PILOT PROJECT REPORT

Regional Infiltration and Inflow Control Program
King County, Washington

October 2004

King County
Department of
Natural Resources and Parks
Wastewater Treatment Division

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Prepared for King County by
Earth Tech Team, Seattle, WA

King County
Department of Natural Resources and Parks
Wastewater Treatment Division
King Street Center, KSC-NR-0512
201 South Jackson Street
Seattle, WA 98104
http://dnr.metrokc.gov/wtd/i-i/

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Primary ETT authors of this document are Eric Bergstrom, P.E.; Jeff Lykken, P.E.; Alison Ratliff; Keith Goss, P.E.; Tom Collins, P.E.; Mike Morgan, P.E. and Hal Mullis. King County staff includes Mary Lundt, Erica Herrin, Marc Errichetti, James Foulk, Mary Ullrich, Zhong Ji, Mark Lampard, P.E., Bruce Crawford, P.E., Paul Glenn, Janice Johnson, P.E., Abraham Araya and Bob Swarner, P.E. Ron Hines, P.E. and Jim Peterson, P.E. provided QA/QC review; and Barbara Whiton was the technical editor.

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*Pilot project agencies

For comments or questions, contact:
Mark Buscher
King County Wastewater Treatment Division
201 South Jackson Street
M.S. KSC-NR-0512
Seattle, WA 98104-3856
206-684-1242
mark.buscher@metrokc.gov

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Acronyms and Abbreviations

AAF	average annual flow
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ADWF	average dry weather flow
ADT	average daily traffic
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
Av/Pk	average-to-peak ratio
AWWF	average wet weather flow
bgs	below ground surface
BMP	best management practice
CALAMAR	Calcul de lames d'eau a l'aide due radar (calculating rain with the aid of radar)
CCTV	closed circuit television
cfm	cubic feet per minute
CFR	Code of Federal Regulations
cfs	cubic feet per second
CIP	cured-in-place
CIPP	cured-in-place pipe
COE	Corps of Engineers (U.S. Army)
CSI	Construction Specifications Institute
CSO	combined sewer overflow
CU	conditional use
CUP	conditional use permit
CWA	Clean Water Act
cy	cubic yard
dBA	decibel, A-weighted
DDES	Department of Development and Environmental Services (King County)
DHI	Danish Hydraulic Institute
DNR	Department of Natural Resources (Washington state)
DNRP	Department of Natural Resources and Parks (King County)
DNS	Determination of Non-Significance
DOF	depth of flow
du	dwelling unit
DWF	dry weather flow

EAC	Executive Advisory Committee
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency (U.S.)
ESA	Endangered Species Act
ESC	erosion and sediment control
ET	evapo-transpiration
ETT	Earth Tech Team
ETS	extended time series
F	Fahrenheit
FELL	focused electrode leak location
ft/sec	feet per second
FWPCA	Federal Water Pollution Control Act
GIS	Geographic Information System
GMA	Growth Management Act (Washington state)
gpad	gallons per acre per day
gpd	gallons per day
gpdlf	gallons per day per linear foot
gpm	gallons per minute
GPS	global positioning system
H_2S	hydrogen sulfide
HDPE	high density polyethylene
hp	horsepower
HPA	Hydraulic Project Approval
IGA	intergovernmental agreement
I/I	infiltration/inflow
ISO	International Organization for Standardization
JPG	Joint Photographic Experts Group (file extension)
KCC	King County Code
km	kilometer
LAM	Local Area Manager
lf	linear feet
Metro	Municipality of Metropolitan Seattle or King County Department of Metropolitan Services
mgd	million gallons per day
MH	manhole

mm	millimeter
MOUSE	Modeling of Urban Sewers (software by DHI)
mph	miles per hour
MWPAAC	Metropolitan Water Pollution Abatement Advisory Committee
MWWF	maximum wet weather flow
NAAPI	North American Association of Pipeline Inspectors
NAR	no apparent reduction
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration (formerly NMFS—National Marine Fisheries Service)
NPDES	National Pollutant Discharge Elimination System
OMP	Operational Master Plan (Regional Wastewater Services Plan)
OSHA	Occupational Safety and Health Administration
PAWS	Public Agricultural Weather System
PDF	portable document format (file extension)
PHS	Priority Habitats and Species Program
PM	particulate matter
POTW	publicly owned treatment works
POW	palustrine open water wetland
ppbV	parts per billion by volume
ppm	parts per million
PSE	Puget Sound Energy
psi	pounds per square inch
psig	pounds per square inch gauge
PUD	public utility district
PVC	polyvinyl chloride
PVD	peak velocity and depth
QA/QC	quality assurance/quality control
RCE	residential customer equivalent
RCW	Revised Code of Washington
RDBMS	Relational Database Management System
RDII	rainfall-dependent infiltration and inflow
ROE	right-of-entry
ROW	right-of-way
RWD	Ronald Wastewater District
RWSP	Regional Wastewater Services Plan

SCC	Snohomish County Code
SCL	service connection liner
SCLL	service connection and lateral liner
SDR	standard dimensional ratio
SEPA	State Environmental Policy Act
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SPU	Seattle Public Utilities
SSES	Sewer System Evaluation Survey
SSO	sanitary sewer overflow
SWD	Seattle Water Department
UV	ultraviolet
WAC	Washington Administrative Code
WISHA	Washington Industrial Safety and Health Act
WLRD	Water and Land Resources Division (King County)
WSDOT	Washington State Department of Transportation
WTD	Wastewater Treatment Division (King County)
WWHM	Western Washington Hydrological Model

Chapter 1

Executive Summary

In December 1999, the King County Council approved the development of a Regional Infiltration and Inflow (I/I) Control Program as part of the Regional Wastewater Services Plan (RWSP). The purposes of the program are to reduce the risk of sanitary sewer overflows and the cost of adding capacity to facilities that convey wastewater to County treatment plants.

In 2000, the County's Wastewater Treatment Division, in cooperation with the local component agencies that it serves, launched an ambitious six-year $41-million I/I control study. The study includes efforts to identify sources of I/I, test the effectiveness of various I/I control technologies, examine the benefits and costs of I/I control, and prepare a regional plan for reducing I/I in local agency collection systems.

Completion of ten I/I control pilot projects in January 2004 marks a major milestone in the study. The following text provides background on the I/I control program and summarizes the experiences gained from the pilot projects.

1.1 What Is Infiltration and Inflow (I/I)?

King County provides wastewater services to 34 local agencies (cities and sewer districts) in its wastewater service area. These agencies own, operate, and maintain pipelines that are tributary to the King County conveyance system. Pipelines in the County system carry the flow from local areas to two major regional wastewater treatment plants—the West Point plant in Seattle and the South plant in Renton.

Most of the conveyance system, except in some areas of the City of Seattle, consists of "separated" sewers intended to collect wastewater from homes and businesses for treatment. In a separated system, a different set of pipes collects stormwater. However, during periods of rain, "clean" stormwater runoff and groundwater may enter the separated sewers.

This clean water, referred to as infiltration and inflow, is expressed in terms of the volume of clean water originating from the total land area being served, or gallons per acre per day (gpad). Recent flow modeling efforts indicate that about 95 percent of I/I in the County's separated sewers originates in local systems, primarily in side sewers on private property and in other sources in these systems.

A few useful definitions…

Infiltration. Groundwater that seeps into sewers through holes, breaks, joint failures, defective connections, and other openings.

Inflow. Stormwater that rapidly flows into sewers via roof and foundation drains, catch basins, downspouts, manhole covers, and other sources.

Lateral sewer. The portion of the individual house sewer pipe that is in the public right-of-way.

Separated sewer. A pipe designed to accept and transport household, industrial, and commercial wastewater and to exclude stormwater sources.

Side sewer. The portion of the individual house sewer pipe that extends from the house to the public right-of-way.

Infiltration is subsurface flow, or groundwater, that seeps into sewers through holes, breaks, joint failures, defective connections, and other openings (Figure 1-1). Infiltration can happen throughout the year, but the volumes are usually greater after large storms or prolonged wet periods.

Inflow is stormwater that rapidly flows into sewers via roof and foundation drains, catch basins, downspouts, manhole covers, and other sources.

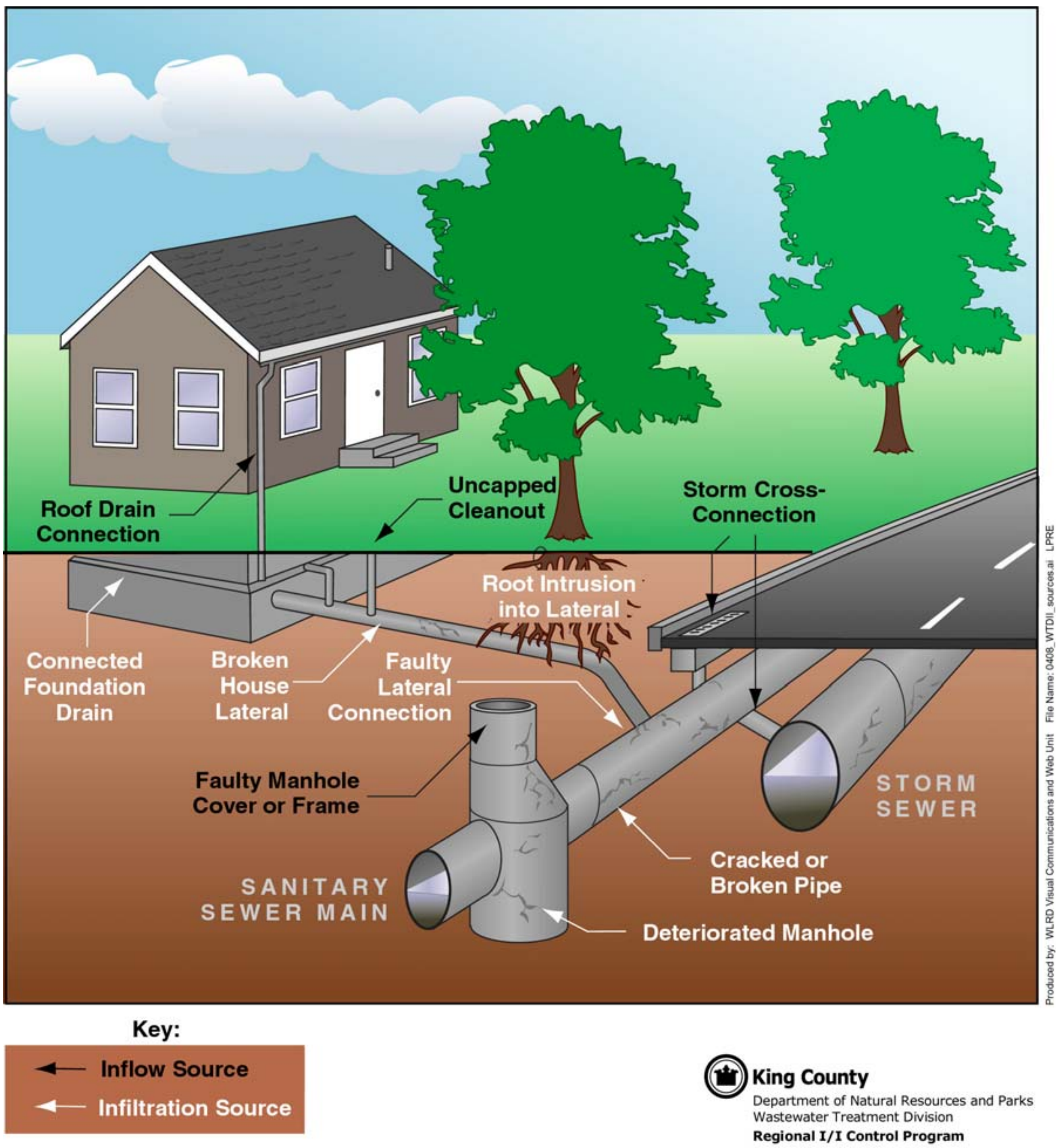


Figure 1-1. Sources of Infiltration and Inflow

1.2 Why Do We Want to Control I/I?

The King County Wastewater Treatment Division's (WTD) mandate is to protect public health and the environment. It meets this mandate by ensuring that there is enough capacity in the conveyance system to manage peak flow and to prevent sewage overflows from occurring in the system. The County defines peak flow as the combination of wastewater expected to be generated at any given time and the I/I predicted to be in the system as the result of a storm or series of storms that, on average, occur only once in 20 years.

Results of recent flow modeling indicate that about 75 percent of the peak flow to the South plant, which serves only separated sewers, comes from I/I. Excess I/I can drive the need for enlarging and replacing conveyance facilities (pipes and pump stations) with facilities large enough to convey these additional flows. If cost-effective methods for I/I control can be identified and implemented, capital costs for conveyance improvements could be reduced by eliminating, delaying, or phasing conveyance projects.

1.3 What Is the I/I Control Program?

The RWSP directs King County to develop a Regional Infiltration and Inflow Control Program that will rehabilitate conveyance facilities to control I/I when (1) the cost of rehabilitation is less than the cost of conveying and treating the I/I flow or (2) when rehabilitation would provide significant environmental benefits.

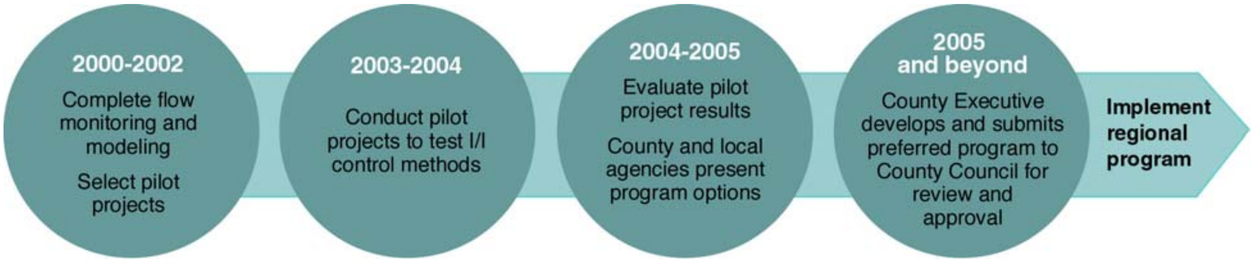


Figure 1-2. Regional Infiltration/Inflow Program Milestones

The first phase of the program is a comprehensive six-year study (Figure 1-2) that began in 2000 and consists of five steps:

- Define current levels of I/I for each local agency tributary to the regional system.
- Select and construct pilot projects to demonstrate the cost-effectiveness of collection system rehabilitation projects.
- Develop model standards, procedures, and policies for use by local agencies to reduce I/I in their systems.
- Identify cost-effective options to remove up to 30 percent of I/I expected to occur in local agency systems during a 20-year peak flow condition.
- Develop a long-term regional I/I control plan for review and approval by the County Council.

1.4 What Have We Done So Far?

To define current levels of I/I for each local agency, about 800 flow meters were installed in drainage basins throughout the separated sewer system to identify sources and volumes of I/I during the winter season. Originally, only one year of monitoring was planned. Another year was added because the first year of monitoring occurred during the region's driest winter in more than 40 years (between November 1, 2000, and January 15, 2001). The second season of monitoring, conducted between November 1, 2001, and January 15, 2002, measured record-setting rains and produced excellent results.

To demonstrate the cost-effectiveness of collection system rehabilitation projects and to gain a better understanding of the issues associated with implementing such projects, ten demonstration I/I pilot projects were constructed in local agency systems. Model standards, procedures, and policies were drafted and then applied to the pilot projects to test how well the standards, procedures, and policies would work to guide future I/I control projects in local systems. Construction of the pilot projects started mid 2003. Construction on the last pilot project was completed in January 2004. Post-pilot-project flow monitoring was completed during winter 2003–2004; results were modeled to determine the effectiveness of the projects in reducing I/I.

1.5 What Are the Next Steps?

Now that the pilot projects are completed and their results are documented, the County will use the flow information collected during the I/I study to conduct a Regional Needs Assessment of its conveyance system that will project when conveyance facilities will exceed the 20-year peak flow capacity standard. An analysis of flow monitoring data for the pilot projects and cost comparisons with traditional methods for providing capacity will be completed by the end of 2004. An Alternatives/Options report will then be prepared and submitted by March 1, 2005. The report will present a set of options for consideration in development of the long-range I/I control program.

As information becomes available on the cost-effectiveness of I/I control, the County will assess the benefits of I/I control measures versus identified conveyance improvements. If I/I measures are deemed more cost-effective in specific areas of the system, related conveyance projects may be delayed, reduced in scope, eliminated, or divided into phases. By December 31, 2005, the King County Executive will submit to the King County Council a plan for a long-term Regional Inflow and Infiltration Control Program. The plan will identify target I/I levels for local systems. It also will identify long-term I/I control measures to meet these targets and to serve as cost-effective alternatives to planned conveyance and treatment projects.

1.6 What Makes the I/I Program Unique?

Several features distinguish King County's Regional Infiltration and Inflow Control Program from other I/I control programs in the country:

- The program is **voluntary.** Other I/I control programs were developed in response to federal or state agency consent orders or other regulatory mandates. King County and local agencies initiated the program in an effort to increase system efficiencies and control wastewater treatment rates.
- The program involves **projects in local systems.** It is unusual for a regional wastewater agency to participate in sewer rehabilitation projects in local systems, including lateral and side sewer projects on private property served by these systems.
- The program tests **new assessment and rehabilitation technologies.** The technical report on the pilot projects contains valuable information that agencies can use as a resource for their I/I control.
- The program included a **comprehensive flow monitoring effort.** With over 800 flow meters installed the first year and 775 the second year, the two-year flow monitoring study enabled the County and local agencies to dramatically improve their understanding of the system.
- Most important, the program is being planned and implemented in **partnership with the local agencies that contribute wastewater to the King County system.** The County has conducted more than 50 meetings and workshops with local agencies since the study began.

Throughout the first phase of the program, King County has been working with the Metropolitan Water Pollution Abatement Advisory Committee (MWPAAC)—a committee composed of representatives from the local component agencies. MWPAAC has worked closely with the County and its consultant in identifying and selecting the pilot projects, developing draft standards, and, most recently, reviewing pilot project results and helping define a range of alternatives for long-term I/I control. Much of the consensus building and decision making has taken place in a series of workshops. These workshops facilitated discussion and generated valuable insights that have helped shape the development of the long-term I/I control plan.

A benefit of this collaboration has been a strengthening of relationships, a better understanding of local and County needs, and a solid foundation for future collaborative projects that could enhance resource management and reduce costs for each agency and its customers.

1.7 How Were the Pilot Projects Selected?

The pilot project selection process showcases the high degree of collaboration that defines the I/I program. Local agencies developed ten criteria to be used to select the locations of the pilot projects and the types of technologies to be implemented in the projects. These criteria stressed the importance of selecting projects that would provide information for future regional I/I control program efforts. Projects were to represent a geographic balance throughout the region, serve as models for future projects, and provide environmental benefits for the region.

To aid the selection process, program staff presented information about candidate basins, including flow data, age of sewer system, and type of pipe. In April 2002, local agencies nominated and voted on basins. They selected nine basins to serve as distinct pilot projects and three basins to be combined into a single pilot project focused on manhole rehabilitation.

1.8 Where Are the Pilot Projects—and What Was Done?

The selected pilot projects (Figure 1-3) include a mix of projects on public and private property in twelve local agency jurisdictions: City of Auburn, City of Brier, Skyway Water and Sewer District (formerly known as Bryn Mawr), Coal Creek Utility District, City of Kent, City of Kirkland, City of Lake Forest Park, City of Mercer Island, Northshore Utility District, City of Redmond, Ronald Wastewater District (formerly known as Shoreline Wastewater Management), and Val Vue Sewer District. The combined Coal Creek, Northshore, and Val Vue projects make up the "Manhole Project."

Work on each pilot project consisted of identifying I/I sources through field investigations, designing and constructing rehabilitation improvements, and monitoring post-construction flows to determine the effectiveness of the rehabilitation.

In the second half of 2002, the program's consulting team performed a sewer system evaluation survey (SSES) to support selection and detailed design of I/I control measures. The survey involved cleaning mainlines and manholes, using closed-circuit TV (CCTV) to identify sources of infiltration, and using smoke testing to identify sources of inflow.

In addition to using the results of the SSES, King County and local agencies applied the pilot project selection criteria and the draft design standards, procedures, and policies—also developed collaboratively with local agencies—to select and design specific technologies to be tested in the pilot projects (Table 1-1). Key objectives were to gain experience with a variety of sewer system repair technologies in manholes, mains, laterals, and side sewers and to stay within the County's $9 million construction budget.

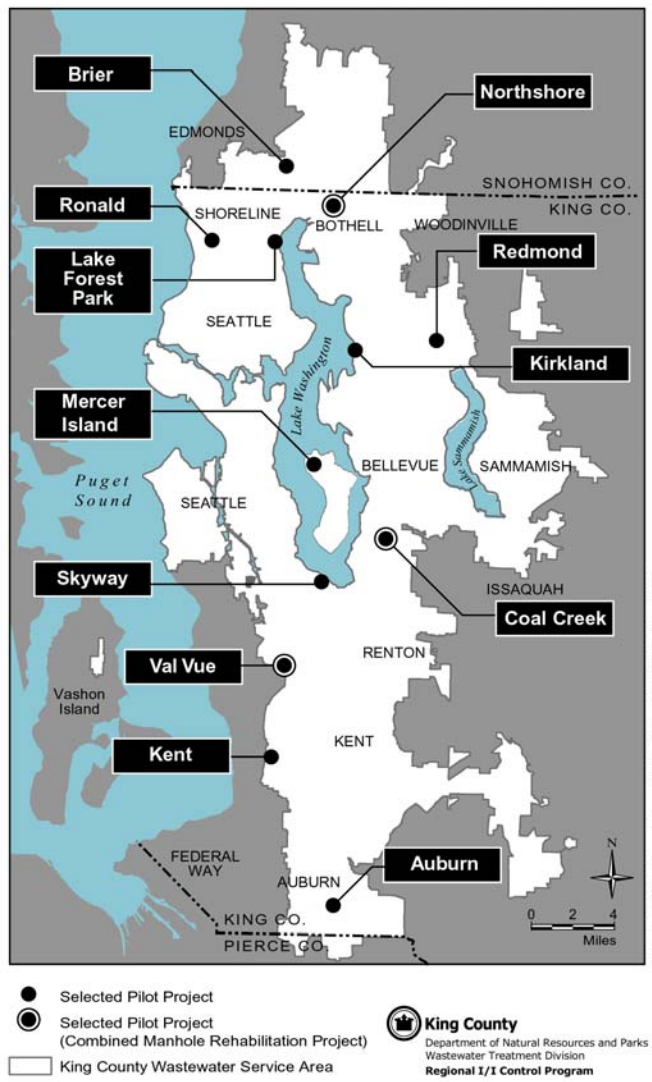


Figure 1-3. Pilot Project Location Map

The selected technologies included lining pipes using a cured-in-place material, replacing pipes by pipe bursting or open-cut methods, replacing manholes, rehabilitating manholes using chemical grouting or epoxy injection and adjusting frames and covers, and installing cleanouts.

The County's consultant designed nine of the ten pilot projects. The Ronald Wastewater District used its own consulting firm for design and construction management for the pilot project in its district. In the Ronald and Skyway pilot projects, the local agencies contributed additional funds above the $900,000 for each project contributed by King County in order to expand the scope of work in their basins.

Results of post-rehabilitation flow monitoring, conducted in each of the pilot project basins during the winter of 2003-2004, were compared with results of pre-rehabilitation flow monitoring. Computer simulation models were developed and then calibrated to the pre- and post-measured flow responses to a continuous 60-year record of storms. The models helped to establish a common basis for determining I/I reduction effectiveness and to project the 20-year peak flow rates in each basin.

Table 1-1. Rehabilitation in Local Sewers

	Mains	Manholes	Laterals	Side Sewers
Auburn	●	●	●	●
Brier	●	●		
Coal Creek		●		
Kent			●	●
Kirkland	●	●	●	
Lake Forest Park	●	●		
Mercer Island	●			
Northshore		●		
Redmond	●	●	●	
Ronald			●	●
Skyway	●	●	●	●
Val Vue		●		

1.9 What Have We Learned From the Pilot Projects So Far?

The pilot projects provided valuable insights into implementation, costs, and effectiveness of I/I control projects. (See the Table 1-2 at the end of this summary.) The most important lesson learned so far is that monitoring and rehabilitation of sewer collection systems can successfully identify, target, and reduce I/I—in large part because of strong collaboration at every step of the process.

The study illustrated that areas with I/I can be identified through comprehensive wet-weather flow monitoring. The project team also learned how to improve monitoring and surveying techniques for future efforts. They learned, for example, that identifying system defects through the SSES would be more effective if the surveys were completed during the wet season. Several sources of infiltration that eluded detection through the SSES—which was completed during the dry season—were subsequently identified during pilot project construction and post-rehabilitation inspection work, both completed during the wet season.

Rehabilitation technologies reduced I/I in eight of the ten pilot projects. The highest reduction (87 percent) occurred in Skyway, where the entire system was rehabilitated. Reductions in Kent (76 percent) and Ronald (74 percent) were also high. All three projects included rehabilitation of laterals and side sewers on private property. This result corroborates the assumption that a high percentage of I/I originates on private property. A 37 percent reduction on Mercer Island, which included only sewer main rehabilitation, further corroborates that a high percentage of I/I originates in laterals and side sewers.

No measurable reduction of I/I from pilot projects in Auburn and Kirkland is likely because only a small percentage of each basin was rehabilitated and the impact of the work on the overall I/I rate was small. The Manhole Project resulted in no measurable reduction (Coal Creek and Val Vue) or only 23 percent reduction (Northshore). These results suggest that very little I/I reduction can result from manhole rehabilitation alone.

Another important lesson learned is that I/I control would not have been possible without the support of the local agencies and private property owners. Owners were engaged before, during, and after the projects through advance public information and education, property owner incentives, and active local agency participation. Property owners helped to locate cleanouts and refrained from using the sewers while construction was in progress.

A few lessons learned…

Sources and volumes of I/I can be identified through comprehensive wet-weather flow monitoring.

Sewer system evaluation surveys are most effective when done in the wet-weather season.

I/I can be reduced through sewer rehabilitation.

A high percentage of I/I tends to originate in side sewers and laterals.

Very little I/I reduction will likely result from manhole rehabilitation alone.

Success of I/I control projects depends on a high level of cooperation with local agencies and private property owners.

Rehabilitating sewer mains at the same time that side sewers and laterals are rehabilitated may be done for a relatively small increase in cost.

Two contractors were responsible for seven of the ten pilot projects. The experiences with all the contractors were very good. Because of the limited number of contractors, these experiences and the successful bid costs may not be representative of future rehabilitation construction contracts.

The final construction cost for the ten pilot projects is $7.8 million. Local agencies contributed $0.67 million; King County contributed the remaining $7.13 million. In addition to construction costs, total pilot project costs shown in the summary table include costs for SSES, design, pre- and post-rehabilitation flow monitoring, construction management, and modeling and analysis. Even though the greatest reductions may occur from rehabilitating side sewers and laterals, experience with the Skyway project and with expanded bids for the Kent and other projects indicates that rehabilitating sewer mains at the same time as side sewers and laterals are rehabilitated can be done for a relatively small increase in cost.

1.10 What’s in the Report?

The following chapters provide more information on the pilot projects. Chapters 2–4 describe the processes involved in selecting pilot project locations and rehabilitation technologies.

Chapters 5–7 describe the implementation of the projects, including design, bidding, administration, and construction. Finally, Chapters 8 and 9 discuss the effectiveness of the projects and the lessons learned.

The information in each chapter is detailed and technical. Its purpose is not only to record what was done but also to serve as the basis for additional studies on the costs and benefits of I/I control measures and as a resource for other agencies in their efforts to control I/I.

The appendices, which are included on a CD, contain data to support the information in the chapters.

Table 1-2. Summary of I/I Pilot Project Results

						20 Year Peak I/I[b]			
	Mains	Manholes (MH)	Laterals (L)	Side Sewers (SS)	% of Basin Improved[a]	Pre-Rehab (gpad)	Post-Rehab (gpad)	Reduction %	Construction Cost	Total Cost
Auburn	●	●	●	●	11% of mains	8,900	8,900	NMR	$384,700	$749,400
Brier	●	●			23% of mains	10,100	5,000	50%	$372,700	$820,400
Kent			●	●	100% of L and SS	12,700	3,100	76%	$1,080,700	$1,446,900
Kirkland	●	●	●		25% of mains	11,000	7,900	28%	$838,200	$1,190,400
Lake Forest Park	●	●			35% of mains	22,500	7,100	69%	$790,400	$1,228,900
Manhole Project		●				17,800	16,300	23%[c]	$200,800	$660,200
Mercer Island	●				70% of mains	8,200	5,200	37%	$815,800	$1,218,600
Redmond	●	●	●		36% of mains	1,000	1,000	NMR	$840,100	$1,273,400
Ronald			●	●	72% of L and SS	18,200	4,800	74%	$1,077,300	$1,531,400
Skyway	●	●	●	●	100% of mains	63,200	8,400	87%	$1,395,200	$1,883,900

NMR = no measurable reduction.

[a] "% Improved" refers to the percentage of the identified elements of the sewer system that were rehabilitated during the pilot project.

[b] The 20-year peak pre-rehabilitation I/I rate is a model-predicted rate; the I/I rates used to select the pilot projects were the measured I/I rates for the maximum storm observed during the flow monitoring period.

[c] The pre- and post-rehabilitation flows shown for the Manhole Project are the combined flows for all three basins in the project. The 23 percent reduction occurred in the Northshore basin; there was no measurable reduction in the Coal Creek and Val Vue basins.

Chapter 2

I/I Pilot Project Selection

This chapter describes how the pilot projects were selected by local agencies, including the establishment of selection criteria, use of mini-basin flow data, project nomination, and voting results.

2.1 Selection Process Overview

Local agencies worked together to define pilot project selection criteria. Based on the criteria and flow information, each agency could then nominate candidate projects. The agencies convened within their three regions to review and forward projects to the whole committee, which selected the final 10. Major steps in this process are summarized in Table 2-1.

Table 2-1. Project Selection Steps

Date	Step
February 29, 2000	Local agency representatives identified potential pilot project selection criteria
April 25, 2000	Agreed on 10 pilot project selection criteria (see Section 2.4)
January and February 2002	King County and consultants identified mini-basins throughout the region with high rates of I/I, based on flow monitoring conducted during two wet seasons: (a) November 2000 to January 2001, and (b) November 2001 to January 2002
February 2002	Local agencies submitted pilot project candidates
March 13 and 19, 2002	Regional meetings held in the north, east, and south for local agency representatives to forward up to 10 project candidates for their region.
April 30, 2002	Local agencies selected final 10 regional pilot projects that best fit the 10 selection criteria

2.2 Egregious Basin Rehabilitation

In advance of the nomination process, the County solicited input from local agencies to identify possible I/I rehabilitation projects based on existing knowledge, flow monitoring by the agency, known illegal and direct connections, or egregious sources of I/I in their respective systems. Several agencies identified possible egregious I/I projects, which were subsequently proposed as pilot projects in the final nomination process.

2.3 Mini-Basin Flow Data

The initial means of identifying candidate projects was based on data collected during two periods of flow monitoring: (a) November 2000 to January 2001, and (b) November 2001 to January 2002. The flow meter data for over 700 mini-basins is documented in *2000/2001 Wet Weather Flow Monitoring* and *2001/2002 Wet Weather Flow Monitoring.* (Refer to Chapter 5 for a discussion of mini-basins.) These technical memoranda present hydrographs of the measured flows and estimates of the I/I rate in each basin for significant storms that occurred during the monitoring periods.

2.3.1 Hydrograph Flow Responses to Rainfall

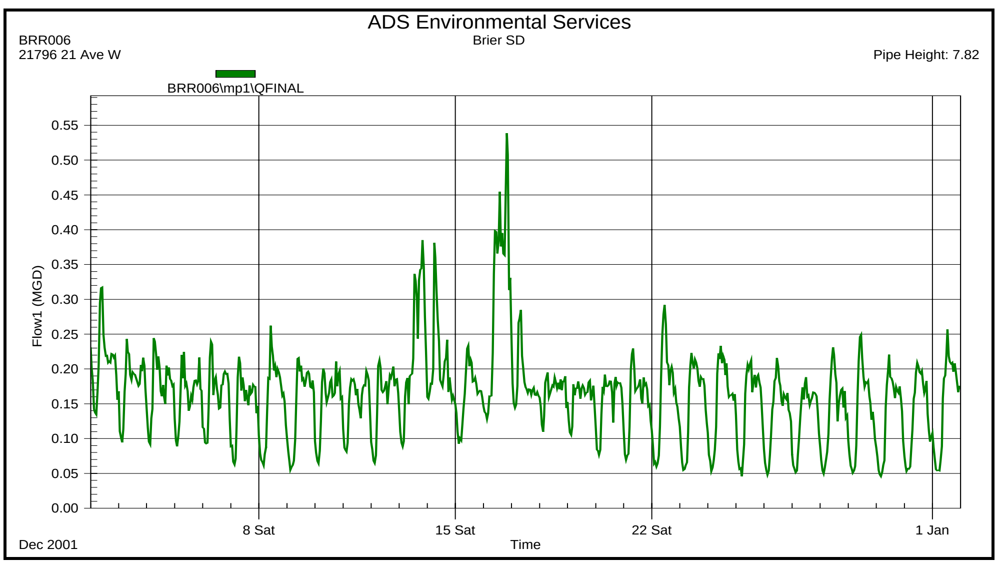
Distinct flow responses shown in the hydrographs suggested potential I/I sources. Identifying the various types of flow responses provided a means of subsequently nominating projects with a variety of I/I sources (see Table 2-2).

2.3.2 I/I Rates

A second piece of information used as a preliminary basis for nominating projects was the calculated I/I rate for each basin. The County's standard for excessive I/I is defined as any amount above 1,100 gallons per acre per day (gpad). As described in *2001/2002 Wet Weather Flow Monitoring*, over half the basins had estimated I/I rates above 2,500 gpad for at least one of the storms monitored during the flow-monitoring period. Some basins exhibited I/I rates over 15,000 gpad.

Table 2-2. Types of Flow Response to Rainfall

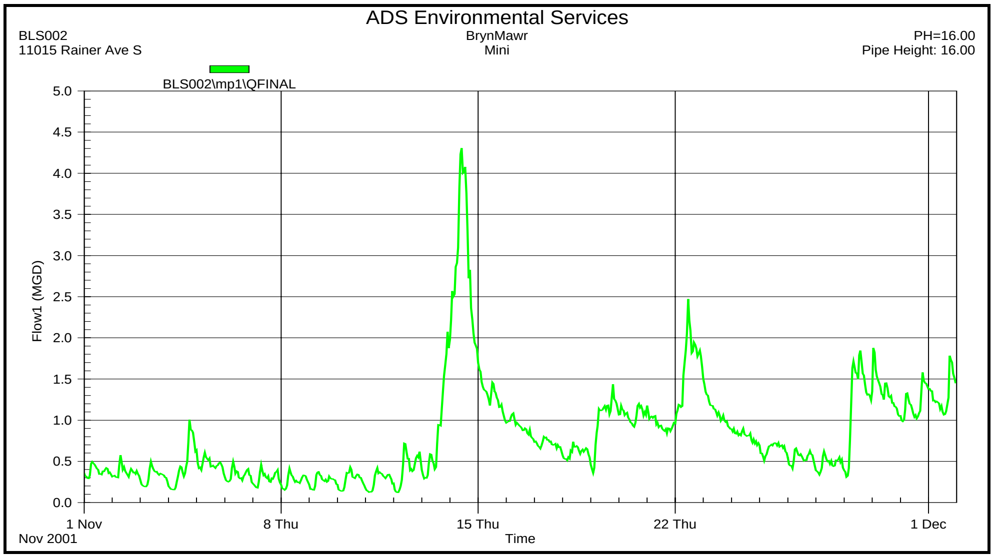
Response Type	Flow Characteristics in Response to Rainfall	Suggested Sources	Sample Hydrograph
Fast response	Sudden increase in flow	**Inflow:** catch basins, roof drains, or other direct connections; **Infiltration:** sources that respond rapidly to rainfall, such as shallow side sewers.	Figure 2-1
Rapid infiltration	Increase in flow during and/or shortly after a rainfall event, with gradual reduction in flow over a relatively short period after the event	**Infiltration:** shallow sources such as laterals, side sewers, foundation drains; and manholes and mains to a lesser extent	Figure 2-2
Slow infiltration	Slow increases in flow hours or days after a storm; increased flow may take several days or weeks after a storm to decline	**Infiltration:** deep sources such as manholes and mains; reflects a rising groundwater level	Figure 2-3



Source: *2001/2002 Wet Weather Flow Monitoring, June 2002*

This hydrograph illustrates the fast response to the December 14 and 16, 2001 storms; City of Brier, Mini-basin BRR006. After the storm the flow returns quickly to the pre-storm rates.

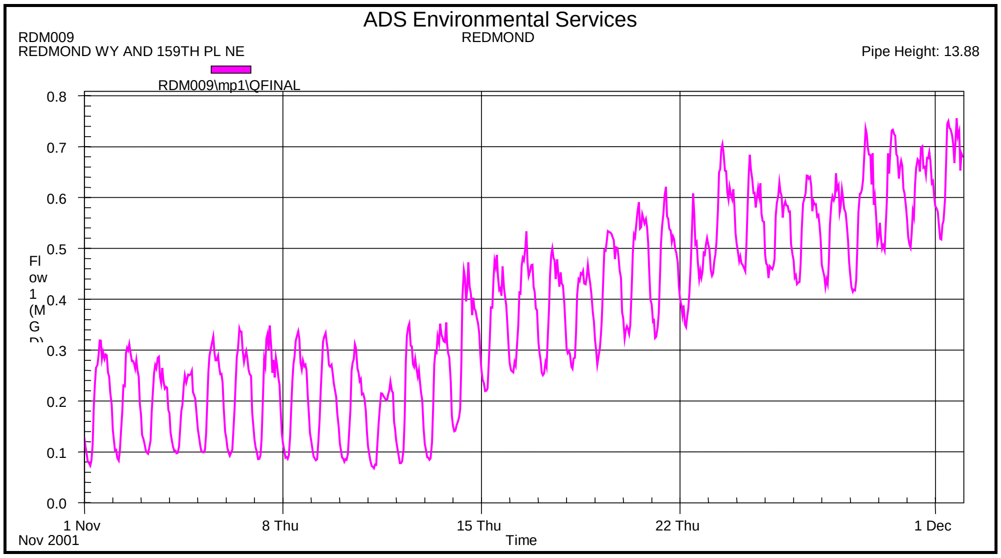
Figure 2-1. Fast Response Hydrograph



Source: *2001/2002 Wet Weather Flow Monitoring, June 2002*

Response to November 14 and 22, 2001 storms; Skyway Sewer District (formerly Bryn Mawr – Lakeridge Sewer District), Mini-basin BLS002. This hydrograph illustrates both fast and slow infiltration response of flow to storms. The rapid infiltration response is seen in the slow decrease of flows.

Figure 2-2. Rapid Infiltration Response Hydrograph



Source: *2001/2002 Wet Weather Flow Monitoring, June 2002*

Response to November 14, 2001 storm; City of Redmond, Mini-basin RDM009. There is no immediate response to the storm; however, the base flow in the system triples in the week following the storm.

Figure 2-3. Slow Infiltration Response Hydrograph

2.3.3 Preliminary Screening of Basin Flow Data

One purpose of the pilot projects was to collect data on the effectiveness of system rehabilitation in reducing I/I. Pre- and post-rehabilitation flow monitoring was used to quantify the reduction. Therefore, it was recognized before the selection process that good flow monitoring data should be available for mini-basins in which the nominated projects were located. The County recommended that agencies consider the following flow data characteristics when nominating projects:

- **The measured I/I rate for the mini-basin should be at least 2,500 gpad.** Because over half the drainage basins had I/I rates above 2,500 gpad, a basin with an I/I rate less than this would not be representative of the basins needing rehabilitation in a future I/I control program. In addition, documenting I/I reduction in a basin with an I/I rate less than 2,500 gpad could be difficult, and would not provide representative conclusions about the effectiveness of rehabilitation techniques.
- **Mini-basin flow data should be consistent and continuous during the two flow monitoring seasons used as the basis for selection.** Specific issues suggesting that a project should not be nominated included gaps in the mini-basin data due to meter malfunction, and flow pattern changes not reasonably attributable to rainfall or other documented system changes.
- **Preferably, the mini-basin should be an upstream basin rather than a flow-through basin.** During development of the flow-monitoring plan, flow data from many basins was quantified by subtracting flow from upstream-monitored basins. This increased the potential for error in measured flows.
- **The flow monitoring site for a pilot project candidate should not be influenced by an upstream constant-speed pump station.** Peak I/I rates are difficult to quantify with this type of a pump station because the measured flow is the pump rate, regardless of the flow through the system. During wet weather the duration of the pump cycle increases; however, the measured flow rate usually remains the same.

2.4 Selection Criteria

At a workshop with local agencies, the County queried agency representatives for ideas about criteria that should be used in selecting pilot projects. At a subsequent workshop, agency participants arrived at a consensus on the pilot project selection criteria. The 10 selection criteria were:

1. Provides geographic balance of pilot projects

It was expected that pilot projects would be chosen in three identified geographic areas of the King County service area: north, south, and east. The west region encompasses the City of Seattle, which was not involved in the pilot program.

2. Meets constructability time frame for the I/I program, including permitting needs

Due to time and budget constraints, extensive permitting processes were infeasible. While it was important to identify all potential projects, nominating projects with major permitting requirements was discouraged. It was expected that most selected projects would require no permitting other than State Environmental Policy Act (SEPA) checklists and local agency utility/street permits.

3. Considers differing geologic conditions/do no harm

It was important to consider differing geologic conditions; however, it was recognized that time and funding issues could preclude projects located in areas with complex geologic conditions. Some issues considered were:

— High groundwater: It was necessary to identify projects that addressed I/I caused by exposure to saturated soils, or that were located beneath water bodies such as a stream or creek.

— Unstable slopes: Projects that could increase slope stability concerns were avoided.

— Wetlands or other water bodies: Due to budget and time constraints, projects associated with wetlands or other water bodies were considered only if they did not require extensive permitting or have environmental concerns.

4. Provides environmental/public health benefits

Pilot projects that accomplished the following were considered:

— Enhanced streamflow: Increased streamflow in dry conditions (by removing groundwater and storm flows not removed by sewer lines), or decreased streamflow in wet conditions (by removing overflows)

— Reduced sewer overflows

— Benefited conditions related to the Endangered Species Act (ESA)

— Improved hazardous health areas: Removed conditions that result in exfiltration

— Reduced public impact: Minimized the effects of traffic disruption and noise

5. Addresses private sewer issues

Agencies wanted to select at least one pilot project that affected private property owners, including a project that addressed I/I on collection lines or side sewers. Private sewer aspects such as roof and foundation drains could be included.

6. Provides a regional impact

The agencies agreed that the location of selected projects should support assessment of basins tributary to planned new or expanded wastewater treatment collection or interceptor facilities. A pilot project might result in findings that would delay or reduce the need for those facilities.

7. Useful as a model for future I/I projects

Providing a sound basis for extrapolating I/I reduction results to the entire region was important.

8. Demonstrates variety of proven technologies and rehabilitation techniques

One purpose of the pilot projects was to demonstrate various I/I removal technologies and techniques. (See Chapter 4 for a description of the technologies and techniques considered for the pilot projects.)

9. Representative of typical I/I problems in the region

It was intended that the type of I/I experienced within the pilot projects be representative of I/I problems in the region.

10. The "Wild Card" criterion – project contributes to program goals but conditions were unanticipated during criteria development

During criteria development, the intention was that this criterion would provide flexibility in addressing unanticipated conditions. It allowed other issues to be considered during the selection process.

2.5 Pilot Project Nomination

Local agencies nominated pilot projects based on the selection criteria, flow data, and on the preliminary screening information. The agencies reviewed this information, and then used nomination forms to submit candidate projects. Nomination forms included: (1) information about the location of the candidate project, (2) the agency's perception of the type of I/I that contributed to the system, (3) whether the agency intended the project to rehabilitate the system to reduce I/I on public or private property, and (4) the I/I rate as reported in *2001/2002 Wet Weather Flow Monitoring.* The nominating agency also documented whether or not and/or how the candidate project met each criterion. Agencies provided additional information about candidate projects, the sewer system's approximate age, type of sewer construction materials, and if Sewer System Evaluation Survey (SSES) work could be quickly completed. Finally, nomination forms included hydrographs illustrating the flow response from the 2001/2002 flow-monitoring period. (See Appendix A for a copy of the nomination form.)

2.6 Intergovernmental Agreement (IGA)

In advance of pilot project selection, each nominating agency provided a letter to King County stating its intent to enter into an agreement with the County. This contractual agreement defined specific requirements for both parties.

During initial startup of the Regional I/I Control Program in 1999, each agency entered into an Agreement, which, in part, allowed the County, its consultants, and contractors to work within the agency's local sewer system. Agencies with a selected pilot project in their system amended the agreement. The amendment covered:

- Specifics on sharing current information, reports, and records following SSES
- Pre- and post-construction flow data
- Modeling of the system
- Definition of scope
- Schedule and location
- Project management
- Financial provisions

The amendment also covered record keeping, community outreach, and environmental review. Amendments were tailored to meet each agency's specific needs.

2.7 Final Pilot Project Selection

Agency representatives attended their regional meetings in the north, east, and south to select up to 10 candidate projects from their region. A list of 66 candidates was reviewed then reduced to 29 at these meetings. The 29 candidate projects are summarized in Table 2-3.

Between the regional meetings in March and April 2002, the list of candidate projects was reduced from 29 to 23. Bellevue withdrew BEL042 and Ronald withdrew RON025. Soos Creek withdrew both of its candidates (SOO002 and SOO029). Coal Creek, Northshore, and Val Vue agreed to combine CCR002, NUD038, and VAL019 into a single candidate project focused on manholes. Locations of the initial candidate pilot projects are shown in Figure 2-4.

In April, local agency representatives reviewed the project selection criteria, proposed pilot basins/projects, and reached agreement on a maximum of 10 pilot projects/basins, not to exceed a construction value of $9 million.

Table 2-3. Candidate Pilot Projects

Pilot Project Candidate Agency	Geographic Region	Mini-basin Meter Number	Measured I/I Rate (gpad)
Auburn	South	ABN002	10,030
Bellevue	East	BEL042[1]	9,314
Bellevue	East	BEL077	7,342
Black Diamond	South	BLA001	3,311
Bothell	North	BOT004	5,938
Bothell	North	BOT011	2,947
Brier	North	BRR004	6,338
Brier	North	BRR006	2,408
Coal Creek	East	CCR002[2]	4,202
Issaquah	East	ISS014	3,572
Kent	South	KNT014	7,709
Kirkland	East	KRK006	6,745
Kirkland	East	KRK011	7,289
Lake Forest Park	North	RON041	7,962
Mercer Island	East	MRC012	13,719
Mercer Island	East	MRPS24	2,797
Northshore	North	NUD024	2,860
Northshore	North	NUD038[2]	6,025
Pacific/Algona	South	PAC005	4,320
Redmond	East	RDM009	5,250
Renton	South	RNT021	4,355
Ronald	North	RON002	11,279
Ronald	North	RON025[1]	4,105
Ronald	North	RON032	7,303
Skyway (Bryn Mawr)	South	BLS002	27,167
Soos Creek	South	SOO002[1]	7,688
Soos Creek	South	SOO029[1]	7,220
Val Vue	South	VAL016	3,726
Val Vue	South	VAL019[2]	4,307

[1] Agencies subsequently chose to withdraw these nominations.
[2] These projects were combined into one.

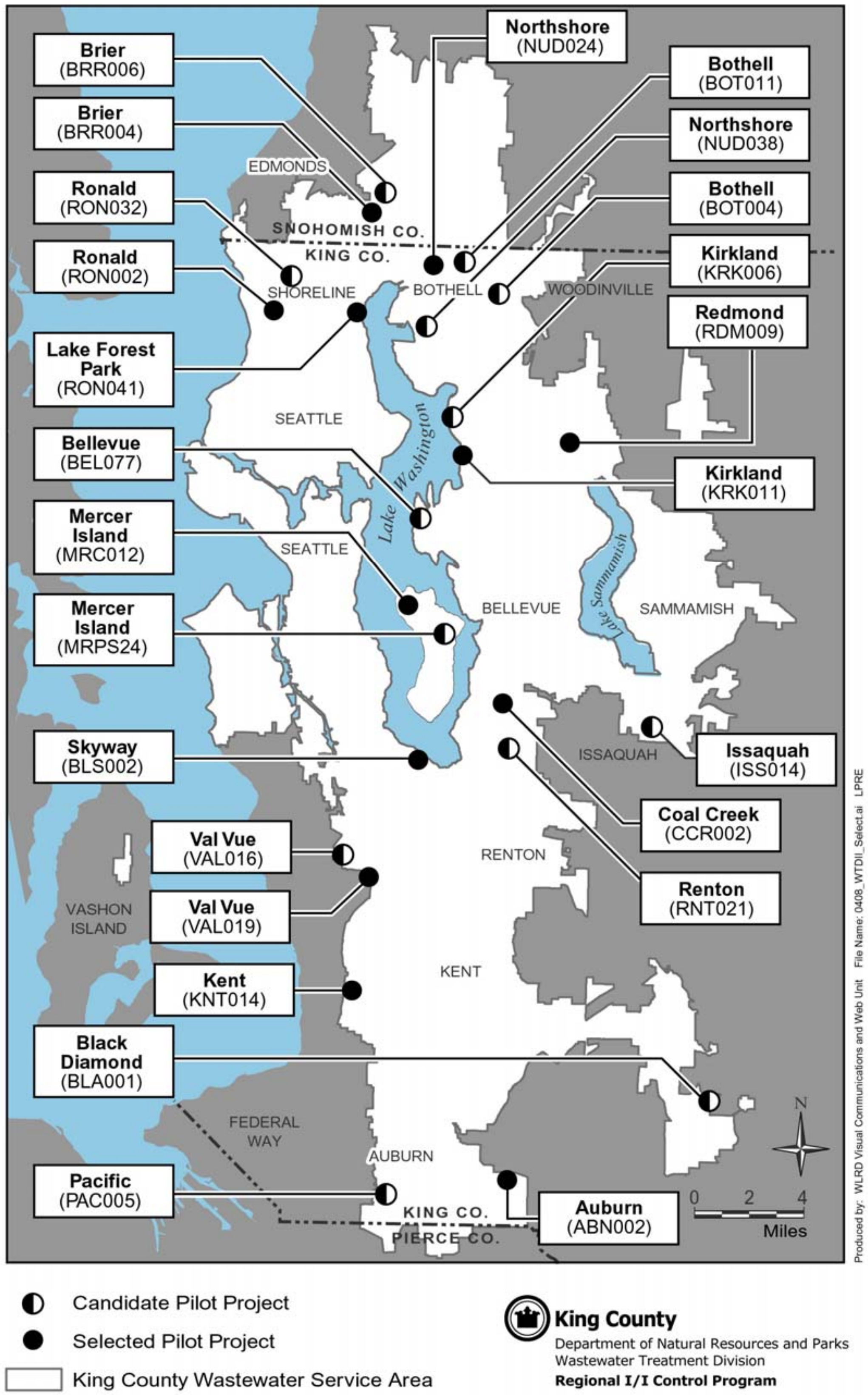


Figure 2-4. Initial Candidate Pilot Projects

2.7.1 Selection Process

Each local agency and workshop attendee received a copy of the completed nomination forms in advance of their workshop (see Appendix A). A presentation board for each candidate project was available at the workshop. Each agency had one voting representative who could vote for 10 separate projects. The final selection process consisted of the following steps:

1. **Presentation of the regional selected projects**

   Local agencies provided additional comments and input about their candidates, including whether or not the agency would contribute additional funding for the rehabilitation improvements. An agency cited its preference if it had two or more projects under consideration.

2. **Open session with "poster" presentation of proposed pilot projects**

   Agency representatives of the candidate project and program representatives discussed the proposed project with individuals.

3. **Voting for pilot projects**

   Representatives voted for projects. To ensure that private property projects were selected, representatives were to vote for at least two proposed private property projects.

4. **Voting results compiled and top 10 presented**

   After voting, the compiled results were presented to workshop attendees.

5. **Alternative list of next 5 to be considered for inclusion in top 10**

   Alternatives were selected in case any of the top 10 pilot projects could not be constructed. Ultimately, six alternatives were selected, two per region.

6. **Confirm criteria were met**

   Workshop attendees discussed the final list of pilot projects in an open forum to gain consensus that selection criteria had been met for top 10 pilot projects.

7. **Finalize list**

   The workshop attendees arrived at a consensus.

2.7.2 Pilot Project Voting Results

The final voting tally is summarized in Table 2-4. The 10 candidates with the highest number of votes were identified as the pilot projects. Following selection of 10 pilot projects, voting representatives selected alternate candidates from the remaining list in the event that one of the 10 projects could not be executed. Two alternate candidate projects from each region (north, east, and south) were selected, as shown in Table 2-4.

Table 2-4. Voting Results

Pilot Project Candidate (Mini-basin Meter No.)	Geographic Region	Number of Votes	Status
Manhole Project (Coal Creek / Northshore / Val Vue) (CCR002 / NUD038 / VAL019)	East / North / South	26	Selected
Skyway (BLS002)	South	24	Selected
Ronald (RON002)	North	24	Selected
Mercer Island (MRC012)	East	20	Selected
Brier (BRR004)	North	19	Selected
Kirkland (KRK011)	East	17	Selected
Redmond (RDM009)	East	17	Selected
Lake Forest Park (RON041)	North	16	Selected
Auburn (ABN002)	South	15	Selected
Kent (KNT014)	South	13	Selected
Bellevue (BEL077)	East	10	1st East Region Alternate
Pacific/Algona (PAC005)	South	9	2nd South Region Alternate
Renton (RNT021)	South	9	1st South Region Alternate
Issaquah (ISS014)	East	9	2nd East Region Alternate
Val Vue (VAL016)	South	8	
Black Diamond (BLA001)	South	7	
Kirkland (KRK006)	East	7	
Bothell (BOT004)	North	6	1st North Region Alternate
Bothell (BOT011)	North	5	2nd North Region Alternate
Mercer Island (MRPS24)	East	4	
Northshore (NUD024)	North	4	
Ronald (RON032)	North	4	
Brier (BRR006)	North	2	

Chapter 3

Pilot Project SSES

Sanitary Sewer Evaluation Survey (SSES) work in each pilot basin was performed to help identify the specific pilot project work to be done, and to provide design information for the techniques to be tested. (Refer to Section 5.2.1 for a discussion of pilot basins.) The three major objectives for the SSES effort included:

- Identify specific I/I sources and system conditions within each pilot basin through the application of a variety of inspection techniques
- Apply a variety of inspection techniques in different locations in an effort to understand the effectiveness of each technique for identifying I/I sources on a program-wide basis
- Apply standardized coding to observed system defects in order to reflect their relative severity

3.1 Investigation Techniques

Investigation techniques for each pilot basin were determined based on flow monitoring data. The flow monitoring data provided flow response characteristics observed at the outlet of the basin. Refer to Section 2.3 for a discussion of flow responses.

The specific type of flow response may indicate the potential sources of I/I such as roof leaders or catch basins (inflow) or cracks in the sewer main (infiltration). Some inspection techniques are better suited for identifying specific sources of I/I. Figure 3-1 presents the approach to the selection of SSES inspection techniques based on the flow response I/I component. The SSES priority identified in the figure establishes the preferred SSES inspection techniques and the order of priority.

Six inspection techniques used in each of the pilot basins included:

- Mainline closed-circuit television (CCTV) inspection
- Smoke testing
- Lateral/side sewer CCTV inspection
- Manhole inspection
- Vacuum testing
- Focused electrode leak location (FELL) testing

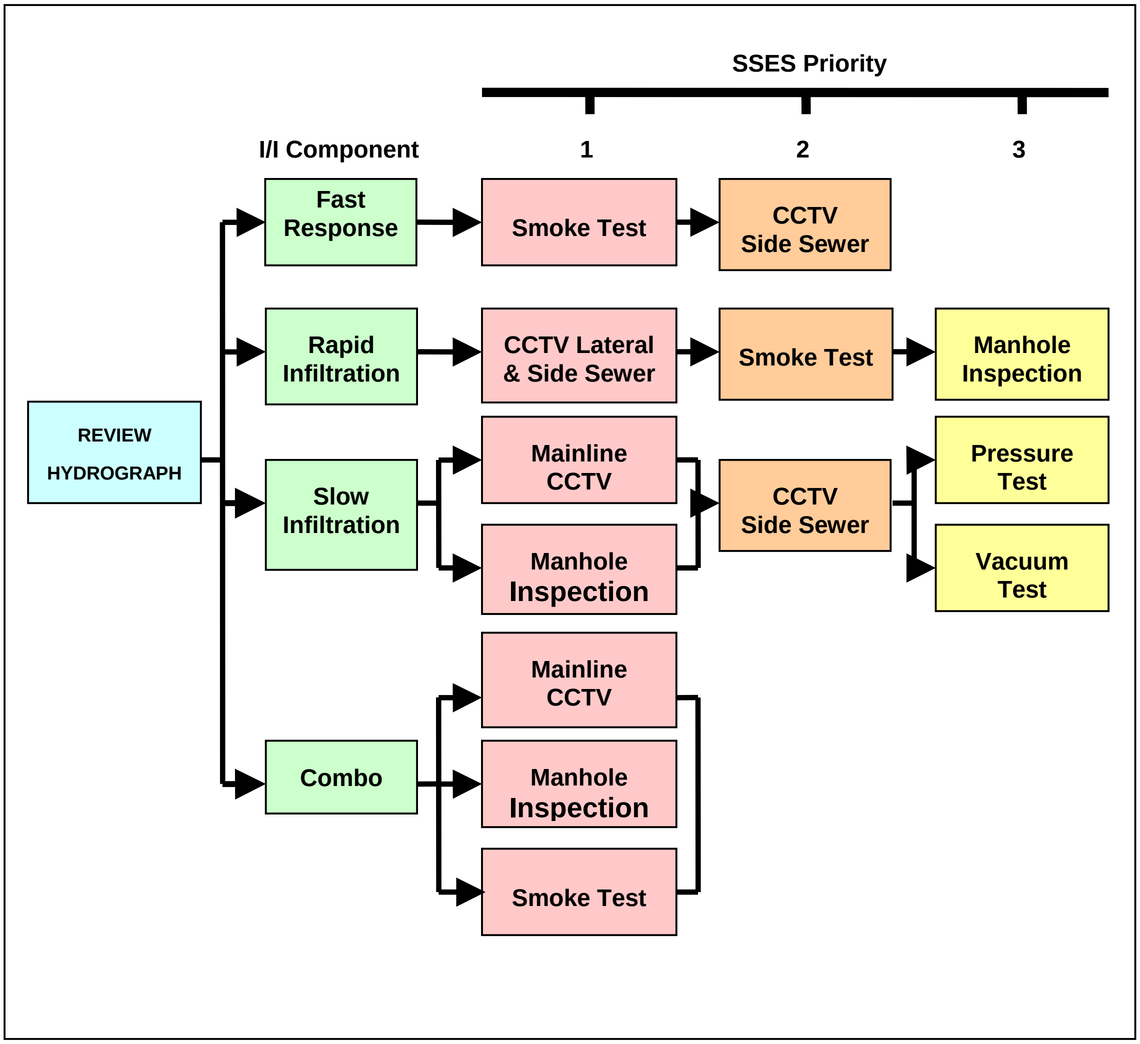


Figure 3-1. SSES Technique Selection Approach

3.1.1 Mainline CCTV Inspection

Visual inspection of the sewer lines, via remotely-operated video cameras, was performed to identify sources of infiltration and to some extent inflow. CCTV inspection also provided a means to identify undocumented connections, as well as the structural, construction, and operational defects present in the pipe. Fieldwork included hydraulic cleaning, root removal, and debris removal as required to facilitate CCTV inspection. Observations were recorded on videotape and as hand-written notes on inspection forms. The condition assessments were applied as one element in determining I/I severity, rehabilitation approach, and also served to determine the degree of system degradation during future condition assessments.

3.1.2 Smoke Testing

Smoke testing is often used to identify inflow sources, or direct connections, from roofs or from the ground surface to the sanitary sewer system. Typically, these connections are pipes from roof drains, cross connections from storm sewer systems, open cleanouts, holes in the sewer pipe that are connected to the ground surface, or submerged manholes. Smoke testing is done by blowing low-pressure, non-toxic, non-staining vapor or “smoke” into a section of the sewer line through the manholes. During the SSES, locations where smoke emerged were recorded as smoke “returns,” including leak severity, leak type, leak source, and surface conditions. Digital photographs were taken of each “return”.

3.1.3 Lateral/Side Sewer CCTV Inspection

Visual inspection of the laterals and side sewers, via remotely-operated video cameras, was performed to identify sources of rapid infiltration and to some extent inflow. CCTV inspection also provided a means to identify bad connections and joints. CCTV inspections were performed on laterals in the right-of-way and side sewers on private property. No pre-cleaning of the laterals/side sewers was performed. Work on private property was limited to basins where “rights-of-access” were obtainable. Two types of CCTV systems were used for lateral/side sewer work. Inspections using lateral launches from the mainline were restricted to about 80 feet up the lateral. Mini-cams launched from cleanouts on private property could inspect about 200 feet down the side sewer.

Lateral and side sewer defects were coded and condition grades assigned for application in determining I/I severity and rehabilitation approach, and also to serve as a quantifiable benchmark when determining the degree of lateral/side sewer degradation during future condition assessments. Property line locations were conducted using a built-in sonde unit (see Section 3.1.6) and surface locators. Observations were recorded on videotape and hand-written on inspection forms.

3.1.4 Manhole Inspection

Visual inspection of manholes was performed to identify sources of inflow, infiltration, and rapid infiltration. Visual inspection of manholes also provided a means to identify undocumented connections, as well as the structural, construction, and operational defects present in the structure. Manhole inspections were completed by entering the manholes with a safety harness, emergency retrieval equipment, gas detection, forced-air ventilators, digital cameras, and a global positioning system (GPS) computer for recording the inspection results in digital format. Digital photographs were taken of four different aspects of the manhole:

- The general area at the surface
- Looking down at the invert
- At specific moderate-to-severe defects identified during inspection
- Looking into the inlet and outlet pipes greater than 6 inches in diameter

Manhole defects were coded and condition grades assigned for application in determining I/I severity, rehabilitation approach, and also to serve as a quantifiable benchmark when determining the degree of manhole degradation during future condition assessments.

3.1.5 Vacuum Testing

Vacuum testing of three manholes was performed to determine the ability of this method to detect I/I defects compared to visual inspection. The test involves isolation of the manhole structure through placement of pipe plugs and application of a vacuum to the structure. Prior to vacuum testing, a soap solution is sprayed on the manhole interior so that a failure point is visible due to the presence of bubbles. Pictures can be taken or the area requiring rehabilitation can be marked. If a vacuum cannot be held for a specified period, defects in the structure allowing air or water to pass are found to be present.

3.1.6 Focused Electrode Leak Location (FELL) Testing

The Focused Electrode Leak Location (FELL) system was applied to selected pipelines to determine the ability of this method to detect I/I defects compared to CCTV inspection of mainlines and laterals. The FELL test system uses a specially constructed electrode called a “sonde” that generates an electric field. The electric field is focused into a narrow disc that is perpendicular to the longitudinal axis of the sonde. A surface electrode (usually a metal stake) is put into the ground at the surface. When the sonde is placed in a non-conducting pipe that contains sewage, the electric current flow between the sonde and the surface electrode is very small. Defects in the pipe that would allow a flow of fluid either into or out of the pipe usually provide an electrical pathway from the sonde through the defect in the wall of the non-conducting pipe, then through the ground to the surface electrode. When the sonde is moving through the pipe and passes close to such a defect, the current between the sonde and the surface electrode increases.

3.1.7 Dye Testing

Dye testing was not used for this SSES work because smoke testing previously identified suspect connections. Dye testing is typically used to confirm surface connections or cross connections that may not be identifiable by smoke testing. A liquid dye is introduced at the upstream point of suspected inflow, such as a roof leader, catch basin, abandoned building connection, or tank. A downstream point, usually a manhole, is monitored to see if the dye is detected.

3.2 Selection of SSES Contractor

Six contractors experienced in collection system investigations were invited by Earth Tech, the prime consultant, to submit proposals for performing the SSES fieldwork. A key issue in the selection of SSES contractors was that they meet minimum standards for inspection equipment and procedures, and reporting, as well as for traffic control. The minimum information to be included in the proposal included team organization, methodology, inventory of equipment, samples of reporting and investigation forms, unit rates for six categories of work, and related experience.

The candidate SSES contractors were provided with the following information:

- Narrative description of the Regional Infiltration and Inflow Control Program and the SSES task and objectives
- Maps of the proposed pilot projects with pipe and terrain data, as available, from King County's geographic information system (GIS)
- Flow data to allow contractors to form some idea of flow depths at various times of the day and under wet weather conditions
- Technical specifications and report forms for cleaning and inspection documentation of defects and pipe condition
- Schedule of estimated quantities per pilot basin, including acreage, length, diameter and material of pipes, number and range of manhole depths, and number of parcels within each pilot basin
- Proposal form listing key tasks, unit rates, and estimated quantities for each pilot basin. Contractors were requested to identify the threshold quantities under each task for which their unit rate would either increase or decrease.

The final selection of the contractor was based on evaluation of the quality of the proposed approach, available resources, adaptability of the contractor to project conditions, and estimated costs.

3.3 Documentation of Defects

A standardized coding system for defects provided a quantitative method of describing the type and severity of a defect and a means of relating information to a location on a specific pipe segment. Coding was easily incorporated into an electronic database that provided a tool for summarizing, querying, or reporting the data (for example, the computation and sorting of the overall condition of a component pipe, lateral, or manhole based on type, severity, and frequency of specific defects).

The North American Association of Pipeline Inspectors (NAAPI) standards and protocol were adapted for use on the project to code defects identified during inspection and testing. The NAAPI codes were incorporated into a condition assessment process used to evaluate the overall condition of pipelines. While there are NAAPI codes that address I/I defects, the system is not specifically tailored for I/I condition assessment. However, the types of defects and conditions that are addressed (cracked pipes, separated joints and connections, root intrusion, staining, and encrustation) are valuable indicators of I/I.

3.3.1 Data Management

All SSES data was stored based on the type of information collected in the field. Contractors submitted field inspection and testing data in an electronic format suitable for incorporation into a computerized database. Each mainline pipe section, lateral pipe section, manhole, and smoke test defect was a single record in a database table.

All tables were integrated into a Relational Database Management System (RDBMS). This allowed linking (relationally) to data outside or within the database, and access through links or interfaces that were specifically designed for the project. Outside the database, linking to the corresponding record in GIS allowed the results to be viewed graphically. Within the database, the RDBMS allowed linking to other database tables containing additional information, such as the defect scoring or condition code, or linking a lateral connection to the corresponding detail on the mainline record. The main RDBMS was in an Oracle® format and the main method of viewing, extracting/retrieval, and reporting of data was performed using a Microsoft Access™ interface.

The types of SSES data collected and the formats available for retrieval of the data from the database are listed in Table 3-1.

