhancements. This decision factor is closely associated with not only the CSSAP but also KUB's CAP. The flow monitoring data, hydraulic model, and future growth patterns justify performance enhancements such as upgrades to a gravity sewer, pump station, or force main.

For example, a pump station is approaching its capacity limitation. Upgrading to larger belts and impellor sizes will increase station capacity. Rehabilitation and replacements to the station will not provide the same end result, so an asset upgrade is the most effective approach.

3.1.4 Maintain Asset

The remaining option is to continue to maintain the asset using KUB's MOM program. Based on information from the CSSAP, if the asset does not meet the criteria for rehabilitation, replacement, or upgrade, then it will be placed into this category. Other programs, such as the GLPM Program and the Pump Station Preventive Maintenance Program, will continue to maintain these assets. KUB will continue to inspect all wastewater assets on a periodic basis and determine if they need to be fixed in the future.

3.2 Correction Prioritization

After the decision has been made to rehabilitate, repair, upgrade, or continue to maintain and evaluate the asset, the next step is to specify the priority for the necessary sewer improvements. These are three influencing factors that will be used to prioritize the improvements:

- System Performance
- Environmental Impact (SSO Reduction/Prevention)

- Public Risk.

Following is a brief description on each of these criteria. Please note that this will not determine if an asset will be fixed or not but will affect the priority and, therefore, possibly the timeframe of when the asset will be fixed.

3.2.1 System Performance

The effect on system performance must be considered when evaluating the need for an asset to be repaired, rehabilitated, upgraded, or whether it will continue to be maintained. The following criteria are considered when evaluating the affect on system performance:

- History of SSOs (blockage versus capacity)
- Frequency of PM required for an asset
- Number of trouble calls received for an asset (i.e., odor complaints)
- Size of asset
- Pump run times
- Records of pump and pump station failures
- Scope of repair (i.e. length of sewer to be repaired)
- Severity of defect in the asset.

Other factors discovered during CSSAP activities will also be considered in establishing the priorities of the IRP.

3.2.2 Environmental Impact

The next criterion that is considered in the IRP for priority setting is environmental impact. This assessment factor addresses the surrounding areas that are impacted by system deficiencies. The considerations assist in prioritizing projects for the positive impacts on the location in the system not only the performance of the system.

The environmental impact is considered for events that have already occurred, and for those that are likely to happen. This approach is not only corrective but also proactive.

3.2.3 Public Risk

Another criterion when setting priorities using the IRP is public risk. These are some important considerations that are used in the IRP to set public risk priorities:

- Location of an asset in relation to
  - Hospitals
  - Schools
  - Residential areas
  - Rural areas
  - Parks/recreation areas
  - High pedestrian traffic areas
- Cultural Impacts (i.e. tourism, etc.).

Please note that this list does not encompass all of the variables that are considered in setting public risk priorities.

3.3 Correction Implementation

After the IRP determines the correction and priority for each particular asset, then each asset will be fixed using the methods presented in Section 4 of this report. The corrections will be packaged into appropriate projects and then implemented.

Various correction alternatives can be combined into one project depending on several factors that include geographic vicinity, downstream impacts, type of corrections, etc. For example, projects have been developed to address all wastewater components in one sub-basin. These projects have included rehabilitation of gravity mains, installation of new laterals, and structural repairs of failed lines. These projects are intended to remove extraneous water and improve system performance. Some lines were determined to require no rehabilitation or replacement; therefore the corrective action for these lines is to continue to maintain assets.

3.4 Evaluate Correction

The operation and maintenance of a wastewater system is a continuous process and must be evaluated on a periodic basis. The IRP is a component of the overall management of KUB's wastewater system and must also be continuously evaluated. KUB's CSSAP goal is to inspect the entire wastewater system once every 12 years. By doing this, the IRP will continue to receive data that will then be updated and evaluated to determine if an asset needs to be rehabilitated, replaced, upgraded, or maintained in present condition. Permanent flow meters will provide information to measure the success of the overall performance of the system.

The IRP itself will also be reviewed to ensure that it maintains an accurate assessment for its corrections using the most up-to-date and cost-effective approaches to fixing assets and also setting appropriate priorities for managing them.

SECTION 4: SANITARY SEWER IMPROVEMENT TECHNIQUES

The IRP contains evaluated and approved sanitary sewer improvement techniques. These techniques have been grouped into five improvement technique categories. Sanitary Sewer Improvement Technique Categories included in the IRP are as follows:

- Pipe Rehabilitation
- Pipe Replacement
- Manhole Rehabilitation
- Manhole Replacement
- Pump Station Rehabilitation
- Pump Station Replacement.

Traditional replacement methods require unearthing and replacing the deficient pipe or manhole (dig and replace method). Trenchless methods use the existing sewer pipe or manhole as a host for a new pipe or liner. Rehabilitation of a sewer component is the most desired technique due to the reduced impact on the surrounding area. Trenchless techniques provide the opportunity to correct pipe deficiencies while causing less disturbance and environmental degradation than the traditional dig-and-replace method. Refer to Appendix A for construction specifications.

4.1 Pipe Rehabilitation

Trenchless pipe rehabilitation methods include the following:

- Cured-in-Place Pipe
- Pipe Bursting
- Slip Lining.

4.1.1 Cured-in-Place Pipe (CIPP)

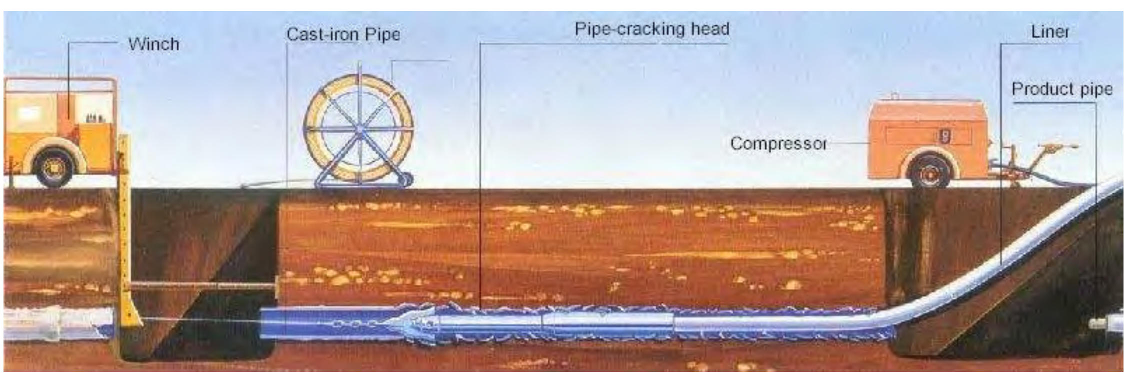
CIPP is a cost-effective technique used to rehabilitate defective sanitary sewer pipes and storm pipes without digging. The pipes in the ground are getting older and more need to be replaced or repaired every day. CIPP is a way to repair defective pipes without disturbing the pavement, sidewalk, landscaping, and other utilities placed over them.

