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Infiltration/Inflow Mitigation and Control for Army Wastewater Collection Systems

by
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A major problem affecting deteriorated Army wastewater collection systems is infiltration—water leaking into the system through cracks in system pipes, manholes, or building laterals. Another substantial problem is inflow, in which relatively pure water is deliberately diverted to the sanitary sewer system through mechanisms such as connecting roof or basement drains. Both types of extraneous water sources are grouped as one variable, commonly referred to as infiltration/inflow (I/I). Installation Directorate of Public Works (DPW) personnel need to be familiar with the causes and effects of I/I, as well as techniques for its mitigation. In terms of money and disruption of installation activity, the cost of replacing sewer systems is very high.

The objectives of this research were to develop a logical, systematic sewer evaluation procedure for identifying I/I problems, and to develop a computer-based tool that will help DPW personnel analyze I/I data and enhance their decisionmaking capabilities.

This report summarizes techniques for gathering I/I data through field investigation, illustrates how to use that data in SIMMS-IIC, provides an overview of SIMMS-IIC, and discusses techniques for I/I control and mitigation, and other sewer system management issues.

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A major problem affecting deteriorated Army wastewater collection systems is infiltration—water leaking into the system through cracks in system pipes, manholes, or building laterals. Another substantial problem is inflow, in which relatively pure water is deliberately diverted to the sanitary sewer system through mechanisms such as connecting roof or basement drains. Both types of extraneous water sources are grouped as one variable, commonly referred to as infiltration/inflow (I/I). Installation Directorate of Public Works (DPW) personnel need to be familiar with the causes and effects of I/I, as well as techniques for its mitigation. In terms of money and disruption of installation activity, the cost of replacing sewer systems is very high.

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The work was conducted by the Environmental Engineering Division (EP) of the Environmental Sustainment Laboratory (EL), U.S. Army Construction Engineering Research Laboratories (USACERL). Fadi A. Karaa is Principal, Planning and Development Applications (PDA), Belmont, MA. The architecture of the software tool developed in this research is based on the PDA computer program SIMMS™. Dr. Edgar D. Smith is Acting Chief, CECER-EP, and William D. Goran is Chief, CECER-EL. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

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INFILTRATION/INFLOW MITIGATION AND CONTROL FOR ARMY WASTEWATER COLLECTION SYSTEMS

1 INTRODUCTION

Background

Wastewater collection systems on Army installations require periodic maintenance and repair (M&R), and occasionally must be upgraded. A well designed, well operated wastewater collection system can effectively handle the changing wastewater flow volumes, serve new facilities, and mitigate the effects of wear and tear on the system. Sewers deteriorate due to internal and external forces. Internal forces include crown corrosion (in which pooled water leads to the production of hydrogen sulfide, which is later converted to sulfuric acid in the moisture on the crown of the pipe), and attack by corrosive or abrasive materials in the wastewater (e.g., industrial wastes). External forces include overburden (soil and traffic), groundwater buoyancy, frost heave, penetration by surrounding tree roots, and differential soil settling.

Both external and internal forces of deterioration are aggravated by the processes of infiltration and inflow. *Infiltration* refers to water leaking into a system through cracks in the collection system pipes, manholes, or building laterals. (Infiltration can take many forms and has a variety of definitions, depending on the infiltration source and method of entry into the system). *Inflow* refers to relatively pure water that is deliberately diverted to the sanitary sewer system through mechanisms such as connecting roof or basement drains.

Both types of extraneous water sources are grouped as one variable, commonly referred to as infiltration/inflow (I/I). Current U.S. Environmental Protection Agency (USEPA) criteria call for I/I in sanitary sewer systems to be reduced as much as economically possible (Smith, Bowker, and Shah 1991).

Installation Directorate of Public Works (DPW) personnel need to be familiar with the causes and effects of I/I, as well as techniques for its mitigation. In terms of money and disruption of installation activity, the cost of replacing existing sewer systems is very high. Numerous innovative rehabilitation techniques that avoid these costs have been developed for mains and laterals (e.g., in-place grouting, various sewer lining methods, trenchless pipe installation), and other techniques have been developed for infiltration into manholes.

To be most effective, control and mitigation of I/I must be integrated into the operations and maintenance (O&M) responsibilities of DPW personnel. But making effective rehabilitation decisions can be complicated, requiring the manager to act on data that may seem highly complex or ambiguous. An automated system that could (1) track the condition of wastewater system infrastructure components and (2) prioritize maintenance needs would provide DPW personnel a powerful new tool for improving water quality management and optimizing the use of M&R resources.

The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to compile a uniform set of sewer inspection procedures for installation O&M personnel, and incorporate the data produced by those procedures into an automated decision-support tool for DPW managers.

Objectives

The objectives of this research are to help Army installations comply with applicable portions of the Clean Water Act by (1) developing a logical, systematic standard sewer evaluation procedure, to be included in regular installation O&M programs to identify I/I problems, and (2) developing a computer-based tool to help DPW personnel analyze I/I data and aid decisionmaking.

Approach

The authors drew upon engineering literature, documentation of Army and government requirements, and field experience to develop a standard procedure for evaluating sewer systems. This procedure was incorporated into a microcomputer software package—SIMMS-IIC*—designed specifically for Army I/I studies and applications.

This report summarizes techniques for gathering I/I data through field investigation, illustrates how to use that data in SIMMS-IIC, summarizes the software procedures for users, and discusses techniques for I/I control and mitigation, determining economic feasibility, and making decisions based on program output. In addition, an outline for developing new design and construction standards to minimize I/I impact on new sewer lines is provided to suggest how Army construction practices may be adapted to recent developments and trends in addressing the problem.

Scope

While both the infiltration and inflow components of I/I are related to the amount of rainfall, a direct relationship between rainfall and infiltration is not necessarily implied by I/I data. Consequently, USEPA introduced a new term to specify that relationship—rainfall-induced infiltration, or RII (USEPA, October 1991). Although their sources of external water are defined differently, I/I and RII both have the same effects on wastewater collection systems. Other types of I/I are also discussed to provide the reader background. These terms may appear in text to clarify specific examples or principles, but the term I/I is used in general discussions of infiltration and inflow; the term I/I encompasses all lesser-known forms of the phenomenon.

The body of this report addresses the identification of I/I problems through systematic inspection, and the sewer rehabilitation decisionmaking process that follows. It is worth noting that a number of sewer design and construction standards can substantially reduce a new system's vulnerability to I/I problems. Appendix A summarizes these standards.

SIMMS-IIC System Requirements

The minimum system requirements for running SIMMS-IIC system are a DOS**-compatible microcomputer with 640K of random access memory, a hard disk with 10 MB of free storage space and a 1.2 megabyte 5.25 in. diskette drive.

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* SIMMS-IIC: Sewer Inventory and Maintenance Management System for Infiltrations and Inflow Control.

** DOS: disk operating system.

SIMMS-IIC is a standalone system occupying three high-density diskettes. SIMMS-IIC does not require any additional software to run. It was developed based on SIMMS (Planning and Development Applications, Newton, MA) using CLIPPER™ and R&R Relational Report Writer™.

Mode of Technology Transfer

A copy of the current version of the software may be obtained from the U.S. Army Construction Engineering Research Laboratories, Attn: CECER-EPO, PO Box 9005, Champaign, IL 61826-9005, telephone 1-800-USA-CERL.

SIMMS-IIC was pilot-tested at Fort McClellan, AL, and is now being field-tested at Fort Devens, MA. User input from Fort Devens will be considered for enhancements to the final product. A demonstration through the Facilities Engineering Applications Program (FEAP) is planned, and a SIMMS-IIC user's manual will be published.

To obtain a copy of SIMMS-IIC contact the U.S. Army Center for Public Works at Fort Belvoir, VA, CECPW-ES, 703-806-5201.

It is recommended that the results of this study be published in a Public Works Technical Bulletin (PWTB). The results may also impact Technical Manual (TM) 5-814-1, *Sanitary and Industrial Wastewater Collection—Gravity Sewers and Appurtenances,* and TM 5-666, *Sewage Treatment Plants and Sewer Systems at Fixed Installations.*

2 DATA ACQUISITION TECHNIQUES FOR SEWER SYSTEM EVALUATION

This chapter will help O&M personnel perform effective I/I analyses by presenting (1) a systematic approach to acquiring data on the sources and magnitudes of system defects, and (2) condition evaluation techniques to support rehabilitation decisionmaking. The data described in this chapter can be used as input to the Sewer Inventory and Maintenance Management System for Infiltration and Inflow Control (SIMMS-IIC), a computer-based O&M decision-support tool described in Chapters 3–5.

Definitions

The following definitions of I/I-related terms are adopted from USEPA regulations (USEPA Office of Water 1990):

> *Infiltration*: Water other than wastewater that enters a sewer system (including sewer system connection and foundation drains) from the ground through such means as defective pipes, pipe joints, connections, or manholes. Infiltration does not include, and is distinguished from, inflow.
>
> *Inflow*: Water other than wastewater that enters a sewer system (including sewer service connections) from such sources as, but not limited to, roof leaders, cellar drains, yard drains, area drains, drains from spring and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, catch basins, cooling towers, storm water, surface runoff, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.
>
> *Rainfall-Induced Infiltration*: Water other than wastewater that enters a sewer system (including sewer service connections and foundation drains) from the ground through such means as defective pipes, pipe joints, connections, or manholes, and which produces a significant, short-term increase in flow in direct response to rainfall.

A number of terms commonly used by specialists in I/I mitigation and control are used in SIMMS-IIC. These terms are defined in Appendix B.

Flow Monitoring

Flow monitoring is commonly used to quantify I/I flows through different portions of a sewer system. Flow can be monitored on a gross level (fewer monitors covering larger areas) or a more detailed basis (greater number of monitors covering smaller areas). The most meaningful flow data are obtained when relatively homogenous areas are monitored directly (i.e., when isolating an area's flow does not require subtraction of flows from an upstream monitor). As in any flow-monitoring program, the accuracy of the data may be limited by surcharging or overflows in the system, or hydraulic conditions at the monitoring sites (flow constrictions, etc.). Some of these limitations can be overcome by the appropriate choice of monitoring equipment (e.g., depth-velocity meters versus level-only recorders) and monitor location.

The traditional approach for analyzing wet weather flows is to subtract the nonrainfall base flow (base sanitary flow plus groundwater infiltration* [GWI] during the period immediately preceding a storm) from the total flow during and immediately following the storm. The resulting flow portion is the rainfall-induced infiltration/inflow RII/I. One method developed for this purpose was to divide the RII/I hydrograph into components, each representing a different response time to rainfall. These components are described quantitatively by three parameters: the percentage of the total storm RII/I volume, the time to peak flow, and the time of flow recession.

If the flow monitoring period is long enough to include storms falling under different conditions (e.g., short, intense storms on dry soil and longer storms on saturated soil), then a comparison of RII/I hydrographs from different types of storms may also indicate the relative significance of RII in the system. From experience it appears that longer, saturated-soil storms produce higher peaks and larger RII volumes than comparable dry-soil storms. For isolated dry soil storms, the RII/I flow may be due entirely or predominantly to storm water inflow (SWI) whereas most of the RII/I flow under saturated soil conditions may be due to RII.

Flow Isolation

Flow isolation, or flow mapping, is a technique commonly used to isolate specific minibasins—reaches of sewer that contribute high I/I flows. The procedure consists of taking simultaneous manual flow measurements at successive branching manholes in the system. Flow isolation is typically conducted during the night, when base sanitary flows are lowest and most of the measured flow can be attributed to I/I. Flow isolation is commonly conducted during nonrainfall periods to isolate GWI. However, it can also be used for RII isolation by taking the measurements during and immediately after rainfall.

Care must be taken when comparing measurements from different locations taken at different times during the rainfall. One way to overcome this problem is to place a continuously recording flow monitor downstream in the subsystem. The simultaneous measurements taken within the subsystem are then projected to a peak flow value based on the ratio of the flow at the time of measurement to the peak flow for the flow monitor location. If flow isolation is conducted sometime after the peak rainfall period, but while the flows are still elevated above normal levels, the measured flow can reasonably be assumed to consist primarily of RII, because the SWI would already have receded.

Flow isolation during rainfall is an effective way to determine the distribution of RII in the subsystem. The RII distribution is used to prioritize portions of the sewer system for rehabilitation and evaluate the cost effectiveness of mitigating RII.

Data Acquisition Plan for I/I Analysis

An I/I analysis is conducted to determine whether any system tributaries are affected by excessive I/I. Through a systematic investigation, the analysis should first identify the presence, flow rate, and type of I/I entering the system through defects in sewer segments, manholes, or service laterals. A system evaluation for rehabilitation planning can then be undertaken to select the most cost-effective means of eliminating excessive I/I. Both point repairs and line repairs can be considered to correct any defects and

* As noted in Chapter 1, there are many specific kinds of I/I, each with different names. This chapter presents some lesser-known forms of I/I to provide background, but all forms have essentially the same effect on sewer system components. In general discussions of I/I throughout this report, the term I/I is used to encompass all other forms of inflow and infiltration mentioned elsewhere in text.

eliminate the I/I, either partially or totally. It is therefore clear that both the effectiveness and service life of rehabilitation tasks are important parameters to consider in the evaluation of rehabilitation alternatives.

The data acquisition process for developing an I/I analysis should include in its first stage a comprehensive flow investigation. In the second stage, a Sewer System Evaluation Survey (SSES) should be undertaken, based on a prioritization plan resulting from the initial system investigation.

Stage 1: Inventory of Existing Conditions

Stage 1, an inventory of the system, includes the following steps:

1. Interviewing personnel who know the installation's water and sewer systems, including system superintendents, facilities managers, and consulting engineers.

2. Collecting and reviewing relevant data, such as previous reports on the system, water consumption data, meteorological data, geological data, wastewater flow data, and groundwater data.

3. Examining street, sewer, water, and topographic maps.

4. Making an inventory of sewage pumping stations to determine capacity, unit O&M costs, and incremental capital costs.

5. Dividing the system into subsystems—tributaries to a pumping station—of 10,000 to 30,000 linear feet* each.

6. Conducting a continuous flow monitoring program within the system to define the effects and distribution of inflow during both high and low groundwater periods.

7. Conducting simultaneous flow measurements at night to determine the magnitude and distribution of infiltration.

8. Locating any excessive I/I flows on the basis of the breakdown of data gathered in steps 1 through 7.

After all of the above steps are completed, Stage 2—a sewer system evaluation survey—may proceed.

A logical and systematic evaluation of a sewer system is necessary to determine the cost-effectiveness of any proposed system rehabilitation and I/I control program. A systematic investigation and analysis of the sewer system identifies the presence, flow rate, and type of I/I conditions that exist through defects in segments, manholes, and service laterals. A system inventory can facilitate rehabilitation planning by helping to identify the most cost-effective way to tackle the system's specific I/I problems.

The purpose of an inventory is to gain a better understanding of the system's features and layout, including the location of key manholes (which are used for both continuous and simultaneous measurements). The inventory is a prerequisite for developing a flow-gaging program and any significant

*U.S. standard units of measure are used throughout this report. A table of metric conversion factors can be found on p 52.

field investigations. It leads to the listing of all parameters related to collection facilities, including sewer segments, manholes, and service laterals. Useful sources of data are:

- Past engineering studies and maps of both wastewater and storm sewer systems, which are used to determine facility parameters such as type of material used, shape, structure, size, inverts, and age. The location of connections with service laterals and storm sewers can also be determined. Drainage patterns can also be defined in order to compute theoretical peak inflows.

- Maintenance records, which can help pinpoint previously encountered problems and defects in system facilities.

- U.S. Geological Survey (USGS) groundwater data and soil conditions, for understanding general groundwater levels and migration conditions in relation to individual project conditions.