Table 3-1. Summary of SSES Data Collected and Retrieval Formats

Type of Data	Format Received	Retrieval Format
CCTV - Mainline	Paper Reports Electronic - database Videotapes	Paper Reports Electronic - database - PDF[1] - GIS Link Videotapes
CCTV - Lateral	Paper Reports Electronic - database Videotapes	Paper Reports Electronic - database - PDF Videotapes
Manhole Inspection	Paper Reports Electronic - database Diskette - Photos	Paper Reports Electronic - database - PDF - GIS Link - Photos with Link Diskette - Photos
Smoke Testing	Paper Reports Electronic - database embedded photos	Paper Reports Electronic - database embedded photos - PDF - GIS Link

[1]portable document format (file extension)

3.4 SSES Results

CCTV inspection of mainlines revealed structural and non-structural defects to varying degrees of severity within seven pilot basins. These included the cities of Auburn, Brier, Kent, Kirkland, Lake Forest Park, Mercer Island, and Redmond. Condition grades for the system components inspected by CCTV, manhole inspection, and smoke testing are summarized in Figure 3-2 and Figure 3-3. Condition Grades from 1 to 5 represent a rising scale of defect severity. Items with Condition Grades 3 and higher have defect severity levels which may indicate potential I/I sources requiring repair. As shown in these figures, 17 percent of mainlines, 10 percent of laterals/side sewers, and 47 percent of manholes tested showed potential need for I/I-related repair.

Inspection of manholes indicated that a significant proportion of the structures have moderate to very serious problems within 11 pilot basins. These included the Coal Creek Utility District, Northshore Utility District, Val Vue Sewer District, Skyway Water and Sewer District, and the cities of Auburn, Brier, Kent, Kirkland, Lake Forest Park, Mercer Island, and Redmond.

Smoke testing revealed relatively few connections to the sewer system within nine pilot basins. These included the Coal Creek Utility District, Northshore Utility District, Val Vue Sewer District, and the cities of Auburn, Brier, Kent, Kirkland, Lake Forest Park, and Mercer Island.

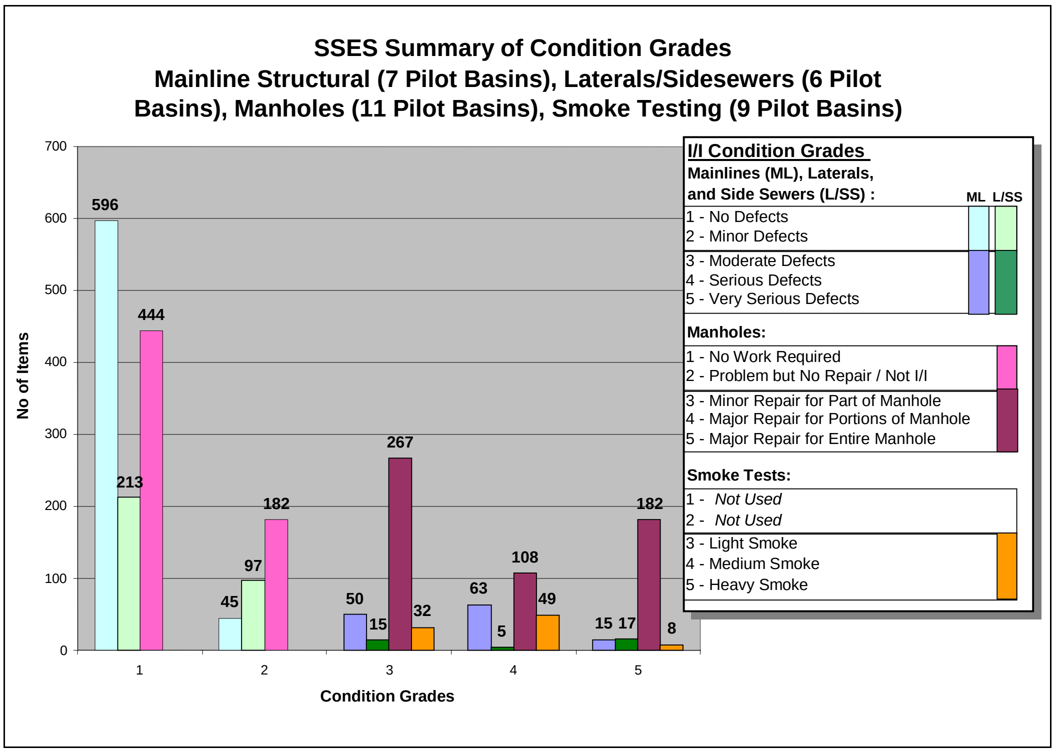


Figure 3-2. SSES Structural Defects Summary

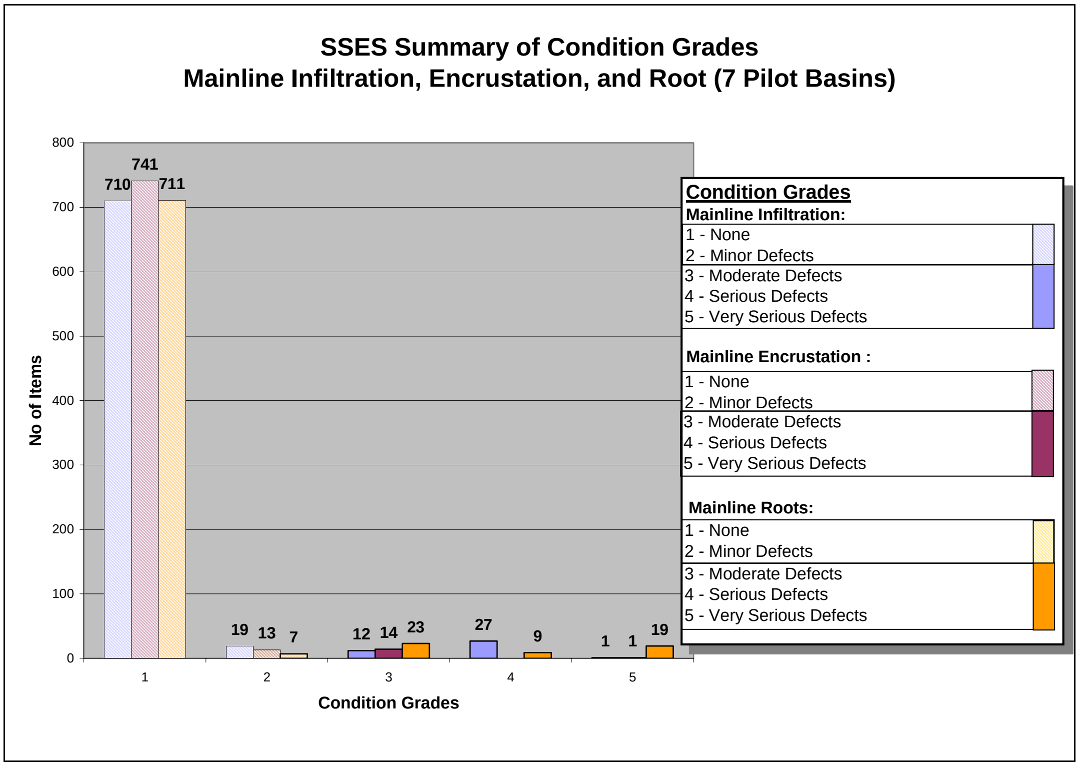


Figure 3-3. SSES Non-Structural Defects Summary

Vacuum testing of the manholes proved to be effective in locating defects in the manhole structures that were otherwise not detected by visual inspection.

FELL testing proved to be effective in locating defects not detected by the CCTV inspection, particularly at pipe joints where potential I/I pathways were detected.

3.5 SSES Costs

The contracted costs incurred to complete the SSES work for all pilot basins, excluding King County and local agency administrative and management time, are summarized in Table 3-2. Overall, the SSES effort cost approximately $1.2 million. Not all the costs can be converted to a unit cost because some of the costs, such as force account work, have no direct dependency on the linear footage of pipe or number of manholes in the system.

Table 3-2. Summary SSES Unit Costs

Task	Quantity	Cost	Unit Cost
Administration (King County, Local Agencies, and Earth Tech Team)	---	$434,000	
General SSES contractor costs (mobilization/demobilization, insurance, permitting, traffic control, project management, documentation/report)	---	$114,000	
Mainline cleaning, CCTV, and coding	141,358 lf[a]	$246,000[b]	$1.74/lf
Laterals and side sewers (CCTV, locates, cleanout installation)	475[c]	$169,000	$356 each
Manhole inspection	1,179	$104,000	$88 each
Smoke testing	209,236 lf	$68,000	$0.32/lf
Force account (unanticipated non-specific SSES work)	---	$86,000	

[a] linear feet
[b] No costs for coding Kent CCTV data included—City provided CCTV data
[c] Number of laterals and side sewers inspected

3.6 Public Involvement

SSES tasks were conducted in both public rights-of-way and on private property. Some activities, such as smoke testing, may be alarming to unprepared citizens or to fire and police departments. Cleaning and inspection operations may be temporarily noisy and disruptive to traffic. In some cases, access to and excavation work on private property was necessary and rights-of-entry needed to be obtained. Therefore, residents, appropriate officials of the local agencies, and local fire departments were informed of the location, timing, and nature of the SSES work. Appropriate agency and County staff were also involved in various aspects of public notification and SSES tasks.

3.6.1 Preliminary Orientation Meetings with Local Agencies

Prior to beginning any fieldwork, orientation meetings were arranged with each local agency. The meetings typically included public works operations staff and traffic control staff. In areas where a sewer district overlapped municipal jurisdictions, appropriate representatives from each jurisdiction were invited to attend the meeting to coordinate public notification, traffic control, and police and fire services, where necessary. The objectives of the orientation meetings were as follows:

- Review the anticipated scope of work and potential impact on community
  - Manhole inspection - traffic control
  - Smoke testing - traffic control and property access
  - CCTV - traffic control and property access

- Identify local requirements
  - Special event days on which to avoid work - for example, Seafair, street carnivals, etc.
  - Traffic control - identify any unique local requirements and ask local agency representatives to facilitate acquisition of any required permits

- Identify contact personnel - identify a chain of responsibility for notification requirements; identify appropriate agency staff, contractor, and County representatives and provide their phone numbers
  - Police - provide notification of location and time of smoke testing and other inspection work
  - Fire - provide notification of location and time of smoke testing
  - Public works or collection system staff - provide notification of location and time of inspection work, coordinate with cleaning and maintenance schedules, obtain assistance in locating and opening difficult manholes

- Identify public notice requirements and format preferences
  - Draft forms
  - Neighborhood block or committee meetings
  - Medium for notification - mailing, media release, door hanger, day-of-event smoke testing signs, County I/I program Web site
  - Schedule for notification

- Determine rights-of-entry requirements
  - Review draft form
  - Determine which staff will get signed rights-of-entry - County or local agency
  - Need for current owner addresses and exact boundaries for notification
  - Determine schedule for completion

- Answer local agency questions

3.6.2 Rights-of-Entry

Rights-of-entry (ROE) were obtained for properties in those pilot projects where side sewer CCTV inspection was performed. As a precaution, pins were placed to mark the location of critical features such as wyes or changes in pipe direction, and in case it became necessary to excavate to retrieve a jammed camera head or to install a cleanout. Typically, the local agency was responsible for obtaining ROEs. King County reviewed the forms used to ensure that the forms covered the County's needs. Some CCTV work on private property was not performed specifically because the ROE could not be signed in a timely manner.

3.6.3 Public Notification

Several forms of public notification were used for the SSES, depending on the type of investigation being conducted.

- CCTV (mains and laterals) and manhole inspections were preceded by a media release about 2 weeks in advance of the work.
- Prior to smoke testing in an area, the residents, businesses, and city officials received written notification from King County. The notification included one document highlighting the Regional Infiltration and Inflow Program, and another document identifying the elements of the study and providing contact information for local agency and King County staff. These notices carried both the local agency and County logos to show partnership in this program. Two days prior to smoke testing, crews delivered notices to each residence or building. At apartment or condominium buildings, the crews notified the site manager and provided enough notices to post either within the building or to distribute to each unit.

  In addition, King County issued media releases for each project area and sent the same information to local community or business organizations. To help notify "pass-through" traffic, several wooden A-frame signs were placed in the area ahead of the crews. These signs identified the program and provided a contact telephone number. The day smoke testing occurred, crews attached a red sign saying "smoke testing in progress". In the City of Kirkland, the public works crews offered the use of their construction light sign to help notify motorists and pedestrians on the smoke testing day. Police and fire departments and local agency contacts received daily schedules of the streets to be smoke tested within their jurisdictions.
- Designated local agency contact representatives were notified at the completion of SSES investigations and informed of any significant preliminary findings.

3.7 SSES Conclusions

Only visual identification of clear water entering the pipes through a specific defect or inappropriate connection can positively identify a source of I/I. Even during seasons of wet weather, it is often difficult to see or videotape a site at exactly the right time and conditions to record actual inflow of clear water. In addition, the amount of I/I varies from one rainfall event to the next. Consequently, identification of I/I sources is generally accomplished through compilation of circumstantial evidence pointing to a given defect, connection, or system condition as a “probable” source of I/I.

SSES investigations for the pilot projects successfully identified actual and potential I/I sources using a variety of inspection and testing techniques. Pilot project areas were selected based on pre-SSES flow monitoring results indicative of high I/I levels. In all pilot basins except the City of Auburn (ABN002) and City of Mercer Island (MRC012), the type and extent of defects and system conditions identified during the SSES were consistent with the observed patterns of the flow monitoring results. For pilot basins ABN002 and MRC012, SSES results did not identify actual or potential I/I sources that were consistent with the flow monitoring results. As a result, a more in-depth assessment was required to determine the source and nature of the excess measured flow.

In MRC012, an inability to identify I/I sources for what appeared to be a high inflow (a sharp spike in the flow) on the metering hydrograph led to re-evaluation of the flow records and further field testing. This revealed hydraulic anomalies at the metering site rather than actual inflow conditions, leading to the conclusion that there was no significant inflow contribution from the basin.

In ABN002, the initial SSES investigations looked beyond the narrow limits of the specific tests being performed (for example, CCTV and smoke testing), resulting in identification of a run of manholes set below the flow line in a drainage swale. In addition, re-evaluation of pre-SSES flow data from the basin meter indicated that the magnitude of recorded peaks was influenced by site conditions, thus impacting the accuracy of the readings.

The application of a variety of inspection techniques in different basins provided a greater understanding of the degree to which these techniques identified potential I/I sources so that they could be applied on a system-wide basis. Of the conventional inspection techniques applied to the pilot basins (CCTV of mainlines, side sewers, and laterals; manhole inspections; and smoke testing), CCTV provided the most complete and definitive data on probable I/I sources. While performing inspections during rain events might be more successful in spotting actual leaks, flows would be higher, resulting in either less pipe exposed for inspection or higher costs for bypassing flows.

FELL was very effective and economical in detecting the watertight properties of the pipe. It was especially effective in detecting leaky pipe joints where none could be identified by standard CCTV methods. The FELL technique does not give information on pipe surface condition and other non-penetrating defects. The FELL equipment and tests are simple to apply and can be readily and economically incorporated into the cleaning phase of pipe inspection work. FELL testing can be a valuable complement to CCTV inspection for general pipe condition assessment. If the objective is solely to identify existing breaks and leaky joints, FELL testing could be used instead of CCTV.

Manhole inspections also provided valuable information, particularly when these inspections were performed during rain events after antecedent rainfall had saturated the surrounding soils. As previously described, vacuum testing in manholes was very successful and economical in identifying small potential leaks at joints and for holes not otherwise apparent upon visual inspection. This is a test that could be applied more often where manholes are thought to be sources of I/I.

Smoke testing did not, for the most part, identify as many significant sources of inflow as expected, although several open connections were located. In most basins, peak I/I flow response was a combination of inflow and rapid infiltration. The relatively small number of returns on the smoke testing suggests that rapid infiltration may be the dominant contributor, or potential interferences (such as sags and debris dams) exist within the pipe and prevent the smoke from escaping.

The application of standardized coding to the observed system defects to reflect the relative severity and location of defects provided a way to consistently characterize defects and to quickly identify severe defects requiring corrective design work. SSES work identifying the location, types, and severity of system defects and overall pipe condition provides specific information to designers so that they may effectively determine appropriate types of rehabilitation and the limits of application.

Chapter 4

Rehabilitation Technology

This chapter describes the rehabilitation technology database developed for the pilot projects and includes a brief description of the major rehabilitation technologies that were considered by designers.

4.1 Rehabilitation Technology Database

Prior to the I/I pilot project design, a database of sewer rehabilitation technologies and products was developed to identify trenchless technologies requiring minor or no excavation. The database includes information on rehabilitation products for sewer mains, manholes, and lateral and side sewers. The purpose of compiling the database was to provide an overview of commercially available rehabilitation technologies that could be included during subsequent design of the pilot projects.

The initial collection of rehabilitation technology information was obtained from work done in Miami-Dade County in 1999. Additional sources of database information included product brochures, videos, samples, phone interviews, seminars, vender meetings, and Web sites.

The database includes information on:

- Installation requirements (for example, cure times, substrate conditions, how a product is applied)
- Application (pipe size, pipe material, pipe shape)
- Contact information (manufacturer, local representative, local installer)
- Installation costs (provided by the manufacturer, local representative, or installer)
- Warranty
- List of local installations
- Life expectancy

The database is organized into three rehabilitation categories: pipes (sewer mains), manholes, and laterals and side sewers (see Table 4-1). In general, the products reviewed reduce infiltration. One exception is “lid sealing” for manhole repair, which corrects or reduces inflow.

Table 4-1. Database Categories

Rehabilitation Category	Sub-category
Pipes (sewer mains)	Spiral Wound PVC Liner Slip Lining Point Repair Pipe Bursting Lining (Other) Groutin Fold and Form Cured-In-Place (CIP) Coating CIP Point Repair Point Repair (Other)
Manholes	Liner Lid Sealer Grouting External Sealant Coating
Laterals and Side Sewers	Slip Lining Pipe Bursting Lining (Other) Grouting Fold and Form Cured-in-Place (CIP) Coating CIP Point Repair Point Repair (Other)

4.2 Rehabilitation Technologies

Following is a brief description of the major rehabilitation technologies that were considered by designers for use on the pilot projects. Designers found these technologies through a product database; standards for sewer construction; review of trade publications; discussions with contractors, suppliers, and manufacturers of rehabilitation technologies; and their own knowledge or experience of trenchless technologies. While an extensive information search was conducted, it is likely that some rehabilitation technologies were missed.

4.2.1 Pipes (Sewer Mains)

Cured-In-Place Pipe

Cured-in-place pipe (CIPP) is a rehabilitation technology where a fabric liner saturated with a liquid resin is placed inside the existing sewer main, inflated, and then cured. The technology is used to provide a lining inside a host pipe to prevent infiltration through defects in the pipe, or it may be used to form a structurally sound new pipe. The process may be used on an entire segment of sewer main between manholes, or in specific locations of a sewer main as a spot repair.

Changing the resin type, fabric type, installation method, cure method, and design condition will vary CIPP. Resin types are typically epoxy, vinylester, or polyurethane. Fabric types are typically polyester felt or fiberglass. The liner is pulled in (usually with a cable) or inverted in the host pipe. Cure method is usually by steam, hot water, ultraviolet light, or ambient air. The design condition is for fully or partially deteriorated pipe.

Pipe Bursting

Pipe bursting is used to replace an entire segment of sewer main between manholes. The process involves replacing an existing pipe by pulling in a new high-density polyethylene (HDPE) pipe and simultaneously bursting the old pipe into fragments with a steel- bursting head. The broken pipe fragments remain in place in the surrounding soil.

Pipe bursting installation techniques are static, pneumatic, or hydraulic. In static pipe bursting, the bursting head is attached to a pulling device (usually a chain, cable, or threaded rods) and is pulled by force of the pulling device. In pneumatic pipe bursting, the bursting head may be attached to a pulling device or not, but receives most of the force by a pneumatic device in the bursting head. In hydraulic pipe bursting, the bursting head has an expansion device that compresses surrounding soil by means of hydraulic jacking prior to the pull into that area.

Pipe Reaming

Pipe reaming is used to replace an entire segment of sewer main between manholes. The process involves a directional drill used with a rotating head to grind the existing pipe into small pieces while pulling in a new pipe of the same or larger diameter.

Chemical Grouting

Chemical grouting of sewer mains is a process where acrylamide grout is pressure-injected into a crack, joint, or lateral connection in a sewer main. A remotely operated grout packer delivers the grout to the selected location. The grout packer is similar to a pipe plug that uses air to inflate bladders at each end of the plug. The grout is then injected under pressure into the annular space between the plug and the sewer main, and then migrates into the cracks and open joints. The flexible and non-cohesive grout remaining on the pipe wall when the grout packer is removed is pulled out, leaving grout in the joint spaces of the pipe.

Sliplining

Sliplining is typically used to line an entire length of sewer main between manholes, although it can be used in shorter portions of the sewer main. Sliplining involves pulling or pushing a smaller diameter pipe or liner into place inside an existing pipe. The sliplined pipe material is typically HDPE or fiberglass, although some other materials may be used. The pipe is typically grouted at the ends or over the length of the pipe.

Spiral Wound Pipe

Spiral wound pipe is a type of pipe used to slipline an existing pipe. This pipe is formed by spirally winding a continuous strip of some material into a pipe by means of a machine placed in the excavation or manhole. Strips can be made of polyvinyl chloride (PVC), HDPE, or steel. The strips are typically 2 to 6 inches wide and have a locking mechanism such that the strips “lock” into adjacent portions of the strip. Spiral wound pipe comes in two types: (1) those which are “wound” to the diameter required for sliplining, and (2) those which are “wound” in a smaller diameter, then twisted to expand the pipe to the host pipe diameter after the wound pipe is in place. There may also be steel wire or rebar placed in the strips to add structural support.

Deformed/Reformed HDPE

Deformed/reformed HDPE is a method for installing a new HDPE pipe or liner inside an existing sewer main. The HDPE pipe is pulled through a die to fold the pipe into a smaller diameter. The pipe is secured with breakaway plastic straps in the deformed position. The pipe is pulled into the sewer main and reformed either by plugging and pressurizing the main or by running a rounding device through the line to break the straps and allow it to form within the existing pipe.

Swage Lining

Swage lining is a method for installing a new HDPE pipe inside an existing sewer main. The HDPE pipe is pulled through a die or set of rollers to neck-down the pipe to a smaller diameter. This method relies on the property of polymeric materials to retain a memory of their original shape. The smaller diameter pipe is then pulled into the host pipe and pressurized to allow it to revert to the original diameter.

Fold and Formed PVC

Fold and formed PVC is a method for installing a new PVC pipe inside the entire segment of sewer main between manholes. The PVC pipe is heated and then folded into a smaller diameter at the factory. Then, after it is pulled into the sewer main, the PVC pipe is heated and pressurized to unfold and form to the shape of the host pipe. The PVC pipe is then cooled to form a rigid pipe inside the host pipe. This process relies on the property of PVC that allows it to be rigid at normal temperatures and flexible at higher temperatures.

4.2.2 Manholes

Interior Cementitious Coatings

Cementitious coatings are applied with a trowel, sprayed on, or poured, and are used to seal cracks on all or portions of the interior of the entire manhole. These coatings typically contain a mix of cement and chopped fibers. The coatings may be sprayed directly on the wall, over a wire mesh, or poured into an HDPE form with rebar. The coatings often contain calcium aluminate as an additive, which provides additional corrosion resistance for the concrete.

Cured-In-Place Fiberglass Manhole Liners

Fiberglass manhole liners are used to line all or portions of the interior surface of the manhole. The liners consist of a fabric liner saturated with a liquid resin. The liner is placed inside the manhole, inflated, and then cured. The fabric typically consists of layers of woven fiberglass bonded to a non-porous membrane, the resin is epoxy, and the curing method is steam. Ladder rungs are removed during installation and may or may not be re-installed.

Paving Rings

A WHIRLyGIG (manufactured by the Whirlygig Company) is a concrete form and cutting gig designed to allow concrete to be poured. It is used to replace the chimney section of the manhole. The WHIRLyGIG has a rigid rubber form that sits on the top of the cone and makes up the interior of the chimney. Concrete is poured around the WHIRLyGIG to the edge of the excavation, and this concrete becomes the new chimney.

Leveling Ring Boots

Leveling ring boots are intended to seal the inside of the chimney section of the manhole. They are made of a circular heavy-ribbed rubber that is held in place with expanding interior stainless steel rings. The boots are installed by simply opening the cover, so no excavation is required. The boots need to be fit around any ladder rungs located in the chimney or the ladder rungs may be removed.

Manhole Pans

Manhole pans fit under the manhole cover and are intended to prevent inflow through holes in the manhole cover. The pans are either HDPE or stainless steel.

Reset Frame and Raise to Grade

Resetting the frame is a method intended to adjust a frame that has moved horizontally and/or to raise the cover above grade to prevent inflow, mostly in non-paved areas (for example, when a cover is located in a slight depression where ponding of water occurs). The installation involves minimal excavation – only enough to allow replacement of damaged concrete leveling rings and addition of new rings to bring the top of the frame above grade.

Cement Patching Grouts

Cement patching grouts are hand-applied grout mixtures used to seal cracks on all or portions of the interior of the manhole. There are many different compositions of these grouts.

Interior Epoxy Coatings

Epoxy coatings are applied as a spray and are used to coat the interior of the entire manhole to form a water/vapor barrier. These coatings are two-part epoxy, typically 100- percent solids by volume. They require abrasive blasting or high-pressure water cleaning for surface preparation.

Interior Polyurethane Coatings

Polyurethane coatings are applied as a spray and are used to coat all or portions of the interior of the entire manhole to form a water/vapor barrier. These coatings are made of urethane resin. They require abrasive blasting or high-pressure water cleaning for surface preparation.

Exterior Coatings

Exterior coatings are used on all or portions of the barrel, cone, and chimney sections of manholes. These coatings are unique in that they require less of a bond than interior coatings, due to the fact that the backfilled soil holds them in place and any groundwater presses the coating onto the manhole. These coatings come in different types: spray-on cementitious, epoxy, or polyurethane; shrink-wrap plastic; and/or adhesive rubber tapes. These coatings require excavation around the manhole.

PVC Manhole Liners

PVC manhole liners are used to line all or portions of the interior surface of the manhole. They are made of sheets of PVC and are mechanically or adhesively connected to the manhole. Mechanical connection is either by: (1) protruding locking shapes of the PVC material which is embedded into grout applied to the interior of the manhole, or (2) by attachment to the manhole by stainless steel anchors with a PVC cap welded over the top of the anchor. Adhesive connection is by a polymer applied to the concrete manhole, which is then bonded to the PVC with an activator.

Pre-Formed Fiberglass or HDPE Manhole Liners

Pre-formed fiberglass or HDPE manhole liners are rigid shapes fabricated at a plant to match the interior size of the manhole. They are used to line the interior surface of the manhole in the base, barrel, cone, and sometimes in the chimney sections. The liner is installed by excavating and removing the manhole cone section. Then the liner is inserted and the cone section replaced. For installations in portions of the manhole, the edges of the liners are grouted to form a seal with the manhole surface.

Chimney Barriers

The I/I Barrier (manufactured by Strike Products) is one proprietary product considered a chimney barrier. It is used to rehabilitate the chimney section of the manhole. The I/I Barrier consists of a rigid medium-density polyethylene riser with a thick base that sits on top the cone section of the manhole. The concrete manhole rings are then stacked on the thick base on the outside of the riser. The riser becomes a barrier to I/I entering the chimney section.

Manhole Covers

Gasketed manhole covers are steel covers with an inset gasket either in the frame or placed between the frame and cover. They are intended to prevent inflow from around the manhole cover.

Solid manhole lids without holes are available, as are plugs for the holes.

HDPE Leveling Rings

HDPE plastic leveling rings are meant to replace concrete leveling rings. The leveling rings are not solid HDPE; rather, they are hollow with support ribs.

New Concrete Leveling Rings

New concrete leveling rings are used to repair the chimney section where existing brick or concrete chimneys have worn out. The leveling rings may be sealed with non-shrink cement grout, a rubber gasket, or butyl rubber mastic. Likewise, the frame may be sealed to the chimney by the use of a rubber gasket or butyl rubber mastic.

Pipe Penetration Repairs

Kor-N-Seal® boots are a proprietary product consisting of a rubber boot that uses an interior stainless steel band to seal to the manhole core drill and an outer stainless steel band to seal to the sewer main. In existing manholes, a remote core drill must be performed to allow use of this gasket.

LCT™ gaskets are a proprietary product consisting of a rubber gasket that can be cast into new manholes and sealed around the sewer main.

Sand collars are a short section of the bell end of a PVC pipe with a gasket. The collar has sand embedded on the outside for grout adhesion. The sand collars are grouted into manhole openings for pipe penetrations.

New Concrete Manholes

New concrete manholes are used to replace existing manholes. The new manholes are typically installed with rubber gaskets between barrel sections. Cement patching grout is typically used on all joints between base, barrel, cone, chimney, and frame sections.

Fiberglass Manholes

Fiberglass manholes are used to replace the base, barrel, cone, and in some cases the chimney portions of existing manholes. The manholes are typically pre-fabricated to ship to the site in one unit. The fiberglass manholes require excavation and full installation, as is required for new concrete manholes.

HDPE Manholes

HDPE manholes are used to replace the base, barrel, cone, and in some cases the chimney portions of existing manholes. The manholes are typically pre-fabricated to ship to the site in one unit. The HDPE manholes require excavation and full installation, as is required for new concrete manholes.

4.2.3 Laterals and Side Sewers

Cured-In-Place Pipe

CIPP installation and products for laterals and side sewers are similar to and in some cases the same as for sewer mains. A fabric liner saturated with a liquid resin is placed inside the existing pipe, inflated, and then cured. The intent is to prevent infiltration through defects in the pipe, or CIPP may be used to form a structurally sound new pipe. The method may be used on all or portions of the lateral or side sewer. A cleanout or excavation is required at some location on the lateral or side sewer to allow access for insertion of the liner.

Pipe Bursting

Pipe bursting is used to replace all or a portion of the lateral and side sewer between the house and sewer main. The process involves replacing an existing pipe by pulling in a new HDPE pipe and simultaneously bursting the old pipe into fragments with a steel bursting head. The broken pipe fragments remain in place in the surrounding soil. A cleanout is usually placed where the pipe-burst lateral connects to existing pipe, either at the house or at the property line.

Pipe bursting of laterals is usually done by the static method due to the lower force required to burst the smaller diameter laterals.

Chemical Grouting

Chemical grouting of laterals and side sewers is a process where a crylamide grout is pressure-injected into a joint or lateral connection point of a lateral or side sewer. The grout is delivered remotely to the location by a mechanism that has two sealing devices; the grout is injected into the entire space between the two. The flexible and non-cohesive grout is pulled out of the pipe in the area between the sealing devices, leaving grout in the joint spaces of the pipe. Where used to seal the connection between the sewer main and lateral, three devices are used, two in the main and one in the lateral.

Service Connection Rehabilitation Liners (SCLs)

The service connection liner (SCL) is a cured-in-place liner used to seal the service connection between the sewer main and lateral. The SCL, installed by remote device, typically consists of a fiberglass fabric and polyester resin. A portion of the liner seals around the opening of the lateral in the sewer main, and a portion (usually 2 to 6 inches in length) is located in the lateral. The SCL is held in place either by an epoxy that forms a bond at the interface between sewer main and lateral, or by mechanical friction between the SCL and the lateral.

Service Connection and Lateral Liners (SCLLs)

The SCLL is a cured-in-place liner used to seal the service connection between the sewer main and lateral and some portion of the lateral and/or side sewer. The SCLL, installed by remote device, typically consists of a felt fabric and polyester resin. A short portion of liner is placed in the sewer main around the full diameter, and a second portion is located a defined distance up the lateral and/or side sewer. The two pieces are attached. Some products can be used for lining more than 80 feet up the lateral. Tees and fittings can sometimes be lined through; however, they are usually excavated to allow for reconnection.

Chapter 5

Pilot Project Design

This chapter describes the pilot project design process, including objectives, definition of basin types, and steps followed. The selection process for system components to be rehabilitated is discussed, as well as the selection process for rehabilitation technologies and products. Public and agency involvement and environmental issues are also described.

> **Note:** The pilot project basin and rehabilitation maps (Figures 5-2 through 5-25) are located at the end of the chapter (section 5.6).

5.1 Design Objectives

The aim of the pilot project design effort was to develop designs that satisfied the following objectives:

- Repair defects in the collection system to reduce I/I
- Repair defects in selected collection system components – including manholes, mains, laterals, and/or side sewers
- Develop rehabilitation improvements which fit within the construction budget
- Use a variety of proven and mostly trenchless rehabilitation techniques to gain experience with different methods and costs of sewer system repair

The Sewer System Evaluation Survey (SSES) results and information obtained about the collection system, basin characteristics, and mini-basin surface features were used in the design effort.

5.2 Pilot and Control Basins

5.2.1 Pilot Basins

During the selection process, project locations were identified on a broad scale, encompassing entire mini-basins. However, it was anticipated that rehabilitation of the entire sewer system in a mini-basin was infeasible due to budget constraints. Therefore, it was assumed that a sub-basin would be delineated within the mini-basin, and that the actual rehabilitation work would be performed within this sub-basin. The sub-basin where the rehabilitation work took place was defined as the “pilot basin”. The pilot basin could encompass either part of or all the mini-basin (see Table 5-1). Figure 5-1 shows the locations of the pilot projects.

Table 5-1. Area Encompassed by Pilot Basin

Pilot Basin Area	Pilot Project
Same as mini-basin	Lake Forest Park, Ronald, Manhole Project (Coal Creek, Northshore, and Val Vue)
Smaller than mini-basin	Auburn, Brier, Kent, Kirkland, Mercer Island, Redmond, Skyway

The decision to delineate a pilot basin within a mini-basin was made during late summer 2002 during the early phases of design. It was acknowledged that one consequence of delineating pilot basins early on in the design process was the necessity of speculating about trends in the defects that had been observed. At the time, a limited amount of the SSES work had been completed. The schedule for delineating pilot basins was driven by the following flow monitoring concerns:

- The need to conduct pre-rehabilitation flow monitoring on the pilot basin if it was smaller than the mini-basin. The proposed pre-rehabilitation flow-monitoring period was November 1, 2002 to January 15, 2003. If the pilot basin was the same as the mini-basin, the flow data from the flow monitoring seasons for 2000/2001 and 2001/2002 were sufficient to characterize the pre-rehabilitation flows.
- The need to conduct field evaluations of the outlet manholes prior to flow monitoring. The suitability of each manhole as a flow monitoring point needed to be evaluated. If the manhole was unsuitable because of poor flow monitoring conditions such as high velocities or susceptible to debris accumulation, the pilot basin needed to be adjusted and other manholes evaluated. This manhole investigation needed to be completed 1 to 2 months in advance of the flow monitoring.

During the design phase for the Auburn and Redmond pilot projects, rehabilitation work was added within the mini-basin, but outside the delineated pilot basin. This effectively created a second pilot basin within the overall mini-basin for these two pilot project areas. King County determined that the mini-basin flow meter could be used to evaluate the reduction effectiveness in the Auburn and Redmond pilot basins. Second pilot basins are identified as Pilot Basin B in Table 5-2 and in Figure 5-2 and Figure 5-11. (Figures 5-2 through 5-25 are located at the end of the chapter.)

To quantify flows for the Kent pilot project, it was necessary to install two flow meters due to the tributary patterns. Flows from Basins A and B were combined for analysis purposes. Figure 5-4 shows the Kent pilot basins.

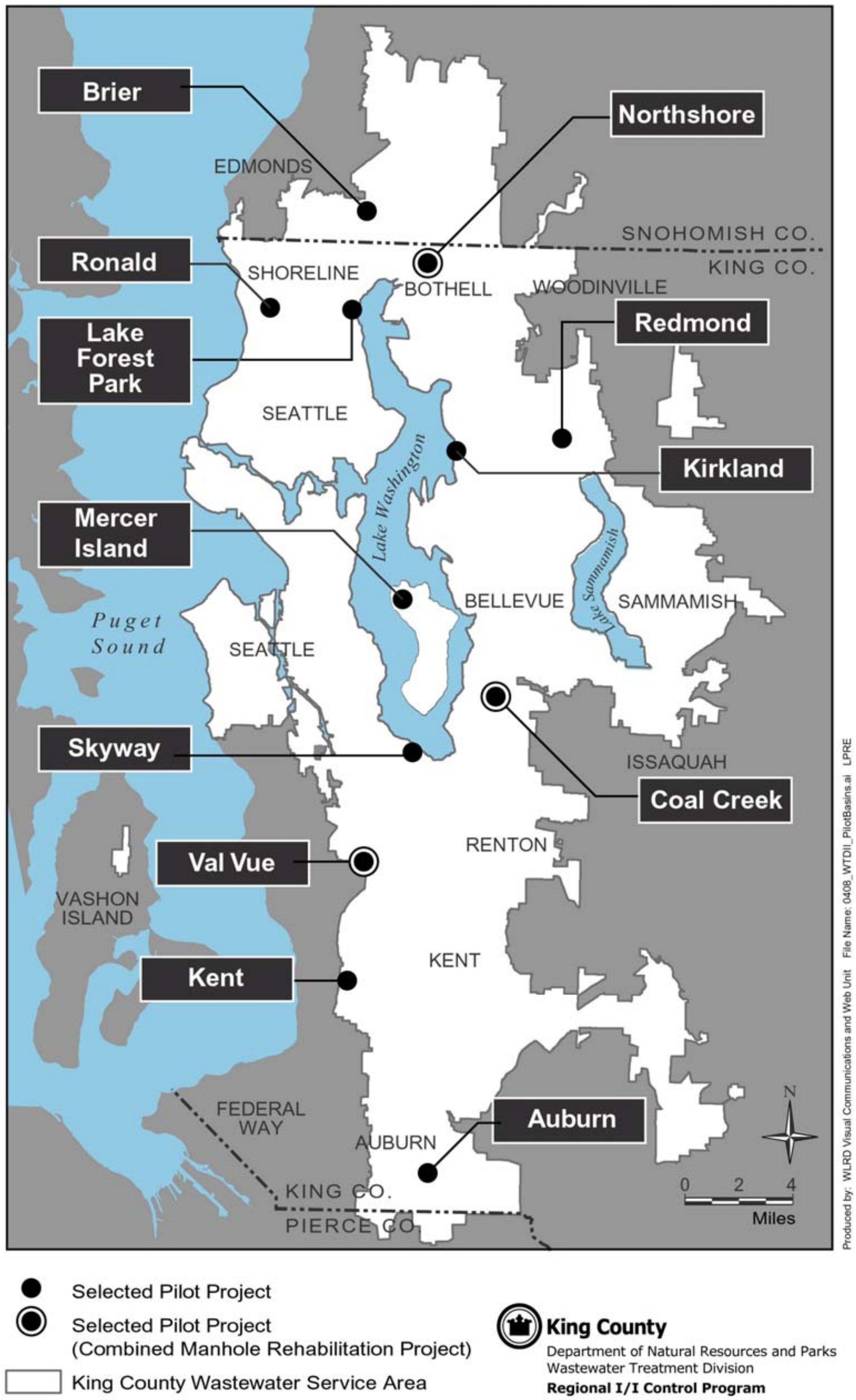


Figure 5-1 Selected Pilot Project Location Map

5.2.2 Control Basins

One of the pilot project objectives was to document I/I reduction resulting from rehabilitation of a sewer system. In order to do so and to obtain comparison data at the same time, it was desirable to simultaneously monitor “control basins” in the vicinity of the pilot basins.

The criteria for establishing a control basin included:

- Basin size similarity to the pilot basin so that the measured flows from each are comparable
- Sewer system similarity to the pilot basin in regard to construction and age
- A flow response to rainfall similar to that of the pilot basin (if the information was available)

With regard to the last criterion, no flow data existed to compare with the pilot basin unless an entire mini-basin was proposed as a control basin. In that case, data could be obtained under the assumption that the mini-basin flow data was representative of the entire basin. The pre- and post-rehabilitation flow monitoring of the pilot and control basins is discussed further in Chapter 8.

Given that the entire mini-basin served as the pilot basin for the Manhole Project (Coal Creek, Northshore, and Val Vue), Lake Forest Park, and Ronald, control basins were selected from other mini-basins in the vicinity of the pilot project. No pre-rehabilitation flow monitoring was conducted in these basins during the winter of 2002-2003 because the flow data from the flow monitoring seasons for 2000/2001 and 2001/2002 were sufficient to characterize the pre-rehabilitation flows. The mini-basin meter numbers used for the control basins were Lake Forest Park--RON039, Coal Creek--CCR009, Northshore--BOT012, Val Vue--VAL017, and Ronald--RON045.

5.2.3 Mini-Basin, Pilot, and Control Basin Size and Features

Figure 5-2 through Figure 5-13 shows the final pilot and control basin boundaries for each of the pilot projects. Table 5-2 shows the acreage and linear feet of sewer main for the pilot basins, control basins, and mini-basins.

The flow meter names as shown in the figures were assigned at the beginning of the 2002-2003 flow monitoring season, and in some cases do not correspond directly with the name of the basin monitored because of the pilot and control basin configuration or subsequent changes in the design. For example, in Figure 5-2, the flow meter measuring flows from Pilot Basin B was named “Auburn Control”. The inconsistency is the result of the lower half of the basin being changed from a control basin to a Pilot Basin B, as discussed in the next section. The “Auburn Control” meter was also installed in the same manhole that was used in previous flow monitoring seasons to measure flows from the entire mini-basin. In Brier, Kirkland, Lake Forest Park, Ronald, and the Manhole Projects, the pilot basin meters were installed for the 2002-2003 flow-monitoring season in the same manhole that was used in the previous flow monitoring seasons to measure flows from the entire mini-basin.

Table 5-2. Pilot Basin, Control Basin, and Mini-Basin Size

Pilot Project Name	Figure No.	Mini-Basin Meter No.	Acres				Linear Feet of Main			
			Total Mini-Basin	Pilot A	Pilot B	Control	Total Mini-Basin	Pilot A	Pilot B	Control
Auburn	Figure 5-2	ABN002	470	292	178	(1)	30,768	18,893	11,876	(1)
Brier	Figure 5-3	BRR004	223	97	--	126	28,583	12,970	--	15,609
Kent	Figure 5-4	KNT014	156	20	21	30	24,649	3,276	3,324	4,855
Kirkland	Figure 5-5	KRK011	162	112	--	50	23,075	16,406	--	6,669
Lake Forest Park	Figure 5-6	RON041	145	145	--	218 (2)	25,873	25,873	--	34,289 (2)
Manhole Coal Creek	Figure 5-7	CCR002	165	165	--	97 (2)	27,550	27,550	--	15,214 (2)
Manhole Northshore	Figure 5-8	NUD038	365	365	--	158 (2)	40,318	40,318	--	17,038 (2)
Manhole Val Vue	Figure 5-9	VAL019	87	87	--	220 (2)	15,250	15,245	--	28,442 (2)
Mercer Island	Figure 5-10	MRC012	140	31	75	34	29,057	22,462	--	6,595
Redmond	Figure 5-11	RDM009	182	73	52	57	35,548	14,900	8,243	12,405
Ronald	Figure 5-12	RON002	95	95	--	104 (2)	13,097	13,097	--	18,624 (2)
Skyway	Figure 5-13	BLS002	156	47	--	38	33,674	10,038	--	8,791

(1) Pilot Basin B in Auburn was also the control basin for the beginning of the 2003-2004 post-rehabilitation flow-monitoring period.
(2) These control basins were separate from the mini-basin selected as the pilot project (See Table 5-1).

5.2.3.1 Pilot Basins with Boundaries Smaller Than the Mini-Basin

For each of the following pilot projects the pilot basin was reduced from the original mini-basin selected for the pilot project. The following sections describe the issues considered in defining the actual pilot basin.

Auburn

The City of Auburn suspected that capacity-related problems were present at approximately the midpoint in the mini-basin. In addition, analysis of the hydraulic sewer conveyance system in the lower half of the mini-basin determined that system capacity was less than the measured peak flows, suggesting error in the flow data. Based on these two issues, a pilot basin was delineated to include the upper half of the Auburn mini-basin just upstream of the point of suspected capacity problems. This area is shown in
Figure 5-2 as Pilot Basin A.

The SSES investigations identified very few defects in the sewer mains and manholes. Several of the laterals and side sewers in the pilot basin were inspected and very few defects were identified. However, defects were identified in the private sewers of the Auburn Adventist Academy (see Figure 5-14). As a result, the rehabilitation effort focused on this private sewer system.

The lower half of the Auburn mini-basin was originally proposed as the control basin; however, subsequent field investigations established that several manholes in the lower portion of the basin were subject to surface inundation. Thus, it was decided that work would also be conducted in the lower portion of the basin primarily for targeting inflow. This area, which became a second pilot basin, is labeled as Pilot Basin B in Figure 5-2.

Brier

In the Brier mini-basin, the SSES showed defects in the sewer mains, manholes, and service connections. The defects were distributed throughout the mini-basin, but were slightly more prevalent in the southern half. Some of the sewer mains were replaced in 1982 with polyvinyl chloride (PVC) pipe. Thus, the pilot project focused on repair of defects in: (a) portions of the system that were not replaced in 1982, and (b) portions of the 1982 system that had failed connections. The southern half of the mini-basin was selected as the Brier pilot basin because of the slightly higher number of defects found in that area. The control basin became the northern half of the mini-basin. The pilot and control basins are illustrated in Figure 5-3.

Kent

In the Kent mini-basin, the SSES investigations identified few defects in the sewer mains, manholes, or service connections. It was concluded that the source of I/I was likely in the side sewers. The northwest portion of the mini-basin, upstream of the city's Linda Heights Pump

Station, was chosen as the pilot basin. This area was selected as the pilot basin for two reasons. First, the City of Kent staff stated that there had been more side sewer problems (such as backups) in this area than in the rest of the mini-basin, and second, the size of this area allowed for all side sewers and laterals to be rehabilitated within the project budget.

Due to the sewer main configuration in the northwest portion of the mini-basin, two flow meters were necessary to quantify flows from this area. There were, in effect, two separate pilot basins adjacent to each other, and the flow monitoring results could be added. These pilot basins are labeled Pilot Basin A and Pilot Basin B, as shown in Figure 5-4.

The control basin was chosen because of its close proximity to the pilot basin and its similarity in acreage and land use. The control basin is shown in Figure 5-4.

Kirkland

In the Kirkland mini-basin, initial SSES results generally revealed defects in sewer mains, manholes, laterals, side sewers, and in several direct inflow sources. It was also known that the sewer main was recently replaced along Lake Washington Boulevard Northeast. Therefore, it was decided that I/I improvements would be performed on side street portions of the collection system located east of Lake Washington Boulevard Northeast.

It was determined that splitting the mini-basin in half would provide two comparable basins due to the similarity in topography and land use density in the narrow north-to-south mini-basin. Either basin could have been selected as the pilot basin; each was roughly the appropriate size for the available construction funds. Pipe condition was about the same in both basins. However, the City of Kirkland had experienced many more maintenance problems with the sewer mains in the northern half of the mini-basin. Thus, the northern half was selected as the pilot basin, as shown in Figure 5-5. The southern half of the mini-basin was selected as the control basin.

Mercer Island

In the Mercer Island mini-basin, significant defects were found by the SSES within the sewer mains and service connections. It was anticipated that the pilot project would focus on rehabilitation of sewer mains and service connections only. The anticipated rehabilitation method was cured-in-place pipe. Based on initial cost estimates for lining sewer mains, a pilot basin was selected in the northern portion of the mini-basin. This pilot basin could be readily monitored, and its selection would allow all sewer mains and service connections within the pilot basin to be rehabilitated within the project budget. A control basin of similar size was selected adjacent to the pilot basin.

As design progressed, it became apparent that by limiting rehabilitation to the sewer main and service connections, the cost would be significantly less than originally anticipated. Therefore, an additional area to be rehabilitated was added in the southern portion of the mini-basin, becoming, in effect, a second pilot basin. The additional area did not include any part of the control basin.

As shown in Figure 5-10, the pilot basin in the northern portion of the mini-basin is labeled Pilot Basin A and the southern portion is labeled Pilot Basin B. The figure also shows the control basin.

Redmond

Within the Redmond mini-basin, the SSES identified defects in all portions of the collection system. However, the hydrograph for the Redmond mini-basin showed that almost all the I/I was slow response, suggesting base infiltration. Well head records showed that the groundwater level within the Redmond mini-basin was approximately at the invert of sewer mains at the low end of the basin during the summer, and was approximately 8 feet higher during the winter. Thus, it was anticipated that repair of sewer mains, service connections, and laterals could be performed anywhere in the mini-basin.

After some initial work, it was discovered that the sewer main at the low end of the system was on a busy arterial, under a railroad bridge, and next to the Sammamish River, which would have complicated rehabilitation construction. Due to these difficulties, it was thought that more I/I defects could be rehabilitated within the project budget in other portions of the mini-basin. Thus, the western portion of the system was left out of the pilot basin.

Two approximately equal areas located in the northeast and southeast portions of the mini-basin were selected as the pilot and control basins. After selecting comparable areas that could be flow monitored, the northeast portion of the mini-basin was designated as the pilot basin and the southeast portion as the control basin. The condition of sewer mains, service connections, and laterals was comparable in both areas. However, a very active commercial area and two principal arterials were located in the southeast area. This would have dictated that work be accomplished at night within a short time frame. The northeast portion had some commercial and multi-family dwellings, thereby requiring some night work, but also had lower-traffic-volume local streets on which to work.

Subsequent to selection of the pilot and control basins, cost estimates were revised. It was determined that some additional work could be performed. The additional work was conducted in the western half of the mini-basin, which, in effect, became a second pilot basin. As shown in Figure 5-11, the northeast portion of the mini-basin is designated Pilot Basin A, the west portion as Pilot Basin B, and the southeast portion served as the control basin.

Skyway

Engineering work related to I/I rehabilitation had been previously completed in the Skyway mini-basin. There was an existing project within the mini-basin that had been bid twice by the local agency. A contract was not awarded due to the fact that bid prices were higher than the project budget. This existing project, located within the southwest portion of the mini-basin, included complete plans and specifications. A review of SSES data confirmed that defects were significant within the area of this project. Defects were noted within the sewer mains, manholes, service connections, laterals, and side sewers. It was decided that for the Skyway pilot project, a full system rehabilitation would be performed. The project area defined for the previous project became the selected pilot basin, thereby allowing use of the existing plans as a base.

An area adjacent to the pilot basin and of similar size was added as the control basin. The pilot basin, mini-basin, and control basin are shown in Figure 5-14.

5.3 Design Process

King County completed the design of all pilot projects with the exception of the Ronald project. The Ronald Wastewater District managed the design and construction of its own pilot project. Information about the design of the Ronald project was provided to the County. It was considered in the selection of rehabilitation technologies and processes along with the other projects.

The design process for the nine County-designed pilot projects was largely conducted as a collaborative effort. A design team was assembled consisting of five designers and two team managers, a lead designer was assigned to each pilot project, and frequent meetings were held to share information among team members. The design team followed the process outlined below.

- Identify types of I/I based on hydrographs
- Evaluate SSES work and identify defects
- Define a variety of system components to be rehabilitated
- Select rehabilitation technologies to be used
- Select which techniques and/or products would be used on each pilot project
- Develop construction drawings and specifications
- Develop engineer’s estimate of cost

Each of these steps is described in further detail below.

5.3.1 Hydrographs and I/I Flow Rates

Hydrographs and I/I flow rates were used during design in several ways:

- The hydrograph flow response suggested which system components contributed to I/I. This allowed SSES efforts to be focused and allowed designers to look more closely at SSES results in various areas of the system.
- Flow response related to rainfall and flow rate information supported design decisions for all portions of the system when SSES information was incomplete.
- Flow rate information allowed designers to judge whether the defects identified in the SSES were significant enough to cause the I/I rate shown, or, whether additional defects existed but were not detected by the SSES.

A copy of the mini-basin hydrographs for the 2001-2002 flow-monitoring season is included in Appendix A along with nomination forms for pilot project candidates.

Table 5-3 summarizes the type of flow responses in each of the mini-basins selected for pilot projects, the I/I flow rate, and the suspected system components which contributed to I/I based on the hydrograph flow response for each mini-basin. Suspected sources were further defined through SSES investigations and designers' knowledge of the collection system.

Table 5-3. Pilot Project Flow Responses, I/I Flow Rates, and Suspected System Components

			Suspected Sources of I/I			
Pilot Project	**Hydrograph Flow Response**	**I/I Flow Rate (gpad)[1]**	**Manhole**	**Sewer Main**	**Lateral and Side Sewer**	**Inflow**
Auburn	Fast response and rapid infiltration	10,030	●	●	●	●
Brier	Rapid infiltration	6,338	●	●	●	
Kent	Fast response and rapid infiltration	7,709	●	●	●	●
Kirkland	Fast response and rapid infiltration	7,289	●	●	●	●
Lake Forest Park	Fast response and rapid infiltration	7,962	●	●	●	●
Manhole Coal Creek	Rapid infiltration	4,202	●	●	●	
Manhole Northshore	Fast response and rapid infiltration	6,025	●	●	●	●
Manhole Val Vue	Fast response	4,307	●		●	●
Mercer Island	Fast response and rapid infiltration	13,719	●	●	●	●
Redmond	Slow infiltration	5,250	●	●		
Ronald	Fast response and rapid infiltration	11,279	●	●	●	●
Skyway	Fast response and rapid infiltration	27,167	●	●	●	●

[1]gallons per acre per day

5.3.2 Identification of Defects Using SSES Data

The largest single factor used when selecting proposed improvements was the SSES data on the type and location of defects. A detailed discussion of the SSES is included in Chapter 3 and in the separate SSES reports prepared for each pilot project.

Manhole and mainline closed circuit television (CCTV) inspections were performed on almost all portions of the system for each pilot project. An exception was the Manhole Project, where only manhole inspections were performed. Smoke testing and lateral CCTV were performed on portions of the system in some pilot projects. Side sewer CCTV was performed less frequently.

While the SSES used a coding system for quantifying defects, pilot project designers used both the coded data and the direct data. The SSES was approximately 70-percent complete when the pilot project design effort began. Designers immediately reviewed the CCTV tapes and other various reports (manhole, smoke test). In order to meet the pilot project schedule, design progressed and major design decisions were finalized as the last SSES data was delivered and reviewed.

Table 5-4 summarizes defects found by pilot project designer review of the raw SSES data. A qualitative description of the severity of defects is provided for each of the system components. This includes:

- Major – defects were found in a significant percentage (greater than 40 percent) of the system components
- Minor – defects were found in a minor percentage (10 to 40 percent) of the system components
- None – essentially no defects (less than 10 percent) were found in the system components
- Unknown – the SSES was not conducted in the system component

A quantitative description was provided for the inflow sources based primarily on smoke testing. In general, very few direct inflow sources were identified through smoke testing. The pilot project basin descriptions for inflow include:

- Few – a small number (generally 20 or less) of inflow sources were found in the basin
- None – essentially no inflow sources were found

The review of the SSES data by the pilot project designers focused on potential sources of I/I, whereas the SSES reports primarily emphasized structural defects. Therefore, there are some inconsistencies between conclusions of the two reviews.

Table 5-4. I/I Defect Locations Based Upon SSES

Pilot Project	Sewer Main	Manhole	Lateral	Side Sewer	Service Connection	Inflow
Auburn[1]	Minor	Minor	Minor	Minor	Minor	Few
Brier	Minor	Minor	Unknown	Unknown	Minor	None
Kent	Minor	Minor	None	Unknown	None	Few
Kirkland	Major	Minor	Minor	Minor	Major	Few
Lake Forest Park	Minor	Minor	Unknown	Unknown	Minor	Few
Manhole Coal Creek	Unknown	Major	Unknown	Unknown	Unknown	Few
Manhole Northshore	Unknown	Major	Unknown	Unknown	Unknown	Few
Manhole Val Vue	Unknown	Minor	Unknown	Unknown	Unknown	None
Mercer Island	Major	None	Unknown	Unknown	Major	Few
Redmond	Minor	Minor	Minor	Unknown	Minor	None
Ronald	None	None	Minor	Major	Minor	Few
Skyway	Major	Major	Major	Major	Major	Few

[1] Defects in the manholes, sewer mains, lateral, and side sewers were identified primarily in the private sewers of the Auburn Adventist Academy. Sewers in the remainder of the basin were generally in very good condition.

5.3.3 Selection of System Components to be Rehabilitated

The next phase of the design met one of the original design objectives; that is, to select a variety of system components to be rehabilitated by the pilot projects. It was desirable to compare removal effectiveness based solely on rehabilitation of specific system components. Designers proposed the system components on which each pilot project would focus. Their proposal was based on suspected defect locations as shown by the hydrographs (Table 5-3) and on locations of known defects as identified by the SSES (Table 5-4).

When SSES data did not clearly identify I/I sources in the system, designers used other information to try to determine the most likely source of I/I. Other information came from the local agencies on existing pipe materials and on any other specific collection system details they knew about. Side sewer cards were obtained from the local agencies to identify the age and type of construction.

Designers met to collaboratively select the variety of system components and combinations of system components to be rehabilitated in the pilot projects. Where needed, projects were adjusted to ensure that the overall variety and combinations were present. It is important to note that not all defects were proposed for rehabilitation on each pilot project. Two examples of this are the Kirkland and Mercer Island pilot projects. Both of these projects identified inflow sources; however, neither project included inflow removal because other system components were selected as the project's primary focus. Table 5-5 shows the sewer system components selected for rehabilitation in each pilot project.

Table 5-5. Sewer System Components to be Rehabilitated

Pilot Project	Sewer Main	Manhole	Lateral	Side Sewer
Auburn Pilot A	●	●	●	●
Auburn Pilot B		●		
Brier	●	●		
Kent			●	●
Kirkland	●	●	●	
Lake Forest Park	●	●		
Manhole - Coal Creek		●		
Manhole - Northshore		●		
Manhole- Val Vue		●		
Mercer Island Pilot A	●			
Mercer Island Pilot B	●			
Redmond Pilot A	●	●	●	
Redmond Pilot B	●	●	●	
Ronald				●
Skyway	●	●	●	●

Figure 5-14 through Figure 5-25 show the location and amount of system component rehabilitation included in the design of each pilot project.

In Auburn, few defects were identified in the public sewer system, and very little work was done in Auburn Pilot A. Auburn Pilot B was chosen as the one pilot basin that would primarily target inflow. This decision came late in the design process when field investigations established that several manholes in this basin were subject to surface water inundation. Minor defects were found in other system components in Auburn Pilot Basin A, but did not appear to account for all of the I/I in the mini-basin. Given that Auburn Pilot Basin B was monitored separately from Pilot Basin A, it was advantageous to target inflow in Pilot Basin B.

Kent was ultimately chosen as the one pilot project to exclusively target laterals and side sewers. The SSES showed only a few defects in the sewer mains and manholes of the pilot basin. About 20 percent of the laterals in the basin were inspected and no defects were found. Designers suspected that there were defects in the side sewers because of the lack of defects in the other system components that were inspected.

One design objective was to repair defects in selected system components. Given that information was unavailable about which side sewers had defects, the decision was made to rehabilitate all laterals and side sewers within the pilot basin where rights-of-entry could be obtained. Rights-of-entry were granted for approximately 95 percent of the parcels within the pilot basin. In this way, Kent became the pilot project that tested the removal effectiveness of rehabilitating all laterals and side sewers within a pilot basin.

Kirkland was originally selected as a pilot basin where side sewers would be included as part of the rehabilitation. However, during design it was discovered that many side sewer alignments were not well known. The pilot basin was located on a hillside where side sewers historically connected to mains on the adjacent lower street, even when they had to cross another lot. While this process changed over time, side sewer cards from adjacent lots often conflicted with each other. The SSES was also inconclusive in determining alignment of many side sewers. It would have been very difficult to develop a construction contract that could identify where the contractor would work as well as provide accurate linear footage estimates for side sewer construction. Thus, Kirkland became the pilot project where sewer mains, manholes, and laterals would be rehabilitated, given that all these components showed defects.

The Lake Forest Park pilot basin had defects that were scattered throughout the mini-basin. Instead of focusing on rehabilitation of all system components within a smaller pilot basin, it was decided that work would be done throughout the mini-basin where defects were found. With this approach, contractor costs could increase due to additional setups; however, there was potential for greater removal effectiveness over a larger area for the total amount of work performed.

For the Mercer Island pilot basin, the work involved only sewer mains and service connections. There were a few inflow sources found by positive smoke tests. Given the age of the system, there may also have been lateral and side sewer defects. Designers chose to focus solely on sewer mains and service connections in this pilot basin, thereby testing removal effectiveness based on just those system components within the public domain.

The Skyway pilot basin had major defects in many system components. It was therefore selected as the pilot basin where a full system replacement would be performed. Within the entire pilot basin, all portions of the collection system were replaced from the house to the lateral connection at the sewer main.

5.3.4 Selection of Rehabilitation Technologies and Techniques

Typical technologies for replacing a sewer main are pipe bursting and cured-in-place pipe. These technologies include many variations in method (called techniques in this report) and individual products.

Designers began with a list of rehabilitation technologies (see Chapter 4), then refined the list based on the following selection criteria:

- Proven process for use in sewer system rehabilitation
- Process well suited to defects and location of selected components
- Regionally available, experienced contractors
- Accepted by the local agency

Not all of the technologies and techniques listed in Chapter 4 could be used; there were only 12 pilot basins in which to try certain processes.

There were also technologies and techniques that did not meet one or more of the selection criteria. This should not negatively reflect on the technologies or techniques that were not chosen, as these may be ideally suited for use in some other situation.

5.3.4.1 Selection of Rehabilitation Technologies

Technologies selected for sewer main rehabilitation included:

- Pipe bursting
- Cured-in-place pipe (CIPP)
- Service connection rehabilitation liners
- Joint grouting
- Dig and replace

Technologies selected for manhole rehabilitation included:

- Replacement with new manholes
- Interior coating
- Fiberglass lining
- Chemical grouting
- Spot repairs/pipe penetrations
- Mechanical chimney barriers

- Frame and cover repairs
- Manhole pans

Technologies selected for lateral and/or side sewer rehabilitation included:

- Service connection and lateral liners (SCLLs)
- CIPP
- Pipe bursting
- Dig and replace

5.3.4.2 Selection of Rehabilitation Techniques and/or Products

To begin the selection process for rehabilitation techniques and products, designers identified the technology that they judged the best fit for the targeted components of their pilot project. Designers then met to collaborate and to ensure that sufficient variety and combinations were represented in the pilot project program.

Some of the technologies selected fell into major categories, such as CIPP. Variation was achieved within this category by specifying a particular product, resin, or fabric for some of the pilot projects and on others by letting the market dictate which of these techniques or products would be selected. In this way, information was obtained on processes that offered benefits other than lowest cost, and on processes that are typically chosen based solely on market factors. Other techniques, such as manhole pans, were less complex and were simply specified on several pilot projects.

Table 5-6 shows the rehabilitation techniques and products selected for each pilot project.

Table 5-6. Selected Rehabilitation Techniques and Products

Pilot Project	Selected Rehabilitation Techniques and Products
Auburn	Pipe burst 2,163 linear feet (lf) main Pipe burst or dig and replace 13 laterals and 19 side sewers Replace 13 manholes Install manhole pans in 9 manholes
Brier	Line 2,938 lf of main with polyester or vinylester resin, contractor’s choice of fabric, inverted CIPP Seal service connection with lateral connection liner[1] Chemical grout 51 manholes or install Poly-Triplex® fiberglass liner[1] (install manhole pans in 8 manholes)
Kent[2]	Line 139 laterals and 172 side sewers with T-Liner®[1] or CIPP

Pilot Project	Selected Rehabilitation Techniques and Products
Kirkland	Pipe burst 4,157 lf of main Dig and replace or pipe burst 74 laterals Replace 18 manholes
Lake Forest Park	Line 8,973 lf of main with epoxy resin, contractor's choice of fabric, inverted CIPP Seal service connection with contractor's choice of liner Install interior cementitious coating or interior grouting in 47 manholes
Manhole Coal Creek[3]	Chemical grout 51 manholes Install interior chimney coating in 15 manholes Replace a paving ring in 1 manhole Install a manhole pan in 1 manhole Install a frame raised to grade in 1 manhole
Manhole Northshore[3]	Chemical grout 76 manholes Install interior chimney boot in 27 manholes Install interior chimney coating in 13 manholes Install raised frames in 7 manholes
Manhole Val Vue[3]	Install cementitious liner in 5 manholes Chemical grout 24 manholes Install interior chimney coating in 5 manholes Install raised frames in 2 manholes
Mercer Island	Install CIPP in 15,635 lf of main with contractor's choice of resin, fabric, insertion method, and design for fully deteriorated pipe Seal service connection with contractor's choice of liner
Redmond	Line 6,057 lf of main with MultiLiner®[1] (polyester or vinylester resin, fiberglass fabric, pulled-in, CIPP) Pipe burst 265 lf of main Seal service connections with TOP HAT™[1] Install T-Liner®[1] in 17 laterals Chemical grout 32 manholes
Ronald	Pipe burst 64 laterals and 209 side sewers
Skyway	Pipe burst or dig and replace 9,524 lf of main and 163 laterals and side sewers Replace 36 manholes

[1]Sole source product
[2]During the design process, Kent was selected as the lateral and side sewer project to use CIPP for rehabilitating the sewer main
[3]The Manhole Project was originally bid to also include interior epoxy, polyurethane, and cementitious coatings. These products were removed from the contract and the project was re-bid. See Chapter 6 for further explanation.

5.3.4.3 Sole Source Products

During design of the pilot projects, several specific products were identified as potentially beneficial for sanitary sewer rehabilitation. In order to try a full range of products for the pilot projects, it was necessary to specify some of these as sole source products to ensure that the proper data was received for evaluation of these technologies. Where sole source products were chosen, one or more of the following criteria were present:

- The product had been used in previous sewer collection system rehabilitation projects; it was not considered experimental, and bid prices could be verified against previous cost information.
- The product was known to offer a technology with the potential to be useful and cost effective in a large number of installations.
- Two or more regional contractors who install similar products, such as CIPP, were expected to bid on the project. The sole source specification required that a specific method be used such as MultiLiner®.
- The product restored sewer collection systems in locations or with methods of installation specifically matching the types of problems found on the various pilot projects.

For each pilot project where a specific product or several products were identified (sole source), there was another pilot project where rehabilitation of the same collection system component with a similar technique was limited only by a performance specification.

Where sole source products were used on County-administered projects, a waiver from its Standard Procurement Procedures was obtained from the County Contracts Division. Sole source products specified in the various pilot project contract documents are shown in Table 5-7.

Table 5-7. Sole Source Products

Pilot Project	Product	Manufacturer	Collection System Component
Brier	Lateral Connection Liner Poly-Triplex® PTLS-4400	Nu Flow Technologies Poly-Triplex® Technologies	Lateral Liner Manhole Liner
Kent	T-Liner®	LMK Enterprises	Lateral Liner
Redmond	MultiLiner® TOP HAT™ T-Liner®	Pacific Multilining Inc. Cosmic Sondermaschinenbau LMK Enterprises	Sewer Main Liner Service Connection Liner Lateral Liner

5.3.5 Contract Specification Development

For 9 of the 10 pilot projects, the design team prepared the technical specifications. Contract specifications followed the Construction Specifications Institute (CSI) format. The design team used the King County standard specification sections as a starting point, modifying some for the work to be performed.

The Ronald Wastewater District used specifications developed by its own design consultant. As managers of their own construction programs, both Ronald and Skyway produced bidding documents and defined the general conditions for the contracts in their areas. For the remaining eight projects, King County administered contracts produced by County Procurement and Contracts Services using the general conditions and bidding documents.

5.3.5.1 Standards and Testing

Standards

In 2002, the Metropolitan Water Pollution Abatement Advisory Committee (MWPAAC) worked with the County and its consulting team to develop draft standards, procedures, and guidelines for I/I control in the region. The design team used these draft standards and procedures during design of the pilot projects. As a result of the lessons learned, these standards and procedures will undergo some changes when the Committee and design team begin to evaluate them in 2004. The draft I/I standards include guidelines on planning, design, construction, testing, inspection, and warranties for both public and private facilities.