The process is done by inverting a flexible (commonly polyester felt) tube with a cross sectional perimeter equal to the inner circumference of the host pipe. The tube is then pressure inverted against the wall of the host pipe from a suitable access point, and heated in-situ (using water, steam, or air) to cure the resin, thus forming a structurally competent lining.

4.1.2 Pipe Bursting

A new main (or pipe) of the same size or larger is attached to a cone-shaped head and inserted into the existing main through a manhole or an excavation pit. As it is pulled through the existing main by pneumatic or hydraulic means, the leading cone shatters the existing pipe in place, leaving a large void where the trailing new main is pulled into place (typically, High Density Polyethylene HDPE). Laterals are reconnected by excavation, but surface disruption is less than with open-cut construction. The advantage of pipe bursting over other trenchless methods is the ability to enlarge the pipe.

Several factors dictate whether pipe bursting is appropriate for the rehabilitation of the sewer line. These considerations include host pipe material, diameter, condition, depth, length, new pipe diameter, soil conditions, peripheral utilities, and service connections. The bursting tool can be used to burst fractural pipes (cast iron, clay, concrete, reinforced concrete pipe-RCP, ABS, and some plastics) with diameters between four and 54 inches.



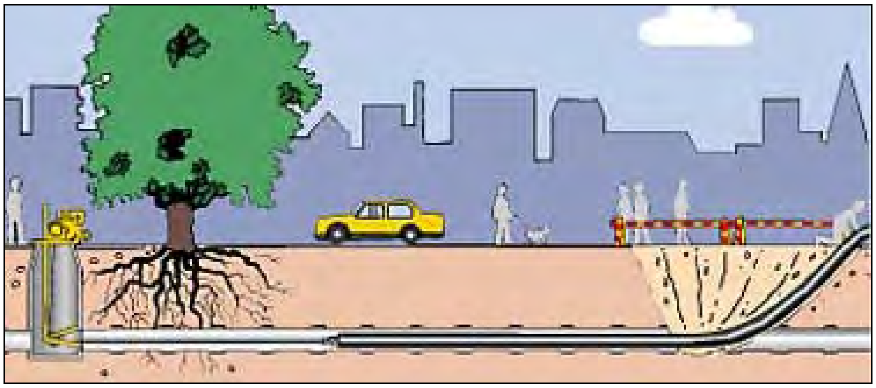
4.1.3 Slip Lining

Slip lining provides an additional, trenchless method of rehabilitating pipes. When existing capacity is sufficient, slip lining is an effective rehabilitation method in which a pipe is inserted into an existing line by either pulling or pushing continuous or short-length pipes, typically HDPE pipe. With traditional slip lining, a lead-in trench is excavated for installation and pipes are butt-welded on the surface of the ground before being winched or jacked into the existing pipe. During the slip lining process, a slightly smaller liner pipe is inserted into the host pipe.

The slip lining technique can be applied to either pressure or gravity pipes. Sanitary sewers can be renewed with minimum excavation. The rehabilitated pipe and lateral connections are leak-tight, corrosion resistant, and may have improved flow capabilities. Sliplining is recommended for pipes ranging from eight to 96 inches in diameter.

Slip lining can be performed rapidly, without disturbing adjacent services or requiring bypass pumping. It makes it possible to repair long lengths of pipe with minimal disruption. Because the liner is structurally sound, it solves problems related to leakage and structural deterioration.

To stop infiltration from migrating down the annular space between the pipes and to provide additional strength, this technique includes grouting the annular space between the lining and the original pipe. Significantly dropped joints, roots, and other impediments to the insertion of the pipe must be repaired or removed prior to installation. Laterals must be reconnected by excavation.



4.2 Pipe Replacement

The traditional method of replacing a sewer or adding a parallel sewer line is digging along the existing pipe. This method of sewer replacement requires unearthing and replacing the deficient pipe (the dig and replace method). The replacement of the deficient pipe may include the installation of a parallel line or re-routing a new line. While trenchless technologies offer less surface disturbances as compared to the dig and replace method, not all system improvements can be accomplished without excavating the sewer system. Examples of when the dig and replace method is required include, but not are limited to, structural deformities or collapsed pipes, severe swags, obstructions which can not be hydraulically removed, offset joints greater than one inch, etc.

4.3 Manhole Rehabilitation

Trenchless manhole rehabilitation techniques, such as spot repairs, cementitious coating, chemical coating, and structural form repair are intended to rehabilitate the deteriorated manholes,. Structural form repairs are used to rehabilitate severely deteriorated manholes. A new manhole is constructed within the existing manhole either by insertion or construction. These techniques will restore the structural integrity of the manhole with no surface disruption. Structural performance is required, particularly in cases where manholes are exposed to groundwater pressure and are leaking. Any material used to reconstruct manholes must be able to resist attack from acids, corrosives, roots, vibration, etc.

4.3.1 Pneumatic Sprayed Cementitious Lining

Cementitious coatings are applied using a pneumatic spray method to repair the interior of the existing manhole (concrete and brick). This process is used to seal all cracks on all or portions of the interior of the entire manhole. These coatings typically contain a mix of cement and chopped fibers. The coatings may be sprayed over a wire mesh, or poured into an HDPE form with rebar. The coatings contain calcium aluminate as an additive, which provides additional corrosion resistance for the concrete.

4.3.2 Chimney Liners

Chimney liners are used to provide a watertight seal that reduces groundwater infiltration between the chimney and the frame. The installation of the internal seals does not require excavation around the manhole or entry into the manhole. These rubber seals are versatile and fit most sizes and manhole types. These seals can be installed in brick and precast manholes.

4.3.3 Manhole Pans

Manhole pans fit under the manhole lid and are intended to prevent inflow through vent and pry holes in the manhole cover. The pans are either HDPE or stainless steel. Air relief valves can be specified for these inserts to allow sewer gases to be released from the manhole, since the ventilation of the lid has been interrupted.

4.4 Manhole Replacement

Manhole replacement requires unearthing and replacing or relocating the deficient manhole (dig and replace method). While trenchless technologies offer less surface disturbances as compared to the dig and replace method, not all system improvements can be accomplished without excavating the sewer system. Examples of when the dig and replace method is required include, but not are limited to, manholes in pipe rehabilitation projects and severe structural deformities.

4.5 Pump Station Rehabilitation

KUB’s pump station maintenance activities focus on sustaining the sanitary sewer collection system’s ability for conveying wastewater to higher elevations or being discharged into gravity or pressurized systems. Typically, three classes of problems can reduce the pump station’s ability to convey wastewater effectively and reliably:

electrical, mechanical, and structural.