Limited Manhole Inspection. While selecting key manholes for the installation of continuous flow recording meters, at least one manhole per subsystem must be inspected. Up to 10 percent of the manholes can be entered, and information recorded on an inspection form (see Appendix D).

Groundwater Monitoring. Groundwater monitoring provides data on the relationship between infiltration rate, gaged flow rates, and groundwater levels. Existing groundwater conditions near the sewer are studied to ensure that optimum conditions exist for the type of investigation being performed during both stages of data acquisition. Data documenting seasonal fluctuations in groundwater level are also gathered.

Piezometric tubes installed through manhole walls are used to monitor the groundwater level. In general, the groundwater monitors are to be installed at key subsystem start and end manholes, or spaced at a rate of one point per 20,000 feet of pipe. Monitors should be checked at least weekly. If it is suspected that changing groundwater levels are not showing up at the monitoring point, the sensor should be removed, cleaned out and reinstalled. Also, when in doubt, an additional monitoring point can be added. It is important to note that infiltration rates of interest in SIMMS-IIC include both the average and peak rates monitored.

Rainfall Monitoring. Rainfall monitoring provides data for comparing variations in gaged flow rates to rainfall intensity and duration, which in turn is used to identify peak inflow and its components. RII is usually measured as a separate mode in the flow distribution due to the time lag between rainfall and infiltration.

Location-specific rainfall data are collected to determine inflow rates during different types of storms. These data in turn are converted into a standard storm event. For this purpose, continuous recording tipping-bucket rain gages are centrally located within the study area (precision=15 minutes; accuracy=0.01 inches). Data collected from rainfall monitoring stations are also acceptable.

Flow Monitoring. The purpose of flow monitoring is to evaluate the accuracy of existing flow records and to develop new flow data. The information provided by flow monitoring will help to locate areas of the system that have excessive I/I and determine if they warrant further investigation. This task should be accomplished as early as possible to avoid costly unnecessary surveying (e.g., cleaning, TV inspection, smoke testing). Flow monitoring may be based on either continuous metering or spot measurement.

The objective of continuous flow monitoring is to obtain the information necessary to accurately analyze the gaged subsystems for (1) infiltration, particularly when groundwater is high during dry periods, and (2) inflow and RII during wet weather.

Flow monitors continuously measure the volume of wastewater in the subsystem. Data are obtained on both dry and wet days for estimating sanitary flow, infiltration, and peak inflow. Continuous metering has to be conducted for a minimum of 10 consecutive weeks between March 1 and June 30, and monitors have to be installed at intervals of about 20,000 linear feet at subsystem boundaries of sanitary sewer.

Continuous flow measurements are made at 15 minute intervals. They are typically calculated using three alternative methods:

- A monitoring device combining a depth sensor and a velocity sensor.
- Continuous flow depth monitoring in conjunction with a weir or flume. (This eliminates concerns about backwater effects, sediment, and slope variations. This method may not be suitable for large diameter pipes.)
- Depth and velocity rating curves when weirs or other hydraulic aids cannot be used due to flow quantity or other physical constraints.

Continuous flow measurements are taken at key manholes during a period of high groundwater to determine the high groundwater infiltration rate. This rate is obtained by deducting the base flow, along with any measured flow resulting from 24-hour industrial operations, from the total flow.

At least two spot measurements, also called simultaneous measurements, are taken at key manholes during a period of low groundwater to determine the low groundwater infiltration rate. This rate is obtained by deducting any measured flow resulting from 24-hour industrial operations, from the total flow. These measurements should be made during the hours of 1 a.m. and 6 a.m. between July 1 and August 30 during dry weather, at least 3 days after any measurable rainfall. The average low groundwater infiltration, as determined by these measurements, is combined with the average high groundwater infiltration to calculate the average annual infiltration. Peak infiltration resulting from rainfall can be deducted from the continuous measurement program, as well as possible spot measurements taken after a storm.

Flow Data Analysis. Flow in a wastewater collection system may consist of three components: (1) base flow of sanitary wastewater, (2) infiltration, and (3) inflow. Base flows fluctuate throughout the day, with minimum flows occurring just after midnight and peak flows usually occurring in late morning hours. Measuring the components of total flow helps to determine whether excessive I/I is occurring.

Base flow refers to flow conditions under low groundwater conditions and in the absence of any rainfall.

Average infiltration refers to the normalized annual infiltration in gallons per day (gpd). Peak infiltration in SIMMS-IIC includes RII since RII-associated flows are due to the same defects as groundwater infiltration.

Average inflow refers to normalized annual inflows in gpd. Peak inflow is a function of rainfall intensity and duration. All flow monitoring data and resultant projected inflow should be based on the 1-year recurrence interval storm. Peak inflow rate can be correlated to peak rainfall intensity for each measurement site. Both power basis and linear regression can be used for extrapolation purposes.

Stage 2: Sewer System Evaluation Survey

The sewer system evaluation survey (SSES) is performed to determine the specific location, estimated flow rate, appropriate method of rehabilitation, and cost of rehabilitation versus the cost of transportation and treatment for each source of I/I. Its purpose is to confirm and add more accuracy to the general findings of Stage 1. The SSES primarily involves flow isolation, detailed field inspection, and recording of the current condition of representative portions of the system--preferably all segments within prioritized subsystems. The SSES is used to help determine:

- Suspected sources of I/I
- Cost estimates for anticipated sewer system evaluation survey field phases
- Cost estimates for necessary system rehabilitation, including benefit/cost ratios.

The following SSES tasks should be performed for all subsystems exhibiting a high groundwater infiltration rate equal to or greater than between 5000 and 10,000 gpd/idm* (to be converted into average annual infiltration rates):

1. Physical survey and flow isolation, to determine the actual physical condition of the sewers, and quantify and distribute infiltration throughout the system.

2. Interim report, to summarize data to date and justify the cost-effectiveness of preparatory cleaning and internal TV inspection of sewers.

3. Preparatory cleaning, to prepare selected sewers for internal TV inspection.

4. Internal TV inspection, to pinpoint infiltration within selected sewers.

5. Evaluation survey report, to determine the cost effectiveness of rehabilitation measures for all infiltration sources identified in the survey. This analysis forms the basis for any proposed rehabilitation program.

The following tasks should be performed for all subsystems considered a high priority on the basis of inflow rate and overall contribution to total system inflow:

1. Above-ground survey, to determine areas subject to ponding or inflow.

2. Smoke testing, to determine any direct connections between storm drains and sanitary sewers.

3. Dye water tracing, to verify and quantify sources of direct inflow, applicable where sources are suspected of having water traps, that caused negative results during smoke testing.

4. Dye water flooding, to verify and quantify sources of direct and indirect inflow. This technique is primarily used to determine the quantity of indirect inflow transferred through the ground from the storm system into the sanitary sewers.

5. House-to-house survey, to determine the number of sump pumps and foundation drains connected to the sanitary sewer.

* idm: inch-diameter per mile.

6. Interim report, to summarize the data obtained to date and cost-effectively justify preparatory cleaning and internal TV inspection of sewers.

7. Preparatory cleaning, to prepare selected sewers for internal TV inspection.

8. Internal TV inspection, to pinpoint inflow within selected sewers.

9. Evaluation survey report, to evaluate all inflow pinpointed during all sewer system survey field activities and perform a cost-effectiveness analysis to determine the need for mitigating excessive inflow. The cost-effectiveness analysis forms the justification for a rehabilitation program to eliminate excessive inflow.

The SSES is performed to determine the specific location of defects, estimated flow rate, appropriate method of rehabilitation, and rehabilitation cost versus cost of transportation and treatment for each defined I/I source. Steps in the SSES include visual inspection, smoke testing, dye water tracing and flooding, and internal TV inspection.

Flow Isolation Gaging Program

This program is implemented in response to the findings of Phases 1 and 2, described in the previous section. Flow isolation is conducted on a sewer segment—also known as a manhole reach—the distance between the entrance of a segment's upstream manhole and the entrance to its downstream manhole, usually about 200 to 300 ft. Infiltration flow isolation is performed during dry weather between midnight and 6 a.m. Flow isolation incorporates portable, precalibrated weirs, or flow depth measurements in conjunction with flow velocity measurements. It is recommended that upstream flow be plugged when possible.

Storm-related flow isolation could also be performed to compute peak inflows for specific manhole reaches. (Peak inflows at specific identified sources are typically either measured (rainfall simulation, dye water tracing, etc.) or theoretical (calculated using the dimensions of manholes, catch basins, roof leaders, etc.)

Six key techniques are employed as necessary in a flow isolation gaging program.

Extensive Manhole and Sewer Inspection

Manhole and sewer inspection allows the identification of the system's physical conditions, including I/I sources. It also provides data for preparatory cleaning and a preventive maintenance program.

For subsystems identified for an infiltration SSES, inspection should take place during the high groundwater period and off-peak wastewater hours. It is assumed that manhole and sewer inventory tasks gather detailed information on material type, structure, shape, cover type, etc. Manhole inspection identifies the existence and severity of inflows from defects in manhole covers, frames, walls, shelf, or invert, and joints between barrel sections.

Sewer segment inspection (using a flashlight or lamp) identifies the existence and severity of inflow from sewer defects, including cracks, misaligned joints, root intrusion, and corrosion.

Smoke Testing

Smoke testing can identify where stormwater and groundwater enter the system. Direct connections can be confirmed with smoke testing. Indirect connections from storm sewers or ditches that require flow through soil seams can also be identified.

Smoke testing should be conducted between July 1 and November 15 during low groundwater periods, and at a significant interval following the previous rainfall. The ground must not be frozen. Residents and facilities managers on affected properties should be notified in advance.

Smoke testing is conducted using two blowers. A smoke blower is placed at the upstream and downstream manholes, which are plugged for the test with air plugs or sandbags. Suspect inflow sources and smoking sources are recorded, and may warrant followup dyed water testing.

Rainfall Simulation

Rainfall simulation is used to identify inflow sources, or in conjunction with flow measurements to quantify inflow from each of the previously identified sources. It is conducted between 1 July and 15 November.

If the Stage 1 investigation showed that major inflow problems occur during periods of intense rainfall, a controlled, systematic check of all storm sewers that parallel or cross the sanitary sewer system or building services should be initiated.

Dyed water flooding can help identify both direct connections to the sanitary sewer and indirect cross-connections between storm sewers, ditches, and the sanitary system. Dyed water flooding may involve private inflow sources and public ones.

Private inflow sources, including downspouts, area drains, patio drains, and other sources originating on individual facilities, may not always be detected during smoke testing. Suspect sources recorded during house-to-house surveys or smoke testing should be flooded without plugging. Clogged drains should be cleared, and freezing conditions should be avoided.

Public inflow sources for dyed water flooding include storm sewers and ditches. It is conducted to detect line segments where there are either direct or indirect connections between storm and sanitary systems. Direct connections are normally detected with smoke testing and confirmed with dyed water flooding. Plugging the storm sewer is not necessary. Indirect cross-connections are normally detected with smoke testing and confirmed with dyed water flooding. Storm sewers are plugged when testing for indirect connections. Fire hydrants are normally used as the water source. A waiting period of at least 1 hour after initiation of flooding should be observed before the test is considered negative. Depth of flow and velocity in the sanitary sewer can be compared before and after the test to estimate the flow rate from any cross-connection that exists.

Dye flooding in conjunction with TV inspection should follow normal dye flooding to identify the exact locations of indirect cross-connections.

TV Inspection

Closed-circuit TV inspection is usually conducted in the second phase of the SSES, because the technique is costly. It is generally performed only at locations where it can be expected to be cost effective. However, recent projects have favored using TV inspection as extensively as possible since the technique allows inspectors to pinpoint the exact locations of any I/I sources.

TV inspection for infiltration sources should be conducted only during high groundwater conditions, between March 1 and June 30. Nighttime flow gaging should be conducted immediately before TV inspection by plugging and weiring one sewer segment at a time.

It is recognized that visual estimation of flow rates is inexact. If sewer segment flow rates during TV inspection are significantly different from nighttime flow gaging, additional field investigations should be conducted to account for the difference. Where service laterals are identified as major sources of infiltration, TV inspection of laterals might be warranted.

It is recommended that, for flow-matching purposes, this second stage of the SSES be performed in the same season as the first, since groundwater conditions vary over time.

Dyed Water Tracing

TV inspection done in conjunction with dye water flooding is called dyed water tracing. This technique can identify the exact location of cross-connections between storm and sanitary sewer systems, whereas dyed water flooding alone cannot identify both the defects and their respective locations.

Dyed water tracing should be performed when temperatures are above freezing. It is preferable to use color TV equipment to ensure adequate observation of the dyed water.

Inflow Balancing

The balancing of the combined flows of all identified sources with the peak inflow rate at the subsystem level (as established by flow monitoring) is essential to confirm the accuracy and completeness of defect location and flow measurements.

Additional investigations may be necessary if the combined flow rates of all identified inflow sources is substantially lower than subsystem-level inflow. This balance must be attained before proceeding to the detailed rehabilitation cost-effectiveness analysis.

Rehabilitation Decisionmaking

Making sewer rehabilitation decisions involves many management, technical, and financial considerations. Some of these considerations may conflict or pose ambiguities for the decisionmaker. The data may not seem adequate for the manager to prioritize rehabilitation needs. Chapters 3–5 discuss a computerized decision-support tool developed by USACERL to provide DPW managers with data analysis, cost estimates, and priority recommendations for rehabilitation decisions.

3 OVERVIEW: SEWER INVENTORY AND MAINTENANCE MANAGEMENT SYSTEM FOR INFILTRATION AND INFLOW CONTROL (SIMMS-IIC)

Program Overview

The SIMMS-IIC sewer rehabilitation computer program is a user-friendly software package for O&M personnel without extensive programming knowledge. The program is built onto a database application, CLIPPER™, a run-time program that can drive SIMMS-IIC without any other database program on the user's computer. See Appendix C for step-by-step installation instructions. To use the program, data are entered into input documents, assigned to a specific subsystem of the sewer's layout, and processed through the computer program. The results of the program's analysis are displayed in accordance with certain listing and query options. Figure 1 shows system input components and Figure 2 shows output components. Figures 3–6 show the program's menu trees.

The Main Selections

The user starts entering data into SIMMS-IIC through INVENTORY. The sewer system should be divided into subsystems. A subsystem generally consists of three components: manholes, line segments, and service laterals (which discharge into a main). Each subsystem contributes an aggregated source of flow that can be isolated. A typical military installation subsystem can be set at any convenient size, but generally range from 10,000 to 30,000 feet of line segments.

The INVENTORY input facility requires a specific set of data on each manhole, line segment, and service lateral in the subsystem. In general, a seven-digit identification number (ID) is required for each subsystem component. For manholes, the user may enter street, city, elevation (rim and invert), type of structure, material, and lid type (all optional). For line segments, the following may be entered: upstream and downstream manhole ID (required), street, city, depth of cover, diameter, length, material, and shape (all optional). For service laterals, the downstream segment ID is required; customer phone number, customer name, street, city, shape, diameter, depth of cover, material, length, connection, and location of the connection are optional. This information is stored under the heading INVENTORY for a specific subsystem.

The CONDITION input facility is where manhole, line segment, and service lateral defects are entered. A listing describing defects (types and severity) is required for each manhole, line segment, and service lateral. More than one defect can be entered for each element in any component of a specific subsystem. The flow type, location, extent, and volume of the defect, a severity ranking (0 to 10 for best case to worst case, respectively), and average and peak flow (in gpd) can be entered for manholes, line segments, and service laterals.

The FLOW ISOLATION input facility is used when CONDITION ASSESSMENT is completed. Flow measurements are entered, either from manhole to adjoining manhole, or from one manhole to another as a subsystem flow measurement. The flows are entered as (1) average and peak infiltration and (2) average and peak inflow. Required information includes the expected percentage of flow reduction and unit costs of the respective flows (capital costs and O&M costs in terms of dollars per gallon per day).