For technical specifications, the County standard specifications provided a starting point. Designers also used other standards, including: (a) standard specifications from other I/I projects within the United States, (b) manufacturers' standards, (c) accepted regional standards such as the *Standard Specifications for Public Works Construction*, known as the Green Book, and (d) the Washington State Department of Ecology’s *Criteria for Sewage Works Design*, 1998, known as the Orange Book. When standards conflicted, the designers used professional judgment to prepare a set of specifications that would meet the objectives of the pilot projects and I/I program.

Portions of the technical specifications also came from designers' experience. Technical sections involving several of the specialized rehabilitation technologies were sent to the manufacturers for review and comment. Designers then evaluated their comments and incorporated selected changes.

For reference standards, designers generally used American Society of Testing and Materials (ASTM) standards, and in some instances, used the American Association of State Highway Transportation Officials (AASHTO) standards.

For quality control, several sections were sent to an independent engineer for review. The sections then went through an internal quality control and quality assurance review by the design team. Finally, sections went through a County quality control and quality assurance review before being approved for advertisement.

Testing

Testing requirements were specified for the pilot projects to see how readily some tests could be used and to maintain inspection control over quality of the product and/or installation. When testing requirements were applied, there was always a reference standard.

5.3.5.2 Contractor Qualification

Contractor qualification sections were added to the technical sections for each of the rehabilitation technologies. Because most of the technologies are relatively new, appropriate qualifications were essential to ensure qualified installation of each process. It was important that the contractors awarded the construction contracts have suitable experience and personnel to perform the work.

Qualification requirements are discussed further in Chapter 6.

5.3.5.3 Warranties

Because most of the rehabilitation technologies are relatively new, contracts required warranties of 18 months to 5 years for most products. A requirement was added for some warranties that both the contractor and the manufacturer (or assembler) equally warrant the products. The typical 1-year warranty was required on all other products and workmanship.

5.3.6 Contract Drawing Development

For all pilot projects except Ronald, design team members prepared contract drawings. For the eight County-administered projects, King County standard title block and drafting conventions were used. When detailed information was required for a particular system component, schedules were used to summarize information. Bold numbering or letters referenced a schedule or construction note on the drawing and typically indicated proposed rehabilitation measures. In this way, the proposed rehabilitation measures were the most dominant feature on the drawings, but did not obscure existing utility information underneath.

An existing set of base drawings from a previous bid was used as a starting point for the Skyway pilot project. These base drawings were modified to update existing utility information, existing features, proposed rehabilitation measures, and to update the title block. For the Ronald project, the Ronald Wastewater District hired its own consultant to develop contract drawings.

All drawings were drafted in AutoCAD® and scaled to be 22 inches by 34 inches full size, which allowed for true scale half-size drawings on 11-inch by 17-inch paper.

For quality control, all drawings went through an internal quality control and quality assurance review by the design team. Finally, sections went through a County quality control and quality assurance review before approval for advertisement.

5.3.6.1 Aerial Photos

Most of the pilot projects included aerial photos in the design drawings. In some cases, the local agency provided aerial photos, and for others, flights were contracted to obtain the photos. New aerial photos were ordered when existing aerial photos were more than a few years old or were taken at an elevation too high to show surface features. New photo instructions were specific about the need to produce 20-scale drawings, which was the scale used for design.

On the Skyway project, aerial photos were supplemented with a visual ground survey to identify significant features that were not clear in aerial photos. These features were then noted on the plans.

One detriment of using aerial photos was that they did not copy well on a copy machine. This was not a problem with bid sets, because all plans were printed from the computer files. However, this was a problem for working documents made from copies of the bid sets. Another difficulty was that the darkness of the photo obscured other features on the plans. Designers solved this problem by using a white line for surface features.

Some of the aerial photos were used in AutoCAD® with the Land Development Desktop module and MrSID® program, which helped project drafters by decreasing file size and re-generation time. Some files were used as Joint Photographic Experts Group (JPG) files in AutoCAD®. While cumbersome, there were no other difficulties with this method.

5.3.6.2 Base Mapping

Base mapping used on the plans was either provided by the local agencies or came from the County Geographic Information System (GIS). This mapping typically included property lines, some existing utilities, existing curb line, and parcel numbers. In addition, the design team obtained maps from utility companies likely to have facilities in the area, particularly for those pilot projects with proposed excavation work.

Parcel numbers were changed to addresses and buildings were labeled in some of the pilot projects.

The accuracy of property line and utility information on the base mapping was not field verified. To deal with this issue, a note was added to drawings stating that the contractor was to verify such information. Most work was done in residential areas where common utilities such as overhead power poles and water meters allowed for approximate property line location determinations. When cleanouts were placed adjacent to the right-of-way, it was noted on the plans that the Project Representative for the County would determine where cleanouts would be placed. When in doubt, the Project Representative could adjust the cleanout location slightly to the right-of-way side of the property line.

Boundary surveys were not performed on any of the pilot projects. Control surveys were performed to provide a basis of control for the aerial photos.

5.3.7 Engineer's Estimate of Cost

Upon completion of the plans and specifications, the design engineers estimated construction costs. Contingency and sales tax were added to arrive at the total construction cost.

The estimates were based on pricing provided by contractors, suppliers, and on each designer's knowledge of the conditions and type of construction activities. The estimated County cost, including contingency and sales tax, was $7,600,000 for all pilot projects. The County budget for construction of the pilot projects was $9,000,000. Thus, the estimated cost was less than the budget at the end of design. Designers kept cost in mind and attempted to provide an overall rehabilitation for each pilot project.

In addition to the costs described above, additional amounts of work and additional funding by two local agencies for work in their jurisdictions was estimated at $1,118,000, and was included in the original design.

Detailed bid tabulations, including the engineer's estimates, are provided in Appendix C. All construction costs were based upon labor rates that conformed with the Washington State Prevailing Wage Rates for Public Works Contracts.

5.3.8 Pilot Project Design Objectives Met

The four objectives of the pilot project design effort were met (refer to Table 5-8). Data were collected on I/I removal and the various rehabilitation technologies, techniques, and products.

Table 5-8. Summary of Pilot Project Design Objectives Met

Objective	Result
Repair defects in the collection system to reduce I/I.	Repair of defects was largely accomplished by targeting the collection system components where the most substantial defects were found or suspected. While it was not the intention to repair all defects within each pilot basin, the final design targeted many of the major defects shown in Table 5-3 and Table 5-4.
Repair defects in selected collection system components, including manholes, mains, laterals, and/or side sewers.	Repair of defects in selected system components was accomplished, as shown in Table 5-5. A good mix of system component types and combinations of components was represented.
Develop rehabilitation improvements within the construction budget	Development of rehabilitation improvements within the overall construction budget was accomplished. The engineer's estimated cost of construction without tax is included in Chapter 6. Adding in tax and subtracting the amount that two agencies contributed resulted in a County cost of approximately $7,600,000 for all pilot projects. The County budget for construction of the pilot projects was $9,000,000.
Use a variety of proven and mostly trenchless rehabilitation techniques to gain experience with different methods and costs of sewer system repair.	The use of a variety of proven and mostly trenchless rehabilitation techniques was accomplished. As shown in Table 5-6, each pilot project offered a different technology or type of system component, product component, or level of contractor choice. This resulted in utilization of the largest possible number of techniques, given the limited number of pilot projects.

5.4 Public and Agency Involvement

5.4.1 Public Involvement

Public involvement responsibilities were coordinated between King County and each of the local agencies. King County offered support and performed some of the tasks as requested by the agencies. Some public involvement responsibilities were delegated to the contractor (as required by the project documents).

Public involvement varied for each project depending on the nature of the work, agency preferences, and whether the work was to take place on private property or within the public right-of-way. One or several public meetings were held in Kent, Kirkland, Redmond, Ronald, and Skyway. County and local agency staff obtained right-of-entry forms for Auburn, Brier, Kent, Kirkland, Lake Forest Park, the Manhole Project, Ronald, and Skyway. Work occurred on private property in Auburn, Brier, Kent, Lake Forest Park, the Manhole Project, Ronald, and Skyway.

Some of the informational items used to convey the message to the public were:

- Public information mailer
  - Meeting announcement
  - Contact neighborhood groups
- Public meeting
  - Computer presentation and graphics
  - Mailer
  - Door hanger
  - Web site
- Right-of-entry request (form to be signed by property owner)
  - Right-of-entry form for investigation and rehabilitation
  - Door-to-door and mailer
  - Project information sheet
- Program Web site with information on pilot projects
- King County and local agency staff available to answer questions
- Project signs describing program

5.4.2 Agency Involvement

The I/I Control Program pilot projects were a cooperative effort between King County and the agencies. This cooperation continued from selection and design through construction.

On each pilot project, design engineers talked to and/or met with the agencies during early stages of the design to confirm basic design direction. Two formal review meetings were scheduled at roughly the 60- and 90-percent completion milestones during design. Agencies were given copies of the plans at these milestones and asked to review and comment on the plans, specifications, and cost estimates.

Agencies provided their standard details and sewer standards prior to the start of the design effort. These standards were followed as closely as possible, while still conforming to the Draft Regional I/I Control Standards and Procedures. Agencies also provided much of the required information for the design including aerial photos, base mapping, utility maps, system information, etc.

At the policy level, MWPAAC members received design progress updates during their monthly meetings.

5.5 Environmental Review and Permitting

5.5.1 Environmental Review

King County staff conducted environmental reviews on all 10 pilot projects. Information used for these reviews included:

- Design team memoranda documenting the basin description, SSES results, proposed rehabilitation measures and quantities, estimated excavation quantities, and required permits
- Environmental technical memoranda documenting research results for hazardous materials, wetland/wildlife, landslide/erosion, and groundwater systems
- Additional information from the I/I Web site and I/I project team, as requested

Through the environmental review, the County determined that the Manhole Project was categorically exempt under Section 197-11-800 of the State Environmental Policy Act (SEPA). Two separate checklists were prepared for the Skyway and Ronald projects, and both were issued a Determination of Non-Significance (DNS). King County was the lead agency for these environmental reviews. No comments were received on either DNS.

For the other seven pilot projects, the County issued a combined review/SEPA checklist/DNS. No comments were received on the DNS.

5.5.2 Permitting

Additional state, county, or agency permits were required for most of the pilot projects. These were either: (a) obtained by the County and included in the bid sets, or (b) the contractor was required to obtain the permit. Following is a list of permit types required on some or all of the pilot projects and the agency responsible for issuing the permit:

- Industrial Waste Discharge Authorization for Trench Dewatering, King County
- Dewatering Discharge Permit, local agency
- Right-of-Way or Street Use Permit, local agency
- Shoreline Permit, local agency
- Side Sewer Permit, local agency
- Clearing and Grading Permit, King County
- Trail Use Permit, King County
- Asbestos Removal Permit, Puget Sound Clean Air Agency and Washington Department of Labor and Industry
- Hydrant Use Permit, local agency

5.6 Pilot Project Basin and Rehabilitation Maps

Figure 5-1 shows the locations of the pilot projects. Figure 5-2 through Figure 5-13 shows the final pilot and control basin boundaries for each of the pilot projects (for more information, refer to section 5.2). Figure 5-14 through Figure 5-25 show the location and amount of system component rehabilitation included in the design of each pilot project (for more information, refer to section 5.3).

> Note: You can view or print larger versions of the pilot project basin and rehabilitation maps (Figures 5-2 through 5-25) using the CD, located in the back of the report.