4.5.1 Electrical Improvements

Electrical defects, such as tripped breakers, blown fuses, bad starter contacts, and other faulty components will inhibit the pump station's maximum operability. Thermography reporting and facility inspection methods are directed toward preventing or reducing the impacts of electrical defects on pump stations. As the electrical deficiencies are identified, they will be resolved during scheduled maintenance activities. In cases where larger scope improvements are required, projects will be developed and implemented.

4.5.2 Mechanical Improvements

Mechanical defects, such as faulty valves, impeller wear, bearing wear, and other pump defects will inhibit the pump station's maximum operability and reliability. Vibration analysis, Pump Efficiency Testing, and facility inspection methods are directed toward preventing or reducing the impacts of mechanical defects on lift stations. As the mechanical deficiencies are identified, they will be resolved during scheduled maintenance activities. In cases where larger scope improvements are required, projects will be developed and implemented.

4.5.3 Structural Improvements

Structural defects involve the degradation of the lift station housing structure, wetwell, and facility surroundings. The improvements associated with the wetwell will be addressed with the techniques described in Section 4.4.3 Manhole Rehabilitation. Any deficiencies identified in the pump station housing or surrounding grounds will be addressed on a case-by-case basis using the most efficient repair techniques.

SECTION 5: ANALYSIS OF SEWER REHABILITATION EFFECTIVENESS

Knowledge of the effectiveness of sewer rehabilitation in meeting project goals is important to direct future phases of work cost-effectively. For programs where rehabilitation objectives are the reduction of RD I/I, it is sometimes difficult to document RD I/I reduction attributed to the rehabilitation. A number of environmental factors may affect RD I/I rates for different storm events, such as antecedent moisture conditions, rainfall intensity and duration, and groundwater elevations.

This section presents a method of analyzing flow and rainfall monitoring data to document RD I/I reduction in KUB's system. The method relies on scientific principles including good data quality control practices and the use of control areas to establish changes in RD I/I between monitoring periods because of environmental factors. Understanding the effects of environmental factors on varying RD I/I between monitoring periods is critical for the accurate assessment of RD I/I reductions resulting from sewer rehabilitation.

RD I/I volumes and rates may vary significantly in a system depending on rainfall intensity, rainfall duration, antecedent moisture conditions (duration since the last rainfall), groundwater conditions, and other factors. Accounting for these factors has been a primary challenge in documenting true RD I/I reductions because pre- and post-rehabilitation monitoring captures data from different rainfall events, usually a year or more apart. Although the impacts on RD I/I from these factors are generally understood, they are difficult to quantify.

By performing simultaneous monitoring of control areas that are characteristically similar to the rehabilitated areas but where no rehabilitation has been performed, a comparison may be made that quantifies the RD I/I reduction that resulted from the rehabilitation itself.

5.1 Data Collection

5.1.1 Flow Monitoring

A program to successfully document RD I/I reduction requires careful planning from the initial data collection phase. Flow monitors must be placed carefully to define sub-basins that are of similar size (in terms of the length of sewer) and that are as homogeneous as possible (in terms of sewer age, pipe material, and land use). Sub-basins containing lengths from 10,000 to 20,000 linear feet have worked best. This size area generally provides enough dry-weather wastewater flows so monitors can be accurately calibrated; however, the area is not so large that significant variation in rainfall would be expected to occur. Controlling the size and homogeneity of sub-basins is important in the early stages of a sewer rehabilitation program while KUB is learning which rehabilitation approaches and techniques are most successful in the system.

The flow monitoring data analysis method relies on the use of control areas, or areas where rehabilitation is not performed, as a basis for documenting changes in RD I/I between monitoring periods that occur because of environmental factors. This allows better documentation of the RD I/I reductions that occur because of the rehabilitation performed. It is desirable for control areas to be similar to the rehabilitation area with which it is associated in terms of geographical location, size, age, pipe materials, and land use. This improves the validity of the assumption that the RD I/I responses from the control area and the rehabilitation area will be similar. Therefore, flow monitors will be located with this goal in mind. It is also desirable to monitor multiple control areas when possible to avoid unforeseen circumstances at one monitoring location from impeding the analysis.

For KUB's purposes, data from permanent and temporary flow monitors will be used. Flow monitoring and data analyses are further described in the CSSAP.

5.1.2 Rainfall Monitoring

Rainfall monitoring is a critical element of the data collection stage. Because the focus is on documenting RD I/I, an accurate measurement of rainfall within each sub-basin is needed for the analysis. Two elements have been found to be important in rainfall monitoring: the season selected for monitoring and the density of monitors. For KUB's purposes, permanent and temporary rain gauges will be used.

RD I/I reduction analysis typically relies on multiple short-term monitoring periods. KUB has performed temporary flow monitoring studies almost exclusively in the late winter and early spring. This is done for two reasons. First, the rainfall events that occur during this period are typically frontal-type events that provide evenly distributed rainfall across a wide area. This improves confidence in analyzing rainfall data. In contrast, cell-type events that occur in the summer and fall can result in highly variable rainfall across a small area making it difficult to determine accurately the rainfall that fell over a sewershed. Second, the groundwater table in Knoxville is at its seasonal high in the late winter and early spring because of the precipitation characteristics and the evapotranspiration cycle of deciduous trees. As a result, groundwater infiltration levels are the highest at this time of year. Monitoring during this period allows analysis of dry-weather infiltration reduction results as well as RD I/I.

The density of rain gauges required for proper analysis is often underestimated. While monitoring during the late winter and early spring reduces spatial variability of rainfall, sufficient rain gauges must be placed to capture variations that will affect analysis results. Typically, one rain gauge is to be placed every two square miles, and not greater than five square miles, for studies to document RD I/I reductions.

5.2 RD I/I Reduction Documentation Method

5.2.1 Hydrograph Decomposition

The data analysis method involves computing RD I/I flows from all monitored areas (both rehabilitated and control areas) during both the pre- and post-rehabilitation periods. The first step of data analysis is to perform a hydrograph decomposition, which isolates the RD I/I response from individual storm events. Typical dry-weather diurnal flow hydrographs are determined for each flow monitor for weekdays and weekend days. These typical dry-weather hydrographs are subtracted from measured flows during a storm event to determine the measured RD I/I flows from an event.

5.2.2 R-Value Calculation

For this analysis, the R-value is defined as the fraction of rainfall over a sub-basin that enters the sanitary sewer as RD I/I. An R-value may be computed for each discreet storm event by dividing the RD I/I volume (determined from the hydrograph decomposition technique described above) by the volume of rainfall over a sub-basin. The average depth of rainfall determines the volume of rainfall over the sewered area of the sub-basin as determined from rain gauge data. High R-values are indicative of sub-basins with high RD I/I, and low R-values indicate a relatively tight system.

