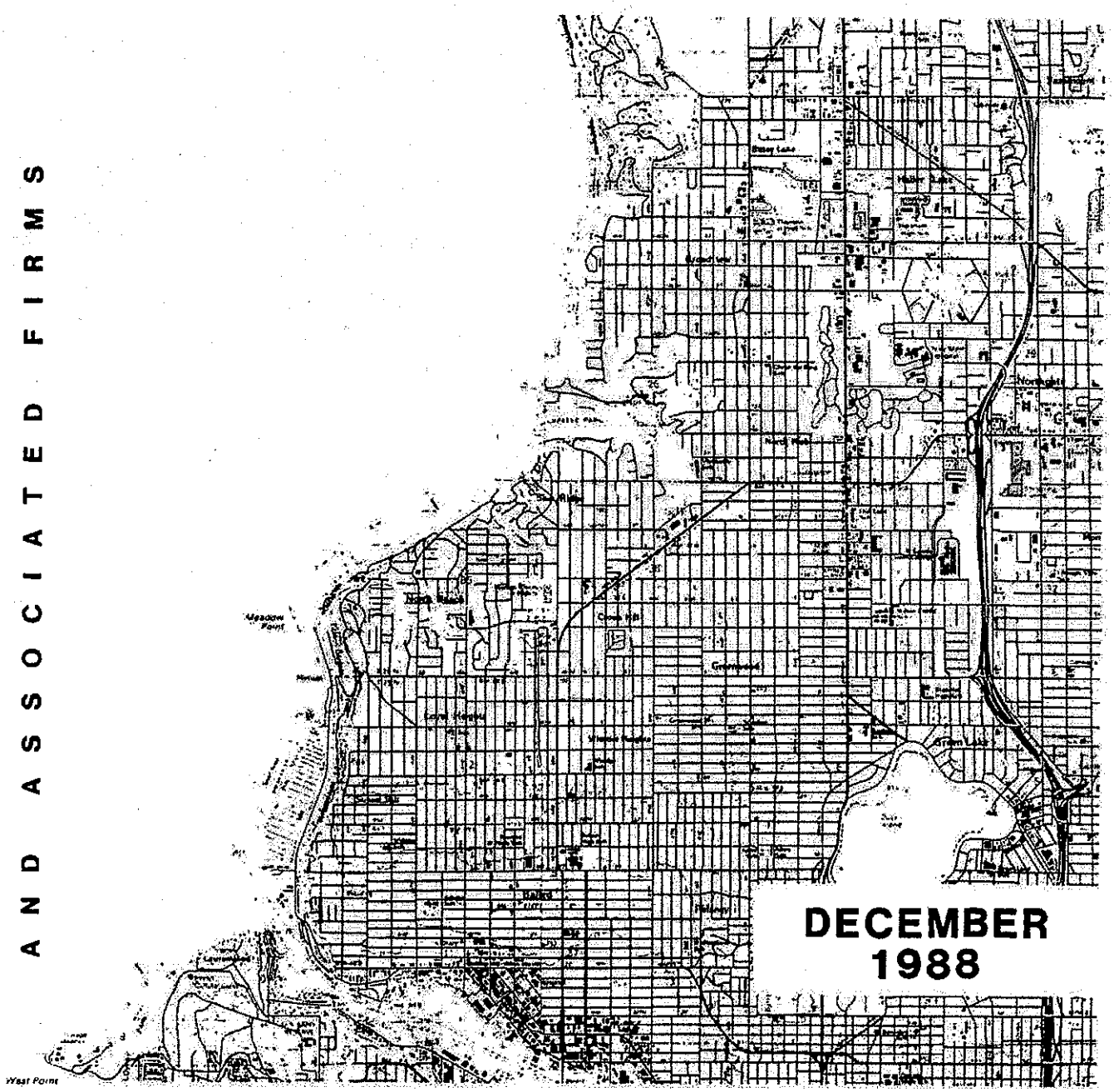
BROWN AND CALDWELL - CONSULTING ENGINEERS
AND ASSOCIATED FIRMS

# INFILTRATION/INFLOW ANALYSIS

# FACILITY PLAN FOR THE CARKEEK TRANSFER/CSO FACILITIES PROJECT




**DECEMBER 1988**

BROWN AND CALDWELL
CONSULTING ENGINEERS

December 15, 1988

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SEATTLE METRO FACILITY PLAN FOR THE
CARKEEK TRANSFER/CSO FACILITIES PROJECT
INFILTRATION/INFLOW ANALYSIS TASK 240

Enclosed are 25 copies of the final Infiltration/Inflow Analysis Report. The report has been prepared consistent with federal Environmental Protection Agency (EPA) and State Department of Ecology (WDOE) regulations and requirements.

The conclusions of the analysis are that current levels of infiltration and inflow are not economically excessive. As such, there is no economic incentive to rehabilitate the collection system for compliance with either the secondary treatment or the combined sewer overflow requirements.

If you have any questions, please call me.

BROWN AND CALDWELL

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**CARKEEK TREATMENT PLANT SERVICE AREA**
**INFILTRATION/INFLOW ANALYSIS**

This infiltration/inflow analysis is an integral part of the Seattle Metro Carkeek Treatment Plant predesign engineering report, and has been prepared consistent with U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (WDOE) regulations and requirements.

The focus of the analysis was: (1) to identify average wet weather infiltration/inflow for determining what flows should receive secondary treatment, and the peak storm-influenced infiltration/inflow value that is not exceeded more than once per year for determining what flows would be subject to WDOE combined sewer overflow (CSO) regulations; and (2) to identify if rehabilitation of the collection system to reduce infiltration and inflow was cost effective for meeting those requirements.

The analysis identified average wet weather flows (AWWF) of 3.73 mgd, which determined that up to 8.4 mgd should receive secondary treatment (WDOE regulations dictate treating up to 2.25 times AWWF), and peak storm-influenced flows for the one-year event of 32.5 mgd, the maximum flow subject to WDOE CSO regulations. Of this peak flow, it was estimated that 6 percent enters the local collection system, 7 percent enters laterals located within public rights-of-way, 57 percent enters private laterals, and the remaining 30 percent is from direct connections such as residential roof drains.

Rehabilitation of the collection system to reduce infiltration and inflow levels to that of a new separate system was estimated to cost $86.8 million. Unit present worth costs of infiltration/inflow removal, based on the one year hydraulic peak, varied from a low of $1.31/gallon up to $19.8/gallon, as compared to the recommended peak flow management program tributary to North Beach and the Carkeek system of 30 cents/gallon and 52 cents/gallon respectively. Unit present worth costs of infiltration removal based on average wet weather flows varied from $7.80/gallon up to $170/gallon as compared to the recommended secondary transfer/West Point treatment alternative of $3.60/gallon.

Thus the conclusions of this infiltration/inflow analysis are that, even though infiltration and inflow is hydraulically excessive compared to typical "separate" sanitary sewer systems, it is not economically "excessive." Thus there are not economic reasons for rehabilitating the collection system for compliance with the secondary and CSO requirements. This conclusion differs

from that presented in the February 1977 Metro analysis, where inflow removal was shown to be potentially economical. The differences in the conclusions can be explained by a change in the regulations. In 1977 the Carkeek collection system was considered a "separate" system, thus dictating that all flows including inflow should receive secondary treatment. Current rules limit inflow treatment to a less costly primary level up to the one year peak, with no treatment required beyond that peak value.

## INFILTRATION/INFLOW ANALYSIS

The purpose of this report is to determine if portions of infiltration and inflow that enter the collection system can be reduced more economically than they can be transported, stored, and treated. Specifically this analysis addresses the City of Seattle sewerage system that is tributary to Metro's Carkeek Park treatment plant.

This report builds upon information previously developed as part of Metro's 1977 Facility Planning process, namely the Metro Carkeek Park Infiltration/Inflow Analysis, February 1977, and the City of Seattle Infiltration/Inflow Analysis, Carkeek Park System, August 1979. Supplementing these reports are Metro's treatment plant flow data, Seattle Water Department water use data, and Puget Sound Council of Governments population data.

Key terms used throughout this report are presented below. The definitions are as adopted by the Federal U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (WDOE).

Infiltration: The water entering a sewer system, including sewer service connections, from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include and is distinguishable from inflow.

Inflow: The water discharged into a sewer system, including service connections, from such sources as, but not limited to, roof leaders, cellar, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross-connections from storm sewers and combined sewers, catch basins, storm waters, surface runoff, street wash waters, or drainage. Inflow does not include, and is distinguishable from, infiltration.

Infiltration/Inflow: The total quantity of water from both infiltration and inflow without distinguishing the source.

Excessive Infiltration/Inflow: The quantities of infiltration/inflow which can be economically eliminated from a sewer system by rehabilitation as determined by a cost-effectiveness analysis that compares the costs for correcting the infiltration/inflow conditions with the total costs for transportation, storage, and treatment of the infiltration/inflow.

## INFILTRATION/INFLOW ANALYSIS REGULATIONS

This infiltration/inflow analysis is subject to regulations promulgated by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology. The specifics of these regulations are identified below.

### Environmental Protection Agency Regulations

The EPA regulations are covered in 40 CFR Section 35.2005, Definitions, and 35.2120, Infiltration/Inflow, as amended in November of 1985. The EPA has also published four documents for preparation of Infiltration/Inflow Analyses, Sewer System Evaluation Surveys, and sewer system rehabilitation as identified below.

Sewer System Evaluation for I/I

Handbook for Sewer System Evaluation and Rehabilitation

Sewer System Evaluation, Rehabilitation, and New Construction, A Manual of Practice

I/I Analysis and Project Certification

Section 35.210, Infiltration/Inflow, is presented in its entirety below.

"(a) The applicant shall demonstrate to the Regional Administrator's satisfaction that each sewer system discharging into the proposed treatment works project is not or will not be subject to excessive infiltration/inflow. For combined sewers, inflow is not considered excessive in any event.

"(b) Inflow. If the rainfall induced peak inflow rate results or will result in chronic operational problems during storm events, or the rainfall-induced total flow rate exceeds 275 gpcd during storm events, the applicant shall perform a study of the sewer system to determine the quantity of excessive inflow and to propose a rehabilitation program to eliminate the excessive inflow. All cases in which facilities

are planned for the specific storage and/or treatment of inflow shall be subject to a cost-effectiveness analysis.

"(c) Infiltration.

"(1) If the flow rate at the existing treatment facility is 120 gallons per capita per day or less during periods of high groundwater, the applicant shall build the project including sufficient capacity to transport and treat any existing infiltration. However, if the applicant believes any specific portion of its sewer system is subject to excessive infiltration, the applicant may confirm its belief in a cost-effectiveness anaysis and propose a sewer rehabilitation program to eliminate that specific excessive infiltration.

"(2) If the flow rate at the existing treatment facility is more than 120 gallons per capita per day during periods of high groundwater, the applicant shall either:

"(i) Perform a study of the sewer system to determine the quantity of excessive infiltration and to propose a sewer rehabilitation program to eliminate the excessive infiltration; or

"(ii) If the flow rate is not significantly more than 120 gallons per capita per day, request the Regional Administrator to determine that he may proceed without further study, in which case the allowable project cost will be limited to the cost of a project with a capacity of 120 gallons per capita per day under Appendix A.G.2.a."

From previous studies it has been shown that the levels of infiltration- and inflow-influenced total daily flows at the Carkeek Park treatment plant are in excess of 120 gallons per capita and 275 gallons per capita respectively. Thus, by definition it is a requirement of the Carkeek Park project that an I/I Analysis be conducted that encompasses a cost-effectiveness analysis of potential sewer rehabilitation methods to eliminate excessive infiltration and inflow. The regulation related to combined sewer overflows in (a) above is superceded by the State requirement that inflow-related overflows shall be controlled to one overflow event per year, as identified in the following section.

In its publication titled "I/I Analysis and Project Certification," the EPA has set specific performance requirements for sewer system rehabilitation projects that receive federal grants. This requirement was a direct response to the ineffectiveness of many EPA funded sewer system rehabilitation programs in the 1970s and early 1980s.

At the end of the one-year performance period (i.e., one year after initiation of sewer system operation), the grantee must certify that the rehabilitation project has achieved an acceptable level of I/I reduction, dictating the need for post-rehabilitation flow monitoring.

A sewer rehabilitation project will be considered certifiable as long as the project is cost-effective (i.e., transport and treatment cost savings exceed rehabilitation costs). Figure 1 illustrates how EPA determines the minimum acceptable I/I reduction using the transport and treatment cost curve from the cost-effectiveness analysis. A separate determination is required for infiltration and for inflow, consistent with the original cost-effectiveness analysis.

The sunk cost is the actual cost of the rehabilitation program. The actual I/I reduction is determined by comparing post-construction flow to the flow data collected during the design study. If this requirement had been in force during the extensive rehabilitation efforts conducted in western Washington in the 1970s, most communities would not have had their projects certified.

State Department of Ecology Regulations

The State's regulations are encompassed in WAC 173-240-050, General Sewer Plan, WAC 173-240-060, Engineering Report, and WAC 173-245-040, CSO Reduction Plan. State guidelines are presented in Chapter 30, Infiltration/Inflow Correction, of the Criteria for Sewage Works Design.

The General Sewer Plan and the Engineering Report regulations require a discussion of infiltration and inflow problems, related overflows and bypasses, and proposed corrections and controls. The guidelines encompassed in the Criteria for Sewage Works Design provide definition of excessive I/I, the approach for conducting the I/I analysis, followup Sewer System Evaluation Surveys, and an overview of collection system rehabilitation techniques for infiltration and inflow elimination. Removal of I/I is required under the following conditions:

1. If excessive I/I is causing overflows or bypassing of treatment facilities.

2. If I/I removal is more cost-effective than expanding the treatment plant.

3. If excessive I/I is causing NPDES permit violations (85 percent removal requirement).

By definition, item 1 above dictates the conduct of this analysis. The findings of the report will address items 2 and 3.