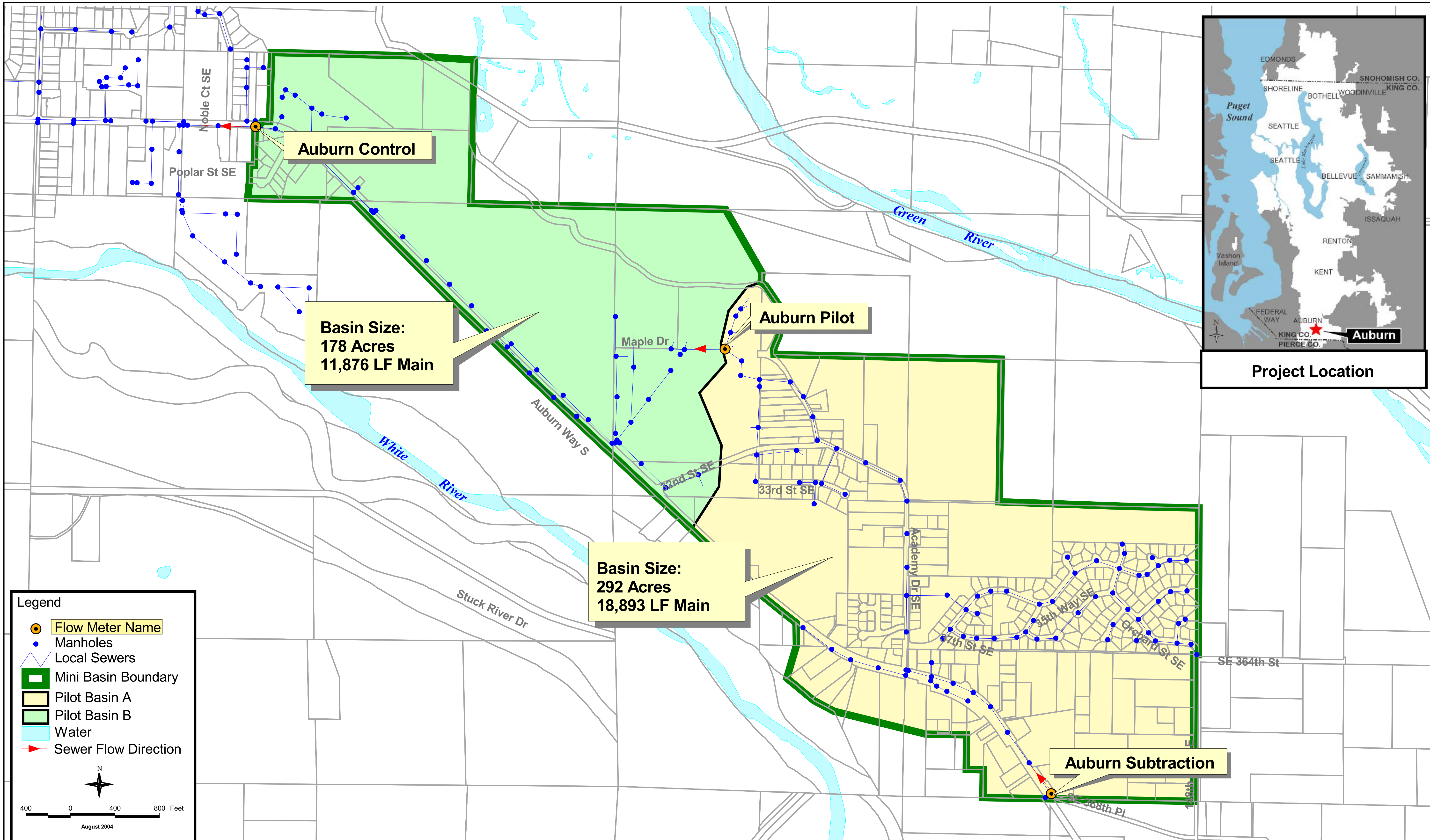


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Figure 5-2

Auburn Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

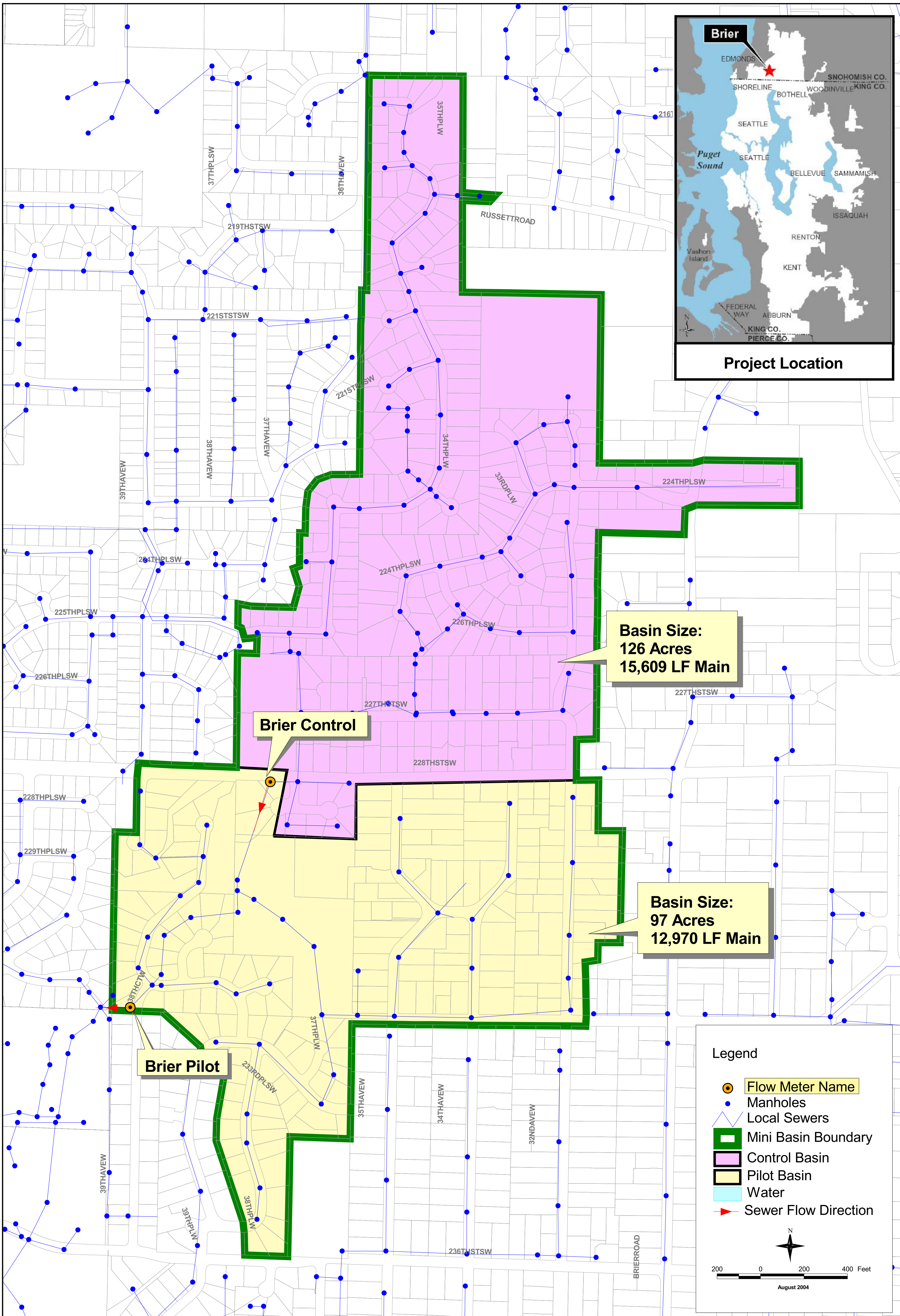

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Figure 5-3

Brier Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

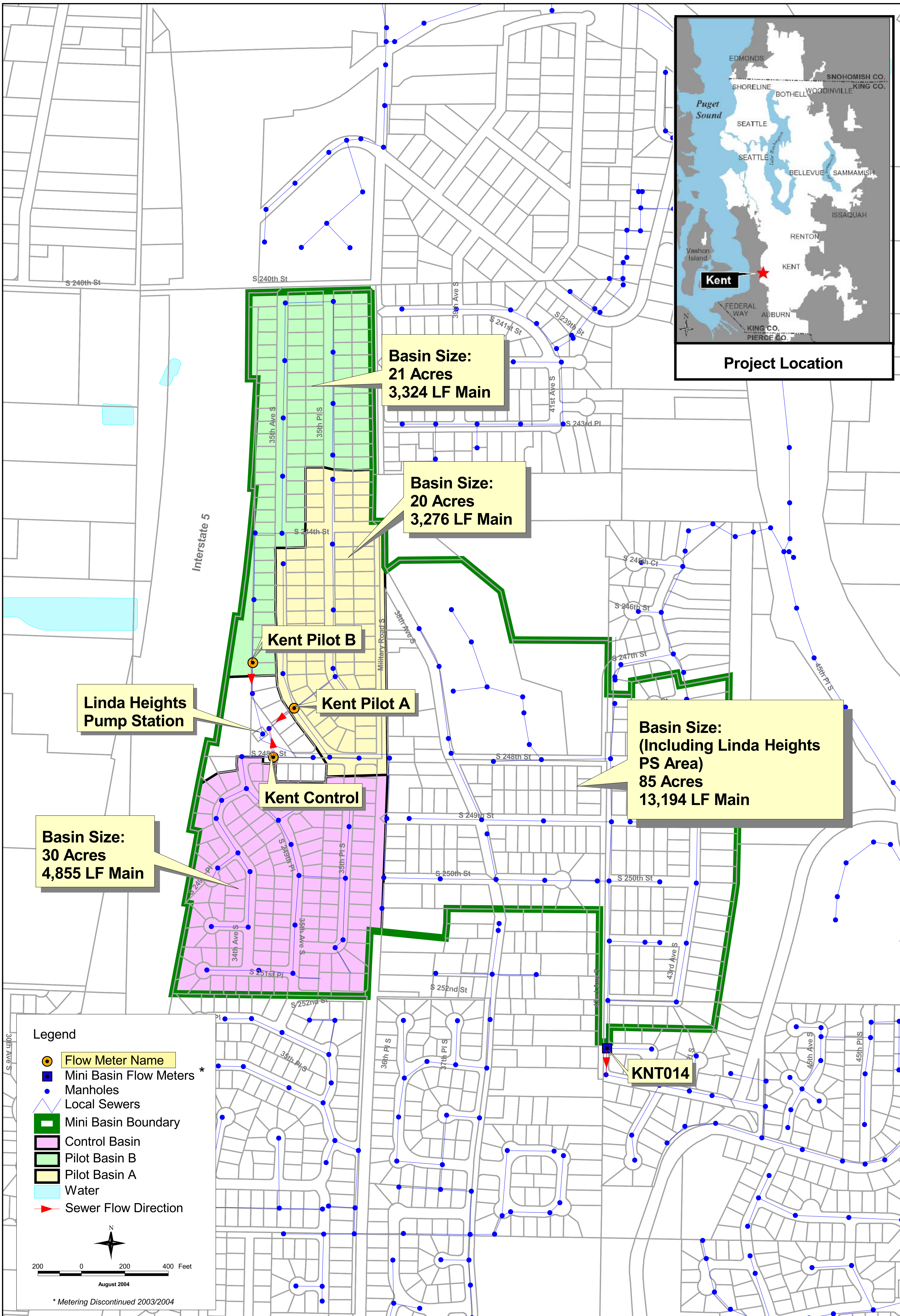

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Figure 5-4

Kent Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

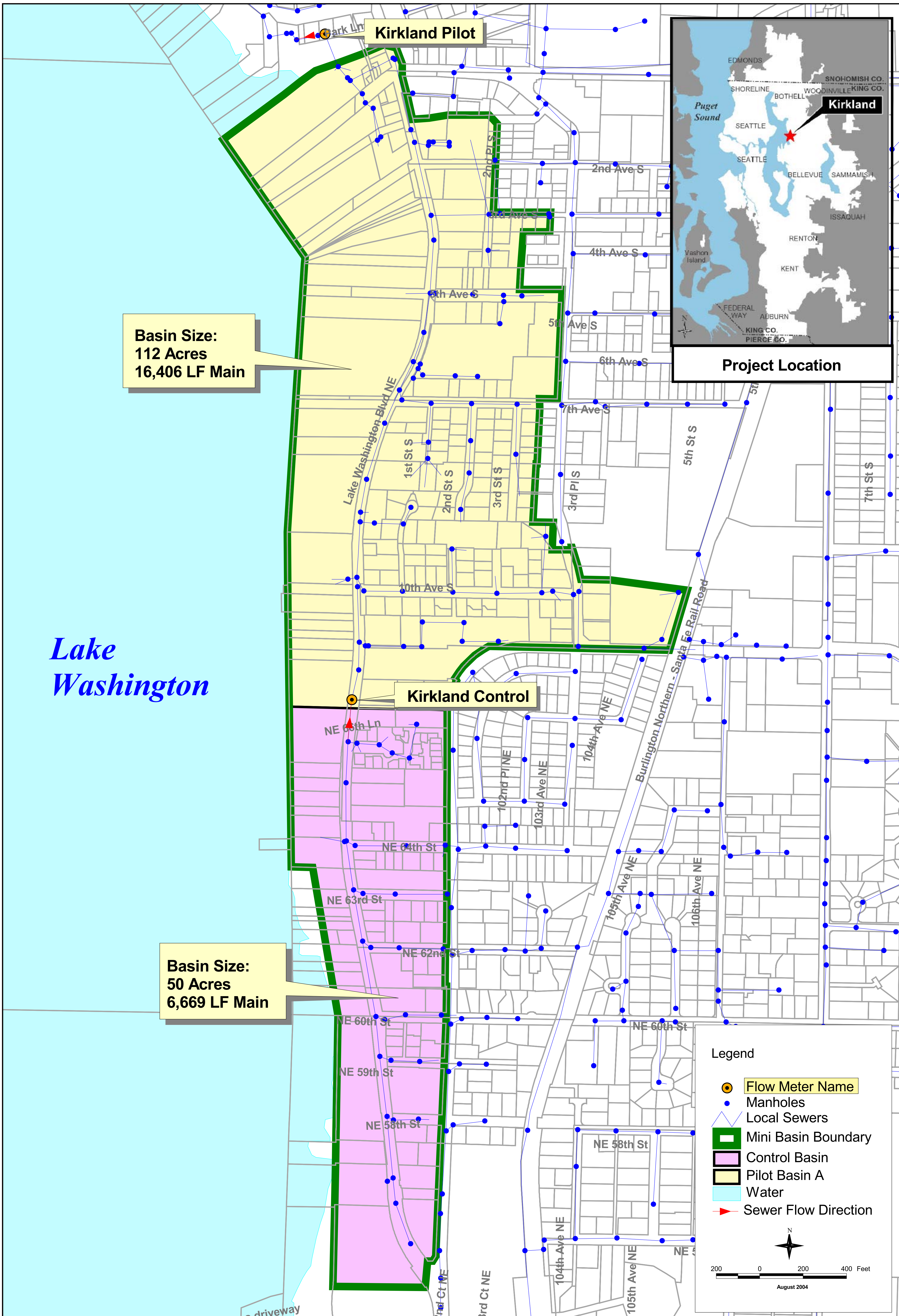

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Figure 5-5

Kirkland Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

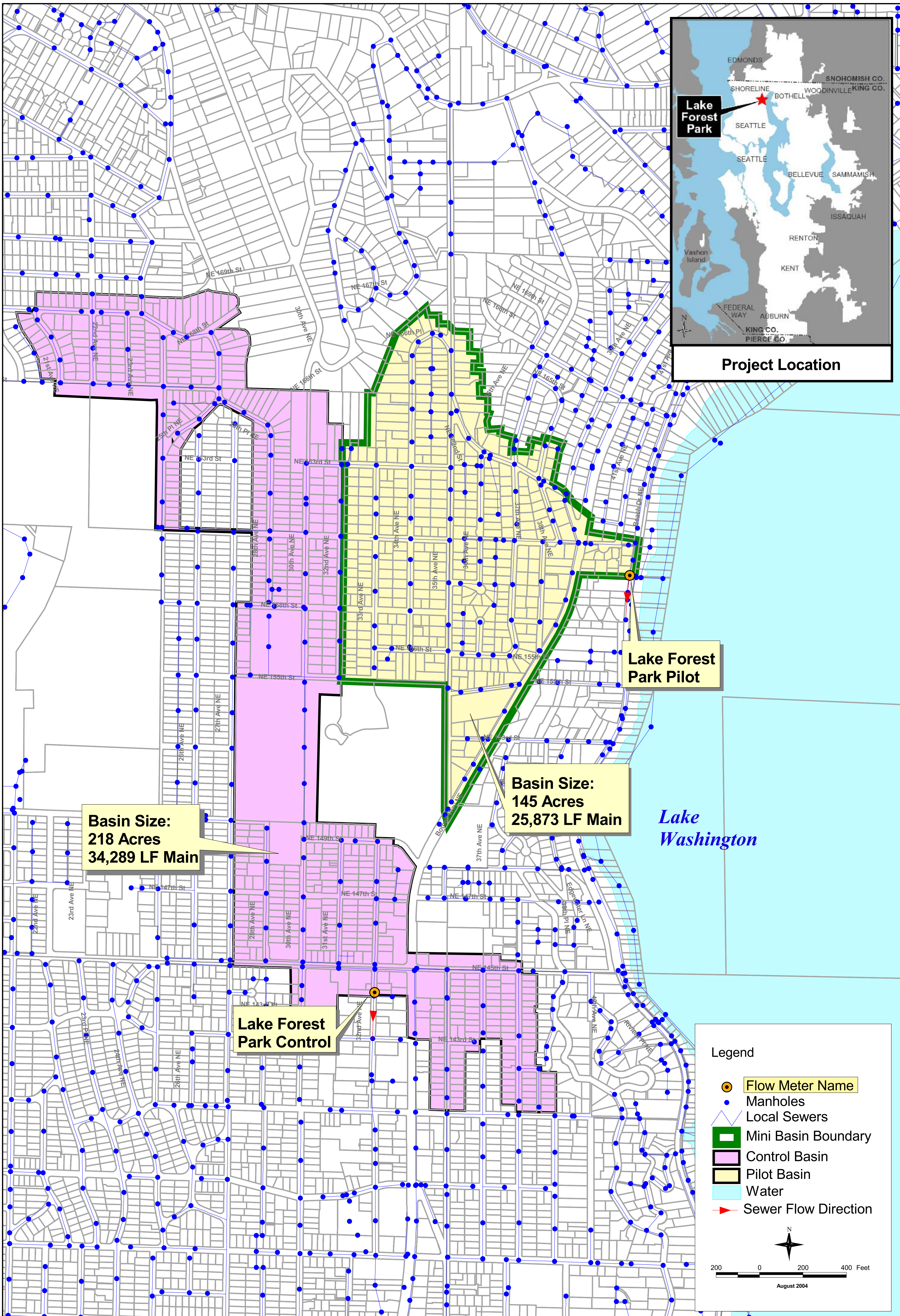

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Figure 5-6

Lake Forest Park Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

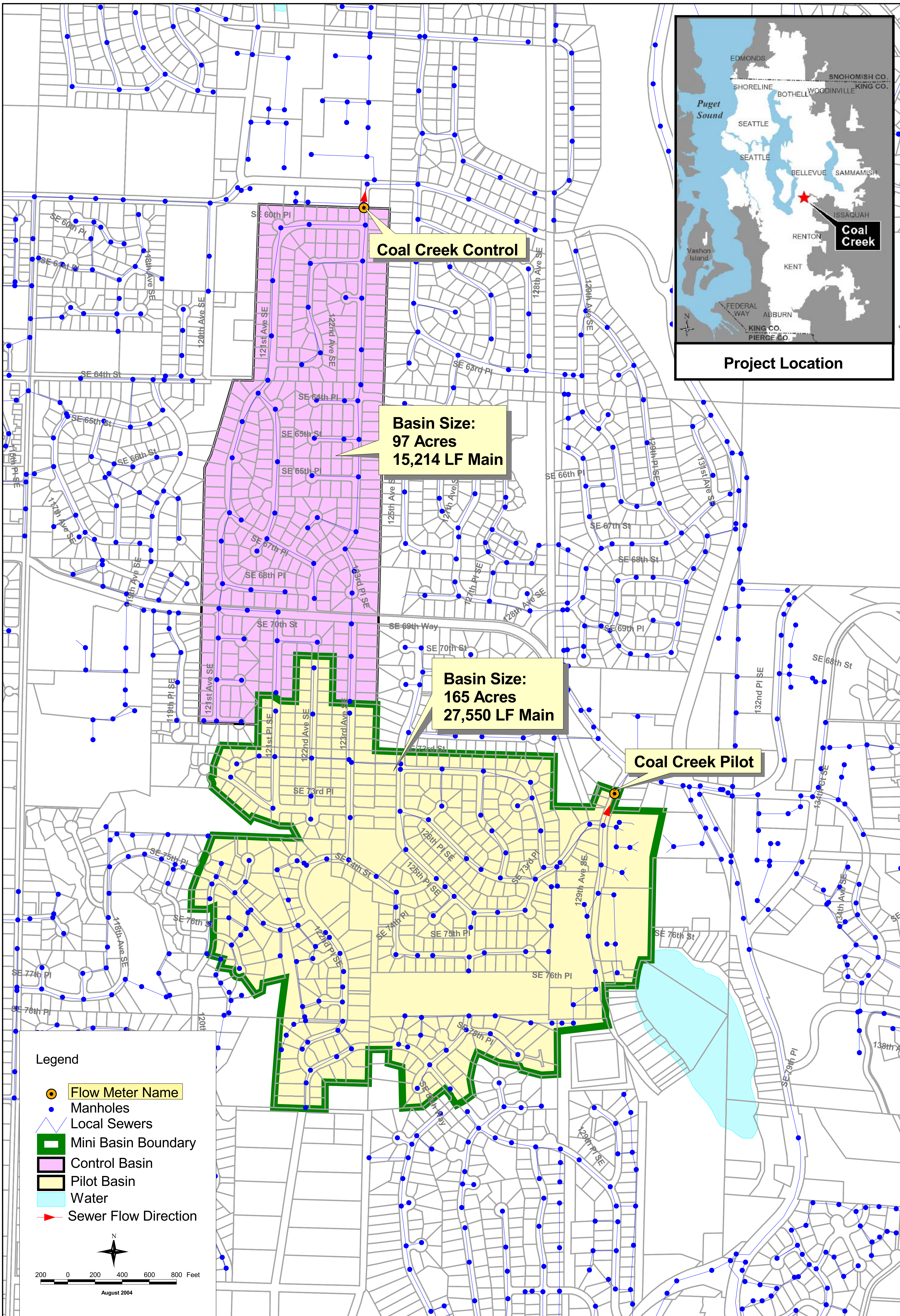

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Figure 5-7

Manhole Pilot Project - Coal Creek - Basins

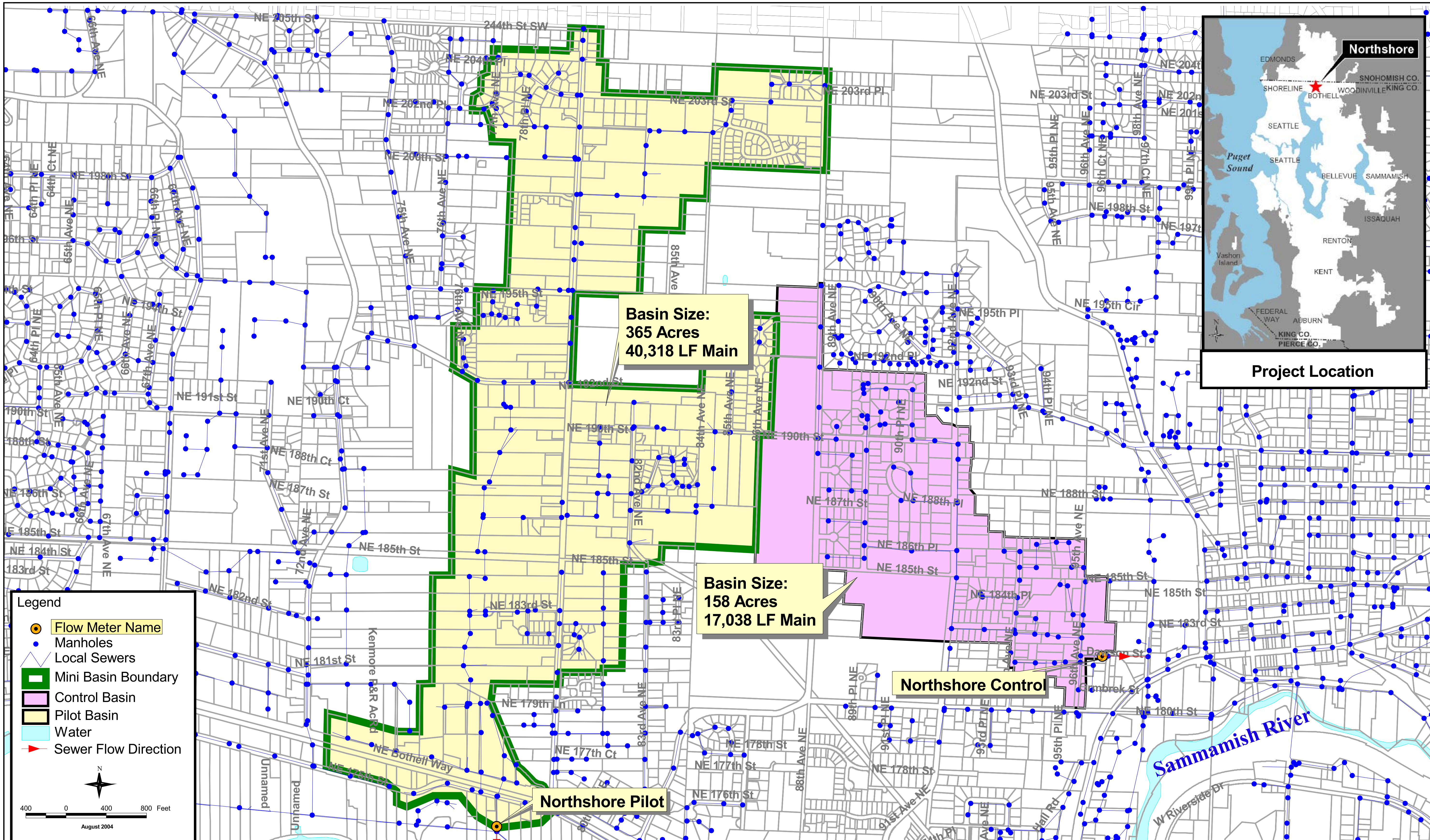

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Figure 5-8

Manhole Pilot Project - Northshore - Basins

Infiltration/Inflow Pilot Project Report

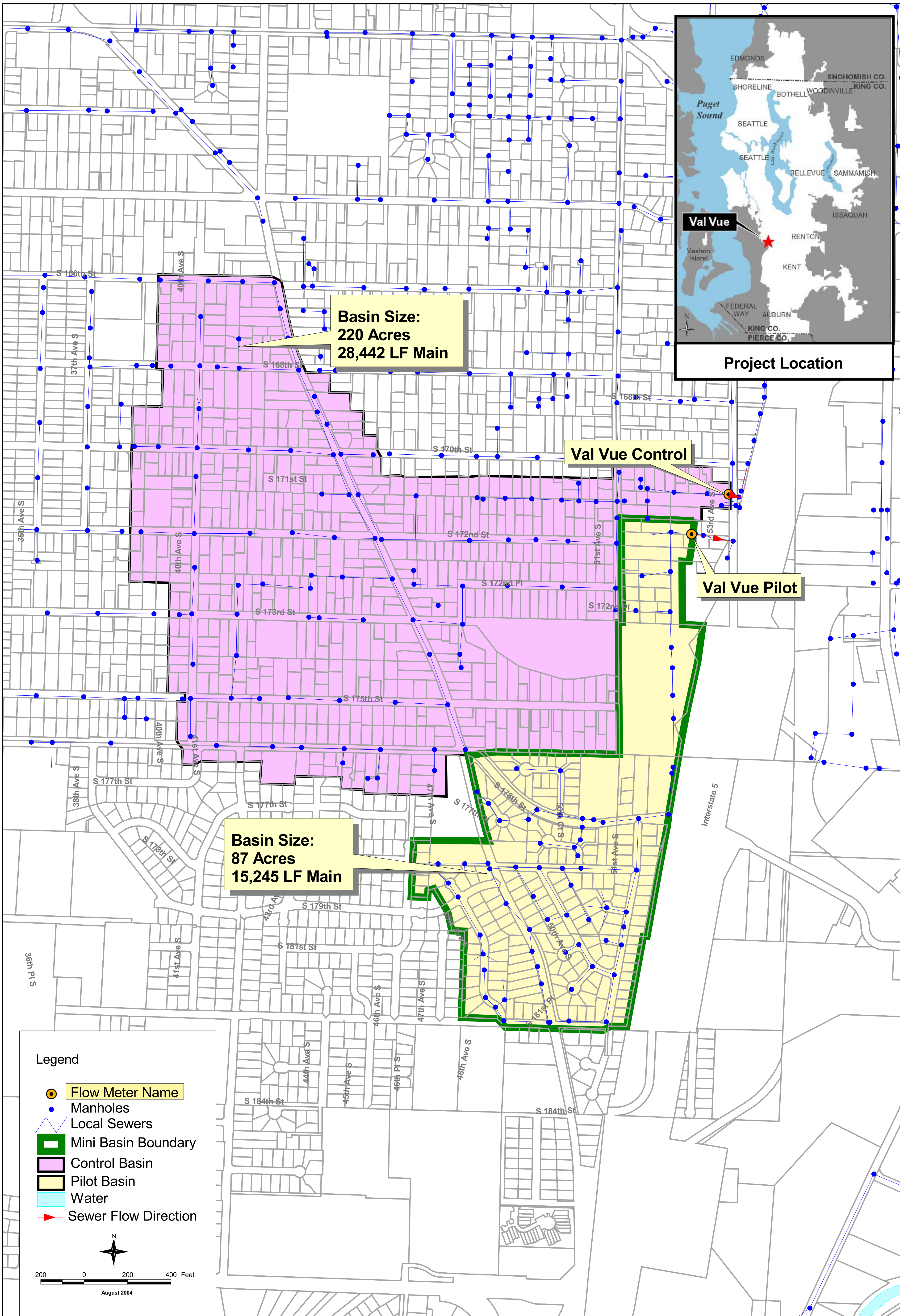

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Figure 5-9

Manhole Pilot Project - Val Vue - Basins

Infiltration/Inflow Pilot Project Report

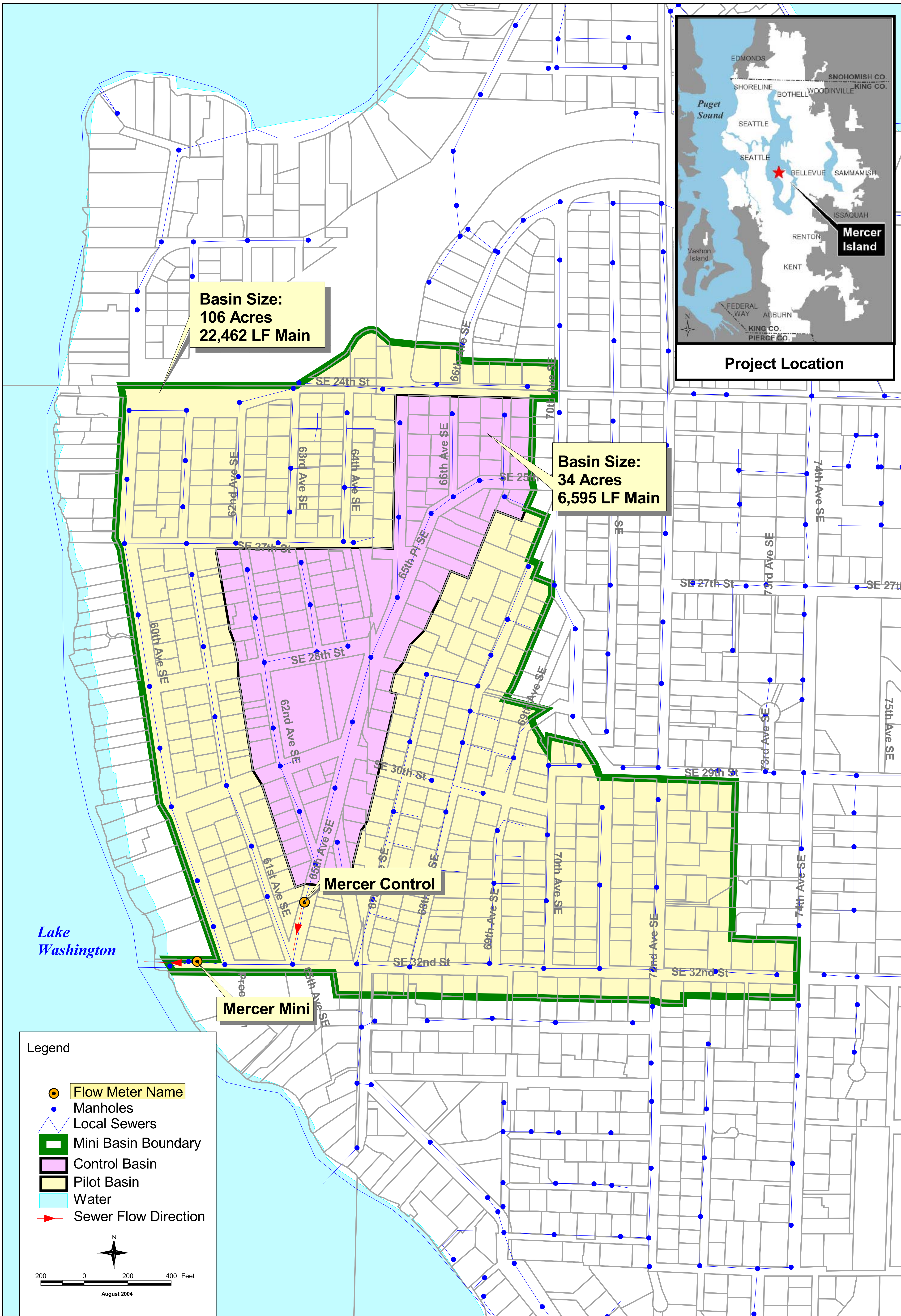

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Figure 5-10

Mercer Island Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

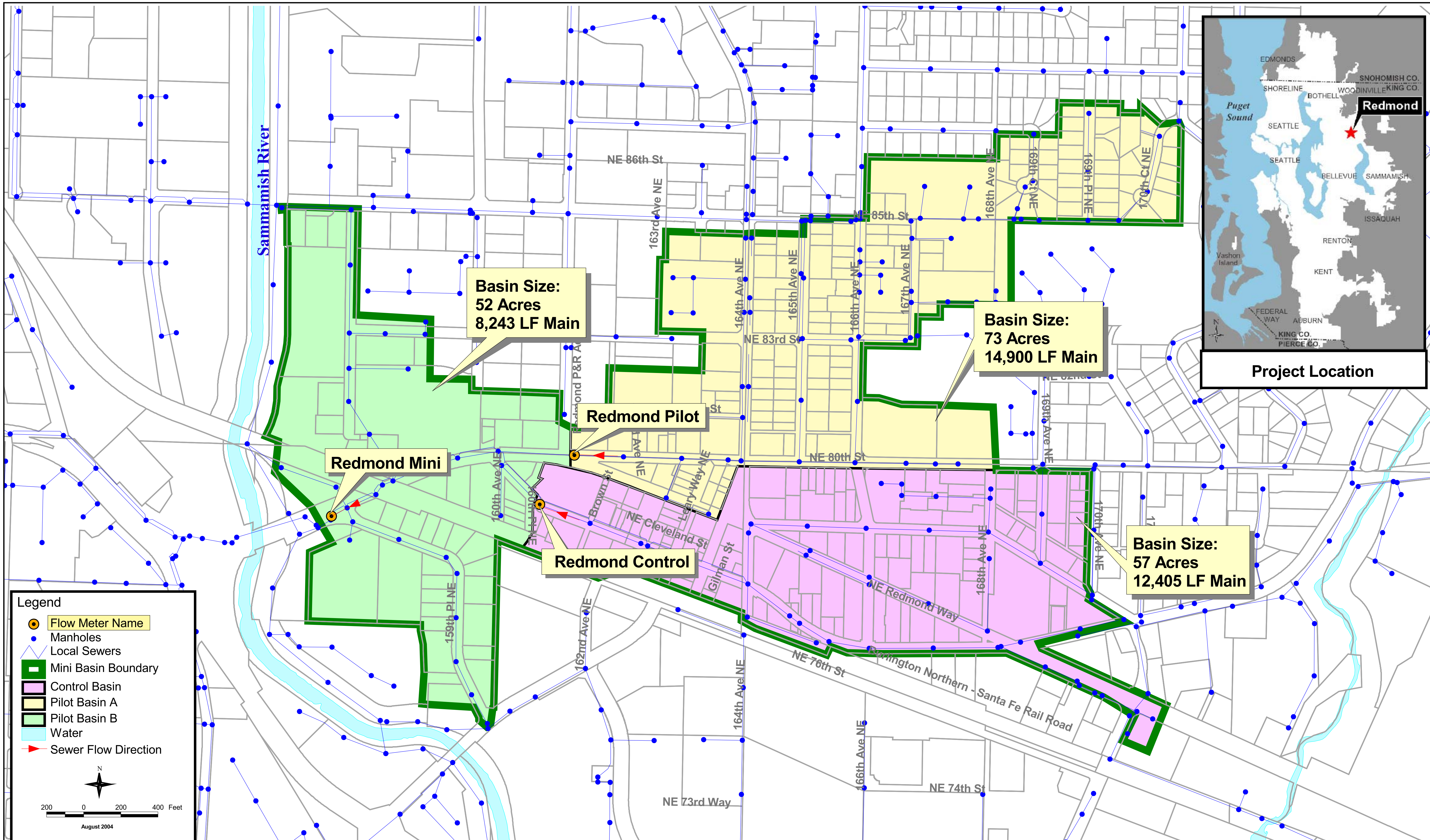

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Figure 5-11

Redmond Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

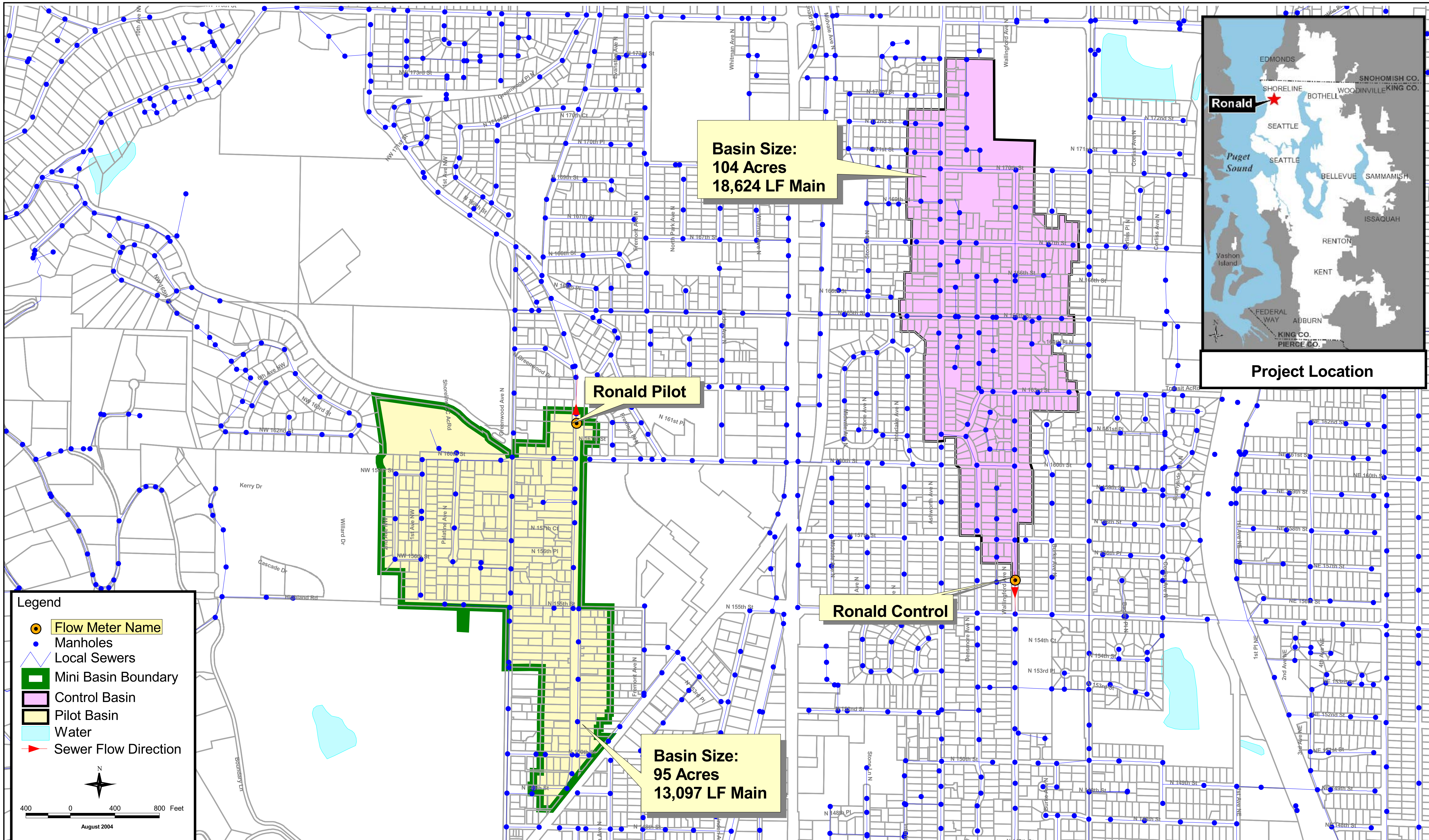

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Figure 5-12

Ronald Pilot Project - Basins

Infiltration/Inflow Pilot Project Report

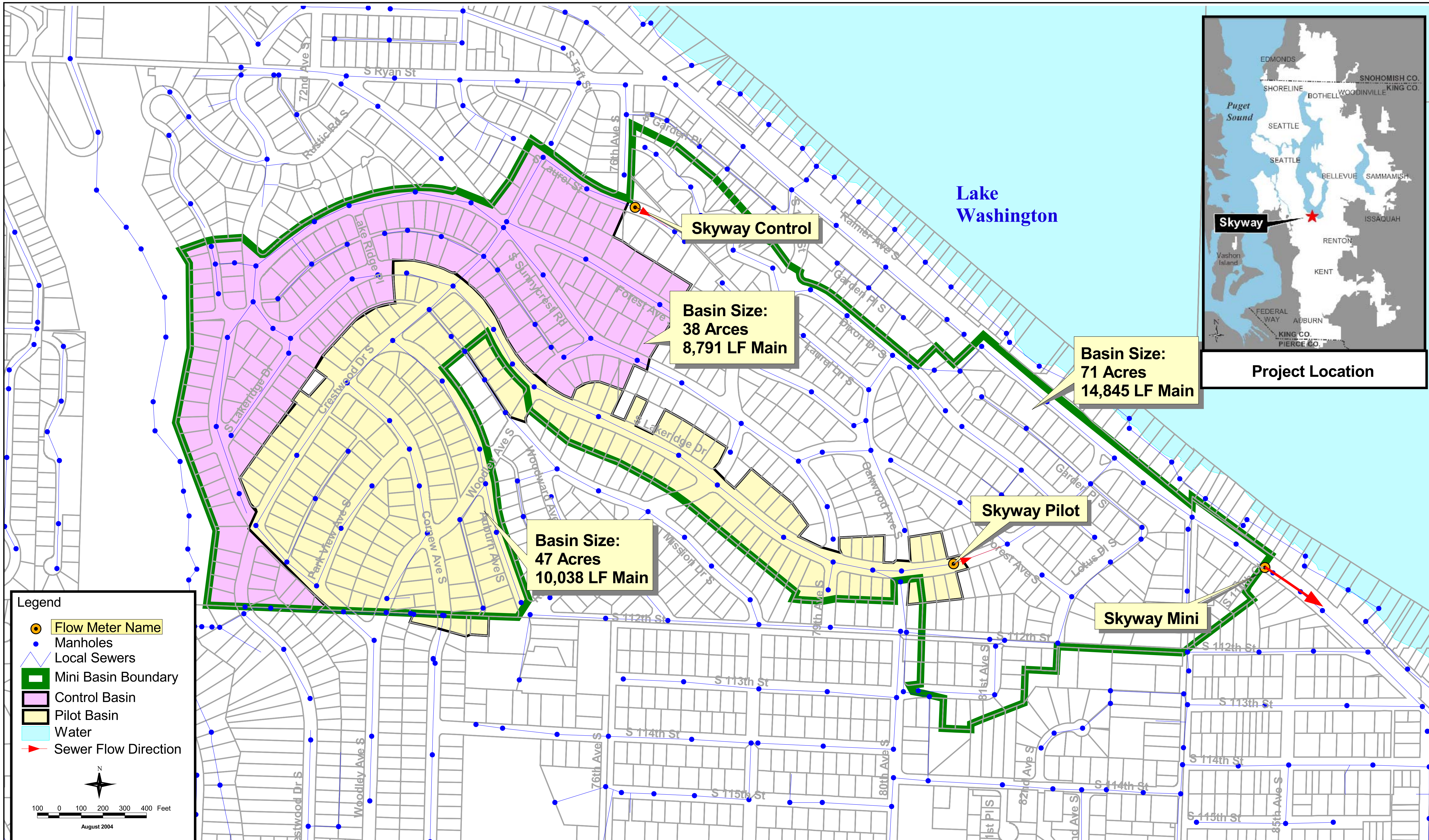

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Figure 5-13

Skyway Pilot Project - Basins

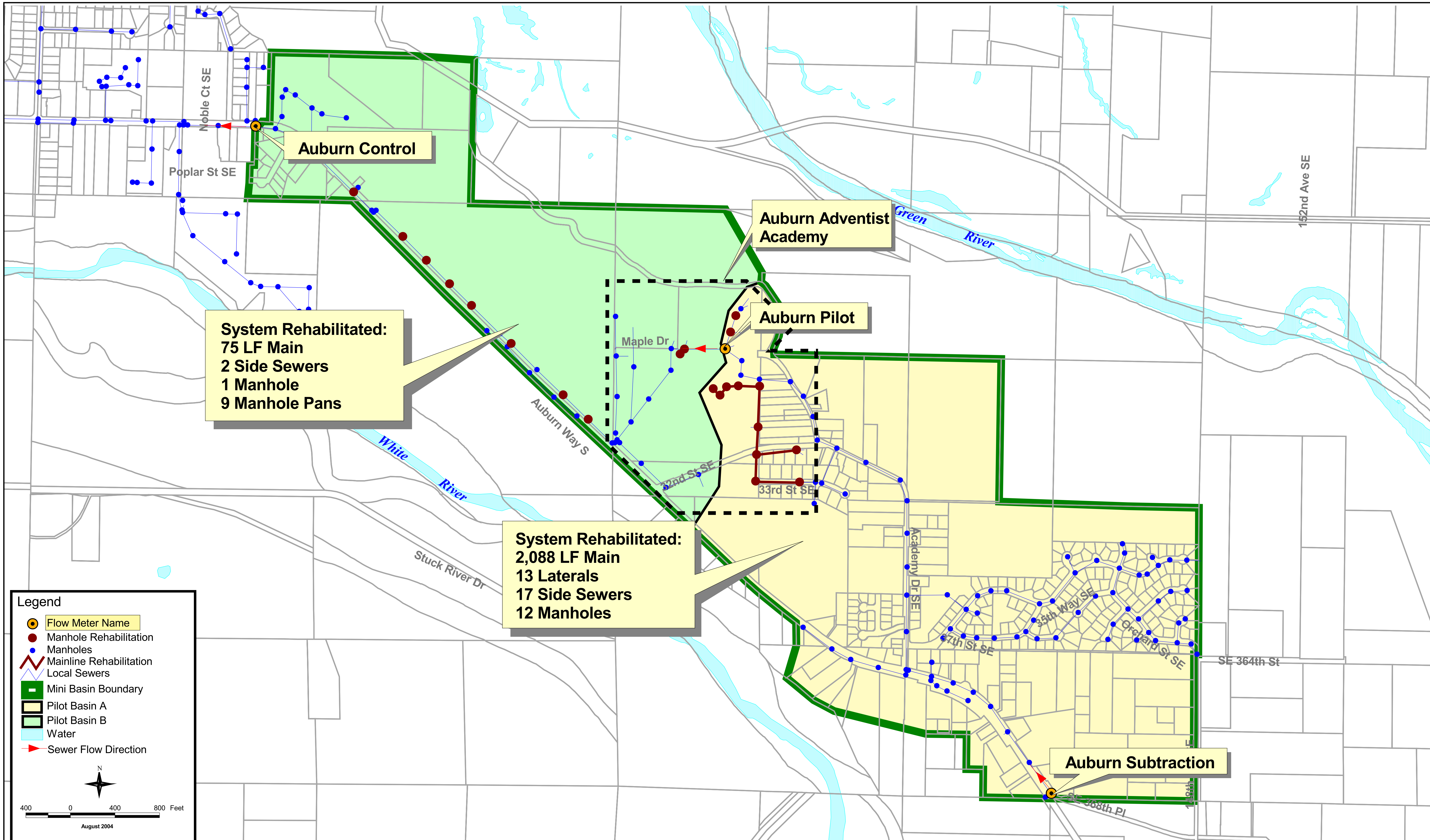

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Figure 5-14

Auburn Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

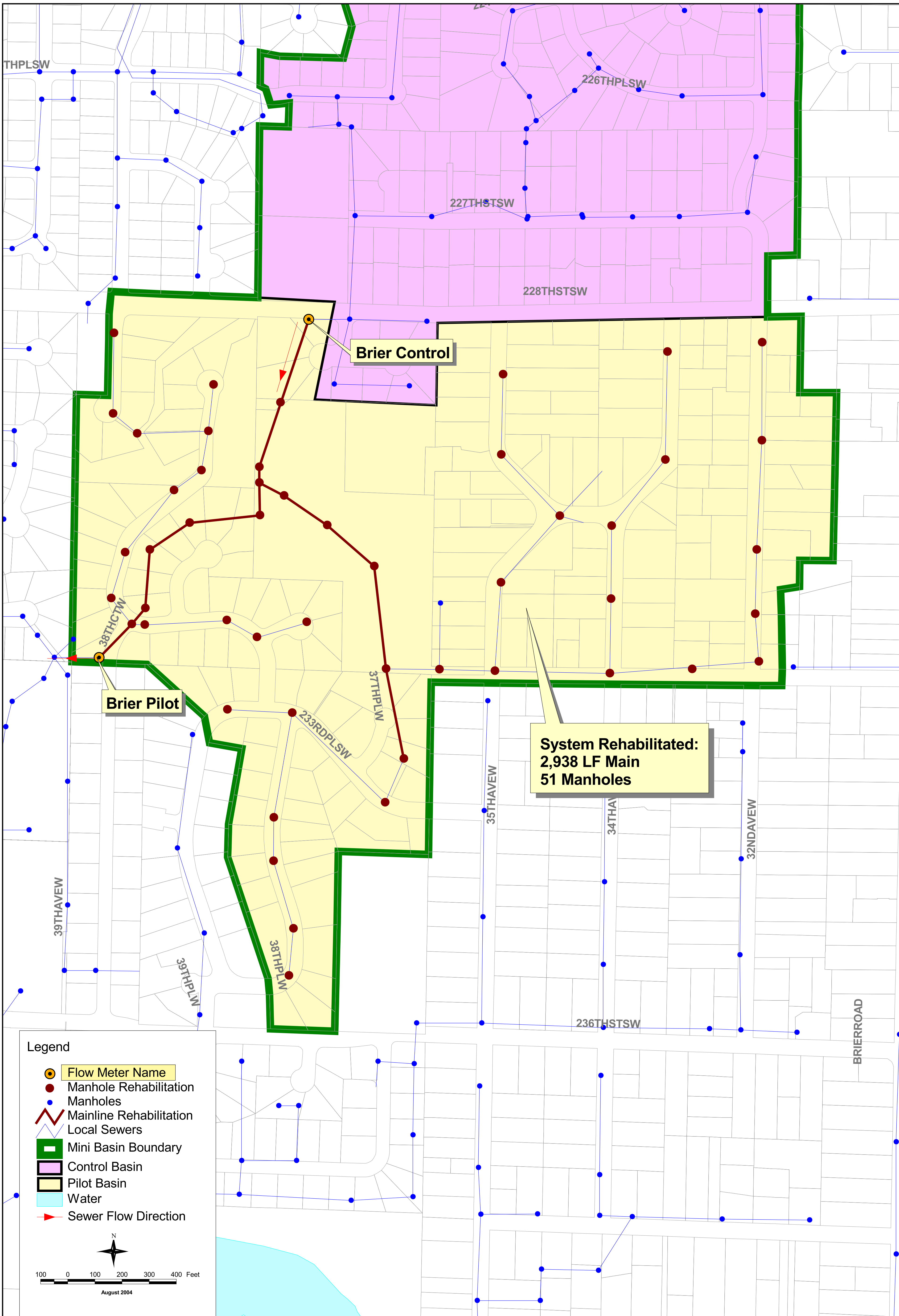

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Figure 5-15

Brier Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

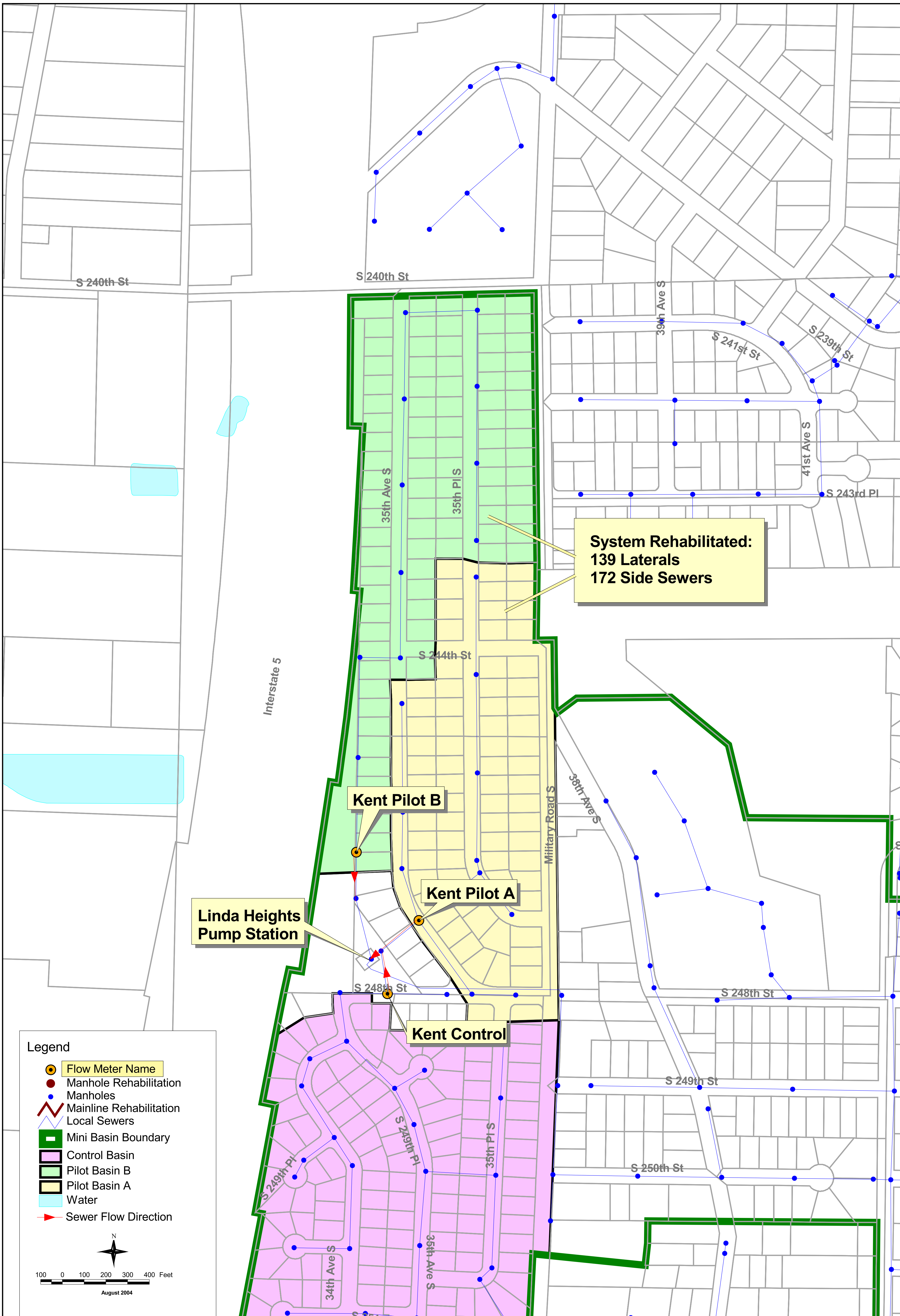

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Figure 5-16

Kent Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

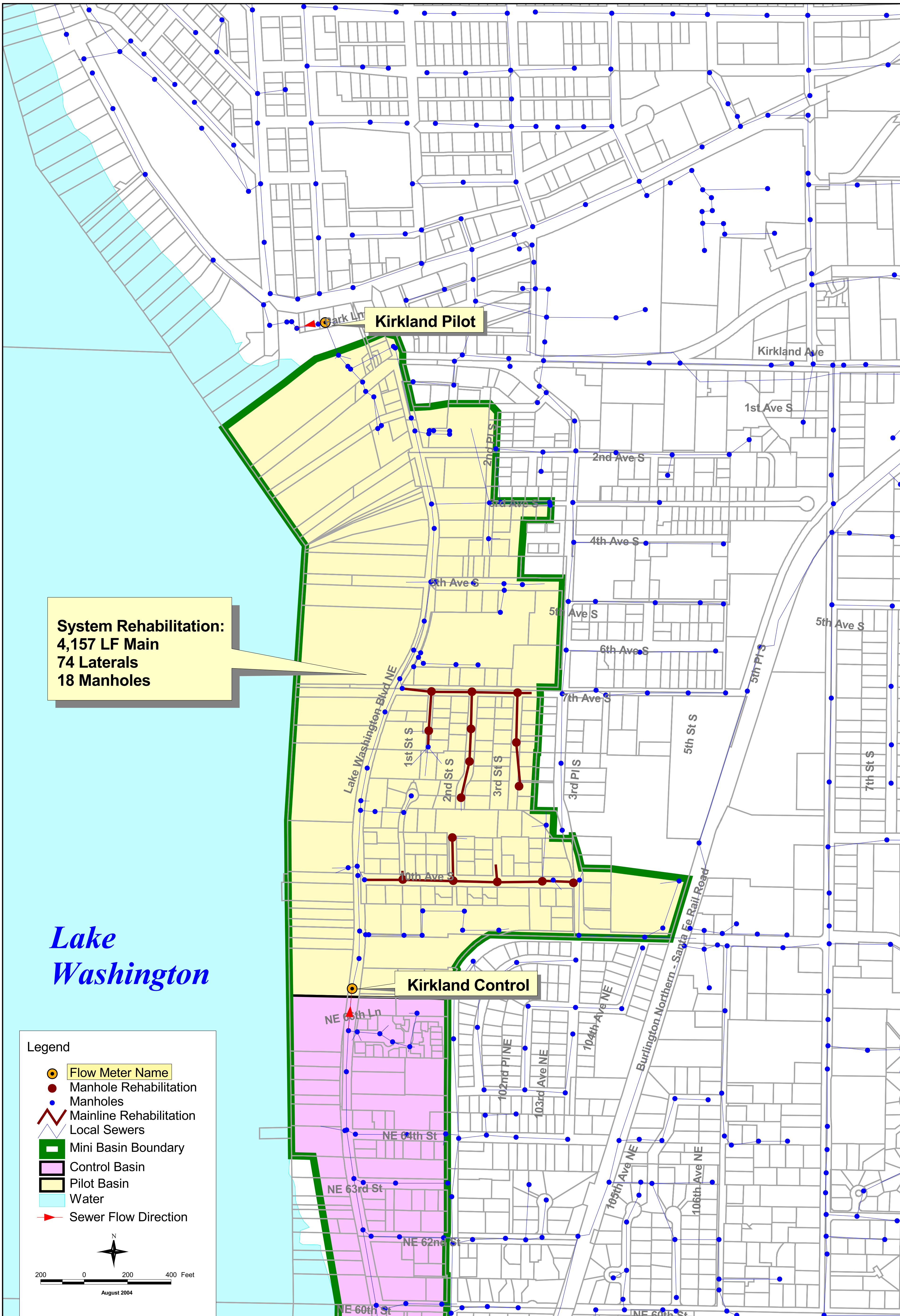

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Figure 5-17

Kirkland Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

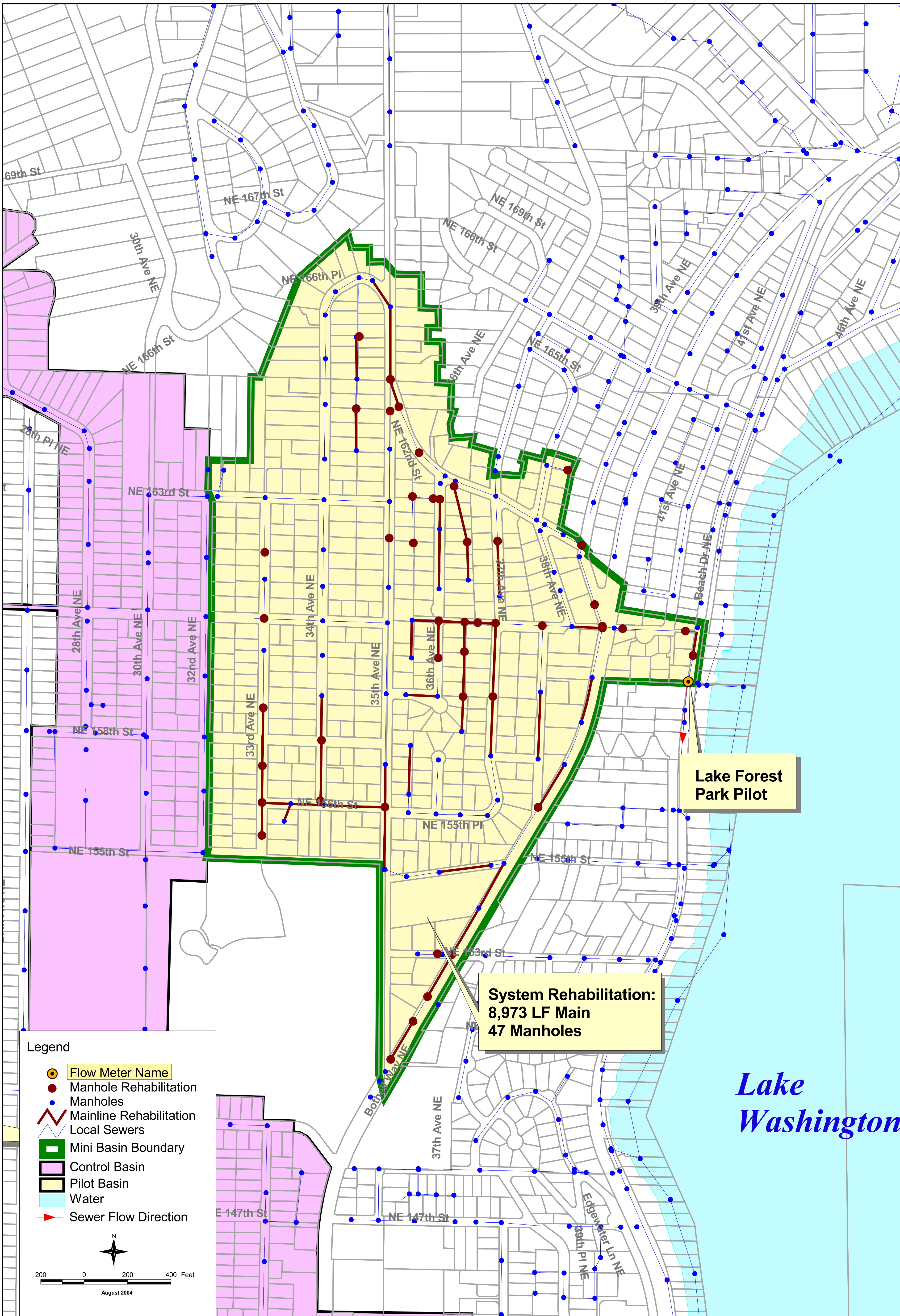

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Figure 5-18

Lake Forest Park Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

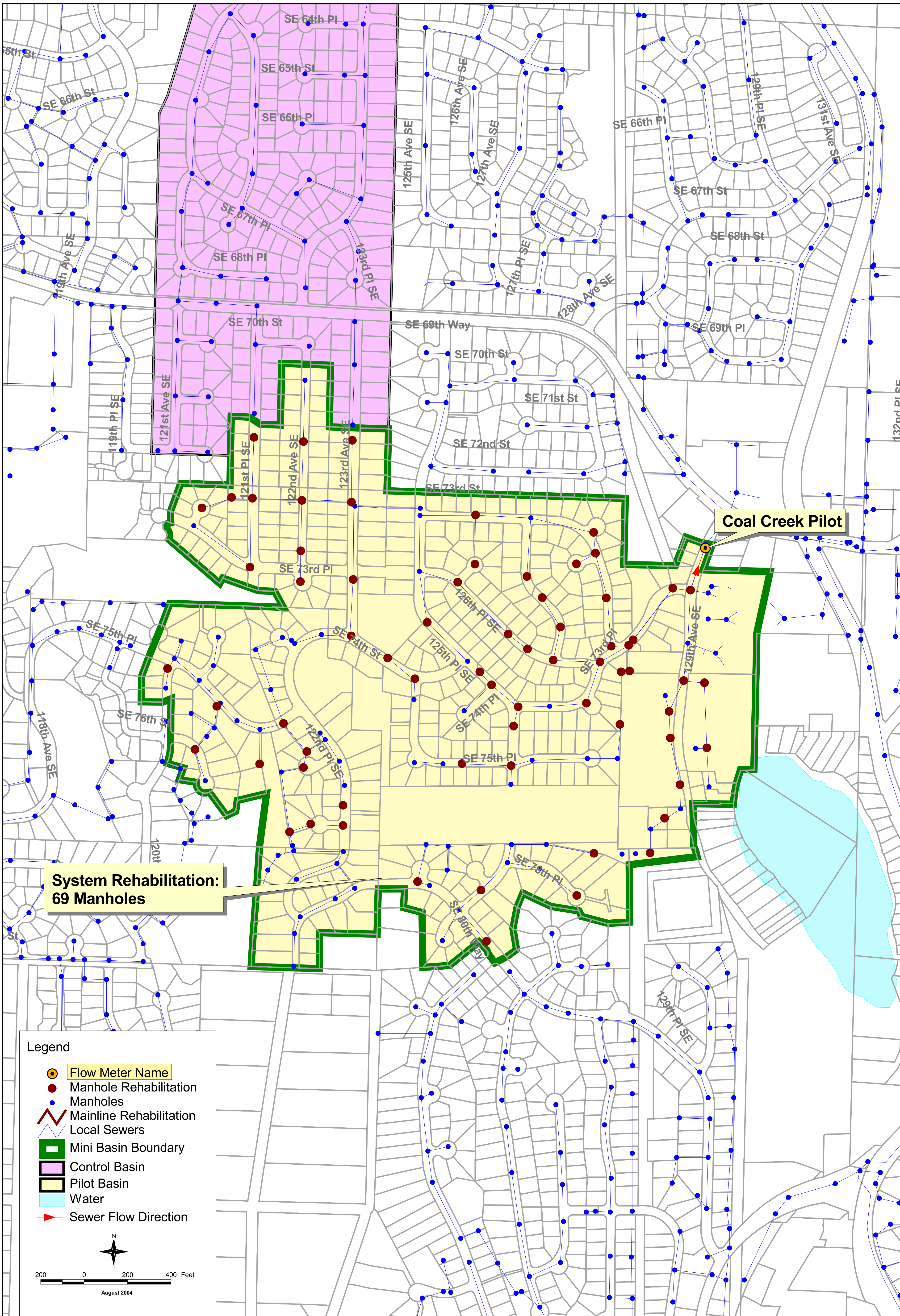

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Figure 5-19

Manhole Pilot Project - Coal Creek - Rehabilitation

Infiltration/Inflow Pilot Project Report

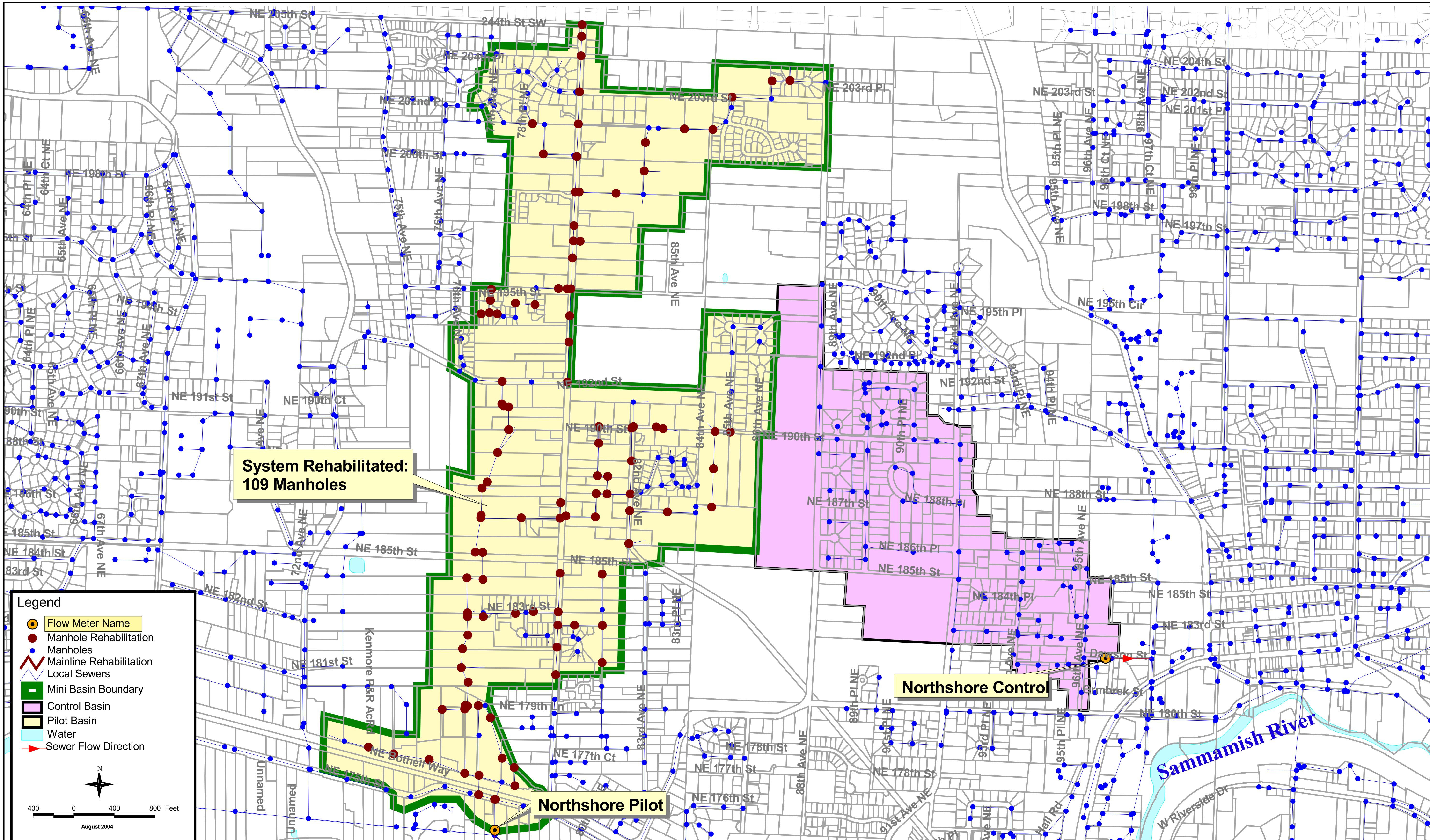

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Figure 5-20

Manhole Pilot Project - Northshore - Rehabilitation

Infiltration/Inflow Pilot Project Report

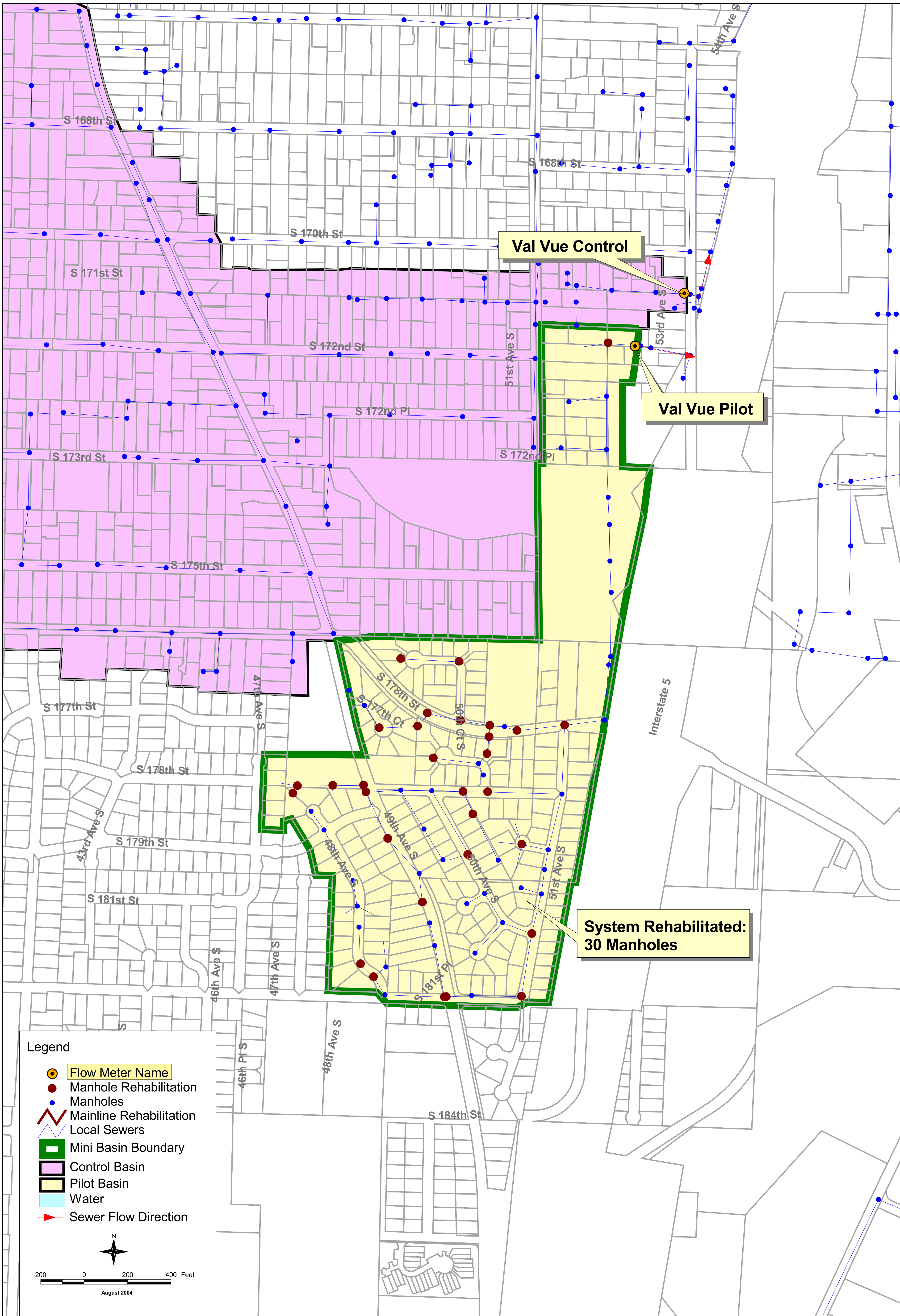

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Figure 5-21

Manhole Pilot Project - Val Vue - Rehabilitation

Infiltration/Inflow Pilot Project Report

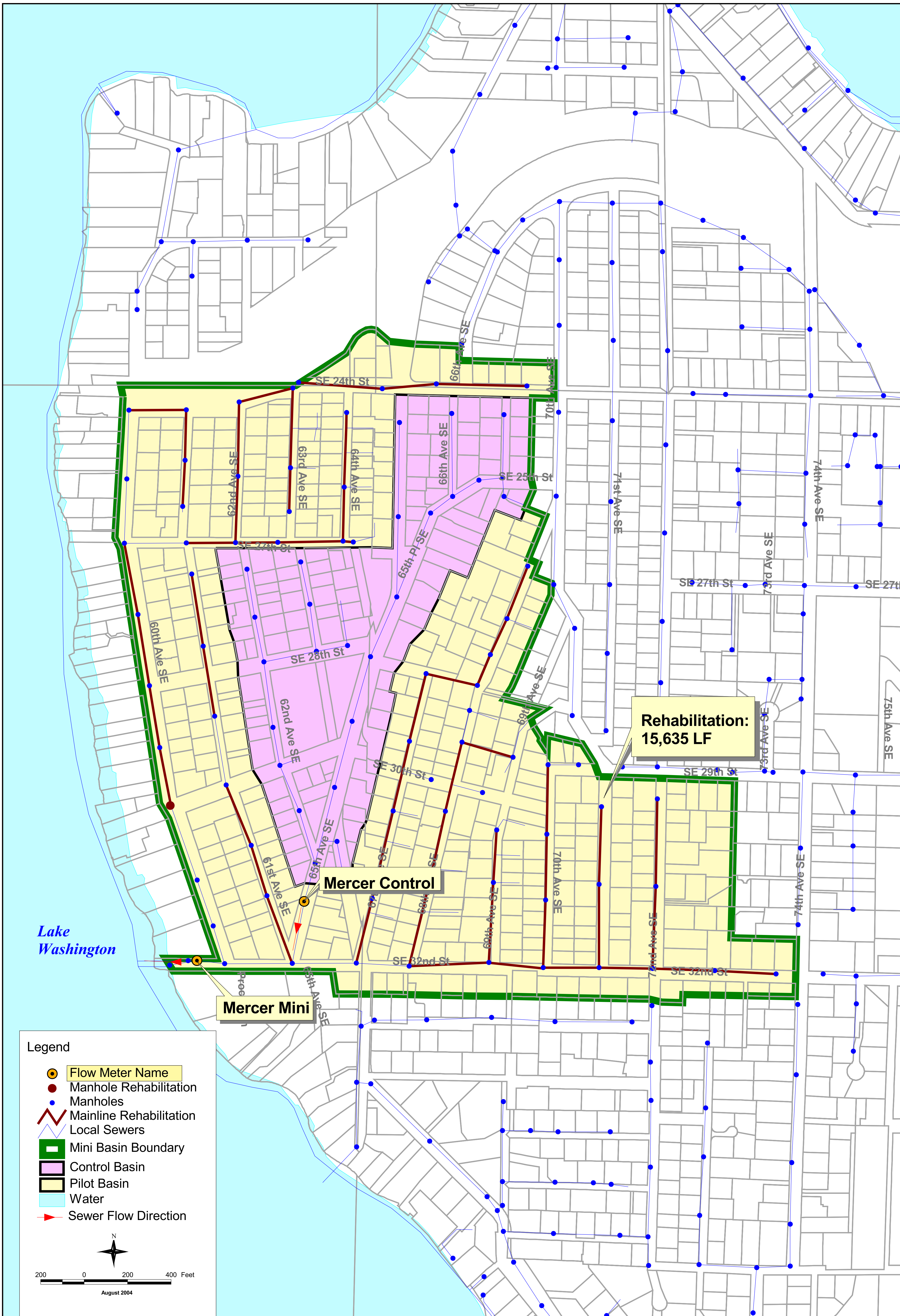

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Figure 5-22

Mercer Island Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

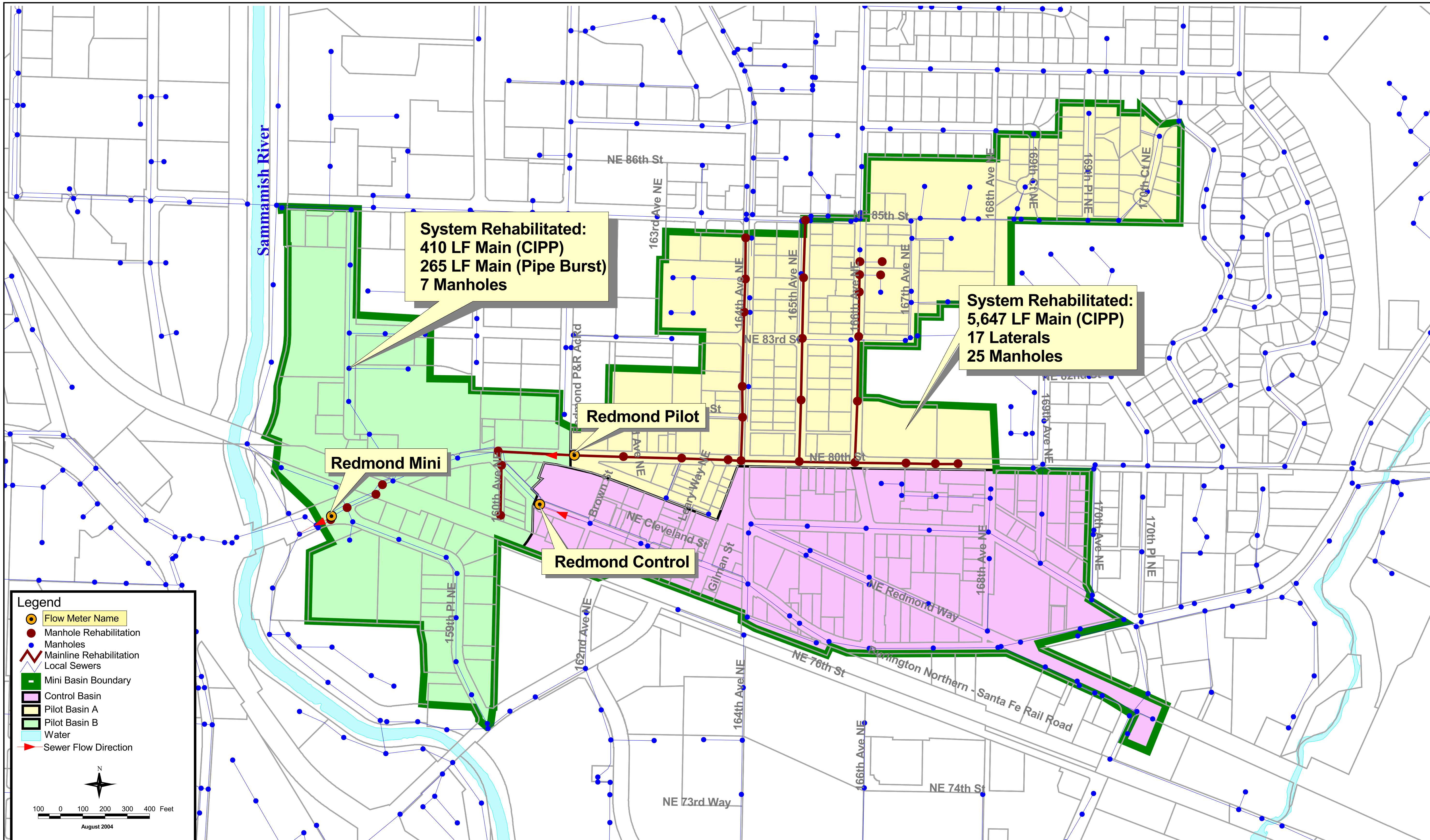

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Figure 5-23

Redmond Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

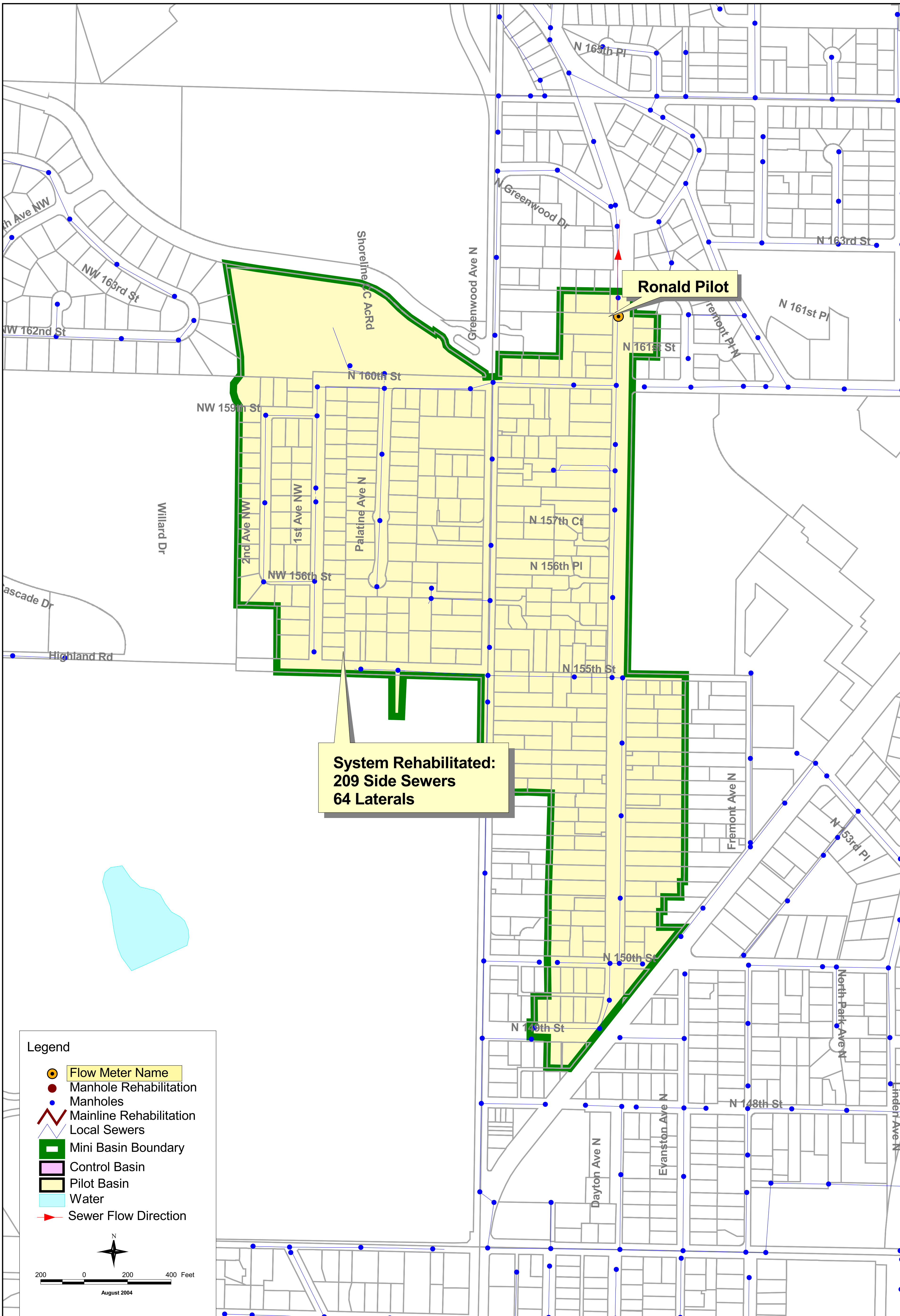

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Figure 5-24

Ronald Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

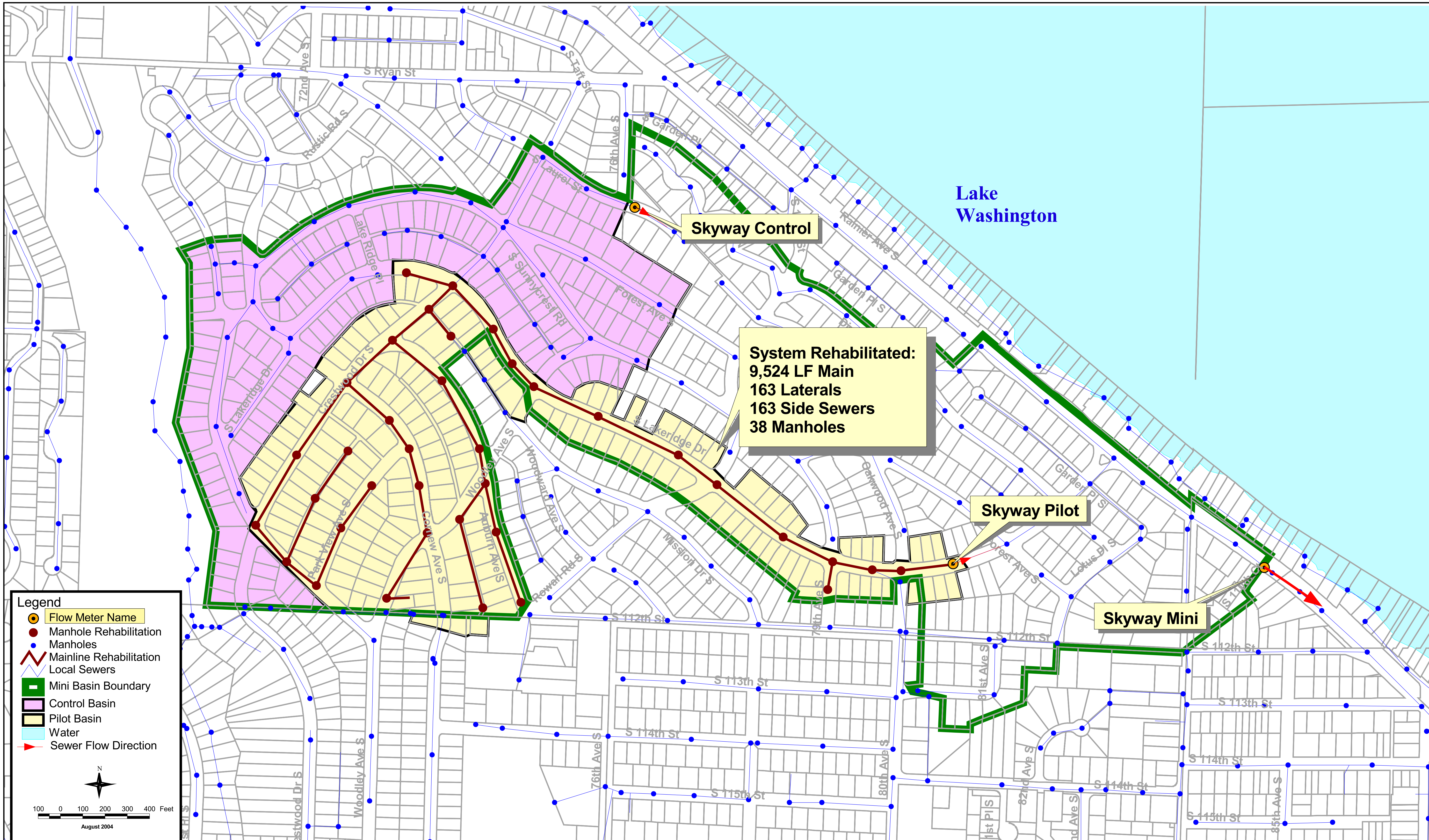

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Figure 5-25

Skyway Pilot Project - Rehabilitation

Infiltration/Inflow Pilot Project Report

Chapter 6

Bidding and Administration

Contract bidding and administration immediately followed design completion for each of the 10 pilot projects. This chapter provides an overview of the qualification requirements for project bidders, the time required to bid and award projects, level of interest and competition from bidders, issues encountered and resolved during bidding, and final contract prices for each pilot project. Two of the pilot projects, Ronald and Skyway, were issued for bid by the respective sewer agency.

6.1 Contractor Qualifications

Sewer rehabilitation using trenchless technologies is a relatively new industry. Many new products are available, and manufacturers and product installers are beginning new ventures within the field. Because the technology is new, it was important to ensure that contractors had suitable experience and personnel trained to perform the work. Selecting experienced contractors ensured that products and technologies used in the pilot projects accurately represented I/I reduction capability.

To ensure sufficient experience, the three lowest bidders were required to submit their qualifications. Technical specifications for each primary rehabilitation technology included minimum qualification requirements for the product manufacturer, product installer, and the field superintendent charged with day-to-day responsibility for field crews. Requirements focused on: (a) years of experience, (b) minimum installed quantity of material for each rehabilitation method, and (c) experience of the field superintendent.

Pilot projects included variety in the type of rehabilitation work to be performed. Thus, it was difficult for a single general contractor to qualify for performing all the work. General contractors typically needed to team with one or more subcontractors when submitting bids in order to satisfy the qualification requirements. For example, on pilot projects utilizing cured-in-place pipe (CIPP), general contractors typically met requirements for installing CIPP in sewer mains. However, to meet the qualification requirements for lining service connections, the general contractor needed to team with a specialty subcontractor to perform this portion of the work.

While it was important that highly competent personnel perform rehabilitation work, it was necessary at the same time to avoid limiting competition by imposing overly strict requirements. Limiting competition would translate into higher bid prices. Careful consideration was given to crafting realistic qualification requirements during the project design. After the requirements for a rehabilitation technology were established, various contractors and product manufacturers were contacted to ensure that a sufficient number qualified.

The following sections summarize the qualifications required for each major rehabilitation technology used in the pilot projects.

6.1.1 Cured-In-Place Pipe

CIPP qualification requirements for sewer mains, laterals, and side sewers were included on the Brier, Kent, Lake Forest Park, Mercer Island, and Redmond pilot projects. The requirements focused on qualifications of the product manufacturer, installer, and field personnel:

- Both the manufacturer and installer were required to have supplied a minimum of 50,000 linear feet of CIPP installations. In some cases the manufacturer and installer were separate entities. In other cases the manufacture and installer were the same company.
- The field superintendent was required to have supervised a minimum of 20,000 linear feet of CIPP installations.
- The general contractor was required to have a minimum of 5 years of experience in sewer rehabilitation projects and familiarity with CIPP processes.
- The lateral cutter (the field person responsible for reinstating the connection between the sewer main and lateral after lining) was required to have at least 6 months of experience. This qualification was required because a poor job of reinstating the connection is one of the most common ways that new CIPP is damaged.
- The liner installer was required to be licensed by the manufacturer to perform CIPP installation.

6.1.2 Service Connection Liners

Service connection liners (SCLs), one of the newer rehabilitation technologies explored by the pilot projects, were utilized where sewer mains were being lined. Qualification requirements included on the Brier, Kent, Lake Forest Park, Mercer Island, and Redmond pilot projects were as follows:

- The manufacturer was required to have supplied a minimum of 200 one-piece liner installations.
- The installer was required to have installed a minimum of 200 one-piece liner installations.
- The field superintendent was required to have supervised a minimum of 200 one-piece liner installations.
- The contractor was required to have a minimum of 5 years of experience in sewer rehabilitation projects and familiarity with CIPP processes.
- The installer was required to be licensed by the manufacturer to perform SCL installations.

- A schedule showing the estimated timing of the SCL installation work was required during the qualification review. The schedule was required due to the County's concern that if only one subcontractor was responsible for a majority of the SCL work, then the overall completion schedule for the pilot projects could not be met.

6.1.3 Manhole Linings and Coatings

Manhole rehabilitation using coatings and linings was performed on the Brier and Lake Forest Park pilot projects. The requirements focused on qualifications of the liner/coating manufacturer and the coating system applicator:

- The contractor was required to provide certification of the manufacturer's qualifications and experience in using the coating system.
- The manufacturer was required to: (a) have a minimum of 3 years of experience, and (b) verify that the coating system had been applied to a minimum of 100 manholes.
- The applicator was required to be the person responsible for the coating work, either as the field superintendent or as the person actually applying the coating.

As discussed in more detail later in this chapter, the Manhole Project was bid three different times. The first two bids sets (neither of which resulted in a contract award) included significant amounts of manhole linings and coatings. The qualification requirements included in these bid sets were the same as those described above.

6.1.4 Manhole Grouting

Manhole grouting was performed on the Brier, Lake Forest Park, Redmond, and Manhole pilot projects. Qualification requirements included for the projects were as follows:

- The contractor was required to provide certification of the manufacturer's qualifications for handling, mixing, and applying the grout system.
- The grout applicator was required to have a minimum of 3 years of grouting experience on a minimum of 50 manholes for the purpose of eliminating infiltration from the structure.
- The applicator was required to be the person responsible for the grouting work, either as the field superintendent or as the person actually performing the grouting work.

6.1.5 Pipe Bursting

Pipe bursting qualification requirements for sewer mains, laterals, and side sewers were included on the Auburn, Kirkland, Redmond, Ronald, and Skyway pilot projects. The requirements focused on the qualifications of the bursting contractor and field personnel. Qualification requirements for the Auburn, Kirkland, and Redmond pilot projects were as follows:

- The contractor was required: (a) to have at least 3 years of pipe-bursting experience, and (b) to have performed at least six pipe-bursting jobs totaling a cumulative 10,000 feet or more.
- The field superintendent was required: (a) to have a minimum of 2 years of pipe bursting experience, and (b) to have supervised a minimum of four pipe bursting projects totaling a cumulative 6,000 feet or more.
- Personnel operating high density polyethylene (HDPE) pipe fusion equipment were required to be trained and certified by the manufacturer and have a minimum of 2 years of experience in fusion welding HDPE pipelines.

Similar qualifications were required for the Skyway and Ronald projects, both of which were managed by the local agency.

6.1.6 Qualifications Review

Qualification reviews were performed on each of the 10 pilot projects prior to contract award. In addition to verifying the requirements described above, the experience of general contractors and key subcontractors and personnel was confirmed by checking references on similar projects. In all cases, the low bidder provided evidence of experience sufficient for contract award.

The qualification review period also provided the County sufficient time prior to contract award to review and assess the likelihood of completing the pilot projects on schedule. Of concern was the fact that two general contractors provided the low bids on 7 of the 10 pilot projects. These contractors demonstrated an ability to complete the projects on schedule and were subsequently awarded the contracts.

6.2 Bidding Schedule

The tight schedule required to meet the I/I program requirements presented a challenge for bidding, awarding, and constructing the pilot projects. It was necessary to substantially complete projects in time to collect post-construction flow monitoring data during the 2003-2004 wet season.

It would have been preferable to stagger bidding of the 10 projects over an extended period of time, beginning in the early months of the year. This would allow exposure of the projects to a wide variety of contractors well in advance of the busy summer construction season. Because designs for most of the pilot projects were not completed before April 2003, it was necessary to bid and award 8 of the 10 projects over a tight 2-month period.

The Skyway project had a scheduling advantage because design work was started by the local agencies before the final pilot projects were selected. For the Ronald project, SSES work, including mainline CCTV and smoke testing, was completed prior to the final pilot project selection. The design for each was completed early in the year, permitting some relief in the time allowed for bidding and for awarding the contracts. Both contracts were advertised in mid-February and were awarded in mid-March, allowing ample time to complete construction.

Design of the eight other contracts was not completed until several months later. Advertisement of these projects was staggered over a 6-week period beginning in late April and ending in June. Table 6-1 shows the schedule for bidding activities on each of the 10 pilot projects.

In order to allow post-construction flow monitoring to begin in November 2003, contracts for the County-administered projects could allow only 90 to 120 calendar days for substantial completion of I/I improvements. Construction activities such as final paving and surface restoration could be completed at a later date as long as the sewer rehabilitation work was complete and the I/I removal effectiveness could be measured.

The bidding and construction schedule for the Manhole Project extended furthest into the year because of problems encountered during contract bidding. The project was significantly revised and was advertised a total of three times due to the lack of competitive bids. Issues encountered during bidding of the Manhole Project are discussed in Section 6.5.

Table 6-1. Bidding Schedule (Year 2003)

Project	First Ad Date	Second Ad Date	Pre-bid Meeting	Bid Open	Complete Qualification Review	Notice to Proceed	Required Substantial Completion Date by Contract
Ronald	18 Feb	25 Feb	N/A	6 Mar	10 Mar	7 Apr	1 Sep
Skyway	18 Feb	25 Feb	26 Feb	12 Mar	18 Mar	16 Apr	1 Nov
Lake Forest Park	29 Apr	6 May	7 May	20 May	4 June	22 July	19 Nov
Brier	13 May	20 May	21 May	27 May	12 June	31 July	28 Nov
Kent	13 May	20 May	21 May	29 May	16 June	4 Aug	17 Nov
Kirkland	15 May	22 May	27 May	5 June	16 June	4 Aug	22 Nov
Redmond	15 May	22 May	27 May	5 June	16 June	4 Aug	22 Nov
Mercer Island	20 May	27 May	29 May	10 June	20 June	30 July	12 Nov
Auburn	27 May	3 June	4 June	10 June	20 June	4 Aug	17 Nov
Manhole Project[1]	8 July	15 July	16 July	22 July	7 Aug	5 Sep	4 Dec

[1]Dates shown are for the awarded Manhole Project.

6.3 Bidding Competition

The pilot projects generated considerable interest during bidding. Table 6-2 shows the number of plan holders and bids received for each of the pilot projects. Had more time been available for advertising, it is possible that submitting articles to national publications that focus on sewer rehabilitation work would have generated additional interest. However, the number of plan holders suggests that a suitable pool of contractors were aware of the projects.

All 10 pilot projects were advertised in the *Seattle Daily Journal of Commerce*. The eight County-administered contracts were also advertised in the *Seattle Times* and in a local minority paper. As shown in Table 6-2, a number of plan holders were from outside Washington and Oregon. Most of these contractors learned of the projects through conversations with the design team and through contact with product manufacturers familiar with the work.

In general, bidding competition was minor for the pilot projects, as shown by the number of bidders (one to four on all projects). This was likely due to: (a) the specialized nature of the work and the limited number of contractors able to meet the qualifications; (b) the overall bidding climate due to contractor workload at the time; and (c) the fact that the cost range of most projects was beyond the bidding capacity of smaller contractors, while too small for non-local larger contractors. Two general contractors completed 8 of the 10 pilot projects.

Table 6-2. Pilot Project Plan Holders

Pilot Project	Number of Plan Holders	Number of Prime Contractors	Number of Contractors Outside WA, OR	Number of Prime Contractors Outside WA, OR	Eventual Number of Bids Received
Auburn	6	6	0	0	2
Brier	16	11	6	3	2
Kent	12	10	3	2	1
Kirkland	10	8	1	1	4
Lake Forest Park	19	10	9	4	3
Manhole Project[1]	10	9	0	0	3
Mercer Island	14	8	7	4	4
Redmond	13	7	6	3	1
Ronald	16	9	3	1	4
Skyway	30	15	3	3	3

[1]Quantities shown are for the awarded Manhole Project.

6.4 Bidding Issues and Addendums

The pre-bid conferences held during project advertisement allowed contractors an opportunity to voice concerns and make recommendations regarding changes to the design. The pre-bid conferences were well attended by the contractors who later submitted bids for the projects.

Issues raised at the Skyway pre-bid conference resulted in several significant changes to the design. Most of the contractors confirmed that pipe bursting of laterals and side sewers is an effective rehabilitation method. However, the additional costs associated with excavating a pit at the right-of-way to install a new cleanout should be considered. Also, the lateral pipe size diameter at this location changed from 6 inches to 4 inches as the pipe extended onto private property. It was noted that significant cost increases would result; the contractor would need to dig a pit for the cleanout and start and stop the pipe burst pull at this intermediate pit. While a cleanout at the right-of-way was required per district standards, the district and the County authorized a change given: (a) the significant cost savings, and (b) assurances by contractors that pipe bursting could be done continuously from the house to the sewer main. The pipe size changed from a 6-inch diameter in the public right-of-way to a 4-inch diameter from the house to the main. This more readily allowed for pipe bursting around bends on private property.

Another change requested by most contractors was elimination of many of the testing requirements, including mandrel testing and air testing of the new sewer mains, laterals, and side sewers. While some testing requirements were modified (for example, mandrel testing for side sewers was revised to a ball test), most were left as project requirements. Additional discussion of field testing performed during the pilot projects is included in Chapter 7.

Another significant issue raised during advertisement of the Skyway project was whether the native soils at the pit excavations could be stockpiled and re-used, or, whether the soil should be immediately hauled offsite and replaced with an imported material. The bid documents originally included a provision for the latter to ensure cleanliness of project sites and private properties. Some contractors were concerned that hauling, disposing of, and replacing the native materials represented an unnecessary expense if the material met the soil property requirements for re-use. In order to allow the contractor flexibility, excavation stockpiling and re-use were allowed, with requirements added for protection and restoration of private property and the right-of-way. The contractor subsequently awarded this contract used all imported material on the job in order to avoid stockpiling on private properties and on narrow residential streets. Other minor changes were made to the Skyway bid documents as a result of the pre-bid conference. The revisions were incorporated into specifications for other pipe bursting pilot projects that followed the Skyway project.

Regarding the remaining pilot projects, contractors raised a limited number of issues. Several questions resulted in minor changes. Issues regarding warranty language and the length of the warranty were raised during advertisement of the initial CIPP pilot projects; these resulted in changes by addenda. There were also issues raised about various submittals and testing requirements. For the most part, these sections remained unchanged in the final contract documents.

6.5 Subcontracting Issues

The most significant issue encountered during advertisement and bidding of the pilot projects was teaming a general contractor with specialty subcontractors. This was an issue particularly when there were similar or competing technologies between the two firms involved. The most apparent example was encountered during bidding of the Manhole Project.

As mentioned previously, the Manhole Project needed to be advertised three times. The design of the project and the organization of the work changed significantly during the process. Initially, the contract documents combined the work in the three pilot basins and included a significant amount of manhole rehabilitation using cementitious, polyurethane, and epoxy liners and chemical grouts. A pre-bid conference for the contract was well attended by the subcontractors who performed each element of the specified work. However, concern was raised that there were no contractors that seemed willing or able to serve as general contractors for the work. Ultimately, there were no bids received for the first contract. Feedback from several of the lining subcontractors after the bid opening indicated that some of the competing lining manufacturers were not willing to work collectively on a combined rehabilitation project. Other factors such as the limited amount of work involving a particular subcontractor, strict warranty requirements, time of year, and current workload for subcontractors may also have contributed to the lack of bids.

After receiving no bids, the County decided to separate the work in the three pilot basins, and prepared standalone contract documents for the manhole rehabilitation work in Coal Creek, Northshore, and Val Vue. The scope of the rehabilitation work remained similar to the work included in the first contract; however, the manhole lining types were segregated by district in hopes of alleviating any conflicts between competing manufacturers and installers. Changes to the warranty requirements were also made to address concerns raised during the first contract advertisement. After advertising the separate contracts, a total of seven bids were received, all of which were well in excess of the engineer’s estimate. At the County’s discretion none of the separated contracts were awarded.

All of the manhole linings were subsequently deleted from the contract after the second advertisement, in favor of a manhole rehabilitation contract using only chemical grout. The work in the three basins was again packaged into one contract since there would be no competing technologies, it was re-bid, and the contract was awarded.

Subcontracting issues were also encountered on several of the CIPP lining projects when some of the contractors that would be performing the sewer main lining were unenthusiastic about teaming with the subcontractors that would be performing lateral rehabilitation work. Although the issue did not preclude the County from awarding any of the CIPP contracts, it may have resulted in a reduced number of bidders.

6.6 Bid Costs

Bid tabulations for each of the pilot projects are included in Appendix C. Table 6-3 shows a summary of the engineer's estimates and the range of bids received for each project.

Five of the ten pilot projects had low bids within 7 percent of the engineer's estimate. The other five projects had low bids with a 15 percent or greater difference from the engineer's estimate. Also, the high bids were a minimum of 20 percent greater than the low bids on all pilot projects where there was more than one bidder. It was difficult to ascertain whether the spread in bids was due to uncertainty concerning project conditions, low bidders underbidding actual costs to obtain work, high bidders overbidding actual costs due to work complexity or current workload, or some other factors. An analysis was conducted by the contracting agencies prior to award. With the exception of the second Manhole Project contract documents, all low bids met the requirements.

Several irregularities were noted among the contracts for similar unit price bid items. The low bid for pipe bursting of 8-inch-diameter sewer mains for the Kirkland pilot project was $95 per linear foot compared to $75 per foot for Auburn and $38 per foot for Skyway, where similar work was included in each bid item. The $38 per foot Skyway bid was significantly below the engineer's estimate for this item. The lower-than-expected cost was mainly attributed to a favorable bidding climate at the time of the project advertisement in mid-February. The cost difference between the Kirkland and Auburn projects for bursting mains was likely due to some imbalance between bid items on the Kirkland project.

Table 6-3. Pilot Project Bid Totals

Pilot Project	No. of Bidders	Engineer's Estimated Construction Cost[1]	High Bidder Price[1]	Low Bidder Price[1]
Auburn	2	$321,000	$410,598	$324,675
Brier	2	$393,000	$512,016	$425,359
Kent	1	$755,000	$1,099,544	$1,099,544
Kirkland	4	$825,000	$1,115,974	$781,775
Lake Forest Park	3	$757,000	$975,770	$801,893
Manhole Project[2]	3	$597,000	$1,112,500	$220,990
Mercer Island	4	$867,000	$870,824	$736,654
Redmond	1	$881,000	$899,117	$899,117
Ronald	4	$1,471,000	$2,296,151	$1,154,660
Skyway	3	$1,864,000	$2,046,745	$1,283,250

[1] All prices exclude sales tax. Sales tax rate was 8.8 percent for all projects except Brier, which was 8.9 percent.
[2] Prices shown are for the awarded Manhole Project contract.

The unit bid prices received on the CIPP projects allowed direct comparison of various liner material types used on the projects. The unit price for 8-inch-diameter sewer main rehabilitation was $55, $45, $38, and $23 per linear foot for the low bidders on Redmond, Lake Forest Park, Brier, and Mercer Island projects, respectively. The higher unit costs for Redmond and Lake Forest Park could be attributed to the use of a fiberglass liner material with epoxy resin, which has a higher material cost and takes longer to install. The low unit cost for Mercer Island could be attributed to allowing greater flexibility in the contractor’s choice of liner and resin materials, which resulted in less expensive materials being used and in generating increased competition between bidders. Some of the materials used on the CIPP projects had improved performance or rehabilitation capability over the others; thus, this also needed to be weighed into the cost comparison.

Table 6-4 shows the unit prices received from the low bidders for the sole source items specified in the contracts. The bid prices for these items were mostly higher than the engineer’s estimates. The higher bid prices were generally attributed to the fact that the products were bid as sole source. With a very limited number of subcontractors licensed to install the products, competition was not promoted. Additionally, cost estimates for these items were typically derived with significant input from the product manufacturers. Manufacturers tended to underestimate the final installed costs.

Table 6-4. Unit Prices for Sole Source Bid Items

Pilot Project	Product	Engineer’s Estimate	Low Bid Price
Brier	Lateral Connection Liner Poly-Triplex® PTLS-4400	$165 per linear foot $385 per vertical foot	$255 per linear foot $445 per vertical foot
Kent	T-Liner®	$75 per linear foot	$118 per linear foot
Redmond	MultiLiner® TOP HAT™ T-Liner®	$55 per linear foot $1,600 each $220 per linear foot	$45 per linear foot $2,800 each $312 per linear foot

The unit price difference in T-Liner® between the Kent and Redmond projects resulted from a difference in installed length, rather than from material or manufacturing costs. There is a relatively minor material cost difference between manufacturing a 20-foot-long T-Liner® versus a longer liner of say, 80 feet. Also, much of the cost of T-Liner® installation is derived in positioning the liner for the inversion process up the lateral. Thus, installation costs on a per-foot basis are much higher for shorter installation lengths, as was the case for the Redmond project.

As noted above, the Manhole Project was advertised and bid a total of three times. The first advertisement received no bids. In order to avoid placing competing general contractors and subcontractors under the same contract, the pilot basins were split into three separate contracts for the second advertisement. Table 6-5 summarizes the bid prices for the second advertisement, where the three low bids received totaled $840,600. A cost analysis was conducted on the bids from the second advertisement. It was concluded that the bids were too high for the amount of work to be completed. The high bids were attributed to large general contractor markups on the lining work and a lack of bidders on the projects.

Table 6-5. Bid Totals for Second Advertisement of Manhole Project

Pilot Basin	No. of Bidders	Engineer's Estimated Construction Cost[1]	High Bidder Price[1]	Low Bidder Price[1]
Coal Creek	2	$210,140	$499,800	$288,870
Northshore	2	$338,835	$730,300	$445,430
Val Vue	3	$71,055	$273,200	$106,300
Total of Low Bids				$840,600

[1] All prices exclude sales tax

For the third advertisement, the rehabilitation work was changed to use chemical grout in place of the manhole liners, and the pilot basins were combined back into one set of contract documents. The resulting low bid was $220,990. This bid price was for rehabilitating approximately the same number of manholes specified in the second advertisement of the project. The bid price for the second advertisement totaled $840,600. While there were likely some savings in contractor administration costs in changing from three contracts to one, the cost difference of $619,610 can mostly be attributed to a switch in technologies used. Although the liners were not used, the second advertisement results provide some useful data for comparing the cost of these technologies to chemical grout.

Chapter 7

Construction

This chapter provides firsthand information collected during construction of the pilot projects. It includes a synthesis of management, pre-construction, and construction issues, describes the practical use of rehabilitation techniques and technologies, lists methods used to inform the public during construction, and provides a general comparison of completed price versus bid price for each project.

Sewer system components (manholes, sewer mains, laterals, and side sewers) are illustrated in Figure 7-1. Sample photos of smoke and dye testing are shown in Figures 7-2 to 7-4, and selected construction techniques and technologies are shown in Figures 7-5 to 7-55.

Note: all figures are located at the end of the chapter (section 7.7).

7.1 Construction Management

Construction management tasks began after the projects were awarded to the selected contractors and the contracts executed. Construction management involved King County staff, the Earth Tech Team, and the 12 local agencies. Table 7-1 shows the function of each entity during design, construction, and inspection. Construction management was accomplished as follows:

- For the majority of the projects, King County and the Earth Tech Team worked together to coordinate construction management and inspection.
- For some projects, the Earth Tech Team served as both designer and construction manager; for others, the Earth Tech Team served as designer and King County provided construction management and inspection.
- For the Skyway project, the Earth Tech Team served as designer and the local agency used its own staff for construction management and inspection.
- For the Ronald project, the agency worked with its consultant through all phases of the project; King County did not provide design, construction management, or inspection services.

Table 7-1. Design, Construction Management, and Inspection Teams

Pilot Project	Designer	Construction Management	Inspection
Auburn	Earth Tech Team	King County	Earth Tech Team
Brier	Earth Tech Team	Earth Tech Team[1]	Earth Tech Team
Kent	Earth Tech Team	King County	King County
Kirkland	Earth Tech Team	King County[2]	Earth Tech Team
Lake Forest Park	Earth Tech Team	Earth Tech Team[1]	Earth Tech Team
Manholes	Earth Tech Team	King County[2]	Earth Tech Team
Mercer Island	Earth Tech Team	Earth Tech Team[1]	Earth Tech Team
Redmond	Earth Tech Team	King County[2]	Earth Tech Team
Ronald	CHS Engineering	Local agency	Local agency and CHS Engineering
Skyway	Earth Tech Team[3]	Local agency	Local agency and Brown & Caldwell

[1] King County Construction Management Services oversaw the Earth Tech Team.
[2] This involved King County staff from Construction Management and the Regional I/I Control Program.
[3] The initial Skyway project designed by Brown & Caldwell, the agency's consultant, included only the rehabilitation of laterals and side sewers. The second design completed by the Earth Tech Team included rehabilitation of sewer mains, laterals, side sewers, and replacement of manholes.

7.2 Pre-Construction Issues

7.2.1 Submittals

As is typical for construction projects, contractors were required to submit information demonstrating how products, processes, and equipment conformed to project specifications.

In addition to standard submittals, contractors submitted information for cured-in-place (CIP) products used for lining sewer mains, laterals, side sewers, and manholes. These product-specific submittals provided a means of documenting the manufacturers' specifications, and were needed by engineers and inspectors in order to familiarize themselves with these new products. As a general rule, CIP products require more submittals compared with the number required for other rehabilitation products; hence, additional review time is necessary. More submittals are required when products are applied and cured in the field rather than in a controlled environment. Quality control for installation of CIP products occurs at the jobsite. The CIP wet-out process may occur in the field or in the manufacturer's factory.

For the pilot projects, submittals also served as means of communicating with contractors about specific products. As described in Chapter 5, a few sole source products were identified in project specifications in order to try a full range of rehabilitation products. In some instances, contractors suggested substitute products. Substitutions were not accepted for sole source products.

7.2.2 Documenting Pre-Construction Conditions

Contractors were required to document pre-construction conditions. Documentation included photos of ground surface and site features, written closed circuit television (CCTV) reports, and CCTV videotapes of the existing pipe conditions. In addition to providing information for comparison to post-construction conditions, pre-construction documentation validates the original design, helping to process change orders.

Pre-construction photos of ground surface and site features proved helpful when work involved excavation or when equipment was used on private property. In some cases, photos were used following restoration to show homeowners their property as it looked before side sewer replacement.

The pre-construction closed circuit television (CCTV) specification required contractors to videotape pipes in which they would be working. The intent was to provide the contractor with information about pre-construction pipe conditions and to allow comparison with older CCTV tapes. As a secondary benefit, CCTV tapes allow contractors to locate side connections and to discover large defects that impact their work.

While the specification required that pipes be cleaned prior to videotaping, it was later noted that pipe cleaning is not always necessary prior to some construction techniques. For example, pipes that are being replaced through pipe bursting do not require cleaning since the old pipe is broken up during the process.

7.3 Experiences with Rehabilitation Techniques and Technologies

Descriptions of rehabilitation technologies are provided in Chapter 4. This section highlights specific experiences with various techniques (methods of performing tasks) and technologies (specific types of products) during rehabilitation of the sewage system.

7.3.1 Sewer Mains

I/I occurs in sewer mains when water leaks through faulty lateral connections, through cracked or broken pipes or open joints, or from illicit connections like storm catch basins. The source of flow (infiltration) is usually groundwater coming from the ground surface or flowing into the pipe from the bottom of the trench.

Trenchless technologies for rehabilitation of sewer mains will typically involve one of the following: (a) installing a lining in the host pipe, (b) repairing damaged sections of existing pipe, or (c) pulling new pipe into the trench occupied by the existing pipe.

7.3.1.1 Cured-in-Place Pipe (CIPP)

Installing cured-in-place pipe (CIPP) in sewer mains involves five major steps:
(1) cleaning and videotaping the host pipe, (2) liner insertion, (3) liner inflation and curing, (4) cool-down period, and (5) reinstating services.

Table 7-2 summarizes the host pipe conditions, products, and methods used for insertion, inflation, and curing of sewer main CIPP.

Table 7-2. Cured-in-Place Pipe Installation Parameters for Sewer Mains

Pilot Project	Host Pipe Design Condition	Lining Product	Insertion Method	Inflation Method	Curing Method
Brier	Partially deteriorated	Polyester resin with polyester felt	Air pressure inversion	Coating on lining	Steam
Mercer Island	Fully deteriorated	Polyester resin with polyester felt	Air pressure inversion	Coating on lining	Steam
Lake Forest Park	Partially deteriorated	Epoxy resin with polyester felt	Water pressure inversion	Coating on lining	Hot water
Redmond	Partially deteriorated	Polyester resin with fiberglass fabric[1]	Pull-in	Separate Bladder	Steam

[1] This sole source product (MultiLiner®) is manufactured by Pacific MultiLining Inc. Refer to Chapter 5 for a discussion of sole source products.

Pros of Installing CIPP in Sewer Mains

- No excavation or associated work is typically required. There are no conflicts with other buried utilities or with caving soils and dewatering.

- Impact on the neighborhood is usually limited to one full day of work for a section of pipe, with a shorter second day for brushing lateral openings.
- Long lengths of pipes may be lined at one time.

Cons of Installing CIPP in Sewer Mains

- CIPP slightly reduces the inside diameter of the host pipe.
- This process does not allow increasing the diameter of the host pipe (as is possible when pipe bursting with high density polyethylene [HDPE] pipe).
- Roots need to be removed before the work is done.
- CIPP follows the old pipe alignment, whether or not that alignment is straight. It does not remove sags or curves in the existing pipe. Larger defects such as offset joints and out-of-round pipes are apparent through the finished liner. Larger defects may not leak after the liner is installed; however, there still may be a structural problem or impacts to flow rates.
- Cutting open or reinstating a lateral creates a large hole in the liner that can be an entry point for infiltration migrating through the annular space between the CIPP and host pipe. Sealing this hole with a service connection liner (SCL), service connection and lateral liner (SCLL), or chemical grout can sometimes be difficult.
- Future work must deal with both the host pipe and CIPP. Making a connection to a lined pipe means putting a hole in both materials, which limits the use of some types of standard sewer fittings. Since the presence of CIPP is likely not typical in a sewer system's pipes, future contractors and agency staff must remain aware of its use and location.
- CIPP is fairly thin, usually 1/8- to 1/4-inch thick, and may be susceptible to damage by maintenance equipment such as jet trucks and CCTV cameras.
- Chemicals in the uncured resin may be hazardous; however, no hazard remains once the material cures.
- There are safety considerations associated with steam and hot water. Protection of people and property is mandatory.

Materials, Processes, and Equipment for CIPP Installation

In addition to standard construction equipment, installation of an inverted, steam-cured CIPP involves the following equipment: steam generator truck, trailer-mounted compressor, refrigerated liner delivery truck, CCTV truck with equipment for cutting open laterals, bypass pumps, and two-way radios.

Pre-Installation Issues for CIPP

The host pipe must be cleaned prior to CIPP installation. Surface preparation of the host pipe was performed by pulling a high-pressure spray head through the pipe (jet cleaning) to remove debris attached to the walls and solids settled in the bottom of the pipe. This debris must be trapped and removed so that it does not cause problems downstream.

The extent of roots growing into the pipe and consequently the amount of root removal required was not known for some of the pilot projects. Light roots may be removed during the jet cleaning process before CIPP is installed. However, jet cleaning will not remove heavier roots, and mechanical equipment may be required.

Installation Issues for CIPP

Access

All sewer main CIPP work required access to manholes located at each end of the host pipe. A typical CIPP section extends from manhole to manhole. Most sewer mains were located in asphalt streets and within road rights-of-way. As a result, access to manholes for installation and curing equipment trucks was fairly easy. A small portion of the work occurred in easements, backyards, and adjacent to creeks, where access to manholes was more difficult than it was for manholes located in streets or parking lots. Special attention to site conditions was necessary and sometimes required hand-carrying equipment to manholes. Here the contractor parked near the most convenient manhole. This meant that in some cases liner inversion continued through intermediate manholes, and two or three host pipes were lined from a single manhole.

In Lake Forest Park, water pressure inversion of a liner required installation of a scaffold tower over the insertion manhole. However, there were some manholes in backyards where scaffolding could not be erected due to the presence of large trees, fences, and steep slopes. In these cases, the contractor requested and received permission to install a standard polyester resin liner (installed with air pressure instead of water pressure) instead of an epoxy resin liner, since air pressure equipment was easier to use in these locations.

Most manhole lids in the basins were 24 inches in diameter. This is typical in most of King County and is adequate for manhole access. However, in Lake Forest Park, manhole lids were 18 inches in diameter, making the contractor's work more difficult.

Manhole depths ranged from approximately 6 feet to over 20 feet. The main impact of deep manholes is the necessity of climbing in and out and working in the bottom of the manhole. The polyester-resin-with-polyester-felt liners and the epoxy-resin-with-polyester-felt liners end above ground. The liner coating is bonded to the felt. After the cure and cool-down phases, the portions of the liner that are vertical in the manhole are cut out and disposed of. The polyester-resin-with-fiberglass-fabric liners end within the channel; they do not extend above ground. These liners have an interior bladder that cannot make the turn to come up out of the manhole.

CIPP installation normally stops at the manhole wall unless the manhole is an intermediate manhole in a multiple pipe liner installation. When two sections of CIPP stop in a single manhole, a determination must be made about whether to smooth-out the flow line in the channel. This decision depends on factors such as pipe slope, condition of the channel, thickness of the CIPP, and whether or not the local sewer agency wants the channel raised. In most of the pilot projects, the channel was left in the existing condition. In Redmond, a thin layer of specialized grout was installed to smooth-out the channel and align it with the CIPP.