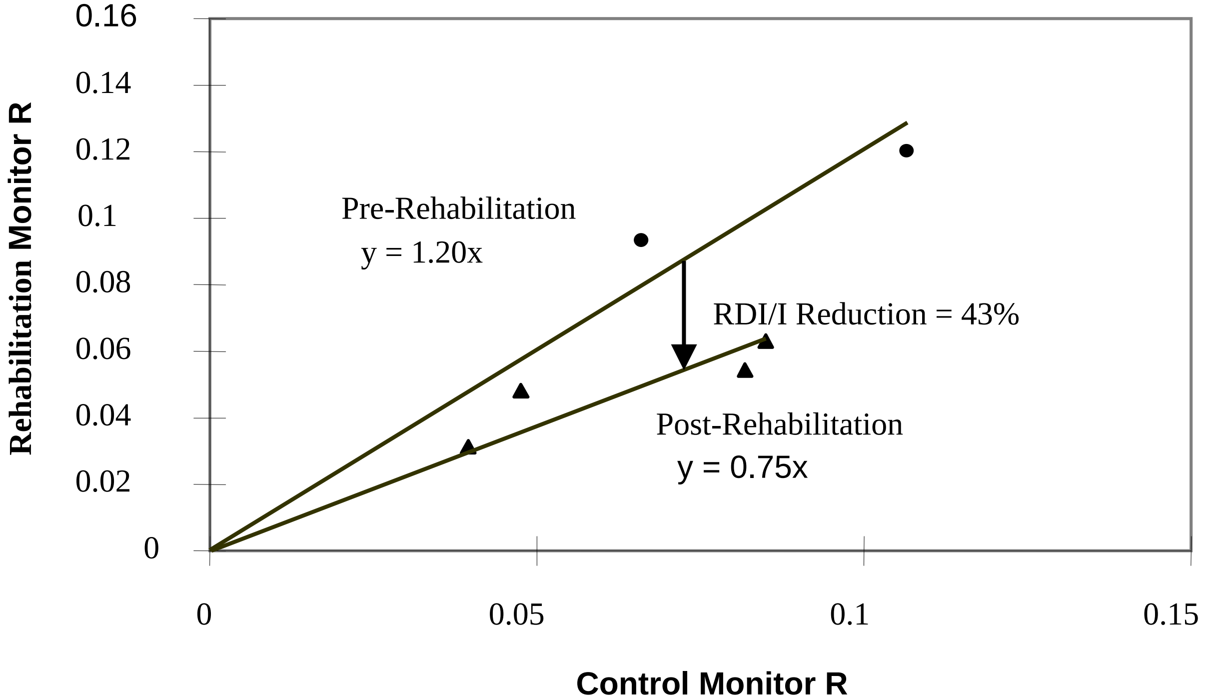
This method of hydrograph decomposition and R-value computation is based on work originally conducted for the East Bay Municipal Utility District in Oakland, California, by CDM and has been successfully applied for sewer system evaluation and modeling studies across the country. The method may be adapted to consider the effects of antecedent moisture conditions and may be applied to support sanitary sewer evaluation and modeling programs.

5.2.3 Linear Regression Analysis -- Preferred Method

After R-values are computed for each rainfall event for each flow monitor, a linear regression analysis is performed to compare the pre- and post-rehabilitation monitoring results. The regression analysis is a method of developing a linear relationship between the R-values of the rehabilitated area and the R-values of a control area. This linear relationship is established during pre-rehabilitation conditions and post-rehabilitation conditions by performing a linear regression between the R-values of the rehabilitated area and control area during each monitoring period. The most common source of problems arises because the method requires that flow and rainfall data be available for both the rehabilitation area and a control area for common storm events.

To apply the method, the R-value for the rehabilitation area is plotted against the R-value for the control area for each storm event for which there is data common to both areas. Then, a linear regression is performed to determine the line of best fit through the data points. A linear regression of R-values between an example rehabilitation area and control area for pre-rehabilitation conditions produced a line of the equation $y = 1.20x$ (Refer to Figure 5-1). Similarly, a regression of R-values between the rehabilitation area and control area for post-rehabilitation conditions produced a line of the equation $y = 0.75x$. For this method of analysis, the regression lines are forced through the point (0,0) because there must be a common condition between the rehabilitation and control areas in which the R-values are both zero.

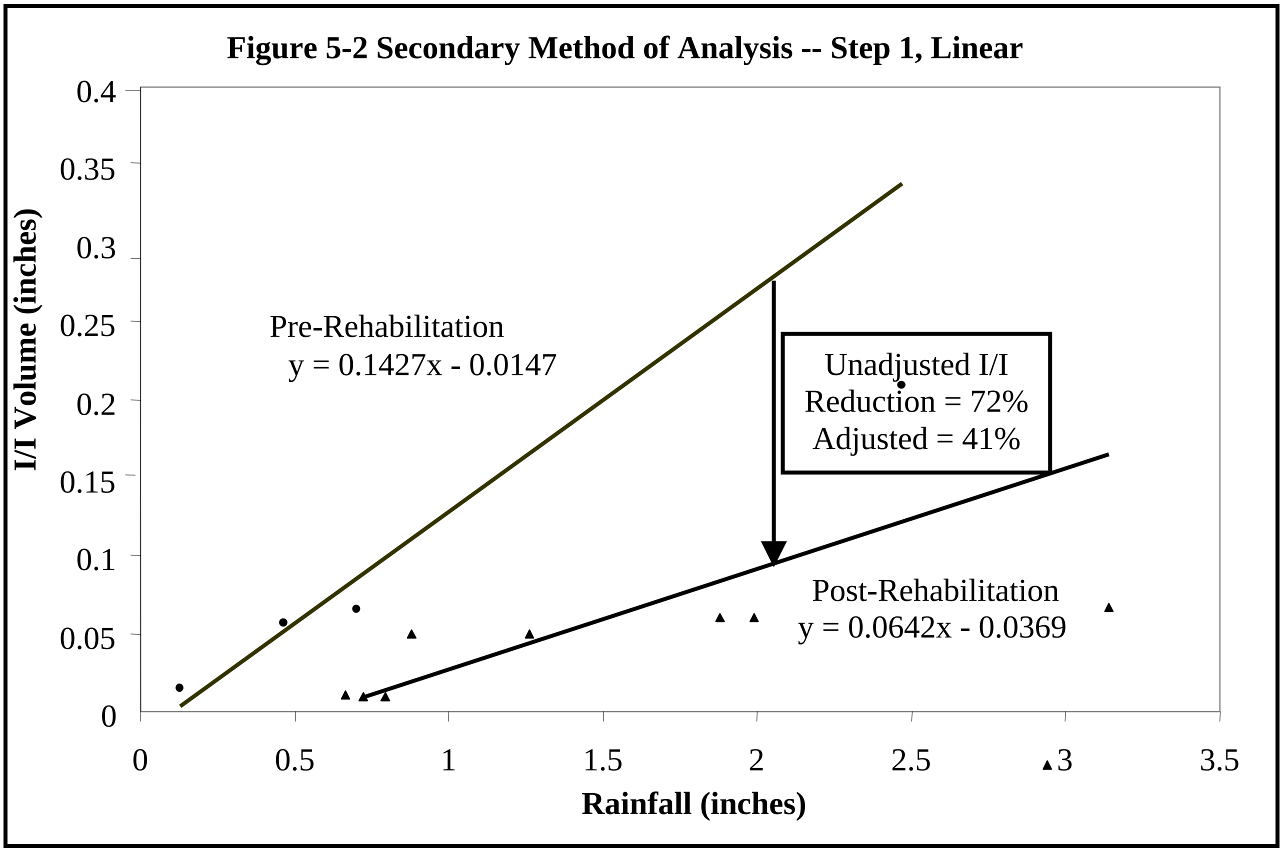
Figure 5-1 Preferred Method of RDI/I Reduction Analysis