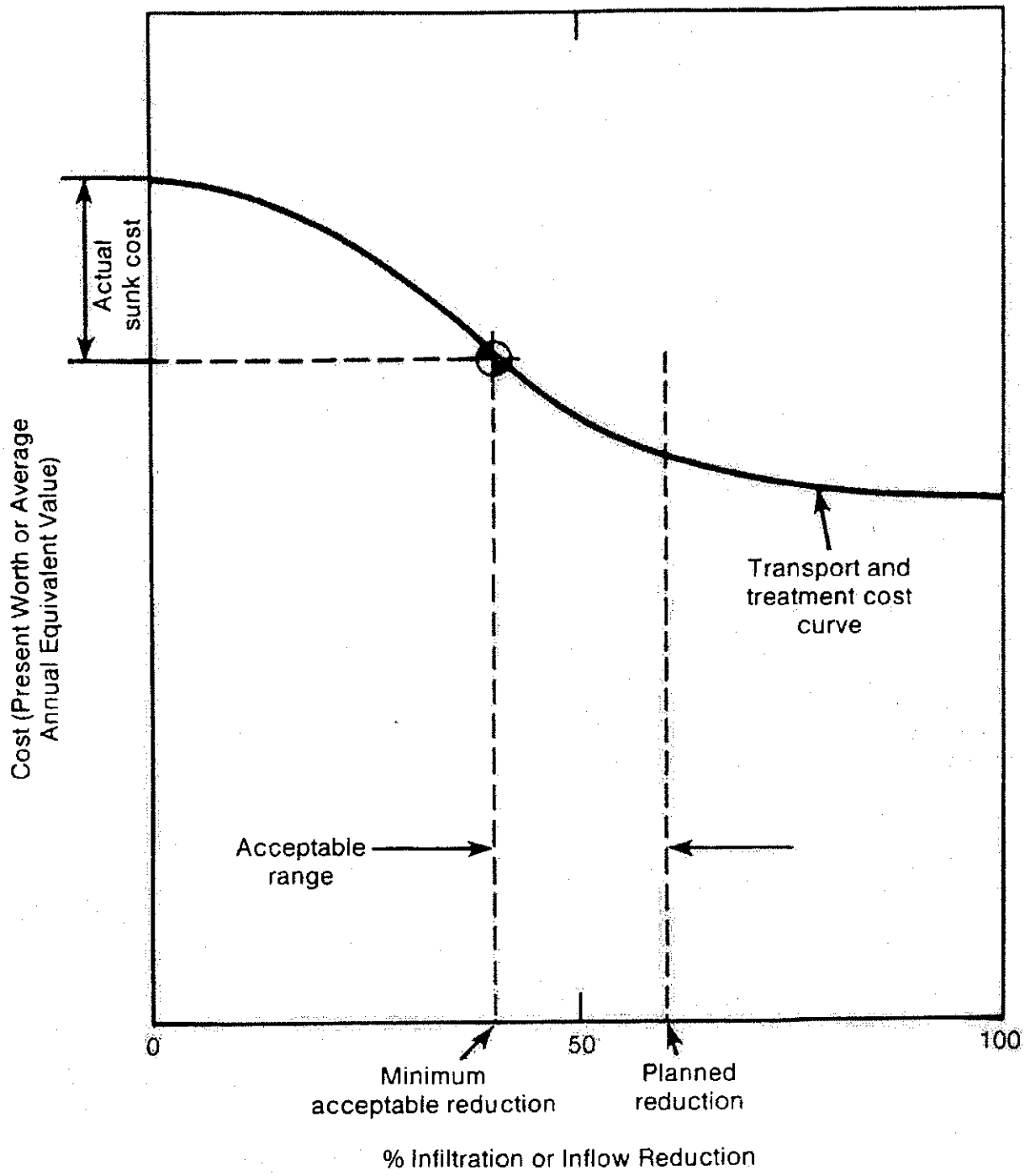



**Figure 1 Determining Acceptable Range of I/I Reduction**

The combined sewer overflow regulations require development of a program for achievement of "the greatest reasonable reduction of combined sewer overflows at the earliest possible date." This has been defined by WDOE as control to no more than one event per year with key progress milestones in the fifth and twentieth years of the control program. Control is defined as either elimination, through modifications to the collection system, or providing a minimum of primary treatment and disinfection prior to offshore discharge. Although the Carkeek Park tributary collection system has never been considered a permitted combined system, the hydraulic response to storms is consistent with that of a combined sewer. This dictates that the rainfall-induced peak inflow rate that will control facility hydraulic sizing is the storm condition that results in collection system flows that are not exceeded more than once per year.

The WDOE guidelines require that the I/I analysis consider the following:

> "The I/I study should ... project community wastewater needs and the impact of the progressive deterioration of the existing collection system over time.
>
> "The data utilized for the I/I study should include a water-use evaluation, a sewage strength evaluation, a maximum-minimum daily flow comparison, or a maximum daily flow comparison with base or night time domestic flow evaluation. For greater accuracy the collection system should be broken down into subsystems with separate measurements of the parameters noted above. Infiltration and inflow studies should be correlated to ground water level and climatological data. Hydrographs correlating I/I and rainfall can be helpful. The study should also include interviews with local contractors, collection system workers and treatment plant operators. Visual inspections of collection system elements should also be performed. Discussions of side sewer construction practice and the age of the collection system shall be included. The final report should include a present worth analysis generating a transportation and treatment cost curve."

The I/I analysis as presented in the following sections is developed consistent with the above guidelines and procedures. The present worth analysis generating the transportation, storage, and treatment cost curve will be developed as part of other subtasks.

# COLLECTION SYSTEM CHARACTERISTICS

The Carkeek Park wastewater treatment plant serves a residential area of approximately 2,400 acres located in the northwest corner of the City of Seattle. The service area is bounded by Puget Sound on the west, 85th Street on the south, Fremont Avenue on the east, and 145th Street on the north. For this analysis, the total area was divided into seven subdrainage areas, as shown in Figure 2. Three subareas (Nos. 2, 3, and 4) flow by gravity to the North Beach pump station and are then pumped to the treatment plant, and the other four subareas (Nos. 1, 5, 6, and 7) flow by gravity to the Metro interceptors leading to the plant.

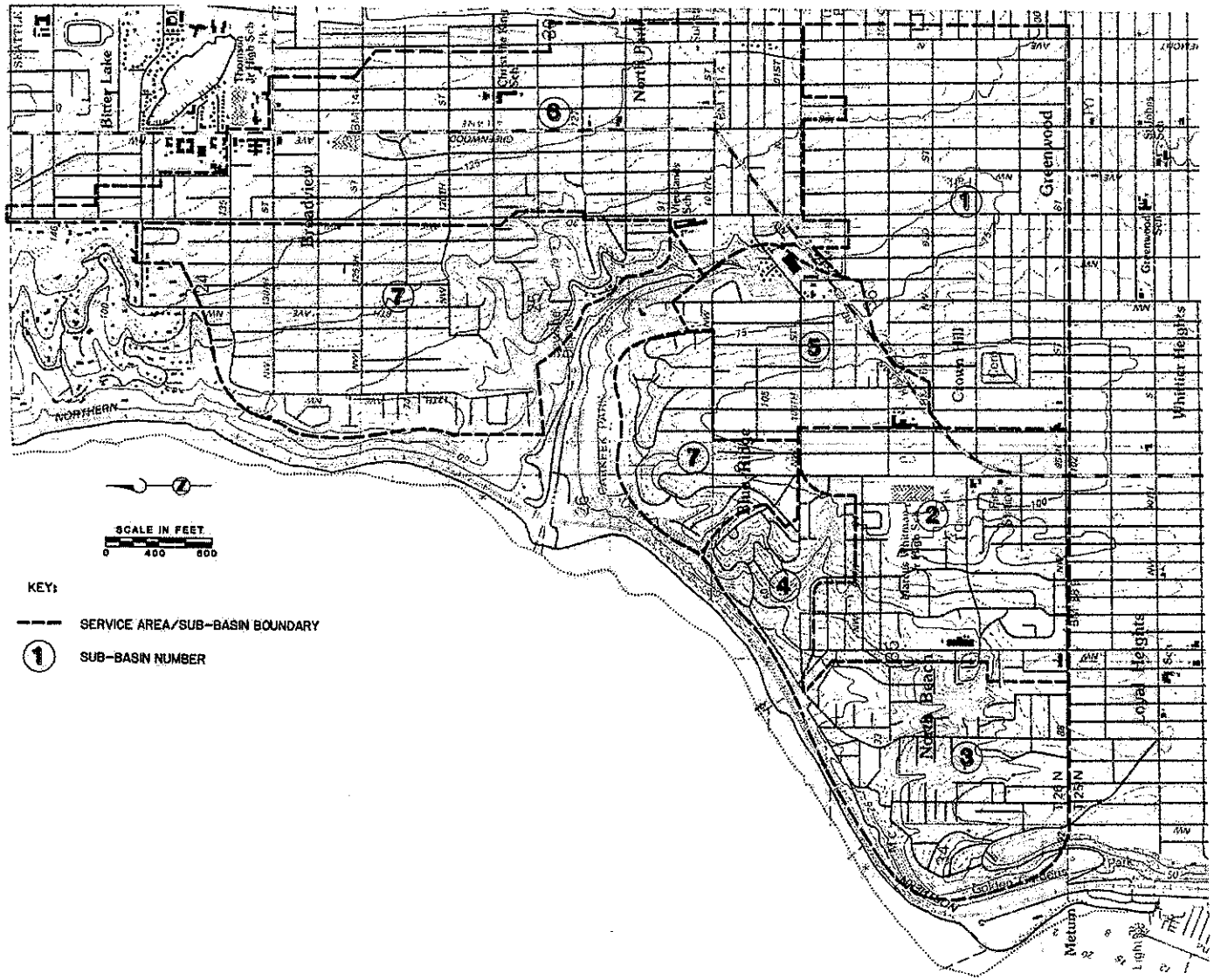
The current population of the service area is 25,600. This figure was developed from 1980 census tract data adjusted to 1988 population levels. The future population in year 2030 is expected to be 25,950. The population was allocated to subareas on the basis of sewered area assuming a uniform density. This is reasonable because the area consists primarily of single-family residences. The number of service connections in each subarea was based on review of the Seattle Sewer Utility "sewer card" records.

## Drainage Basins

Subdrainage basins were selected to more accurately define and locate infiltration and inflow; basin delineation was determined by the installed system characteristics. Sub-basin flow data was based on the monitoring conducted by Metro and Seattle's engineering staff as part of their 1977 and 1979 studies. The data was obtained from flow depth monitors installed in key manholes at the outlet point of each sub-basin. The tributary area upstream of the manhole then became a subdrainage area used in the analysis. An inventory of sewers by subdrainage basins including length by each diameter size, subdrainage service area, tributary population, and service connections is shown in Table 1. Sewered area and sewer inventory data were obtained from City of Seattle base maps.

Approximately 650 acres of the system drain by gravity to the North Beach pump station located at N.W. 100th Street and Triton Drive N.W. This area is characterized by steep ravines and steep bluffs along the waterfront. Three small local pumping stations serve portions of the areas along the waterfront in addition to Metro's North Beach pump station, which serves all the 650 acres. The flows are pumped from North Beach pump station via a 14-inch diameter force main along the waterfront and up Piper Creek canyon to the treatment plant.

The remaining service area flows by gravity to the Metro interceptor or force main which runs through Piper Creek canyon.

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SEATTLE, WASHINGTON

CARKEEK PARK TRANSFER/
CSO FACILITIES PROJECT

METRO Municipality of Metropolitan Seattle

FIGURE 2: CARKEEK SERVICE AREA AND SUB-BASINS

# Table 1. Carkeek Collection System Characteristics

| Subbasin Number | Area, acres | Population[a] | Sewer System, feet 6" | 8" | 10" | 12" | 15" | 18" | 21" | 24" | 30" | Laterals, Number[b] | Inch Diameter Miles City | Laterals City | Laterals Private[c] | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Beach PS | | | | | | | | | | | | | | | | |
| 2 | 303 | 3220 | 0 | 44930 | 5125 | 265 | 985 | | | | | 1139 | 81.18 | 25.89 | 38.83 | 145.90 |
| 3 | 248 | 2475 | 2680 | 32460 | 3930 | 1310 | 935 | 1830 | | 220 | | 906 | 72.54 | 20.59 | 30.89 | 124.02 |
| 4 | 102 | 715 | 415 | 9630 | 1570 | 825 | 580 | 850 | | | | 253 | 24.46 | 5.75 | 8.63 | 38.83 |
| Subtotal | 653 | 6410 | 3095 | 87020 | 10625 | 2400 | 2500 | 2680 | 0 | 220 | 0 | 2298 | 178.18 | 52.23 | 78.34 | 308.75 |
| Carkeek Plant gravity | | | | | | | | | | | | | | | | |
| 1 | 463 | 6305 | 21275 | 56915 | 1270 | 2620 | 340 | 1665 | 670 | 200 | | 2449 | 128.99 | 55.66 | 83.49 | 268.13 |
| 5 | 193 | 1630 | 5849 | 21380 | | | | | | | | 549 | 39.04 | 12.48 | 18.72 | 70.23 |
| 6 | 553 | 6370 | 17395 | 79330 | 6585 | 5975 | | | | | | 2456 | 166.02 | 55.82 | 83.73 | 305.56 |
| 7 | 561 | 5235 | 6650 | 60230 | 7365 | 5145 | 1520 | 2620 | 310 | 360 | 150 | 1826 | 141.43 | 41.50 | 62.25 | 245.18 |
| Subtotal | 1770 | 19540 | 51169 | 217855 | 15220 | 13740 | 1860 | 4285 | 980 | 560 | 150 | 7280 | 475.47 | 165.45 | 248.18 | 889.11 |
| Total | 2423 | 25950 | 54264 | 304875 | 25845 | 16140 | 4360 | 6965 | 980 | 780 | 150 | 9578 | 653.65 | 217.68 | 326.52 | 1197.86 |

[a] Population in 2030 based on facility plan forecasting
[b] Based on analysis of Seattle Engineering Dept sewer cards
[c] Assumes 4" diam. laterals and total lateral length of 75 ft, 30 feet within City right of way and 45 feet on private property

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Most of the subareas which flow by gravity to the treatment plant have moderate slopes except near Carkeek Park, where slopes are steeper. A bog area exists in a region of mild slope between N.W. 85th and N.W. 97th Streets and 6th Avenue N.W. and Greenwood Avenue North (subdrainage area 1).