The REHABILITATION PROGRAM facility processes the information entered through INVENTORY, CONDITION, and FLOW ISOLATION. A SUBSYSTEM SELECTION allows the user to instruct SIMMS-IIC whether to run the selected subsystem through the program. A USER-TASK OVERRIDE facility allows the user to fill in a rehabilitation task other than the one selected by SIMMS-

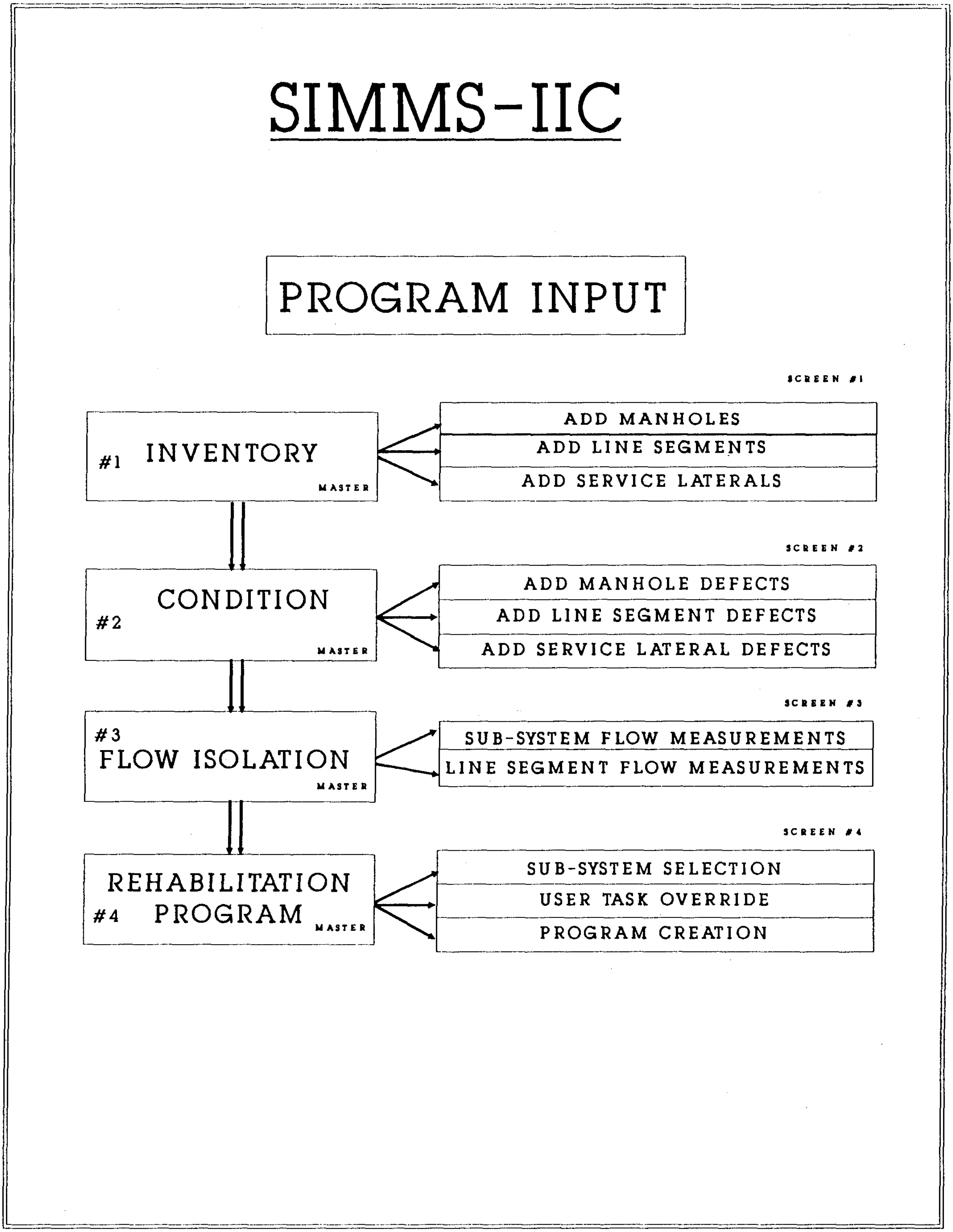

Figure 1. Flowchart for SIMMS-IIC Program Input.

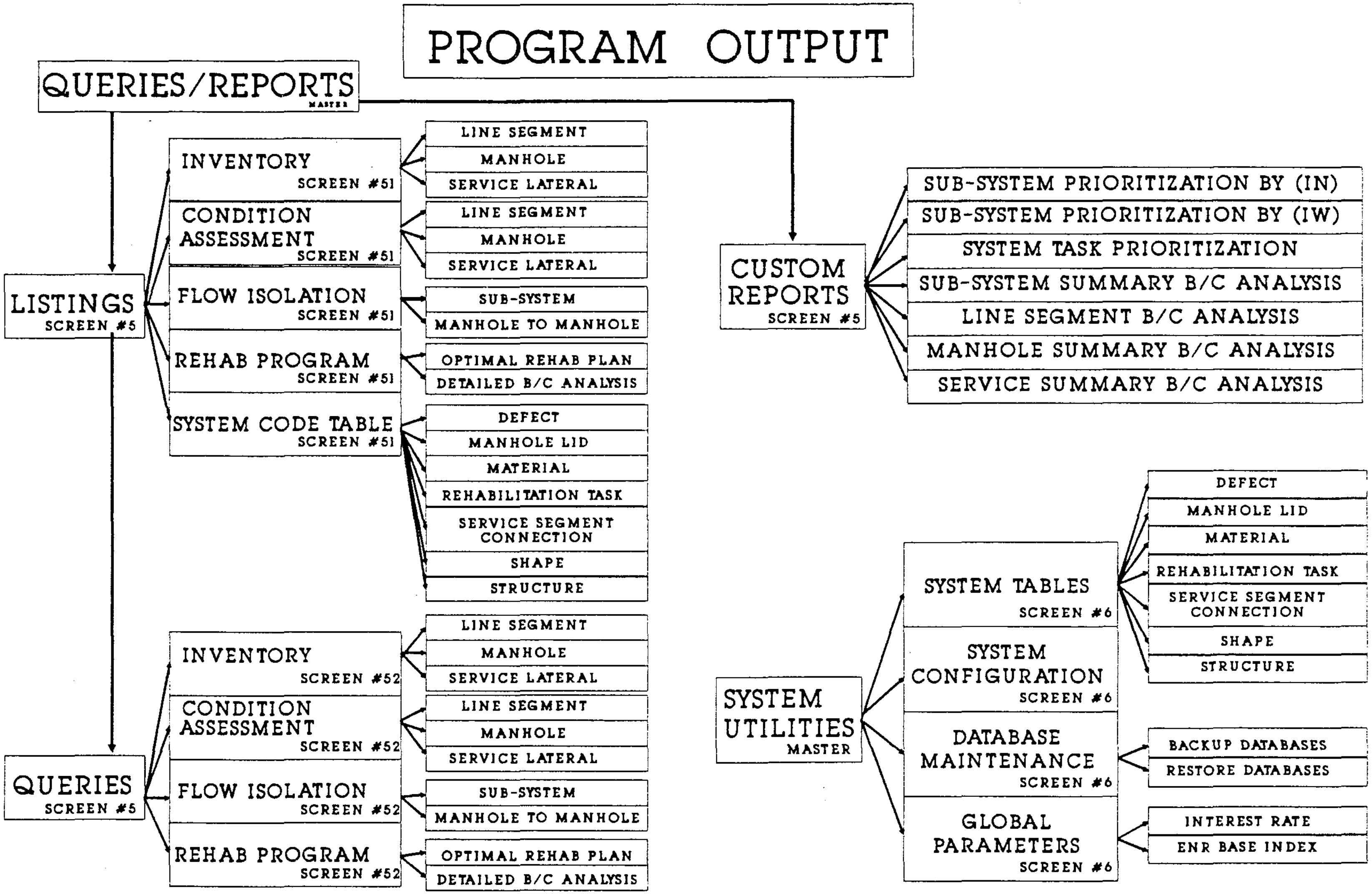

Figure 2. Flowchart for SIMMS-IIC Program Output.

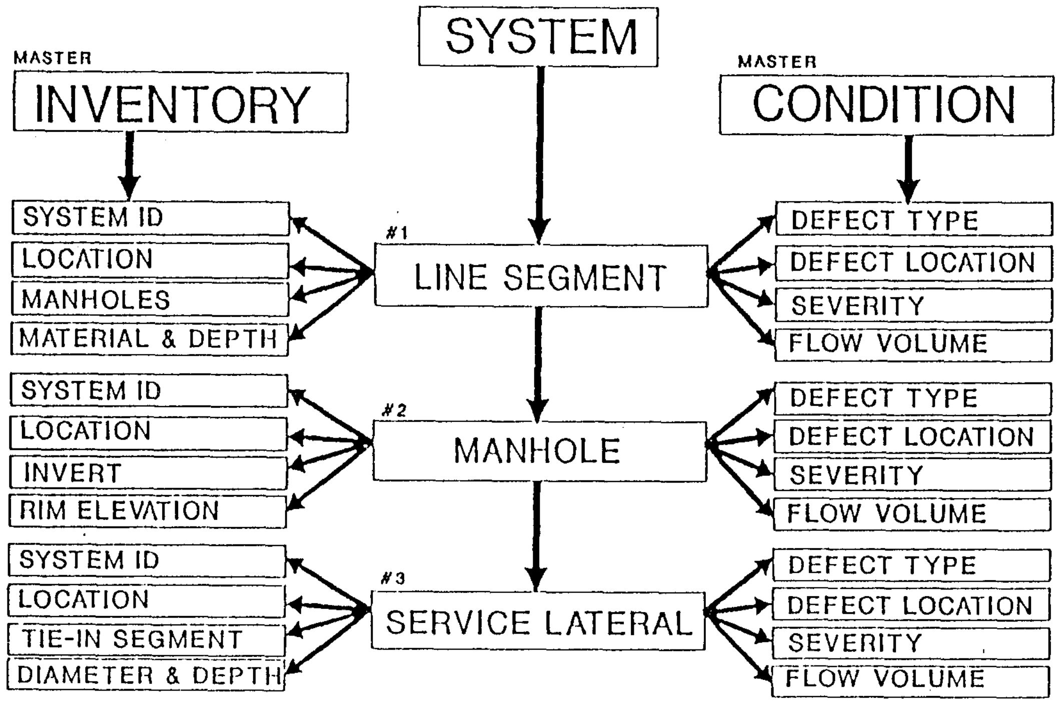

Figure 3. Main System Menu Tree.

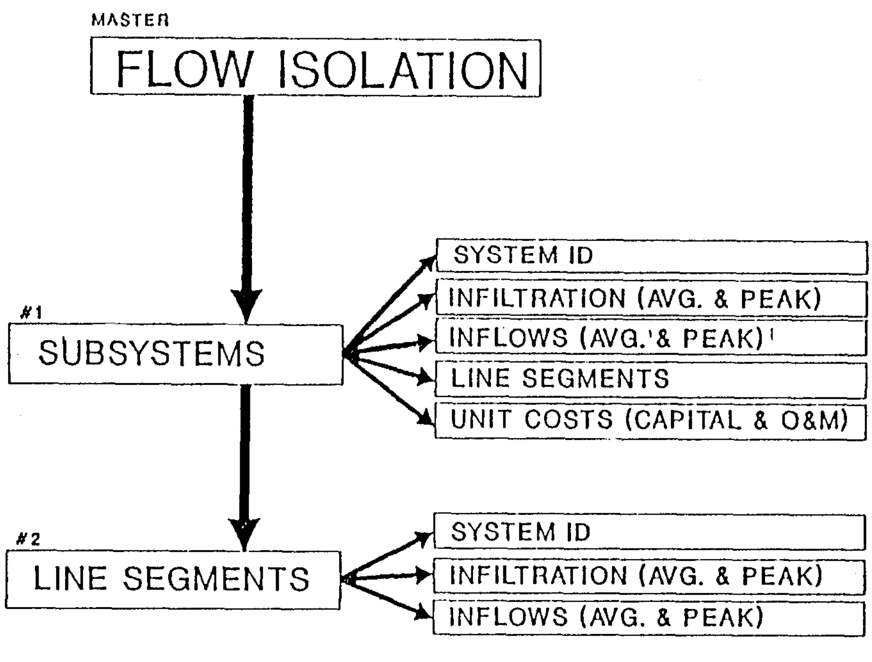

Figure 4. Flow Isolation Menu Tree.

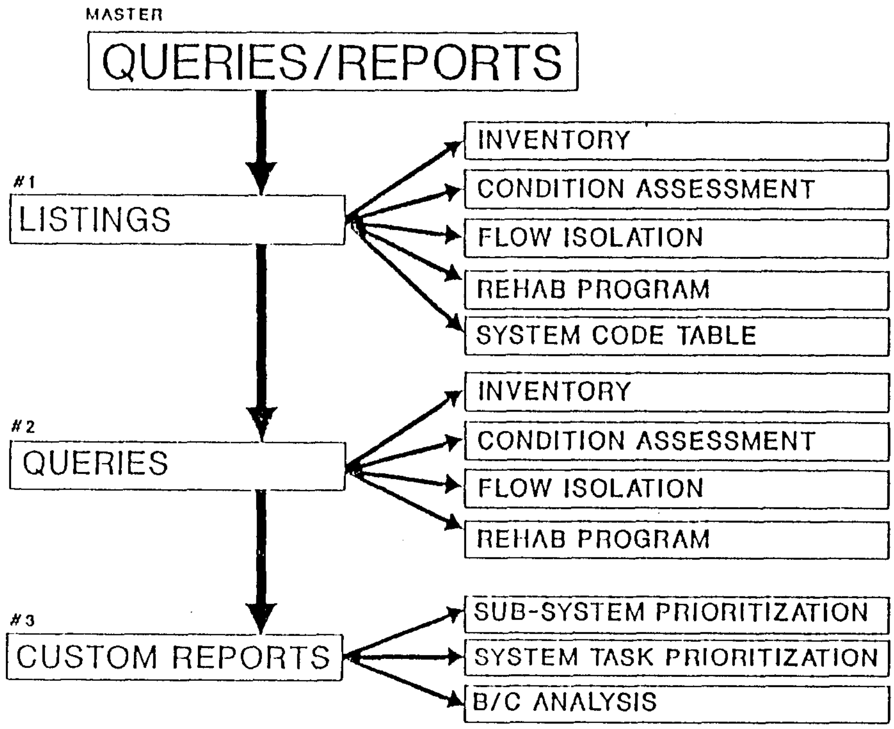

Figure 5. Queries and Reports Menu Tree.

