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