The resulting RD I/I reduction is computed by determining the difference in the slopes of the lines from pre- to post-rehabilitation conditions. For this example, using data from the PSFS Phase 1 analysis, an RD I/I reduction of 43 percent was achieved. Note that a potential limitation of this method is that flow-monitoring data is needed from the same storm events at both the rehabilitated area and the control area to complete the analysis. While this is a limitation of the analysis, it is believed that having data from both areas for the same events makes the analysis more defensible. However, if the amount of monitoring data is limited and there are few common events between the rehabilitated and control areas, a secondary method of analysis may be used.

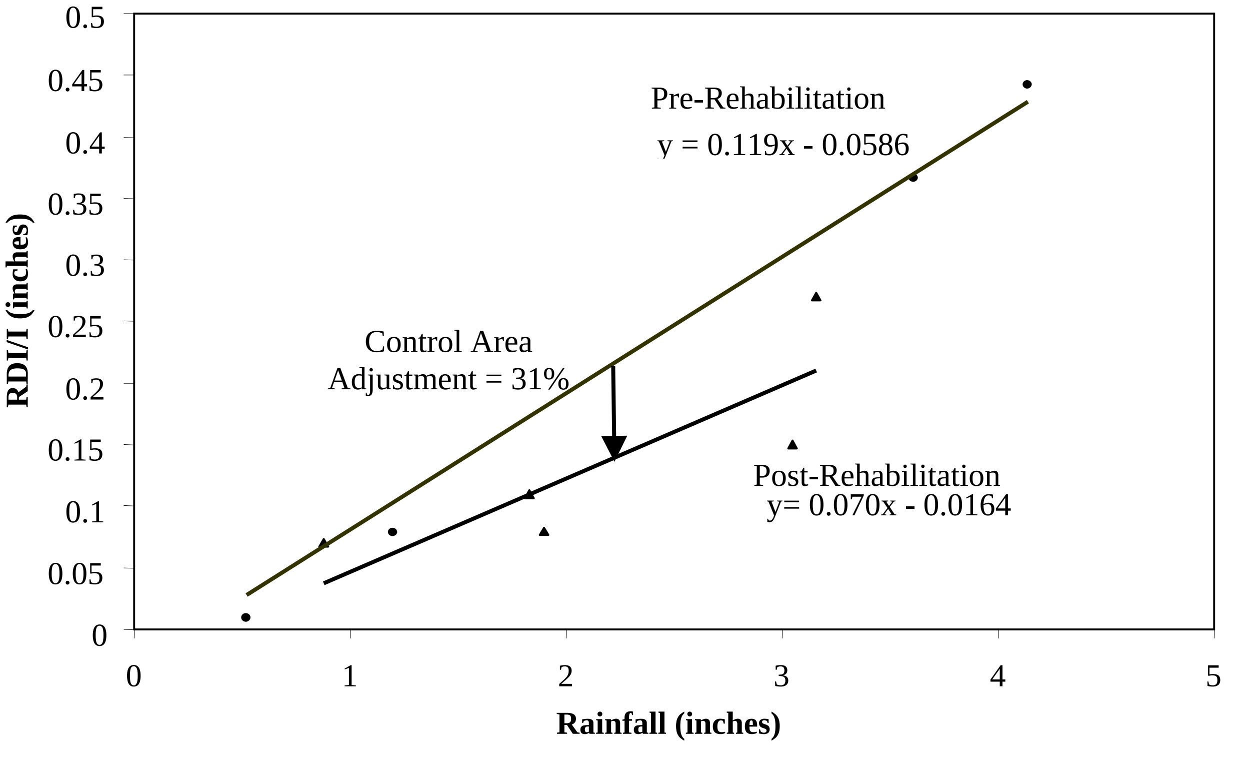
5.2.4 Linear Regression Analysis -- Secondary Method

A secondary method of computing RD I/I reductions from sewer rehabilitation is based on a linear regression analysis of rainfall vs. RD I/I at a monitoring site both before and after rehabilitation (Refer to Figure 5-2). In the case of this analysis, the line of best fit is not restricted to pass through the point (0,0). In most cases, the line will pass through a positive x-intercept, which corresponds to an initial abstraction of rainfall that occurs prior to any RD I/I response. This regression analysis is performed using the pre-rehabilitation data first, and then a separate regression analysis is performed on the post-rehabilitation data. The results of both of these regressions are plotted on Figure 5-2. The reduction in the slope of the line of best fit indicates a reduction in RD I/I. However, because RD I/I may change between monitoring periods because of other environmental factors, an adjustment is needed based on the results of the control area.



A similar linear regression analysis was performed on the flow data for the control area during both the pre- and post-rehabilitation periods (Refer to Figure 5-3). This analysis was performed to determine the change in RD I/I between the pre- to post-rehabilitation periods in the control area, where no rehabilitation was performed. This analysis showed that RD I/I in the control area decreased from the pre- to post-rehabilitation periods as a result of environmental factors.

Figure 5-3 Secondary Method of Analysis -- Step 2, Control Area



Because the control area regression showed a reduction in RD I/I between the pre- to post-rehabilitation periods, the assumption is made that some reduction in RDI/I in the rehabilitation area was also a result of environmental factors, and not solely the rehabilitation that was performed. Therefore, the RD I/I reduction attributed to the rehabilitation is reduced by the percent reduction in the control area. As a result, the RD I/I reduction attributed to the rehabilitation in this sewershed by this method is gross RD I/I reduction (72 percent) minus the control area RD I/I reduction (31 percent) or 41 percent. This estimated RD I/I reduction compares well to the estimate using Method 1 for this example, which was 43 percent.