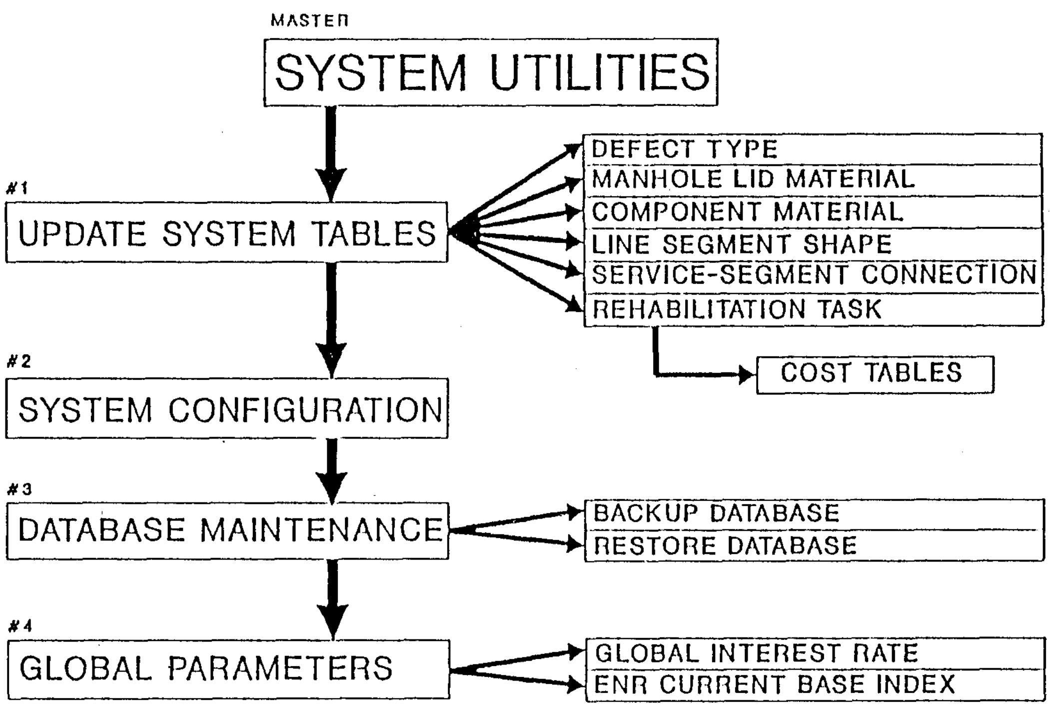

Figure 6. System Utilities Menu Tree.

IIC. The purpose of this option is to allow the user to apply a specific rehabilitation option over an entire subsystem. A PROGRAM CREATION facility initiates data processing for the selected subsystem to produce an array of reports for the selected subsystem. This facility is the final step of SIMMS-IIC, and it may require a significant amount of time for the computer to create the program.

No data entry is required for the QUERIES/REPORTS facility. This option lists the results of the program run for a selected subsystem. The QUERIES/REPORTS listing is the output of all information previously entered for the subsystem. This output includes the original information within the INVENTORY and CONDITION ASSESSMENT stages, an optimal rehabilitation plan—detailed by cost analysis—with a summary by cost analysis, and other integrated listings.

SYSTEM UTILITIES contains the SYSTEM TABLES and SYSTEM CONFIGURATION, DATABASE MAINTENANCE, and GLOBAL PARAMETERS options. SYSTEM TABLES is an inclusive listing of the various defects, materials, shapes, structures, and rehabilitation tasks—with their corresponding three-letter codes—that the system uses in its analyses. These tables are easily expandable, enabling the user to add new or site-specific defects, materials, rehabilitation tasks, etc., to the database. SYSTEM CONFIGURATION addresses system compatibility with the user's computer and printer hardware configuration. DATABASE MAINTENANCE is employed periodically to backup or restore databases. In the current SIMMS-IIC prototype, GLOBAL PARAMETERS includes the options INTEREST RATE and ENR* BASE INDEX, which govern the engineering economic analysis of the various rehabilitation options.

Every menu selection in SIMMS-IIC is programmed for easy entry and exit. Pressing the return button backs the user out of the current selection, and eventually back to the main menu. This user-friendly feature makes it virtually impossible for a user to get "lost" in the program. Furthermore, the function and selection criteria of each menu choice were designed in plain English and are largely self-explanatory.

Two Examples

An illustration of data, runs, and results analysis for two subsystems is provided in the pages that follow. The two subsystems used for illustration here and later in this report are real, selected from a Midwestern Army installation. These examples illustrate some of SIMMS-IIC's important capabilities, but are not exhaustive in scope.

The two subsystems selected for these examples were named 001 and 100. Subsystem 001 consisted of 26 manholes, 26 line segments, and one documented service lateral, for a total of 16.64 inch-miles of pipe. Subsystem 100 had 32 manholes, 32 line segments, and three documented service laterals, for a total of 22.24 inch-miles. Only *documented* service laterals were included in these examples, but the typical subsystem might be expected to have more than are included here. Since both subsystems were taken from the same installation, the sewer structures and materials were very similar. The manholes were all internal-drop manholes made of brick, with cast iron screw-close tops ranging in drop depth from 5 to 10 ft. The segments were either 8 in. or 10 in. circular vitrified clay pipes.

Sewers are designed for a service life of 25 to 50 years. Both sample subsystems were about 45 years old, so defects were expected and rehabilitation techniques for both subsystems were almost identical. Most defects in the line segments were root intrusion, various types of cracks, pipe joint leaks,

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*ENR: *Engineering News-Record.*

invert sags, area drain connections, and catch basin connections. Typical manhole defects included bad base and pipe joints, corroded rungs, cracked frame seals, rim seal leaks, and root intrusions. The few service laterals inspected had joint leaks, foundation drain connections, and root intrusions.

Both subsystem inspections were performed on contract by a private-sector engineering firm. The two sample subsystems were singled out for inspection from a total of 22 based on extensive flow monitoring data. The inspection included physical inspection of the manholes and TV inspection of the line segments. The contractor's report data were then entered into SIMMS-IIC. The contractor's report was studied closely for any observations that might require use of USER TASK OVERRIDE. The program was then run, and the software identified rehabilitation tasks appropriate for the specific defects encountered. A condensed version of the results is printed in Appendix E.

Matching Rehabilitation Tasks and Defects

Rehabilitation tasks can be assigned to defects based on their efficiency in correcting the specific defect and their benefit/cost ratio. The efficiency factor for each rehabilitation task is entered, and the benefit/cost ratio is calculated by the SIMMS-IIC. Application of the rehabilitation task to the defect is decided in SYSTEM TABLES under SYSTEM UTILITIES. For each task, a list of defects is given. Task application is denoted by a star (asterisk) next to the defect. Defects without a star are not considered for the respective rehabilitation task. Selecting the defect and pressing the space bar changes that defect's task application. Additional defects and rehabilitation tasks can also be added through SYSTEM TABLES. The user decides whether or not SIMMS-IIC considers a task applicable to a specific defect.

Several tasks are assigned for I/I in line segments. The most common (and most costly) is excavation and replacement. This task is recommended when the structural integrity of a pipe has deteriorated severely. Typical examples of deteriorated structural integrity are seen when segments of pipe are missing, pipe is crushed or collapsed, the pipe has large cracks (especially longitudinal cracks), the pipe is significantly misaligned, additional pipeline capacity is needed, or—for point repairs—where short lengths of pipeline are damaged too seriously to be rehabilitated effectively by any other means. Due to the cost and inconvenience of excavation and replacement, the task is usually considered only as a last resort.

Alternatives to replacement include chemical grouting, pipe insertion, inversion lining, and cement lining. Each technique has its advantages and disadvantages.

In chemical grouting, pressurized chemical grout is applied to the inner wall of the pipe. Chemical grouting is mainly used to seal leaking joints, small holes, and minor cracks. Chemical grouting offers no structural reinforcement, so badly offset joints and larger cracks should not be repaired with this technique.

Pipe insertion, or sliplining, is used to rehabilitate pipelines by sliding a flexible liner pipe of slightly smaller diameter into an existing pipeline. Pipe insertion can be used to rehabilitate pipelines with severe structural problems, such as extensive cracks, unstable surrounding soil, misaligned joints, severe corrosion, or massive root intrusion problems. Pipe insertion reduces pipe capacity, but forms a continuous, watertight length within a defective existing pipe.

Inversion lining is formed by inserting a flexible tube into a pipe. This flexible pipe is inverted and cured in place against the inner wall of the original pipe with hot water, air, or steam. Two types of inversion lining are resin-impregnated lining and thermoset lining. The pliable nature of the tube before curing allows installation around curves, filling of cracks, bridging of gaps, and maneuvering through pipe defects. Special resins are available to provide acid resistance. Wall thickness can be custom designed for more structural strength, and excavation is not required to install this material.

The two types of cement lining considered for spot repairs are shotcrete and cement mortar. Shotcrete lining provides structural support, especially against corrosion, but application is limited to man-entry-size pipes. Cement mortar, however, can be applied to a wide range of sizes, and it has an acid-resistant layer that can extend a structure's useful life.

Manhole rehabilitation tasks are directed at either (1) the sidewall and base or (2) the frame and cover. Tasks considered for sidewall and base rehabilitation include grouting, liners, cement, and coatings. The use of grouts, liners, and cement is similar to applications for line segments. Coatings can be applied on interior walls for protection against corrosion and infiltration. Either epoxy or polyurethane coatings are used, but both tend to have a short service life. Rehabilitation tasks considered for manhole frame and cover include sealing with resin-coated tape, cover replacement, frame replacement, installation of a prefabricated lid insert, plugging lid holes, raising the frame, and sealing the frames to the corbels.

Service lateral rehabilitation tasks are similar to those for line segments, and include replacement, chemical grouting, and sliplining. Disconnection of the service lateral is also considered for inflow problems.

Other information, required for determining rehabilitation task application is life expectancy, efficiency, cost per unit, cost compared to depth, cost compared to size or type, and materials and shapes that the task can be applied to.

The input of accurate costs and figures and the application of rehabilitation tasks suitable to the defects are both very important in obtaining the optimal sewer rehabilitation solution. The user should spend as much time as necessary to ensure that these data are up to date and accurate.

Table 1 summarizes the suitability of rehabilitation tasks to the three basic system components. The tasks are listed as applicable to infiltration (IN) or inflow (IW).

Table 1

Suitability of Rehabilitation Tasks to Sewer System Components

Line Segments		Manholes		Service Laterals	
IN	**IW**	**IN**	**IW**	**IN**	**IW**
Grouting Insertion Inversion lining Cement lining Shotcrete Replacement	Disconnection	Coatings Grouting Liner Replacement	Cement and Epoxy Resin tape Cover/frame replacement Prefab lid insert Plugging holes Raising frame Sealing frame to corbels Hydraulic cement	Grouting Insertion Replacement	Disconnection

System Tables for Examples

Tables 2, 3, and 4 contain the specific selection of SYSTEM TABLES for the two examples outlined earlier. These tables are included for reference to the examples only. At different locations, the selection of tasks to mitigate a specific defect may differ from the examples discussed here.

Table 2

Manhole Infiltration System Table

Manhole Infiltration Inflow	**Infiltration**	**Coatings**	**Grouting**	**Replacement**	**Liner**	**Inflow**	**Cement & Waterproof Epoxy**	**Resin Sealing Tape**	**Manhole Cover/Frame Replacement**	**Prefabricated Lid Insert in F/C**	**Plugging of Holes**	**Raising of Manholes Frame**	**Seal Frames to Cobels**	**Hydraulic Cement**
Bad Base Joint	IN	X	X	X	X		X	X						X
Broken Manhole Cover	IW										X			
Broken Frame	IN	X		X	X		X			X				X
Bad Pipe Joint	IN		X		X		X							X
Corroded Rung	IW									X				X
Cracked Frame Seal	IW				X		X			X				
Could Not Open														
Corbel Leak	IW											X		
Displaced Ring and Frame	IW									X	X			
Leaking Joints in Cone	IN	X	X	X	X		X	X						X
Leaking Joints in Riser	IN	X	X	X	X		X	X						X
Missing Manhole Cover	IW								X					
Pick holes in Manhole	IW								X		X			
Root Intrustion	IN		X		X									X
Rim Seal Leak	IW										X			

Table 3

Line Segment Infiltration System

Line Segment Infiltration Inflow	**Infiltration**	**Cement Lining**	**Grouting**	**Insertion**	**Replacement**	**Inversion Lining Resin-Impregnated**	**Shotcrete**	**Thermosett Lining**	**Inflow**	**Disconnect Connection**
Area Drain Connection					X					X
Catch Basin Connection					X					X
Circumferential Crack		X	X		X	X	X	X		
Indirect Connection to Storm System					X					X
Illegal Tap Connection					X					X
Illegal Tap Leakage					X					X
Invert Sag					X	X				
Joint Leak		X	X	X	X	X	X	X		
Longitudinal Deep Crack				X	X	X	X			
Longitudinal Shallow Creek		X		X		X	X	X		
Pipe Cement Corroded		X		X	X	X	X	X		
Pipe Crushed or Collapsed				X	X					
Pipe Crown Sag				X	X			X		
Pipe Joint Deteriorated or Open			X	X	X	X	X	X		
Pipe Joint Misaligned					X	X		X		
Pipe Joint Offset					X	X		X		
Pipe Slabout and Holes				X	X	X	X	X		
Protruding Laterals					X					X
Roof Leader Connection					X					X
Root Intrusion			X	X	X	X	X	X		
Reinforcing Steel Corroded		X		X	X		X	X		
Service Connection Leak					X					X
Small Holes in Wall		X	X			X	X	X		
Transversal Deep Crack				X	X		X			
Transversal Shallow Crack		X	X	X		X	X	X		
Reinforcing Steel Cone				X	X		X			

Table 4

Service Lateral Infiltration System

Line Segment Infiltration Inflow	**Infiltration**	**Replacement**	**Grouting**	**Sliplining**	**Inflow**	**Disconnect Connection**
Area Drain Connection		X				X
Foundation Drain Connection		X				X
Joint Leak Service		X	X	X		X
Roof Leader Connection		X				X
Root Intrusion			X	X		
Service Cement Corroded				X		
Service Crushed or Collapsed		X				X
Service Holes			X			
Service Indirect Connection		X				X
Service Joint Deteriorated				X		
Service Joint Leaking			X			
Service Joint Offset/Misplaced		X		X		X
Service Longitudinal Crack				X		
Sump Pump Connected		X				X
Service Root Intrusion			X	X		
Service Transversal Crack			X			

4 FUNCTIONAL SPECIFICATIONS FOR SIMMS-IIC

The functional specifications for SIMMS-IIC are based on the development of an installation I/I reduction plan. The major modules of a plan are:

1. Facilities Inventory
2. Data Acquisition Plan
3. Condition Evaluation
4. Rehabilitation Task Analysis
5. Rehabilitation Planning.

Facilities Inventory Module

The first step is to subdivide the system into facilities, which fall into one of three categories:

1. Manholes, each of which is cross-referenced to the specific manhole immediately downstream.

2. Sewer segments, also known as manhole-to-manhole reaches, which extend from one manhole to an adjacent downstream manhole.

3. Service laterals, each of which is connected (and cross referenced) to a specific sewer segment.

Data Acquisition Plan Module

To execute a data acquisition plan, a sewer system must be divided into subsystems (sometimes called *minisystems*), and each subsystem must be prioritized on the basis of flow-isolation analyses.

Division Into Subsystems

Subsystems are sections of sewer lines of 20,000 to 30,000 linear ft, bounded by key manholes chosen for their adequacy for the performance of I/I measurements. Each segment will belong to only one subsystem. The manholes and service laterals belonging to a subsystem are identified on the basis of their connections to member segments.

Observations are made at the subsystem level to record both average and peak flows as an expected yearly average (in gpd). Where applicable, flow rates in gpd per inch-mile are then computed internally by SIMMS-IIC .

Typically, instruments will be installed in the selected key manholes to measure I/I components. Both continuous and spot measurements are performed to establish the inflow and infiltration components of the flow.