Installation Time

CIPP installation is typically accomplished in 1 day. Installation time for a 600-foot-long liner is not substantially longer than the installation time for a 200-foot-long liner. However, installation of a longer liner may require more time for setup, cutting open the laterals, and cleanup. In general, the longer the liner and the more service connections that are on the liner, the longer the work day will be. On the pilot projects, it was very rare for the work to take less than 10 hours, even for short liners or liners with no connections. A typical day ran from 7 a.m. to 6 p.m. A 12-hour block of time is recommended as a minimum for each liner installation.

More complex liners also need more setup and cleanup time. Installation of a liner where access is an issue (for example, near a creek where bypass pumping is required) may take up to 15 to 16 hours. Liners installed in multiple pipes and liners with many service connections require extra time.

Setup and liner insertion is normally a fairly quick process, requiring approximately 2 to 3 hours in most cases. Curing the liner requires another 2 to 3 hours. During this time, there is very little for the crew to do other than clean up and prepare for reinstating the service connections. On the pilot projects, part of the crew sometimes left the job at this time. Cool-down takes about 1 hour. For an average section of sewer main with multiple connections (as typically occurs in a residential neighborhood), about half the installation time is required for reinstating the laterals. In most of the CIPP sewer main projects, brushing the laterals (that is, cleaning up and smoothing the edges with a wire brush attached to an air-powered motor) was performed later because the crew ran over the day’s time limit.

Unforeseen circumstances sometimes resulted in the crew working late into the night. When this was the case, the contractor was required to notified neighbors impacted by the delay.

Liner Diameter and Length

On the pilot projects, liner diameters for sewer mains were 8 inches, 10 inches, and 12 inches. Liner lengths ranged from a minimum of 30 feet to a maximum of 600 feet. On the CIPP pilot projects, the average liner length was between 200 and 300 feet.

A liner’s length is limited by many factors, including the capabilities of the curing equipment, the liner’s weight, condition of the host pipe, capacity of the insertion equipment (for example, air compressors, length of hoses), and the necessity to reinstate services by the end of the allowed workday. On several pilot projects it made sense to install a long liner; for instance, when manhole access was difficult along a creek or in an easement.

Some issues experienced with long liners are:

- In one case, the air line for the lateral cutter equipment was too short to reach a lateral near the end of a 600-foot run of CIPP. The liner was installed through two intermediate manholes. In order to cut open the last lateral, the crew was forced to take down their setup at the upstream manhole and move to an intermediate manhole. The time required to cut out laterals, combined in this instance with a second setup, made for a very long day, well past the daily shutdown time required by the contract. When this occurred, the inspector notified city and County staff of the difficulties and work continued until all the laterals along the line were opened.
- When a liner with many connecting laterals was installed, extra time was required during liner installation to deal with installation concerns and issues like traffic control and access to the manholes. As a result, the cutting crew started late in the day. In order to open the laterals, the cutting crew had to work late into the evening. Crews learned that they needed to cut open the laterals as soon as possible after cool-down was complete. Brushing the laterals could be done the next day while the next liner was installed.

Installation of long liners may be deemed favorable from a contractor’s viewpoint because it represents a higher production rate. However, on the pilot projects, the local agency’s need to have the sewer system back in service at the end of the day was a fundamental issue. Any restrictions specific to a particular sewer main should be clearly stated in the construction documents.

There is no minimum liner length as long as there is a manhole at each end of the pipe. The minimum liner length used for the pilot projects (30 feet) resulted from the fact that pipes shorter than 30 feet did not have manholes at each end. During the pilot project design process, plans for lining shorter pipes (less than 30 feet) were included. However, these plans could not be implemented for "dead end" pipes. A very short liner would likely be installed in a manner similar to that of a point repair; that is, the liner would be placed on a packer rather than installed using the inversion process. The length would be dependent on the length of the packer. A packer is a long plug that is placed inside the pipe and expanded with air pressure. For a CIPP spot repair the packer is wrapped with a section of epoxy-impregnated felt liner and inflated in place. The epoxy then cures and the packer is deflated and removed.

Curing Temperature

The capability of curing equipment is the most critical factor in limiting liner length, assuming that the liner can be placed in the host pipe and that time is not an issue. Heating equipment must provide the correct amount of heat necessary to cure the liner, and must be able to deliver heat evenly throughout the liner, or the liner will not cure evenly. Any uncured portions of the liner may collapse and block the flows in the sewer main. Curing temperatures range from 150 to 200 degrees Fahrenheit (F). An 8-inch-diameter liner that is 200 feet long may cure in an hour, while a 12-inch-diameter liner that is 600 feet long may take 3 or more hours.

Although liners may be cured under ambient conditions, time constraints and resin chemistry prevented the contractors from doing an ambient cure on any of the CIPP pilot projects. Ambient curing takes considerably longer than the other curing methods and was not used.

A long liner or a large diameter liner may be susceptible to difficulties during the curing process if the heat source is insufficient to heat the entire pipe. For steam-cured liners, a potential curing issue is insufficient temperature of the steam. Heat loss is most likely to occur toward the tail end of the liner; therefore, temperature of the steam exiting the liner must be higher than the specified minimum temperature.

For the pilot projects, there was only one liner installation where this situation occurred. The liner was installed in a 600-foot, 12-inch-diameter sewer main through multiple intermediate manholes along a creek. In this case, the steam exiting the liner never achieved the temperature required to cure the liner. After cool-down, large wrinkles were observed in the last 5 feet of the liner. Groundwater may also have been a factor in this instance because the host pipe was buried adjacent to a creek where groundwater was present. The groundwater may have absorbed some of the heat from the curing process.

Pipe Elevation and Water Pressure

When water is used for the inversion process, the operators must pay attention to the elevations of the pipe ends. For a relatively “flat” sewer main, the height of the top of the manifold and the depth of the manhole determine the water pressure. For example, a typical sewer main might have a 1-foot fall, an 8-foot-deep manhole, and a height of 15 feet for the manifold. This translates to 24 feet of head on the tail end of the liner, or 10.4 pounds per square inch (psi).

While this pressure is reasonable for a flat pipe, the pressure can be much higher at the downstream end of a pipe with a steep grade. As a case in point, assume a 30-foot fall, an 8-foot-deep manhole, and a height of 5 feet for the manifold. This represents 43 feet of head at the downstream end, or 18.6 psi. These pressures impact the liner and can squeeze resin out of the liner, cause the liner to burst, or cause other difficulties. Water hammer (that is, a shock wave effect) may also be a problem.

One of the liners in Lake Forest Park was installed on a steep grade. During installation, the tail end of the liner entered the downstream manhole, then the end of the liner detached from the hose inside the liner and broke open. All the water flushed into the sewer, and there was evidence that the liner collapsed as the water escaped. The crew pulled back the end of the liner, closed the bottom end, and put water back into the liner. After the cure was complete, review of CCTV videotape indicated that there were several wrinkles in the liner and one place where the liner projected into a lateral. It was necessary to dig up this lateral connection and replace it with a polyvinyl chloride (PVC) tee. This experience was attributed to excess water pressure and possibly water hammer.

Pull-In Liners versus Inversion Liners

One benefit of a pull-in liner is that during the insertion process, the crew has physical control of each end. The liner is in place before it is inflated. A potential concern is that the liner can get snagged as it is dragged through the sewer main. Friction acts on the liner and pipe as the liner is pulled in the bottom of the pipe.

In contrast, an inversion liner will not snag. It moves through the pipe like a tire rolling down a road. Friction acts on the liner as it turns inside out. This type of liner is inflated as it advances through the pipe. And, unlike the pull-in liner, the crew has direct control of only one end of the liner as it is installed. The crew controls the point where the liner turns right-side-out and moves down the pipe on its own, powered only by water or air pressure. The control is the tail rope, which prevents the liner from moving too fast. The tail rope may be used to back up or pull out a liner that has stalled, if the rope is strong enough. If the rope breaks, the liner must be attached to a winch or truck bumper and pulled out. A pulled-out liner cannot be re-used; a new liner is required.

For inversion liners, water pressure may be a more reliable inversion method than air pressure because of the mass involved. Water with sufficient pressure and volume is usually available from a nearby fire hydrant. Though air pressure has benefits, air is harder to control.

Slowing down the advance of an inversion liner is the job of the tail rope (or the lay-flat hose when water pressure inversion is used). During the pilot projects, there were instances in which a liner was not slowed down and stopped in time.

- In one case, a liner being installed using the water pressure inversion process broke loose and ended up 20 feet down the next pipe. The water flowed into the sewer and the liner collapsed. The liner had to be pulled back, the end reconfigured, and more water added to re-inflate the liner. The collapsed liner had wrinkles and jutted into a lateral, necessitating several repairs.
- In another instance, the liner crew did not slow down the liner as it came into an intermediate manhole, exposing a worker stationed in the manhole to possible injury. The worker was stationed in the bottom of the intermediate manhole to guide the liner through the manhole toward the next pipe; however, as the liner entered the manhole, it inflated within the manhole. (Note: the worker was not injured in this incident.) The crew could have cut off the liner and ended the liner in this manhole; however, they managed to “un-invert” the liner (back it up the pipe by pulling on the tail rope) and complete the installation by guiding it into the downstream pipe. “Un-inverting” the liner involved lowering the inflation pressure to a point where the tail rope could pull back the liner without allowing the liner to totally deflate.

Field Quality Assurance/Quality Control and Data Collection

Field quality assurance/quality control (QA/QC) for CIPP involved watching or measuring time, temperature, pressure, and insertion speed. The contract specifications called for a data logger to monitor and record temperature and pressure over time. The temperature was monitored using two thermo-resistors, one placed at each end of the liner. The two thermo-resistors and a pressure gauge were connected to the data logger. The inspector calculated liner insertion speed on some of the pipes.

Initially, contractors gathered data logger information in the form of a spreadsheet or graph and provided it to the engineers. The quantity of data collected was huge, and it was determined that the inspector could more easily record the information. After a few liners were installed, the requirement for using a data logger was dropped and the inspectors manually gathered the data.

Bumps and Wrinkles

Several types of bumps and wrinkles were observed in the CIPP. The cause of some bumps was readily apparent, such as when the CIPP encased a rock. Sometimes, however, the cause of some types of wrinkles was more difficult to determine. It was speculated that possible causes included installation speeds that were too fast or installation pressures that were too high, as well as other potential installation problems. Some experiences with bumps and wrinkles included:

- **Bumps in the CIPP:** Some CIPP appeared to cover rocks, span open joints in the host pipe, or cover an encrustation or patch of grout. In almost all cases, bumps in the CIPP were very smooth and the engineer felt these bumps would not impact flows in the pipe.
- **Longitudinal wrinkles:** Wrinkles that are longitudinal in the pipe may interfere with flow if they are near the bottom of the pipe and are susceptible to catching debris. When these wrinkles occur at the end of a pipe, they may interfere with the installation of a plug. They can also create a difficult track for the wheels on a CCTV camera. Wrinkles at a lateral connection point may interfere with the service connection liner (SCL) or the service connection and lateral liner (SCLL). Some experiences with longitudinal wrinkles included:
    - In at least one case, the main cause of wrinkles was determined to be installation of a liner that was too large in diameter for the host pipe. This could also be seen where there was a short section of smaller diameter sewer pipe within the main. The inspector/engineer determined that these wrinkles would not impact pipe flows.
    - On one project, a piece of small diameter rope was present between the liner and the host pipe. The rope was left in place because it could not be removed before the curing process started. Again, this was determined not to be a problem for the flows in this pipe.
    - In another pipe, a liner had three large wrinkles within a 5-foot section. The liner was too long, and the steam used for curing did not contain enough heat to cure the tail end of the liner. Therefore, the wrinkled section of liner was removed and replaced with a spot repair liner. This replacement liner matched the other liner and no further impact to the pipeline was noted.

Most of the CIPP projects had some type of wrinkle or bump in one or more of the completed liners. In most cases it was determined that the wrinkle or bump would not impact the flows in the pipes. Some wrinkles or bumps were obviously part of the original pipe and were not a problem associated with installation. In a few cases it was believed possible that the problem would have an impact on flows and a repair was required. Repair costs were almost always covered as part of the bid price.

- **Circumferential wrinkles:** The potential impact of circumferential wrinkles on flow is more drastic than longitudinal wrinkles because they are perpendicular to the flow line. The cause of this type of wrinkles is not known.

- **End-of-pipe wrinkles:** During installation, polyester-resin-with-polyester-felt liners and epoxy-resin-with-polyester-felt liners end above ground and attach to their manifolds. The cured vertical portion within the manifold is removed and disposed of. End-of-pipe wrinkles are caused because the liner makes a 90-degree turn at the bottom of the manhole. These wrinkles occur at the top of the liner where it comes out of the sewer main. They do not normally interfere with flow, but do make it difficult to install a plug in the pipe.
- **Orange peel wrinkles:** After the liner is saturated with resin, called the wet-out process, it is put in cold storage until installation. Storage may be for a day or as long as a week. The resin contains styrene, which has a softening effect on the coating bonded to the liner. Softening of the coating causes the coating to expand, creating orange peel wrinkles. It is believed that the wrinkles become more noticeable the longer the liner is held in storage. The sooner the liner is installed after wet-out, the less likely that orange peel wrinkles will occur. These wrinkles are more like a texture than a wrinkle and have much less impact on the liner than the previously mentioned wrinkle types. On the pilot projects, orange peel wrinkles were not repaired.
- **Polyester-resin-with-fiberglass-fabric wrinkles:** This liner is installed by dragging the liner in place. A thick plastic bladder, slightly oversized and wrinkled, is located inside the liner and contains pressurized air during inflation and curing. The wrinkles in the bladder fill with resin when the bladder is inflated and the liner is compressed. Wrinkles become apparent when the bladder is removed. Large wrinkles may trap portions of the bladder and the bladder may rip when it is removed, leaving fragments of bladder hanging inside the pipe. These voids may fill with fine materials like sand, but appear not to impact flow in the pipe. They also appear not to affect the strength of the liner, because the wrinkle is in the resin and not in the fiberglass fabric.

Resin Slugs

The liners used for the majority of the Lake Forest Park pilot project consisted of an epoxy resin impregnated in polyester felt. The contractor used the water pressure inversion process for installing the liner and hot water for curing.

As the liner inverted, a pool of resin pushed ahead of the liner. When this pool of resin passed a lateral, a portion of it moved into the lateral. This resin then cured and created a hard, wedge-shaped slug behind the dimple in the CIPP. These slugs were roughly 1 inch to 2 inches thick and ran about 8 inches into the lateral. The epoxy resin may have been less viscous than the resin normally used by the contractor. In addition, too much resin may have impregnated the felt in this liner.

When the lateral cutter unit began cutting a hole in the CIPP, the cutter encountered the slug attached behind the dimple at the lateral connection. The bit on the cutter unit was not long enough to cut through the slug, and often only the upper half of the lateral was opened. Sometimes the lateral cutter bit popped these slugs loose, but the slugs did not always come out of the lateral. The slugs were difficult to remove, and it was necessary to grind them out to completely open the laterals. This issue was unique to the Lake Forest Park pilot project.

Out-of-Round Host Pipe

CIPP works in out-of-round sewer mains as long as two conditions are met: (1) the pull-in or inversion liner fits inside the pipe (that is, the pipe is not collapsed or otherwise blocked), and (2) any required follow-up equipment, such as a camera or lateral cutter, fits inside the liner. Note that CIPP may not always be an appropriate repair for out-of-round pipes, depending upon the structural condition of the host pipe.

Steam Bubbles

For the pilot projects, the hot water used to cure CIPP was created in two ways: (1) a diesel-fired boiler heated the water directly, or (b) a steam generator injected steam into the water within the liner, where heat transfer occurred. There is some danger associated with steam generators used in this manner. The steam adds air to the water and if enough air is introduced, it can “burp” back out the top of the liner equipment. One contractor’s employee was slightly hurt during this process, after which the contractor switched to the diesel-fired boiler method.

End-of-Liner Epoxy Seals

Two types of end-of-liner epoxy seals were specified for the CIPP pilot projects. The first type of specified seal consisted of an epoxy coating between the host pipe and the liner (Type 1). The second type of seal consisted of an epoxy grout packed around the end of the liner where it projected inside the manhole (Type 2).

For Type 1 seals, the specification stated that the interior of the host pipe shall be coated with epoxy for the first 18 inches before liner installation and curing. The intent of the Type 1 seal was to prevent water from leaking into the manhole from the annular space between the host pipe and the liner. This void was a concern because liners typically shrink slightly during the cool-down phase.

The contractor initially resisted using epoxy due to concern that heat from the curing process would affect the epoxy or that chemical incompatibility between the epoxy and polyester resin would prevent curing. The contractor subsequently tried the epoxy and it worked very well, although typically only a 6-inch seal was used rather than the 18 inches specified. Future designers may want to specify an 8-inch to 12-inch epoxy seal and verify that this work is done correctly. Verification requires that the inspector watch the work. Note that applying the epoxy between the host pipe and liner is difficult work. A worker must kneel in the bottom of the manhole and reach his or her arm inside the sewer main to apply the epoxy. Rarely did an inspector have adequate access to verify that this work was done correctly. The inspectors did not enter any manholes because the manholes were considered confined spaces.

No epoxy seals were required on the Lake Forest Park project because the liner resin was epoxy. In the designer’s/inspector’s opinion, the epoxy adhered very well to the pipe and there was no annular space between the host pipe and the liner.

For the Type 2 epoxy seal, the epoxy grout was placed at the junction where the liner came into the manhole. The intent was that this would also seal the end of the liner, protect the lip of the liner where it extends inside the manhole wall, and make a smooth transition to prevent debris from catching on the transition. In practice, this work was dependent on how the liner was cut after it cured. Cutting out the excess liner was usually done with a Sawzall, a type of large saber saw. This cut was often very rough and the saw blade was typically rammed against the concrete so that there was very little lip. The epoxy placement was somewhat rough and haphazard; however, the epoxy was very tenacious and appeared to adhere well. For the Redmond project work which took place in early December in very cold weather, the subcontractor plugged flows to keep water out of the manholes, cleaned out the joint, used a heat gun to warm up the concrete and dry it out, then applied the epoxy. The process took about 2 hours per manhole. This crew also came back and added epoxy cement in the channels to slightly raise the channel surface and smooth it out.

Based on the pilot project experience, the Type 1 method is recommended over Type 2 when the goal is to prevent water from leaking into the manhole from the annular space between the host pipe and liner. While the Type 2 epoxy seal may close this gap, the amount of surface area is much smaller than for a Type 1 seal and is more susceptible to damage because it is exposed inside the manhole. A Type 2 seal should be used if there is a desire to protect the lip of the liner where it extends inside the manhole wall and make a smooth transition to prevent debris from catching at this point.

Leaks from the Annular Space

The annular space is the gap created between the host pipe and the CIPP when the liner shrinks during cool-down. Any leakage of water through the host pipe fills this gap and allows water to move behind the CIPP. This water can then leak through any holes in the CIPP, at a cut-open connection point, or at defect locations in the SCL or SCLL.

On the Mercer Island and Brier pilot projects, the contractor provided a post-liner videotape of the liner after the laterals were cut open but before any SCL, SCLL, or chemical grouting work was done on the lateral cutouts. On some of the lateral cutouts, water was observed to be leaking out of the annular space between the host pipe and the liner. In some cases, water was also leaking down the lateral so that it was difficult to tell if the leakage was from the annular space or from the lateral. Although this may not be the case for all liners, some type of repair product should be considered to prevent this leakage. For the Mercer Island pilot project, all of the cutouts received a TOP HAT™ (for more information on TOP HATS™, see Section 7.3.3.4). For the Brier pilot project, half the cutouts received a TOP HAT™ and half had a chemical grout injected into the voids. This grout, AV-100, filled the annular space and any cracks in the connection or pipe joints within the first foot of the lateral.

On the Lake Forest Park pilot project, the liner was a felt fabric and the resin was epoxy. The construction inspector reported that there appeared to be a very tight bond between the CIPP and the host pipe. He attributed it to the epoxy and noted that there appeared to be no gap between the host pipe and the CIPP where the CIPP was cut open for service connections. The use of an epoxy-impregnated liner may mean that a TOP HAT™ or grout is not needed to prevent leaks from the annular space.

On the Redmond pilot project, the fiberglass liner did not have a lengthwise sewn seam like that found in the felt fabrics; instead, the multiple layers of fiberglass fabric overlapped. This layering, in conjunction with the inherent strength of the fiberglass, appeared to limit shrinkage of the liner and hence reduce the amount of annular space.

Leaks from Holes

There were two causes of holes in the liners. The most common cause was misalignment when the lateral cutter was drilling a hole. This occurred in approximately 5 percent of the laterals that were cut open. This usually occurred because the operator misjudged the location of the lateral (that is, the dimple was not visible or the footage counter was incorrect). Often these holes were covered by a TOP HAT™. In four or five instances a spot repair was required.

A much less common occurrence was holes in the coating for those products in which the coating was bonded to felt. The holes occurred at some point before the liner was installed in the sewer main. If a hole was discovered during the wet-out process when a vacuum was applied to draw resin into the liner, a patch was glued in place over the hole. If the hole in the bonded coating occurred during the liner inversion process, the felt was exposed to air or water pressure. Under certain conditions, this pressure may have washed out the wet resin and left the felt with no resin. These holes appeared to be very small and may or may not have leaked water. On all the CIPP projects, holes were repaired through the spot repair process.

Cutting Laterals

The quality of the work when cutting laterals is very dependent on the skills of the operator, since the operator is working remotely and viewing the work with a camera roughly 16 inches from the opening. Some experiences during the lateral cutting process included:

- The bit may run into the host pipe, lateral pipe, or the existing fitting. If the connection is PVC or the fitting has a rubber gasket, the bit may easily damage these materials. Working around PVC pipe is more difficult than working around concrete pipe because PVC is so much more susceptible to damage. In concrete pipe, the cutter bit usually hits the concrete but does no damage; in fact, the operator usually runs the cutter bit against the concrete as a guide.
- In some cases, the dimple in the liner where the lateral is located may not be readily visible. The operator may miss the dimple with the bit and put a hole in the liner.
- The division of work between the contractor and his subcontractors may not be addressed in the construction contract. Coordination between the contractor and an SCL or SCLL subcontractor can be an issue. For example, some of the pilot projects required that an SCL (TOP HAT™) be installed at the lateral connection. The contractor lined the pipe and cut and brushed the lateral. In a few cases when the TOP HAT™ crew came in to install the SCL, the crew had to do some additional cutting or brushing before they could install their product. This was due to the fact that the opening was too rough and might pop the bladder on their machinery, or because the connection had not been fully opened.

Reinstatement of Service Connections

The work involved with reinstating service connections is very dependent on the skills of the operator and the capabilities of the machinery. There are several limitations to the capabilities of the cutter unit for reinstating services connections, including:

- In several cases, the contractor determined that the cutter unit would not fit through a section of pipe. Had the contractor proceeded with lining the pipe and covering a lateral, the cutter unit would not have been able to reach the connection and cut it open.
- The bit on the cutter unit can be moved in three dimensions, but there are limits to its reach. In several cases, the liner was installed and the cutter unit was incapable of cutting out the coupon. In one instance, the lateral connection was located at the top of the pipe near a joint. In another instance, the sewer main and lateral sections of pipe were not inline and there was a sag under the lateral. Because of the geometry of this situation, the head of the cutter unit was too low for the bit to reach the connection and cut out the coupon. The crew backed out the cutter unit, raised the bit in its collet, put the unit back down the main, and successfully cut the coupon. However, a lot of time was required to set up for this cutout. The bit ran very close to the main when moving in and out of the pipe, bumping and scarring the CIPP as it was moved along the pipe. In another instance, the CIPP extended up the lateral too far and the cutter could not reach the correct location. A subcontractor, paid by the contractor, used a special cutter unit to cut out and clean up this connection.

The limitations of standard equipment being used by CIPP contractors may affect the applicability of CIPP. These equipment limitations also apply when products such as SCLs or SCLLs are installed.

7.3.1.2 CIPP for Sewer Main Spot Repairs

In several of the projects, the contractor used a spot repair to fix a defect in the newly installed CIPP. Repairs were undertaken to address leaks, large wrinkles that had to be removed, holes in the CIPP and holes punched by a lateral cutter, or weak places in the CIPP. For this type of work, if the rest of the pipe was not defective, a short section of CIPP was installed at a specific defect location. For the pilot projects, this work involved installing either a short (4 feet long or shorter) or long (between 4 and 8 feet long) section of CIPP over the defect. Sometimes two short spot repairs were used instead of one long one.

In other projects a spot repair was called for by itself, usually to fix a single hole or joint defect in the existing sewer main.

Pros of CIPP for Sewer Main Spot Repairs

- Spot repair CIPP allows a small point repair for a single defect.
- Most full-length liner systems have a short version for spot repairs.

Cons of CIPP for Sewer Main Spot Repairs

- It may be simpler to line the whole pipe under certain conditions rather than install a spot repair, especially if more than spot repair is specified for a single pipe.
- The ends of the spot repair can become places for snagging debris and may become maintenance issues.
- Spot repair may rely on adhesion to the host pipe more than full-length liners do. Because of this, epoxy resins need to be specified.
- Spot repairs placed on top of existing CIPP further reduce the inside diameter of the pipe.

Materials, Processes, and Equipment for CIPP Spot Repairs

Several types of spot repair CIPP were used in the pilot projects.

- In Redmond, two products were used. The first was LMK Enterprises' spot repair liner. This version of their main line product was wrapped around a packer, dragged into place, inflated, and cured at ambient temperature. The contractor used a "hot" epoxy to make the repair liner cure more quickly.

  The second product, Multiliner, was a shorter version of the full-length polyester-resin-with-fiberglass-fabric product. The repair liner was dragged into place, the bladder inflated, and then the liner was steam cured.
- In Brier and Mercer Island, the contractor wrapped a section of liner around a packer, dragged it into place, and inflated the packer. The resin used was a fast-setting epoxy.

Installation Issues for CIPP Spot Repairs

Methods

When shorter repair liners (up to 4 feet long) were installed, the contractor placed the liner on a packer, which was inflated when in position. The packer was flexible enough to be installed into the pipe by bending it within the manhole. The packer was also a flow-through type that allowed at least a portion of the sewage to flow through the packer during the operation. The packer and CCTV equipment were contained in a CCTV truck and required a crew of two or three people. To avoid the use of hot water or steam curing equipment for short liners, the resin was cured under ambient conditions. The resin was a fast-curing or "hot" epoxy. Fast-curing or "hot" epoxies and use of a packer is recommended over other CIPP spot repair methods.

Installation of longer repair liners (between 4 feet and 8 feet long) is similar to that of full-length CIPP. (For longer repair liners, a packer is usually too short to be used for installation.) The liner was inverted or dragged into place and steam cured. In one case, the contractor installed two short CIPP spot repairs instead of one longer section of liner. This worked, but left four edges instead of two edges.

Installation Time

Installing a short spot repair liner using a flow-through packer and “hot” epoxy was a simple process and took less than an hour. The epoxy appeared to adhere well to the liner, and no problems were noted during construction. Any future issues with spot repairs may be indicated in the warranty inspection.

Installing a long spot repair liner using the most common liner installation process (that is, inverting the liner or dragging it into place and then steam curing) was at least as much work as installing a full-length liner. In Redmond, three CIPP spot repairs were planned for a 95-foot section of 14-inch-diameter pipe. Each repair liner took an entire night to install, and required all the equipment used for a full-length liner installation. In hindsight, it may have been less costly and time consuming to have lined the entire pipe.

Polyester-Resin-with-Fiberglass-Fabric Spot Repairs

Several issues were encountered during installation of the polyester-resin-with-fiberglass-fabric spot repair. The MultiLiner® version of a CIPP spot repair is a short, pull-in-place liner with an interior bladder for pressurization and steam containment during the curing process. (Note: MultiLiner® is a sole source product identified for testing in the pilot projects. See Chapter 5 for a discussion of sole source products.) Like the full-length version, this spot repair liner has an exterior plastic liner outside the fabric to contain the resin; it does not have the sliding foil like the full-length version. This leaves a layer of plastic in the annular space between the host pipe and the fiberglass liner. The plastic layer was cut back no more than 6 inches on each end of the lining to expose the resin to the pipe. The two 6-inch strips were the only part of the liner allowed to adhere to the pipe. This spot repair method relies heavily on a limited-area adhesion. In one instance, the liner failed to seal a leak so chemical grouting was used to seal the leak.

In addition, the ends of the liner were problematic when the MultiLiner® CIPP was used. In the full-length version, the interior bladder projects into the manhole, and a canvas wrap helps contain the pressure to prevent bladder explosion. This is not possible for the spot repair, because the entire operation occurs within the pipe. Popping the bladder was a concern. The operators kept the pressure in the bladder very low; however, the groundwater pressure was equal to or marginally higher than the pressure within the bladder, making this liner subject to exterior water pressure during the cure. This may be part of the reason why one of these liners failed to stop a leak.

Curing a MultiLiner® spot repair liner required the same equipment as the full-length version, and cure time was the same. Compared to the short spot repair liners using a flow-through packer and “hot” epoxy, installation of the MultiLiner® spot repair liner is very time consuming.

7.3.1.3 Pipe Bursting

Pipe bursting was performed for both sewer mains and side sewers/laterals. Pipe bursting includes several major steps: (1) excavate a pit at each end of the sewer main for removing the old manhole, when necessary; (2) excavate a pit at each service connection; (3) weld the high-density polyethylene (HDPE) pipe; (4) install the new pipe by pulling it with a cable and bursting the old pipe; (5) install new manholes, when necessary; (6) reinstate service connections; and (7) backfill and restore the area. Pipe bursting side sewers/laterals also requires excavation of a pulling pit and an insertion pit. The pulling pit may be at the connection point of the lateral to the main.

Pros of Pipe Bursting

- Minimal excavation is required when compared to open trench installation of sewers.
- Roots need only be removed well enough to get the pulling cable through the pipe.
- Roots should not be an issue in the future because there are no joints in the HDPE pipe.
- This process allows upsizing of the pipe.

Cons of Pipe Bursting

- HDPE pipe follows the old pipe alignment, whether or not that alignment is straight. Pipe bursting does not remove sags or curves in the existing pipe, although it may smooth them out if they are abrupt.
- HDPE pipe may not be absolutely round after installation (although there were no cases during construction of the pilot projects where pipes were out-of-round to the point of being unacceptable).
- Excavation and associated restoration work is required, which is not typically the case for CIPP processes.
- Future work needs to deal with the HDPE pipe. This may include issues such as welding on new connections. Since the presence of HDPE pipe is likely not typical in a sewer system, future design engineers, contractors, and agency staff must remain aware of its use and location.

Materials, Processes, and Equipment for Pipe Bursting

Pipe Material, Sizes, and Color

The material used for the pipe-bursting portion of the pilot projects consisted of 6-inch and 8-inch-diameter HDPE pipe, with a standard dimensional ratio (SDR) of 17. In two of the pilot projects, the existing mains were 6 inches in diameter and were replaced with 8-inch-diameter pipe. In the other projects, the existing pipe was replaced with the same diameter pipe.

For the pipe bursting projects, both gray and black HDPE pipe was used for replacement pipe. It was determined that gray pipe is preferable to black pipe due to the effect of color on the ability to view CCTV images. The use of gray HDPE pipe improves the image since camera lights reflect better off the lighter color. While it is more difficult to view CCTV images taken in black HDPE pipe, it is not impossible. There is normally enough dirt or condensation on the walls of the pipe to reflect some of the light and to allow an acceptable view of the condition of the upper portion of the pipe. What is not visible when looking at CCTV images taken inside black HDPE pipe is anything below the water level. The light reflects off the water and away from the camera, so there is no light coming back to the camera; the area below the flow line is thus invisible. The availability of gray pipe is an issue because black is by far the most common. Given a choice, however, the use of gray HDPE pipe is recommended.

Welding and Debeading of HDPE Pipe

No failure of butt welds on HDPE pipe was experienced during pipe bursting. (The only HDPE failures involved the bursting head pulling off the end of the HDPE pipe, which was not related to the welding process.)

The pilot project specifications required debeading of the HDPE pipe. Debeading is the process of removing the bead left by welding on the interior of the pipe. The idea was to smooth out the inside of the pipe to prevent debris from catching on the bead and to keep the inside diameter full size. However, contractors pointed out the potential for damaging the inside of the pipe during this process, especially if performed by an inexperienced crew, as well as the unwieldy nature of the required equipment. The added cost associated with debeading was also considered. After consultation with the agencies, the debeading requirements were removed from the specifications by addendums to the contracts.

Fittings Used with HDPE Pipe

The main fittings used with HDPE pipe were welded HDPE saddles, ductile iron mechanical couplings, standard polyvinyl chloride (PVC) couplings, and a PVC coupling reinforced by an internal fiberglass band. All these fittings appeared to work well with HDPE pipe. Although they were allowed, no electrofusion fittings were used on any of the pilot projects, simply because the contractors elected to use other products.

The ductile iron mechanical couplings and the standard PVC couplings worked well for connecting HDPE to ductile iron or PVC pipe. However, the PVC fittings reinforced by an internal fiberglass band fit the HDPE pipe but were too large to fit the ASTM D-3034 PVC pipe, which is a standard sewer pipe. When the fitting was too large for the PVC pipe, the pipe clamp rolled off the fitting. It was determined that because of the reinforced fiberglass band and because of manufacturing tolerances of the fitting and ASTM D-3034 PVC pipe, these fittings should not be used to connect HDPE pipe to PVC pipe.

Pipe Bursting Equipment

Pulling equipment used in pipe bursting can range widely in size. Man-portable pieces of equipment are capable of being assembled inside a manhole and connected to a small trailer-mounted hydraulic pump. Large equipment can be 25 feet tall and mount to a medium or large track hoe. Equipment size affects installation rates.

For pipe bursting projects, excavation equipment was typically the largest piece of equipment that could access the excavation site. This included large track hoes, rubber-tired backhoes, and Bobcat®-sized excavators. Dump trucks were used to move excavated soils and backfill, and front-end loaders were used around larger stockpiles.

The specifications called for data loggers for the pipe bursting pulling equipment and the welding equipment. The data loggers were specified for the purpose of recording welding temperatures and pressures; however, the pipe bursting contractor's equipment was not capable of using data loggers. After discussions with the engineers, it was determined that there was no need for this requirement considering the size of the pipe being installed and that it was for a gravity sewer application. Instead, a hand-held infrared thermometer was used to monitor welding temperatures and the bead was visually inspected as it rolled over. Additionally, the crews doing the butt fusion welding were trained and certified and had sufficient experience to do the work. However, it is recommended that data loggers be considered for pipes larger than 12 inches in diameter, for critical pipes, or for pipes to be operated under pressure.

Installation Issues for Pipe Bursting

Access

Pipe bursting involved access issues for: (1) excavation equipment, and (2) stringing out and moving the HDPE pipe. Access for excavation equipment depended on the type of equipment used. Large track hoes were rarely used very far off the asphalt or in backyards. Equipment used for pulling the HDPE pipe into the ground stayed in the street. A more challenging issue concerned where to lay 200 to 400 feet of welded HDPE pipe. This long run of pipe could not usually be kept in the street because it would block multiple driveways. The contractor typically found a location, like an empty lot or playfield, to stockpile the welded pipe for the entire project. The pipe was then dragged to the insertion pit. The pipe spent very little time above ground in the way of the public. On the Redmond project, the subcontractor borrowed a construction supply yard for one night. The pipe was welded and installed in one night, resulting in minimal impact on the construction supply yard business.

Manhole Work

Pipe bursting work on sewer mains required dealing with manholes. In almost all cases, the manhole was removed and replaced with a new one. It was determined during design that saving the manhole was typically not cost effective, and that attempting to leave it in place usually interfered with the bursting process. Manhole replacement was a simple process. Per the requirements, the lid was set to match the existing grade. Placing a level between the pipe stubs coming into the pipe bursting excavation helped set the channel in the bottom of the manhole.

There was a slight sag on either side in some of the newly placed manholes. This may indicate that more attention should be devoted to setting the base of the manholes. It might also be related to the fact that there is a sharp curve in the pipe at the excavation, and there is a tendency for that curve to stay in place for a period of time after the bursting operation. New manhole elevations were not surveyed during construction.

There were a few instances where the manhole was located at the end of a pipe run at the edge of the project. It was easier to leave the manhole in place and make the connection in a pit directly adjacent to the manhole. For example, one such manhole was located close to a building foundation. In Redmond, a case involved a manhole located in a busy street with new asphalt. The contractor assembled a small pipe-bursting piston assembly inside the receiving manhole and pulled the sewer main into the manhole, leaving the existing manhole in place. When the pipe burst was completed the hole around the HDPE pipe was simply grouted. The HDPE pipe still required a launching pit. Pipe bursting with this smaller equipment was accomplished at a rate of about 1 foot per minute.

Installation Time

The pipe bursting process normally followed the following production schedule:

- On the first day, excavations were completed and covered with steel plates to open the road for traffic. The pipe was also welded and prepared for installation.
- On the second day, the bursting occurred, the manholes (or temporary connections) were made, and the service connections were temporarily made. The contractor typically let the pipe relax for a day before making the connections permanent.
- On the third day, the permanent connections were made and the excavations were backfilled and compacted. Another crew did restoration work, sometimes at a later date to allow for increased production. For example, temporary asphalt patches were installed after the backfill was complete, but permanent patches waited until the end of the project.

For sewer mains, pipe bursting itself was actually a small part of the work. The two pieces of pulling equipment the contractor used were attached to either a medium or large track hoe. The equipment was capable of pulling a typical 300-foot run of pipe in less than half an hour. Depending on the complexity of the situation (traffic, manholes, number of connections, other buried utilities, etc.), the crews could usually complete two pulls (one run of pipe bursting is called a “pull”) a week, in addition to working on laterals and side sewers. The length of the pull was much less important than the required setup time.

When bursting the sewer mains, the service connections were excavated in advance of the bursting. The service connections were always cut loose, that is, a section was cut out of the lateral next to the tee. That way, when the bursting head advanced down the sewer main, it would break through the tee but not damage the lateral. To make the service connection, the crew welded on a side saddle and drilled the hole in the sewer main, then connected the lateral.

Maximum Length of Pulls

The maximum length of a single pull is probably limited more by the logistics of working in a residential area than by pipe length. On the pilot projects, pulls were limited to one run of sewer main, usually between 200 feet and 300 feet long. However, the crews could pull up to 400 feet if necessary. In a few cases, the crews pulled through an intermediate manhole.

Other factors that enter into the length of a pull are friction on the pipe and the pipe shear strength. Dry soils have a tendency to make the pulls more difficult. On the few failures, the problem was limited to the bursting head pulling away from the HDPE pipe (the head bolts sheared out of the HDPE). When this happened the end of the HDPE pipe was trimmed and the head reinstalled.

The size of the old and new pipes affects the pull. When the new pipe is the same size as the old pipe, the pull is easier. When a larger size pipe is pulled into a smaller pipe, the pull requires more force.

Depth and Size of Pipe Bursting Pits

Excavation pits at manholes were usually less than 12 feet deep; sewers located in residential neighborhoods typically do not need to be deeper than 12 feet. Sewer mains associated with deeper manholes were candidates for cured-in-place liners rather than pipe bursting.

Pit size depended on the depth of the old pipe and the ability of the HDPE pipe to curve into place. Pit length was increased as the sewer main depth increased in order to accommodate the radius of the HDPE pipe going into the pit. A launching pit for an 8-inch-diameter sewer pipe in the range of 10 feet deep was approximately 12 feet long and was the width of the trench box. Where the launching pit was used to place two pipes, the pit was longer. The pits for service connections were smaller; the size of the pit depended on whether or not the pit was also being used as a pulling pit for a side sewer/lateral pipe burst.

In one case, the pipe was pulled into an existing manhole, so there was no excavation work at the manhole. The launching pit and pits for reconnections were sized as described above.

Most of the sewer mains were located in asphalt streets. Excavation work required cutting the asphalt and dealing with the associated traffic control and trench shoring. The primary concern during pipe bursting excavations was safety and working around other utilities.

Reinstatement of Connections

Service connections were reinstated at the sewer main by welding on an HDPE saddle. Welding consisted of holding a curved heater plate between the sewer main and the saddle. After the heater plate was removed, the saddle was pressed against the sewer main with a 5-foot-long pry bar. After the saddle was welded in place, a hole saw was used to cut the sewer main. The service end of the saddle was plain-end pipe, so a coupling was used to connect the lateral. In Redmond, where the lateral was not pipe burst, a short PVC spool pipe connected the saddle on the sewer main to the existing lateral using two couplings.

Field Quality Assurance/Quality Control

Field quality assurance/quality control (QA/QC) for pipe bursting involved visually monitoring or measuring the following items:

- Visual inspection of HDPE welding
- Pressure tests to determine that the pipe was not defective
- Ball testing to determine the roundness of the pipe

No HDPE sewer mains failed any of the testing so repairs were not needed.

7.3.1.4 Chemical Grouting of Sewer Mains

Chemical grouting of sewer main pipe joints was not part of the original design for the pilot projects. However, chemical grouting was mentioned in some of the CIPP specifications because it was believed that a contractor might need to use this process before the final rehabilitation work occurred. Very little of this type of work was done. In fact, it was used for sewer mains in only two instances:

- One pipe on the Lake Forest Park project was chemically grouted because CIPP could not be installed; the pipe was too deformed and the lateral cutting and TOP HAT™ equipment would not fit. This was the only pipe in the pilot projects where grouting was the only work completed on the pipe.
- In Redmond, chemical grouting was used prior to installing two CIPP spot repairs.

It was possible to inject grout as long as the packer could be accurately placed and the plugs could seal the pipes. Since the void space between the packer and the host pipe was filled with grout and the grout was set in place, removal of the packer left a lot of grout inside the pipe. This grout was partially scraped loose as the packer was removed; the grout flowed down the sewer. It was believed that any grout that remained stuck to the pipe would eventually fall off or wash off during high flows. Note that visible grout does not serve a purpose; instead, it is the hidden grout that prevents leaks.

Pros and Cons of Chemical Grouting of Sewer Mains

Because chemical grouting was used in no more than a few instances, only a limited assessment of its pros and cons can be made. Grouting does stop some visible leakage from pipes, and it is fairly inexpensive when compared to other rehabilitation products. If there are drawbacks to chemical grouting, they are probably the open questions about the product’s service life as well as its ability to stop root intrusion. Problems may or may not become apparent during the warranty inspection.

Materials, Processes, and Equipment for Chemical Grouting of Sewer Mains

The equipment required for chemical grouting was contained in a truck dedicated to this type of work. The self-contained truck included hose reels, the grout packer with CCTV camera, hoses, pumps, two grout tanks, and a remote winch.

Pre-Installation Issues

Surface preparation involved cleaning the pipes with a high-pressure spray of water.
Visible roots were removed prior to chemical grouting. It is unknown whether or not roots will reappear in the future. No herbicides were applied as part of the grouting work.

Installation Issues

Access

Access to manholes at either end of the sewer main was required for grouting equipment. The grout truck was parked at one manhole and a remote-controlled winch was placed at the second manhole to maneuver the grout packer into position.

Installation Time

As previously mentioned, there was a single pipe in the pilot projects where grouting was the only work completed. The pipe was approximately 300 feet long and the crew completed the work in one day. It is possible that production could be higher if more than one pipe was involved.

Field Quality Assurance/Quality Control

Field QA/QC involved measuring the quantity of grout used and monitoring the pressure gauge on the packer with the CCTV camera.

7.3.2 Manholes

I/I occurs at manholes when water leaks through any portion of the manhole. The source of flow is usually water (inflow) that is either flowing over the ground surface or rapidly migrating just below the ground surface, or groundwater (infiltration) from a trench or water table located just below the surface.

For manholes, rehabilitation products are applied either inside the manhole or from the outside. When products are applied inside the manhole, excavation can normally be avoided. Most of the manhole rehabilitation work for the pilot projects was performed from the interior of manholes. All of the work that occurred on the manholes was performed on manholes without structural problems.

Excavation at manholes was limited to the area around the chimney. There were no manholes in which the entire manhole was exposed and an exterior product was used, such as a shrink-wrap. Very few manholes were excavated if the lid was located in asphalt.

Manholes were completely replaced in the sewer main pipe bursting projects, and no exterior products were used on new manholes.

7.3.2.1 Installation Time for Manhole Rehabilitation

Installation time varied according to the type of rehabilitation method used (see Table 7-3). When the rehabilitation method was frequently used (for example, chemical grouting), the production rate was greater and easier to quantify. For products used in very limited quantities (for example, the WHIRLyGIG used for paving rings), the production rate was very low. Because of the nature of these pilot projects, some contractors had never before used these products. Contractors sometimes had to work with (or without) input from the manufacturer or local representative.

Table 7-3. Manhole Rehabilitation Installation Time

Manhole Rehabilitation Method	Production Rate
Interior cementitious coatings for manholes[1]	2 to 6 per day, depending on manhole depth, scheduling and preparation work required
Chemical grouting for manholes[1]	1 to 4 per day, depending on manhole depth and severity of cracks
CIP fiberglass manhole liners[2]	1 to 2 per day, depending on manhole depth and access
Paving rings	1 day for excavation and installation. There was only one paving ring installed so production could be higher.
Leveling ring boots	1 to 3 hours, depending on chimney depth and condition, and removal of ladder rungs
Interior chimney coatings	1 to 2 hours, depending on chimney depth and condition
Manhole pans	15 to 30 minutes per pan. Production depended on traffic control.
Reset frame and raise to grade	1 to 4 hours, depending on traffic control and asphalt restoration
Cement patching grouts	Typically part of other work

[1] Vacuum testing separate
[2] No testing performed

7.3.2.2 Interior Cementitious Coatings for Manholes

Two spray-on cementitious coatings were used in three of the pilot projects. These coatings adhere to the wall of the manhole. Because of this bond, there is no gap behind the liner and no water moving behind the liner.

The channels were not coated with this product. The coating stopped around the edges of the bench in the bottom of the manhole.

Pros of Interior Cementitious Coatings for Manholes

- The work requires minimal preparation and coatings are easy to install. A fairly high production rate is possible.
- Installation does not require tracking down small cracks, as is necessary in chemical grouting.

Cons of Interior Cementitious Coatings for Manholes

- Coatings do not address leaks at the pipe penetrations.
- Cementitious coatings may be susceptible to cracking and leaking in the chimney area. (In contrast, a sprayed-on plastic-type coating may come “unbonded” and water may form behind the coating like a blister. The blister then breaks and the liner falls off the manhole wall.)

Materials, Processes, and Equipment for Interior Cementitious Coatings for Manholes

Both cementitious coating products used were calcium aluminate cements: Quadex (used in the Val Vue and Redmond projects) and Strong-Seal® (used in the Lake Forest Park project). These products contain a mix of cement and chopped fibers. The powdered product is mixed with water and pumped through a hose. An air compressor attached to the nozzle adds air to the mixture and helps splatter the product in place. The last step is to trowel it smooth.

Equipment included mixers and pumps mounted to a small trailer towed behind a pickup.

Pre-Installation Issues for Interior Cementitious Coatings for Manholes

Surface preparation involved pressure washing the walls of the manhole with water.

Installation Issues for Interior Cementitious Coatings for Manholes

Access

All the manholes that received a coating were easily accessed because they were located in or near pavement. For manholes further removed from a paved surface, the crews had to contend with limits on hose lengths or use hand-applied coatings. The depth of the manholes and the diameter of manhole lids was not an issue for the crews.

Coordination with Other Rehabilitation Work

This product was installed after all other work was done so there were no coordination issues with other aspects of the rehabilitation work. The manholes were only out of service during vacuum testing, which usually took less than 10 minutes.

Installation Time

Two to six manholes per day can be rehabilitated using the interior cementitious coating repair. Work depended on the manhole depth, scheduling of work, and required preparations before the coating could be installed.

Field Quality Assurance/Quality Control

Quality control involved measuring pH before installation, monitoring the thickness of the coating, and recording the quantity of powdered product used in the manhole.

7.3.2.3 Chemical Grouting for Manholes

The basic process of chemical grouting is to drill holes through the manhole and inject a grout mixture into the crack and into the soil behind the manhole. The grout reacts with both sources of water: (1) the water being pumped along with the grout, and (2) any water that is behind the manhole. Large cracks may be filled with a cement-patching grout or oakum to keep as much grout as possible in the crack. The drilled holes are then covered with a cement grout.

Approximately one-third of the chemical grouting in manholes sealed leaks around pipe penetrations. Half of the grouting plugged leaks in wall seams, cracks, and chimneys. The rest of the grout plugged leaks where the base of the manhole, including the channel, was defective. Bases with problems included those that were cast-in-place concrete and saddle manholes.

Pros of Chemical Grouting for Manholes

- Chemical grouting requires minimal preparation and is fairly easy to install.
- The grouting product is kept in the cracks and in the soil outside the manhole, so exposure to conditions inside the manhole is limited.

Cons of Chemical Grouting for Manholes

- Chemical grouting requires drilling holes in the manhole structure.
- The process requires filling large cracks to limit grout from entering the manhole rather than sealing the leaks.
- The work requires a skilled technician who knows where to drill the holes and how to mix the product and its additives.
- Large quantities of grout may be needed, depending on the void on the outside of the structure.
- Chemical grout is susceptible to drying out when exposed to air. This may or may not be a problem, depending on soil conditions.
- Grout is susceptible to root growth.

Materials, Processes, and Equipment for Chemical Grouting of Manholes

Two chemical grouting products were used on manholes in four of the pilot projects. Both products were hydrophilic (that is, attracted to water) grouts. Scotch-Seal™ 5610 by 3M™ was used for the Manhole Project and in Brier, Redmond, and Lake Forest Park.

Two different contractors used the Scotch-Seal 5610™ product. The mix ratio recommended by the manufacturer for this product is 8 parts water to 1 part grout. Various additives may be added as fillers or to control foaming and gel time. One contractor used only the grout and water in a 1:1 or 2:1 proportion using a hand-operated pump. The other contractor used the same product in an 8:1 ratio using a mechanical pump and used additives to control the reaction time. While the grout mixed at the 1:1 or 2:1 ratio sealed the leaks, the ramifications of not following the manufacturer's recommendations is unknown.

In all four projects, the entire manhole was subject to vacuum testing after chemical grouting. Testing equipment usually included a vacuum pump and various plugs. The manholes were out of service only during vacuum testing, which usually took less than 10 minutes.

In three of the basins (Northshore, Val Vue, and Redmond), the contractor discovered manholes with many small cracks, and anticipated spending 2 days per manhole. The contractor requested and received permission to change to a spray-on cementitious coating instead of grouting.

Pre-Installation Issues for Chemical Grouting for Manholes

Surface preparation involved pressure washing manhole walls where heavy debris was present.

Installation Issues for Chemical Grouting for Manholes

Access

Most of the manholes receiving chemical grouting were easily accessed because they were located in or near pavement. Manholes further from a paved surface or along creeks required the contractor to use either longer hoses or a portable hand-operated pump.
The depth of the manholes and the diameter of manhole lids did not restrict the contractor in any way.

Installation Time

Chemical grouting repairs were completed at a rate of one to four per day, depending on manhole depth and the severity of cracks. The chimneys were very often the part of the manhole with the most leaks and required the most time and materials.

Quantity of Work

During construction, the biggest concern contractors expressed was the difficulty in determining from the Sewer System Evaluation Survey (SSES) report how much chemical grouting would be needed to fix the leak. It was not until the contractor performed a pre-grouting vacuum test that the number of cracks and holes became apparent. Some manholes that appeared to have problems as described in the SSES report passed the pre-grouting vacuum test. In that case, no grouting was done. On the other hand, there were manholes with no defects noted in the SSES report that failed the pre-grouting vacuum test and were grouted. The SSES inspection was primarily a visual inspection and frequently could not identify small cracks that needed to be grouted.

Field Quality Assurance/Quality Control

Quality control utilized vacuum testing, so a manhole was tested until it passed the vacuum test.

7.3.2.4 Cured-in-Place Fiberglass Manhole Liners

Cured-in-place (CIP) fiberglass manhole liners manufactured by Poly-Triplex® Technologies were installed in 16 manholes in Brier. (Note: Poly-Triplex® PTLS-4400 is a sole source product identified for testing in the pilot projects. See Chapter 5 for a discussion of sole source products.) The installation process is similar to CIPP installation in that the manhole liners consist of a fabric that is impregnated with resin, inflated in an existing manhole, and cured with steam.

It is recommended that CIP fiberglass liners receive extensive testing and evaluation before they are used. Analysis should focus on issues such as strength, quality control, surface preparation and bond strength, and coordination with other products such as the pipes and ladder rungs. Consideration must be given to the way this product is installed; for example, how the bottom of the manhole, with the channels, is addressed and how a defect or leak is repaired.

Pros of CIP Fiberglass Manhole Liners

- Minimal preparation is required.
- The finished product is visible and can be inspected at any time. Any defects should be visible to an inspector.
- The fiberglass liner does not appear to be susceptible to root problems.

Cons of CIP Fiberglass Manhole Liners

- Installation requires a trained crew.
- Quality control measures are limited and are all done in the field.
- Ladder rungs need to be removed, and replacement may be difficult. The city staff chose not to reinstall the ladder rungs due to costs and warranty concerns.
- Chemicals used (resins and solvents) may be hazardous if spilled or splashed on the skin or in the eyes. The crews used disposable overalls, gloves, and safety glasses when working with these chemicals. The resin is fully exposed to the atmosphere and may easily spread to the ground or to other exposed surfaces. Cleanup operations (rinsing with hot water) also have the potential to spread chemicals onto streets and into catch basins and ditches.
- The structural capability of the liner needs to be considered. The thickness of the liner and wrinkles and bumps may impact strength. Because the liner conforms to the inside of the manhole, any deformations in the manhole are apparent in the liner. These deformations and the fact that liners are installed in the field may impact the liner's strength.
- Chemical grouting may be required for larger leaks before the liner is installed, especially for pipe penetrations.
- Wet-out quality control may be limited because the work is done completely in the field. The only factory fabrication is cutting and sewing the liner fabric.
- Bonding to the manhole wall may be an issue.
- Joints in the liner and seams at pipe penetrations have the potential to leak.
- Future work in the manhole will need to deal with the fiberglass liner. Because the presence of fiberglass liners is likely not typical in a sewer system’s manholes, future contractors and agency staff must remain aware of their use and location.

Materials, Processes, and Equipment for CIP Fiberglass Manhole Liners

In Brier, a chemical grout product made by Prime Resins called Prime-Flex was used to fix leaks prior to installation of the fiberglass manhole liners. The use of Prime-Flex was limited to leaks through pipe penetrations.

Repairs to an improperly installed liner were made with a resin-based mastic. The impact of these repairs on the structural integrity of the liner and/or the liner's ability to prevent leaks is unknown.

The Poly-Triplex® Technologies liner is made of two layers of woven fiberglass bonded to a non-porous membrane and impregnated with an epoxy resin. There is an internal inflation bladder to contain the air pressure, and steam is used to cure the liner. The liner is wet-out and cured in the field. During the pilot projects, accurate measurement in the field of the resin proportions was a concern. In addition, minor amounts of dirt and small leaves were sometimes imbedded in the resin.

During the mixing, application, and liner installation process, the resin sometimes splattered off the plastic lay-down area. When the plastic was removed, hot water was used to wash off the equipment. The runoff from cleaning was not controlled and either soaked into the ground or ran into the gutter.

The equipment was housed in a 30-foot-long truck plus trailer. The equipment included: a small crane mounted to the back of the truck, a steam generator, plywood and sheet plastic for creating a work surface for the wet-out, a manifold to seal the top of the liner, a pressure washer, a generator, and an air compressor.

The crane was used if the truck could back up to the manhole; otherwise, the wet-out liner was hand-carried to the manhole on the sheet plastic and lowered into the manhole by hand.

Pre-Installation Issues for CIP Fiberglass Manhole Liners

Surface preparation involved pressure washing the walls of the manhole. Chemical grouting of large leaks was required before the liner could be installed.

Installation Issues for CIP Fiberglass Manhole Liners

Access

Half of the manholes receiving fiberglass liners were easily accessed because they were located in or near pavement. The other half of the manholes were located along a creek, requiring the contractor to carry the liner to the manhole.

The depth of manholes and the diameter of manhole lids did not restrict the contractor in any way. The weight of the wet-out liner increased for deeper manholes. If a truck could not back up to a deep manhole location, the liner installation required several additional people to carry the liner's weight.

Coordination with Other Processes and Products

The fiberglass liners were installed after CIPP was installed in sewer mains. The subcontractor who installed the fiberglass liner was responsible for making the seal between the manhole liner and the pipe liner.

Installation Time

The production rate for CIP fiberglass manhole liners was one or two installation per day, depending on manhole depth and access. The preparation work and resin curing times and temperatures were not an issue, as they did not affect the flow of sewage through the manhole.

Reinstatement of Service

Half the manholes (those with minimal flows) were out of service only while the liner was installed and cured, or usually less than 2 hours.

For the remainder of the manholes, flow rates required bypass operations. During liner installation and cure at these manhole locations, a half section of pipe arched over the channel. After the liner was in place, the pipes were plugged for about 15 minutes so that fast-setting mastic could be spread in the channel.

Field Quality Assurance/Quality Control

Quality control involved visual inspection. No vacuum testing was specified or performed.

Condensate Removal

After the liner was cured, there was typically as much as 100 gallons of condensate to be pumped out of the inside of the bladder. This water was warm but clean (it had not been exposed to chemicals), so it was normally pumped to a catch basin.

Ladder Rungs

It was necessary to remove the ladder rungs in the manhole before the liner was installed. Access after removal of the ladder rungs was by rope ladder or by hanging off a safety tripod.

While removal of the ladder rungs was necessary, replacement of the rungs was optional in the pilot projects. Installation of ladder rungs by anyone other than the contractor installing the liner would void the warranty. In Brier, the ladder rungs were not replaced.

Leak Concerns

Fiberglass manhole liners may come “unbonded” (as may be the case for sprayed-on plastic-type coatings as well). Water can form behind the liner like a blister. When fiberglass liners are used, the blister will probably not break and the liner will not fall off the wall. Instead, the water behind the liner seeks the weakest point in the liner. The water moves down the wall until it reaches either the wall/floor seam or the opening in the wall where the pipe enters the manhole. These two transition points were of concern during the pilot projects due to their potential to allow leaks if not properly sealed.

The floor of the manhole was covered with a flat fiberglass manhole layer that was installed separately from the vertical portion of the liner. This flat piece was placed on the bottom of the manhole and pushed into the channels. Inflation of the bladder pressed the liner into the channels.

The other transition point is located where the fiberglass liner meets the sewer CIPP as it enters the manhole. During the pilot projects, it was noted that this was an awkward joint and there was almost no overlap of materials. This was also the point where the work of the general contractor met the work of a subcontractor. It is possible that material compatibility could be an issue. Leaks at this joint might come from two places: (1) from behind the fiberglass manhole liner, or (2) from the annular space between the host pipe and the CIPP in the sewer main.

At those manholes that required a bypass during liner installation and cure (a half-section of pipe arched over the channels), it was necessary to cut out the liner to expose the channel. The pipe penetrations also had to be cut open. This work involved the use of a saber saw or grinder, which left a rough edge. Mastic was used to seal these edges.

Some leak concerns need further evaluation. It is unknown if wrinkles and bumps in the fiberglass liner limited the liner's structural integrity. Similarly, it is not clear whether ladder-rung holes in the liner could become a point for future leakage.

Post-Installation Inspection

An inspection was conducted approximately 3 months after installation of the fiberglass manhole liners when King County field crews installing flow meters noted manhole defects. Defects were identified in approximately half the manholes:

- Inspectors noted the presence of large bubbles in the liners, evidence that liners had come "unbonded" from the concrete. These bubbles ranged from 1 square foot in area to strips 1 to 2 feet wide running the full depth of the manhole.
- In some manholes, leaks were observed at the transition joint between the sewer main CIPP and the fiberglass manhole liner. It was apparent that this connection was of concern; the connection might also create issues for CCTV use and for installing pipeline plugs.
- There were also leaks from the connection between the round fiberglass layer on the bottom of the manhole and the vertical portion covering the walls. This is not a sewn joint; instead, the bottom piece is placed flat, pressed down into the channels, and flapped up against the wall. The vertical portion of the liner is supposed to lap over this piece. However, the liner is installed "blind." That is, the crew has a window in the manifold and a light inside during the installation, but the bladder is white plastic. The crew cannot see the liner itself; therefore, they cannot tell if the liner has snagged on the walls or if this joint is in place before the cure starts. Crews made repairs using a mastic version of the liner resin.

7.3.2.5 Paving Rings

The WHIRLyGIG is a concrete form and cutting gig designed to allow concrete to be poured. The concrete replaces a set of stacked leveling rings with solid concrete. A paving ring was installed at only one manhole.

Pros of Paving Rings

- A paving ring provides a solid concrete chimney with very limited potential for leaks.
- The product has excellent structural strength; however, future designers may need to assess traffic loading impacts on the manhole.
- The concept lends itself to decorative paving rings around manholes.

Cons of Paving Rings

- A day and a half was required for installation of the single paving ring on the pilot project. This impacted traffic for a longer period than most other manhole rehabilitation processes and products.
- Installation requires cutting the asphalt and excavation in a very small area.
- Concrete must be protected until it is cured.
- A concrete delivery truck must be scheduled and must be able to get to the manhole.
- Although the completed paving ring will stop I/I, a paving ring appears to represent more of a structural repair rather than an I/I rehabilitation product.

Materials, Processes, and Equipment for Paving Rings

The asphalt was scored the recommended 1 foot beyond the edge of the frame and jack-hammered loose. Crews excavated by hand. The WHIRLyGIG concrete form was installed and a concrete truck delivered several cubic yards of concrete. Other than a concrete truck and a compressor, only hand tools were needed.

Installation Issues

Access

The one manhole receiving this treatment was located in asphalt on a residential street.

The depth and diameter of the chimney are limitations. The plastic form is only 24 inches high, so it cannot accommodate a deeper chimney depth (that is, 24 inches plus the depth of the frame). There are also some limits to chimney diameter.

Installation Time

It took one and a half days for excavation and installation of the paving ring. It is assumed that production would be higher, but there was only one ring installed for this pilot program (in Coal Creek).

A significant amount of time and effort was required for installation. The excavation work was difficult because the contractor dug the hole the recommended 12 inches outside the frame. A bigger hole meant that more concrete needed to be poured and finished. The concrete was a fast curing mix. In addition, it was necessary to cover the manhole with a steel plate for a day to protect the concrete until it cured. The steel plate was set on wood blocks to keep it above the concrete. This created a temporary traffic hazard, so traffic control cones were placed around the area until the concrete cured.

Reinstatement of Service

The manhole was never taken out of service.

Field Quality Assurance/Quality Control

Quality control was limited to visual inspection of the work.

Ladder Rungs

Ladder rungs were removed in the chimney of this manhole, leaving the first rung approximately 30 inches from the top of the frame. New ladder rungs can be installed if desired, but they were not installed in this case.

7.3.2.6 Leveling Ring Boots

Leveling ring boots were used to stop leaks in the chimney section. These boots were specified for several manholes. After seeing how well they worked they were substituted for two other products. Although installation required a fair amount of preparation work, the inspector and project engineer were optimistic about the effectiveness of this rehabilitation technique because of the flexibility of the product.

Pros of Leveling Ring Boots

- No excavation is required.
- Product is very flexible.
- This is a mechanical repair product, so it does not require adhesion (in contrast to a coating product). However, adhesion of any repair cement is necessary.

Cons of Leveling Ring Boots

- The product requires a moderate amount of time to install and results in some impacts to traffic.
- Interfering ladder rungs have to be removed and cannot be replaced.
- Hydraulic pressure will make the plastic bulge between the bands.
- Deep chimney sections require more than one boot or extension, thereby increasing cost and installation time.
- The inside diameter of the chimney section is reduced, which makes the manhole harder to access.

Materials, Processes, and Equipment for Leveling Ring Boots

Leveling ring boots are made of high-density polyethylene (HDPE) plastic and are meant to fit inside the existing concrete rings. The circular heavy ribbed plastic is held in place with expanding stainless steel rings. Extensions to the basic ring allow the boot to fit deeper into chimneys. No excavation is required. The outside diameter of the boots is selected to match the inside diameter of the chimney section. The standard boot is 12 inches deep and the extensions were each 6 inches deep.

Installation Issues

Installation Time

It takes 1 to 3 hours to install leveling ring boots, depending on chimney depth and condition, and whether or not ladder rungs have to be removed.

Surface Preparation

Surface preparation requires removing sharp objects or things that might puncture the boots, and removing loose material. The areas of leveling rings that will be located under the stainless steel expansion bands are patched with cement grout to make them round and smooth so that the bands fit.

Ladder Rungs

The ladder rungs need to be removed and are not reinstalled afterward.

7.3.2.7 Interior Chimney Coatings

Interior chimney coatings are designed to provide a waterproof flexible seal to prevent leaks and avoid excavation. This type of product is applied to the inside of the chimney and requires extensive surface preparation.

Pros of Interior Chimney Coatings

This product provides a flexible coating in the chimney area, an area of the manhole typically subject to heavy vibration and traffic loading.

Cons of Interior Chimney Coatings

- Installation requires a fair amount of surface preparation and warm temperatures. This preparation work appears to be critical in making this product work properly. Cement patching grouts under the coating may be susceptible to cracking, which may in turn cause the coating to fail.
- Long term testing has not been performed.

Materials, Processes, and Equipment for Interior Chimney Coatings

The two-part urethane coating product was spread on the interior of the chimney section and extended down into the cone and up into the frame.

No excavation was required. Only hand and small power tools were needed.

Pre-Installation Issues for Interior Chimney Coatings

Of particular interest is the need to have a smooth surface for the coating. The surface of the chimney was made smooth by chipping out bumps and filling voids. Loose concrete was removed and voids were filled with cement. A grinder was used to remove rust from the inside of the cast iron frame. The surfaces were heated because it was very cold when this work was done. The ideal temperature for installation is above 65 degrees F.

Installation Issues for Interior Chimney Coatings

Access

The manholes where this repair work took place were located in asphalt and non-asphalt areas. Work was done with hand tools and small power tools. There were no limits to accessing the manholes.

Almost all the manholes in the pilot projects had a 24-inch-diameter lid and a corresponding diameter chimney. The main seal had a height of 10.5 inches and the extension was 7.5 inches tall. Combinations of these dimensions allowed most chimney depths to be accommodated. The manufacturer requested only basic dimensions; presumably this product will work for standard manholes of the type seen in areas with 8-inch-diameter pipe.

Installation Time

Installing interior chimney coatings takes 1 to 2 hours, depending on chimney depth and condition.

A significant amount of time and effort was associated with this product. The preparation work was extensive. Any cement products used to smooth out the interior surface of the chimney are susceptible to cracking, which may cause the coating to fail.

Reinstatement of Service

The manholes were never taken out of service.

Field Quality Assurance/Quality Control

Quality control involved visual inspection of the work.

Ladder Rungs

Ladder rungs were not removed from the chimney. The coating was applied around the ladder rungs.

7.3.2.8 Manhole Pans

Manhole pans are designed to fit under a manhole lid with the edges fitting between the frame and lid. The idea is to trap water flowing in through any holes in the lid during a storm event. Pans typically have a vent system and drain valve. The drain valve allows the pan to drain a trickle of water to prevent the pan from staying full after the storm is over. During the storm the pan is filled with water, but any volume greater than the amount the pan holds will theoretically not go down the manhole. This is dependent on the location of the manhole; that is, whether it is in a depression that fills with water and cannot drain away from the manhole or infiltrate into the ground, or if it is near a stream and the lid is underwater during a storm event. Pans are typically made of HDPE plastic or stainless steel.

The pans received by the contractor did not work with manholes that had locking lids, and these were the majority of the lids in the pilot projects. For this reason alone, many of the pans were not installed.