5.3 Summary

To summarize:

- Rates and volumes of RD I/I vary at a given site as a result of a number of environmental factors, including antecedent moisture conditions, rainfall intensity and duration, and groundwater conditions.

- The successful reduction of RD I/I resulting from sewer rehabilitation may be documented through the use of methods based on a comparison of rehabilitated areas to control areas, where no rehabilitation has been performed. This comparison to a control area quantifies the RD I/I reduction that may be attributed to the rehabilitation as opposed to reductions that may result from other environmental factors.

- Collection of flow and rainfall data from rehabilitated areas and control areas for common rainfall events, where spatial variation in rainfall is small, provides the most defensible RD I/I reduction results. Controls areas should be selected that are in close proximity to the rehabilitation area and that are characteristically similar based on age, land use, pipe materials, and soil types.

- RD I/I reductions achieved from sewer rehabilitation are system dependent and can be highly variable depending on the system condition and rehabilitation method employed. The use of methods to document I/I reductions achieved can help guide KUB to apply the methods found to be most effective on their system on future phases of sewer rehabilitation.

KUB performed post-rehabilitation flow monitoring in 2006 to evaluate the effectiveness of completed rehabilitation projects in nine mini-basins. The results were compared to the pre-rehabilitation flow monitoring data. The study showed significant reductions in RD I/I volume and peak flows as a result of rehabilitation. KUB will continue to perform post-rehabilitation monitoring on future rehabilitation projects and compare them to targets assumed to be achievable in the development of the CAP/ER and other IRP components.

SECTION 6: IRP IMPLEMENTATION LIST

Refer to the tables below for a list of phase one IRP system improvement projects.

First Creek Project Descriptions

Project ID	Project Name	Project Description
1-1	Upper First Creek Collector Project (Mini-basin 1A1, 2A2, and 3D1)	Find and fix work to identify and address cause of overflow in the vicinity of 4811 Beverly Road, 4144 Oakland Drive, and 5511 Dogwood Road.
1-2	Lower First Creek Collector Project (Mini-basin 8B2)	Find and fix work to identify and address cause of overflow in the vicinity of 2412, 2514, 2528, 2806, 2808, 2900, 2528, 2700, and 2808 Tecoma Drive, 3501 Whittle Springs Road, Islington Avenue, 1800 Linden Avenue, 2524 Underwood Place, and 3008 Valley View Drive.
1-3	First Creek Storage Tanks	Design and construction of the upper First Creek storage tank and lower First Creek storage tank.
1-4	Lower Fountain City Pipe Replacement Project	Replace approximately 2,293 lf existing sewer with 36-in sewer.
1-5	Upper Fountain City Pipe Replacement Project	Replace approximately 1,053 lf of existing sewer with 12-in, 1,856 lf with 24-in, and 595 lf with 27-in pipe.
1-6	Sub-basin 08A1 Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of Broadway and Powers Street, and Broadway and Ridgeway Lane.
1-11	Fountain City Trunkline Replacement Phase IV Project	Replace approximately 724 lf of existing sewer with 15-in, 1,823 lf with 18-in, and 444 lf with 24-in pipe.
1-12	Cedar Lane Area Sanitary Sewer Rehabilitation Project	Pipe rehabilitation of approximately 8,500 lf of existing sewer.
1-13	Fair Drive Sanitary Sewer Rehabilitation / Replacement Project	Pipe replacement and rehabilitation of approximately 8,200 lf of existing sewer.
1-14	Wilderness Road Area Gravity Sewer Replacement Project - Phase II	Replace approximately 1,200 lf of existing 8-in, 340 lf 10-in, and 3,900 lf of 12-in pipe.
1-15	Replace trunk sewer upstream of lower storage unit	Replace approximately 3,700 lf of existing 54-in, and 331 lf of 18-in pipe.
1-16	Clearview Street Sewer Project	Replace approximately 4,060 lf of existing 8-in, 227 lf 10-in, and 181 lf of 12-in pipe.
1-17	Fountain Road Trunkline Sewer Improvement Project	Replace approximately 321 lf of existing 12-in, 430 lf 15-in, and 2,880 lf of 16-in pipe.
1-18	Greenfield Drive Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 2333, 2352 Greenfield Lane and 2826, 2820 North Hills Boulevard.

First Creek Project Descriptions, continued

Project ID	Project Name	Project Description
1-19	Edgewood Drive Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1620 Edgewood Avenue.
1-20	Vine Middle School Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 214 Bertrand Street.
1-21	College Park Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 106 College Park Lane.
1-22	E. Jackson Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 400 E. Jackson Avenue.
1-23	Oglewood Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1307 Oglewood Avenue.
1-24	Fulton Short Line Project	Replace approximately 520 lf of existing 8-in pipe.
1-25 (IAP 6)	Sub-basins 3&4 Rehabilitation Project	Rehabilitation to reduce R to 2% in Sub-basins 03B1, 03B2, and 04B1.
1-26	Cherry Street Rehabilitation Project	Find and fix work to identify and address cause of overflow at 1918 Cherry Street.
1-27	Fair Drive Replacement Project	Find and fix work to identify and address cause of overflows at 2538, 2541, and 2544 Fair Drive.

Second Creek Project Descriptions

Project ID	Project Name	Project Description[1]
2-1	Lower Second Creek Replacement/Rehabilitation at I40/I275 Junction	Replace approximately 1,300 lf of existing sewer with 30-in sewer, replace approximately 3,100 lf of existing sewer with 36-in sewer, replace approximately 1,200 lf of existing sewer with 42-in sewer, and rehabilitate approximately 2,400 lf of trunk line between replacement segments.
2-2	Lower Second Creek Replacement/Rehabilitation at Woodland	Replace approximately 2,500 lf of existing sewer with 30-in sewer and rehabilitate approximately 1,200 lf of trunk line between replacement segments.
2-3	Second Creek Rehabilitation of Sub-basin 23E1 Near Woodland and Central	Rehabilitation in Sub-basin 23E1 to reduce R value to 2%

Second Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
2-4	Dutch Valley Collector Rehabilitation (Sub-basin 10B1)	Rehabilitate 10-in collection system piping in Sub-basin 10B1.
2-5	Rickard and Wilson Collector Rehabilitation (Sub-basin 10C1)	Rehabilitate 10-in collection system piping in Sub-basin 10C1.
2-6	Pilleaux Pump Station Collector Rehabilitation (Sub-basin 5A4)	Rehabilitate approximately 19,600 LF of sewer in Sub-basin 5A4.
2-8 (IAP 10)	Subbasin 15 Rehabilitation	Rehabilitation in Sub-basin 15D2 to reduce R value to 2%.
2-9	Second Creek Trunk Sewer Improvements Phase I	Replace approximately 4,100 lf of existing sewer with 30-in sewer
2-10	Second Creek Trunk Sewer Improvements Phase II	Replace approximately 3,700 lf of existing sewer with 30-in sewer, replace approximately 1,400 lf of existing sewer with 36-inch sewer.
2-11	Burnside Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 2523 Burnside Street.
2-12	Camelia Road Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of Camelia Road and Merchant Drive and 412 Merchant Drive.
2-13	Cedar Heights Road Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 5511 Cedar Heights Road and 5605 Pinecrest Road.
2-14	Central Avenue Pike Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 5500 Central Avenue Pike.
2-15	1000 block Elm Street Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1025 Elm Street.
2-16	1600 block Elm Street Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1611 Elm Street and 801 West Oldham Avenue.
2-17	Shasta Drive Rehabilitaiton Project	Find and fix work to identify and address cause of overflow in the vicinity of 5108 Fennel Road and 805 Shasta Drive.
2-18	Nicholas Road - Clinton Highway Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 4500 Nicholas Road and 4200 Clinton Highway.