Sewer Construction

Sewers in this area were first constructed in 1930 with most of the system being built in the 1950s and early 1960s. One of the first major sewer construction projects in the nation after the Second World War was the construction of sewers in this area under the jurisdiction of the Greenwood Sewer District. Pipes used in sewer construction up to and including most of the construction in this area were made of concrete with mortar joints. However, in the flat area south of Holman Road from N.W. 97th Street to N.W. 85th Street and from Greenwood Avenue to 7th Avenue N.W., the soil is a fibrous, wet and highly compressible peat ranging from zero to 18 feet in depth. Sewers constructed by the Greenwood Sewer District in this very wet and spongy area utilized corrugated metal pipes (CMP). Records are not clear as to how much corrugated pipe was used; however, it is believed that at least 10,000 feet was installed in this area. Little is known about the type of joints used with the corrugated metal pipe; however, it has been reported that little if any testing was required to determine tightness of the corrugated metal pipe. Since the watertable in this area is just below the surface, infiltration could be expected to be high the year round. The City has in their 1989 Capital Improvement Plan a project to replace 5,100 feet of CMP with reinforced concrete rubber gasket pipe in Subarea 1, equivalent to 6 percent of the City subarea collection system.

Stormwater Drainage

Stormwater ponding and leaking stormwater transfer lines are potential sources for both inflow and infiltration. The provision of efficient stormwater collection facilities and sealed stormwater transfer lines and ditches will reduce the possibility of these waters entering the sanitary sewer system. Points at which storm sewers and surface drainage ditches cross sanitary sewers have historically been sources of infiltration/inflow. Localized ponding in addition to being a potential inflow source feeds upper groundwater tables to become a potential infiltration source. In addition, provision of an adequate storm drain system reduces the temptation to utilize the sanitary sewer to solve a local drainage problem.

Most of the Carkeek Park service area storm drainage system is limited to open ditches alongside roads. The only area with an extensive storm sewer system is the area south of Holman Road between 8th Avenue N.W. and Greenwood Avenue N.W. This area was

originally a boggy area and has poor natural drainage. The storm sewers in this area transport the flow along 8th Avenue N.W. to N.W. 105th Street, where it discharges into Piper Creek, which then flows to Puget Sound. Piper Creek has had about 15 rock dams placed in the stream to help dissipate energy and reduce erosion. Several other short stretches of storm sewers exist between N.W. 105th Street and Carkeek Park, and in the North Beach area. These storm sewers, except North Beach storm sewers, also discharge to Piper Creek. Thus extensive removal of direct connections will require potential upgrading of the local drainage systems, and possibly additional measures to prevent erosion of Piper Creek.

Groundwater

Groundwater, as an established groundwater table, a temporary perched table, or percolating through the soil during and as a result of storms, is a potential infiltration source. A knowledge of the extent and level of groundwater relative to the sanitary sewer system can identify those areas subject to infiltration. For dry season periods, assuming no yard irrigation, the established groundwater table is the only infiltration source, and only those sewers below the table, regardless of open joints or other structural defects, will be subject to infiltration. However, during the rainy season, percolating groundwater and temporary perched tables confuse the issue, making the identification of infiltrating sewers much more difficult. Typically through the rainy season established groundwater levels rise, covering more of the sewer system and increasing the hydrostatic head on previously submerged areas. The direct influence of the seasonal fluctuating groundwater table in the Carkeek Park service area is well illustrated.

Analysis of available established groundwater level data indicated that during the summer season those areas adjacent to streams and the area south of Holman Road between 8th Avenue N.W. and Greenwood Avenue N.W. have sewers below the groundwater table. During the wet season all the collection system is subject to percolating, temporary perched, and rising established groundwater tables.

## INFILTRATION/INFLOW QUANTIFICATION

The foundation of the infiltration/inflow analysis is the quantification of the total system infiltration/inflow and the allocation to the system components. WDOE's criteria for the Carkeek service area is control of storm-influenced overflows to no more than one event per year. Thus for this analysis it is the flow resulting from storm conditions that results in the one-overflow event that controls the initial sizing criteria for transport and treatment facilities. Thus for this analysis the

flow values of infiltration and inflow that determine alternative facility sizing is the peak value, namely the peak hour rate from the one event per year condition. Annual costs of operation and maintenance are a function of flow volume.

The basin flow and total system flows are by definition the product of the wastewater discharged to the collection system, ground water leaking into the system (infiltration), and, during storms, storm inflow. Each of these flow parameters varies: wastewater flows vary throughout the day reflecting the living and working patterns of the community; infiltration varies on a seasonal basis increasing through the rainy season as ground water levels rise; and inflow varies dependent on recent rainfall events and the characteristics of the specific storm.

To meet WDOE criteria, the critical flow values for the Carkeek Park wastewater program are: (1) the average flow for the wet weather season (discharged wastewater plus average wet season infiltration/inflow) because it defines how much flow shall receive secondary treatment (2.25 times average wet weather flow--AWWF); and (2) the peak hour flow that on average is not exceeded more than once per year (discharged wastewater plus maximum month peak hour infiltration plus peak hour inflow) because this defines the flows that have to be managed under the CSO control element of the program. To identify the secondary and CSO flow values, and to provide a basis for allocating the infiltration and inflow flows to the collection system components, we need to define maximum month infiltration, average wet weather infiltration, dry season minimum infiltration, and the one year event peak hour infiltration and peak hour inflow.

In summary, to conduct the analysis the following flow data is required for each sub-basin:

1. Base wastewater flow and its diurnal characteristics.

2. Infiltration:

   Dry season minimum, mgd
   Wet season, mgd
   Maximum month, mgd
   Maximum peak hour, mgd
   Annual volume, MG

3. Inflow (resulting from the one overflow event rainfall condition):

   Maximum peak hour, mgd
   Annual volume, MG

Base Wastewater Flow

Two different methods can be used to estimate base wastewater flows: (1) analysis of water use data, and (2) plant diurnal flow characteristics. Wastewater flows attributable to residential, commercial, and industrial uses are related to water consumption. Since lawn watering and other nonsewer water uses are minimal during winter months, domestic winter water use consumption is more representative of domestic wastewater flow. Water consumption data from the Carkeek Park service area was analyzed from Seattle Water Department records. For 1987, domestic winter water use averaged 1.69 mgd. For the current tributary population of 25,600, winter water consumption is equivalent to 66 gallons per capita per day. Assuming 90 percent of delivered water enters the sewer, this is equivalent to 60 gallons per capita per day. From previous analysis in the 1985 facility plan, commercial employment sewage contributions were estimated at 20 gallons per employee.

Another way to estimate wastewater base flows is to analyze plant early morning flows, a time when wastewater discharge is at a minimum, and then compare with daily average flows for nonstorm-influenced days. Minimum flows are made up of infiltration plus minimum wastewater flows.

$$Q\ min = Q\ w\ min + infiltration \qquad (1)$$

Average daily flows are made up of wastewater flows plus infiltration.

$$Q\ av = Q\ w\ av + infiltration \qquad (2)$$

The relationship of average wastewater flow to minimum flow on the basis of tributary population has been documented by a number of researchers. For the Carkeek Park service area, based on data developed in Wastewater Engineering by Metcalf & Eddy, typically the relationship is:

$$Q\ w\ min = Q\ w\ av \times 0.34 \qquad (3)$$

By substituting equation (3) in (1) above, the following expression can be developed:

$$Q\ min = Q\ w\ av \times 0.34 + infiltration \qquad (4)$$

By analysis of any 24-hour nonstorm influenced flow data, assuming no change in infiltration for the 24-hour period, and applying equations (2) and (4), infiltration and base wastewater flow can be estimated.

Typical values for the 1987 dry season were average daily flows of 2.5 mgd and minimum flows of 1.4 mgd. Applying this

data to equations (2) and (4) indicates that infiltration is approximately 0.83 mgd and sewage flow is 1.67 mgd. Thus, based on this approach, the per capita residential sewage contribution was 62 gallons per day, assuming 20 gallons per employee for the estimated 4,000 commercial employees.

These values are consistent with those developed in the 1985 Secondary Facilities Plan. For this analysis, sewage flows are based on 60 gallons/day/resident and 20 gallons/day/employee, and calculate out to 1.61 mgd in 1988. In 2030, based on a projected residential population of 25,950 and commercial employment of 6,660, sewage flows will be 1.69 mgd.

Total System Infiltration and Inflow

Total system infiltration and inflow characteristics were determined from analysis of treatment plant influent flow data for the years 1985, 1986, and 1987. To assist the analysis the three years of data, including maximum hour, minimum hour, and total daily flow for each day, were entered into a computer data file for subsequent manipulation as further described below. Infiltration values for nonstorm days were calculated by (a) deducting the minimum base sewage flows from minimum recorded daily flows; and (b) deducting the base sewage volume from the daily volume and then taking the average value. For storm days, infiltration was calculated by analysis of the nonstorm days immediately following the storm and applying the value to the preceding day to determine storm infiltration effect.

Inflow characteristics were similarly determined by initial analysis of plant data. For each day plant maximum, minimum, and daily flows are recorded. Storm inflow was calculated by deducting the sum of base sewage flow plus infiltration from the recorded daily flow, adjusted to reflect the base sewage diurnal characteristics and the timing of the peak plant flow.

For this analysis the inflow value of importance is the peak hour value resulting from the one event per year condition, an event that results in overflows upstream of the treatment plant at the North Beach pump station and exceeding the plant's influent metering capacity. To cover the missing and limited data, a hydraulic model was used simulating flows within the Carkeek Park system. To provide the necessary data, the model provides estimates of the three flow components--base sewage flow, infiltration, and inflow--in response to the rainfall record. To provide peaking conditions, the model is designed to provide hourly estimates of parameters. The available plant records and monitoring records were used to calibrate and verify the simulation program constructed to implement the model, with determination of seasonal infiltration and inflow values as described above. The program was then used to fill in missing information through simulation of the system over the available

long-term rainfall record. The resulting simulation data base of historical flow and loading conditions is used to provide statistical distribution and definition of the one-year event for the current collection system. A more detailed description of the hydrologic simulation model is described below.

Hydrologic Simulation

The infiltration and inflow into any sewerage system is a function of immediate and past rainfall. In summary, the hydrologic simulation model is designed to generate a continuous hourly flow trace in the sewer system as a function of a continuous hourly rainfall trace (44 years of record). The details of converting a continuous rainfall trace into these components of flow are described below.

Infiltration. Water infiltrating into a sewer system depends on the depth of groundwater above the sewer (a long-term continuous process), and/or water available in the saturated zone surrounding the sewer (a more short-term process). The rate of infiltration also depends on the physical condition of the sewer.

Empirical evidence suggests that infiltration depends on a time series of past rainfall, from a relatively immediate response in areas where the sewer is close to the surface and in poor condition, to a long-term response where the groundwater table influences the process. In this simulation, the infiltration process is described by adding components that are due to rainfall over the periods of (a) the previous 24 hours, (b) the previous seven days, (c) the previous 30 days, and (d) the previous six months. The longer time components reflect the influence of changes in the groundwater table. The technique adopted is essentially equivalent to that used in the EPA Storm Water Management Model (SWMM) as described in the SWMMIII Users Manual. The technique is shown in the following equation:

$$\text{Infiltration} = Cd*R1 + Cw*R7 + Cm*R30 + Cs*R180 + Basinf$$

where: Cd = a coefficient describing the response to rainfall over the past 24 hours.

Cw = a coefficient describing the response to rainfall over the last 7 days.

Cm = a coefficient describing the response to rainfall over the last 30 days.

Cs = a coefficient describing the response to rainfall over the last 180 days.

R1, R7, R30, R180 = corresponding rainfall depths over the respective periods.

Basinf = Minimum expected infiltration rate.

The above equation is used to estimate the infiltration rate during any hour of the simulation. In practice, as in this case, the various coefficients were found by calibration. This involved observing the response of infiltration to past rainfall by direct plots, and multiple regression analyses after removal of inflow from the observed record. The various components are fine tuned by comparison of the simulation with recorded flows over an extended period.

Inflow. By definition, the source of inflow is from tributary service area that is directly connected to the sanitary sewers via illegal or purposeful connections. The connected area is ordinarily assumed to be only impervious surface in standard I/I analyses. Some pervious surface may be connected, as in combined systems, or where cross-connections to a stormwater system exist.

To simplify the simulations, inflow is computed by the rational method. Inflow from impervious surfaces in any hour of the simulation is simply the product of the rainfall depth that occurred that hour times the impervious surface area. Where pervious surfaces are known to be connected, inflow from these sources is generated in the same way after subtraction of a rainfall abstraction to account for infiltration. Pervious area runoff is the product of the hourly rainfall less the estimated infiltration rate times the estimated pervious surface connected. Pervious surface runoff is obviously zero if the rainfall does not exceed the estimated surface infiltration capacity. In the current simulation, the infiltration capacity does not vary with antecedent rainfall.

The simulation requires an estimate of the directly connected pervious and impervious surface area. Alternatively, these values may be determined by calibration to match observed hydrographs with simulated values, the approach adopted in this analysis.

The service area has been broken down into 7 sub-basins for simulation. These include the basins showing the highest infiltration/inflow from previous studies so that the affect of correction efforts may be examined directly.

Sanitary Flow Simulation. The domestic wastewater component of flow was simulated by applying an average diurnal normalized hydrograph to the average estimated domestic sewage flow. The resulting hydrograph is normalized by division by the average value to give a hydrograph of percentage of average flow by hour of the day.