Prioritization and Disaggregation Rules

SIMMS-IIC performs flow disaggregation calculations for prioritizing subsystems. The SIMMS-IIC flow-disaggregation process assumes the following sequence of tasks:

1. Flow isolation for each subsystem is performed both for peak and average I/I.

2. Subsystems are prioritized for order of investigation

3. Manhole-to-manhole flow is measured for each prioritized subsystem

4. Detailed investigation of defects, severity, flow, etc., is conducted for some critical manhole-to-manhole reaches.

It may reasonably be assumed that flow isolation within a selected subsystem is performed for *n* manhole-to-manhole (mtm) reaches, where *n* is smaller than or equal to the total number of reaches, N. If the subsystem consists of N mtm reaches, then n is smaller than or equal to N. (Ideally, in selected subsystems, all reaches are isolated). Note that *n* may be different for infiltration and inflow. Therefore, two approaches can be envisioned:

1. Isolated measurements for each segment are conducted. This allows disaggregation of the measured I/I flows among the identified conditions within the segment.

2. Isolated measurements are not made for each member segment. The disaggregation process is then undertaken to distribute the total measured flow to all defects identified in each subsystem component.

The following disaggregation rules apply to both average and peak infiltration or inflow. Any defect, depending on whether it causes infiltration or inflow, is assigned a peak and an average flow. Thereafter, the word *flow* refers to one of the four elements: peak infiltration, average infiltration, peak inflow, or average inflow.

Disaggregation Rule 1 applies at the mtm level to the set of *n* reaches (isolated). For isolated mtm reaches, flow is disaggregated among defects belonging to a segment, its upstream manhole, and connected service laterals as follows:

- Measured flows at the defect level are assigned to the defect (unchanged)
- Total measured flows (tmf) are calculated
- The difference between the isolated flow at the reach level and the tmf is computed
- This difference is allocated to defects with unmeasured flows, based on their severities.

Disaggregation Rule 2 applies at the subsystem level to the set of (*N-n*) nonisolated reaches:

- Measured flows from isolated reaches are totalled, and denoted by the total isolated reach flow (tirf)
- The difference between subsystem level flow and tirf is computed
- This difference is allocated to defects in nonisolated reaches, based on their severities.

There are two exceptions to each disaggregation rule. Exceptions to Rule 1 (the mtm level) are:

1. If the sum of the measured defect flows exceeds the isolated mtm reach-level flow, then the nonmeasured defects are not allocated any flow. This sum then governs for manhole-to-manhole reach flow in lieu of the mtm isolated flow. In this instance, the analyst may question the measured defect flows or the isolated mtm reach flow, and ask for further investigation of the specific reach.

2. If, based on Rule 1, the flows allocated to nonmeasured defects are unreasonably large, the detailed investigation of the reach is deemed inadequate. The analyst might ask to reinvestigate

the reach to look for unidentified defects that may be contributing to the larger-than-expected flows.

Exceptions to Rule 2 (the subsystem level) are:

1. If the sum of isolated reach flows exceeds the subsystem-level flow, then the nonmeasured defects are not allocated any flow. In such a case, the analyst may question the accuracy of the subsystem-level flow measurements.

2. If, based on Rule 2, the flows allocated to nonmeasured defects are unreasonably large, further investigation is deemed necessary. This may require isolation of some formerly nonisolated mtm reaches, followed by detailed investigation of defects in some of the key reaches.

Based on these readings, some specific subsystems will be prioritized for further detailed study and analysis using thresholds for total peak inflow and average infiltration rate.

The prioritization of subsystems is undertaken for the set of subsystems that contributes collectively to 80 percent of the total peak inflow. Subsystems are analyzed in detail for infiltration purposes if their rate of infiltration is larger than 5000 gpd/in.-mile. These subsystems will be targeted for SSES stages 1 and 2 (See Chapter 2).

The Data Acquisition Module provides most of the data necessary for evaluating the condition of different facilities.

Condition Evaluation Module

For every facility type, defects are identified and categorized for inflow or infiltration through the SSES. Each segment, manhole, and service lateral is evaluated to determine the existing conditions and their extent. Information is obtained primarily to identify Infiltration (IN) and Inflow (IW) sources and extents. Each inventory element generally has more than one observation. These field observations are mapped for all segments, manholes, and service laterals. Flow allocation to different defects follows, with measured flow rates assigned first to defects as applicable. This flow allocation only takes place for subsystems selected for SSES (data acquisition Stage 2). For these subsystems, two approaches are possible:

1. Isolated measurements from manhole to manhole (one sewer segment) are conducted. This allows the disaggregation of the measured I/I flows among the identified conditions within the segment.

2. Isolated measurements are not made for each of the member segments. The disaggregation process distributes the total measured flow over a subsystem to all defects identified in each of its components.

It is worth describing the flow disaggregation technique adopted for both of the above cases, whereby if flow parameters are not specified for each individual observation, a method of disaggregating the overall measured flow for the subsystem to each of the individual observations will be undertaken, based on the severity of each condition. Because the results will only be approximate, it is strongly recommended that individual flow measurements are made to estimate I/I peaks and averages at the inventory-element level.

From the total I/I quantities observed over a subsystem, the sum of individually observed or calculated flow quantities for each segment, manhole, or service lateral are subtracted. If no individual quantities are available as part of the SSES, the balance quantity will be disaggregated among the observed conditions of the remaining inventory components based on their severity of defects. Similar disaggregation of the flow from one manhole to the next is also undertaken among observed conditions for segments with specific isolated flow measurements.

The Condition Evaluation Module assigns each facility a set of defects with related inflow or infiltration measurements or calculations.

Rehabilitation Task Analysis Module

For each facility needing rehabilitation, the Rehabilitation Task Analysis module analyzes different rehabilitation tasks, and evaluates alternatives to generate the most cost-effective approach. For elimination or correction of an inflow source, only spot repairs are considered. Both spot repairs (such as chemical grouting) and line repairs (such as sliplining) are considered to correct an infiltration problem.

Various rehabilitation techniques are available for effective control of I/I. Each technique is specifically suited to certain types of problems, depending on the pipe's physical parameters. Each technique also has a different level of efficiency in controlling I/I. For example, spot repairs of pipe cracks are less efficient than line repairs due to groundwater migration issues. Techniques are defined for each type of facility, with their range of applicability and their ability to eliminate or correct specific defects.

For each observed condition of each inventory item, SIMMS-IIC identifies the most cost-effective spot techniques (comparing the cost of rehabilitation to the total of capital and O&M cost savings). Then all potential line techniques that could rectify all observed I/I conditions are also evaluated for cost-effectiveness. However, this module provides an override facility for inputting an expert's task recommendation for an inventory item or observed condition. Note that the expert's choice may be to do nothing, contrary to the SIMMS-IIC recommendation. The override facility ensures that final decisions are always in the hands of the installation's sewer system experts.

To calculate cost-effectiveness, SIMMS-IIC computes an annual adjusted unit cost based on unit cost, lifespan, and the global interest rate. The resulting figure is used in all cost/benefit analyses of alternative techniques. Such an approach helps in normalized comparison of tasks with different lifespans. The cost of rehabilitation techniques is compared to the total savings—the sum of capital cost savings in peak flow reduction and O&M cost savings in sustained (average) flow reduction.

The Rehabilitation Task Analysis Module allows the development of the most cost-effective rehabilitation strategy at the facility level. These strategies are then used in the Rehabilitation Planning Module for ranking and resource-allocation purposes.

Rehabilitation Planning Module

Specific I/I control programs can be created using the most suitable and cost-effective rehabilitation techniques for the various observed field conditions. To accomplish this, the subsystem components to be rehabilitated are identified. Only the inventory items belonging to prioritized subsystems are chosen for study. The facility-level rehabilitation strategies derived in the Rehabilitation Task Analysis Module are ranked according to cost-effectiveness, and combined in a list representing the rehabilitation program.

As previously mentioned, manual overrides are allowed to take expert opinions into account, as well as other external issues related to bundling* or budget constraints.

Warning to SIMMS-IIC users: The software can maintain only one active rehabilitation program. Every time a program is rerun, all previous values will be overwritten. Also, if the SIMMS-IIC program file is reloaded, all acquired data will be lost. It is recommended that all data regularly be backed up to floppy diskettes through the Database Maintenance menu, which is found in the System Utilities menu.

* bundling: the integration of diverse task recommendations into a single cost-effective solution, even if it means "over-rehabilitating" some parts of the system. For example, it may be more cost-effective to slipline several contiguous segments than to slipline only a few while spot-repairing intervening segments along the same main.

5 SIMMS-IIC INFORMATION STRUCTURE

The five major elements in the SIMMS-IIC information structure are:

1. An inventory log at the component level
2. A subsystem (minisystem) level of flow measurement to identify targeted subsystems for I/I reduction
3. Condition evaluation databases for different surveyed components
4. Databases for rehabilitation techniques and their ranges of effectiveness
5. A rehabilitation program database to develop a cost-effective program at the overall network level.

These elements correspond to the five software modules discussed in detail in Chapter 4. Other important components of the information structure are the system tables (in the Utilities module), and software elements that support SIMMS-IIC's analytic and reporting facilities.

Inventory Log

Details on inventory are recorded under the categories of manholes, segments (mains), and service laterals.

Manholes

Fields of interest for a manhole are:

- Manhole ID
- Street Location (nearest door number, name of street, name of street type, and city)
- Type of structure
- Material of construction
- Rim elevation
- Invert elevation
- Depth
- Lid type.

As manholes typically designate end points of a segment, a terminal cleanout facility should be considered a manhole for inventory purposes.

Segments

Fields of interest for the main line-segments are:

- Segment ID
- End manhole IDs (up- and down-stream)
- Shape of cross section
- Material of construction
- Street location (street name, street type name and city)
- Diameter
- Length
- Depth of cover
- Number of service connections.

Service Laterals

Fields of interest for service laterals are:

- Service number
- Address of service (door number, street name, street type name, city)
- Customer name
- Customer telephone number
- Downstream segment ID
- Distance of connection to segment from the upstream manhole, measured along the length of main
- Type of connection
- Shape of cross section
- Diameter
- Length
- Depth of cover
- Material of construction.

Subsystem-Level Flow Measurement

Because an elaborate cost/benefit analysis is involved in evaluating both infiltration and inflow contributions at the component level, the following fields are relevant for obtaining information that will be used to compare costs at that level:

- Subsystem ID
- Name of subsystem
- Average overall infiltration
- Peak overall infiltration
- Percentage infiltration reduction expected
- Average overall inflow
- Peak overall inflow
- Percentage inflow reduction expected
- Unit capital cost for infiltration
- Unit capital cost for inflow
- Unit O&M cost for infiltration
- Unit O&M cost for inflow
  - Member segment ID
  - Average isolated infiltration
  - Average unit isolated infiltration (gpd/in.-mile)
  - Peak isolated infiltration
  - Surveyed for infiltration sources?
  - Average isolated inflow
  - Average unit isolated inflow (gpd/in.-mile)
  - Peak isolated inflow
  - Surveyed for inflow sources?

Condition Evaluation

SIMMS-IIC incorporates an interface between inventory databases with condition evaluation databases to assess the sources and extent of I/I for manholes, segments, and laterals.

Manhole Condition Evaluation

Fields of interest are:

- Manhole ID
  - — Location of condition
  - — Infiltration or Inflow?
  - — Observed condition (leaky cover, damaged wall etc.)
  - — Extent of condition (appropriate units)
  - — Severity (scale of 0 to 10, no flow to extensive)
  - — Average flow quantity
  - — Peak flow quantity.

Segment Condition Evaluation

Fields of interest are:

- Segment ID
  - — Location of condition (linear feet from upstream manhole and relative clock-hand position)
  - — Infiltration or Inflow?
  - — Observed condition (illegal tap, joint leak, etc.)
  - — Extent of condition (appropriate units)
  - — Severity of I/I (scale of 0 to 10, no flow to extensive)
  - — Average flow quantity
  - — Peak flow quantity.

Service Lateral Condition Evaluation

Fields of interest are:

- Service Number
  - — Location of condition (linear feet from connection to line segment)
  - — Infiltration or Inflow?
  - — Observed condition (sump pump, roof leader, etc.)
  - — Extent of condition (appropriate units)
  - — Severity of I/I (scale of 0 to 10, no flow to extensive)
  - — Average flow quantity
  - — Peak flow quantity.

Rehabilitation Techniques

Manhole Rehabilitation Task

Fields of interest are:

- Task ID
- Task description
- Corrects infiltration or inflow?
- Efficiency
- Spot repair?
- If not spot repair, compute cost on number, depth, etc.?
  - — Suitable materials of construction
  - — Suitable type of construction
  - — Corrects conditions
- Expected life of task
- Unit cost.

Segment Rehabilitation Task

Fields of interest are:

- Task ID
- Task description
- Corrects infiltration or inflow?
- Efficiency
- Spot repair?
- If not spot repair, compute cost on length, diameter, etc.?
- Suitable range of pipe diameter (from, to)
- Suitable range of pipe depth (from, to)
  - — Suitable shape of cross section
  - — Suitable material of construction
  - — Corrects conditions
- Expected life of task
- Unit cost.

Service Lateral Rehabilitation Task

Fields of interest are:

- Task ID
- Task description
- Corrects infiltration or inflow?
- Efficiency
- Spot repair?
- If not spot repair, compute cost on length, number, etc.?
- Suitable range of pipe diameter (from, to)
- Suitable range of pipe depth (from, to)
  - — Suitable shape of cross section
  - — Suitable type of joint to main
  - — Corrects conditions

- Expected life of task
- Unit cost.

Rehabilitation Program

Fields of interest for the rehabilitation program database are:

- Inventory ID
- Rehabilitation task (if line repair, **** otherwise)
- Average measured infiltration
- Peak measured infiltration
- Average infiltration after rehabilitation
- Peak infiltration after rehabilitation
- Average measured inflow
- Peak measured inflow
- Average inflow after rehabilitation
- Peak inflow after rehabilitation
- Total average flow reduction
- Total peak flow reduction
- Capital cost savings
- O&M cost savings
- Cost of line repair technique
- Cost-benefit ratio
  - — Observed condition
  - — Rehabilitation task (if spot repair, **** otherwise)
  - — Average measured flow (infiltration or inflow)
  - — Peak measured flow (infiltration or inflow)
  - — Average flow (IN or IW) after rehabilitation
  - — Peak flow (IN or IW) after rehabilitation
  - — Capital cost savings
  - — O&M cost savings
  - — Cost of technique
  - — Cost/benefit ratio.

After the data are entered, reports can be generated in order of decreasing cost-effectiveness, with running totals of anticipated flow reduction, cost of rehabilitation, and potential annual savings for I/I control tasks.

The user can rerun the project many times to perform "what-if" analyses until an appropriate rehabilitation plan is obtained. Because override of the plan is permitted at all stages, the practicality of the schedule can be ensured.

System Tables

Sewer system components may be built from different materials, employ different structural designs, have several different kinds of defects, or may require several different rehabilitation techniques. To give SIMMS-IIC the most flexibility in choice and inclusion of system characteristics, a number of system tables are incorporated into the software to accommodate these data. Two examples of system tables are shown in Figure 7.