Second Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
2-19	Cumberland Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1000 Phillip Fulmer Way, 1509 Cumberland Avenue, and Seventeenth Street and White Avenue.
2-20	Sierra Road Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 5609 Sierra Road.
2-21	Morelia Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 120 E. Morelia Avenue.
2-22	Dale Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 345 Dale Avenue.

Third Creek Project Descriptions

Project ID	Project Name	Project Description[1]
3-2	Subbasin 11 Rehabilitation Project (approximately 25% rehabilitation)	Find and fix work to identify and address cause of overflow in the vicinity of 5815 Wooded Acres Drive, 6512 Shaftsbury Drive, and 6525 Tewksbury Drive.
3-3	Subbasin 9 Rehabilitation Project	Rehabilitation to reduce R to 2% in Sub-basins 09A1, 09A2, 09A4, and 09D1.
3-4	Upper McKamey and Third Creek Road Replacement Project	Replace approximately 3,141 lf of existing sewer with 36-in sewer and approximately 1,500 lf with 15-in sewer.
3-5	Third Creek Storage Facility Project	Design and construction of a storage facility in Third Creek Basin (approximately 4.5 MG storage on Land Parcel # 093GB006)
3-6	Interstate 40 and Middlebrook Pike Trunk Replacement Project	Replace approximately 400 lf of existing sewer with 15-in sewer, 750 lf with 24-in sewer, 2,000 lf with 30-in sewer, and 7,000 lf with 36-in sewer.

Third Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
3-7	Neyland Drive Trunk Replacement Project	Replace approximately 5,900 lf of existing sewer with 48-in sewer.
3-8	Third Creek Bike Trail Pipe Replacement Project	Replace approximately 1,200 lf of existing sewer with 24-in sewer.
3-11	Sutherland Avenue Collector Rehabilitation Project (Sub-basin 28B1)	Find and fix work to identify and address cause of overflow in the vicinity of 3110, 3204, and 3208 Sutherland Avenue, 409 North Bellemeade Avenue, Sutherland Avenue and North Bellemeade Avenue, and 5824 Stoneleigh Road.
3-12	Clinch and 21st Street Collector Rehabilitation Project (Sub-basin 35B3)	Find and fix work to identify and address cause of overflow in the vicinity of Twenty First Street and Twenty First Street and Laurel Avenue.
3-14	McKamey Road Interconnection Project	Project will involve constructing a hydraulic connection between the upper and lower McKamey Road Sewers.
3-15	Ball Camp Pike Improvement Project	Replace approximately 600 lf of existing sewer with 12-in sewer.
3-16	Painter Avenue Trunk Rehabilitation Project	Replace approximately 2,200 lf of existing sewer with 48-in sewer and 200 lf with 54-in sewer.
3-17	McKamey Road Relief Sewer Project	Construct approximately 3,600 lf of 15-in sewer and 1,400 lf of 18-in sewer.
3-20	Citico Street Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 600 and 605 Citico Street.
3-21	Deerfield Road Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 4428 Deerfield Rd.
3-22	Fountain Drive Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 4337 Fountain Drive.

Third Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
3-23	Hillvale Circle Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of the SSO at Hillvale Circle.
3-24	Montgomery Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 3624 Montgomery Avenue.
3-25	Rolling Ridge Interconnection Project	Replace Rolling Ridge pump station with gravity sewer.
3-26	PCP, CPE, and CCP	Wastewater evaluation studies of the Kuwahee WWTP.
3-27	Montgomery Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1811 and 1816 Sterchi Street and 3608 and 3618 Montgomery Avenue.
3-29	Highland Hills Road Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 409, 411, and 419 Highland Hills Road.

Fourth Creek Project Descriptions

Project ID	Project Name	Project Description[1]
4-1	Chukar Road Rehabilitation (Sub-basin 32A3) Project	Find and fix work to identify and address cause of overflow in the vicinity of 410, 2513, 2621, 2624, 2644, and 2645 Chukar Road.
4-2	Gleason Drive Collector Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 8013 and 8044 Gleason Drive.
4-3	Middlebrook Pike Rehabilitation (Sub-basin 27C3) Project	Find and fix work to identify and address cause of overflow in the vicinity of 7350, 7351, and 7424 Middlebrook Pike.
4-4	Northshore Drive Trunk Replacement Project	Replace approximately 3,600 lf of existing sewer with 36-in sewer (IAP 2).

Fourth Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
4-6	Shadyland Drive Rehabilitation (Sub-basin 36A2) Project	Find and fix work to identify and address cause of overflow in the vicinity of 7000 Rotherwood Drive and 7112 and 7712 Shadyland Drive.
4-17	Storage Tank	Storage upstream of Walker Springs Pump Station.
4-18	Papermill Phases I, II, and III Project	Replace approximately 3,500 lf of existing sewer with 15-in sewer and approximately 1,000 lf with 36-in sewer.
4-19	Northshore Drive Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 5501 and 6410 Northshore Drive and Northshore Drive and Lyons Bend Road.
4-21	Black Bear Road Project	Find and fix work to identify and address cause of overflow in the vicinity of 2313 Black Bear Road.
4-22	Nightingale Lane Project	Find and fix work to identify and address cause of overflow in the vicinity of 6614 and 6617 Nightingale Lane.
4-23	5205 Bent River Blvd Project	Find and fix work to identify and address cause of overflow in the vicinity of 5205 Bent River Boulevard.
4-24	Kerri Way Project	Find and fix work to identify and address cause of overflow in the vicinity of 7505 Kerri Way.
4-25	Lonas Drive Project	Find and fix work to identify and address cause of overflow in the vicinity of 4930 Lonas Drive.
4-26	Midpark Drive Project	Find and fix work to identify and address cause of overflow in the vicinity of 1721 Midpark and Midpark and Beard Drive.
4-27	Southfork Project	Find and fix work to identify and address cause of overflow in the vicinity at 2501 Miss Ellie Drive (private).
4-28	Queensridge Pump Station Upgrade Project	Upsize Queensridge Pump Station.