## Infiltration/Inflow Characteristics

The infiltration and inflow characteristics for the seven sub-basins and total system based on the modelling analysis is presented in Table 2. Infiltration values are presented for dry season flows, wet season flows, maximum month daily average, peak hour, and average annual values. Inflow is presented for peak hour and annual volume. From the presented data, dry season minimum, maximum month average infiltration, and average wet season infiltration/inflow values are 0.43, 3.16, and 2.04 mgd respectively; peak hour infiltration is 7.15 mgd; and peak hour inflow is 23.62 mgd. Annual average infiltration and inflow volumes are 471 and 76 MG respectively.

Table 2. Subarea Infiltration and Inflow Characteristics

| Subbasin number | Base domestic, 1988[a] | Infiltration | | | | | Inflow | | Average wet season I/I, mgd |
|---|---|---|---|---|---|---|---|---|---|
| | | Minimum season, mgd | Dry season, mgd | Max month, mgd | Peak hour, mgd | Annual, MG | Peak hour, mgd | Annual, MG | |
| North Beach PS | | | | | | | | | |
| 2 | 0.19 | 0.039 | 0.100 | 0.41 | 1.02 | 55.9 | 1.14 | 7.0 | 0.24 |
| 3 | 0.15 | 0.169 | 0.340 | 1.07 | 2.18 | 171.7 | 2.17 | 15.0 | 0.67 |
| 4 | 0.04 | 0.002 | 0.004 | 0.02 | 0.32 | 2.4 | 1.88 | 10.3 | 0.05 |
| Subtotal | 0.38 | 0.21 | 0.444 | 1.50 | 3.52 | 229.9 | 5.19 | 32.4 | 0.96 |
| Carkeek Plant gravity | | | | | | | | | |
| 1 | 0.41 | 0.189 | 0.380 | 1.49 | 3.06 | 206.1 | 4.00 | 16.2 | 0.83 |
| 5 | 0.11 | 0.003 | 0.010 | 0.02 | 0.07 | 4.5 | 0.67 | 3.0 | 0.03 |
| 6 | 0.40 | 0.012 | 0.030 | 0.08 | 0.27 | 15.8 | 4.19 | 4.7 | 0.08 |
| 7 | 0.31 | 0.011 | 0.030 | 0.07 | 0.21 | 14.1 | 9.58 | 20.2 | 0.15 |
| Subtotal | 1.23 | 0.22 | 0.450 | 1.66 | 3.62 | 240.6 | 18.42 | 44.0 | 1.09 |
| Total | 1.61 | 0.43 | 0.894 | 3.16 | 7.15 | 470.5 | 23.62 | 76.4 | 2.04 |

[a]Base residential sewage flow at 60 gallons/capita/day and commercial employment at 20 gallons/capita/day.

Design flow values projected for the year 2030 are presented in Table 3. Based on a 2030 service area residential population projection of 25,950 and a commercial/industrial employment projection of 6,660, the base sewage flow is projected at 1.69 mgd. As the small population increase will be served by the existing collection system, current infiltration and inflow values are assumed, assuming no extensive rehabilitation of the collection system, to be representative of future values. The flow required to receive secondary treatment, based on 2.25 times the projected average wet weather flow of 3.73 mgd, is 8.4 mgd.

The peak flow projected for the one year event flow that defines the maximum flow subject to the CSO regulations is 32.5 mgd.

Table 3. Average Wet Weather Flow, mgd

| Subbasin number | Base sewage, 2030[a] | Average wet season infiltration/ inflow | Average wet weather flow | Peak hour infiltration/ inflow | Peak hour flow |
|---|---|---|---|---|---|
| North Beach PS | | | | | |
| 2 | 0.19 | 0.24 | 0.43 | 2.16 | 2.35 |
| 3 | 0.15 | 0.67 | 0.82 | 4.35 | 4.50 |
| 4 | 0.04 | 0.05 | 0.09 | 2.20 | 2.25 |
| Subtotal | 0.38 | 0.96 | 1.34 | 8.71 | 9.10 |
| Carkeek plant gravity | | | | | |
| 1 | 0.44 | 0.83 | 1.27 | 7.06 | 7.50 |
| 5 | 0.11 | 0.03 | 0.14 | 0.74 | 0.85 |
| 6 | 0.44 | 0.08 | 0.52 | 4.46 | 4.90 |
| 7 | 0.31 | 0.15 | 0.46 | 9.79 | 10.10 |
| Subtotal | 1.30 | 1.09 | 2.39 | 22.04 | 23.35 |
| Total | 1.69 | 2.04 | 3.73[b] | 30.77 | 32.45[c] |

[a]Based on 2030 service area population projections.
[b]Secondary treatment flow sizing 2.25 times 3.73 = 8.4 mgd.
[c]Peak hour one-year event flow = 32.5 mgd. Flows subject to CSO regulation 8.4 to 32.5 mgd.

## Infiltration Allocation

For each of the seven subareas, the sum of infiltration occurring within service laterals and local agency sewers was identified above. To determine the effectiveness of rehabilitation efforts, the allocation of the infiltration values to the system components is required. The components of the collection system are illustrated in Figure 3. Components of the collection system that are subject to infiltration include City-owned interceptors, local sewers and manholes, City-owned service laterals to the right-of-way/private property line, and the privately owned service laterals from the property line to the service connection. Inflow sources include roof downspouts, area drains, and leaking manhole covers. For non-storm periods potential infiltration sources are groundwater and yard irrigation; and for storm periods, groundwater, perched groundwater, and rainfall percolating through the ground. Infiltration was allocated to the system components as identified in Table 4.

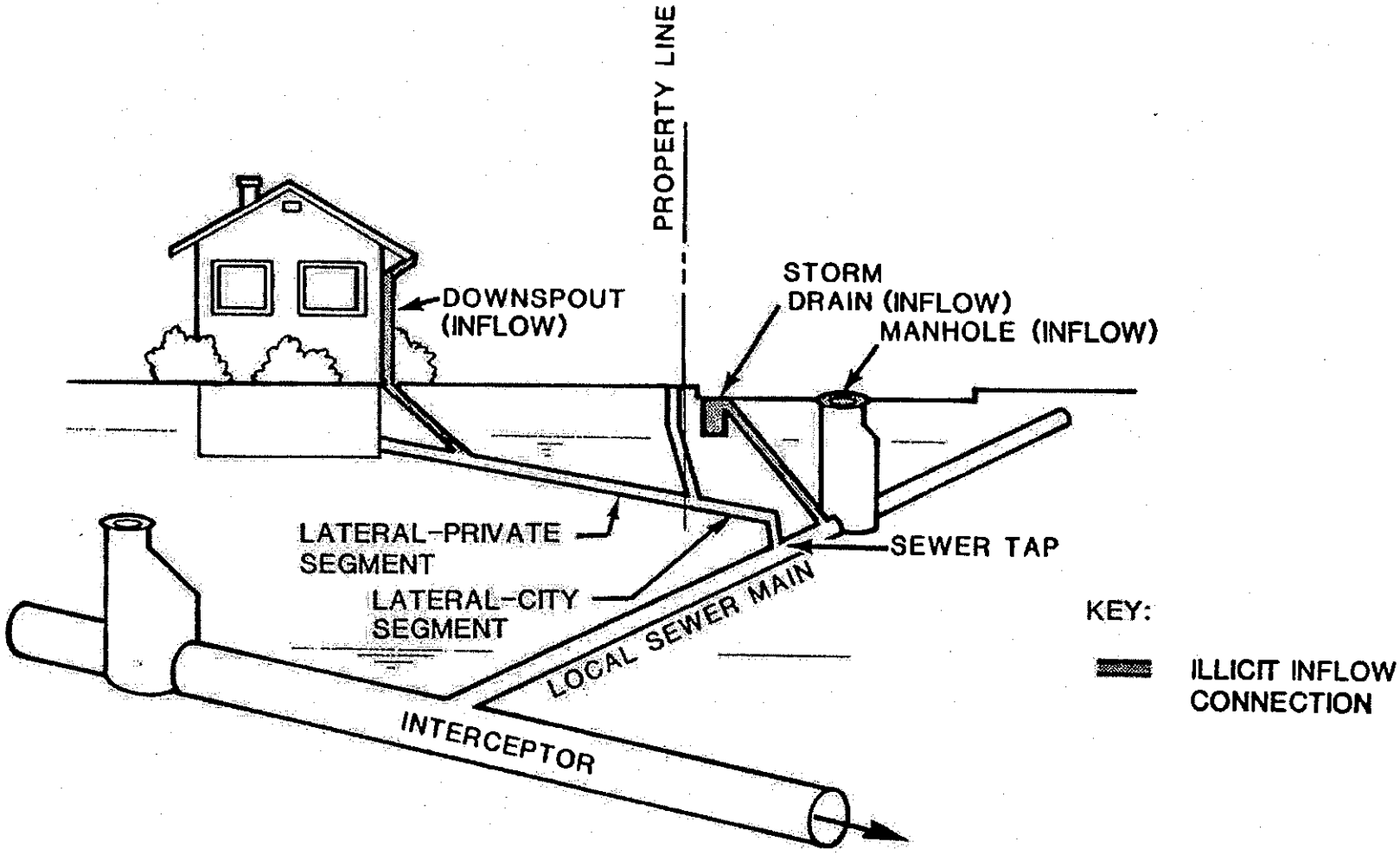


Figure 3 Collection System Components

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Table 4. Collection System Component Infiltration Allocation

| Infiltration component | City sewer | Lateral | |
|---|---|---|---|
| | | City right of way | Private |
| Dry season minimum, mgd | a | -- | -- |
| Maximum month--wet season, mgd | b | b | b |
| Peak hour--maximum month, mgd | -- | c | c |

[a]100 percent allocated to City Sewer.
[b]Allocated proportional to inch-diameter-mile of three components.
[c]Allocated proportional to inch-diameter-mile of the two elements of the lateral.

## Inflow Allocation

By definition, inflow is limited to storm periods. Inflow sources are roof drains, area drains and near surface open joints and cracks in the collection system (the laterals). Roof and area drain sources, which act like an impervious connected area, can be eliminated by disconnection or relocation to storm sewers. Elimination of inflow from near surface laterals, which act like a pervious connected area, requires either replacement or rehabilitation of the line. Inflow sources were allocated to private service laterals and unknown direct connections in the ratio of pervious or impervious connected area to total connected area, respectively. The impervious to pervious connected tributary areas were determined from the hydraulic simulation model, with the boundaries of impervious or pervious never exceeding 80 percent or being less than 20 percent.

## Infiltration/Inflow Collection System Component Allocation

The allocation of I/I to the system components based on the above assumptions is summarized in Table 5. From this table of the predicted peak hour I/I flow of 32.17 mgd resulting from the one year overflow event storm, 1.88 mgd/6 percent is shown to enter the local collection system; 2.29 mgd/7 percent is shown to enter the laterals located within public right-of-way; and 18.27 mgd/57 percent is shown to enter private laterals. The remaining 9.73 mgd/30 percent is from unidentified direct connections. The relative infiltration values in terms of gallons per day per capita and in terms of component element inch-diameter-mile, and inflow values in terms of gallons per day per capita and in terms of gallons per sewered acre per day, are shown in Table 6. The per capita flow rate during the period of the highest ground water table (i.e., maximum month non-storm flows) is 190 gallons per day per capita, and during peak storm flows is 1,300 gallons per day per capita, both in excess of EPA's 120 and 275 gpcd values respectively, thus dictating this analysis be conducted.

## Table 5. Allocation of I/I to System Components, mgd

| Subbasin Number | Local Collection System Minimum Infil | Local Collection System Max Month Infil | Local Collection System Total | Local Agency Laterals Max Month Infil | Local Agency Laterals Peak Hour Infil | Local Agency Laterals Total | Private Laterals Max Month Infil | Private Laterals Peak Hour Infil | Private Laterals Inflow | Private Laterals Total | Direct Connection Inflow | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Beach PS | a | b | | b | c | | b | c | d | | d | |
| 2 | 0.039 | 0.206 | 0.245 | 0.066 | 0.249 | 0.315 | 0.099 | 0.373 | 0.23 | 0.70 | 0.93 | 2.19 |
| 3 | 0.169 | 0.527 | 0.696 | 0.150 | 0.492 | 0.641 | 0.224 | 0.737 | 0.50 | 1.46 | 1.98 | 4.78 |
| 4 | 0.002 | 0.011 | 0.013 | 0.003 | 0.024 | 0.026 | 0.004 | 0.036 | 0.34 | 0.38 | 1.36 | 1.78 |
| Subtotal | 0.21 | 0.74 | 0.95 | 0.22 | 0.76 | 0.98 | 0.33 | 1.15 | 1.07 | 2.54 | 4.28 | 8.76 |
| Carkeek Plant gravity | | | | | | | | | | | | |
| 1 | 0.189 | 0.626 | 0.815 | 0.270 | 0.988 | 1.258 | 0.405 | 1.483 | 2.32 | 4.21 | 2.18 | 8.46 |
| 5 | 0.003 | 0.009 | 0.012 | 0.003 | 0.003 | 0.006 | 0.005 | 0.004 | 0.15 | 0.16 | 0.45 | 0.63 |
| 6 | 0.012 | 0.037 | 0.049 | 0.012 | 0.016 | 0.029 | 0.019 | 0.024 | 3.48 | 3.52 | 0.87 | 4.47 |
| 7 | 0.011 | 0.034 | 0.045 | 0.010 | 0.009 | 0.019 | 0.015 | 0.014 | 7.81 | 7.83 | 1.95 | 9.85 |
| Carkeek Park | | | | | | | | | | | | |
| Subtotal | 0.22 | 0.71 | 0.92 | 0.30 | 1.02 | 1.31 | 0.44 | 1.52 | 13.76 | 15.73 | 5.45 | 23.41 |
| Total | 0.43 | 1.45 | 1.88 | 0.51 | 1.78 | 2.29 | 0.77 | 2.67 | 14.83 | 18.27 | 9.73 | 32.17 |

[a] 100% allocated to local collection system.
[b] Increment from max month to dry season porportioned to local collection, local agency, and private laterals based on inch-diam-mile.
[c] Increment from peak hour to max month allocated proportional to inch-diam-mile of the two components.
[d] Allocated peak inflow to private lateral and direct connections based on ration between pervious or impervious area to total connected area, repectively, with ratios not to exceed 0.8 or be less than 0.2.