Pros of Manhole Pans

Due to so few pans being installed during the pilot projects, judgment about their performance must be reserved until the warranty inspection occurs. Other than solid locking lids, pans seem to be a feasible alternative for keeping inflow from passing through any holes in the manhole lid.

Cons of Manhole Pans

The pans specified for the pilot projects required that the locking lugs in the manhole frame be removed. It was decided that this was unacceptable, so most of the pans were deleted from the contracts. (Other manufacturers may be able to provide pans that prevent this conflict.) Very limited information was available from the manufacturer for sizing and installing the stainless steel pans specified for this project because the manufacturer did not respond when contacted.

Plastic pans were not specified because it was believed that traffic driving over the lids would wear out the lip that fits between the iron lid and frame and the pan would drop into the bottom of the manhole. Plastic pans may be feasible where the manholes are not subject to traffic.

Installation Issues for Manhole Pans

Access

The manholes where this work was performed were located in asphalt and non-asphalt areas. Opening the lid and cleaning the seat were the only tasks involved, so there were no apparent limits to accessing the manholes.

Installation Time

It takes 15 to 30 minutes per pan to install. The production rate depended mainly on traffic control requirements.

Reinstatement of Service

The manholes were never taken out of service.

Field Quality Assurance/Quality Control

Quality control involved verifying that the pans were correctly installed.

Manhole Pan Fit

The seat area under the lid had to be cleaned with a scraper. Attaching the lid’s cable to the manhole (to prevent it from falling into the manhole) would require other small hand or power tools.

The main problem with the manhole pans was that they did not fit in a frame that had lugs for locking bolts, at least not without grinding off the lugs. The pans were deleted from several projects for this reason. Other potential problems might be discovered in the future. Note that only stainless steel pans were specified. Plastic pans might not have this fit problem, although plastic manhole pans need to be evaluated for use in traffic lanes.

7.3.2.9 Reset Frame and Raise to Grade

This work involved replacing damaged concrete leveling rings and adding new rings to bring the top of the frame above grade with the intent of limiting or eliminating inflow. Some of the manholes needed only a layer of cement on top of the existing leveling ring to seal the gap between the ring and the frame. Problems with the leveling rings were attributed to settling and deterioration from traffic loading or having the area around the manhole raised, such as during an asphalt overlay or landscaping.

Pros of Reset Frame and Raise to Grade

This process places the lid and frame above the ground surface, thereby preventing water from flowing over the lid and into the pick holes.

Cons of Reset Frame and Raise to Grade

- The work usually requires excavation around the manhole. For these pilot projects, excavations in asphalt were considered too expensive for the perceived benefit, so some were deleted and repaired with other products.
- In some areas, raising the lid and frame above grade would have created a driving hazard. When this was the case, the work was not performed.

Materials, Processes, and Equipment for Reset Frame and Raise to Grade

This work was done with a jackhammer and hand tools.

Installation Issues for Reset Frame and Raise to Grade

Access

The manholes where this work was performed were located in asphalt and non-asphalt areas. Manholes located in asphalt required an asphalt patch. Manholes located in grassy areas needed only hand excavation and minimal restoration work.

Installation Time

Resetting frames took 1 to 4 hours, depending on traffic control and asphalt or grass restoration issues.

Reinstatement of Service

The manholes were never taken out of service.

Field Quality Assurance/Quality Control

Quality control involved visual inspection of the work.

7.3.2.10 Cement Patching Grouts

Cement patching grout products were used to patch cracks, patch voids prior to coatings, and seal the holes created during chemical grouting. The number of cracks in the manhole was the main factor that determined the type of product used.

Pros of Cement Patching Grouts

- All of the products appeared to stop leaks based on visual inspection. The amount of product used depended on the size of the crack.
- Cement patching grouts are easy to apply.

Cons of Cement Patching Grouts

These products are susceptible to cracking and spalling. These characteristics may not be immediately apparent, but may appear sooner or later depending on the manhole location and conditions.

Materials, Processes, and Equipment for Cement Patching Grouts

This work involved only hand tools.

Installation Issues for Cement Patching Grouts

Installation Time

This work was usually done as part of other rehabilitation work and did not add a significant amount of time.

Field Quality Assurance/Quality Control

In some cases, quality control involved visual inspection of the work. In other cases patching grouts were used in conjunction with work like chemical grouting or coatings, where vacuum testing was specified.

It was also common for a cement product to be used to seal a chimney for a vacuum test; however, the vacuum test was specified only for the portion of the manhole below the top of the cone. Usually the contractor elected to seal the chimney because the vacuum testing equipment would not fit at the top of the cone. The ladder rungs were in the way.

7.3.3 Laterals and Side Sewers

I/I occurs at laterals and side sewers when water leaks in through faulty connections, cracked or broken pipes, open joints, pipes damaged by root intrusion, illicit foundation drains and roof drains, and uncapped or broken cleanouts. The source of flow may be water (inflow) that is either flowing over the ground surface, or water (infiltration) that is rapidly migrating just below the ground surface or flowing in to the pipe from the bottom of the trench.

Rehabilitation products for laterals and side sewers are similar to those used for sewer mains, and typically address lining, repairing, or replacing existing pipe.

7.3.3.1 Cured-in-Place Pipe for Laterals and Side Sewers

CIPP was installed in some side sewers in Kent. This was the only project where this type of product was used for side sewers. The original design called for a combination of service connection and lateral liners (SCLLs) and CIPP for lining the laterals and side sewers from the sewer main to the houses. When the side sewer was longer than 80 feet (the maximum length of a T-Liner®; for a description of T-Liners®, see Section 7.3.3.4), the rest of the pipe was to be lined with CIPP.

This work was similar to installing CIPP in a sewer main, with three exceptions:

- Lateral and side sewer pipes were typically only 4 inches or 6 inches in diameter.
- There were no manholes available, so a pit was excavated at each end of the pipe.
- The lateral and side sewer pipes were typically not straight and had a variety of bends, tees, wyes, reducers, etc. In some cases, there were multiple legal or illegal connections that needed to be reconnected or disconnected after installation of the CIPP. Sometimes the side sewer consisted of more than one pipe. Most of these points needed to be excavated to allow access to the pipe.

Pros of CIPP for Laterals and Side Sewers

Lining a straight lateral or side sewer with CIPP appears to be a viable rehabilitation technique when the pipe does not have complex fittings and is not collapsed or obstructed by roots.

Cons of CIPP for Laterals and Side Sewers

- Liners can be difficult to install because pipes on private property are rarely straight and usually have a variety of complex fittings. The process of installing CIPP in side sewers is complicated unless the pipes run straight from the building to the sewer main and there is an absolute minimum of fittings and reducers.
- It is necessary to dig and repair defects (such as crushed pipe) before liner installation.

- As with any work done on private property, the agency needs to acquire rights-of-entry (ROE) before construction begins. When work is inspected and restoration is complete, contractors must obtain restoration releases.

Materials, Processes, and Equipment for CIPP for Laterals and Side Sewers

Lining of laterals and side sewers was done using processes similar to those used for lining sewer mains. However, lateral and side sewer liners were always inverted into place and cured using steam, ambient temperatures, or “hot” resins. The contractor usually stopped the liner in a “receiving pit” and made the connection to the building stub with a fitting.

Excavation was done by hand, or by small walk-behind track hoes in places such as backyards. Front yards were easier to access with a standard rubber-tired backhoe. When excavation was done on private property, the equipment operator placed the dirt on tarps or plywood to help protect grass and other landscaping. The equipment used for small diameter inverted CIPP cured with steam included: a steam generator truck, wet-out trailer, CCTV truck, wheelbarrow compressor, vactor truck or jet cleaner truck, root cutting equipment, small generators, and two-way radios.

Pre-Installation Issues for CIPP for Laterals and Side Sewers

Surface preparation involved pulling a high-pressure spray head through the pipe to remove debris attached to the walls and solids settled in the bottom of the pipe.

Side sewers often contained large quantities of roots. In Kent, the quantity of roots was larger than indicated in the predesign Sewer System Evaluation Survey (SSES). This was partly due to the fact that only a small portion of the side sewers were viewed with a CCTV camera during the SSES. The roots needed to be cut out before the CCTV push camera and locating transmitter could be used, then cut again and completely removed before the liner was installed. Excessive quantities of roots impact production but are a good indicator of I/I potential.

Excavation and replacement of collapsed or badly damaged sections of pipe was needed in some cases. In some cases it would have been easier to simply dig and replace the entire sewer.

Installation Issues for CIPP for Laterals and Side Sewers

Access

Considerations for accessing the pipes on private property are similar to any work done on private property.

Field operations required access to the service pipe at both ends.

Installation Time for Liners

Installation time was based on a per-liner basis, not on liner length. The crews installed an average of one or two liners per day. This included preparation work such as installing cleanouts and excavation. Installation time was very dependent on pit depth, complexity of piping, scheduling, and preparation work required. Pipes with many fittings and bends and shared side sewers made the work even more complex and time consuming.

Coordination with Other Processes

The side sewer and lateral CIPP work had to be coordinated with the T-Liners® in Kent, so there were two separate crews. There was a third crew digging pits and a fourth crew doing CCTV work and removing roots. Another coordination issue was the need for PVC fittings to connect these two types of liners. Finding, locating, and dealing with side connections, bends, tees, wyes, reducers, and other fittings was another large part of the work.

Pit Depth, Size, and Location

Pits excavated on private property were usually shallower than those needed in the public right-of-way. The pits were typically the same dimensions as those needed for pipe bursting and had the same considerations for restoration and working around other utilities. The pits were typically located at the ends of the pipe, wherever cleanouts were installed, and at side connections and fittings.

Minimum and Maximum Liner Lengths

Because lateral and side sewer pipes are small in diameter, the maximum possible liner length is probably shorter than for liners installed in a sewer main, and more so for a 4-inch liner than a 6-inch liner. The longest 6-inch lateral/side sewer liner installed was approximately 120 feet. The longest 4-inch lateral/side sewer liner installed was approximately 50 feet. No problems were noted during construction with the exception of the extensive preparation work required.

There is probably no minimum length for this type of liner. However, at some point, it is easier to dig and replace a pipe rather than install a short liner.

Use of Cleanouts

Cleanouts were used mainly for cleaning operations and for placing a CCTV camera inside the pipe. Note that the small-diameter CIPP is easier to install if the contractor has access to each end of the pipe. This usually meant that there was a pit at each end of the pipe and the cleanout was installed after the liner was done.

Field Quality Assurance/Quality Control

Field QA/QC for small-diameter liners involved monitoring the curing time, temperature, and pressure. The CIPP was also inspected by running a CCTV camera through the pipe.

Temperature of the released steam was measured at the end of the liner with an infrared thermometer. Pressure was manipulated by use of a valve and recorded as the cure progressed. Data collectors were not used, although they were specified.

Complexity of Side Sewers

The work of actually locating the side sewer, then constructing the repair, was complicated. The large number of shared pipes, complex fittings, convoluted piping, and the use of wye fittings for bends made these liners very difficult to install. Any large defect in the pipe, such as a crushed pipe, required a dig-and-replace repair before the liner could be installed in the remainder of the pipe. More excavations were required if the liner hit a snag, or if the liner came to a wye fitting and could not make the bend.

Property Issues

Because of the large quantity of roots in the side sewers, this work may have caused some backups and claims before the actual rehabilitation work even began. In general, the property owners felt that once the contractor started working on their side sewers, any backups or other problems were the contractor’s fault.

Change in Rehabilitation Technology

Note that these side sewer liners were installed in combination with T-Liners® in the laterals and the same subcontractor installed both (see Section 7.3.3.4 for a description of T-Liners®). The T-Liner® and side sewer CIPP work was of good quality. However, after approximately 20 houses received a liner, King County and the general contractor determined that the low production rate, root problems, and the complexity of the piping made CIPP an inefficient method of completing this work. The remaining side sewers were rehabilitated by pipe bursting.

7.3.3.2 Pipe Bursting – Laterals and Side Sewers

Pipe bursting of laterals and side sewers was done similarly to pipe bursting of sewer mains with the following differences:

- Laterals and side sewers were typically 4 inches or 6 inches in diameter, which made the pull-through of new pipe easier than in 8-inch-diameter and larger pipes. The 4-inch-diameter pipe came in rolls and was easier to drag into position than 6-inch-diameter pipe.
- Pits (at cleanouts, side connections, and fittings) needed to be excavated on private property. Pits were usually no more than 6 feet by 6 feet and were shallower on private property than at the sewer main.
- Laterals and side sewers were usually not straight pipes. The pipes typically consisted of a variety of bends, tees, wyes, reducers, etc. In some cases, multiple legal or illegal connections needed to be reconnected or disconnected. The side sewer sometimes consisted of more than one pipe. The connection points needed to be excavated but the crew could usually pull through most fittings.

Pros of Pipe Bursting for Laterals and Side Sewers

- Minimal excavation is required when compared to open trench installation of sewers.

- Roots need only be removed well enough to get the pulling cable through the pipe.
- Roots should not be an issue in the future because there are no joints in the HDPE pipe.
- Where necessary, the pipes can be upsized. In situations where two neighbors share part of a lateral, some contractors can pull two independent 4-inch-diameter lines or upsize to a 6-inch-diameter service line.

Cons of Pipe Bursting for Laterals and Side Sewers

- HDPE pipe follows the old pipe alignment, whether or not that alignment is straight. Pipe bursting does not remove sags or curves in the existing pipe, although it may smooth them out if they are abrupt. The typically steeper pipes on private property may make sags less of an issue than for flatter sewer mains.
- HDPE pipe may not be absolutely round after installation (although there were no cases during construction of the pilot projects where pipes were out-of-round to the point of being unacceptable).
- Excavation and associated restoration work is required. Some private property owners might assume that further backups or other problems are associated with the work performed.

Materials, Processes, and Equipment for Pipe Bursting of Laterals and Side Sewers

The HDPE replacement pipe used during pipe bursting for side sewers and/or laterals was either 4 inches or 6 inches in diameter. The pipe used for side sewers and laterals was easier to work with than the HDPE pipe used for sewer mains, because a shorter length was typically needed.

The 4-inch-diameter pipe is much more flexible than the 6-inch-diameter pipe, which reduced the size of the launching pit and required less layout room. It is also possible to get 4-inch-diameter pipe in longer, coiled rolls, thereby reducing the number of welds. The 6-inch-diameter pipe is much stiffer, comes in lengths that need to be welded, and requires more layout room. The 6-inch-diameter pipe could be stored in the homeowner’s yard in one or two pieces until needed.

The 4-inch-diameter pipe was used most often for service to a single-family residence. The 6-inch-diameter pipe was used for some single-family residences if required by the local agency or if the service was already 6 inches in diameter. The 6-inch-diameter pipe was also used if multiple houses were connected to one service for those portions of the service line where the flows were in common.

The contractor preferred using 4-inch-diameter pipe wherever possible for side sewers. In some instances where there was a shared side sewer, the contractor pulled in two 4-inch-diameter pipes in place of an existing 6-inch-diameter pipe.

Large track hoes were rarely used in backyards or very far off the asphalt. In backyards, excavations were mainly performed using a Bobcat®-sized track hoe or by hand. The side sewer pipes were fed into the ground at these locations. The equipment pulling the pipe into the ground stayed in the street.

Installation Issues for Pipe Bursting of Laterals and Side Sewers

Access

Considerations for accessing the pipes on private property are similar to any work done on private property.

Installation Time

Crews could typically prepare for two or three pulls one day and complete the pulls the next day, assuming the setups were fairly simple. Installation time also depended on the number of bursting operations on a piece of property. For example, a sewer pipe might run across the front yard, turn at a 60-degree angle along the side yard, and turn again at a 90-degree angle along the back of the house. This combination might require three pulls. A third day was usually necessary for restoration work.

Length of Pulls

The minimum length of a single pull for pipe bursting laterals was approximately 40 feet. For shorter lengths, it was usually easier to open-cut the trench and lay new pipe. Laying new pipe was usually done with PVC pipe instead of HDPE. In Kirkland, pipe bursting was performed for a few short lateral runs because the number of buried utilities would have made open excavation difficult.

The maximum length of a single pull for pipe bursting side sewers was 300 feet. The limiting factors on private property were access for the equipment and bends in the pipe. For example, neither the contractor’s medium nor large track hoe could get into most backyards. Typically the insertion pit was in the backyard and the receiving pit was wherever it was most convenient, usually in the front yard or street.

Excavation Depths

The work for pipe bursting of a whole service (lateral plus side sewer) was a combination of a deeper excavation at the main and a shallower excavation on private property.

Excavations for reconnection of laterals to the sewer main were less than 12 feet deep. Side sewer excavations on private property ranged from 3 feet deep for houses with slab-on-grade construction to about 9 feet deep for houses with basements.

On the Ronald project, there were a few laterals as deep as 20 feet. The engineer specified that these laterals be repaired with CIPP in order to avoid deep excavations. However, the contractor requested and received permission to excavate the laterals and replace them. This was allowed based on the contractor’s ability to do an excellent job at excavation work. The contractor’s excavations were neat and clean, the shoring work was good, and the work was done quickly.

7.3.3.3 Chemical Grouting of Lateral Connections

Very little grouting of lateral connections occurred, all of it in the Brier project. Grouting was done: (1) instead of installing a TOP HAT™ at connections to the sewer mains where the CIPP was cut open (for more information on TOP HATS™, see Section 7.3.3.4), or (2) in old concrete pipes where no other rehabilitation work was done. Groundwater was leaking out of the annular space between the host pipe and the new liner before the grouting took place. The grouting stopped this leakage.

Pros and Cons for Chemical Grouting of Lateral Connections

Chemical grouting was used in only a few instances, so only a limited assessment of its pros and cons can be made. Grouting did stop some visible leakage from pipes, and it is fairly inexpensive when compared to other rehabilitation products. If there are drawbacks to chemical grouting, they are probably the open questions about the product’s service life as well as its ability to stop root intrusion. This product will be further evaluated during the warranty inspection.

Materials, Processes, and Equipment for Chemical Grouting of Lateral Connections

Chemical grouting at the point where a lateral connects to the sewer main was accomplished with a process similar to that used for grouting sewer mains. The same type of grout was used (Avanti’s AV-100). The only difference was that the packer had three plugs (two within the sewer main and the third consisting of a sleeve that plugged the lateral) as compared with two plugs for chemical grouting of sewer mains.

Installation Issues for Chemical Grouting of Lateral Connections

The equipment, surface preparation, access issues, limitations, root issues, and field QC issues were the same as for chemical grouting of sewer mains.

Installation Time

A well-trained crew could complete chemical grouting work for approximately 10 to 15 connections per day. In the pilot projects, chemical grouting was used for a limited number of connections, and these were spread over a large area. This limited productivity to less than 10 connections per day.

Packer Placement and Sealing

The only limit to this grouting is whether or not the equipment can be accurately placed and whether the plugs can seal the pipes.

In one case, a wye fitting in the lateral was too close to the connection and could not be sealed; the connection could not be grouted.

7.3.3.4 Service Connection Liners (SCLs) and Service Connection and Lateral Liners (SCLLs)

The intention of installing SCLs and SCLLs for rehabilitation of laterals and side sewers was to prevent leaks either in the joint between the lateral and the sewer main or in the lateral and side sewer pipe itself. This leakage can come from two places: (1) the void space between the sewer main CIPP and the host pipe, or (2) holes or open joints in the connection or service pipe.

In the pilot projects, TOP HAT™ was the only brand of SCL used and T-Liner® was the only brand of SCLL used. (Note that both are sole source products. For a discussion of sole source products, see Chapter 5.) These products were used almost exclusively on 4-inch and 6-inch-diameter side sewers connected to 8-inch and 10-inch-diameter sewer mains. In almost all cases, the sewer mains were lined with CIPP.

The work required for a T-Liner® was usually more complicated than for a TOP HAT™, because access to a cleanout was needed, and the T-Liner® work often had to be coordinated with complicated pipes and other liners being used further up the pipe.

Service Connection Liners (TOP HATS™)

In general, installation of TOP HATS™ was a smooth process with good production rates. The quality of preparation work was critical. Because the general contractor did preparation work, there were a few conflicts when the TOP HAT™ installer started work. The TOP HAT™ crew was well prepared to clean up any problem openings, although this was apparently not in their contract with the general contractor.

Most of the TOP HATS™ appeared to adhere well to the host pipe. However, failures did occur when the TOP HAT™ did not seal the connection or did not adhere to the host pipe (which usually contained a liner). Surface preparation of the inverted liner to facilitate adhesion of the TOP HAT™ was discussed with the manufacturer. In addition, TOP HATS™ did not extend far enough up the pipe to cover the first joint. TOP HATS™ typically extend 4 inches up the lateral. The designers thought that a TOP HAT™ would cover the first joint up the lateral, though this was rarely the case.

Pros of SCLs

- The product seals the void between the sewer main CIPP and the host pipe.
- A fairly high production rate can be achieved with an experienced crew.
- There is minimal impact to customer service. The side sewer may be plugged for less than 15 minutes.

Cons of SCLs

- This is a relatively new product so there is a limited pool of qualified contractors. There were no local qualified contractors, so a single contractor mobilized from out of state to install the SCLs for all projects.
- The TOP HATS™ were not likely to seal the first joint up the lateral. Failure to adequately seal against the lateral or the joint may allow future leaks.
- The TOP HAT™ relies mainly on adhesion and secondarily on a mechanical "lock" into the defective connection. Adhesion between the TOP HAT™ and the CIPP has not been tested. To date, it appears that testing has been done only for adhesion to the host pipe.
- There is no way to test a TOP HAT™ after installation. Leaks are visible only when I/I is present and a CCTV catches it on film.
- The costs ranged from $1,200 to $2,000 per connection.

Materials, Processes, and Equipment for SCLs

TOP HATS™ are a factory wet-out product that is installed with an air-pressurized packer and cured with ultraviolet (UV) light. The resin is polyester and the fabric is a mixture of woven and chopped fiberglass. A two-part epoxy is applied to the surface of the TOP HAT™ that comes in contact with the pipe.

For mains larger than 12 inches in diameter, use of a TOP HAT™ robot was required.

Equipment for SCL installation is located at the manholes. One truck contains all the following equipment: TOP HAT™ robot with internal camera and UV lighting system, external CCTV camera, air compressor, lateral cutter/grinder unit for root cutting and lateral cleaning, small generator, and two-way radios. The process also requires the use of a jet cleaner truck.

Pre-Installation Issues for SCLs

Surface preparation included pulling a high-pressure spray head through the sewer main to remove debris attached to the area around the TOP HAT™ and inside the lateral. The spray head may or may not remove debris inside the lateral. The hole cut in the liner had to be smooth; this characteristic depended on the abilities of the crew cutting and on brushing laterals in the sewer main CIPP.

Most of the time, high-pressure cleaning equipment was used to remove roots before TOP HAT™ installation. The TOP HAT™ crew sometimes had to use its own lateral cutter/grinder unit for root cutting and lateral cleaning up inside the lateral.

Installation Issues for SCLs

Access for SCLs

Access to the connection was through manholes at each end of the sewer main. Crews parked the truck adjacent to one manhole and set up appropriate traffic control measures.

Coordination with Other Processes and Products

Coordination was required when a TOP HAT™ was used with a liner installed in the sewer main. TOP HATS™ can be installed as soon as the lateral is cut open and brushed; however, because separate crews install liners and TOP HAT™, there is typically some time lag.

Installation Time

The crew installed 10 to 16 TOP HATS™ per day. This did not include cutting and brushing open the CIPP, which was done by the sewer main CIPP crew. Installation time for TOP HATS™ depended on the quality of the lateral cutting and brushing work. Any additional work needed to prepare the connection could cut production roughly in half. For example, in Lake Forest Park, crews needed to remove resin slugs in the side lateral before the TOP HATS™ could be installed. In Mercer Island and Lake Forest Park, TOP HAT™ production was on the high end because almost every connection received a TOP HAT™. In Redmond and Brier, fewer TOP HATS™ were installed; however, they were spread out over a greater area, necessitating more setups.

Field Quality Assurance/Quality Control

Field QA/QC for SCLs involved timing the UV light exposure, watching the bladder pressure, and visual inspection via attached cameras. No other in-place testing was possible.

Service Connection and Lateral Liners (T-Liners®)

The service connection and lateral liners (SCLLs) were all T-Liners®. This is a field wet-out product that was installed by inverting the liner into place. Besides the lateral liner, the completed T-Liner® has a full-circle component inside the sewer main. The portion of the liner inside the lateral and side sewer follows the pipe and covers defects, similar to any other CIPP product.

Pros of SCLLs

It is easiest to install CIPP of any type (whether it is installed in a sewer main, side sewer, or if a T-Liner® is installed in a lateral) in a straight section of pipe. Any additional piping items such as reducers, fittings, bends, or wyes make the work much more complicated. The following is a discussion of T-Liners®; however, it may apply to any type of SCLL installed in a lateral.

- For a T-Liner® installed in a single pipe side sewer with a straight run of pipe, the only time excavation is required is if a cleanout needs to be installed. The cleanout at a building is usually shallower than a cleanout closer to a sewer main.
- Steam curing takes less time than ambient curing.
- There is very limited potential conflict with other buried utilities, caving soils, dewatering, etc.
- Impact on the property owner is usually limited to one or two partial days of work.

- Long lengths of pipe, up to 80 feet, may be lined. It may be possible to line longer lengths of pipe as the technology improves.

Cons of SCLLs

- The pool of qualified contractors is limited. For the pilot projects, there were no local qualified contractors, so a contractor mobilized from out of state.
- Ambient curing takes longer than steam curing.
- A T-Liner® slightly reduces the inside pipe diameter. In a 4-inch-diameter pipe, this may be a significant decrease, especially if the liner becomes wrinkled during installation.
- A T-Liner® does not allow upsizing of the pipe, as is possible with pipe bursting and with open excavation and pipe replacement.
- When the current technology is used for pipes longer than 80 feet, the section of pipe beyond 80 feet requires some other type of rehabilitation work.
- Roots need to be removed. Roots could be a future problem if they migrate into a void between the liner and host pipe.
- The SCLL follows the old pipe alignment exactly, whether or not that alignment is straight. The CIPP will not remove sags or curves in the existing pipe. Larger defects such as offset joints and out-of-round pipes are apparent through the finished liner. These problems are more likely to occur in a side sewer than in a sewer main because the piping on private property is typically more complex.
- Installation of liners in side connections and shared sewers is complex. Additional excavation work may be required for various piping configurations and sections of PVC. PVC fittings may be required at these points. T-Liners® may go smoothly through a 45-degree bend, but 90-degree bends and wye fittings make installation more difficult. Reducers may also present installation issues.
- The upstream end of a T-Liner® ends within the host pipe. It can be difficult to control placement of the end of the liner because the work is done remotely.
- Future work will need to deal with both the host pipe and the liner. Because the presence of CIPP is likely not typical in a sewer system's pipes, future contractors and the property owner must remain aware of its use and location.
- CIPP is fairly thin in comparison to an HDPE pipe; therefore, CIPP may be more susceptible to holes and there may be more wear and tear by maintenance equipment.
- Chemicals used (resins and solvents) may be hazardous if spilled or splashed on the skin or in the eyes. The crews used disposable overalls, gloves, and safety glasses when working with these chemicals. No hazard remains once the material cures.

Materials, Processes, and Equipment for SCLLs

The required trucks and equipment were located at the manholes. A CCTV push camera was located at the cleanout. The image from the push camera was visible on a TV screen at each manhole. The trailer contained the wet-out materials and most of the equipment. Equipment included: a fifth-wheel trailer for wet-out of the liner and storage of materials and tools, steam generator equipment mounted in a pickup truck, T-Liner® launch tube with lay-flat hose, remote reel for winching launch tube in place, CCTV camera truck, CCTV push camera, wheelbarrow air compressor, small generators, and two-way radios.
The process also required the use of a jet cleaner truck.

Pre-Installation Issues for SCLLs

Surface preparation involved pulling a high-pressure spray head through the pipe to remove debris attached to the walls and solids in the bottom of the pipe.

In Kent, root removal became a large part of the work. Root removal was necessary to allow a camera to examine the pipe and to install a liner through the pipe.

Excavation and replacement of a bad section of pipe was sometimes needed.

Installation Issues for SCLLs

Access

The connection was accessed remotely from within the sewer main. The contractor needed access to the manholes at each end of the sewer main and at a cleanout located near the building. Cleanouts were installed if they did not exist.

Coordination with Other Processes and Products

Coordination was required when a T-Liner® was used with CIPP installed in the sewer main.

Installation Time

The rate of production of T-Liners® depends upon the number of liners installed in each manhole-to-manhole setup. A set up for T-Liner® installation requires a truck with a winch located at one manhole and another truck with liner inflation and curing equipment at the other manhole in a segment of sewer. A cable needs to be installed from one manhole to the other to winch the T-Liner® installation equipment into place. There is a setup time required each time the trucks have to move to a new location, which reduces the overall production rate in terms of T-Liners® installed per day.

T-Liner® installation time also depends on the skill level of the operators and whether or not steam was used for curing. Heat accelerates the rate of cure. In Kent, the crew installed about two T-Liners® per day using an ambient temperature cure. Ambient temperature curing took about 3 hours per T-Liner®.

In Redmond, the manufacturer’s crew typically installed four T-Liners® per night. This crew used steam for the curing process, which meant the cure took only half an hour. Overall production might have been higher except for the fact that the work was done at night and installation locations were spread out over a large area, necessitating more setups.

Liner Length

The maximum length of a T-Liner® installed in any of the pilot projects was 35 feet, although the manufacturer stated that T-Liners® are designed to extend as far as 80 feet.

The minimum length of a T-Liner® installed in any of the pilot projects was 5 feet.

Field Quality Assurance/Quality Control for SCLLs

Field QA/QC for SCLLs involved timing the wet-out and curing processes, watching the bladder pressure, monitoring steam temperature, and visual inspection using both the CCTV cameras. Based on the post-construction CCTV video, the liners in Redmond and Kent were installed properly with a minimal amount of wrinkling. The only problem noted was that on one T-Liner®, the portion of the liner inside the sewer main did not seal. It flapped loose and partially blocked flow in the main. The repair involved placing two spot repair liners on the ends of the T-Liner® while avoiding covering the connection opening.

7.3.4 Replacement of Sewer Pipes Using Open Excavation

Open excavation to replace laterals and side sewers with PVC pipe occurred in several places in some of the pilot projects. No sewer mains were replaced using open excavations. Open excavation work is standard practice when installing new sewers and is discussed in this report only to contrast it with trenchless rehabilitation work.

Pros of Open Excavation

- New pipe is a known quantity in that it is easy to inspect before backfill.
- New pipe may be placed in a different location than the original pipe. Unlike CIPP and pipe bursting, open excavation does not rely on the old alignment, so sags in the pipe do not occur. For example, a trench may be excavated in a different location to avoid landscaping or a large tree. Open excavation may also allow the side sewer to be straighter or allow splitting of a shared sewer.
- Old broken pipes or complicated configurations can be simplified or re-routed.

Cons of Open Excavation

Open excavation entails larger quantities of backfill and more restoration work compared to trenchless methods.

Materials, Processes, and Equipment for Open Excavation

The gasketed PVC pipe and fittings used were based on ASTM D-3034 standards. Sewer pipe was laid by level or laser and pressure tested before connections were made.

Open excavation work was performed the same as new sewer construction, except that excavation and restoration were complicated by existing surface features and required coordination for sewer shutdown. The work typically involved more hand digging and smaller excavators than are used in new construction.

Installation Issues for Open Excavation

Installation Time

The Kirkland project had 78 laterals replaced through open excavation. Production time depended on the qualifications of the crew and the complexity of the piping.

Private Property Construction

One pilot project selection criterion was to conduct I/I rehabilitation work on private property. Four out of the ten pilot projects involved extensive rehabilitation work on private property: Auburn, Kent, Ronald, and Skyway. Three other pilot projects involved entering onto private property to access easements where local agency-owned sewer mains or manholes were located. These were the Manhole Project (Northshore, Coal Creek, and Val Vue), Brier, and Lake Forest Park.

7.3.5 Work in Easements Requiring Private Property Access

In many cases, contractors could not easily access local agency-owned sewer mains and manholes located within easements by following the easement alone. Easements often ran through backyards with fences and landscaping or along sensitive areas such as creek beds, making it difficult for contractors to follow the easement in doing their work. Often the best way to access the area needed for work was to cross directly through the private property adjacent to the easement—people's yards. In most cases, this necessitated gathering right-of-entry (ROE) agreements with each of the affected property owners. For two of the agencies, easement agreements authorized entry onto private property to access the easement. The ROE agreements involved restoration commitments and included limitations on the timeframe in which work was to be completed. Most of the property owners involved agreed to grant this access. King County sent out public education materials along with the ROE forms to inform property owners about the need for the work and to explain why King County, in cooperation with their local agency, was conducting work in their system.

7.3.6 Work on Private Side Sewers

Though each had its own unique issues and approach, the four pilot projects involving work on private property offered many common lessons for conducting I/I rehabilitation work on private side sewers. Working on private property poses a complex set of challenges. Outlined below are several items to think about when designing private property I/I projects.

7.3.6.1 Rehabilitation Methods Used

The three primary methods for private property side sewer rehabilitation used on these projects included: (1) pipe bursting, (2) CIPP, or (3) dig and replace.

CIPP is ideal for host pipes with minor defects, such a cracks that do not affect the roundness of the pipe, or for pipes not obstructed with roots or defects. The amount of preparatory work associated with root removal in Kent established that CIPP was not a cost effective method of rehabilitation for side sewers. The extent of root intrusion was not known until construction began. CIPP is also less desirable when there are branches or wyes in the side sewer. Each junction of this type requires excavation.

Pipe bursting depends less upon the condition of the host pipe and is preferred when combined with rehabilitation of the sewer main using pipe bursting. It does require a pulling pit and an insertion pit; however, the overall impact is typically minimal.

Dig and replace creates the most surface disruption; however, if there are minimal surface obstructions such as plants, rockeries, or patios and if the side sewer is not deep it may be the most cost effective method of replacing a side sewer.

7.3.6.2 Special Design Issues and Contract Requirements

The lateral/side sewer location, alignment, depth, condition, and configuration are valuable pieces of information in selecting a rehabilitation method and in the success of construction. The amount of information that is available from the property owner or the sewer agency in the form of sewer cards or as-built information may help determine the preferred method of rehabilitation. Side sewer condition, as in the case of the Kent pilot project, also determines if CIPP is appropriate. In many cases if the information is not available, it is probably more cost effective to incorporate the field investigation into the construction contract. If the investigative work is completed in advance of construction, it will likely duplicate efforts that are subsequently required during construction, such as excavating a pit at the foundation to install a cleanout so a CCTV can be run through the side sewer. If pipe bursting is used as the rehabilitation method the same pit could be used for the insertion pit.

For private sewer system rehabilitation, the information needed for design includes the building configuration, routing of the side sewer, and critical surface features. Access limitations need to be identified in the drawings. Aerial photos can provide an easy method of identifying the configuration of structures within a basin. Because work is likely being done on both private property (with rights-of-entry) and public property, an accurate right-of-way map may not be needed. For the contract it is important to establish the extent of restoration that will be provided by the contractor, and this needs to be coordinated with the rights-of-entry. If the information about the alignment and depth of the side sewer is not known in advance of construction, pay items need to be included in the contract for pits at specified depths.

7.3.6.3 Access Issues – Right-of-Entry

In order to gain access to private property, King County or the agency first obtained signed right-of-entry agreements from the property owners. Right-of-entry agreements granted the local agency and King County and their contractors access to the property for all pilot project related work, including installation of cleanouts, CCTV work on the side sewer, and installation of liners or new pipe. Allowances were made in the right-of-entry form for full dig and replacement of the side sewer if conditions did not allow trenchless technology to be applied. Rights-of-entry also gave the County or local agency the ability to withdraw the property from the project for any reason. It was made clear to the property owners that an ROE was not a promise to do the work.

ROE agreements granted access for specific windows of time each day and stated that 48-hour notice would be given prior to beginning construction activity on the property. King County supplied 48-hour notices for most of the contractors. These bright orange notices reminded residents that their sewers would be impacted for the day and that they should refrain from doing laundry, running dishwashers, taking showers, or even using the toilets at this time. These notices were used during the SSES work and again during construction. Some lessons learned are that the notices need to be date-stamped and that contractors should add their phone number to the notice. Another lesson learned is that property owners must be notified when the work is delayed from the scheduled date. There were property owners who made an effort not to use water, only to find out that the work was delayed. While most understood, several were understandably upset about a second impact, especially if they were homebound.

The ROE agreements stated that the County or agency would be responsible for making a reasonable effort to restore the property, as near as possible, to its pre-construction condition. For some projects, local agencies requested that language be added to exempt native invasive plants, brush, and weeds from restoration requirements. Property owners assumed full responsibility for maintaining the landscaping after restoration was complete. Property owners also assumed responsibility for future maintenance, cleaning, or repair of their side sewer. All work was warranted to follow provisions of the manufacturers' warranty periods. The agreements terminated at the stated termination date or 180 days after completion of construction and restoration. A lesson learned is that termination dates should be extended to allow for inspection prior to termination of the warranty.

Obtaining ROE agreements from all or most of the property owners in the pilot project basin was a very labor-intensive activity and took approximately 2 months of continued communication and follow-up to obtain all the necessary signatures. When pilot projects for private property were originally selected, most of the local agencies committed to obtaining the necessary ROE agreements for allowing King County and its contractors to conduct the work. Later, most local agencies could not honor this commitment due to lack of available resources. With the exception of the local agencies that managed their own pilot projects and one other that obtained its own agreements, King County took responsibility to collect ROE agreements for the projects.

Public meetings helped to educate property owners about the project benefits and impacts. Several ROE agreements were signed and turned in at public meetings. In addition, several educational flyers were sent to property owners along with the agreements. Return envelopes were provided to help ensure a response. For approximately 50 percent of the properties, it was necessary to send reminder letters with additional copies of the ROE agreements. When this did not work, a third attempt was made by visiting property owners in person, explaining the project, and asking for agreements or leaving brightly colored reminder notices as door hangers. Personal visits were necessary for about 25 percent of the properties. It was typical that approximately 10 percent of property owners were unreachable. Repeated attempts to contact or locate property owners were sometimes successful.

For all projects, less that 5 percent of the property owners in the pilot basin would not sign an ROE agreement; these properties were excluded from the project. In Kent, for example, only 5 out of 159 property owners (or 3 percent) declined to sign the ROE agreement. Kent may have had such a high return rate due to the fact that most property owners either shared a side sewer with at least one other neighbor or a neighbor's side sewer ran through their property. These configurations were made clear to the property owners. They were informed that if they declined to sign an ROE agreement, their neighbors would also need to be excluded because of the need to cross different properties to conduct the work. Other projects involving shared side sewers showed similar results.

7.3.6.4 Construction Impacts

Construction involved various impacts to neighborhoods, roads, and yards. Large excavations were made each day either in the roadway or in yards. If work was not completed by the end of the day, it was necessary to cover pits in the road or driveway with steel plates, or plywood if the pit was in a yard. Excavation pits ranged in size from small pits 3 feet long by 3 feet wide by 3 feet deep to large pits 12 feet long by 8 feet wide by 15 feet deep. The smaller pits were typically associated with work on private property, whereas the larger pits were associated with pipe bursting pits for the sewer main and lateral connections. Contractors covered or removed excavated materials and construction debris to minimize impacts to the neighborhood. Excavation involved large pieces of equipment being left within the project site for the duration of construction either on private property or within the right-of-way. Work hours were restricted to specific times according to each jurisdiction. However, construction ran late into the evening at times, especially for the CIPP projects.

Additional impacts included temporary disruption of sewer service. Occasional sewer backups occurred due to construction activities. King County, local agencies, or the contractor responded immediately for cleanup and repair and health specialists checked that cleanups were satisfactory. It was very important to have inspectors who could work with the public when unexpected construction delays impacted the neighborhood. Delays were often due to longer-than-expected curing time for the CIPP, or for stuck equipment.

7.3.6.5 Restoration

Contracts required contractors to restore surfaces and landscaping damaged during the course of conducting their work. This included turf renovation or replacement, planting replacement, irrigation system component repair or replacement, and repairs to or replacement of other site features such as fencing, rockery, driveways, etc. that were affected by construction. Contracts also required a 1-year warranty for all site restoration.

ROE agreements contained language indicating that contractors would make reasonable efforts to restore the property as near as possible to previous conditions. Following completion of their work, contractors were required to obtain signed restoration releases from property owners. About 5 percent of releases were not signed, several due to property owners' differing expectations about what restoration meant.

Lessons learned include the need to inform property owners and the public about the potential for minor and superficial markings on the pavement by construction equipment. Property owners should also be notified that pipe bursting does not correct low spots in their system.

7.3.6.6 Local Agency Involvement

It was important for local agencies to be involved during all phases of their local project because the directly affected properties belong to their customers. Local agencies were an additional resource for the public and had the most direct and on-going relationship with their customers. Agencies participated at different levels in their pilot projects depending on the complexity of the project, their available resources, or other commitments. Ronald and Skyway were the most actively involved local agencies, gathering rights-of-entries, working with the public, and managing construction and inspection. Ronald and Skyway answered their customer’s questions directly and will therefore benefit the most from future goodwill within their service area.

7.4 Public Education and Involvement

Various methods were used to keep the public aware of pilot project status and to foster communications. The following is a sampling of the methods used to get information to the public and property owners in the vicinity of each project.

- At least four 24-inch by 36-inch metal traffic signs were posted around the construction area. Signs were located to make them visible to the greatest number of people and to notify pass-through foot and car traffic of the project. The signs included the official I/I project name, the King County logo, the name and logo of the agency, construction period, and a phone number. The phone number connected the caller to a King County or agency representative via a message pager.
- Prior to construction, mailings were sent to all property owners and homes within the project area. This expanded mailing list provided both renters and owners with the same information.

- Public meetings were held prior to construction. Some local agencies wanted several meetings to inform the public and others wanted none. The County staff took their direction from the local agencies for scheduling these meetings. For the Ronald and Skyway projects, the local agencies scheduled meetings and invited County staff to participate. In Ronald, the local agency sponsored three meetings. The first two were for general information to help answer the public's questions and to begin gathering signed rights-of-entry. About 50 people attended each of these meetings. The third meeting was to introduce the contractor and to answer any new questions.
- Contractors were required to leave 48-hour notices on the doorsteps of the properties before doing work on the street. Sometimes contractors left notices with more or less notice depending on the weekend schedule.
- The process of gathering rights-of-entry allowed property owners an opportunity to learn about their local I/I project and to ask questions.
- Project staff had direct communications with staff from large public facilities such as schools. Due to the construction schedule, most schools were not in session, but sports groups were scheduled to use the school fields. Therefore, it was important to communicate with district-level and local school staff. For example, on weekends the Little League used the Brier Elementary School fields and the League's contact was the Edmonds School District's Assistant Sports Director. He was given advance notification of potential weekend work. Some of the work in Brier occurred after the new school year began, so contractors tried to work on non-student school days or after school was dismissed.
- Another source of direct communications was phone calls from the public directly to the city or the local agency. For example, a person calling about work in the Coal Creek Basin might call the Coal Creek Utility District or the City of Newcastle. Both were able to answer questions or to provide the project message phone number.
- The King County I/I Program's Web page highlighted the pilot projects. (See http://dnr.metrokc.gov/wtd/i-i/.) The partnering local agency's logo, name, and contact name were also on each pilot project page. Individuals could click on this logo for a direct link to the local agency's Web site if one was available.
- Refer to Chapter 3 for information about public involvement during initial SSES work.

7.4.1 Intergovernmental Agreement Process

All 34 of the County's component agencies signed Intergovernmental Agreements (IGAs) in 1999 or 2000 when the program first began. This provided the County the opportunity to clean, inspect, and install flow meters into the local agency lines during the initial phase of the program. The local agencies with pilot projects amended these IGAs to reflect the roles and responsibilities of each party and the pilot cost covered by the County. For lessons learned, IGAs should add specific language to identify a public 24-hour contact and to cover how both will handle questions or complaints regarding backups, noise, traffic, and restoration issues.

7.5 Experiences with Construction Issues

This section highlights general construction issues experienced during the pilot projects. These issues include disconnection of illicit connections, abandonment of unused sewer pipes, traffic control, time constraints and scheduling, sewer bypass methods, night work, noise, post-construction rehabilitation, testing, record drawings, and safety.

7.5.1 Disconnection of Illicit Connections

Illicit connections are pipes connected to the sanitary sewer that are carrying something other than sewage. Illicit connections to the sanitary sewer include storm pipes, French drains, yard drains, foundation drains, roof drains, sump pumps, or other water sources. Although these are valid methods of dealing with groundwater or surface water, they should not be hooked to the sanitary sewer. When discovered, these sources of groundwater or surface water should be disconnected and routed to an alternative disposal system such as a ditch or storm sewer.

In this report, the word *illicit* is defined as an “illegal” connection (although the connection may not be illegal depending on the applicable codes in a jurisdiction) to the sanitary sewer. Some of the connections listed above may not be illicit if they occur under a house or if the plumbing code in effect at the time of construction required that they be connected to the sanitary sewer. One example is a sump pump in the crawl space under a house; the building code may say that the pump must be connected to the sanitary sewer.

It was fairly rare during the pilot projects to discover an illicit connection to the sewer main in the right-of-way. This is probably because the illicit connection would occur in a street, and agency staff would likely notice the excavation. Many illicit connections occur on private property. The typical illicit connection was a roof drain system connected to the sanitary side sewer instead of to a storm pipe. This type of illicit connection was usually discovered during smoke testing. Other types of illicit connections were more likely discovered when the contractor was replacing the side sewer or lateral and the connection was traced to its source. These illicit connections were probably made either by the property owner or a contractor when building or working on a house.

Of the 10 pilot projects, only the Skyway, Kent, and Ronald projects discovered and repaired illicit sources of I/I. In the Brier project, one roof drain connection was discovered during smoke testing and was re-routed as part of the construction contract. On the remaining pilot projects, the inspectors and project representatives discovered hints of illicit connections during the work; however, these were rarely pursued for disconnection or repair.

Disconnection of an illicit connection typically means finding another place to route flows instead of allowing them to connect to the sanitary sewer. In most cases, this requires open excavation and installation of a new pipe to re-route the flows to a new discharge location. Discharge locations may include roadside ditches, street gutters, storm piping systems, or simply allowing the water to soak into the ground via splash blocks or infiltration trenches.

Pros of Disconnection of Illicit Connections

- This process disconnects illicit sources of non-sewage water from the sanitary sewer system.

Cons of Disconnection of Illicit Connections

- Finding the illicit connection requires extensive exploration work.
- The work requires design of a new route for the offending pipe or pump discharge.
- Research is required into codes and local legal requirements.
- Extensive communication is required with property owners and their neighbors.
- Easements and permission to work on private property may be required. Easements may also be required if the new pipe needs to go across a neighbor's property.
- Permits from one or more agencies may be required.
- Coordination is required with agencies whose jurisdiction covers stormwater and/or groundwater discharge.
- Excavation and restoration work can be extensive.

Materials, Processes, and Equipment for Disconnection of Illicit Connections

Typical materials needed for disconnection of illicit connections were PVC pipe, fittings, and couplings, plus soils materials and restoration items. The equipment required was the same as that normally used for open excavation trenching.

The work typically involved more hand-digging and smaller excavators than are typically used for new construction. Existing surface features could complicate excavation and restoration work

A design process for new pipe was needed to re-route the illicit connection. The design process sometimes required permitting, easements, and communication with the affected property owner and neighbors, and other tasks associated with this type of work.

Disconnection Issues

Disconnection Time

Disconnection of illicit connections depends on the particular situation; this type of work can be expensive and time consuming. The first step requires tracing the pipes to determine how they are connected. This involves exploratory work like dye testing, locating the pipe horizontally and vertically, and CCTV work to trace the pipe. Illicit connections are typically discovered during construction when the contractor and engineer are already busy and would rather not deal with the problem.

The exploratory work then leads to a design process. When the illicit connection is discovered during construction, the design of a new pipe must occur rapidly and there must be a way to pay the contractor for additional work. An alternative is to have the property owner do the work with a private contractor or for the contracting agency to do this task.

For the pilot projects, once the design and related issues were resolved, the pipe work was usually straightforward. However, preparing for the construction work required a large portion of staff time for design and coordination; the exploratory work had to be done to find defects and connections; and other construction issues had to be addressed such as construction costs, change orders, easements for new drain pipes, and related problems. In some cases, there was no simple solution and the decision was made to leave the illicit connection in place. Several times illicit connections were discovered during construction and either the change order costs were prohibitive or the pipe could not be disconnected without a sump pump design or there was not time to implement a repair.

Examples of Disconnection Issues

Some issues encountered with disconnection of illicit connections included:

- One jurisdiction did not allow splash blocks for downspouts, so new buried piping was needed to route the flow to the roadside ditch.
- In several cases, there was nowhere else to route a pipe or the flow because of topography or pipe slope requirements. In that case, the illicit connections were simply reconnected to the sanitary sewer. A decision was made not to utilize sump pumps for storm piping problems.
- There were instances in which disconnection could subject a building foundation to groundwater conditions with the potential to cause future problems. It was a program goal that no system improvements for I/I would create new problems for the homeowner or his neighbors or the agency.
- Another example of the level of effort required for this type of work involved a roof drain system connected to a side sewer. Smoke testing indicated the connection, so the work was added to the design. During construction, dye testing and a side-launch CCTV camera traced the problem pipe. A transmitter on the camera was used to locate the pipe and measure its depth. It was determined that only one out of eight downspouts from this house was connected to the side sewer, and only 20 percent of the roof area was draining to the side sewer. The homeowner was helpful and open to the work being done. The repair was simple and took only a few hours. Nevertheless, a lot of contractor time and staff team time was used to coordinate re-routing of this pipe.

7.5.2 Abandonment of Unused Sewer Pipes

The only sewer pipes abandoned during the pilot projects were side sewers and laterals. Abandonment typically meant not reconnecting the pipe when the sewer main was rehabilitated. This work was similar to disconnection of illicit connections, except that an abandoned pipe did not have to be reconnected or re-routed like a storm pipe.

Abandoned pipes ranged from capped tees at the sewer main to 100-foot-long side sewers running to buildings that were no longer in existence.

For the Redmond project, the plans included abandonment of several hundred feet of old and defective sewer mains. The plan called for extending these laterals to sewer mains across the street that were designated for CIPP work. This effort was deleted due to budget and schedule constraints.

Pros of Abandonment of Unused Sewer Pipes

- This process allows old, unused, uncapped, and often leaky side sewers and laterals to be disconnected from the sewer system.
- For CIPP, the liner is simply allowed to cover the connection and the opening is not cut open.
- For pipe bursting, the HDPE pipe is allowed to burst through the connection and a construction pit is not needed.

Cons of Abandonment of Unused Sewer Pipes

- The process usually requires extensive exploration work and communication with property owners to verify that the pipe has in fact been abandoned.

Materials, Processes, and Equipment for Abandonment of Unused Sewer Pipes

In some cases, agencies required that abandoned pipes be tracked on drawings or that concrete be used to plug abandoned pipes.

The process started with determining if the pipe was really abandoned. The pipe was usually traced to find out where it led. Tracing typically required a combination of CCTV work and dye testing. Sometimes the pipe was capped at the sewer main; however, it often ran to the edge of the right-of-way before it stopped or ran onto private property. Effort was aimed at verifying that everyone involved, including nearby property owners, knew where the pipe was located and that it was being abandoned.

Abandoning capped tees was simpler. The pipe did not need to be traced. The agency typically made a determination that if property owners wanted to connect at this location in the future, they were required to go through the normal process for a new sewer connection.

Abandonment Issues

Because this work was incidental to the rehabilitation process, costs were not tracked and it would be difficult to calculate a production rate. The cost associated with this work is the time-consuming task of tracing down abandoned pipes not already identified by the local agency.

Although the connection is not being used, the agency may desire the pipe to remain connected to the sewer to avoid reconnecting it in the future.

In one case, a liner covered an active side sewer. This was discovered during review of the post-construction CCTV tapes. Because the property owner was on vacation, or because the side sewer leaked into the soil, there was no backup of the sewer line. In general, contractors were more likely to reconnect an abandoned pipe instead of taking the risk of a backup.

7.5.3 Traffic Control

Traffic control was required for local access roads, arterials, and several within-town state highways. Work on arterials required the use of flaggers and signs. Traffic control was minimal for most residential streets. On residential streets, traffic control involved the use of cones and of flaggers where traffic flow was greater and at intersections. If the work was concentrated at one manhole, there was typically only one flagger. For operations that required using the entire street (such as sewer main pipe bursting), two or more flaggers were typically required. Two flaggers were also required for manholes located on curves in the roadway or shoulder area.

The speed limit is 35 miles per hour (mph) on the state highway running through downtown Redmond. The slow speed and presence of traffic lights at most intersections made traffic control relatively simple. The work was done at night, which required lighted signage and multiple flaggers on busier streets.

The speed limit is 45 mph on the state highway running through Lake Forest Park, but traffic routinely goes faster. This highway has a dedicated bus lane (the outside lane) that runs on the shoulder of the road. Vehicles turning right also use this lane. The project manholes were located in this bus lane. Traffic control consisted of signs, parking a truck with flashing lights in the lane, and notification provided to the bus transit department.

As part of the right-of-way permit process, the contractors submitted traffic control plans for review by the project engineers and local city staff. Where a project was done for a sewer agency, the local city was the reviewing agency. Because most of the work was trenchless in nature and very little excavation was required, the right-of-way permit process went smoothly and traffic control was rarely an issue. Even where the pipe bursting work required excavation in the streets (in Kirkland and in Skyway), traffic control did not raise many concerns.

7.5.4 Time Constraints and Scheduling

The contracts required reconnection of sewer lines by evening time. Pipe bursting work easily met this time constraint. Pipe bursting work generally occurred between 7 a.m. and 5 p.m. This schedule worked because the contractor had an excavation open at the connection and could make a temporary connection for a building, so service was not interrupted. However, experience showed that the period of time between 7 a.m. and 5 p.m. was insufficient for CIPP installation. When CIPP was installed, there was no ability to make a temporary connection. CIPP installation time is also heavily dependent on field QC issues, the curing process, and on the process of opening the laterals after the cool-down phase.

In Redmond, the work was done at night, so businesses were typically closed while the work took place. The time constraint for this project was related more to traffic considerations rather than in keeping the buildings in service.

One of the major scheduling concerns regarded work that occurred on elementary school property in Brier. Construction crews were present on school property approximately 10 times. This required coordination with the school district and with organizations that used school property (mainly a weekend soccer league) when school was not in session. The work usually occurred when school children were not on campus, either during in-service days or on weekends.

7.5.5 Sewer Bypass Requirements

Rehabilitation of sewage system components sometimes required installing or constructing a temporary bypass. This section describes bypass operations that took place during sewer main CIPP operations, during pipe bursting, and while work was conducted on manholes, laterals, and side sewers.

Bypass Methods during Sewer Main CIPP Operations

It was necessary to implement bypass methods during installation of many of the liners. A bypass during CIPP operations is more critical than it is during pipe bursting; other than wet-out, the entire CIPP process takes place inside the host pipe. Also, the CIPP process takes longer than pipe bursting. Below is a list of the methods used and some of the associated concerns.

- **Plug the upstream pipe(s) and use the upstream pipes for storage:** This method was commonly used and worked well in most cases, as long as the upstream pipe(s) could store the flow without causing a backup. Issues that needed to be identified included the size of the storage pipe, the quantity of flow, the pipe grade, and the location of the low point on the pipe (whether the low point was located in the plumbing in a house or in a manhole). During the pilot projects, several backups into houses were attributed to this bypass method.
- **Plug the upstream pipe(s) and use bypass pumps:** This method was used less commonly than the previously described method. It was typically used when flow was more than that which could be handled by upstream storage. This bypass method involved plugging an

upstream pipe(s) and pumping the sewage to a downstream manhole or adjacent part of the system. Pump sizing depended on flows; however, the specifications required that pumps have the ability to handle almost any possible flow condition. The pumps used were normally oversized in anticipation of high flows. There were a few cases where pumps were required at multiple sites.

- **Use a vactor truck to pump out a manhole or cleanout:** This method is similar to plugging the upstream pipe(s) and using the upstream pipes for storage. The difference is that the contractor monitors the lateral or manhole and vacuums out the water when necessary. This bypass method was used in the Redmond pilot project because of a requirement to maintain service for certain businesses, apartments, and senior housing. Note that most of the work in Redmond was done at night when the businesses were closed. This method is a noisy process due to the vactor pump. There were a few complaints so the contractor attempted to reschedule the work.
- **Use flow-through plugs:** Spot repairs often consisted of a section of liner wrapped around a flow-through plug. The plug was pulled into place and inflated, and the sewage flowed through the pipe in the center. A flow-through plug for an 8-inch-diameter sewer pipe had a 2- or 3-inch-diameter center. This method worked well for flows of less than approximately 20 percent depth of flow. Greater flow had a tendency to back up in the sewer main. The flow-through plug was typically in place for less than half an hour.
- **Use flow-through plugs and allow flow past the outside of the deflated liner:** On the Brier pilot project, an upstream pipe was plugged during installation of a liner. Because there was too much flow and no bypass pumps were available, the possibility existed of a spill from the upstream manhole. The contractor allowed the liner to deflate and the sewage flowed between the host pipe and the outside of the liner. It is possible that debris was caught between the host pipe and the liner when the liner was re-inflated; however, there was no evidence of lumps or bumps in the liner on the post-construction CCTV tape.

Bypass operations were uncommon during CCTV operations. While the pipes were cleaned before the camera went through, there were usually normal flows in the pipe when the camera was moving in the pipe. During high flow conditions or where there was a deep sag in the pipe, upstream pipes were plugged in several instances to reduce flows and allow an adequate view of the pipe.

Note that all these bypass methods relate to liner installation in the sewer main, not in the service connection. The contracts required that the contractor notify property owners before work began. Once the liner was in place and being cured, a backup was possible for the service connection; however, the only water that could back up was water used by the property owner. There were no backups into houses during the pilot projects attributed to lining over the laterals.

Bypass Methods during Pipe Bursting

Bypass methods used during pipe bursting usually consisted of plugging the upstream pipe and storing the wastewater until the temporary connections were made. In most of the pipe bursting projects, this method was adequate because these were upstream basins with minimal flow and the work was done in the summer. If a pipe was disconnected for a short time or if there was almost no flow through the pipe (for example, no flow out of a side sewer because the homeowner was away), the contractor usually let the flow go into the bottom of the excavation.

Bypass Methods during Manhole Rehabilitation

The bypass methods used during manhole rehabilitation were similar to those described for sewer main CIPP operations; that is, upstream pipe(s) were plugged and either used for storage or the sewage was pumped to another part of the system. In addition, flow-through plugs or half pipes were used during installation of fiberglass liners.

A bypass was needed only during vacuum testing or fiberglass liner installations. The vast majority of the rehabilitation work on manholes was done while sewage was flowing.

Bypass Methods during Lateral and Side Sewer Rehabilitation

Rehabilitation of a side sewer, either by pipe bursting or by installing CIPP, usually put the customer out of service for the entire day. There were a few cases where customers were out of service for more than one day, but a temporary connection allowed them to use their service while the contractor was not working on the pipe.

The use of SCLs, SCLLs, and chemical grouting of the connection usually blocked the side sewer for less than an hour. These methods plugged the lateral during the work but were not in position long enough to back up the customer’s service line. Coordination with the homeowners went smoothly during this type of work.

7.5.6 Night Work

Night work took place only for the Redmond pilot project. Various types of lighted traffic control equipment and heavy use of flaggers occurred throughout all phases of the work. All work typically started at about 9 p.m. and ran until 5 a.m. Work also occurred on weekends on some occasions.

For daytime construction, the contract specified that service to all customers must be reconnected by 5 p.m. each day. On some occasions, CIPP work was not finished until late in the evening, well after dark. In one case, a liner problem led to a dig and replace repair that was not completed until 6 a.m. the following morning. This late work was unplanned and forced the contractor to either track down lighted traffic control equipment or work in the dark without adequate equipment. Unanticipated night work should be addressed in the contractor’s traffic control plan.

7.5.7 Noise

In Redmond, almost all of the work was done in a commercial area and at night. Because the businesses were closed at night, noise was not a problem. In a few cases, the work occurred near homes and apartments where noise at night was a potential concern. The contractor tried to use the louder equipment before people went to sleep. The rest of the equipment was fairly quiet.

Table 7-4 shows some of the equipment used in the pilot projects, ranked from loudest (1) to quietest (8).

Table 7-4. Equipment Ranked by Noise Level

Pipe Bursting Equipment		CIPP and Manhole Equipment	
Rank (noise level)	**Equipment**	**Rank (noise level)**	**Equipment**
1	Vactor truck	1	Vactor truck
2	Trailer-mounted compressor	2	Trailer-mounted compressor
3	Chainsaw	3	Steam generator truck
4	Track hoe/backhoe	4	Vacuum pump for testing
5	Track hoe with bursting rig	5	Bypass pump
6	CCTV van with lateral cutter	6	Jetter truck
7	Portable generator	7	Refrigerated truck
8	HDPE welding equipment	8	CCTV van with lateral cutter

7.5.8 Restoration

The most expensive restoration cost items were concrete sidewalk replacement and asphalt patching required by pipe bursting and open excavation work. Because there were many pits in the streets, many small asphalt patches were required. The contractor placed and rolled cold mix asphalt after the backfill was complete and maintained the cold patch for the duration of the project. Based on agency requests, the contractor needed to constantly maintain the cold mix patches. After the pipe bursting and open excavation work was completed, a subcontractor was hired to replace the cold mix with a hot mix patch. For the Kirkland project, an overlay was not scheduled; however, an overlay was scheduled for the roads in Skyway. Minimal asphalt patching was required on the Auburn project because a limited number of pipes were replaced. In Ronald and Kent, the work was done on laterals and side sewers rather than on sewer mains, so there were very few patches.

Another expensive restoration cost item was digging pits on private property for pipe bursting or side sewer CIPP installation. This work was somewhat intrusive from the viewpoint of property owners and led to a few disagreements and claims. Issues ranged from harm done to plants to claims of cracked driveways. Obtaining signed restoration releases from homeowners was difficult in some cases and in other cases the releases were not signed, due to differing expectations of acceptable levels of restoration. The contracts stated that the responsibility for second party claims began with the contractor. The contractors were very diligent in solving these claims.

Installation of a cleanout was required for a few SCLLs. Restoration was limited to patching the grass or adding decorative bark to the landscaping.

Work on the interior of manholes was done within the manhole, so no restoration work was involved. Access to manholes on private property did not disturb any landscaping and did not create a need for restoration.

7.5.9 Testing

This section describes testing of rehabilitation products during construction or testing that occurred soon after construction was completed. The plan for warranty testing for winter 2004/2005 is also described.

Testing of Sewer Main CIPP

Testing of sewer main CIPP included material strength tests. Table 7-5 shows the results of several lab tests on CIPP samples from the pilot projects.

Table 7-5. CIPP Test Results

Product (Pilot Project)	Minimum Specified Flexural Strength / Flexural Modulus	Test Results Flexural Strength / Flexural Modulus
Polyester resin with polyester felt (Mercer Island)	Flex. Strength = 4,500 psi Flex. Modulus = 300,000 psi	Flex. Strength = 9,900 psi[1] Flex. Modulus = 422,000 psi
Polyester resin with fiberglass fabric (Redmond)	Flex. Strength = 10,000 psi Flex. Modulus = 800,000 psi	Flex. Strength = 35,000 psi[1] Flex. Modulus = 2,170,000 psi

[1] Test results reflect the average of five tests.

Both flexural strength and flexural modulus tests were based on ASTM D790.

Testing also involved a low-pressure air test of the liner before any connections were cut open. There was only one case where a liner failed the air test and this was attributed to a problem with plugging the end of the pipe. There were some air tests where the air pressure did drop slightly during the test but the pipe did not fail the test. Future designers may want to consider including a low-pressure air test in the specifications to qualify the crews at the beginning of a project, then using air testing only on a random basis.

Testing of HDPE Pipe

Testing of HDPE pipe involved a low-pressure air test performed before any connections were made. There were no cases where new HDPE pipe failed an air test. Future designers may want to consider including a low-pressure air test in the specifications to qualify the crews at the beginning of a project, then using air testing only on a random basis.

Vacuum Testing for Manholes

Vacuum testing was specified for manholes that received chemical grout or cementitious coatings. These manholes were subjected to a vacuum test before and after construction. In the preliminary test, liquid soap was sprayed on the inside of the manhole. After the vacuum was created and the manifold was removed, soap bubbles indicated where leaks occurred. Another indicator of leaks was whether or not the vacuum test drew in a lot of water. The locations of leaks were documented on test reports, which allowed the inspector and contractor to concentrate on these leaks. A pass/fail vacuum test was performed after the construction work. Additional work was required until the manhole passed the test.

This vacuum testing appears to have been very successful and was a good measure of the quality of work.

Pressure Testing for Chemical Grouting of Sewer Mains and Lateral Connections

Testing for the chemical grouting method involved watching the pressure gauge on the packer equipment, with the CCTV used to position the grout packer. The pressure increased as the grout was injected and stabilized as the grout set. The CCTV tapes were submitted as a record of the process and test results.

Testing of New PVC Pipe

Testing of new PVC pipe involved standard low-pressure air testing.

Visual Inspection of Sewer Mains, Side Sewers, and Laterals

Once the lateral connections were cut open and a lateral or side sewer product was installed, it was very difficult to perform any type of testing other than visual inspection. Visual inspections proved important, especially if the inspection occurred during wet weather conditions when leaks were visible.

Problems noted during testing occurred in several locations: (1) at the lateral cutout; (2) at the ends of the liners where the liners terminated in a manhole; and (3) where the liner had a hole, either from a liner defect or where the lateral cutter operator punched a hole in the wrong location while looking for a dimple.

Visual Testing for Manholes

Visual testing was the only method used for testing chimney coatings, leveling ring boots, the WHIRLyGIG, and manhole pans.

Planned Warranty Testing

The Notice of Substantial Completion for each project was issued prior to February 1, 2004. The majority of the project warranties expire 18 months after the date on the Notice of Substantial Completion. Warranty inspections will be made prior to August 1, 2005. Most of these warranty inspections are planned for winter 2004/2005. The intent of the inspections is to document the condition of the projects for two reasons:
(1) to allow any necessary repairs specified under the warranty, and (2) to provide feedback on installed products.

As of this report's completion date, no final warranty inspections had occurred. King County staff will complete CCTV work for warranty inspections. King County and the Earth Tech Team will review the tapes. The agencies may also be involved in the inspection process. A supplement to this report will be issued when results of the warranty inspection process are complete. Plans include examination of a sample of rehabilitated manholes, mains, laterals, and side sewers. Additional testing will be performed where the sampling indicates a need and where specific problems are noted by the agencies or suspected by King County or the Earth Tech Team.

Some preliminary inspections have been performed. These inspections were aimed at problems discovered during the punch list phase. The problems were noted either by the agency or the project representative and are to be fixed before warranty inspection occurs.

7.5.10 Record Drawings

The record drawings focused on two items: (1) updated schedules of work on the drawings, and (2) updates on the work that occurred on private property. The contract drawings for all projects were updated to indicate changes. In two projects, separate sewer cards or permits were created to document the work that occurred on private property. Updates of work on private property took the most amount of time for the contractors. Because the drawings were somewhat schematic, especially for the Manhole Project and the CIPP-related projects, there were very few changes on the plan view images.

7.5.11 Safety

Safety Considerations for CIPP

Basic safety issues for CIPP installation involved standard work items such as traffic control, enclosed space entry, and working around sewage. More specialized tasks included working with chemicals (sometimes in confined spaces), steam and hot water, and scaffolding.

Safety Considerations for Pipe Bursting

Pipe bursting safety issues involved typical work items like excavation shoring, traffic control, confined space entry, and working around sewage, as well as more specialized work such as HDPE welding and cable pulling. While there were a few broken cables, cables were contained in either the old pipe or within the tube of the equipment during pipe bursting operations. No chemicals (like those used during CIPP operations) were required.