Fourth Creek Project Descriptions, continued

Project ID	Project Name	Project Description[1]
4-31	Kingston Pike @ Gallahar View Project	Find and fix work to identify and address cause of overflow in the vicinity of 8401 and 8403 Kingston Pike.
4-32	PCP, CPE, and CCP	Wastewater evaluation studies of the Fourth Creek WWTP.

South Knoxville / Knob Creek Project Descriptions

Project ID	Project Name	Project Description[1]
S-1	Ginnbrook Pump Station Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of Ginnbrook Pump Station
S-2	Goose Creek Trunk Sewer Replacement and Siphon Upgrade Project	Replace approximately 230 lf of existing sewer with 12-in sewer, Replace approximately 1100 lf of existing sewer with 15-in sewer, Replace approximately 1000 lf of existing sewer 30-in sewer, Replace approximately 60 lf of existing sewer with 36-in sewer
S-5	South Knoxville/Knob Creek Storage Facility	Design and construction of an approximately 4 MG storage facility
S-6	Sevier Avenue and Jones Street Collector Project	Rehabilitate approximately 3,100 lf of existing sewer and reroute approximately 352 lf of 8-in sewer
S-9	Ellis Road Rehabilitation Project	Find and fix work to rehabilitate approximately 3,940 lf of sewer in the vicinity of 6555 Chapman Highway, 6516 Jackie Lane, 212 Ellis Road, and 6528 Jackie Lane.
S-10	Mini-basin 41A6 Rehabilitation Project	Find and fix work to rehabilitate approximately 13,000 lf of sewer in Sub-basin 41A6 in the vicinity of 701 Lake Forest Rd.
S-11	Ford Valley Pump Station Upgrade Project	Upgrade pump station
S-14	Stone Road Rehabilitation Project	Rehabilitation in 41B1 to reduce R value to 2%
S-15	Trunk Replacement in Sub-basin 40A2 Project	Replace approximately 2,800 lf of sewer with 24-in sewer
S-16	Woodson Drive Trunk Replacement and Pump Station Upgrade Project	Replace approximately 260 lf of existing sewer and upgrade pump station

South Knoxville / Knob Creek Project Descriptions, continued		
Project ID	**Project Name**	**Project Description[1]**
S-17 (IAP 4)	Island Home Rehabilitation Project	Find and fix work to rehabilitate approximately 9,400 lf of existing sewer in the vicinity of 5320 McNutt and McNutt Road pump station
S-18 (IAP 3)	South Haven Phases I & II Project	Relocate, rehabilitate and upsize approximately 4,700 lf
S-19 (IAP 1)	Maryville Pike Pipe Replacement Project	Replace approximately 800 lf of existing sewer
S-20	Avenue A Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 530 Avenue A
S-21	Alpine Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 3609 Alpine Avenue.
S-24 (IAP 5)	East Ford Valley Rehabilitation Project	Rehabilitation in Sub-basin 41A4 to reduce R value to 2%
S-25 (IAP 11)	South Haven Phase III Project	Rehabilitation in Sub-basin 40F1 to reduce R value to 2%
S-26	Trunk Sewer Replacement Project in Sub-basin 40F1	Replace 700 lf of existing sewer with 18-inch sewer
S-27	Trunk Sewer Replacement Project in Sub-basin 41A4	Replace approximately 175 lf of existing sewer with 12-inch sewer and 3,700 lf of existing sewer with 15-inch diameter sewer
S-28	Trunk Sewer Project	Trunk sewer project to correct reverse slopes in vicinity of 3430 Blount Ave
S-29	4500 block Sevierville Pike Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 4523 Sevierville Pike.

Williams Creek Project Descriptions		
Project ID	**Project Name**	**Project Description[1]**
W-1	Sub-basin 19A2 Rehabilitation	Rehabilitation to reduce R to 2% in Sub-basin 19A2.
W-2 (IAP 9)	Williams Creek Trunk Line Replacement (Downstream of Golf Course)	Replace approximately 3,100 lf of existing sewer with 36-in sewer.
W-3	Rehabilitation of Trunk Sewer	Replace approximately 6,100 lf of existing sewer with 24-in sewer.
W-4	E. Fifth Avenue Sewer Replacement Project	Find and fix work to identify and address cause of overflow in the vicinity of 2555 Fifth Avenue and 2565 E. Fifth Avenue.

Williams Creek Project Descriptions, continued		
Project ID	**Project Name**	**Project Description**[1]
W-5	Groner Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 1114 Groner Road.
W-6	Selma Avenue - Harrison Street Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 2806 Selma Avenue, 509 Harrison Street, and 515 Harrison Street.
W-7	Sunset Avenue Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 2614 Sunset Avenue.
W-8	South Elmwood Street Rehabilitation Project	Find and fix work to identify and address cause of overflow in the vicinity of 121, 129 and 133 South Elmwood Street.
W-9	Williams Creek Trunk Line Replacement (Sub-basin 19A1)	Replace approximately 360 lf of existing sewer with 15-in sewer.

Love's Creek and Eastbridge Project Descriptions[1]

Project ID	Project Name	Project Description[1]
L-1	Asheville Highway west of I-40 Trunk Replacement	Replace approximately 5,030 lf of existing 18-in pipe.
L-2	Boyds Bridge Pike and Holston Hills Trunk Replacement	Replace approximately 4,190 lf of existing 10-in, 500 lf of 12-in, and 330 lf of 15-in pipe.
L-3	River View Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 4102, 4200, 3722, 3716, and 4014 Holston Hills Road.
L-4	Asheville Highway Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 5411 Asheville Highway.
L-5	Brentwood Shortline Repair	Find and fix work to identify and address cause of overflow in the vicinity of Brentwood Road
L-6	Holston Hills Road Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 4716 Holston Hills Road.
L-7	Magnolia Avenue Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 3301 Magnolia Avenue.

Love's Creek and Eastbridge Project Descriptions[1], continued

Project ID	Project Name	Project Description[1]
L-8	McDonald Drive Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 3415 McDonald Drive.
L-9	Shelbourne Road Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 3001 Shelbourne Road.
L-10	Washington Court Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 4436 Washington Court.
EB-1	Maloneyville Road Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of Maloneyville Road (MH 93-1, 93-7, 93-10, and at the lift station).
EB-2	Strawberry Plains Pike Rehabilitation	Find and fix work to identify and address cause of overflow in the vicinity of 8616, 8714, and 9005 Strawberry Plains Pike.

[1]Approximate sizing and extents of each project is given for planning level purposes. The exact sizing and extent of each project will be determined during preliminary design. Other modifications to the projects may occur during preliminary design. For example, it may be determined that parallel relief sewers would be more cost effective than replacement sewers for some projects. Any modifications will be explained in the quarterly updates submitted after approval of the Phase 1 CAP/ER.