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# Table 6. Subarea I&I Relative Values

| Subbasin Number | Local Collection System Peak Infil | Inch-diam -mile | gpdpidm | Local Agency Laterals Peak Infil | Inch-diam -mile | gpdpidm | Private Laterals Peak Infil | Inch-diam -mile | gpdpidm | Total Infil-tration | Inch-diam -mile | gpcpd | Inflow Peak | Sewered Area | gpapd | gpcpd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Beach PS | | | | | | | | | | | | | | | | |
| 2 | 0.245 | 81.18 | 3024 | 0.315 | 25.89 | 12156 | 0.705 | 38.83 | 18145 | 1.032 | 145.90 | 7075 | 0.930 | 303.00 | 3070 | 289 |
| 3 | 0.696 | 72.54 | 9595 | 0.641 | 20.59 | 31140 | 1.458 | 30.89 | 47203 | 2.299 | 124.02 | 18537 | 1.985 | 248.00 | 8002 | 802 |
| 4 | 0.013 | 24.46 | 544 | 0.026 | 5.75 | 4595 | 0.381 | 8.63 | 44142 | 0.079 | 38.83 | 2044 | 1.364 | 102.00 | 13376 | 1908 |
| Subtotal | 0.955 | 178.18 | 5359 | 0.982 | 52.23 | 18808 | 2.543 | 78.34 | 32464 | 3.411 | 308.75 | 11046 | 4.279 | 653.00 | 6553 | 668 |
| Carkeek Plant gravity | | | | | | | | | | | | | | | | |
| 1 | 0.815 | 128.99 | 6317 | 1.258 | 55.66 | 22609 | 4.208 | 83.49 | 50405 | 3.961 | 268.13 | 14772 | 2.176 | 463.00 | 4699 | 345 |
| 5 | 0.012 | 39.04 | 319 | 0.006 | 12.48 | 444 | 0.158 | 18.72 | 8469 | 0.026 | 70.23 | 374 | 0.451 | 193.00 | 2335 | 276 |
| 6 | 0.049 | 166.02 | 295 | 0.029 | 55.82 | 512 | 3.524 | 83.73 | 42083 | 0.120 | 305.56 | 394 | 0.870 | 553.00 | 1574 | 137 |
| 7 | 0.045 | 141.43 | 318 | 0.019 | 41.50 | 460 | 7.835 | 62.25 | 125862 | 0.093 | 245.18 | 378 | 1.952 | 561.00 | 3479 | 373 |
| Subtotal | 0.921 | 475.47 | 1938 | 1.312 | 165.45 | 7927 | 15.725 | 248.18 | 63361 | 4.200 | 889.11 | 4724 | 5.448 | 1770.00 | 3078 | 279 |
| Total | 1.876 | 653.65 | 2870 | 2.294 | 217.68 | 10538 | 18.268 | 326.52 | 55948 | 7.611 | 1197.86 | 6354 | 9.727 | 2423.00 | 4014 | 375 |

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# COST EFFECTIVE ANALYSIS

To estabish whether the infiltration/inflow is excessive or non-excessive requires that a cost effective analysis of the acceptance or removal of the infiltration/inflow be undertaken. Infiltration/inflow is considered excessive if the estimated cost for its transport, storage, and treatment is greater than the estimated cost of its removal by rehabilitation of the sewer system.

## Infiltration/Inflow Removal

Infiltration/inflow is removed from a collection system by rehabilitating the pipes and disconnecting non-wastewater discharges. Rehabilitation can upgrade a collection system to reduce infiltration to the level of a new sewer (250 gallons per day per inch-diameter-mile). Disconnection of non-wastewater sources can reduce all inflow allocated to those sources.

Costs for rehabilitating the collection system are directly related to the component, its length, structural condition, number of manholes requiring repair, and the number and nature of stormwater cross-connections. Rehabilitation cost-effectiveness will be maximized if infiltration/inflow is concentrated in localized areas.

## Rehabilitation Methods for Reduction of Infiltration and Inflow

This section identifies potential sewer system rehabilitation methods and procedures appropriate to the Carkeek Park service area for reducing current levels of infiltration and inflow. The listing of rehabilitation methods reflects the age of the Carkeek Park system and its current condition. The infiltration control measures are by definition procedures focused on repair and/or replacement of the collection system to restore the hydraulic integrity of the pipes and manholes. The inflow control measures encompass potentially two elements; namely (1) disconnection of the drainage source from the sanitary sewer and rerouting to a storm drain, and (2) where there is no alternative storm drain system, provision of a new storm drain system.

## Rehabilitation Methods and Procedures

The potential rehabilitation procedures to reduce current levels of infiltration and inflow are summarized in Table 7. Of the infiltration control procedures, chemical grouting is not appropriate due to the age of the collection system. As such, it will not be given further consideration.

Table 7. Potential Rehabilitation Procedures to Reduce I/I

| Source | System component | Rehabilitation method |
|---|---|---|
| Infiltration | Sewer system | Chemical grouting[a]<br>Polyethylene slip lining<br>Inversion lining (In-situ form)<br>Replacement |
| | Manholes | Joint grouting<br>Replacement |
| | Side sewers | Polyethylene slip lining<br>Inversion lining (In-situ form)<br>Replacement |
| Inflow | Manholes | Lid sealing<br>Regrade lid<br>Access shaft sealing |
| | Illicit connections<br>Downspouts<br>Foundation drain<br>Storm drain/<br>cross connection | Disconnect/reconnect to alternative storm drainage[b] |

[a]Not appropriate due to age/condition of collection system.
[b]Some areas of Carkeek basin will require construction of a storm drain system.

Inflow control by disconnection of current inflow sources of roof leaders and area drains will require, in many areas of the Carkeek Park service area, provision of a new storm drain system. Any storm drain system design will have to be compatible with the non-point drainage program currently being developed by the City.

The estimated project costs for the presented rehabilitation procedures are presented in Table 8. Sewer repair costs indicate that inversion lining and replacement have similar costs, while polyethylene lining offers potential savings of up to 40 percent. However, the costs of polyethylene lining are impacted by the number of laterals that have to be hooked up.

For this analysis the following assumptions have been made for rehabilitation of the system components. Local collection system rehabilitation assumes the use of polyethylene lining of sewers and grouting of all manholes. Laterals in the public right-of-way are assumed to be replaced and private laterals rehabilitated by polyethylene lining. Inflow control costs include disconnection costs for roof leaders and provision of an alternative storm drainage system where the existing system is inadequate to accept additional storm drainage.

Table 8. Project Costs for Rehabilitation Procedures to Reduce I/I

| Control method | Cost, $/foot[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sewer diameter, inches | | | | | | |
| | 8 | 10 | 12 | 15 | 18 | 21 | 24 |
| INFILTRATION CONTROL | | | | | | | |
| Sewer Repair | | | | | | | |
| Preparation, including cleaning and TV inspection | 4 | 4 | 4 | 4 | 5 | 5 | 5 |
| Polyethylene lining[b] | 44 | 49 | 53 | 57 | 75 | 82 | 96 |
| Inversion lining[c] | 76 | 96 | 116 | 144 | 172 | 200 | 230 |
| Replacement[d] | 73 | 87 | 108 | 148 | 159 | 190 | 220 |
| | Unit cost[a] | | | | | | |
| Manhole Repairs | | | | | | | |
| Joint grouting | 1,200 | | | | | | |
| Replacement | 5,500 | | | | | | |
| Side Sewer Repair[e] | | | | | | | |
| City | | | | | | | |
| Polyethylene lining | 1,200 | | | | | | |
| Inversion lining | 1,200 | | | | | | |
| Replacement | 1,800 | | | | | | |
| Private | | | | | | | |
| Polyethylene lining | 1,600 | | | | | | |
| Inversion lining | 1,600 | | | | | | |
| Replacement | 2,100 | | | | | | |
| INFLOW CONTROL | | | | | | | |
| Manhole Repairs | | | | | | | |
| Replace lid | 1,500 | | | | | | |
| Lid sealing | 800 | | | | | | |
| Illicit Connection Disconnects | | | | | | | |
| Downspout, each | 600 | | | | | | |
| Foundation drain | 2,700 | | | | | | |
| Storm drain/cross connection | 1,100 | | | | | | |

[a]All costs adjusted to an ENR of 4770.
[b]Unit costs include work pit excavation, mobilization, and polyethylene liner. An additional 70 percent was added for sales tax, allied costs, and contingencies.
[c]$6.00 per inch/diameter/foot quoted by Gelco--October 1986 + 70 percent.
[d]Costs include pipe, manholes, miscellaneous appurtenances, installation, bedding and backfill testing, contractor's overhead and profit, plus 70 percent for sales tax, allied costs, and contingencies. Cost presented assumes 8- to 15-foot cut in stable soil.
[e]Cost for installation of a cleanout at or near the property line (if required) is not included. Cost presented assumes 75 feet of 4-inch diameter pipe, 25 feet City lateral, 50 feet private lateral, + 70 percent for sales tax, allied costs, and contingencies.

It is assumed that each of these rehabilitation methods will be successful in reducing infiltration and inflow levels to those of a new separate sanitary sewer system. The hydraulic assumptions are that infiltration will be reduced to an infiltration value of 250 gallons/day/inch diameter mile, and that inflow will be contained to a maximum value of 500 gallons/sewered acre/day. Based on these values, the potential infiltration and inflow removal values for the collection system components are presented in Table 9. Complete systemwide infiltration/inflow removal would reduce the estimated one-year event peak infiltration/inflow by 30.6 mgd, from 32.2 mgd down to 1.5 mgd.

Rehabilitation Costs

The costs to rehabilitate the collection system components, based on the above rehabilitation methods, are estimated at $86.8 million, as shown in Table 10. To rehabilitate the collection system to reduce infiltration levels to that of a new system is estimated to cost $52.6 million, of which $20.1 million is for rehabilitation of the local collection system, $17.2 million for replacement of laterals within the public right-of-way, and $15.3 million for rehabilitation of private laterals. To disconnect inflow sources and provide an alternative storm drain system is estimated to cost $34.0 million, of which $5.9 million is for disconnecting roof drains and $28.2 million for providing an adequate storm drain system.

Based on the allocated infiltration and inflow values to the system components, the unit costs of eliminating I/I are presented in Table 10. The unit costs vary from a low of 37 cents per gallon, expressed in terms of peak hour flow, as a result of rehabilitating private service laterals in Subarea 7, up to $700.00 per gallon as a result of replacing the local agency laterals in Subarea 6.

Prioritized Infiltration and Inflow Removal

The ranking of each collection system component based on the cost effectiveness of eliminating infiltration and inflow is presented in Table 11. The tabular data in Table 11 are presented graphically in Figure 4. The vertical axis represents project costs and the present worth cost, as there is no additional annual O&M cost applicable to the rehabilitation methods. The horizontal axis is peak hour infiltration and inflow, where 100 percent represents 32.17 mgd, the peak hour one per year flow event as identified in Table 5.

The ranking indicates that focusing on rehabilitation of private service laterals in Subareas 1, 3, 4, 6, and 7 is the most cost effective approach. This is validated by field experience in other communities where laterals have been shown to be the major source of infiltration. The issue of actually being able to

## Table 9. Subarea Potential I&I Removal

| Subbasin Number | Local Collection System Peak Infil | New sys Infil | Potential removal | Local Agency Laterals Peak Infil | New sys Infil | Potential removal | Private Laterals Peak Infil | New sys Infil | Potential removal | Direct Connection Peak Inflow | New sys Inflow | Potential removal | Total Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Beach PS | | | [a] | | | [a] | | | [a] | | | [b] | |
| 2 | 0.245 | 0.020 | 0.225 | 0.315 | 0.006 | 0.308 | 0.705 | 0.010 | 0.695 | 0.930 | 0.152 | 0.779 | 2.007 |
| 3 | 0.696 | 0.018 | 0.678 | 0.641 | 0.005 | 0.636 | 1.458 | 0.008 | 1.450 | 1.985 | 0.124 | 1.861 | 4.625 |
| 4 | 0.013 | 0.006 | 0.007 | 0.026 | 0.001 | 0.025 | 0.381 | 0.002 | 0.379 | 1.364 | 0.051 | 1.313 | 1.724 |
| Subtotal | 0.955 | 0.045 | 0.910 | 0.982 | 0.013 | 0.969 | 2.543 | 0.020 | 2.524 | 4.279 | 0.327 | 3.953 | 8.356 |
| Carkeek Plant gravity | | | | | | | | | | | | | |
| 1 | 0.815 | 0.032 | 0.783 | 1.258 | 0.014 | 1.244 | 4.208 | 0.021 | 4.187 | 2.176 | 0.232 | 1.944 | 8.158 |
| 5 | 0.012 | 0.010 | 0.003 | 0.006 | 0.003 | 0.002 | 0.158 | 0.005 | 0.154 | 0.451 | 0.097 | 0.354 | 0.513 |
| 6 | 0.049 | 0.042 | 0.007 | 0.029 | 0.014 | 0.015 | 3.524 | 0.021 | 3.503 | 0.870 | 0.277 | 0.594 | 4.118 |
| 7 | 0.045 | 0.035 | 0.010 | 0.019 | 0.010 | 0.009 | 7.835 | 0.016 | 7.819 | 1.952 | 0.281 | 1.671 | 9.509 |
| Subtotal | 0.921 | 0.119 | 0.802 | 1.312 | 0.041 | 1.270 | 15.725 | 0.062 | 15.663 | 5.448 | 0.885 | 4.563 | 22.299 |
| Total | 1.876 | 0.163 | 1.713 | 2.294 | 0.054 | 2.239 | 18.268 | 0.082 | 18.187 | 9.727 | 1.212 | 8.515 | 30.654 |