Safety Considerations for Manhole Rehabilitation

Manhole rehabilitation required attention to safety issues such as traffic control, confined space entry, and working around sewage. More specialized tasks included working with chemicals (usually in confined spaces), steam, and hot water during the fiberglass manhole liner installation process. Standard safety concerns were addressed for the use of power tools, hand tools, and small specialty tools like powder-actuated nailers.

7.6 Costs

Construction costs, including change orders, are summarized in Table 7-6. Local sales tax was 8.8 percent except in Brier where it was 8.9 percent.

Table 7-6. Summary of Construction Costs

Pilot Project	Original Contract Amount[2]	Final Cost of Contract Bid Items[1]	No. of Change Orders	Cost of Change Orders[1]	Completed Cost with Change Orders[1,3]	Percent Difference
Auburn	$353,246	$353,246	2	$31,491	$384,737	9%
Brier	$463,215	$412,588	1	-$39,904	$372,684	-20%
Kent	$1,196,304	$1,196,304	2	-$115,652	$1,080,652	-10%
Kirkland	$850,571	$824,215	1	$13,974	$838,189	-1%
Lake Forest Park	$872,460	$798,589	1	-$8,169	$790,420	-9%
Manhole Project	$240,437	$188,855	1	$11,968	$200,823	-16%
Mercer Island	$801,480	$801,479	2	$14,321	$815,800	2%
Redmond	$973,670	$820,397	3	$19,711	$840,108	-14%
Ronald[4]	$1,256,270	$1,011,672	1	$65,595	$1,077,267	-14%
Skyway[4]	$1,396,176	$1,361,085	1	$34,121	$1,395,206	0%

[1]Includes Washington state sales tax

[2]Based on original bid quantities

[3]Based on final installed quantities of original bid items

[4]Agency contributed money toward construction costs

7.7 List of Figures

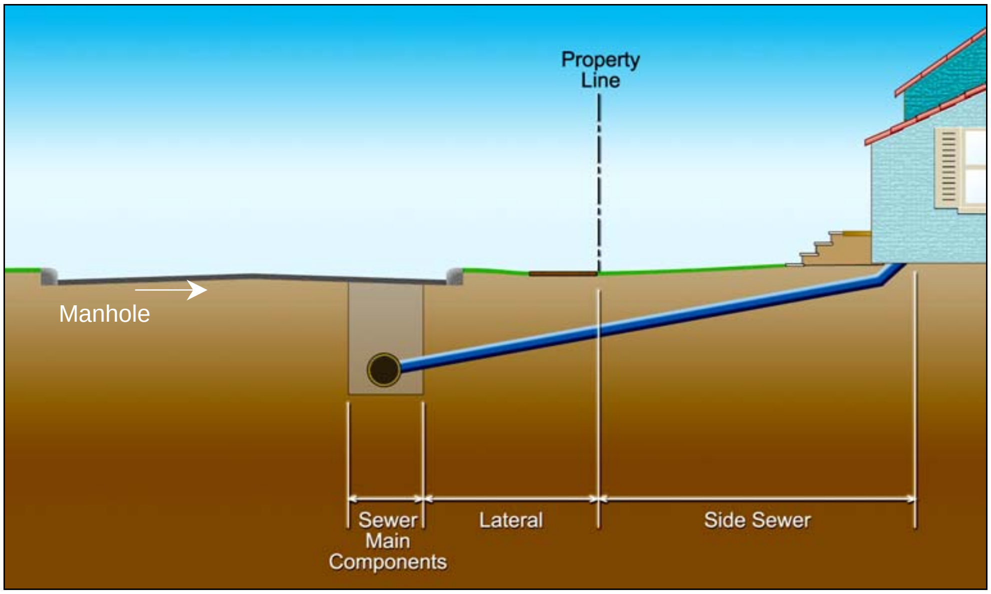


Figure 7-1. Sewer System Components

Smoke emanating from ground during smoke testing indicating cracks or defects in the buried side sewer.

Figure 7-2. Smoke Testing 1

Smoke emanating from ground during smoke testing.

Figure 7-3. Smoke Testing 2

Dye testing confirming down spout connected to ditch rather than sanitary sewer.

Figure 7-4. Dye Testing

Entire operation for installation of one section of sewer main CIPP.

Figure 7-5. Cured-in-Place Pipe 1

Scaffolding supporting water inversion equipment for installation of CIPP in sewer main. Boiler truck is in the background.

Figure 7-6. Cured-in-Place Pipe 2

Crew installing CIPP using the air inversion method.

Figure 7-7. Cured-in-Place Pipe 3

Steam exiting tail end of CIPP during the curing process.

Figure 7-8. Cured-in-Place Pipe 4

CIPP in bottom of channel. Liner was installed through this manhole and the portion of the liner above the spring line of the channel was removed after curing.

Figure 7-9. Cured-in-Place Pipe 5

Liner failed to fully inflate in this 12-inch-diameter sewer main at downstream manhole. Wrinkles extended several feet up the pipe and were not fully cured. Last run of pipe was re-pressurized and additional steam was applied. Short section of liner was then removed and a spot repair installed.

Figure 7-10. Cured-in-Place Pipe 6

A 4-foot section of blue liner wrapped around a packer in preparation for a CIPP spot repair. Blue resin is fast curing epoxy.

Figure 7-11. Cured-in-Place Pipe 7

Epoxy resin slug that pooled in a lateral connection to a sewer main during the installation of the CIPP in the sewer main. The slug is held adjacent to a sample pipe section with a lateral connection to illustrate the location of the slug in the field. The slug was removed during the reinstatement of the lateral connection.

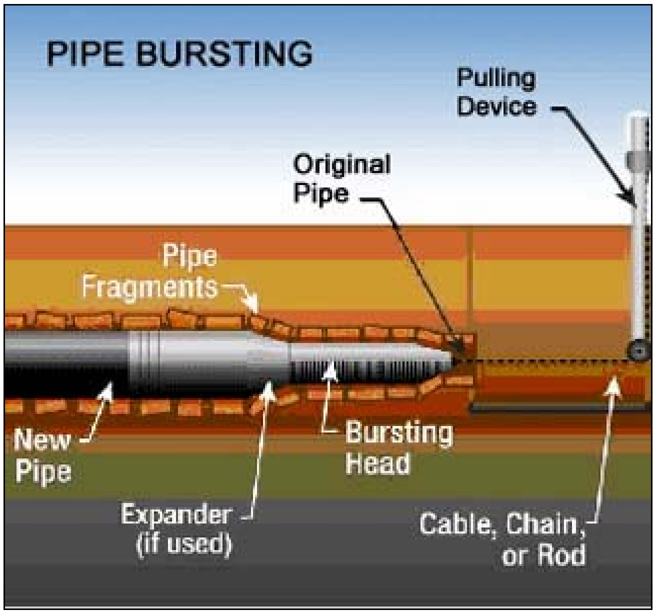
Figure 7-12. Cured-in-Place Pipe 8

Epoxy resin slugs removed from laterals.

Figure 7-13. Cured-in-Place Pipe 9

Epoxy resin slug removed from laterals.

Figure 7-14. Cured-in-Place Pipe 10



Schematic of pipe bursting operation.

Figure 7-15. Pipe Bursting 1

Gray HDPE sections being welded into long lengths.

Figure 7-16. Pipe Bursting 2

Sections of welded HDPE ready to be dragged into position.

Figure 7-17. Pipe Bursting 3

Pipe bursting head attached to an 8-inch-diameter HDPE pipe. Note extra fins.

Figure 7-18. Pipe Bursting 4

Pipe busting head being pulled into position to start the bursting operation.

Figure 7-19. Pipe Bursting 5

Small pipe bursting equipment consisting of a pair of 2-foot-long hydraulic cylinders and pressure plate. This equipment is capable of being used inside an existing manhole.

Figure 7-20. Pipe Bursting 6

Pipe bursting pressure plate and cable ready to begin pull.

Figure 7-21. Pipe Bursting 7

Trackhoe configured for pipe bursting. Note hydraulic motor, boom, and pressure plate.

Figure 7-22. Pipe Bursting 8

Trackhoe positioned at pulling pit during pipe bursting.

Figure 7-23. Pipe Bursting 9

Pipe bursting of a lateral. Pull was approximately 40 feet long.

Figure 7-24. Pipe Bursting 10

Manhole chimney in need of repair.

Figure 7-25. Manhole 1

Manhole with indications of settlement in the pavement that likely subject the cover to inundation during rainfall. The large number of pick holes in the lid also allows free flow of surface water into the manhole.

Figure 7-26. Manhole 2

Fiberglass manhole liner prior to wet-out.

Figure 7-27. Manhole 3

Layering of fiberglass manhole liner prior to wet-out.

Figure 7-28. Manhole 4

Fiberglass manhole liner being wet-out in the field.

Figure 7-29. Manhole 5

Fiberglass manhole liner being lowered into manhole.

Figure 7-30. Manhole 6

Note the manifold is still attached and the manhole is being ventilated.

Figure 7-31. Manhole 7

Fiberglass liner before trimming.

Figure 7-32. Manhole 8

Fiberglass manhole liner trimmed at the manhole ring.

Figure 7-33. Manhole 9

Leak in a cured fiberglass manhole liner.

Figure 7-34. Manhole 10

Manhole that has been raised slightly above grade to prevent surface inundation.

Figure 7-35. Manhole 11

Equipment for spraying cementitious grout on the inside surfaces of a manhole.

Figure 7-36. Manhole 12

Sprayed-on cementitious grout that has been smoothed with a trowel.

Figure 7-37. Manhole 13

Manhole lid below grade and subject to inundation from surface water running off the roadway.

Figure 7-38. Manhole 14

Manhole pan in place. Lid will fit back in place on frame.

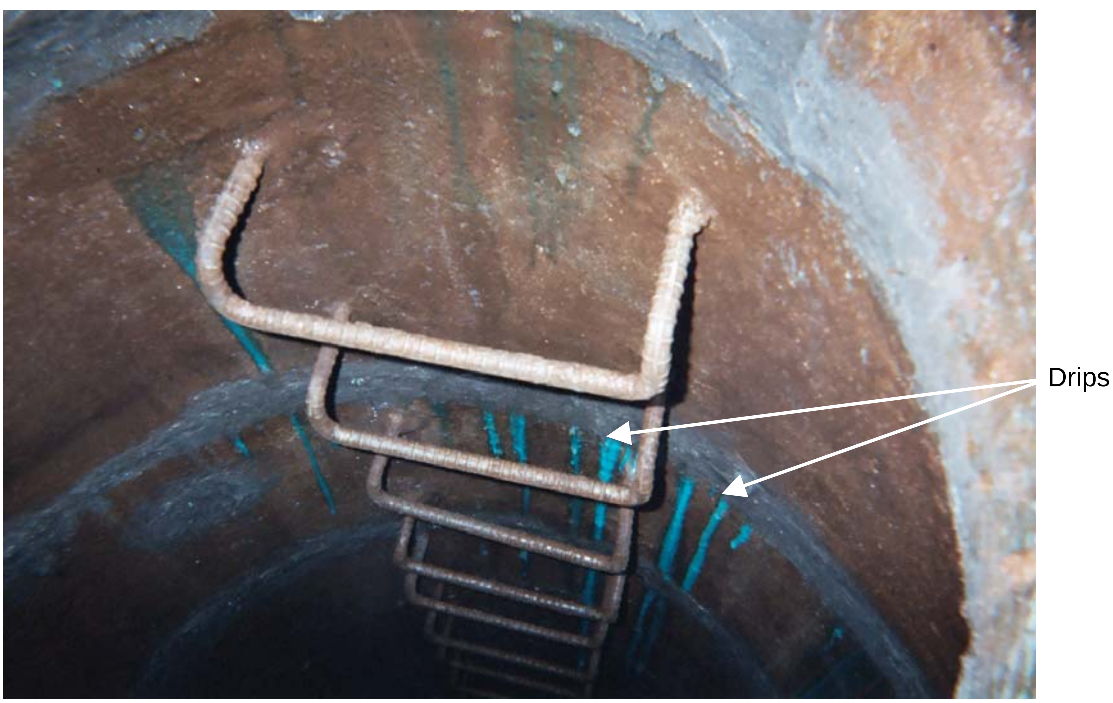
Figure 7-39. Manhole 15

Other available manhole pans. Note: pan will not allow locking lid to be installed.

Figure 7-40. Manhole 16

Chemical grouting operation for manholes.

Figure 7-41. Manhole 17



Drips are chemical grout leaking back into manhole through defects.

Figure 7-42. Manhole 18

WHIRLyGIG tool assembled.

Figure 7-43. Manhole 19

Manhole with lid, frame, and leveling rings removed; ready for WHIRLyGIG installation.

Figure 7-44. Manhole 20

Plastic concrete form in place and being trimmed by the WHIRLyGIG tool.

Figure 7-45. Manhole 21

Frame in position on top of plastic concrete form.

Figure 7-46. Manhole 22

Concrete being poured to create solid concrete collar.

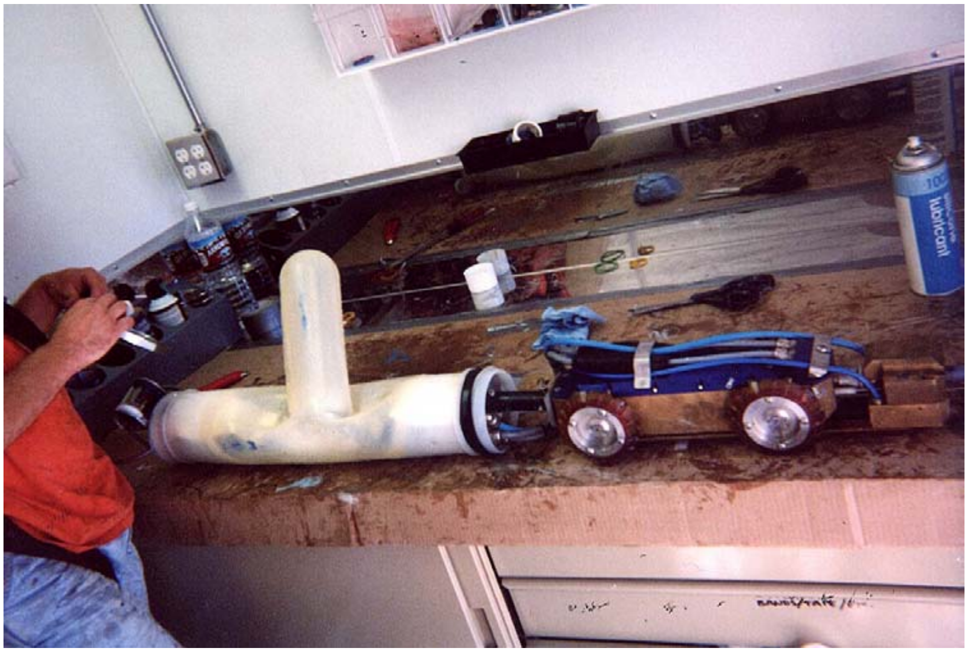
Figure 7-47. Manhole 23

Completed concrete collar. Steel plate is required to protect fresh concrete and must be blocked up to avoid touching concrete. This may preclude allowing cars to drive over the plate.

Figure 7-48. Manhole 24

Specialty packer for chemical grouting the connection between a lateral and sewer main.
Yellow packer will inflate inside the lateral.

Figure 7-49. Lateral and Side Sewer 1

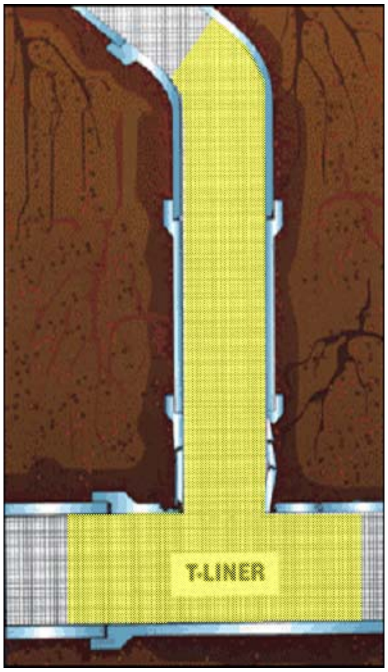


TOP HAT™ packer. Wheeled robot moves packer into position. White bladder will place TOP HAT™ into position.
Bladder contains ultraviolet (UV) lights and a closed circuit television (CCTV) camera.

Figure 7-50. Lateral and Side Sewer 2

TOP HAT™ packer with TOP HAT™ in position. Blue paste is epoxy that will seal TOP HAT™ to service connection.

Figure 7-51. Lateral and Side Sewer 3



Schematic of a T-Liner®.

Figure 7-52. Lateral and Side Sewer 4

T-Liner® installation equipment located at downstream manhole. Similar equipment is located at the upstream manhole as the liner is placed inside the sewer main.

Figure 7-53. Lateral and Side Sewer 5

Trailer for field wet-out of T-Liners®.

Figure 7-54. Lateral and Side Sewer 6

Large bypass pumping operation to allow construction of improvements in a section of sewer main.

Figure 7-55. Bypass Pumping System

Chapter 8

Rehabilitation Effectiveness

8.1 Introduction

A key objective of the pilot project effort was to measure and evaluate the effectiveness of sewer system rehabilitation. Rainfall and flow data from each pilot and control basin were used to determine if rehabilitation improvements resulted in reduced I/I. For comparison purposes, information was collected both before rehabilitation improvements (pre-rehabilitation) and after construction (post-rehabilitation). The data also provided a basis for modeling analysis to quantify pre-rehabilitation I/I, post-rehabilitation I/I, and I/I reduction.

Required tasks for estimating I/I reduction and determining rehabilitation effectiveness were:

- Defining the pilot basin (see Chapter 5)
- Monitoring flow (pre- and post-rehabilitation)
- Monitoring rainfall
- Modeling flow (pre- and post-rehabilitation)

8.2 Pilot Project Basins

As described in Chapter 5, the pilot projects consisted of both pilot basins and control basins. The basin where the rehabilitation work was actually performed was defined as the pilot basin; the pilot basin could encompass either part of or all the mini-basin.

Control basins were established in the vicinity of the pilot basins and were monitored simultaneously. The purpose of establishing control basins was to provide a flow record in a nearby basin in which there was no I/I rehabilitation effort. The change in flow response of the pilot basin between the pre-rehabilitation and post-rehabilitation monitoring seasons could be compared with the change in flow response of a basin without I/I reduction.

To evaluate I/I reduction separately from the modeling analysis, the measured flows from the control basins were compared with the measured flows collected from the pilot basins during both the pre- and post-rehabilitation periods.

8.3 Flow Monitoring

The pilot projects were conducted as part of a larger regional infiltration and inflow program, as described in Chapter 1. In support of the regional program, over 775 flow meters were placed throughout the King County service area during the 2000/2001 and 2001/2002 wet seasons. Documentation for the flow monitoring conducted during these two periods is provided in the following:

- *2000/2001 Wet Weather Flow Monitoring, May 2001*
- *2001/2002 Wet Weather Flow Monitoring, June 2002*

8.3.1 Pilot Project Flow Monitoring Periods

8.3.1.1 Pre-Rehabilitation Flow Monitoring

For the pilot projects in which the pilot basin boundary was the same as the mini-basin boundary, flow data collected in 2000/2001 and 2001/2002 was considered sufficient to establish existing, or pre-rehabilitation conditions. These projects included Lake Forest Park, Ronald, and the Manhole Projects (Coal Creek, Northshore, and Val Vue).

Additional flow monitoring was needed to measure pre-rehabilitation conditions where pilot basins and control basins were smaller than the original mini-basin. These projects included Auburn, Brier, Kent, Kirkland, Mercer Island, Redmond, and Skyway. The additional pre-rehabilitation flow monitoring took place from November 1, 2002 to January 15, 2003. Pilot basin boundaries and flow meter locations are presented in Chapter 5, Figures 5-2 to 5-13. A summary of the 2002/2003 pre-rehabilitation monitoring is presented in Appendix D.

8.3.1.2 Post-Rehabilitation Flow Monitoring

Post-rehabilitation flow monitoring was conducted for all the pilot and control basins associated with the pilot projects. For pilot basins, flow monitoring was conducted to assist in evaluating the effectiveness of rehabilitation. For control basins, post-rehabilitation flow monitoring was conducted to provide comparison to pre-rehabilitation flow data in a basin with no I/I reduction.

The proposed period for post-rehabilitation flow monitoring was November 1, 2003 to January 15, 2004. However, the actual initiation of flow monitoring in each basin depended on completion of rehabilitation improvements. In some cases, post-rehabilitation flow monitoring began before the November 1 target date; in other cases, it began after November 1. Table 8-1 presents the start and end of flow monitoring data used to estimate I/I reduction for all monitoring periods at all sites.

Table 8-1. Flow Monitoring Duration Summary

Basin Name	Flow Meter Name	Pre-Rehabilitation Monitoring			Post-Rehabilitation Monitoring
		2000-2001	2001-2002	2002-2003	2003-2004
Auburn Pilot A	Auburn Pilot			11/4/02–4/24/03	10/27/03–2/4/04
Auburn Pilot B	Auburn Control	11/1/00–1/15/01	11/1/01–1/15/02	11/4/02–4/23/03	10/8/03–2/4/04
See Note	Auburn Subtraction	11/1/00–1/15/01	11/1/01–1/15/02	11/4/02–5/1/03	10/27/03–2/4/04
Brier Control	Brier Control			11/5/02–6/1/03	12/1/03–2/6/04
Brier Pilot	Brier Pilot	11/1/00–1/15/01	11/1/01–1/15/02	11/5/02–5/30/03	12/16/03–2/6/04
Coal Creek Control	Coal Creek Control	11/1/00–1/15/01	11/1/01–1/15/02		10/31/03–2/4/04
Coal Creek Pilot	Coal Creek Pilot	11/1/00–1/15/01	11/1/01–1/15/02		12/15/03–2/4/04
Kent Control	Kent Control			10/31/02–5/27/03	10/9/03–3/8/04
Kent Pilot A and B	Kent Pilot A and B			10/31/02–5/27/03	1/16/04–3/8/04
Kent Mini	Kent Mini	11/1/00–1/15/01	11/1/01–1/15/02		
Kirkland Control	Kirkland Control			11/5/02–6/17/03	10/7/03–2/4/04
Kirkland Pilot	Kirkland Mini	11/1/00–1/15/01	11/1/01–1/15/02	11/6/02–7/13/03	10/9/03–2/4/04
Lake Forest Park Control	Lake Forest Park Control	11/1/00–1/15/01	11/1/01–1/15/02		11/3/03–2/6/04
Lake Forest Park Pilot	Lake Forest Park Pilot	11/1/00–1/15/01	11/1/01–1/15/02		11/5/03–2/6/04
Mercer Control	Mercer Control			11/1/02–7/21/03	10/7/03–2/4/04
Mercer Island Pilot	Mercer Mini	11/1/00–1/15/01	11/1/01–1/15/02	3/5/03–4/20/03	10/21/03–2/4/04
Northshore Control	Northshore Control	11/1/00–1/15/01	11/1/01–1/15/02		10/31/03–2/6/04
Northshore Pilot	Northshore Pilot	11/1/00–1/15/01	11/1/01–1/15/02		12/15/03–2/6/04
Redmond Control	Redmond Control			11/1/02–7/22/03	11/21/03–3/2/04
Redmond Pilot A	Redmond Pilot			11/1/02–7/22/03	12/1/03–3/8/04
Redmond Pilot B	Redmond Mini	11/1/00–1/15/01	11/1/01–1/15/02	12/12/02–6/1/03	10/21/03–3/2/04
Ronald Control	Ronald Control	11/1/00–1/15/01	11/1/01–1/15/02		10/31/03–2/26/04
Ronald Pilot	Ronald Pilot	11/1/00–1/15/01	11/1/01–1/15/02		10/22/03–2/26/04
Skyway Control	Skyway Control			10/29/02–5/2/03	10/6/03–2/2/04
Skyway Pilot	Skyway Pilot			10/29/02–5/2/03	10/9/03–2/2/04
Skyway Mini	Skyway Mini	11/1/00–1/15/01	11/1/01–1/15/02		11/20/03–2/2/04
Val Vue Control	Val Vue Control	11/1/00–1/15/01	11/1/01–1/15/02		10/31/03–2/17/04
Val Vue Pilot	Val Vue Pilot	11/1/00–1/15/01	11/1/01–1/15/02		10/22/03–2/17/04

Note: The Auburn subtraction meter measured flows from an upstream basin that was subtracted from the Auburn pilot meter to establish flows in the Auburn pilot A basin.

Flow monitoring continued beyond the proposed January 15, 2004 completion date to collect measured flows during additional wet weather events. For the purpose of determining I/I reduction, measured flows were collected until the beginning of February 2004. The last significant storm during this period occurred January 29, 2004.

8.3.1.3 Field Verification

Field verifications (site calibrations) were performed during flow meter installation and throughout the duration of the project. Performing site calibrations was important for verifying that each flow meter accurately measured flows. Field verification consisted of manually measuring flow velocity and depth and comparing these numbers to meter readings.

During the 2002/2003 and 2003/2004 monitoring periods, King County field personnel entered the manhole at each site and confirmed velocity using a portable velocity meter. Depth was confirmed using a ruler with 1/8th-inch increments.

At five sites monitored both in 2002/2003 and 2003/2004, a calibrated weir was used to verify flow instead of the portable velocity meter. The weir was used in locations where the flow was considered too low to conduct a site calibration using a hand-held velocity meter.

Detailed documentation regarding the frequency and results of site calibrations is provided in Appendix D.

8.3.2 Flow Monitoring Data Processing

Raw data collected by flow meters underwent several processes to achieve the status of "final" data. This series of steps was necessary to develop confidence and reliability in the measured flow data. Final data were used to quantify dry weather flow and I/I. Final data were also used for model calibration.

8.3.2.1 Data Review

Data review, that is, the process of evaluating depth and velocity readings recorded by the flow meter, was conducted by field crews during weekly data collections and by the analyst as processing continued during monitoring. Data collection involved downloading information from the flow meter to a laptop computer. Field crews reviewed the data to ensure that flow meter sensors were operating correctly and to look for invalid data resulting from sensors affected by debris. Invalid depth or velocity readings can be recorded when the depth or velocity sensors require cleaning, or if a sensor has failed and requires replacement. Debris such as rags, paper, and grease can build up on sensors during normal operation and if the sewer experiences surcharging.

8.3.2.2 Data Editing and Finalization

If the flow meter sensor equipment becomes fouled, the data collected is not a valid representation of the depth and/or velocity of flows at the site. For this reason, the data was edited to ensure that only valid data was used in sequential quantity and I/I calculations. (Note that raw data with invalid depth and velocity readings were preserved to allow subsequent evaluation of the data review and editing process.) Invalid velocity data can often be "reconstituted." Velocity reconstitution is discussed in Appendix D.

Data editing is the process of identifying invalid data or applying modifications to correct inaccurate raw data. Corrections to raw data were performed only when justified with additional field information. A data analyst evaluated field verification data by plotting it in conjunction with a scatter plot of the flow meter data. The field verification points that fell within the scatter plot confirmed that the flow meter sensors and field verifications were consistent and no further velocity or depth adjustments were required. If field verification points fell outside the scatter plot, they could be used to adjust the depth and/or velocity data.

In some cases, the raw data was determined to be invalid; however, there was insufficient information to correct the raw data. In these cases, the invalid data was excluded from the final data. See Appendix D for additional information.

The method by which invalid data was documented depended on the type of flow meter equipment and the capability of the software available for data editing. Three types of flow meters were used, and the associated software varied. With some types of flow meter software, it was possible to attach a descriptive identifier ("flag") to each record. The flag could be used to retain the data record (date, time, and entity value) in the database, but exclude invalid data from the final flow quantities. For other types of software, it was necessary to delete the invalid data from the final flow so it was not included in the final flow calculation. For quality assurance/quality control (QA/QC) and/or auditing purposes, the raw flow data was retained for comparison with the final flow data.

8.3.3 Flow Monitoring Data Issues

During the 2002-2003 flow-monitoring period, the "uptime percent" was an average of 94 percent. The uptime percent is defined as the percentage of total data points recorded by a flow meter and considered valid. When uptime was less than 100 percent, some of the collected information was considered invalid; this part of the data was not used for quantity or I/I calculations.

At nine sites, data uptime was 100 percent. At the nine other sites, there were data losses ranging in duration from 3 days to a little over 3 weeks. At seven of these sites, the uptime percent was still at or above 92 percent, even with the data loss time taken into consideration. At the sites with the most significant data gaps (Redmond Pilot and Brier Control), the uptime percent was approximately 70 percent and 82 percent, respectively.

In an effort to diagnose and minimize data loss during the 2002/2003 pre-rehabilitation flow monitoring period, King County staff and the monitoring equipment vendor investigated possible reasons for the data loss. Data loss appeared to be caused by three factors:

1. Mismatches in computer software versions between the flow meter and the laptop computer used to download the data
2. Low battery voltages
3. Meter “lock up” (that is, when the meter fails to record data) during field verification

The first two concerns were easily corrected. Mismatches in computer software were corrected by ensuring that necessary updates were synchronized and completed. Low battery voltages were corrected by changing batteries either every 2 weeks or whenever the battery voltage dropped below 10 volts.

It was determined that meter “lock up” was a function of field installation and maintenance. Correcting meter lock up during field verification required adjustment of the protocol used for conducting field verifications. If lock up occurred after the field crew left the site without re-activating the meter (resending site setup data to the meter), data loss took place between the site visit and the next data download. This issue was addressed by re-activating after each download and field verification.

During the post-rehabilitation period, the uptime percentage improved in comparison to the pre-rehabilitation period. For the 28 sites monitored and for an average of 100 collection days, the uptime was 97 percent. As indicated by the improved uptime percent during post-rehabilitation flow monitoring, the corrective measures appeared to be successful. Data losses during the post-rehabilitation period ranged from 1 day to about 1 week at nine sites. The data losses during post-rehabilitation monitoring resulted primarily from meter malfunction.

8.4 Rainfall Monitoring

Rainfall in each pilot and control basin was quantified using two methods:

- Rainfall was measured using a county-wide rain gauge network
- Rainfall was estimated using radar technology and rain gauge data

The primary purpose for quantifying rainfall in each pilot and control basin was to develop input for flow modeling (see Section 8.5).

8.4.1 Rainfall Time Series

A rainfall time series is a record of rainfall over a long period of time. Rain gauge data from the City of Seattle and from the County’s Water and Land Resources Division and Wastewater Treatment Division were combined into one representative rainfall time series for each pilot and control basin.

The centroid (area center) of the basin was chosen as the point-of-reference for distance estimates to the three closest rain gauges that triangulated each basin (Figure 8-1). In cases where the three closest gauges were missing significant amounts of data, the next closest gauge was also added to the combination. Gauges collected data every 5 minutes. Gauges that did not work properly during any given period were excluded from the analysis altogether. See Appendix E for a list of the gauges used for each pilot and control basin, and for a list of the gauges near the pilot and control basins that were excluded due to data quality concerns.

Rainfall time series were generated for each project basin using an inverse distance-weighted interpolation scheme. The interpolation scheme was based on the assumption that gauges further from a modeling basin reflect the basin rainfall less than closer gauges. The weighting power (exponent that determines how mathematically dependent the final interpolated value is on the distance between the gauge and the basin centroid) was set to the square. Other weighting powers were considered; however, the square is assumed among the scientific community to be an optimal standard.

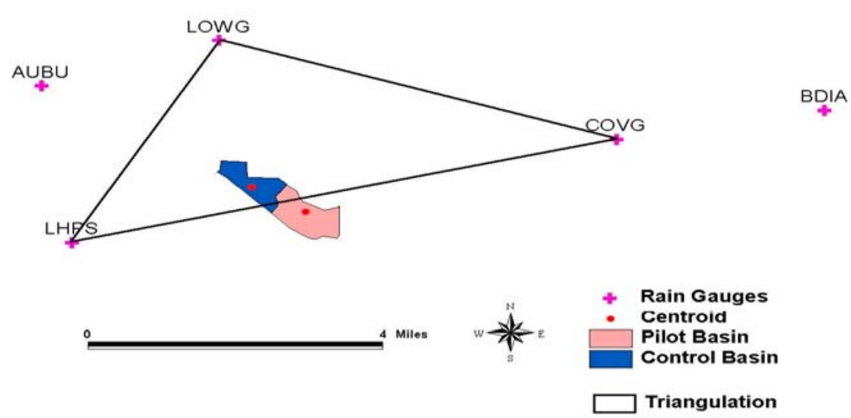


Figure 8-1. Rainfall Gauge Triangulation

8.4.2 CALAMAR Time Series

CALAMAR (calcul de lames d'eau a l'aide du radar, which translates as "Calculating Rain with the Aid of Radar") was used to calculate rainfall during all storm events corresponding to the flow monitoring periods. (Note that CALAMAR was not developed for the 2000-2001 flow-monitoring period. See Appendix E for additional detail.)

CALAMAR is based on comparing rain gauge values to radar reflectivity at multiple locations, and statistically calibrating the radar reflectivity over a calibration zone. The CALAMAR process allows a finer resolution in geographic coverage than would be obtainable with rain gauges alone. Reflectivity images are acquired from the National Weather Service NEXRAD radar system and processed into rainfall over pixels with geographic resolution of 1 square kilometer (km^2) (per pixel) and a temporal resolution of 5 minutes. To ensure calibration efficiency, eight calibration zones (200 to 500 km^2 each) were set up for the King County service area.

The relationship between pixels and the basin area was defined using the Geographic Information System (GIS). CALAMAR was used to generate rainfall time series during moderate to heavy rainfall events only. The CALAMAR event time series was substituted into the averaged rain gauge time series to become a composite time series. See Appendix E for additional information on the CALAMAR technology and how CALAMAR was developed for this project.

8.5 Flow Modeling

This section provides the background, approach, and methodology pertaining to the development of models to simulate flows. Section 8.6 provides more information about how I/I reduction was identified and estimated for each pilot basin.

Flow modeling of the pilot and control basins was used to determine whether rehabilitation improvements resulted in reduced peak I/I. A modeling software package (MOUSE, or Modeling of Urban Sewers) developed by the Danish Hydraulic Institute (DHI) was used for continuous simulation of rainfall-dependent I/I and for quantifying the I/I entering the sewer system in each pilot and control basin. Pre-rehabilitation and post-rehabilitation simulation results were compared to identify I/I reduction. Reduction in the 20-year peak I/I was also estimated using the models developed for each pilot basin.

Using measured rainfall data as input, MOUSE Rainfall-Dependent Infiltration and Inflow (RDII) hydrologic models were calibrated to observed sewer flow response in each pilot and control basin. RDII is a MOUSE software module for continuous modeling of the runoff process. Calibration of the MOUSE hydrologic models to simulate flow response from each basin relied on matching measured flows; these flows were measured over the course of available wet seasons, depending on data availability. Note that this calibration approach differs from the more common approach of focusing only on matching flows during discrete wet weather events.

Utilizing all of the measured flow data in the calibration process allowed selection of well-tuned parameters to define infiltration flows, which are highly dependent on antecedent (ground moisture) conditions. A key factor influencing selection of this calibration approach is the fact that in King County, infiltration is commonly a significant component of I/I.

8.5.1 Modeling Overview and Background

Hydrologic models quantify the flow out of a basin in response to rainfall. The model simulates the hydrologic transformation of rainfall into the I/I that enters the sewer system in the basin.

The input needed for MOUSE hydrologic models is based on the characteristics of each basin, and is briefly described below:

- **Basin description:** Basin characteristics such as total area, slope, and impervious/pervious surface area
- **Base wastewater flow data:** A flow record during dry periods to assess base wastewater discharge from industrial/commercial/residential land use, and to establish base infiltration
- **Rainfall:** A continuous rainfall time series for a study area

The *hydrologic* model output is a series of hydrographs (graphs of flow versus time) for specified time periods at particular basin outlets. In turn, the hydrographs are inputs to a *hydraulic* model, which simulates routing the flows through a conveyance system. Figure 8-2 shows a typical exchange of data between the hydrologic and hydraulic models.

Note that hydraulic models convey flows generated by hydrologic models from one basin to another. The models are typically based on a conveyance system's physical characteristics, such as pipe length, pipe material, pipe slope, roughness coefficient, manhole geometry, and others. The extensive hydraulic capability available in MOUSE was not needed for the pilot project modeling because the sewer system was not simulated in detail. A simplified approach was adopted (see Section 8.5.2).

The hydrologic and hydraulic models are coupled together to represent and quantify how a system behaves with respect to I/I. Modeled I/I consists of multiple components (see Figure 8-3). During dry weather, only wastewater and a relatively constant amount of clear water, or infiltration flow, are present. During wet weather, there is usually a fast response almost immediately after rainfall begins; the response continues throughout the rainfall event. Typically, there is also a response that builds and decays more slowly in response to the rainfall event.

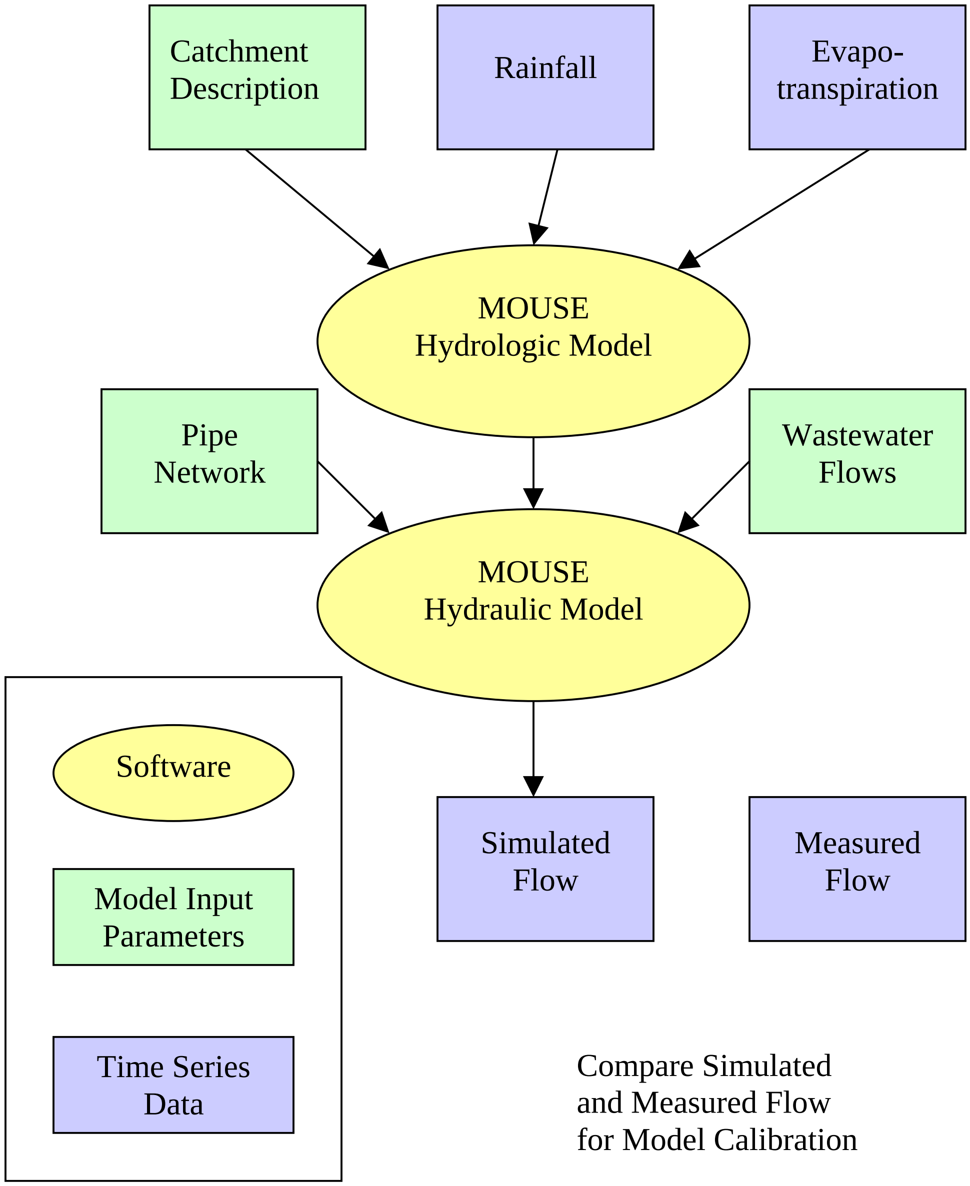


Figure 8-2. MOUSE Hydrologic and Hydraulic Model Components

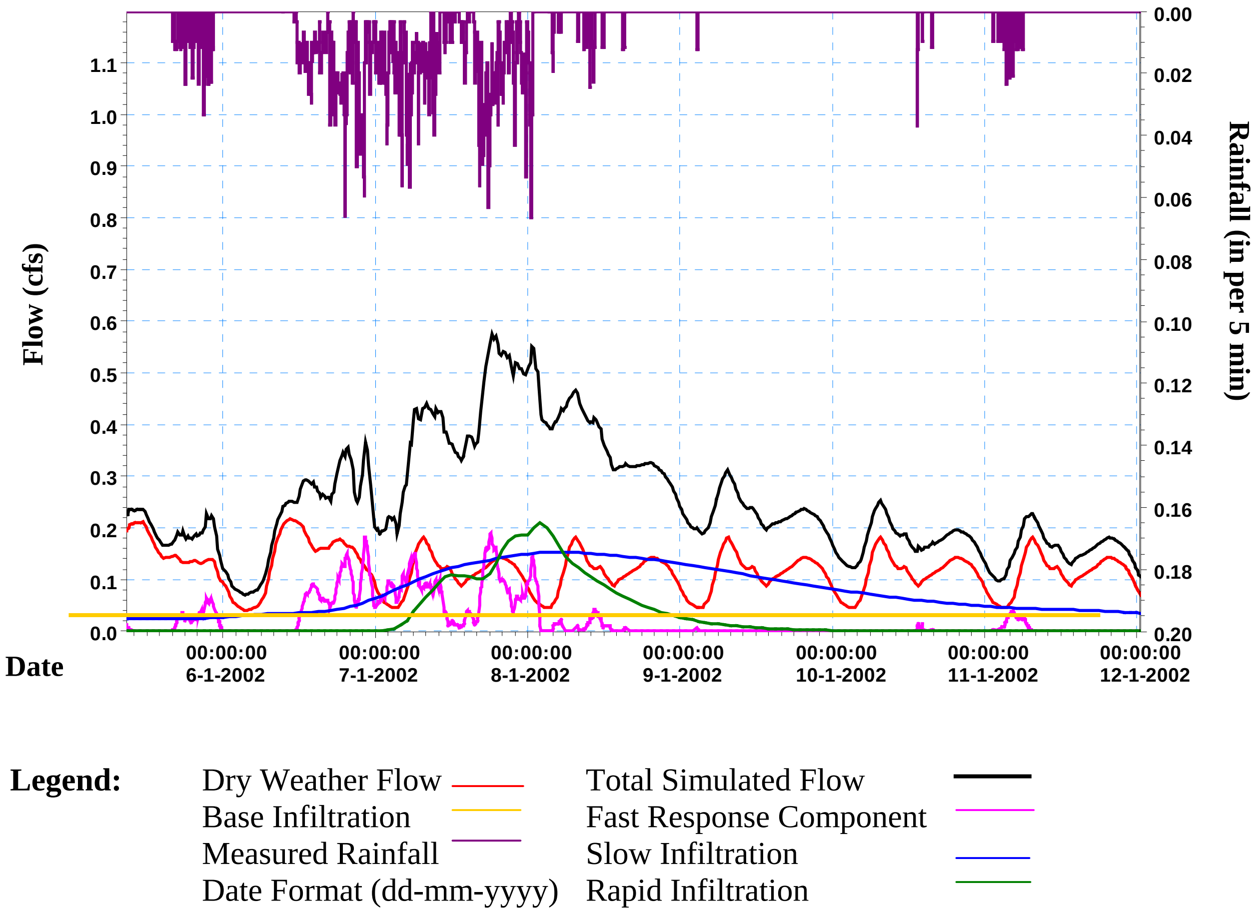


Figure 8-3. Simulated Flow Components

These observations of real-world flow patterns provide a basis for establishing mathematical representations for each component of wastewater and I/I flow. The time series flow data for all types of wastewater and I/I flow can be added together to equal the total outlet flow for each basin. The following types of flows were used by the hydrologic models developed for the pilot projects:

- **Dry weather flow estimated from flow data:**
  - **Diurnal wastewater flow from homes and businesses:** This type of flow is the only component intended for conveyance by the sanitary sewer system. Its magnitude varies, usually in a daily diurnal pattern as part of the dry weather flow (the dry weather flow is shown in Figure 8-3).
  - **Base infiltration:** This type of infiltration is flow that continuously enters the sanitary sewer system, even during extended periods of dry weather. Because this flow does not correlate with rainfall, it is likely that it originates from permanent groundwater formations coincident with the sewer system. Base infiltration is assumed to remain generally constant with time and adds together with the diurnal wastewater flow to become dry weather flow.

- **Wet weather flow based on response to rainfall:**
  - **Fast response:** This type of flow represents a quick response to rainfall events within the basin. Fast response flow may consist of runoff from impervious areas. In a separated sewer system, this type of flow should not be in the wastewater stream. During large rain events, however, runoff from saturated pervious areas may also contribute to fast response. Within the modeling approach, the defining characteristic of fast response is that unlike infiltration flow, it is largely insensitive to antecedent conditions. Model A is the MOUSE module that is used to simulate fast response.
  - **Rapid infiltration:** This type of infiltration is the most rapid of the three infiltration flow components represented in the modeling approach. Rapid infiltration response is typically due to infiltration near infrastructure imperfections in which the ground becomes temporarily saturated. Rapid infiltration characteristically starts and ends with each rainfall event. Unlike fast response, the amount of rapid infiltration response may be larger due to antecedent rainfall or may be smaller due to a lack of antecedent rainfall. MOUSE RDII is the module used to simulate rapid and slow infiltration. Rapid infiltration is the overland flow component of MOUSE.
  - **Slow infiltration:** This type of infiltration is flow that responds more slowly to individual rainfall events. Slow infiltration is typically related to the rise and fall of groundwater in response to rainfall. Slow infiltration generally does not start until well after the start of the rainfall, and continues well past the end of it. Slow infiltration is the sum of "interflow" and "groundwater flow" in the MOUSE RDII module.

8.5.2 Modeling Approach

Models representative of the pilot and control basins were developed, with corresponding basin delineation and flow meter placement (see Figures 5-2 to 5-13). The models included the best available input information at the time of model development. The models were developed as follows:

- The model configuration was developed from an existing King County GIS database (see Section 8.5.2.1).
- Rainfall input was developed from a network of rainfall gauges and from CALAMAR (see Section 8.4.2).
- Evapo-transpiration (ET) input was developed from a Washington State University agricultural database that uses weather stations to calculate the required model input (see Section 8.5.2.3).

The models were calibrated to all available flow data by adjusting modeling parameters until modeled hydrographs qualitatively “fit” flow meter hydrographs for each basin. See Table 8-1 for a summary of collection dates for flow data from each basin. Section 8.5.3 presents additional detail regarding the calibration process.

8.5.2.1 Hydraulic Model Input

The hydrologic model basin parameters were developed from an existing King County GIS database. The parameters were based on the physical characteristics of each basin.

The hydraulic model conveyance parameters were developed to convey the flows from one basin to the next without backwater effects (flow constriction). The piping parameters were generically set for all basins and do not represent the true infrastructure. This is a standard modeling method at this scale. Only the hydrological components of the network of basins are of concern; the hydraulics of the network of piping within each basin is relatively unimportant. To maintain free-flow conditions, the piping was specified as smooth, circular concrete pipes with a 5-foot diameter and a 200-foot length. The connecting manholes were all designated as 5 feet in diameter, with a ground level of 30 feet and an invert (pipe bottom) that dropped 1 foot for every manhole as the layout progressed downstream.

8.5.2.2 Rainfall Input

Rainfall time series were developed for the pilot project basins as model input. The rainfall derived for each basin was used as input into the MOUSE model. As described in Section 8.5.1 and illustrated in Figure 8-2, rainfall time series feed the MOUSE continuous hydrologic process used to simulate flows from each basin.

As described in Section 8.4, the rainfall time series for each basin was developed as a composite of CALAMAR data and rain gauge data. Rain gauges were not specifically installed in each basin. Therefore, it was necessary to combine the data from multiple gauges located near each basin to estimate the rainfall that actually occurred within the basin boundary. Because the rainfall data were used for model input, complete data sets without gaps were required. In addition, to enhance the data collected from the rain gauges, CALAMAR was utilized to obtain better geographic coverage than would be obtainable with rain gauges alone. Because CALAMAR was only available for individual rainfall events, rain gauge data was still necessary to develop the rainfall time series for each basin encompassing the time prior to and during the pre-rehabilitation and post-rehabilitation periods.

8.5.2.3 Evapo-transpiration Input

An evapo-transpiration (ET) time series, used for all modeling basins, was developed as model input. The ET time series accounted for rainfall loss during rainfall events and enabled the model to “dry out” during non-rainfall time periods. The series was developed from weather station data obtained from the Washington State University Public Agricultural Weather System (PAWS) database. The Puyallup weather station was the closest to the King County service area where ET is measured. Data gaps were filled by the next closest weather station in Mount Vernon. The modeling effort used the Penman Grass reference ET values that were calculated from the weather station data at a 24-hour interval. Penman Grass ET is the daily reference crop ET from an extensive surface of 3-to-6 inches tall, green grass cover of uniform height which is actively growing, completely shading the ground, and not short of water.

8.5.3 Model Calibration

Calibration is used for nearly every kind of scientific modeling. Physically based models generally have some parameters that can be directly measured and others that cannot. During calibration, the values of non-measurable parameters are adjusted to satisfy the input/output relationship of the modeled system. This is accomplished by running the model using incremental iterations of values for one or more of the unknown parameters. For the pilot and control basins, model calibration entailed adjusting the model parameters that controlled the magnitude and shape of simulated I/I flows. The outputs from successive model iterations were compared with measured values for the output parameters (such as flow, for a hydrologic model). When the modeled output closely and consistently matched the measured output, the model was considered calibrated.

The procedure for selecting parameter values to calibrate each of the flow components is complex. It requires a detailed understanding of the relationship between parameter values defined in MOUSE and the resulting simulated flow response. The calibration procedure typically begins by first defining the less variable components of flow, such as dry weather flow. Therefore, the initial steps of calibration involve comparing and calibrating model simulations to records collected during periods of dry weather. After dry weather calibration is completed, the effort focuses on matching simulation results to recorded wet weather flows. In general, the procedure involves targeting particular periods of the observed flow record to first match hydrograph volume, then matching peak flow and shape.

8.5.3.1 Calibration Flow Time Series

MOUSE model “runs” (a run is defined as a single iteration of model calculations, representing a single parameter combination) were compared to the collected flow data. The flow data was collected at several monitoring sites and generally could be directly compared with the modeling results for each basin. However, the calibration process for some of the pilot and control basins was based upon the addition or subtraction of data between two or more different meters (see Table 8-2).

The subtractions and additions were completed by comparing upstream and downstream measured flow hydrographs. Flow travel time lags were corrected for as well as any other effects that might inhibit the subtraction. The final subtracted data was averaged over a 60-minute moving interval. Note that when calibration relied on addition or subtraction of data, the data was considered valid only for time periods when valid data was collected at all required meters.

Table 8-2. Calibration Flow Definition

Basin Name	Calibration Flow Basis	Calibration Flow Definition
Auburn Pilot A	Meter Subtraction	Auburn Pilot A minus Auburn Subtraction
Auburn Pilot B	Meter Subtraction	Auburn Pilot B minus Auburn Pilot A
Brier Control	Single Meter	Brier Control
Brier Pilot	Meter Subtraction	Brier Pilot minus Brier Control
Coal Creek Control	Single Meter	Coal Creek Control
Coal Creek Pilot	Single Meter	Coal Creek Pilot
Kent Control	Single Meter	Kent Control
Kent Pilot	Meter Addition	Kent Pilot A plus Kent Pilot B
Kirkland Control	Single Meter	Kirkland Control
Kirkland Pilot	Meter Subtraction	Kirkland Pilot minus Kirkland Control
Lake Forest Park Control	Single Meter	Lake Forest Control
Lake Forest Park Pilot	Single Meter	Lake Forest Pilot
Mercer Island Control	Single Meter	Mercer Island Control
Mercer Island Pilot	Meter Subtraction	Mercer Island Pilot minus Mercer Island Control
Northshore Control	Single Meter	Northshore Control
Northshore Pilot	Single Meter	Northshore Pilot
Redmond Control	Single Meter	Redmond Control
Redmond Pilot A	Single Meter	Redmond Pilot A
Redmond Pilot B	Meter Subtraction	Redmond Pilot B minus (Redmond Pilot A plus Redmond Control)
Ronald Control	Single Meter	Ronald Control
Ronald Pilot	Single Meter	Ronald Pilot
Skyway Control	Single Meter	Skyway Control
Skyway Pilot	Single Meter	Skyway Pilot
Val Vue Control	Single Meter	Val Vue Control
Val Vue Pilot	Single Meter	Val Vue Pilot

Note: Locations and relationships between meters are presented in Figures 5-2 to 5-13.

8.5.3.2 Dry Weather Calibration

The first step in the calibration process for each model basin was to match simulated flows with flows measured during dry weather. The dry weather flows measured at the beginning of each monitoring period were used to define and calibrate dry weather flow input into the model. Dry weather flows were represented in MOUSE using three components (see Figure 8-4 for additional detail):

1. The daily diurnal pattern above the daily minimum flow
2. The portion of the daily minimum flow estimated to be wastewater (the remaining flow below the daily minimum flow was assumed to be base infiltration)
3. The portion of the daily minimum flow estimated to be dry weather infiltration (base infiltration)

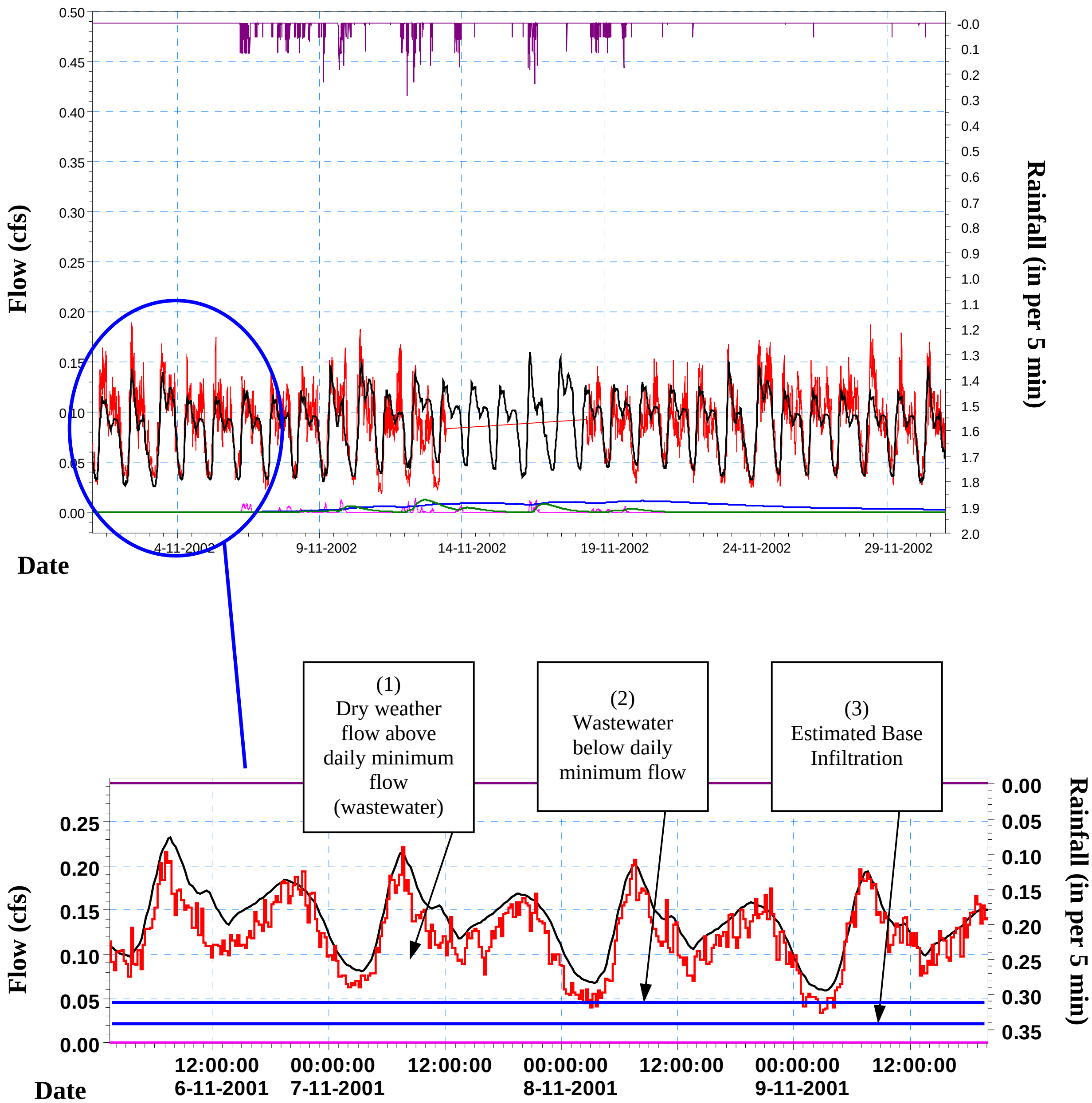


Figure 8-4. Dry Weather Flow Calibration

To calibrate each basin to existing conditions, the amount of dry weather flow was derived from the available measured flow data. Because monitoring data was available during dry periods, it was not necessary to use population to determine the wastewater contribution in each basin (population can provide an estimate of the wastewater contribution in the absence of flow data collected over dry periods).

8.5.3.3 Wet Weather Calibration

As explained in Section 8.5.1, MOUSE represents wet weather I/I as three distinct responses: fast response, rapid infiltration, and slow infiltration. During the calibration process, each wet weather flow component was “tuned” (partially calibrated) individually in order (from the slow infiltration response to the fast response). Then an overall final tuning was done.

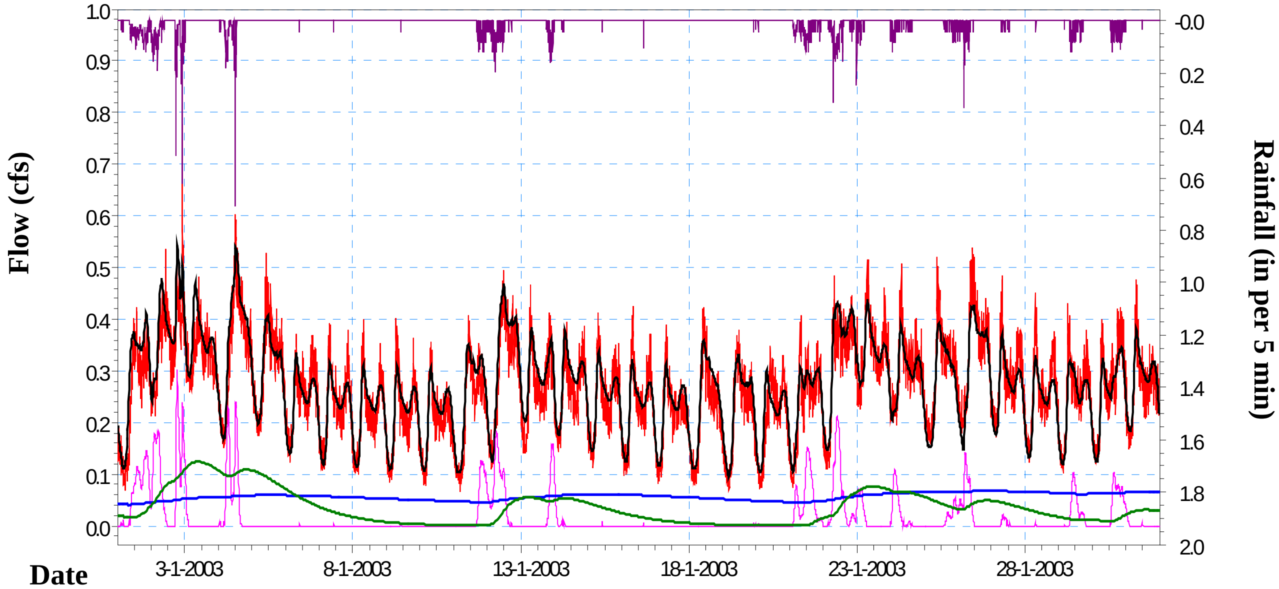
Tuning for the slow infiltration response was done by matching the diurnal dry weather flow pattern to the flow data before and after storm events as well as at the end of the monitoring season. If the slow infiltration response component was adjusted correctly, the dry weather flow pattern matched the flow data at the higher flow around the storm events. This approach was a way of separating out the component into flows that were primarily dependent on the addition of the slow infiltration component.

Tuning for the rapid infiltration component was done by matching storm event volumes and shapes with special attention to matching the flow recession of the storm events. The rapid infiltration component was primarily responsible for the recession limb of the storm event. Measured flow responses to all storms were used for calibration; however, it was typically not possible to match simulated flows to measured flow responses for all storms. In these cases, more emphasis was placed on matching flow responses to large, rather than small storms.

The last component to be tuned was the fast response component. The fast response component was tuned to match storm peaks. With regard to shape and peak, this effort involved fine-tuning the rapid infiltration response. Large storms were matched at the cost of smaller storms when there were inconsistencies.

After all components were tuned, calibration was finalized by adjusting all components together until the best model-to-flow data “fit” was achieved. Reduced emphasis was placed on periods with unreliable or inconsistent diurnal wastewater flow patterns (such as holidays). Figure 8-5 presents a plot of simulated flow (black) versus measured flow (red). Rainfall (purple) is included on the reverse second Y-axis for reference. Also included for reference are the wet weather I/I components: fast response (magenta), rapid infiltration (green), and slow infiltration (blue). Plots showing the match between simulated and measured flow for the entire calibration of each pilot and control basin are included in Appendix F.

The calibration process was based on the monitored flow data. The confidence in final model parameter combinations decreased when large amounts of data were missing or not collected. See Appendix F for a qualitative assessment of model confidence and final reduction results.



Legend: Measured Flow; Measured Rainfall; Date Format (dd-mm-yyyy); Total Simulated Flow; Fast Response Component; Slow Infiltration; Rapid Infiltration

Figure 8-5. Model Calibration Example

8.5.4 Estimated 20-Year Peak Flows

King County has adopted a 20-year flow capacity standard for conveyance facilities that transport wastewater from local agencies to County treatment plants. This means the facilities must have capacity for flows of a magnitude that can be expected on an average of once every 20 years (20-year return period). This corresponds to a 5-percent chance of such flows or higher occurring in any given year. To maintain consistency with King County capacity standards, the difference in the 20-year flow established for pre-rehabilitation versus post-rehabilitation was used to estimate rehabilitation effectiveness.

To estimate the benefits of I/I reduction, it is also necessary to estimate reduction in the 20-year flow achieved through system rehabilitation. It is unlikely that an event as infrequent as the 20-year flow will be measured during a short monitoring period; therefore, alternative methods were developed to estimate the 20-year flow. Many traditional methods, such as the "design storm approach," equate rainfall probability to flow probability. These methods become unreliable when flow of a given magnitude can result from a range of rainfall events. As antecedent conditions become more significant in determining flow response, it becomes increasingly difficult to correlate flow to a single rainfall event. The design storm approach lacks the ability to account for varying geographic coverage, antecedent conditions, or impacts from successive rainfall events, all of which are common in this region. An additional consideration is the sensitivity of flows resulting from rainfall received over successive days, weeks, or even months.

The method used to estimate the 20-year flow for each basin consisted of conducting an extended simulation and performing a frequency analysis on the simulated flows. Through calibration of the continuous simulation model to measured flows, the parameters describing each basin were adjusted to represent the processes that transform rainfall to infiltration and inflow. The model can then be used to simulate flow response from a long-term rainfall time series that includes large, infrequent rainfall events. By simulating a continuous, long-term period, this approach accounts for the effects of antecedent conditions.

8.5.4.1 20-Year I/I Flow Estimation Procedure

After the hydrologic model for each basin was calibrated, it was simulated with a 60-year extended time series (ETS) of precipitation as input. The ETS were developed to facilitate application of continuous simulation hydrology despite variability of mean annual precipitation and infrequent rainfall event volumes throughout the study area. The ETS applicable to the King County study area were developed by adjusting the 60-year SeaTac rainfall record to match the storm statistics of the time series records at over 50 precipitation gauges located in the lowlands of western Washington. More specifically, a series of statistical scaling functions were used rather than a single scaling factor. The scaling functions provide for scaling rainfall amounts at the 2-hour, 6-hour, 24-hour, 72-hour, 10-day, 30-day, 90-day, and annual durations.

The 60-year simulation produces a time series of flows at the basin outlet. This 60-year flow time series can be used to determine flow frequency, which includes estimating the 20-year peak I/I flow from each model basin. The procedure for estimating the 20-year peak I/I flow can be summarized in the following steps:

1. Develop and calibrate a basin model using rainfall and flow data measured in the basin.
2. Simulate flow response with the calibrated model using the 60-year extended time series (ETS) of precipitation as input.
3. Extract, rank, and plot the simulated peak I/I flows.
4. Estimate the 20-year I/I flow from the plot of peak flows.

The ETS simulation produces 60 years of simulated flows at the basin outlet. From this information, a plot can be made of peak flow magnitude versus return period such as the one shown in Figure 8-6. A best-fit curve was used to interpolate between the plotted points with a return period greater than 1 year. The estimated 20-year flow was determined by selecting the flow from the plotted best-fit curve with a return period of 20 years. See Appendix F for the plots of the frequency analysis (regression) curves for the modeled basins.

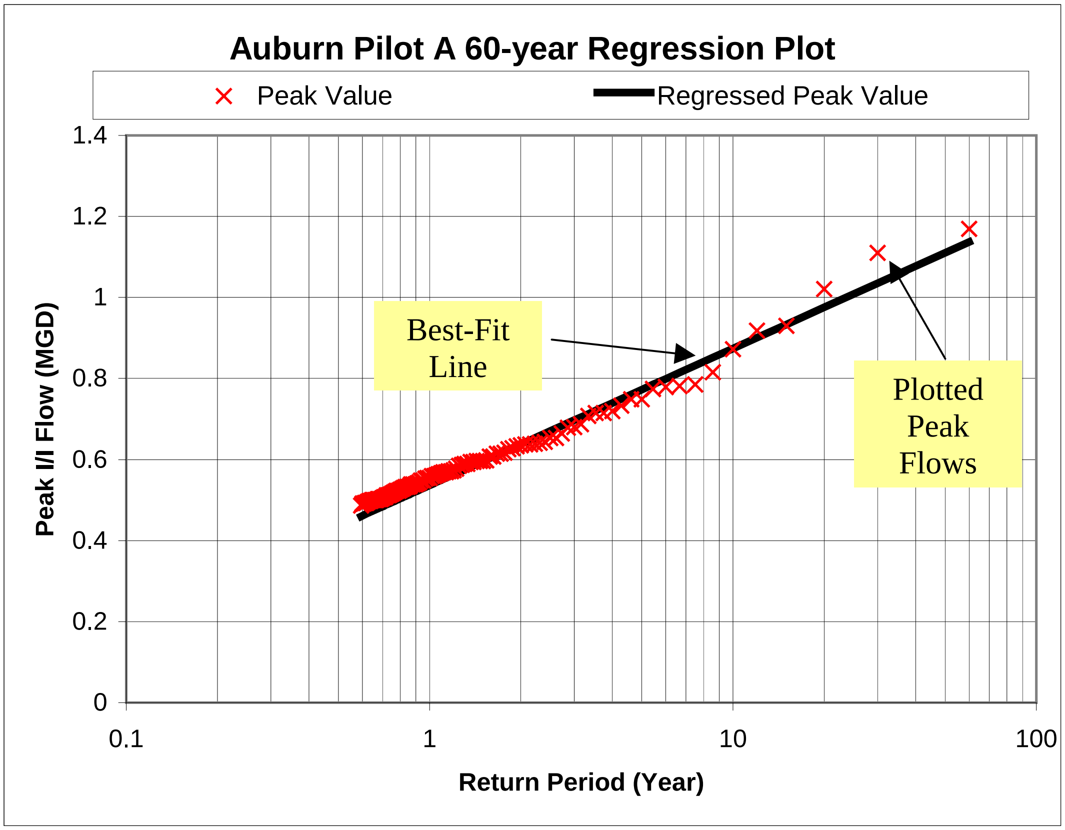


Figure 8-6. Assigning Return Intervals to Peak Simulated Flows

This process relies on several key assumptions. The ETS were derived using the SeaTac rainfall record, which is the longest continuous record of rainfall data in the eastern Puget Sound lowlands. It was assumed to be representative of rainfall patterns likely to occur in the service area, after adjustments were made to account for annual and peak rainfall differences throughout the region. Another key assumption is that a calibrated model can simulate flow response from any rainfall time series. Representation of multiple flow components and calibration to varied conditions provides a reasonable basis for such an extrapolation assuming that the events calibrated to are large enough to be able to project out to the 20-year event. See Appendix F for a model confidence table.