LINE SEGMENT DEFECT TABLE

LIMITED TO 90 DEFECT. SAMPLE OF DEFECTS BELOW

CODE	DEFECT	CODE	DEFECT
ADC	AREA DRAIN CONNECTION	BYP	BYPASS
CBC	CATCH BASIN BROKEN	COB	C.O. BROKEN
CPD	C.O. PLUG DEFECT	CRC	CIRCUMFERENTIAL CRACK
CWF	CLEAR WATER FLOW	ICS	INDIRECT CONNECT. TO SS
IDC	IN DRAIN CHANNEL	ITC	ILLEGAL TAP CONNECTION
JTL	JOINT LEAK	LDC	LONGITUDINAL DEEP CRACK
MHB	MANHOLE BENCH	MHC	MANHOLE COVER
MHR	MANHOLE RING	MWC	MANHOLE WALL/CONE
NSV	NO SMOKE FROM VENT	OEP	OPEN ENDED PIPE
PCC	PIPE CEMENT CORRODED	PCP	PIPE CRUSHED/COLLAPSED
PCS	PIPE CROWN SAGE	PJD	PIPE DETERIORATED/OPEN
PJM	PIPE JOINT MISALIGNED	PJO	PIPE JOINT OFFSET
RDC	ROOF DRAIN CONNECTION	ROO	ROOT INTRUSION

MANHOLE DEFECT TABLES

LIMITED TO 90 DEFECT. SAMPLE OF DEFECTS BELOW

CODE	DEFECT	CODE	DEFECT
BBJ	BAD BASE JOINT	BCV	BROKEN MANHOLE COVER
BHD	BENCH HEAVY DETERIORATED	BKF	BROKEN FRAME
BPJ	BAD PIPE JOINT	BRO	BROKEN
CCR	CONE CRACKED	CDR	CORRODED RUNG
CFS	CRACKED FRAME SEAL	CHD	CONE HEAVY DETERIORATED
CRK	CRACKS	DRF	DISPLACED RING & FRAME
INC	INVER CRACKED	MMC	MISSING MANHOLE COVER
PAR	PONDING AREA	RCR	RING CRACKED
RBG	RING BELOW GRADE	RHD	RIND HEAVY DETERIORATED
RMA	RING MISALIGNED	ROO	ROOT INTRUSION
WHD	WALL HEAVY DETERIORATED	UTO	UNABLE TO OPEN

Note: these two examples are not universal. The actual content of system tables will vary according to system layout, component design, and materials used in a given system.

Figure 7. Two Examples of System Tables.

SIMMS-IIC includes system tables for the following fields:

- Type of manhole structure
- Type of manhole cover
- Material of construction
- Shape of cross-section
- Service-to-segment connection type
- Observed manhole field condition (with unit of measure)
- Observed segment field condition (with unit of measure)
- Observed service lateral field condition (with unit of measure).

Providing a global capability to allow expansion of the system tables provides flexibility. However, because the suitability of tasks is directly linked to each parameter, such a facility can become very cumbersome. Therefore, it is important to limit the potential growth of these tables of parameters to a predefined maximum to control the numbers of fields in each rehabilitation task record.

Provisions are made for recording two global parameters: interest rate and the ENR cost index base. Updates of these global parameters enables automatic system-wide update of all costs.

Defect Categorization and Condition Assessment

The SIMMS-IIC data acquisition plan produces a listing of defects in manholes, segments, and service laterals. Each defect is typically associated with a source of infiltration or inflow. Typical defects related to different facility types are specifically addressed by SIMMS-IIC:

Sewer Segment Defects

- Pipe crown sag (PCS)
- Invert sag (IVS)
- Reinforcing steel gone (RSG)
- Reinforcing steel corroded (RSC)
- Pipe joint deteriorated or open (PJD)
- Pipe joint leaking (PJL)
- Pipe joint offset (PJO)
- Longitudinal shallow crack (LSC)
- Longitudinal deep crack (LDC)
- Root intrusion (ROO)
- Small holes in wall (SHW)
- Transversal shallow crack (TSC)
- Transversal deep crack (TDC)
- Pipe crushed or collapsed (PCS)
- Pipe cement corroded (PCC)
- Pipe slabouts and holes (PSH)
- Illegal tap leakage (ITL)
- Illegal tap connection (ITC)
- Roof leader connection (RLC)
- Catch basin connection (CBC)
- Area drain connection (ADC)
- Indirect connection to storm system (ICS)
- Service connection leak (SCL).

Manhole Defects

- Pick holes in manhole (PHM)
- Rim seal leak (RSL)
- Corbel leak (COL)
- Cracked frame seal (CFS)
- Broken frame (BKF)
- Displaced ring and frame (DRF)
- Missing manhole cover (MMC)
- Corroded rung (CDR)

- Leaking joints in cone (LJC)
- Leaking joints in riser (LJR)
- Bad base joint (BBJ)
- Bad pipe joint (BPJ)

Service Lateral Defects

- Joint leak service (JLS)
- Service joint deteriorated or open (SJD)
- Service joint leaking (SJL)
- Service joints offset (SJO)
- Service longitudinal crack (SLC)
- Service root intrusion (SRO)
- Service transversal crack (STC)
- Service crushed or collapsed (SCS)
- Service cement corroded (SCC)
- Service holes (SHL)
- Service indirect connection to storm system (SIC).

Rehabilitation Cost-Effectiveness Analysis

After defects around the system are identified as sources of infiltration or inflow, peak and average flow rates are derived by one of the three following methods:

1. Direct measurement or visual estimation

2. Theoretical estimation of flows using data on tributary area, intensity of storm, coefficient of runoff for catch basins, area drains, roof leaders, etc.

3. Computation using a prorated distribution of flows across all defects in a subsystem or an isolated segment that was not covered by either of the above methods. This distribution is based on the severity of each defect.

Based on the peak and average flow rates for each defect, the annual O&M and capital costs arising from the defects are estimated. These costs result from the transportation and treatment of flows.

For each subsystem, two unit capital costs per gpd are assigned for peak infiltration and peak inflow, and are used to compute capital costs at the defect level. Similarly, two unit O&M costs per gpd are assigned for average infiltration and average inflow, and are used for O&M computations at the defect level.

Rehabilitation Task Costing

Rehabilitation measures, referred to here as tasks, are identified for each inventory type. Detailed descriptions of rehabilitation methods and their applicability can be found in USACERL Technical Report N-88/25, *Wastewater Collection System Rehabilitation Techniques for Army Installations* (Maloney and Briassoulis 1988).

The following sections discuss representative costs associated with major pipeline rehabilitation techniques. Costs are based on the 1984 ENR 20-cities Construction Cost Index of 4109, adjusted for inflation. The inflation adjustment was based on an ENR inflation factor of 4883 (ENR, 20 January 1992). Future ENR inflation adjustments can be entered as necessary. Additional cost figures are included from other sources (Brown & Caldwell 1984).

Costs of Pipeline Removal and Replacement

Table 5 reports removal and replacement costs in dollars per linear foot, both for different diameter values and different depth values. These results were reported in Brown & Caldwell (1984), and assumed projects of 1000 linear feet or more, use of reinforced concrete pipes for diameters over 48 in., and use of reinforced concrete or clay for diameters under 48 in.

Backfill bedding materials were assumed to be wasted, and would not be used for the new pipe. The depth of new backfill bedding was assumed to be of 12 in. below the pipe bottom.

Grouting Preparation Costs

The following considerations were used in estimating grouting preparation costs for remote pipes between 6 and 42 in. (as reported in Table 6):

- Minimum project size of 1000 ft
- Large number of cracks and joint problems
- Herbicide treatment is used inside the pipe to kill intruding roots
- Root removal and cleaning before and after using herbicide treatment
- Average or heavy root intrusion inside the pipe.

Grouting Costs

Table 7 reports remote grouting costs for pipes ranging in diameter between 6 and 42 in. The following factors were considered in the estimates:

- Minimum project size of 1000 linear feet
- Different pipe materials
- Cost is calculated in dollars per crack or per joint
- Two instances of cold/wet weather and average conditions
- Grouting will be required for 50 percent of the joints.

Table 8 reports manned-entry chemical grouting costs for pipes ranging in diameter between 48 and 99 in. The following factors were considered in the estimates:

- Minimum project size of 1000 linear feet
- Different pipe materials
- Cost is calculated in dollars per crack or per joint
- Two instances of cold/wet weather and average conditions
- Grouting will be required for 50 percent of the joints.

Cement Mortar Lining Costs

Table 9 reports costs per linear foot for cement mortar lining.

Table 5

Costs of Pipeline Removal and Replacement

Diameter (in.)	Depth (ft)					
	10	15	20	25	30	35
12	48	53	68	83	100	113
14	62	69	84	103	124	146
18	75	83	101	125	151	177
21	90	99	119	151	181	200
24	103	114	143	176	202	224
27	119	131	165	193	222	253
30	137	151	183	215	244	283
33	150	170	202	228	273	311
36	185	188	220	253	301	342
39	189	204	233	278	325	363
42	200	220	257	307	348	395
45	219	228	276	323	366	416
48	231	257	303	347	396	448
54	262	283	333	380	440	499
60	295	321	372	428	491	559
66	---	357	408	476	543	618
72	---	392	455	525	600	684
78	---	438	499	573	654	749
84	---	487	548	630	722	818
90	---	525	594	678	775	889
96	---	573	642	737	844	957
99	---	606	633	773	889	1002
Source: Brown & Caldwell 1984.						

Reinforced Shotcrete Lining Costs

Unit costs for this task are reported in Table 10, in dollars per linear foot. The costs are valid for projects of at least 1000 feet, and for both circular and noncircular pipes of equivalent circumference.

Pipe Insertion Unit Costs

Table 11 reports pipe insertion unit costs in dollars per linear foot, using either extruded polyethylene or extruded polybutelyne pipe liner for a range of diameter of 4 to 40 in. Table 12 reports pipe insertion unit costs for high-density extruded polyethylene pipe liner for diameters ranging from 40 to 63 in. Table 13 reports these unit costs for resin-impregnated fabric inversion lining. Table 14 reports these unit costs for reinforced thermosetting resin pipes for a diameter range of 8 to 66 in.

Table 6

Grouting Preparation Costs

Diameter (in.)	Root Removal and Cleaning	Heavy Root Removal and Cleaning	Root Kill, Removal, and Cleaning	Heavy Root Kill, Removal and Cleaning
6	0.60	0.90	1.20	1.80
8	0.90	1.20	1.80	2.40
10	1.20	1.50	3.00	3.60
12	1.20	1.50	4.20	4.80
15	1.50	2.10	6.00	6.80
18	2.10	2.70	8.30	8.90
21	2.40	3.00	10.70	11.60
24	2.70	3.30	13.10	14.00
27	3.30	3.90	16.60	17.80
30	3.60	4.50	20.20	21.40
33	3.90	5.10	23.80	25.60
36	4.20	5.40	27.60	29.10
39	4.80	6.00	33.00	34.50
42	5.10	6.20	37.20	39.20
Source: Brown & Caldwell 1984.				

Line and Spot Repairs

In addition to the sewer line repairs discussed above, other line and spot repairs can be made to rehabilitate sewer manholes, segments, and service laterals for infiltration control. Infiltration sources can be corrected both with spot or pair tasks, such as chemical grouting, or line repair tasks such as excavation and replacement, and sliplining.

Inflow sources also can be corrected or eliminated through spot repair, such as manhole cover replacement or disconnecting a storm runoff area drain from the sanitary sewer.

An average annual equivalent charge is computed for each rehabilitation task, based on the amortization of rehabilitation costs over the service life of the system.

Rehabilitation Decisionmaking for Infiltration Correction

For each infiltration source, appropriate spot repair tasks are identified. Each spot repair task has a specified service life and an efficiency ratio, which is the ratio of flow eliminated to total flow identified. Candidate rehabilitation tasks are identified, and their benefit/cost ratios are computed as the ratio of annual equivalent O&M and capital cost savings, to the annual equivalent charge for each task. The task with the highest benefit/cost ratio is selected to handle the defect. No task is selected if the benefit/cost ratios of all candidate tasks are smaller than 1:1.

Table 7

Remote Grouting Costs

Diameter (in.)	Work Performed in Cold and Wet Weather	Work Performed in Average Condition
6	26.00	20.00
8	30.00	26.00
10	35.00	30.00
12	45.00	33.00
15	65.00	45.00
18	81.00	58.00
21	95.00	74.00
24	111.00	86.00
27	123.00	95.00
30	137.00	107.00
33	150.00	117.00
36	166.00	130.00
39	174.00	137.00
42	190.00	146.00
Source: Brown & Caldwell 1984.		

Table 8

Manned Entry Chemical Grouting Costs

Diameter (in.)	Work Performed in Cold and Wet Weather	Work Performed in Average Condition
48	476.00	377.00
54	535.00	436.00
60	654.00	535.00
66	712.00	674.00
72	951.00	793.00
78	1090.00	912.00
84	1248.00	1031.00
90	1427.00	1209.00
96	1605.00	1387.00
>99	1736.00	1450.00
Source: Brown & Caldwell 1984.		

Table 9

Cement Mortar Lining Costs

Diameter (in.)	Simple Large Job, Minimal Restriction	Smaller Jobs, Some Restrictions
6	12.00	21.00
12	13.00	25.00
15	14.00	27.00
18	15.00	30.00
21	16.00	32.00
24	16.00	33.00
27	17.00	36.00
30	17.00	38.00
33	18.00	40.00
36	19.00	42.00
39	20.00	44.00
42	21.00	47.00
45	22.00	49.00
48	23.00	52.00
54	24.00	57.00
60	27.00	61.00
Source: Brown & Caldwell 1984.		

For infiltration, line repair tasks—which are assumed to correct all defects—are also possible. The applicable line repair task with the highest benefit/cost ratio is identified and compared to the set of spot repairs selected for the inventory facility. The most cost-effective option—whether a line or spot technique—is selected.

This process, applied to the set of defects in the system, results in the creation of a system-wide M&R program—a set of tasks to be accomplished across the system. Total program costs and savings are computed, and a composite system benefit/cost ratio is identified.

It is useful to repeat that an override function is always available to allow human expertise to be the final judge on the necessity for spot or line repairs. This override facility should be considered for bundling purposes, to perform what-if analyses, or for matching budgets to program costs.

Rehabilitation Decisionmaking for Inflow Correction

For each inflow source, appropriate spot repair tasks are identified. Each spot repair task has a specified service life and an efficiency ratio, which is the ratio of flow eliminated to total flow identified. Candidate rehabilitation tasks are identified, and their benefit/cost ratios are computed as the ratio of

Table 10

Reinforced Shotcrete Lining Costs

Diameter (in.)	Good Alignmnet, No Groundwater	Poor Alignment, Some Dewatering
48	119.00	149.00
54	136.00	178.00
60	149.00	205.00
66	164.00	232.00
72	183.00	257.00
78	197.00	279.00
84	215.00	302.00
90	231.00	322.00
96	245.00	345.00
99	253.00	353.00
Source: Brown & Caldwell 1984		

annual equivalent O&M and capital cost savings to the annual equivalent charge for each task. The task with the highest benefit/cost ratio is selected to handle the inflow source. No task is selected if the benefit/cost ratios of all candidate tasks are smaller than 1:1.

Table 11

Pipe Insertion Unit Costs

Diameter (in.)	Good Alignment, No Groundwater	Poor Alignment, Some Dewatering
4	10.00	18.00
5	11.00	21.00
6	13.00	25.00
8	17.00	31.00
10	19.00	38.00
12	23.00	45.00
14	26.00	51.00
16	30.00	58.00
18	33.00	65.00
20	37.00	71.00
22	40.00	79.00
24	45.00	92.00
28	58.00	115.00
32	70.00	137.00
36	82.00	158.00
40	94.00	183.00

Source: Brown & Caldwell 1984.

Table 12

Pipe Insertion Unit Costs
Using High-Density Extruded Polyethylene Pipe Liner

Diameter (in.)	Good Alignment, No Groundwater	Poor Alignment, Some Dewatering
40	95.00	189.00
42	100.00	196.00
48	117.00	232.00
55*	125.00	250.00
63	149.00	297.00

*Referenced to USEPA "Sewer System Infrastructure Analysis and Rehabilitation Report."

Source: Brown & Caldwell 1984.

Table 13

Pipe Insertion Unit Costs for Resin Impregnated Fabric Inversion Lining

Diameter (in.)	Good Alignment, No Groundwater	Poor Alignment, Some Dewatering
6	30.00	48.00
8	42.00	63.00
10	55.00	80.00
12	70.00	96.00
15	81.00	125.00
18	90.00	145.00
21	101.00	168.00
24	113.00	187.00
27	123.00	209.00
30	133.00	232.00
33	123.00	256.00
36	152.00	276.00
42	172.00	317.00
48	196.00	363.00
54	214.00	408.00
60	228.00	452.00

Source: Brown & Caldwell 1984.