[a] Assumes new system infiltration of 250 gal/inch-diam-mile
[b] Assumes new system inflow reduction of 500 gal/acre

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## Table 10. Subarea Rehabilitation Costs, $

| Subbasin Number | Local Collection System | Local Agency Laterals | Private Lateral | Direct Connection Discon | Direct Connection New Storm | Direct Connection Total | Total | Cost per gallon: Local Collection System | Cost per gallon: Local Agency Laterals | Cost per gallon: Private Lateral | Cost per gallon: Total Infil | Cost per gallon: Direct Connection | Cost per gallon: Total Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Beach PS | [a] | [b] | [c] | [d] | [e] | | | | | | | | |
| 2 | 2,452,150 | 2,050,200 | 1,822,400 | 522,720 | 1,170,000 | 1,692,720 | 8,017,470 | 10.89 | 6.65 | 2.62 | 5.15 | 2.17 | 3.99 |
| 3 | 2,149,920 | 1,630,800 | 1,449,600 | 1,115,136 | 3,720,000 | 4,835,136 | 10,065,456 | 3.17 | 2.56 | 1.00 | 1.89 | 2.60 | 2.18 |
| 4 | 701,055 | 455,400 | 404,800 | 766,656 | 1,530,000 | 2,296,656 | 3,857,911 | 97.57 | 18.23 | 1.07 | 3.80 | 1.75 | 2.24 |
| Subtotal | 5,303,125 | 4,136,400 | 3,676,800 | 2,404,512 | 6,420,000 | 8,824,512 | 21,940,837 | 5.83 | 4.27 | 1.46 | 2.98 | 2.23 | 2.63 |
| Carkeek Plant gravity | | | | | | | | | | | | | |
| 1 | 4,114,710 | 4,408,200 | 3,918,400 | 1,306,800 | 3,045,000 | 4,351,800 | 16,793,110 | 5.26 | 3.54 | 0.94 | 2.00 | 2.24 | 2.06 |
| 5 | 1,279,763 | 988,200 | 878,400 | 261,360 | 2,595,000 | 2,856,360 | 6,002,723 | 475.82 | 409.12 | 5.71 | 19.80 | 8.07 | 11.70 |
| 6 | 5,223,095 | 4,420,800 | 3,929,600 | 557,568 | 8,130,000 | 8,687,568 | 22,261,063 | 701.89 | 302.14 | 1.12 | 3.85 | 14.63 | 5.41 |
| 7 | 4,190,010 | 3,286,800 | 2,921,600 | 1,219,680 | 8,055,000 | 9,274,680 | 19,673,090 | 433.01 | 377.58 | 0.37 | 1.33 | 5.55 | 2.07 |
| Subtotal | 14,807,578 | 13,104,000 | 11,648,000 | 2,787,840 | 21,825,000 | 24,612,840 | 64,172,418 | 18.45 | 10.32 | 0.74 | 2.23 | 5.39 | 2.88 |
| Total | 20,110,703 | 17,240,400 | 15,324,800 | 5,793,480 | 28,245,000 | 34,038,480 | 86,714,383 | 11.74 | 7.70 | 0.84 | 2.38 | 4.00 | 2.83 |

[a] Assumes polyethylene lining and grouting of manholes at 400' centers.
[b] Assumes replacement ($1800/lateral).
[c] Assumes polyethylene or inversion lining at $1600/lateral.
[d] Assumes disconnection of roof leaders and downspouts at $2400 per inflow source. Inflow source computed as impervious connected area/1200 sq ft per source.
[e] Assumes cost of new storm drain system at $15,000 per acre.

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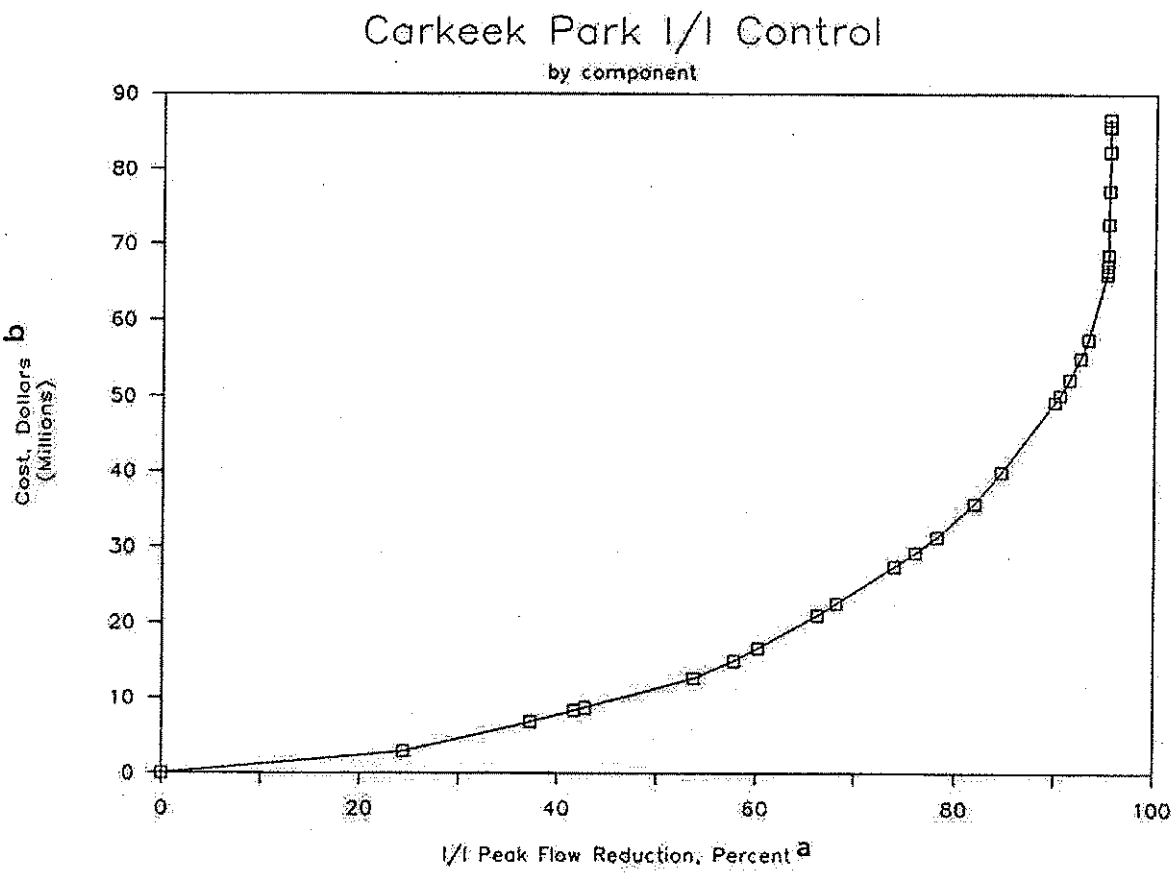



[a]100 percent is equivalent to 32.32 mgd.

[b]Project cost and present worth cost.

**Figure 4** Carkeek Cost-Effectiveness of Infiltration/Inflow Control by Collection System Component

implement repair of private laterals, recognizing there are restrictions on the use of public funds for private facilities, together with the issue of access to the laterals is a significant institutional/political issue that would have to be addressed if rehabilitation is shown to be cost effective.

Table 11. I&I Control Ranking, by Component

| Rank | Basin | Type | Cost/gallon | Cost |
|---|---|---|---|---|
| 1 | 7 | PL | 0.37 | 2,921,600 |
| 2 | 1 | PL | 0.94 | 3,918,400 |
| 3 | 3 | PL | 1.00 | 1,449,600 |
| 4 | 4 | PL | 1.07 | 404,800 |
| 5 | 6 | PL | 1.12 | 3,929,600 |
| 6 | 4 | DC | 1.75 | 2,296,656 |
| 7 | 2 | DC | 2.17 | 1,692,720 |
| 8 | 1 | DC | 2.24 | 4,351,800 |
| 9 | 3 | LAL | 2.56 | 1,630,800 |
| 10 | 3 | DC | 2.60 | 4,835,136 |
| 11 | 2 | PL | 2.62 | 1,822,400 |
| 12 | 3 | LCS | 3.17 | 2,149,920 |
| 13 | 1 | LAL | 3.54 | 4,408,200 |
| 14 | 1 | LCS | 5.26 | 4,114,710 |
| 15 | 7 | DC | 5.55 | 9,274,680 |
| 16 | 5 | PL | 5.71 | 878,400 |
| 17 | 2 | LAL | 6.65 | 2,050,200 |
| 18 | 5 | DC | 8.07 | 2,856,360 |
| 19 | 2 | LCS | 10.89 | 2,452,150 |
| 20 | 6 | DC | 14.63 | 8,687,568 |
| 21 | 4 | LAL | 18.23 | 455,400 |
| 22 | 4 | LCS | 97.57 | 701,055 |
| 23 | 6 | LAL | 302.14 | 4,420,800 |
| 24 | 7 | LAL | 377.58 | 3,286,800 |
| 25 | 5 | LAL | 409.12 | 988,200 |
| 26 | 7 | LCS | 433.01 | 4,190,010 |
| 27 | 5 | LCS | 475.82 | 1,279,763 |
| 28 | 6 | LCS | 701.89 | 5,223,095 |

LCS= Local Collection System
LAL= Local Agency Laterals
PL = Private Lateral
DC = Direct Connection

Inflow removal is typically the most cost-effective I/I approach if removal is simply disconnection from the sanitary sewer and hooking into the adjacent storm sewer. However, in the Carkeek Park service area there is no adequate storm drain system, thus the costs of any extensive inflow control effort has to include provision of a new storm drain system.

A review of Table 10 indicates that addition of the storm drainage system increases the inflow removal costs from a low of 1.25 times in Area 2 to a high of 13 times in Area 6. If an adequate storm drainage system was available, inflow unit costs would range from $0.21 per gallon in Area 7 to a maximum of $1.99

per gallon in Area 5, as such being the most cost-effective control action.

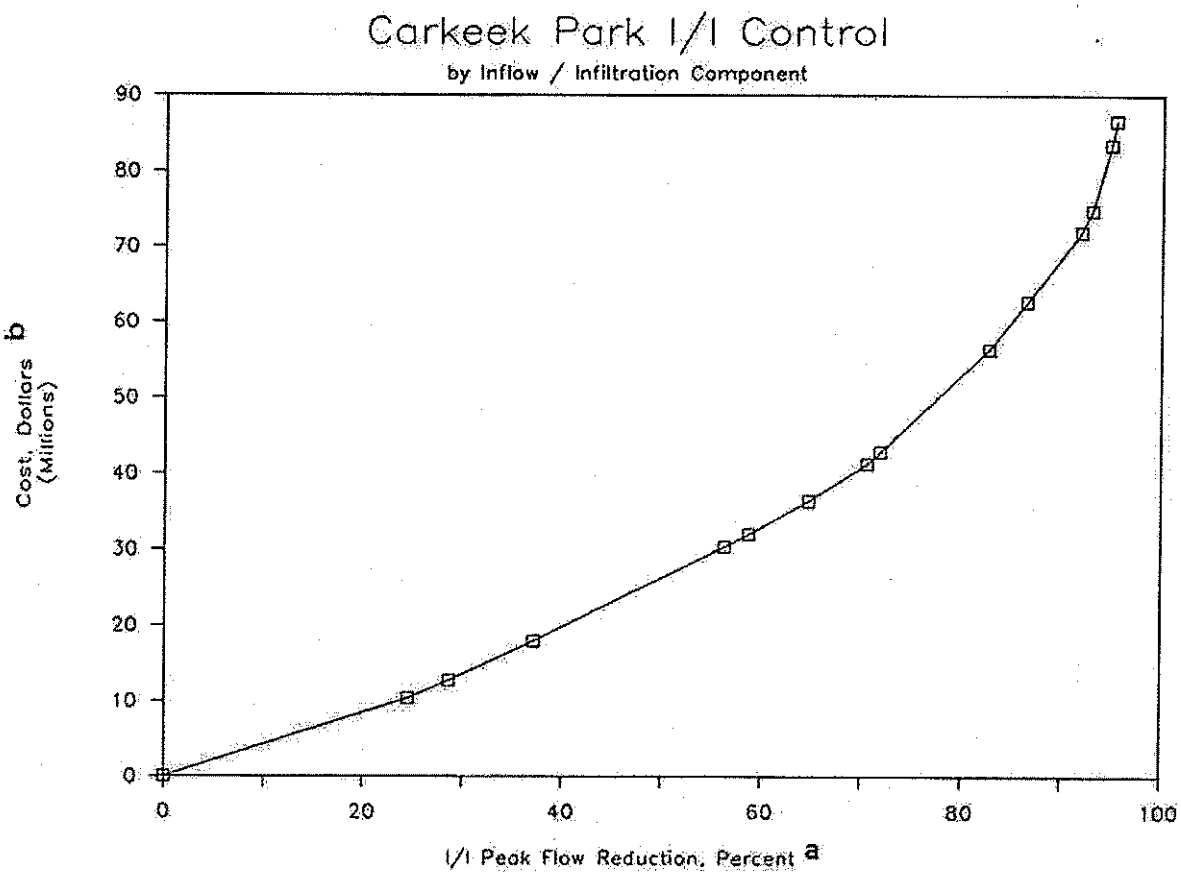
In Table 11, unit costs were identified for rehabilitation of the three sewer components of each sub-basin, namely the City collection system, the City lateral, and the private lateral. However, experience has shown it is not appropriate to attempt to reduce infiltration by limiting rehabilitation to one component in a sub-basin. For example, rehabilitating just the City sewer typically has resulted in the ground water rising and then leaking into the laterals. Thus total basin rehabilitation is the only effective approach for infiltration reduction. A new ranking with total basinwide infiltration measures and separate inflow control measures is presented in Table 12, with the data presented graphically in Figure 5. As would be expected, the apparent cost effectiveness of I/I control is reduced; however, experience would show that the Figure 4 numbers are optimistic and reality is best represented by the information presented in Table 10 and Figure 5.