8.5.4.2 Pre-Rehabilitation 20-Year Flow Estimates

Table 8-3 presents the pre-rehabilitation 20-year peak flow estimates for each control and pilot basin using the approach and methodology described in previous sections. Frequency analysis was conducted independently on four flow components of interest: total flow, total I/I (total flow minus diurnal wastewater flow), fast response, and slow response (the sum of slow and rapid infiltration). It should be reiterated that the flows presented in Table 8-3 were estimated using flow modeling of the pilot and control basins; thus, they differ from the flows used for pilot project selection, which were derived from measured flows. For each flow component included in Table 8-3, the 20-year flow is presented in million gallons per day (mgd) and in gallons per acre per day (gpad). These 20-year flow values estimated for pre-rehabilitation conditions provide the initial basis for determining I/I reduction.

Table 8-3. 20-Year Peak Flow Estimates for Pre-Rehabilitation Conditions

Basin Name	Total Flow		Total I/I		Fast Response[1]		Slow Response[1]	
	(mgd)[a]	(gpad)[b]	(mgd)	(gpad)	(mgd)	(gpad)	(mgd)	(gpad)
Auburn Pilot A	1.1	9,900	1.0	8,900	0.5	4,500	0.7	6,400
Auburn Pilot B	1.2	31,400	1.1	29,100	0.5	12,800	0.7	20,100
Brier Control	0.5	4,600	0.5	4,100	0.2	2,100	0.3	2,700
Brier Pilot	1.0	10,700	0.9	10,100	0.1	700	0.9	9,800
Coal Creek Control	1.2	12,000	1.1	11,000	0.4	3,700	0.8	8,500
Coal Creek Pilot	1.2	8,000	1.1	7,400	0.4	2,500	0.8	5,700
Kent Control	0.1	4,700	0.1	4,000	0.0	700	0.1	3,300
Kent Pilot	0.6	14,000	0.5	12,700	0.0	1,000	0.5	12,000
Kirkland Control	0.8	17,900	0.7	15,200	0.4	9,300	0.4	8,800
Kirkland Pilot	0.9	11,700	0.9	11,000	0.4	5,200	0.6	7,200
Lake Forest Park Control	2.7	14,700	2.6	13,900	1.0	5,300	2.2	12,000
Lake Forest Park Pilot	3.2	22,900	3.2	22,500	1.0	7,000	2.5	17,900
Mercer Island Control	0.4	12,100	0.4	11,400	0.1	3,900	0.3	9,200
Mercer Island Pilot	0.9	8,900	0.9	8,200	0.5	4,800	0.6	5,500
Northshore Control	0.7	6,300	0.6	5,800	0.2	1,600	0.6	5,200
Northshore Pilot	1.0	6,900	1.0	6,600	0.3	2,200	0.8	5,200
Redmond Control	0.2	3,200	0.1	1,100	0.0	400	0.0	800
Redmond Pilot A	0.2	2,600	0.1	1,000	0.0	300	0.0	600
Redmond Pilot B	0.6	12,800	0.5	11,000	0.0	400	0.5	10,700
Ronald Control	1.1	12,100	1.0	11,100	0.5	5,500	0.8	8,400
Ronald Pilot	1.7	18,900	1.7	18,200	0.3	2,800	1.5	16,400
Skyway Control	1.7	44,500	1.7	43,800	0.7	18,000	1.4	36,600
Skyway Pilot[2]	2.7-3.1	58,700-67,600	2.7-3.1	57,700-66,700	0.4-0.8	8,700-17,300	2.5-2.7	54,000-59,500
Val Vue Control	0.9	4,400	0.8	3,900	0.4	2,100	0.6	3,200
Val Vue Pilot	0.3	4,400	0.3	3,800	0.2	2,700	0.2	2,600

[a] million gallons per day [b] gallons per acre per day

1 - The fast and slow response values do not sum to the total I/I. The tool developed to estimate the 20-year peak flows treats each of the responses independently. The fast response peak may not coincide with the slow response peak.

2 - Two equivalent calibrations using different sets of parameters were developed for the Skyway pilot; therefore, ranges of rates were identified.

8.6 I/I Reduction

8.6.1 I/I Reduction Estimated with Modeling

Modeling analysis was used to estimate I/I reduction achieved in each pilot project basin through system rehabilitation. The modeling approach tasks are presented in Figure 8-7. Pre-rehabilitation I/I quantities for each pilot and control basin were determined with models calibrated to available measured flow and rainfall data collected prior to rehabilitation. The pre-rehabilitation 20-year peak I/I flow contributed by each basin was then determined through frequency analysis of simulated flows generated from 60-year ETS simulations. Pre-rehabilitation 20-year peak I/I estimates are presented in Table 8-3.

The first step in the process of quantifying I/I reduction was to simulate the post-rehabilitation period using the models calibrated to pre-rehabilitation conditions. In essence, the pre-rehabilitation models were used to simulate flows expected from each basin if rehabilitation improvements were not constructed. If the simulated flows from the pre-rehabilitation model were higher than the flows measured during the post-rehabilitation period, then it could be concluded that the rehabilitation improvements resulted in decreased I/I. Figure 8-8 illustrates an example in which I/I was reduced with rehabilitation. The result from the model calibrated to pre-rehabilitation conditions simulates higher flows (gray) during the post-rehabilitation period than the measured flows (red).

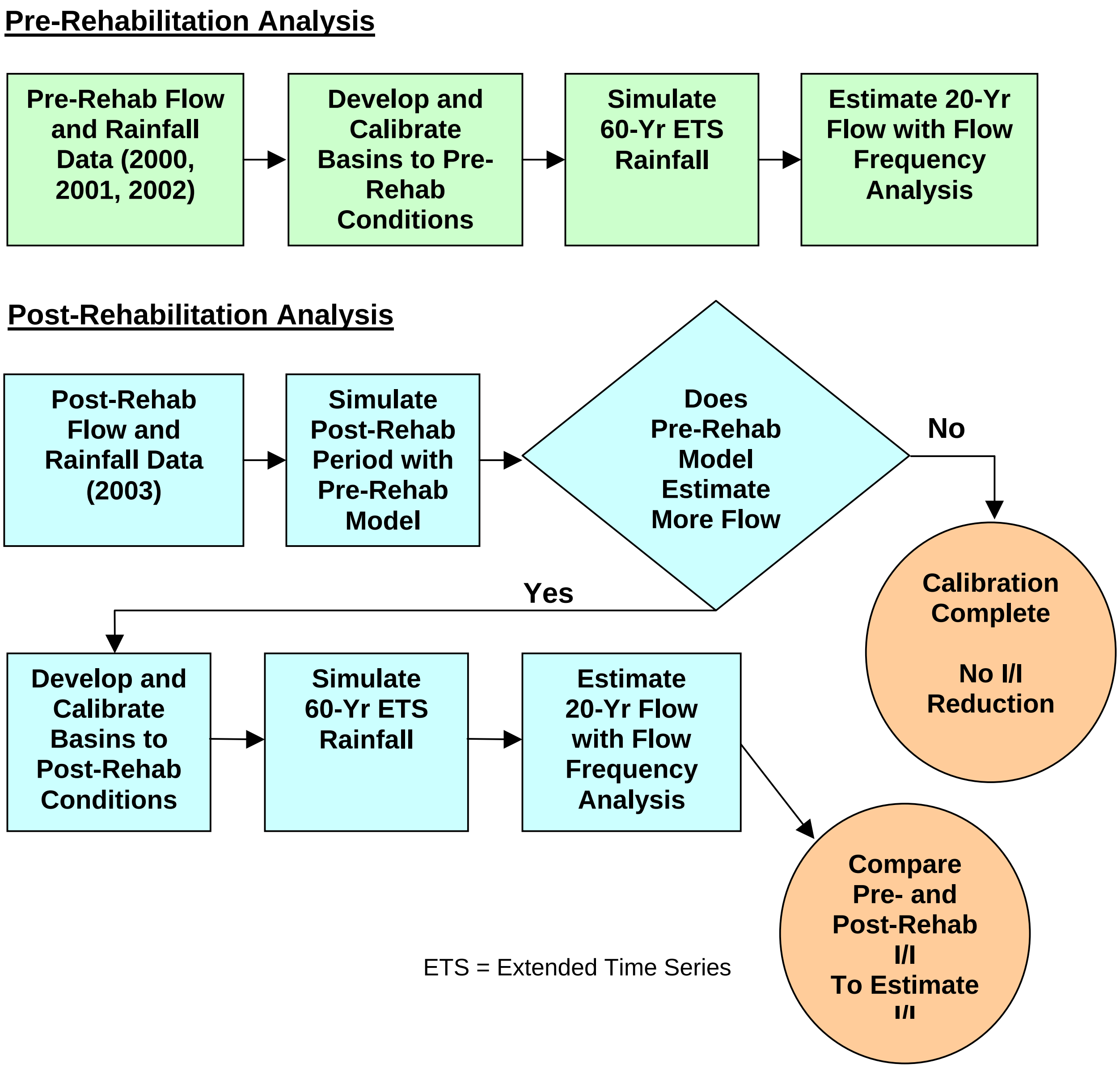


Figure 8-7. Modeling Approach for Estimating I/I Reduction

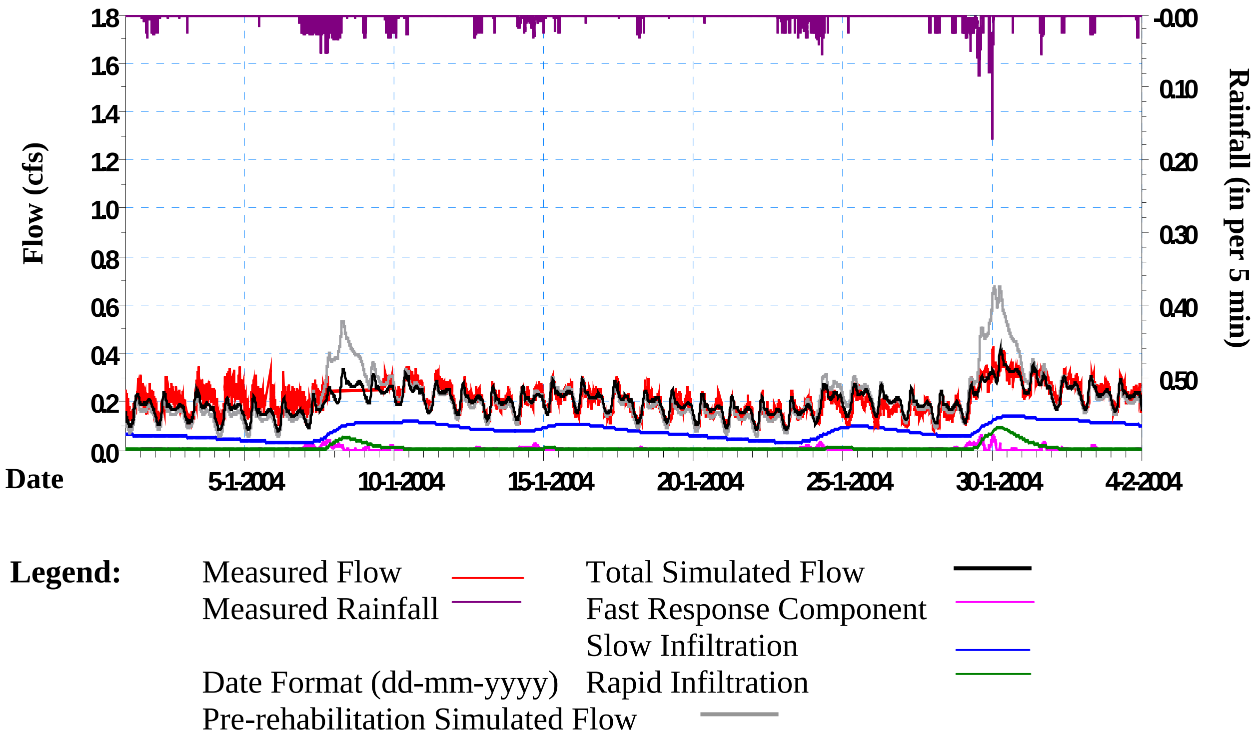


Figure 8-8. Post-Rehabilitation Flow Data with Model Calibrated to Pre- and Post-Rehabilitation Conditions

For most pilot project basins, there was clearly a reduction in I/I; however, for some basins, I/I reduction was not apparent. In cases where the model calibrated to pre-rehabilitation conditions simulated flows equal to or less than the measured flow during the post-rehabilitation period, it was concluded that I/I was not reduced by rehabilitation improvements.

For basins where I/I was reduced, additional modeling tasks were required to quantify the amount of I/I reduction. The next step was to recalibrate the MOUSE model to match post-rehabilitation measured flows. The model calibration process is described in Section 8.5.3. After calibrating to post-rehabilitation conditions, the flow frequency analysis was conducted to estimate post-rehabilitation 20-year peak I/I flow. I/I reduction was estimated by comparing the 20-year peak I/I flow before and after rehabilitation improvements were constructed (see Figure 8-9 for an example). I/I reduction estimates for each pilot basin are presented in Table 8-4. Plots showing the simulated and measured flow for each pilot and control basin during the post-rehabilitation period are included in Appendix F.

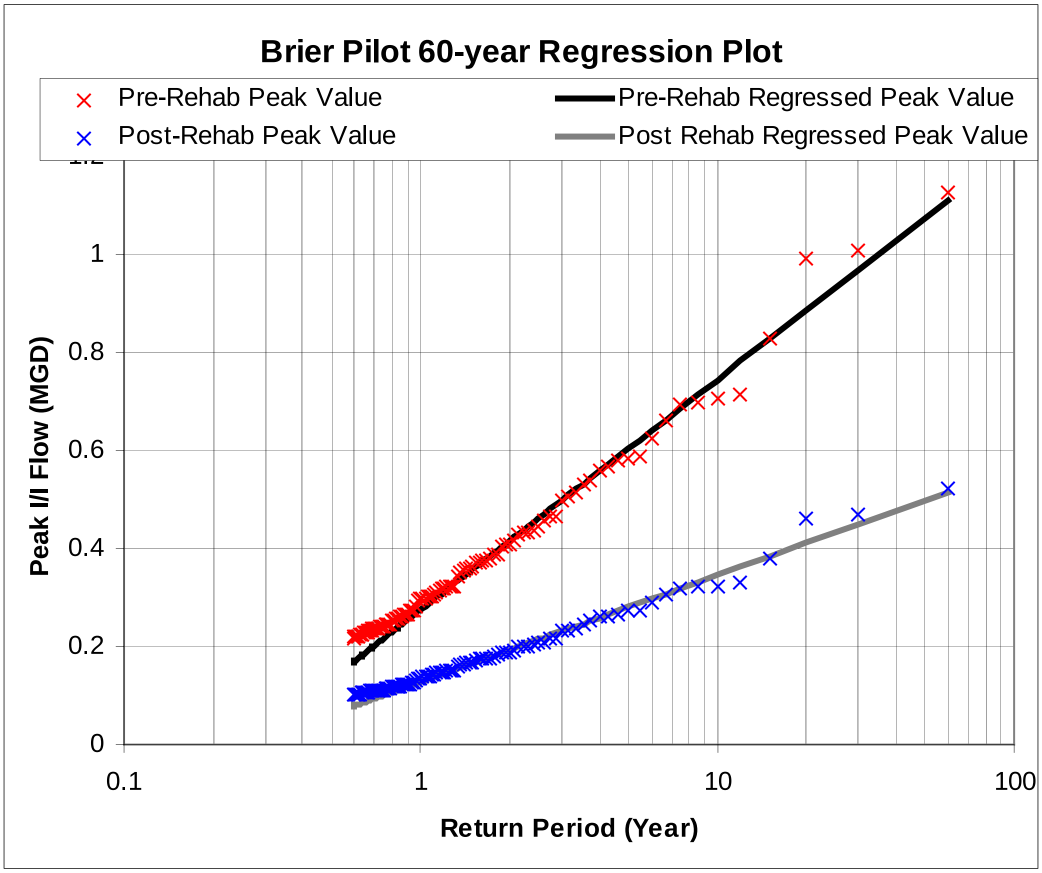


Figure 8-9. Flow Frequency Comparison of Pre-Rehabilitation and Post-Rehabilitation Model Results

Table 8-4. Pilot Project I/I Reduction Estimated from Model Results

Basin Name	Mains	Manholes (MH)	Laterals (L)	Side Sewers (SS)	% Improved[1]	Total I/I Pre-Rehab (gpad)	Total I/I Post-Rehab (gpad)	Total I/I Reduction %	Fast Response Reduction %	Slow Response Reduction %
Auburn Pilot A	•	•	•	•	11 of Mains	8,900	8,900	NAR[2]	NAR[2]	NAR[2]
Auburn Pilot B		•			19 of MH	29,100	29,100	NAR	NAR	NAR
Brier Pilot	•	•			23 of Mains	10,100	5,000	50	0	55
Coal Creek Pilot		•			52 of MH	7,400	7,400	NAR	NAR	NAR
Kent Pilot[3]			•	•	100 of L and SS	12,700	2,400-3,700	71-81	0	75-85
Kirkland Pilot	•	•	•		25 of Mains	11,000	7,900	28	41	19
Lake Forest Park Pilot	•	•			35 of Mains	22,500	7,100	69	55	71
Mercer Island Pilot	•				70 of Mains	8,200	5,200	37	50	26
Northshore Pilot		•			64 of MH	6,600	5,100	23	49	17
Redmond Pilot A	•	•	•		36 of Mains	1,000	1,000	NAR	NAR	NAR
Redmond Pilot B	•	•			8 of Mains	11,000	11,000	NAR	NAR	NAR
Ronald Pilot			•	•	72 of L and SS	18,200	4,800	74	60	74
Skyway Pilot[3]	•	•	•	•	100 of System	58,700-67,600	7,800-8,900	86	74-85	88-90
Val Vue Pilot		•			45 of MH	3,800	3,800	NAR	NAR	NAR

1 " % Improved" refers to the amount of rehabilitation improvement completed for identified elements of the sewer system. For example, for Coal Creek, the 52% value indicates that 52% of the manholes in the pilot basin were improved. "% Improved" for mains is quantified based on length of sewer main improved. Manholes, laterals, and side sewers are quantified based on the number of each element improved relative to the total number present in the pilot basin (i.e., laterals and side sewers were <u>not</u> quantified based on "% of length improved").
2 No Apparent Reduction (NAR)
3 Two equivalent calibrations using different sets of parameters were developed for Skyway and Kent and therefore a range of rates were identified

8.6.2 I/I Reduction Estimated Using Control Basins

An alternative to estimating I/I reduction with modeling is to calculate I/I reduction using measured flows from the pre-rehabilitation and post-rehabilitation monitoring periods. It would not be appropriate to simply compare measured flows in the pilot basins from pre-rehabilitation to post-rehabilitation conditions because the rainfall events and antecedent conditions throughout each monitoring period are unique. However, the measured flows from the control basins can be compared with the pilot basins for the two different monitoring periods. Although the two monitoring periods have different rainfall signatures and antecedent conditions, the relative difference between the pilot and control basins should be the same from period to period. If the relative difference changes from one monitoring period to another, then a reduction can be quantified. Comparing pre-rehabilitation and post-rehabilitation measured flow data in each pilot basin and corresponding control basin can determine the I/I reduction in each pilot basin.

The general approach to determine I/I reduction was to compare the pilot versus control ratio computed for individual rainfall events before and after rehabilitation improvements. Percent reductions were calculated for peak values and 48-hour volume (from the start of a given storm event). A more detailed description of the task sequence is provided below:

1. Subtract the diurnal wastewater flow during selected storms from the pre-rehabilitation data for both the pilot and control basins.
2. Identify and record peak total I/I and 48-hour total I/I volume during the selected storms (for both the pilot and control basins) from the pre-rehabilitation data.
3. Calculate the average pilot versus control ratio for both peak total I/I and 48-hour total I/I volume.
4. Calculate the projected I/I from the pilot basin using the average of the calculated ratios and flow data from the post-rehabilitation control basin. (The projected values represent what the peak total I/I and 48-hour total I/I volume would have been had the pilot basin not been rehabilitated.)
5. Compare the projected values (for the post-rehabilitation pilot basin) with the post-rehabilitation measured values (for the same basin) and the I/I rehabilitation. Calculate effectiveness as percent reduction.

I/I reduction estimates derived from the measured flow data are presented in Table 8-5.

Table 8-5. Pilot Project I/I Reduction Estimated from Measured Flow

Site Name	Peak Flow	Modeled 20-year Total I/I (See Table 8-4)	48-Hour Volume
	% Reduction	% Reduction	% Reduction
Auburn Pilot A	Not Applicable (NA)	No Apparent Reduction (NAR)	NA
Auburn Pilot B	NA	NAR	NA
Brier Pilot	36	50	40
Coal Creek Pilot	39	NAR	41
Kent Pilot	60	71-81	56
Kirkland Pilot	28	28	18
Lake Forest Park Pilot	65	69	61
Mercer Island Pilot	44	37	21
Northshore Pilot	82	23	82
Redmond Pilot A	NA	NAR	NA
Redmond Pilot B	NA	NAR	NA
Ronald Pilot	57	74	17
Skyway Pilot	77	86	85
Val Vue Pilot	NA	NAR	NA

1 The NA designation differs from the NAR designation in that the analysis could not be done for anything with a NA designation. The level of reduction is unknown.
2 The peak-to-peak ratio analysis was done on peaks much smaller than the 20-year event and does not represent a 20-year reduction.

While this approach may be used to quantify the I/I reduction independently of the modeling results, some issues became apparent as the data was analyzed. The flow data based approach relies on peak flow ratios (or flow volume ratios) and the presence of data gaps in some cases severely limited an already small sample of data points. In theory, this approach requires a reasonably large data set to generate statistically acceptable ratios.

Another issue was inconsistency in the pilot versus control ratio among measured storms. This relatively simple approach does not distinguish between different types of I/I flow. It also does not represent the non-linear nature of I/I response to rainfall events of various sizes or with varying antecedent conditions. During the 2002/2003 pre-rehabilitation monitoring period, there was a limited number of large storm events from which to generate ratios. The small number of storm events led to a relatively high standard deviation in the statistical analysis of the pilot versus control ratios. Also, the limited number of large storm events during the post-rehabilitation monitoring period did not allow generation of many data points that would show consistency in percent reduction or effectiveness of the rehabilitation.

Determining peak I/I flows cannot be achieved when pump stations influence flow monitoring sites. This was the case for Val Vue. The Val Vue pilot basin shows negative 48-hour I/I volume reduction and 70 to 80 percent peak I/I reduction when pre- and post- rehabilitation data are compared. The percent reduction analysis could not be applied to Val Vue data.

The percent reduction analysis also was not performed for the Auburn and Redmond pilot basins. A control basin was unavailable at the Auburn site for comparison against the Auburn Pilot Basin A. The Redmond basin was missing too much data during the pre-rehabilitation monitoring period for the analysis to give reasonable results.

8.7 Rehabilitation Effectiveness

Section 8.6 presented the approach to quantifying I/I reduction and the estimated I/I reduction achieved in each pilot basin. Estimating I/I reduction in each pilot basin was a relatively direct and quantitative process. Comparing results obtained in different pilot basins to determine the rehabilitation effectiveness of different techniques was less direct. Because of the small sample size, it was necessary to consider many characteristics of each individual pilot basin to put the I/I reduction quantities in perspective. Section 8.7 presents pertinent information about I/I reduction achieved in each pilot basin.

8.7.1 Auburn Pilot Basin A

In Auburn Pilot Basin A, few defects were identified in the public sewer system. The Sewer System Evaluation Survey (SSES) investigations of the public system identified very few defects in the sewer mains and manholes. Several of the laterals and side sewers in the pilot basin were inspected and very few defects were identified. However, defects were identified in the private sewer of the Auburn Adventist Academy. As a result, the rehabilitation effort focused on this private sewer system. In terms of the total length of sewer main in the pilot basin, approximately 11 percent of the system was rehabilitated. While only a small percentage of the basin was rehabilitated, the improvements targeted almost all the identified defects in the basin.

Flow measurement in Auburn Pilot Basin A was more challenging than in other pilot and control basins. To isolate the flow from Pilot Basin A, flow from an upstream pump station (Auburn Subtraction meter) was subtracted from flow measured at the Pilot A meter. As a result, it was difficult to quantify the net flow from Pilot Basin A. Model results did not indicate any I/I reduction in Pilot Basin A. In this instance, it is likely that the challenging flow monitoring conditions would have allowed recognition of only dramatic I/I reduction (greater than 75-percent reduction).

8.7.2 Auburn Pilot Basin B

Auburn Pilot Basin B was proposed after field investigations established that several manholes in the basin were prone to surface inundation. The completed improvements targeted these potential inflow sources. To isolate the flow from Pilot Basin B, flow from the upstream Pilot Basin A was subtracted from flow measured at the Pilot B meter. The pump station influence from the Auburn Subtraction meter (see Section 8.7.1) was present at both the Pilot A and Pilot B meters. As a result, it was difficult to quantify the net flow from Pilot Basin B.

Model results indicated the presence of significant I/I in Pilot Basin B in the form of both fast response and rapid infiltration. Model results did not indicate any I/I reduction in Pilot Basin B. The presence of multiple private sewer systems that were not inspected and substantial I/I not attributed to fast response suggest that the Pilot B improvements targeted only a fraction of the potential I/I sources in the basin. In this instance, it is likely that the challenging flow monitoring conditions would have allowed recognition of only dramatic I/I reduction (greater than 75-percent reduction).

8.7.3 Brier Pilot Basin

In the Brier Pilot Basin, rehabilitation improvements focused on mains and manholes. Approximately 23 percent of the system was rehabilitated in terms of the total length of sewer mains in the basin. Side sewers and laterals were not inspected prior to construction. Reduction in the 20-year peak I/I was estimated at 50 percent based on model results.

8.7.4 Coal Creek Pilot Basin

The Coal Creek Pilot Basin was one of three projects that focused solely on repair of manholes. Improvements were based on visual inspection of manholes to identify sources of inflow, infiltration, and rapid infiltration. Approximately 52 percent of the manholes in the pilot basin were rehabilitated. Model results did not indicate any I/I reduction resulting from the completed improvements.

8.7.5 Kent Pilot Basins A and B

Rehabilitation improvements in the Kent Pilot Basin A and Pilot Basin B focused on side sewers and laterals. The SSES showed some defects in mains and manholes, but few located in the pilot basin. Due to the proximity of a downstream pump station, monitoring of the pilot area was required at two locations. Because both pilot basins were small and appeared to be similar, they were considered together as one pilot basin in the modeling analysis. Nearly 100 percent of the side sewers and laterals were rehabilitated. Reduction in the 20-year peak I/I was estimated at 71 to 81 percent based on model results.

8.7.6 Kirkland Pilot Basin

In the Kirkland Pilot Basin, SSES results revealed defects in mains, manholes, laterals, side sewers, and in several direct inflow sources (e.g., foundation drains, downspouts, roof drains). Kirkland was originally selected as a pilot basin where side sewers would be included as part of the rehabilitation. However, due to complications, side sewers were excluded. The completed improvements consisted of mains, manholes, and laterals. Approximately 25 percent of the system was rehabilitated in terms of the total length of sewer mains in the pilot basin. Unlike in other pilot basins, the construction budget determined the amount of rehabilitation work in the Kirkland Pilot Basin. In the other pilot basins, the lack of improvements in a fraction of the system was a result of the absence of defects in those areas. Reduction in the 20-year peak I/I was estimated at 28 percent based on model results.

8.7.7 Lake Forest Park Pilot Basin

Improvements in the Lake Forest Park Pilot Basin focused on mains and manholes. Approximately 35 percent of the system was rehabilitated in terms of the total length of sewer mains in the basin. Side sewers and laterals were not inspected prior to construction. Reduction in the 20-year peak I/I was estimated at 69 percent based on model results.

8.7.8 Mercer Island Pilot Basin

In the Mercer Island Pilot Basin, significant defects were found by the SSES within the mains and service connections. A few inflow sources were found by positive smoke tests. Given the age of the system, there may also have been defects in laterals and side sewers, but these components were not inspected prior to construction. Designers chose to focus solely on mains and service connections in this pilot basin, thereby testing removal effectiveness based on those system components. Approximately 70 percent of the system was rehabilitated in terms of the total length of sewer mains in the basin. Reduction in the 20-year peak I/I was estimated at 37 percent based on model results.

Flow measurement in the Mercer Island Pilot Basin was challenging. To isolate the flow from the pilot basin, flow from the upstream control basin was subtracted from flow measured at the Mercer Island Pilot Basin meter. In addition, it was discovered that hydraulics downstream of the meter location inhibited the ability to accurately measure velocity over the full range of flow conditions. In order to utilize measured flow at the Mercer Island Pilot Basin meter, a correction to the raw measured values was required for periods of high flow (see Appendix D).

8.7.9 Northshore Pilot Basin

The Northshore Pilot Basin was one of three projects that focused solely on repair of manholes. Improvements were based on visual inspection of manholes to identify sources of inflow, infiltration, and rapid infiltration. Approximately 64 percent of the manholes in the pilot basin were rehabilitated. Reduction in the 20-year peak I/I was estimated at 23 percent based on model results. One significant direct inflow source was also eliminated, contributing an unknown proportion of the 23-percent reduction estimate.

8.7.10 Redmond Pilot Basin A

Within the Redmond mini-basin, the SSES identified defects in all portions of the collection system. However, due to complications during the formulation and design of the Redmond Pilot, a portion of the selected mini-basin was designated as Redmond Pilot A. Rehabilitation improvements focused on mains, manholes, and laterals. Approximately 36 percent of the system was rehabilitated in terms of the total length of sewer mains in Pilot Basin A. Model results did not indicate any I/I reduction resulting from the improvements. The good quality flow data for this basin did not limit recognition of I/I reduction. Model results estimated the 20-year peak I/I to be just 850 gpad, which is comparable to the least amount of I/I in King County wastewater service area mini-basins.

8.7.11 Redmond Pilot Basin B

As previously mentioned, the content of the pilot project improvements in Redmond were modified during design. Significant defects were identified in the downstream portion of the Redmond mini-basin. Rehabilitation improvements in the Redmond Pilot Basin B consisted of selected spot repairs. Less than 5 percent of the system was rehabilitated in terms of the total length of sewer mains in Pilot Basin B. To isolate the flow for Pilot Basin B, flow from both the upstream control basin and Pilot Basin A were subtracted from flow measured at the Pilot Basin B meter.

The most challenging aspect of analyzing this pilot basin was the apparent link between flows in the adjacent Sammamish River and I/I flows in Pilot Basin B. Model results did not indicate any I/I reduction resulting from the completed improvements.

8.7.12 Ronald Pilot Basin

Flow monitoring indicated that this basin had significant I/I--approximately 11,000 gpad. Table 8-3 shows total flow for the Ronald pilot basin to be 18,000 gpad. However, previous Ronald Wastewater District (RWD) sanitary sewer evaluation work in this basin (sewer main and manhole inspection and smoke testing) revealed relatively few faults. Only 7 sewer main faults were noted, and about 10 faults that could allow I/I were observed on private property. With so few defects in the sewer main, the most likely source of I/I must be the side sewers and laterals. Those components were the focus for the pilot project work. Approximately 72 percent of side sewers and laterals were rehabilitated. Reduction in the 20-year peak I/I was estimated at 74 percent based on model results.

8.7.13 Skyway Pilot Basin

In Skyway, the pilot project consisted of full system rehabilitation (mains, manholes, side sewers, and laterals). Within the entire pilot basin, all portions of the collection system were replaced from the house to the lateral connection at the main. With a pre-rehabilitation 20-year peak I/I between 58,700 and 67,600 gpad, the Skyway pilot basin had the highest I/I in the King County wastewater service area. Nearly 100 percent of the system was rehabilitated in terms of the total length of sewer mains in the pilot basin. Reduction in the 20-year peak I/I was estimated at 87 percent based on model results.

8.7.14 Val Vue Pilot Basin

The Val Vue pilot basin was one of three projects that focused solely on repair of manholes. Improvements were based on visual inspection of manholes to identify sources of inflow, infiltration, and rapid infiltration. Approximately 45 percent of the manholes in the pilot basin were rehabilitated. Model results did not indicate any I/I reduction resulting from the improvements. In this instance, it is likely that the challenging flow monitoring conditions, influenced by nearby pump stations, would have allowed recognition of only dramatic I/I reduction (greater than 75-percent reduction).

Chapter 9

I/I Rehabilitation Project Costs and Lessons Learned

This chapter provides an overview of the overall infiltration and inflow (I/I) rehabilitation pilot project costs and the primary lessons learned during execution of the projects. The lessons learned relate to such issues as project selection, rehabilitation approaches, and documentation of a project's effectiveness. This chapter's purpose is to summarize useful information as guidance to the ongoing King County I/I Control Program. It may also be helpful to individuals involved in other I/I programs.

Lessons learned as presented in this chapter are not prioritized in any order of importance. The lesson is stated in bold and supporting comments follow. The relevance of these lessons to other programs varies depending upon the nature of the specific program. Note that the 10 pilot projects represent only a small cross section of the basins included in King County's I/I Control Program, and the construction rehabilitation methods and products utilized were limited by funds and time. Hence, it is difficult to draw broad conclusions about I/I rehabilitation based on these pilot projects alone.

9.1 I/I Rehabilitation Project Costs

The final construction cost for the 10 pilot projects, including local sales tax, was $7.80 million. Local agencies contributed $0.67 million and King County contributed $7.13 million.

In addition to construction costs, the total pilot project costs include the Sewer System Evaluation Survey (SSES), design, pre- and post-rehabilitation flow monitoring, construction management, and modeling and analysis. Table 9-1 summarizes each project's costs.

Table 9-1. Summary of Pilot Project Costs

	Auburn	Brier	Kent	Kirkland	Lake Forest Park	Manhole Project	Mercer Island	Redmond	Ronald	Skyway	TOTAL
SSES	$173,800	$163,600	$75,400	$117,300	$122,100	$124,800	$129,100	$134,300	$110,200	$70,000	$1,220,600
Design	$96,100	$145,700	$177,900	$154,700	$186,600	$222,300	$132,600	$193,800	$145,000	$238,400	$1,693,100
Pre-Rehabilitation Flow Monitoring	$9,000	$9,000	$9,000	$9,000	$9,000	$27,000	$9,000	$9,000	$9,000	$9,000	$108,000
Construction	$384,700	$372,700	$1,080,700	$838,200	$790,400	$200,800	$815,800	$840,100	$1,077,300	$1,395,200	$7,795,900
Construction Management	$72,200	$115,800	$90,300	$57,600	$107,200	$44,600	$118,500	$82,600	$176,300	$157,700	$1,022,800
Post-Rehabilitation Flow Monitoring	$8,500	$8,500	$8,500	$8,500	$8,500	$25,400	$8,500	$8,500	$8,500	$8,500	$101,900
Modeling / Reporting	$5,100	$5,100	$5,100	$5,100	$5,100	$15,300	$5,100	$5,100	$5,100	$5,100	$61,200
TOTAL	$749,400	$820,400	$1,446,900	$1,190,400	$1,228,900	$660,200	$1,218,600	$1,273,400	$1,531,400	$1,883,900	$12,003,500

9.2 Success of Reducing I/I

Service basins with I/I can be identified through comprehensive wet-weather flow monitoring programs and in many cases, I/I can be successfully reduced through rehabilitation of the sewer collection system.

Regional flow monitoring was conducted throughout the winters of 2000/2001 and 2001/2002 within mini-basins. This flow monitoring, coupled with the data interpretation program, identified service basins with relatively high I/I. The information was subsequently used as one factor in the selection of suitable pilot projects.

Rehabilitation methodologies used in the pilot basins were selected, designed, and constructed based on flow data and the SSES investigations.

Rehabilitation efforts reduced I/I in 7 of the 10 pilot projects. In one pilot project basin, a maximum reduction of 87 percent was achieved through a complete system replacement. The pilot projects demonstrate that monitoring and rehabilitation of sewer collection systems can successfully identify, target, and reduce I/I.

9.3 Lateral and Side Sewer Sources of I/I

There is a strong indication that in many service basins, a high percentage of I/I originates in laterals and side sewers.

In the Kent and Ronald pilot projects, the focus of system rehabilitation was laterals and side sewers only. An I/I reduction effectiveness of approximately 75 percent in each indicates that in these cases, the majority of I/I originated in laterals and side sewers.

In the Manhole Project, manhole rehabilitation resulted in very little I/I reduction. This signifies that I/I sources in the basin are from other sewer system components.

In the Mercer Island pilot project, which included only sewer main rehabilitation, a 37-percent reduction in I/I indicates that a high percentage of I/I originates in other system components, most likely laterals and side sewers.

However, in Lake Forest Park, I/I was reduced by 69 percent by rehabilitating sewer mains and manholes only. Therefore, while laterals and side sewers may be highly suspect sources of I/I, it is necessary to evaluate flow data, review the results of SSES investigations, and possibly use pre-rehabilitation system modeling to identify likely sources of I/I.

9.4 Sanitary Sewer Evaluation Survey (SSES) Effectiveness

The extent and need for SSES work (videotaping sewer mains, laterals, and side sewers with a closed circuit television [CCTV] camera; smoke testing; dye testing; and performing manhole inspections) depends on the rehabilitation work to be performed. In order to identify the most appropriate method of rehabilitating a collection system component, some level of SSES work must be completed. However, SSES alone will not always identify all sources of I/I or the extent to which I/I is entering collection system components.

SSES investigations to identify sources of infiltration are most effective during the wet weather season.

SSES investigations, including pipe videotapes and manhole inspections, identified several defects and the general condition of system components in each project; however, there was no clear correlation between identified defects and the extent of I/I known to occur in the system. A factor contributing to this was that most SSES investigations were completed during the relatively dry summer months when many infiltration sources were inactive.

Several sources of infiltration that eluded detection during SSES investigations were identified during pilot project construction work completed during the wet season, and through the post-rehabilitation inspection also performed during the wet season. For example, the Mercer Island post-rehabilitation CCTV inspection of sewer mains identified several laterals with small but continuous flows of clear water, suggesting an infiltration source in the lateral or side sewer. During construction in the wet season, infiltration that had eluded detection during the summer SSES investigations was identified at several manholes.

While SSES work (primarily CCTV data) completed in the wet season may identify more sources of infiltration, it will probably remain difficult to establish a good correlation between identified defects and the I/I known to occur in a basin. Ideally, inspection should be completed during or immediately after a storm. This may not be feasible due to the infrequency of storm events that activate the sources of I/I. Also, during storm events, the high flow rate in sewer pipes may prevent effective CCTV inspection. In the interest of increasing the percentage of I/I sources identified through SSES work, these investigations should be completed during the wet season when I/I sources are most likely to be active. Smoke testing for direct connections and defects is still presumed to be most effective in the dry weather months, however, due to the lower likelihood of smoke being inhibited by water in the pipes, p-traps, and soil.

SSES investigations may not be effective at identifying all sources of I/I.

A number of SSES techniques were used for the pilot projects, including manhole inspections; CCTV inspection of sewer mains, laterals, and side sewers; and smoke testing. As previously discussed, many sources of I/I eluded detection because the SSES work was completed in the summer. In addition, some I/I sources were not identified because of deficiencies in the SSES technique. For example, smoke testing identified only a small number of inflow sources in the pilot projects. This could have been because obstructions in the sewer pipes prevented migration of smoke, or there simply may have been very few inflow connections. In some cases, I/I sources were part of the building plumbing and could not be easily removed. Also, smoke testing does not identify many rapid sources of I/I such as sump pumps, foundation drains, or inflow connection pipes with water traps that are filled with water. Because of the small number of inflow sources identified through smoke testing, very few inflow removal improvements were implemented as part of the pilot projects. In a proposed I/I rehabilitation project where flow data indicates an extremely fast response, smoke testing should be considered. In a number of cases, such as in basins where the response to storm events is less immediate, the cost and time required to conduct smoke testing may not be justified.

CCTV inspections of laterals and side sewers did not effectively identify all sources of I/I in these pipes. CCTV inspection methods involve either pushing a camera through an access point such as a cleanout, or using a side-launch camera from the sewer main. A majority of homes in pilot project areas had no cleanouts on the side sewer; therefore, using a conventional push camera was not an option unless a new cleanout was installed. Even when access is available, there may be inactive sources of I/I at the time of inspection. In addition, side sewer branches that cannot be observed during the inspection may include sources of I/I.

In a number of instances, a side launch camera inspection was terminated because the camera encountered a wye, a sharp bend, or a defect that prevented advance of the camera head. This prevented comprehensive investigation of the entire run of piping. Additionally, at the time of the SSES investigations, the use of side-launch cameras was limited to a length of approximately 80 feet; longer side sewer runs were not completely accessible.

When side-launch camera inspections were successful, they provided some data that was subsequently used to focus design efforts. In the Ronald project, the side-launch CCTV inspection was fairly successful; it identified the fact that about 20 percent of laterals and 66 percent of side sewers had defects. This was the basis of focusing the Ronald project primarily on side sewers. The other benefit of the side-launch camera inspection was that it provided an opportunity to locate the side sewer at the right-of-way line on the ground surface above the pipe using a locating transmitter attached to the camera head. This provided a horizontal location where the contractor could excavate a pit. Generally, the side-launch CCTV inspection was successful in laterals that were in reasonably good condition and did not have complicated piping configurations.

SSES should also include an assessment of the number of residences or businesses with sump pumps in the crawl space or basement that discharge to the sanitary sewer. Sump pumps that cannot be disconnected may limit the I/I removal effectiveness of an I/I rehabilitation project. SSES investigations should also extend to the foundations of the house to ensure that no foundation drain connections are overlooked.

9.5 Selection of System Components to Rehabilitate

When developing a lateral and side sewer I/I rehabilitation project, it is important to consider the cost of also rehabilitating sewer mains.

While the pilot project results suggest that a high percentage of I/I originates from laterals and side sewers, consideration should be given to the marginal additional cost of including sewer mains when developing a lateral and side sewer I/I rehabilitation project. In Skyway, work in the project area was bid in 1998 as primarily a lateral and side sewer project with a bid price of $0.9 million; however, a construction contract was never awarded. For the King County I/I pilot project, the work was expanded to also include bursting 9,500 linear feet of sewer mains and replacing 38 manholes, with a successful low bid of $1.3 million. The difference in the bid prices suggests that adding the sewer mains and manholes to the project was quite economical. During execution of the Kent project, the contractor proposed expanding the project scope to include sewer mains and manholes for a relatively small additional cost. The economy of rehabilitating sewer mains at the same time as laterals and side sewers was also confirmed by many of the contractors bidding on the pilot projects.

Adding the sewer mains and manholes to a lateral and side sewer rehabilitation project can be cost effective for a number of reasons:

- For pipe bursting projects such as Skyway and Kent, excavating a pit at the sewer main to reconnect the lateral to the sewer main is common to pipe bursting the sewer main and pipe bursting the lateral. Pipe bursting both mains and laterals under the same project may be economically attractive because performing the sewer main and manhole work adds the cost of pipe and manhole materials, but adds few additional pulling and insertion excavations.
- The contractor has already mobilized for the project.

The decision to include sewer mains and manholes in a lateral and side sewer rehabilitation project should be investigated from the perspective of long-term asset management as well as for providing additional I/I control.

9.6 Determining I/I Reduction Effectiveness

Accurate flow data collected during significant rainfall events and computer simulation modeling is required to quantify I/I reduction resulting from rehabilitation projects.

Collection of pre- and post-rehabilitation flow data is a critical part of determining the effectiveness of I/I reduction projects. Collecting open-channel flow data in small-diameter (8- to 12-inch) sewers is very challenging. However, by dedicating staff and resources to flow monitoring and by performing routine maintenance and field verifications on flow meters, flow data was successfully recorded for more than 95 percent of the monitoring period.

In order to collect accurate data, the team recognized the following factors that complicate flow monitoring:

- Wide ranges of flows, from low flows (less than 10 gallons per minute [gpm]) and low depths of flow (less than 1 inch in an 8-inch-diameter pipe), are difficult for meters to accurately measure.
- High flows and velocities with frequent debris accumulation on flow meter equipment can result in inaccurate data and require frequent maintenance.

The flow monitoring staff used area velocity meters that measure depth of flow, which can be used to calculate the cross sectional area of flow and an average velocity across the area of flow. It is difficult to measure flows with portable area velocity flow meters under low flow conditions because minor changes may not be accurately measured. Additionally, developing a reliable flow data record is complex given meter malfunctions, unique hydraulic anomalies at some sites, and erratic flow patterns that prevent establishment of normal dry weather sanitary sewer flow patterns. I/I reduction analysis also requires flow measurements from periods before and after the rehabilitation work. This may necessitate removing and then reinstalling a flow meter at a later date, which can result in data inconsistencies between monitoring periods due to installation and calibration differences.

The flow monitoring program for pilot projects should emphasize selection of flow monitoring sites and flow meter technology that will provide reliable results and consistent data, particularly if the flow meter will be installed for one season, removed, and then reinstalled for another monitoring season. Consideration should also be given to installing fixed monitoring equipment that will remain in place from one season to the next and provide consistent results between flow monitoring periods. Confidence in flow data increases as the flow rate increases (depth measurements at higher flows are more accurate than those for low flows). As pilot basin size increases, larger flows can be monitored and the I/I flows reduced as a result of rehabilitation can be more accurately quantified.

Three methods to quantify I/I reduction are as follows:

- Compare the flow response to storms before and after rehabilitation
- Evaluate the changes in flow response in a control basin and a rehabilitation basin
- Model by computer simulation

The first method was not used for this program because of the unique nature of storm events and the differences in antecedent (ground/trench) conditions at the beginning of a storm. The second and third methods were both evaluated as part of this program and computer simulation modeling was selected as the preferred method. Using a control basin (a similar basin without rehabilitation) provided reasonable estimates of the effectiveness of rehabilitation work; however, a number of issues can contribute to inaccuracies, including the difference in flow response between the control basin and the rehabilitation basin. Computer simulation modeling calibrated with the rehabilitation basin flow data provided the most reliable method of representing the actual system response to storm events and ultimately the I/I reduction achieved.

9.7 Working on Private Property

Maintaining a good working relationship among the contractor, contracting agency, and private property owners is imperative to performing successful I/I rehabilitation work on private property.

The approximately 75-percent I/I reduction achieved in the Kent and Ronald pilot projects demonstrates that lateral and side sewer rehabilitation is effective for I/I control. However, there were and continue to be significant concerns over performing work on private property due in part to the required interaction between agencies and property owners.

Factors that contributed to successful private property pilot projects included coordination and communication between all parties, advance public information and education, dedicated staffing for the project by the agencies and contractor, property owner incentives, and active local agency participation. Advance public education gained support for and understanding of the project from Ronald, Skyway, and Kent property owners. Therefore, a high percentage of property owners were engaged in the projects; property owners understood how they could participate, such as helping to locate cleanouts and refraining from using the sewer while construction was in progress. Active local agency participation was also extremely important for maintaining communication; the contractual relationship for sewer service is between the property owner and the local agency.

9.8 Successful Pilot Project Implementation

A collaborative process between King County and the local agencies resulted in pilot project success. The collaborative process was used to establish selection criteria, select project locations, establish intergovernmental agreements (IGA), and to coordinate during design and construction of the projects.

The 34 local agencies served by King County selected the pilot projects for the I/I Control Program. This was a consensus-based process that required the input and concurrence of these agencies. The collaborative process received praise and positive support from local agencies and helped keep them engaged in the program. King County considers this process very successful and it is being considered as a model for other implementation efforts. Any future program that requires the involvement of multiple stakeholders must establish processes that incorporate input from all parties.

Significant time and resources were necessary for administering construction of 10 concurrent pilot projects.

Simultaneous construction of 10 pilot projects required considerable time and resources to administer due to the duplicate administrative efforts required for multiple contracts. Options to reduce this impact include expanding the scope of individual projects or sequencing the contracts.

9.9 Rehabilitation Construction

Establishing minimum contractor experience requirements in the bidding documents helped ensure that qualified contractors were awarded the pilot project construction contracts.

During pilot project design, minimum experience requirements were established in the contract specifications for the variety of technologies applied to the projects. Pilot project objectives included demonstrating proven rehabilitation techniques and establishing the necessary experience requirements for ensuring that products would be installed correctly.

The trenchless sewer rehabilitation industry is unique in that a limited number of contractors in the local area are qualified to perform the work. For these pilot projects, two contractors were ultimately responsible for 8 of the 10 contracts. This limited representation of contractors on the pilot projects may not reflect the experiences anticipated on future rehabilitation projects.

When developing I/I rehabilitation construction contracts, consider the suitability of selected technology combinations and the combinations of contractors and subcontractors required for the work.

During pilot project design, there was interest in combining trenchless rehabilitation techniques and technologies to suit the needs of a specific project, and also to test a large cross section of techniques and products. This approach was somewhat incompatible with current practices of the contractors that perform trenchless sewer rehabilitation, and resulted in conflicts between contractors in a number of cases. No contractors submitted bids the first time the Manhole Project was issued for bid. For this project, a number of competing manhole rehabilitation products were included under a single contract and the response from potential bidders was that there was no interest in working cooperatively with manufacturers and installers of competing technologies.

The Ronald project was primarily a pipe bursting project, but also included several laterals to be rehabilitated using a cured-in-place lateral lining system. The laterals to be rehabilitated were very deep, and it was thought that the necessary excavations at these locations for pipe bursting would be prohibitively expensive. During construction the contractor proposed and was allowed to pipe burst these laterals because of the difficulty of mobilizing and coordinating the cured-in-place pipe (CIPP) contractor for these few laterals.

Glossary

aquifer — A layer of permeable rock or soil underlain by impermeable material that is capable of storing significant quantities of water and through which groundwater flows. The saturated portion of an aquifer is referred to as the zone of saturation. An unconfined aquifer is one in which the water table defines the upper water limit. A confined aquifer is sealed above and below by impermeable material. A perched aquifer is an unconfined groundwater body supported by a small impermeable or slowly permeable unit.

average dry weather flow (ADWF) — The average non-storm related wastewater flow between May and October. Composed of the average base flow and the average infiltration/inflow (I/I).

average wet weather flow (AWWF) — The average flow between November 1 and April 30. Composed of the average base flow and the average infiltration/inflow (I/I).

backfill — The operation of refilling an excavation, usually after some structure or pipeline has been placed. Also the material placed in an excavation in the process of backfilling.

base flow — Wastewater flow (not including inflow and infiltration) originating from residential, commercial, and industrial sources. Base flow can also refer to the portion of streamflow contributed by groundwater as opposed to runoff.

best management practice (BMP) — A method, activity, or procedure for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to Section 208 of the Federal Clean Water Act (40 CFR 130). Best management practices may include schedules of compliance, operation and maintenance procedures, and treatment requirements.

brushing laterals — The process where an air-powered motor with a wire brush head is placed in the sewer main and is used to clean up and smooth the edges of the liner where the liner was cut open for a service connection. Also prepares the connection for application of other products.

bypass — A diversion of flow around all or part of the treatment plant in emergencies.

Clean Water Act (CWA) — The Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.) as amended by the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500 and PL 93-243). Regulates discharge of pollutants into surface waters of the United States.

Code of Federal Regulations (CFR)	A codification of the general and permanent rules published in the Federal Register by the executive departments and agencies of the federal government.
coliform bacteria (fecal coliform)	Bacteria found in the intestinal tracts of mammals. The presence of high numbers of fecal coliform bacteria in a water body can indicate the recent release of untreated wastewater and/or the presence of animal feces. These organisms may also indicate the presence of pathogens that are harmful to humans.
combined sewers	A conveyance system designed to carry both wastewater and stormwater.
combined sewer overflow(CSO)	An overflow of combined sewers into surface waters when flows in the system exceed the capacity of the wastewater conveyance system. King County categorizes its CSO locations as either controlled or uncontrolled. Controlled CSO locations meet the Washington State Department of Ecology requirement that allows for no more than one untreated discharge per year.
control basin	A drainage basin similar to a pilot basin where no work was performed; it was used to compare the impact of change in the pilot basin as a result of rehabilitation.
conveyance system	A system, consisting of trunks, interceptors, force mains, pump stations, and other facilities which move wastewater from one place to another.
critical areas	Wetlands; streams; areas with a critical recharging effect on aquifers used for drinking water supply; fish and wildlife habitat conservation areas; frequently flooded areas; and geologically hazardous areas.
cured-in-place	Process of curing a resin that has been saturated in a fabric. The fabric is typically formed within an existing structure and will provide a rigid lining when the resin has fully cured.
cured-in-place pipe (CIPP)	Cured-in-place liner cured within a host pipe.
cutting laterals	The process where an air-powered motor with a cutter head is placed in the sewer main and is used to cut CIPP at the service connection. Typically a dimple in the liner shows where the hole is located.
dewatering	The removal of groundwater to reduce the flow rate or diminish pressure. Dewatering is usually done to improve conditions in surface excavations and to facilitate construction. Can also refer to removing water from a basin, tank, reservoir, or other storage unit, or from solid material such as the solids that are a byproduct of wastewater treatment.

discharge - direct or indirect	The release of treated or untreated wastewater into the environment. A direct discharge of wastewater flows into surface waters. An indirect discharge of wastewater enters a sewer system. Also used to describe water from a groundwater dewatering operation that enters surface water (direct), or a storm sewer (indirect), or to describe stormwater discharged to surface water.
drainage basin	Area that is drained by a river and its tributaries.
drawdown	Lowering of the water level in an aquifer, well, reservoir, or other body of water.
drop structure	A structure that would be built inside the influent portals to lower the wastewater conveyed from the shallower diversion structures to the deeper influent tunnel.
Earth Tech Team	A collection of firms led by Earth Tech that are providing consulting services to King County on the Regional I/I Control Program. The firms include KCM Tetra Tech, HDR Engineering, Cosmopolitan Engineering Group, Rosewater Engineering, ADS Environmental Services, Financial Consulting Solutions Group, Shannon and Wilson, and Triangle Associates.
easement	Rights obtained from a landowner to use a parcel of land for a specific purpose, such as for an underground pipeline or utility or for vehicular or pedestrian access to a road or sidewalk.
effluent	Treated wastewater that leaves the treatment plant.
Endangered Species Act of 1973, as amended (ESA)	Federal statute that provides protection for species of fish, wildlife, and plants that are listed as threatened or endangered.
Environmental Impact Statement (EIS)	A document that discusses the probable significant adverse environmental impacts of a development project or a planning proposal, discusses reasonable mitigation of identified impacts, and evaluates alternatives to the project and/or proposal. EISs are required under certain circumstances by the National Environmental Policy Act (NEPA) and/or Washington State Environmental Policy Act (SEPA).
exfiltration	Water that is discharged from a wastewater conveyance system into the ground through corroded or broken pipes or pipe joints.
fast response to rainfall	The water that quickly enters a wastewater conveyance system in response to rainfall. Typically this may be from pipe connections from storm sewers or combined sewers, catch basins, downspouts, and/or other surface runoff.
fill	Material used to raise the level of a low area or to make an embankment.
final design	The final phase of project design when contract plans and specifications necessary for bidding are prepared, and information needed by suppliers and contractors to construct the facility is provided. Follows predesign.

flow meter	A gauge that shows the rate of flow or volume of a fluid. In wastewater treatment, flow meters measure how many million gallons of wastewater moves through the system per day.
geographic information system (GIS)	A system of computer software, hardware, data, and personnel that helps manipulate, analyze, and present information that is tied to a spatial (usually a geographic) location.
gravity sewer	A sloping sewer pipe in which wastewater can flow by gravity.
groundwater	Water that infiltrates into the earth and is stored in the soil and rock within the zone of saturation below the earth's surface. Groundwater is created by rain, which soaks into the ground and flows down until it is collected at a point where the ground is not permeable. Groundwater then usually flows laterally toward a river, lake, or ocean. It is often used for supplying wells and springs.
groundwater table	The upper limit in the soil of underlying material permanently saturated with water.
Growth Management Act (GMA)	A Washington state law (Chapter 36.70A RCW), guided by procedural criteria and adopted by the Washington State Department of Community Development, that provides a legal framework and guidance for preparation of comprehensive plans, development regulations, and other land use planning for local governments.
head	The potential energy of water above a point. Head may be measured in either height (feet or meters) or pressure (pounds per square inch or kilograms per square centimeter).
host pipe	The existing sewer main or side sewer pipe inside which a liner is installed or within which a pipe bursting head is dragged.
hydrogen sulfide (H_2S)	A gas produced in sewers and digesters by anaerobic decomposition. Is detectable in low concentrations by its characteristic ”rotten egg“ odor, deadens the sense of smell in higher concentrations or after prolonged exposure, and damages the human nervous system from high exposure. Also converts to an acid when exposed to water and corrodes unprotected wastewater pipelines.
hydrograph	A series of flows and their associated times coming from one or more sub-basins. Hydrographs are used as input to King County’s hydraulic routing model to simulate the flows through trunk and interceptor systems.
hydrologic analysis	The study of the intensity and frequency of rainfall and the subsequent distribution and magnitude of flow into the wastewater conveyance system.
hydrologic cycle	The cycle of the earth’s water supply from the atmosphere to the earth and back, including precipitation, transpiration, evaporation, runoff, infiltration, and storage in water bodies and groundwater.

impervious surface	Any impenetrable material that prevents infiltration of water into the soil. Examples include rooftops, roads, parking lots, sidewalks, patios, bedrock outcrops, and compacted soil.
infiltration	The water that enters a wastewater conveyance system from the ground through means such as corroded or broken pipes, pipe joints,foundation drains, etc..
infiltration/inflow (I/I)	The total quantity of water from both infiltration and inflow without distinguishing the source.
inflow	The water discharged into a wastewater system from sources such as roof leaders, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, surface runoff, and street wash waters.
lateral	The portion of the private sewer service pipe on public right-of-way. Where the sewer service pipe is on private property, it is called a side sewer. See also “side sewer”.
local agencies	Water and sewer districts that receive wholesale wastewater services from King County.
manhole	A vertical shaft covered by a lid at ground level that provides access for maintenance of an underground pipe.
maximum wet-weather flow (MWWF)	The maximum daily wastewater flow during the wet winter months on rainy days. It is composed of maximum daily wastewater flows plus the maximum wet-weather infiltration/inflow during an approximately annual rainfall event.
Metropolitan Water Pollution Abatement Advisory Committee (MWPAAC)	MWPAAC advises the King County Council and Executive on matters related to water pollution abatement. It was created by state law and consists of representatives from the cities and sewer districts that operate sewer systems in King County. Most of these cities and sewer districts deliver their sewage to King County for treatment and disposal.
mini-basin	Drainage basins that were delineated as part of the 2000-2001 and 2001-2002 flow monitoring seasons. These basins were divided based on approximately 20,000 linear feet of sewer main within the basin.
mitigation	Avoidance of adverse impact by not taking a certain action or parts of an action; minimizing adverse impacts by limiting the degree or magnitude of the action and its implementation; rectifying an adverse impact by repairing, rehabilitating, or restoring the affected environment; reducing or eliminating an adverse impact over time by preservation and maintenance operations during the life of the action; compensating for adverse impacts by replacing or providing substitute resources or environments.

National Environmental Policy Act (NEPA)	Federal legislation establishing national policy that environmental impacts will be evaluated as an integral part of any major federal action. Requires the preparation of an Environmental Impact Statement (EIS) for all major actions significantly affecting the quality of the human environment (42 U.S.C. 4321-4327).
National Pollutant Discharge Elimination System (NPDES)	Section 402 of the federal Clean Water Act. Prohibits discharge of pollutants from a point source into (navigable) surface waters of the United States unless a permit is issued by the Environmental Protection Agency, a state, or (where delegated) a tribal government on an Indian reservation. These permits are referred to as NPDES permits and, in Washington state, are administered by the Washington State Department of Ecology.
open cut	A method for installing pipe near the surface, also called “trenching.” The open-cut method consists of three stages: digging a trench and stockpiling excavated materials; installing pipe in the trench; and backfilling the trench and restoring the surface.
packer	An inflatable plug that is placed inside a pipe and expanded with air pressure.
peak flow	The highest base flow and infiltration/inflow expected to enter a wastewater system during wet weather at a given frequency that the treatment plant is designed to accommodate.
pH	A measure of acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions. The number value increases with increasing alkalinity and decreases with increasing acidity. The pH scale ranges from 0 to 14.
pilot basin	That portion of a mini-basin where rehabilitation work was actually performed for the pilot projects.
pilot project	Mini-basin that was selected as a demonstration rehabilitation project for the King County I/I Control Program.
pit	An excavation to facilitate trenchless underground construction such as pipe bursting.
point source	A stationary location or fixed facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution, such as a pipe or ditch. A discharge pipe from a wastewater treatment plant or factory is a point source.
predesign	The initial phase of a project design process.
pump station	For wastewater purposes, a structure that houses pumps and other equipment for lifting wastewater in pipes to higher elevations so that it can continue to flow by gravity.

rapid infiltration	Infiltration into a wastewater conveyance system that is characterized by a rapid increase in flow during and/or shortly after a rainfall event, with gradual reduction in flow over a relatively short period after the event. This response is not as fast as inflow and is sustained longer than inflow.
Regional Wastewater Services Plan (RWSP)	A capital improvement program adopted by the King County Council in December 1999 to provide wastewater services to the King County Service Area through 2030.
Reinstating a service connection	Cutting the CIPP or tapping into the high density polyethylene (HDPE) pipe at the service connection so sewage can again flow into the main.
Relational Database Management System (RDBMS)	The database management system used during the Sewer System Evaluation Survey (SSES). Use of RDBMS facilitated links to information within or outside the database (for example, linking to GIS allowed the results to be viewed graphically).
residential customer equivalent (RCE)	A means by which King County charges its component agencies for wastewater services. For example, the charge for individual customers—single-family, multi-family, commercial, or industrial—in the City of Seattle is based on water consumption, which is converted into RCEs by dividing the monthly water consumption by 750 cubic feet. Component agencies outside the City of Seattle that do not measure residential water use charge each single-family house as one RCE; these agencies use the same method as the City of Seattle for their multi-family, commercial, and industrial customers.
return period	Average interval of the time or number of years between events of a given magnitude or larger (for example, peak discharge).
Revised Code of Washington (RCW)	A compilation of laws of the State of Washington published by the Statute Law Committee.
right-of-entry	A document signed by a property owner allowing work to occur on the property or access across the property.
right-of-way	A public or private right to use linear portions of properties, typically for roadway, railway, or utility purposes. Rights-of-way may be established through deeds or easements.
sanitary sewer	A pipeline that carries household, industrial, and commercial wastewater.
sanitary sewer overflow (SSO)	Untreated or partially treated overflows from a separated sewer in a wastewater conveyance system.
separated sewer	A wastewater pipe designed to accept and transport household, industrial, and commercial wastewater and to exclude stormwater sources.
sewage	See wastewater.

sewer	A pipe that carries wastewater and/or stormwater runoff from the source to a treatment plant or receiving water. Sanitary sewers carry household, industrial, and commercial wastewater. Storm sewers carry runoff from rain or snow. Combined sewers are used for both purposes.
shelf	The underwater equivalent of a plateau.
shoring	Props or posts of timber or other material in compression used for temporary support of excavations, formwork, or unsafe structures.
side sewer	The portion of the private sewer service pipe on private property. Where the sewer service pipe is on public right-of-way is called a lateral. Also see "lateral."
slow infiltration	Infiltration into a wastewater conveyance system that is characterized by a slow increases in flow during a rainfall event.. This increased flow may take several days or weeks after a storm to decline.
sole source	Specifying a product that only one manufacturer provides.
staging area	An area used for a number of purposes, such as parking and storing of materials and equipment, to support construction activities.
State Environmental Policy Act (SEPA)	A Washington state law (Chapter 43.21C RCW) that requires state agencies and local governments to consider environmental impacts when making decisions regarding certain activities, such as development proposals over a certain size, and comprehensive plans. As part of this process, environmental impacts are documented and opportunities for public comment are provided.
storm drain	A system of gutters, pipes, or ditches used to carry stormwater from surrounding lands to streams, lakes, or other receiving water. Also refers to the end of the pipe where the stormwater is discharged.
storm sewer	A pipe (separated from sanitary sewers) that carries only stormwater runoff from buildings and land surfaces.
stormwater	The portion of precipitation that does not percolate into the ground or evaporate. Stormwater flows across the ground surface in channels or ditches, or flows within pipes.
surcharge	The process of filling a conveyance pipe as a means to control sanitary sewer overflows.
surface water	Any water, including fresh water and salt water, on the surface of the earth.
suspended solids	Particles of organic or inorganic pollutants that float on the surface of, or are suspended in, wastewater and that cloud the water. Refers to sand, mud, and clay particles as well as solids in wastewater.
T-Liner®	A proprietary service connection and lateral liner (SCLL). A CIP product that lines a short section of the sewer main and up into the lateral. A product of LMK Enterprises.

TOP HAT™	A proprietary service connection liner (SCL). A CIP product that seals the connection of a lateral to the sewer main. A product of Cosmic Sondermashinenbau.
trenching	See open cut.
trenchless technology	A category of construction techniques that require little or no trenching to construct the improvements.
ultraviolet disinfection (UV)	A means to disinfect treated wastewater prior to discharge or reuse. Ultraviolet light penetrates the cells of microorganisms and destroys their ability to reproduce.
urban growth area (UGA)	Areas designated by counties in Washington state under the Growth Management Act within which urban growth is encouraged and outside of which growth can occur only if it is not urban in nature. Areas must be designated sufficient to accommodate projected growth for a 20-year period, and public services and utilities must be provided to serve the projected growth within the UGA.
Washington Administrative Code (WAC)	The codified regulations adopted by various Washington state agencies through the rule-making process.
Washington State Department of Ecology (Ecology)	The state agency designated by the Environmental Protection Agency (EPS) to be responsible for developing, implementing, and enforcing environmental protection laws and policies, including the state Clean Water Act and the Shoreline Management Act. Ecology issues the NPDES permit, which allows a wastewater treatment plant to operate.
wastewater	The water and wastes from homes and businesses that enter pipes and are transported to treatment plants for treatment and disposal.
water table	The upper surface of the zone of saturation of groundwater.
weir	An obstruction in the wastewater flow that is used to measure or control flow.
wetland	Land with saturated soils that are at least periodically inundated and that under normal conditions support vegetation suited to such environments. Wetlands include swamps, marshes, and bogs.