Table 14

Pipe Insertion Unit Costs for Reinforced Thermosetting Resin Pipes

Diameter (in.)	Good Alignment, No Groundwater	Poor Alignment, Some Dewatering
8	24.00	35.00
10	31.00	43.00
12	37.00	50.00
14	45.00	62.00
16	52.00	69.00
18	61.00	79.00
20	69.00	86.00
22	75.00	94.00
24	82.00	101.00
27	93.00	117.00
30	105.00	128.00
33	119.00	144.00
36	127.00	155.00
39	142.00	169.00
42	151.00	183.00
45	163.00	197.00
48	176.00	208.00
54	199.00	238.00
60	215.00	260.00
66	333.00	287.00

Source: Brown & Caldwell 1984.

6 SUMMARY

Infiltration and inflow are two serious problems associated with the deterioration of sewer systems on Army installations and elsewhere. Both problems are grouped as one variable, commonly referred to as infiltration/inflow (I/I). I/I is a result of poor sewer design or system deterioration, and it can in turn accelerate sewer system failure. In terms of money and disruption of installation activity, the cost of replacing sewer systems is very high. These costs can be controlled, mitigated, or minimized through systematic application of good sewer inspection, data acquisition, and analytic procedures. This report details such an integrated set of procedures, and outlines a computerized decision-support tool—SIMMS-IIC—that can supplement and enhance the rehabilitation decisionmaking capabilities of DPW personnel.

Through field investigations and data collection, sources of I/I are located. The most appropriate repair tasks, whether spot repairs or line repairs, are identified. Using SIMMS-IIC, candidate rehabilitation tasks are identified, and their benefit/cost ratios are computed, using the ratio of annual equivalent O&M and capital cost savings to the annual equivalent charge for each task. The task with the highest benefit/cost ratio is selected to handle each defect. No task is selected if the benefit/cost ratios of all candidate tasks are smaller than 1:1. When prescribed dissimilar tasks would result in unwarranted complications or costs in contracting for repairs, tasks may be bundled into a single, cost-effective approach.

This process, when applied to all defects in a system, becomes a system-wide M&R program—a set of tasks to be applied over the entire sewer system. Total program costs and savings are computed, and a composite system benefit/cost ratio is identified.

SIMMS-IIC provides an override function to allow human expertise to overrule the program's rehabilitation recommendations. This override facility may be used for comparing bundling strategies, performing what-if analyses, or matching program costs to budgets.

METRIC CONVERSION FACTORS

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 mi	=	1.61 km
1 gal	=	3.78 l
1 psi	=	6.89 kPa

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APPENDIX A: Design and Construction Standards for New Sewers

Effective design and construction standards can ensure that new sewer mains, manholes, and service laterals are built to minimize the potential for RII. Such standards are equally important for sewer system rehabilitation.

Design Standards

Appropriate modifications to sewer design practices can help minimize future RII in new systems. Such modifications include (1) decreasing the permeability of granular backfills, (2) reducing interconnections between backfills of various utilities, (3) control of migration fines, (4) reducing the number of pipe joints, (5) providing flexibility to reduce settlement stress and breakage, (6) sealing pipe and manhole connections, and (7) control of lateral installations.

Reduction of Granular Backfill Permeability

Granular backfill in pipe trenches can drain (dewater) surrounding soils, increasing settlement potential for both the pipe and the ground surface. This causes stress that can create RII sources in the buried pipeline. Furthermore, the granular backfill acts as a permanent hydraulic conduit (French drain) along the exterior of the pipeline. This hydraulic conduit can channel large quantities of water to damaged joints and pipe defects. The permeability of granular backfill can be reduced by adding impermeable trench cutoff walls (trench plugs), adding cement or bentonite clay to granular backfill, or specifying well graded backfill material. Each of these measures can retard the infiltration rate.

Reduction of Utility Backfill Interconnections

A problem related to backfill permeability is the common practice of using granular backfill where utilities cross. This is done because adequate compaction is difficult to achieve when utility trenches are close, either vertically and horizontally. Granular backfill (e.g., pea gravel) can be more tightly compacted with less effort than finer backfill. As implied above, however, granular backfill material also channels water collected in the shallower utility trenches into the backfill surrounding the sanitary sewer, which is almost always the deepest utility. Trench plugs can be installed where utilities intersect to prevent this connection.

Control of Migrating Fines

The smallest backfill particles (fines) can be carried away by water moving through the trench, resulting in pipe subsidence. To avoid this problem, trench plugs are sometimes installed in trenches with steep slopes—especially those below normal groundwater levels. Migration of fines from above may leave a pathway for RII to rapidly reach the sewer pipe. Defects in the pipe then provide a path for the soil and water to follow. Impermeable trench plugs as an integral feature of sewer design can help to control this problem.

Reduction in the Number of Pipe Joints

Pipe with fewer joints is desirable because all joints are potential RII sources. The vitrified clay pipe used in the past for sewer mains and service laterals had joints as close as 2 ft apart. The joints, which were sealed with mortar, were subject to cracking and deterioration. New pipe materials, such as polyethylene, PVC (polyvinyl chloride), or ABS (acrylonitrile butadiene styrene) can provide virtually jointless construction. Fewer joints make it easier to determine the source of problems detected following construction. Reducing the number of joints used will also probably reduce problems with roots growing into pipe joints.

Reduction of Settlement Stresses

Stress points occur at the connections of the main and lateral, the lateral and the building, as well as manholes, cleanouts, and other structures. Stress points may also occur in trenches where underlying soil conditions change. The pipe's ability to handle different amounts of settlement is important: unless the pipe transfers a part of the overburden soil load to the supporting soil, the pipe must carry the entire load. Flexible connections may be provided by installing two joints close together or by using flexible materials such as rubber couplings. Flexible connections between laterals and sewer mains are highly important because these connections are major sources of leakage.

Sealing Joints at Manhole Connections

Sealing pipe connections at manholes is as important as providing flexibility. Manholes generally have greater hydrostatic pressures outside the manhole than within. Most manholes have no seep ring or water stop around the pipe as it enters the manhole. Many pipe materials used today, such as PVC and polyethylene, do not bond well to concrete manholes. Some additional means of sealing the pipe connection to the manhole is required to prevent infiltration into this joint. Rubber seals have been developed for small pipes. Tape seals, which are composed of bentonite and butyl rubber mixtures with adhesive backing, wrap around the pipe to form an expansive seal.

Control of Laterals

Laterals are extremely important because they may represent more than half the total length of collection system piping. RII through laterals has been shown to be very high in many areas. This is due partly to the limited degree of construction inspection normally provided, and because laterals typically receive little or no routine maintenance. Exterior cleanouts allow ready access for testing; ideally, there should be one two-way connection at the street and one at the building. To minimize RII, each lateral connection at the main should be closely inspected, and the connection should use a manufactured sanitary tee, wye, or a saddle. Pipe penetrations (hammer taps) should be replaced. Cutoff walls or trench plugs in the lateral trench can be used, particularly where grade change or lateral length is great and granular backfill is used.

Construction Standards

Construction standards imply conformity to the design intent. This conformity is accomplished by inspecting and testing.

Regular Inspection

Stringent construction standards for sewer lines cannot be met without adequate inspection. Major sewer construction should be monitored continually. Although this would be ideal with laterals, it is impractical to provide more than a periodic inspection during construction. For example, postinspection viewing does not reveal whether backfill compaction is adequate, trench plugs have been installed, or flexible couplings have been provided.

Performance Testing

Stringent standards for leak testing (air pressure or water) should be set and achieved. Since results at the time of testing are probably the best the pipe will ever achieve, stringent test standards are necessary to assure acceptably low levels of infiltration over the life of the pipe.

There is generally no limitation on the length of pipe that may be subjected to performance (leakage) testing. However, testing any length shorter than a complete segment is impractical, as is testing more than one segment at a time. Therefore, the standard unit for performance testing is the sewer segment.

Because permissible leakage is a function of pipe length, greater losses are allowed for longer reaches. Current standards permit some joint leakage as a practical necessity to accommodate current construction capabilities. However, one joint may be responsible for 90 percent of the leakage in a test section. If a test of 40 joints includes one badly leaking joint, the section may pass the test. Although the testing of individual joints could eliminate this problem, such testing can be costly and time consuming. However, testing of individual joints is recommended for piping 18 in. in diameter and larger.

APPENDIX B: Terms Used in SIMMS-IIC

AVERAGE INFILTRATION: Total estimated or measured infiltration over 1 year, divided by 365 days.

AVERAGE INFLOW: Total estimated or measured inflow over 1 year, divided by 365 days. Equivalent to the normalized flow of the 1 year 6 hour design storm.

BASE WASTEWATER FLOW: Sanitary sewage flow, including domestic commercial and industrial flow, but *not* including infiltration/inflow.

BUILDING SERVICE CONNECTION: The point where a building service lateral connects to the public sewer, typically through a wye or tee joint (with a chimney for deep public sewers).

BUILDING SERVICE LATERAL: The pipe from a building to a public sewer.

BENEFIT/COST RATIO: The ratio of the savings in transportation and treatment generated by I/I removal to the cost of removal.

COMBINED SEWER: A sewer intended to serve as both a sanitary and a storm sewer.

DEFECT: A point source of infiltration/inflow.

EXCESSIVE INFILTRATION/INFLOW: The quantity that can be economically eliminated from a sewer system through rehabilitation, as determined by a cost-effectiveness analysis.

GROUNDWATER MIGRATION: The tendency of groundwater to move from a rehabilitated defect to a previously inactive (nonleaking) defect.

INFILTRATION: Water entering a sewer system or service laterals from groundwater, through (but not limited to) such means as defective pipe joints, or failed pipe sections, connections, or manhole walls. (See RAINFALL-INDUCED INFILTRATION.)

INFLOW: The water discharged into a sewer system as a result of rainfall. Inflow does not include, and is distinguished from, infiltration. Inflow is typically classified as one of two modes:

Direct inflow—Attributable to inflow sources and sewer system defects that immediately discharge runoff into a sewer system from definable drainage areas. Sources include roof-drain leaders, catch-basin connections, yard and area drain connections, and runoff entry through manhole covers. Direct inflow usually begins immediately after rain begins, and ends shortly after the rain stops.

Indirect inflow—Attributable to inflow sources and sewer system defects that contribute extraneous clear water as a result of precipitation-induced short-term increases in soil moisture and groundwater levels. Indirect inflow normally continues well after precipitation stops, and is usually most evident during periods of high groundwater and precipitation. Indirect inflow sources include sump pump, foundation drain, or stormwater sewer interconnections to sanitary sewers.

INTERNAL INSPECTION: The inspection of previously cleaned conduits by physical, photographic, or video methods.

KEY MANHOLE: The manhole through which the entire flow from a subsystem or district passes.

MANHOLE REACH: The section between the entrance of the upstream manhole of a sewer segment and the entrance to downstream manhole of the segment.

OVERFLOW: A structure designed to bypass sewage to a storm sewer or body of water during heavy flows, due to insufficient sanitary system capacities.

PEAK INFILTRATION: In SIMMS-IIC, regular infiltration plus rainfall-induced infiltration, usually taking place under high-groundwater conditions or following a peak inflow occurrence.

PEAK INFLOW: In SIMMS-IIC, the highest degree of flow through an inflow source following a peak design storm.

RAINFALL-INDUCED INFILTRATION: The result of a storm, either concurrently or after inflow.

REHABILITATION: Repairs performed on sewers, manholes and other sewer system appurtenances that allow excessive infiltration/inflow.

SANITARY SEWER: A sewer intended to carry only sanitary and industrial wastewaters from residences, commercial buildings, and industrial plants.

SEWER SYSTEM EVALUATION SURVEY (SSES): A systematic examination of the tributary sewer systems or subsystems that may allow excessive infiltration/inflow. The SSES determines the location, flow rate, and cost of correction for each infiltration/inflow source.

SIMMS-IIC: Sewer Inventory and Maintenance Management System for Infiltration and Inflow Control.

STORM SEWER: A sewer intended to carry only storm water, surface runoff, street-wash waters, and drainage.

SUBSYSTEM: An individual drainage basin that is part of a collection system, usually consisting of 10,000 to 30,000 linear feet of sewer segments.

TOTAL PROJECT COST: The cumulative cost of the SSES and rehabilitation, plus the cost of transporting and treating the remaining infiltration/inflow (excluding base flow).

TRANSPORTATION AND TREATMENT COSTS: Consists of both a capital cost related to sizing sewerage and associated facilities to accommodate peak I/I and an O&M cost related to the annual I/I rate.

VISUALLY ESTIMATED INFILTRATION/INFLOW: The rate of infiltration or inflow observed and estimated during internal inspection.

APPENDIX C: SIMMS-IIC System Requirements, Installation, and Configuration

The following information is provided to help SIMMS-IIC users set up and configure their computer systems to run the SIMMS-IIC software. A copy of the current version of the software may be obtained from the U.S. Army Construction Engineering Research Laboratories, Attn: CECER-EPO, PO Box 4005, Champaign, IL 61826-4005, telephone 1-800-USA-CERL.

System Requirements

The minimum system requirements for running SIMMS-IIC system are a DOS*-compatible microcomputer with 640K of random access memory, a hard disk with 10 MB of free storage space, and a 1.2 megabyte 5.25 in. diskette drive.

SIMMS-IIC is a standalone system occupying three high-density diskettes. SIMMS-IIC does not require any additional software to run. It was developed based on SIMMS (Planning and Development Applications, Newton, MA), using CLIPPER™, and R&R Relational Report Writer™.

Installation

To install SIMMS-IIC, the following steps are required:

1. Go to the root directory of the hard disk from the DOS prompt.

   C:\XXXX\> CD\ «┘

2. Create a subdirectory named "SIMMSIIC".

   C:\> MD SIMMSIIC «┘

3. Get into the SIMMSIIC subdirectory.

   C:\> CD SIMMSIIC «┘

4. Insert the SIMMS-IIC system disk into a floppy drive (A:, for example).

5. Copy all the files from the diskette into the SIMMSIIC directory.

   C:\SIMMSIIC> COPY A:*.* /v «┘

NOTE: Substitute the appropriate drive specification letter of your floppy drive in place of A:, if necessary.

6. Remove the first SIMMS-IIC disk and repeat Step 5 with the other two SIMMS-IIC disks. Store the original floppy disks in a safe place. SIMMS-IIC is now installed on your system.

*DOS: disk operating system.

7. Reboot your machine before launching SIMMS-IIC.

Configuration

The following two steps may be necessary to modify your computer system setup and configuration to allocate enough memory to SIMMS-IIC. If you have problems launching or operating SIMMS-IIC, it is recommended that you modify your AUTOEXEC.BAT and CONFIG.SYS files as follows:

- Append the following command to the AUTOEXEC.BAT file (located at C:\)

  SET CLIPPER=F27;R64

- Append the following commands to your CONFIG.SYS file (located at C:\)

  FILES=44
  BUFFERS=30

After completing these changes, reboot your machine.

NOTE: Consult your operating system manual for instructions on appending commands to the AUTOEXEC.BAT and CONFIG.SYS files. *Do not* edit the CONFIG.SYS file if it includes a value for FILES or BUFFERS higher than those specified above. Other programs on your system may specify a higher value, and changing those values may create problems.

Launching SIMMS-IIC

To operate SIMMS-IIC, change the current directory to C:\SIMMSIIC. Then, at the C:\SIMMSII> prompt, type:

SIMMSIIC «┘

WARNING: If the SIMMS-IIC program file is reloaded later, all data entered up to that point will be deleted.