Table 12. I&I Control Ranking, by Subbasin

| Rank | Basin | Type | I/I rehabili-tation cost | Peak I/I cost, $/gallon |
|---|---|---|---|---|
| 1 | 7 | Infil | 10,398,410 | 1.33 |
| 2 | 4 | Inflow | 2,296,656 | 1.75 |
| 3 | 3 | Infil | 5,230,320 | 1.89 |
| 4 | 1 | Infil | 12,441,310 | 2.00 |
| 5 | 2 | Inflow | 1,692,720 | 2.17 |
| 6 | 1 | Inflow | 4,351,800 | 2.24 |
| 7 | 3 | Inflow | 4,835,136 | 2.60 |
| 8 | 4 | Infil | 1,561,255 | 3.80 |
| 9 | 6 | Infil | 13,573,495 | 3.85 |
| 10 | 2 | Infil | 6,324,750 | 5.15 |
| 11 | 7 | Inflow | 9,274,680 | 5.55 |
| 12 | 5 | Inflow | 2,856,360 | 8.07 |
| 13 | 6 | Inflow | 8,687,568 | 14.63 |
| 14 | 5 | Infil | 3,146,363 | 19.80 |

## Cost Effectiveness of Rehabilitation

The information presented above included data for all the sub-basins tributary to the Carkeek Park Treatment Plant, including areas that drain by gravity to the North Beach Pumping Station as well as basins that drain directly to the Carkeek Park plant. To evaluate the cost effectiveness of North Beach Pumping Station options, the area tributary to the station needs to be considered separately; similarly flow reductions in the non-North Beach tributary area have no direct bearing on North Beach Pumping Station decisions.




[a]100 percent is equivalent to 32.32 mgd.
[b]Project cost and present worth cost.

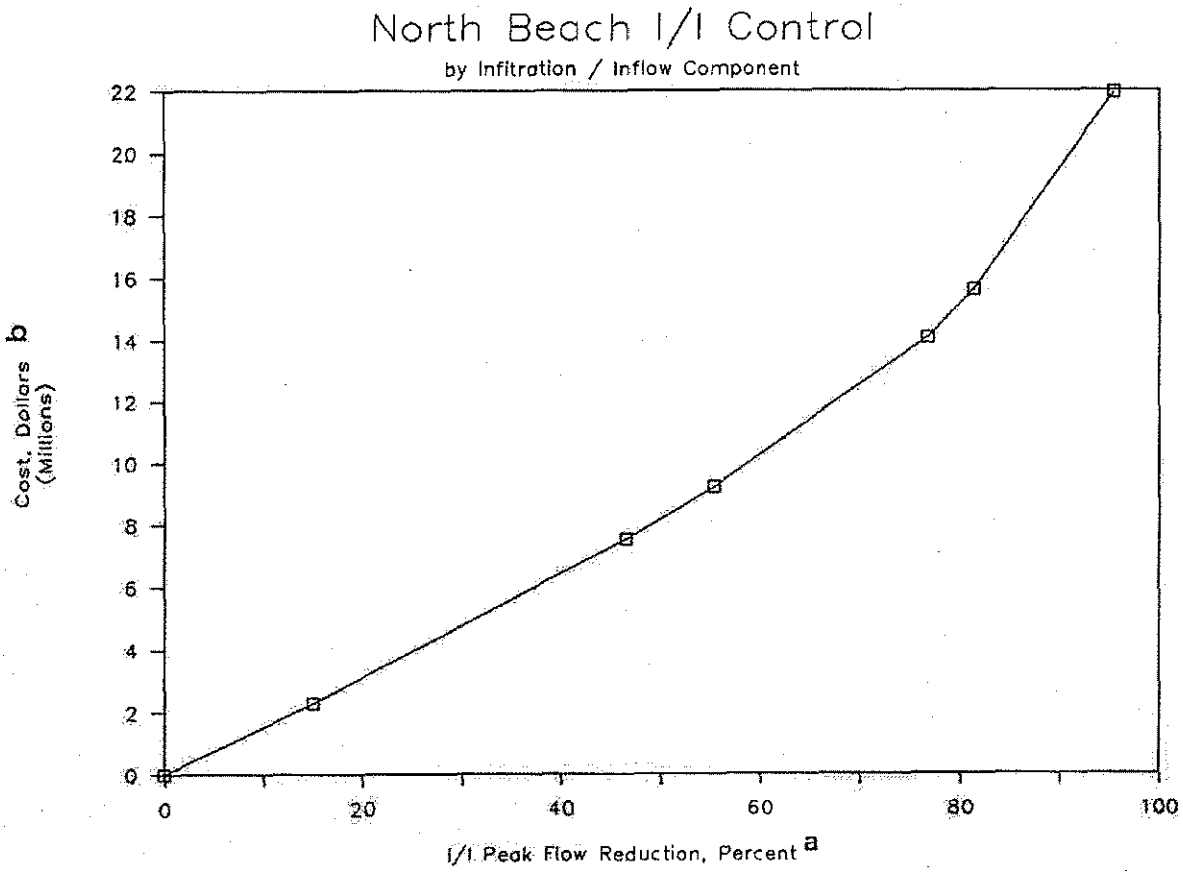
Figure 5 Carkeek Cost-Effectiveness of Infiltration and Inflow Control

North Beach Pumping Station Tributary Area. The ranking of the infiltration and inflow control options for the three sub-basins tributary to the North Beach Pumping Station (Sub-Basins 2, 3, and 4) are presented in Table 13. The information in Table 13 for peak I/I flows is presented graphically in Figure 6. The vertical axis represents project costs and present worth costs. The horizontal axis is peak hour infiltration and inflow, where 100 percent represents 8.76 mgd, the peak hour one-per-year flow event as identified in Table 5. To reduce the one-per-year peak hour flows, including wastewater discharges, to the 3.8 mgd effective capacity of the North Beach Pumping Station would require a reduction in I/I of 5.4 mgd or 62 percent. Based on the data in Table 11, this would require rehabilitation of the collection system in Subarea 3 and inflow control in Subareas 2 and 4 and 20 percent of Subarea 3 for a total project cost of $10.2 million.

Table 13. I&I Control Ranking--North Beach

| Rank | Basin | Type | I/I rehabilitation cost, $ | Peak I/I cost, $/gallon | Average wet weather infiltration cost, $/gallon |
|---|---|---|---|---|---|
| 1 | 4 | Inflow | 2,296,656 | 1.75 | -- |
| 2 | 3 | Infil | 5,230,320 | 1.89 | 7.81 |
| 3 | 2 | Inflow | 1,692,720 | 2.17 | -- |
| 4 | 3 | Inflow | 4,835,136 | 2.60 | -- |
| 5 | 4 | Infil | 1,561,255 | 3.80 | 31.20 |
| 6 | 2 | Infil | 6,324,750 | 5.15 | 26.40 |

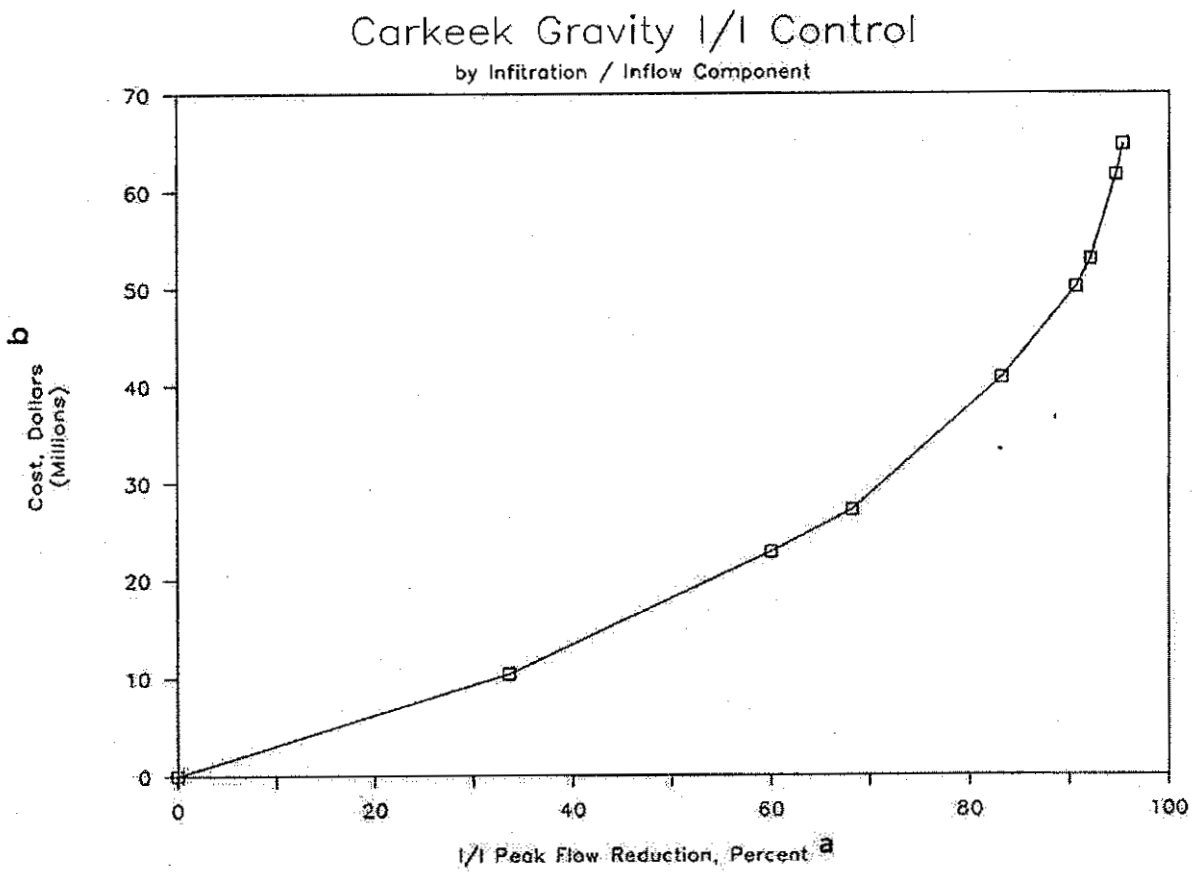
Carkeek Park Treatment Plant Gravity Tributary Area. The ranking of the infiltration and inflow control options for the four sub-basins directly tributary by gravity to the Carkeek Park Treatment Plant (Sub-Basins 1, 5, 6, and 7) are presented in Table 14. The information in Table 12 for peak I/I flows is presented graphically in Figure 7. The vertical axis represents project costs and present worth costs. The horizontal axis is peak hour infiltration and inflow, where 100 percent represents 23.56 mgd, the peak hour one-per-year flow event as identified in Table 5.




[a]100 percent is equivalent to 8.76 mgd.

[b]Project cost and present worth cost.

**Figure 6 North Beach Tributary Area Cost-Effectiveness of Infiltration and Inflow Control**




[a]100 percent is equivalent to 23.56 mgd.
[b]Project cost and present worth cost.

Figure 7 Carkeek Gravity Tributary Area Cost-Effectiveness of Infiltration and Inflow Control

Table 14. I&I Control Ranking--Carkeek Gravity

| Rank | Basin | Type | I/I rehabilitation cost, $ | Cost, $/gallon | Average wet weather infiltration cost, $/gallon |
|---|---|---|---|---|---|
| 1 | 7 | Infil | 10,398,410 | 1.33 | 69.3 |
| 2 | 1 | Infil | 12,441,310 | 2.00 | 15.0 |
| 3 | 1 | Inflow | 4,351,800 | 2.24 | -- |
| 4 | 6 | Infil | 13,573,495 | 3.85 | 170.0 |
| 5 | 7 | Inflow | 9,274,680 | 5.55 | -- |
| 6 | 5 | Inflow | 2,856,360 | 8.07 | -- |
| 7 | 6 | Inflow | 8,687,568 | 14.63 | -- |
| 8 | 5 | Infil | 3,146,363 | 19.80 | 105.0 |

Determination of Cost Effectiveness

This analysis has quantified the infiltration and inflow by sub-basin, estimated the costs of its removal by sub-basin and by component within the sub-basins, and identified the unit costs of I/I removal. Whether it is cost effective to reduce peak hour flows by rehabilitation will be determined by comparison with the alternative costs of the optimized mix of conveyance, storage, and treatment. The recommended program is transfer of 2.25 times AWWF to West Point to receive secondary treatment and a combination of pumping station modifications, storage, and treatment for management of additional storm-generated flows up to the one year event peak value.

Collection system rehabilitation measures that reduce peak flows will reduce the storm-influenced flows that have to be managed. Collection system rehabilitation measures that reduce average flows reduce the size of the flow that has to be transferred. Inflow controls are effective in reducing peak flows but have no effect on infiltration values and thus the sizing of the secondary transfer system. Infiltration controls reduce both peak flows and average infiltration values.

If the present worth unit costs to address the overflow at the North Beach Pumping Station are more than $1.75 per gallon and the present worth unit costs to address the gravity transported flows in excess of the secondary conveyance capacity are more than $1.31 per gallon, then it may be more cost effective to rehabilitate the collection system.

The cost effective analysis of the areas tributary to the North Beach Pumping Station and by gravity to the Carkeek plant are developed below.

North Beach Tributary Area

The North Beach Pumping Station capacity of 3.8 mgd is adequate to handle transfer of the tributary base secondary flows of 3.02 mgd (2.25 times AWWF). The recommended program for the North Beach service area is focused on handling the flows in excess of the 3.02 mgd value up to the 9.0 mgd projected for the one-year return flows. This is accomplished by increasing the transfer capacity of the pumping station to 5.0 mgd and provision of 0.28 MG of storage to handle the flow above 5.0 mgd. In Table 13, the rehabilitation measures are listed in the order of their cost-effectiveness, with inflow control in Basin 4 at $1.75/gallon the most cost-effective, followed by infiltration control in Basin 3 at $1.89/gallon.