For SIMMS-IIC to display and print results, the system must operate entirely on the same drive. The default drive for SIMMS-IIC is the C: drive. If you want to run the program on any other drive, you must change the SIMMS-IIC output drive specification. This may easily be done through the System Configuration menu, under System Utilities.

APPENDIX D: Sample Forms for Sewer System Component Evaluation

The following three forms show the information required for SIMMS-IIC program data input. The forms are recommended for field use by installation utility personnel conducting sewer system inspection. The information content of the forms should be required as part of the output from future contractors' inspection, survey, or evaluation activities.

Service Lateral Inspection Form

Subsystem ID ______________________________

Service ID ______________________________

Building Number ______________________________

Street ______________________________

City______________________________

Telephone ______________________________

Diameter ______________________________

Length ______________________________

Location of connection ______________________________

Depth of cover ______________________________

Shape of cross section ______________________________

Material ______________________________

Type of connection ______________________________

Defect ______________________________

Extent of defect ______________________________

Location ______________________________

Type of flow (infiltration or inflow) ____________________

Severity (best case 1-10 worst case) ____________________

Inflow: Avg ____________________ Peak ____________________

Infiltration: Avg ______________ Peak ____________________

Line Segment Inspection Form

Subsystem ID ______________________________

Segment ID ______________________________

Location (street, city) ______________________________

Manholes: upstream ______________ downstream ____________

Diameter ______________________________

Length ______________________________

Depth of cover ______________________________

Material ______________________________

Shape ______________________________

Defect ______________________________

Extent of defect ______________________________

Location ______________________________

Type of flow (infiltration or inflow) ____________________

Severity (best case 1-10 worst case) ____________________

Inflow: Avg ________________ Peak ____________________

Infiltration: Avg ____________ Peak ____________________

Defect ______________________________

Extent of defect ______________________________

Location ______________________________

Type of flow (infiltration or inflow) ____________________

Severity (best case 1-10 worst case) ____________________

Inflow: Avg ________________ Peak ____________________

Infiltration: Avg ____________ Peak ____________________

Manhole Inspection Form

Subsystem ID ______________________________

Manhole ID ______________________________

Location (street, city) ______________________________

Elevation ______________________________

Rim ______________________________

Invert ______________________________

Depth ______________________________

Type of Structure ______________________________

Material ______________________________

Lid type ______________________________

Defect ______________________________

Extent of defect ______________________________

Location ______________________________

Type of flow (infiltration or inflow) ______________________________

Severity (best case 1-10 worst case) ______________________________

Inflow: Avg ______________ Peak ______________

Infiltration: Avg ______________ Peak ______________

Defect ______________________________

Extent of defect ______________________________

Location ______________________________

Type of flow (infiltration or inflow) ______________________________

Severity (best case 1-10 worst case) ______________________________

Inflow: Avg ______________ Peak ______________

Infiltration: Avg ______________ Peak ______________

APPENDIX E: Program Printout Examples

This appendix is intended to provide the user an overall idea about the capabilities of the SIMMS-IIC report printout. The documentation and hard copies obtained from the program can be generally divided into two categories: subsystem data and code tables.

Subsystem Data

The following types of printouts can be generated for the entire inventory or for each subsystem separately. The attached example includes two subsystems that were listed separately: subsystem 001 and subsystem 100. All reports may be reviewed on the monitor screen or printed as hardcopy on paper. The main difference between listings and queries is that a listing involves all data while a query sorts data by subsystem. The following examples are obtained under the subsystem query selection to distinguish and dissociate the two separate systems.

The first set of printouts list the input or data obtained and entered for subsystems 001 and 100:

- Line segment query
- Manhole query
- Service lateral query
- Line segment defect query
- Manhole defect query
- Service lateral defect query
- Subsystem flow isolation.

The second set of printouts list the output produced for the subsystems 001 and 100:

- Optimal rehabilitation plan query
- Detailed benefit/cost analysis query.

Code Tables

The code table lists the three-lettered code entered as data into the program for each respective item or defect. Items or defect types may be added or deleted from the code tables to customize the program applications to specific locations or user conditions. The following types of code tables can be found within the program menus:

- Line segment defect code listing
- Manhole defect code listing
- Service lateral defect code listing
- Manhole lid code table
- Material code table
- Connection code table
- Shape code table
- Structure code table.

The task code table lists the rehabilitation tasks, their suitability, and the costs. Again, tasks may be added, modified, or deleted. The following can be found within the program menus:

- Segment infiltration rehabilitation task code table
- Segment inflow rehabilitation task code table
- Manhole infiltration rehabilitation task code table
- Manhole inflow rehabilitation task code table
- Service lateral infiltration rehabilitation task code table
- Service lateral inflow rehabilitation task code.

Input Sample

Sewer Inventory and Maintenance Management System
Rehabilitation Planning for I/I Control

United States Army Construction Engineering research Lab
PDA(TM) - Collection System Management

Date:02/07/92 LINE SEGMENT QUERY Page:1

Segment ID/ Sub-system ID	Location: Street Name / City	Manholes: Upstream/ Downstream	Features: Diameter/ Length/	Inch-mile	Depth of Cover	Material/ Shape
SG0000001 0001	SO. 8TH AVE FORT	MH000021A MH000021L	10.00in 108.0 ft	0.20	8.00ft	VTC VITRIFIED CLAY CIR CIRCULAR
SG0000002 0001	8TH & "K" STR FORT	MH000021J MH000021A	10.00in 89.0 ft	0.17	8.00ft	VTC VITRIFIED CLAY CIR CIRCULAR
SG0000003 0001	SO. 8YH AVE FORT	MH000021W MH000021L	8.00in 90.0 ft	0.14	8.00ft	VTC VITRIFIED CLAY CIR CIRCULAR

Date:02/08/92 SEGMENT DEFECT QUERY (by Segment ID) Page:1

Segment ID	Street City	Def Cde	Defect Name	Extent of Defect	@ Location	TF	SR	IN(GPD) Avg	IN(GPD) Peak	IW(GPD) Avg	IW(GPD) Peak
SG0000006	SO. 8TH AVE FORT	PJM	PIPE JOINT MISALIGNED	2.00 no	24'AND 27' DOWNSTREAM	IN	3	800.0	1900		
		PCP	PIPE CRUSHED OR COLLAPSED	4.00 ft	25'UPSTREAM CAMERA COULDNT PASS	IN	9	6000.0	10000		
		LDC	LONGITUDINAL DEEP CRACK	3.00 ft	DOWNSTREAM END	IN	8	5000.0	9000		
SG0000007	SO. 8TH AVE FORT	SCL	SERVICE CONNECTION LEAK	1.00 in	FROM ADJACENT WAREHOUSE	IN	4	900.0	1600		
SG0000008	SO. 8TH AVE FORT	LDC	LONGITUDINAL DEEP CRACK	2.00 ft	18' DOWNSTREAM	IN	5	1400.0	2800		
		PJO	PIPE JOINT OFFSET	1.00 no	42' UPSTREAM	IN	3	700.0	1500		

Date:02/07/92 MANHOLE QUERY Page:1

Manhole ID/ Sub-system ID	Location Street/ City	Elevation Rim/ Invert	Depth (ft)	Type of Structure/ Material/ Lid type
MH000021A 0001	S 8TH AVE FORT	6.00 4.00	2.00	CCH COMBINED CHAMBER CSI CAST IRON CIN CAST IRON - SNUG CLOSE
MH000021B 0001	SO.8TH AVE FORT	4.60 5.00	9.80	IND INTERNAL DROP PCC PRECAST CONCRETE CIN CAST IRON - SNUG CLOSE
MH000021C 0001	SO. 8TH AVE FORT	6.00 4.50	9.50	IND INTERNAL DROP PCC PRECAST CONCRETE CIN CAST IRON - SNUG CLOSE

Date:02/08/92 MANHOLE DEFECT (by Manhole ID) QUERY Page:1

Manhole ID	Street City	Def Cde	Defect Name	Extent of Defect	@ Location	TF	SR	IN(GPD) Avg	IN(GPD) Peak	IW(GPD) Avg	IW(GPD) Peak
MH000010A	2ND STR FORT B	CFS	CRACKED FRAME SEAL	1.00 no		IN	3	300.0	600.0		
MH000010D	2ND STR FORT B	CDR	CORRODED RUNG	1.00 ft		IN	4	1800.0	0.0		
MH000010E	2ND STR FORT B	ROO	ROOT INTRUSION	1.00 no		IN	6	2700.0	0.0		

Date:02/07/92 SERVICE LATERAL QUERY Page:1

Service ID/ Sub-system ID	Segment ID/	Customer Name/ Street/ City/ Telephone	Diameter/ Length	Depth of Cover	Shape of Cross Section/ Material	Connection @/ Type of Connection
SR0000001 0001	SG0000014	WAREHOUSE SO. 8TH AVE FORT ( ) -	8.00in 44.0 ft	7.00ft	CIR CIRCULAR PVC POLY-VINYL CHLORIDE	40.00 TJT 'T' JOINT
SR0000101 100	SG0000130	ARMORY 4TH STR FORT B ( ) -	8.00in 120.0 ft	7.00ft	CIR CIRCULAR VTC VITRIFIED CLAY	45.00 YJT 'Y' JOINT

Date:02/08/92 SERVICE DEFECT (by Service ID) QUERY Page:1

Service ID	Street City	Def Cde	Defect Name	Extent of Defect	@ Location	TF	SR	IN(GPD) Avg	IN(GPD) Peak	IW(GPD) Avg	IW(GPD) Peak
SR0000001	SO. 8TH AVE FORT	SRO	SERVICE ROOT INTRUSION	3.00 ft	AT PIPE CONNECTION	IN	4	400.0	1200.0		
		SJO	SERVICE JOINTS OFFSET/MISALIGNE D	1.00 number	AT PIPE CONNECTION	IN	3	100.0	500.0		
		FDC	FOUNDATION DRAIN CONNECTION	1.00 no		IN	6	2800.0	5800.0		

Date:02/08/92 SUB-SYSTEM INFILTRATION REPORT Page:1

Subs ID	Total Inch-mile	No of Segments	No of Manholes	No of Services	Infiltration ..Avg.. (GPD)	...Peak.. (GPD)	Exp Red	Average/ Inch-mile
100	13.55	32	32	0	2000000	4000000	100	147601
0001	3.85	26	26	4	160000	700000	100	41558
	17.40	58	58	4	2160000	4700000		124138

Date:02/08/92 SUB-SYSTEM INFLOW REPORT Page:1

Subs ID	Total Inch-mile	No of Segments/ Manholes/ Services	Inflow ..Avg.. (GPD)	...Peak.. (GPD)	Exp Red	Peak/ Inch-mile	%Peak
0001	3.85	26 26 4	20000	80000	100	20779	2.23
100	13.55	32 32 0	1500000	3500000	100	258303	97.77
	17.40	58 58 4	1520000	3580000			

Date:02/08/92 MANHOLE TO MAMNHOLE FLOW ISOLATION QUERY Page:1

Segment ID	Upstream Manhole ID	Sub-system ID	# of SR	Infiltration-GPD .Avg..	Infiltration-GPD ..Peak..	Inflow - GPD .Avg..	Inflow - GPD ..Peak..
SG0000001	MH000021A	0001		400	900	300	600
SG0000002	MH000021J	0001		1400	2000	0	
SG0000003	MH000021W	0001		6000	8000		
SG0000004	MH000021K	0001					
SG0000005	MH000021V	0001					

Date:02/08/92 SUB-SYSTEM FLOW ISOLATION QUERY Page:1

Sub-system ID	Sub-system Name	Total Inch-mile	No. of Segments Manholes Services	Infiltration ..Avg.. (GPD)	Infiltration ...Peak.. (GPD)	Infiltration Average/ Inch-mile	Infiltration Exp Red (%)	Infiltration Capit. Cost $/GPD	Infiltration O&M Cost $/GPD	Inflow ..Avg.. (GPD)	Inflow ..Peak... (GPD)	Inflow .Peak/..... Inch-mile	Inflow Exp Red (%)	Inflow Capit. Cost $/GPD	Inflow O&M Costs $/GPD
0001	FORT EXAMPLE	3.85	26 26 4	160000	700000	41558	100	2.50	2.00	20000	80000	20779	100	2.50	2.00
100	FORT B	13.55	32 32 0	2000000	4000000	147601	100	1.05	1.20	1500000	3500000	258303	100	1.25	1.22

Output Sample

Date:02/08/92 OPTIMAL REHABILITATION PLAN QUERY Page:8

REHABILITATION PROGRAM CREATED BY: MATT on February 3, 1992 at 16:21
Base. ENR Index:4109 Interest Rate:8.00%

Defect Number	Location of defect	Defect	Task	Isolated (GPD) Peak/ Average	Removbl. (GPD) Peak/ Average	Removed (GPD) Peak/ Average	Savings ($) Capital/ O&M	Benefit ($/Year)	EAC ($/Year)	Benefit to Cost Ratio (B/C)
000001	AROUND UPSTREAM MANHOLE	ROO	G002 GROUTING	4500.0 2200.0	4500.0 2200.0	4050.0 1980.0	10125.00 3960.00	14085.00	5.22	2698.28
000002	25' UPSTREAM	SHW	G002 GROUTING	230.0 60.0	230.0 60.0	207.0 54.0	517.50 108.00	625.50	5.22	119.83
Segment ID:SG0000014	*Line Repair*		R001 REPLACEMENT	1300.0 440.0	1300.0 440.0	1300.0 440.0	3250.00 880.00	4130.00	969.68	4.26

Date:02/08/92 SYSTEM TASK PRIORITIZATION Page:1

REHABILITATION PROGRAM CREATED BY: FAK on February 8, 1992 at 01:49
Base ENR Index:4109 Interest Rate:8.00%

Sub-syst	Inventory ID	Fl Ty	Task Code	Defect Number	Defect	Location of defect	Benefit ($/Year)	EAC ($/Year)	Benefit to Cost Ratio (B/C)	Rehabilitation Cost ($)	Cost of Program
√ 0001	SG0000017	IN	R001			*Line Repair*	73450.00	620.31	118.41	6090.00	6090.00
0001	SG0000016	IN	G002	000001	ROO	OBSTRUCTED, COULD NOT TELEVISE	41400.00	5.22	7931.03	35.00	6125.00
0001	SG0000015	IN	G003	000003	PJD	12' UPSTREAM	25650.00	5.96	4303.69	40.00	6165.00
0001	SG0000004	IN	G002	000003	ROO	EXTENSIVE AT UPSTREAM MANHOLE	19800.00	5.22	3793.10	35.00	6200.00
0001	SG0000001	IN	G003	000002	JTL		18720.00	5.96	3140.94	40.00	6240.00

Date:02/08/92 SUB-SYSTEM SUMMARY B/C ANALYSIS Page:1

Infiltration				Inflow							
..Peak... Isolated Removed Balance	Average Isolatd Removed Balance	Removable Peak/ Removable Average	Savings... Capital O&M	..Peak... Isolated Removed Balance	Average Isolatd Removed Balance	Removable Peak/ Removable Average	Savings... Capital O&M	Cumulative Cost of Tasks	Total...... Benefit	Cumulative. Yearly Costs	Benefit Cost Ratio
Sub-system ID:0001											
Sub-system Name:FORT EXAMPLE			Inchmile:3.85								
700000	160000	700000	399116	80000	20000	80000	7500	71999	602008	12453	48.34
159647	96456	160000	192912	3000	*******	20000	2480				
540353	63544			77000	-*******						
Sub-system ID:100											
Sub-system Name:FORT B			Inchmile:13.55								
4000000	2000000	4000000	8400	3500000	1500000	3500000	0	43744	152962	6531	23.42
8000	111420	2000000	133704	0	0	1500000	10858				
3992000	1888580			3500000	1500000						

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