The impacts of rehabilitation on peak flows, storage volume, and pumping capacity requirements are presented in Table 15. To eliminate storage requires implementation of inflow control in Subbasin 4 and infiltration control in Subbasin 3. To eliminate having to increase the capacity of the North Beach Pumping Station requires implementation of inflow control in Subbasin 2. The cost of rehabilitation for inflow control in Subbasins 2 and 4, and infiltration control in Subbasin 3, is $9.22 million. This compares to the cost of managing current flows of $2.69 million.

Table 15. North Beach Storm Flow Management Cost-Effective Determination

| Rehabilitation action | Peak flow, mgd | | Rehabilitation present worth cost, $ | Holding tank | | Pumping station | | Pumping station and holding tank present worth cost, $ |
|---|---|---|---|---|---|---|---|---|
| | Reduction | Net | | Size, MG | Present worth cost, $ | Capacity, mgd | Present worth cost, $ | |
| Existing conditions | 0 | 9.09 | 0 | 0.28 | 1,150,000[a] | 5.0 | 1,540,000[b] | 2,690,000 |
| Inflow, Basin 4 | 1.31 | 7.78 | 2,297,000 | 0.13 | 675,000 | 5.0 | 1,540,000 | 2,215,000 |
| Infiltration, Basin 3 | 2.76 | 5.02 | 7,527,000 | 0 | 0 | 5.0 | 1,540,000 | 1,540,000 |
| Inflow, Basin 2 | 0.78 | 4.24 | 9,220,000 | 0 | 0 | 5.0 | 1,540,000 | 1,540,000 |
| Inflow, Basin 3 | 1.86 | 2.38 | 14,055,000 | 0 | 0 | 3.8 | 0[c] | 0 |

[a]Capital $1.09 million + $3,000/year O&M.
[b]Incremental capital cost above maintaining at 3.8 mgd + incremental O&M at $6,000/year.
[c]Cost of upgrading reliability for 3.8 mgd at $0.5 million common to all alternatives.

The rehabilitation costs and storage/transfer costs are presented in Figure 8. The least cost programs to manage the peak flows are to provide 0.28 MG of storage and upgrade the North Beach Pumping Station to provide 5.0 mgd of capacity. Implementation of infiltration control in Subbasin 3 would reduce the AWWF by 0.6 mgd and thus the secondary transfer requirement by 1.36 mgd (2.25 times 0.6) to 7.04 mgd. The estimated present worth cost saving of this flow reduction is $2.71 million, as

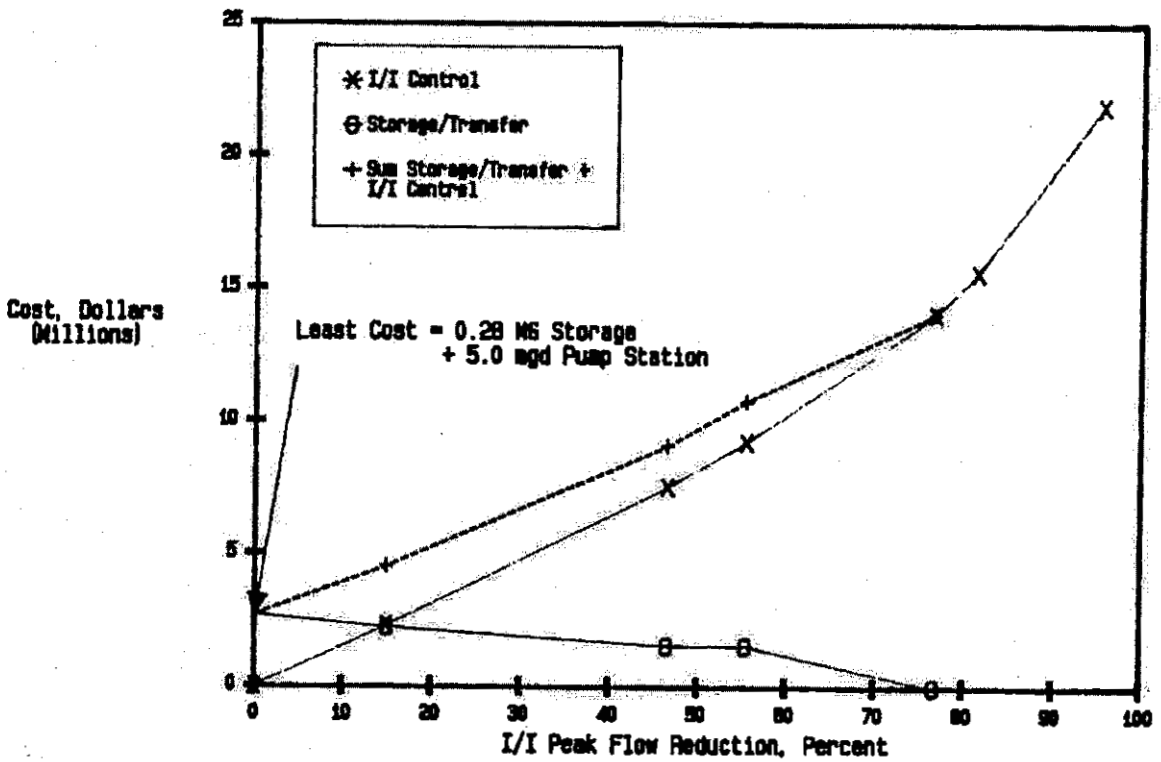



Figure 8 North Beach Tributary Area Storm Flow Management Cost Effective Determination

shown in Table 16. As this is significantly less than the $4.56 million net cost of Subbasin 3 infiltration rehabilitation (Table 15), it is also not cost effective, from a secondary transfer cost basis, to rehabilitate the collection system.

Table 16. North Beach Infiltration Control Secondary Transfer Cost Savings

| Rehabilitation action | AWWF, mgd | Secondary transfer, mgd[a] | Present worth costs, $ | | | | Savings |
|---|---|---|---|---|---|---|---|
| | | | Pumping station | Transfer | Treatment | Total | |
| Existing conditions | 3.73 | 8.40 | 6,056,000[a] | 7,253,000[b] | 0[c] | 13,309,000 | 0 |
| Infiltration, Basin 3 | 3.13 | 7.04 | 5,690,000 | 7,253,000 | (2,340,000)[d] | 10,603,000 | 2,706,000 |

[a]Pumping station capital cost $5.48 million + $37,000/year O&M.
[b]Conveyance pipeline capital cost $7.02 million + $13,000/year O&M.
[c]Base condition West Point accepts 3.73 AWWF/8.4 peak.
[d]Capital cost savings at West Point 0.6 mgd at $2.51/gallon + 154 MG at $300/MG.

## Carkeek Service Area

The recommended program for Carkeek flows is transfer of 8.4 mgd (2.25 times the average wet weather flows from the North Beach service area and those flows that drain by gravity to the Carkeek Plant) to West Point to receive secondary treatment. Flows in excess of 8.4 mgd up to the 28.0 mgd projected for the one-year return flow will be managed by a combination of storage and treatment on the Carkeek Park treatment plant site.

In Table 14, rehabilitation measures are listed in the order of their cost-effectiveness, with infiltration control in Subbasin 7 at $1.33/gallon the most cost-effective, followed by infiltration control in Subbasin 1 at $2.00/gallon.

The impacts of rehabilitation on peak flows, storage/treatment capacity, and pumping capacity are presented in Table 17. Implementation of infiltration control in Subbasin 7 reduces storage requirements to 0.40 MG, made up of the converted treatment plant plus additional net storage of 0.04 MG. Implementation of infiltration control in Subbasin 1 eliminates the need for additional storage beyond that provided by the converted treatment plant.

Table 17. Carkeek Service Area Storm Flow Management Cost Effective Determination

| Rehabilitation action | Peak flow, mgd | | Rehabilitation present worth cost, $ | Storage | | Treatment plant present worth cost, $ | Storage/treatment plant present worth cost, $ |
|---|---|---|---|---|---|---|---|
| | Reduction | Net | | Size, MG | Present worth cost, $ | | |
| Existing conditions | 0 | 28.40 | 0 | 0.72 | 7,754,000[a] | 2,643,000[b] | 10,397,000 |
| Infiltration, Subbasin 7 | 7.84 | 20.56 | 10,398,000 | 0.04 | 1,934,000 | 2,643,000 | 4,577,000 |
| Infiltration, Subtasin 1 | 6.21 | 14.35 | 22,839,000 | 0 | 0 | 2,643,000 | 2,643,000 |

[a]Storage capital cost $7.32 million + $24,000/year O&M.
[b]Treatment plant modification capital cost $2.10 million + $30,000/year O&M.

The present worth cost of collection system rehabilitation in Subbasins 1 and 7 is $22.8 million. The present worth cost of providing 0.72 MG of storage and converting the existing Carkeek primary plant to an intermittent storm weather treatment plant is $10.4 million.

The rehabilitation costs and storage/treatment costs are presented in Figure 9. The least cost program to manage the peak storm flows is to convert the existing primary treatment plant to an intermittent storm weather treatment plant and construct 0.72 MG of storage. Implementation of infiltration control in Subbasin 7 and Subbasin 1 will reduce the AWWF by 0.15 mgd and 0.83 mgd respectively. Thus the secondary requirements would be reduced to 8.1 mgd and 6.2 mgd respectively. The estimated present worth cost savings for these reduced transfer flows are presented in Table 18 and are $0.56 million and $5.18 million respectively. This compares to the net costs of $4.58 million and $10.5 million from Table 17. Thus it is also not cost effective from a secondary transfer cost basis to rehabilitate the collection system.

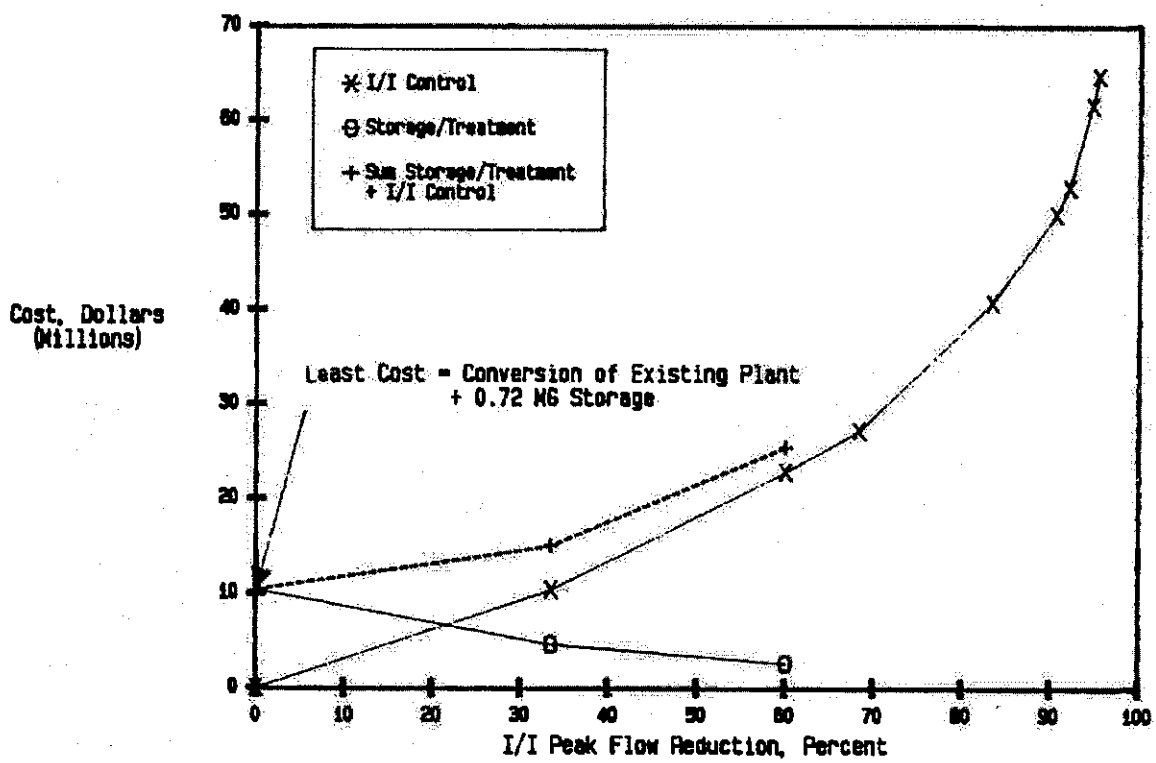



Figure 9 Carkeek Service Area Storm Flow Management Cost Effective Determination

Table 18. Carkeek Infiltration Control Secondary Transfer Cost Savings

| Rehabilitation action | AWWF, mgd | Secondary transfer,[a] mgd | Present worth costs, $ | | | | Savings, $ |
|---|---|---|---|---|---|---|---|
| | | | Pumping station | Transfer | Treatment | Total | |
| Existing condition | 3.73 | 8.40 | 6,056,000[a] | 7,253,000[b] | 0[c] | 13,309,000 | |
| Infiltration, Basin 7 | 3.58 | 8.06 | 5,946,000 | 7,253,000 | (453,000)[d] | 12,746,000 | 563,000 |
| Infiltration, Basin 1 | 2.75 | 6.19 | 4,900,000 | 5,870,000 | (3,199,000)[d] | 7,571,000 | 5,175,000 |

[a]Pumping station capital cost $5.48 million + $32,000/year O&M.
[b]Conveyance pipeline capital cost $7.02 million + $13,000/year O&M.
[c]Base condition, West Point accepts 3.73 AWWF/8.4 peak.
[d]Capital cost savings at West Point based on $2.51/gallon AWWF + $300/MG for O&M.