BROADVIEW SEWER INVESTIGATION

Project Summary Report

Prepared for

Seattle Public Utilities

July 2010

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BROADVIEW SEWER INVESTIGATION

Project Summary Report

Prepared for

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Executive Summary

This report summarizes the results of a study of the sanitary sewers in the Broadview area conducted over 2 years from 2008 to 2010. Broadview is located in northwest Seattle and includes the area between NW 130th Street, N and NW 105th Street, Fremont Avenue N, and NW Blakely Court. The study investigated alternatives to improve the performance of Broadview sanitary sewer system.

Broadview is primarily a residential community of about 990 acres that was constructed in the 1950s. It is served by a separate sanitary sewer system and a limited drainage system. The sanitary sewer receives higher than expected rates of inflow and infiltration.

The Broadview study included smoke testing conducted in 2008 to supplement smoke testing performed in the western portion of the neighborhood in 1998. Twelve flow monitors collected flow data from September of 2008 through February 2009, and were used to calibrate a sanitary sewer system model. This model (EPA – SWMM5) was used to analyze base and storm induced flow and various alternatives to improve the function and capacity of the system. Key segments of the sanitary sewer system located near historic backups were inspected and cleaned, both as an action to improve system performance, and to evaluate the condition of the sanitary sewer. Information on historic backups was collected from SPU records and from community input.

Five areas were identified as the focus for analysis based on the data collected:

- 1st Avenue NW and N and NW 115th Street
- N and NW 105th Street
- 12th Avenue NW
- 6th Avenue NW
- Dayton Avenue NW

Four alternatives were developed and evaluated to improve capacity:

- Alternative 1 – Replacement of main sanitary sewer pipes
- Alternative 2 – Removal of inflow
- Alternative 3 – Reduction of infiltration
- Alternative 4 – Removal and reduction of inflow and infiltration (I/I)

In addition, other options of a preventive nature including enhanced maintenance and use of backflow preventers were examined.

During the study period, funding opportunities enabled SPU to complete two short sections of pipe replacement that were relatively low cost and high benefit. The construction and total project cost associated with replaced pipe for 12th Avenue NW are included in Appendix A and discussed in later sections. These addressed problem areas at 1st Avenue NW and N and NW 115th Street, and at N and NW 105th Street by removing capacity constraints and reducing the risk of backups except during extreme storms events. This is further described in Alternative 1.

Alternatives 2 and 3 modeled the potential effects of reducing respectively inflow or infiltration to the capacity of the system. A range of theoretical scenarios were modeled to test the sensitivity of the system to this approach. In some cases it was determined that additional monitoring was warranted to confirm initial results. In these cases although preliminary results are described, final study conclusions are pending contingent on confirmation. Finally an Alternative 4 modeled a combination of both inflow and infiltration to determine if this would provide sufficient capacity for 12th Avenue NW.

Besides these specific areas, the study also includes recommendations that are area wide in nature, such as the value of reducing inflow through the use of Green Stormwater Infrastructure (GSI) where possible and cost-effective.

It should be noted that this was an investigative study, and does not represent a preliminary engineering report. Before specific projects are designed to be included in SPU's capital improvement plans, a more detailed analysis of the cost and benefits of the options is done, compared to other projects, and funding identified.

Chapter 1: Introduction

This document summarizes the results of a study of the Broadview area shown in Figure 1. The objective of the study is to evaluate the effectiveness of different engineering approaches to improve the performance of Broadview sanitary sewer system. Companion documents to this report include the Problem Identification Technical Memorandum (Herrera 2008b), which provides more detail of the existing conditions in Broadview, and the Broadview Sewer System Study Area Modeling Report (Herrera 2009), which is a detailed report on the hydrologic and hydraulic modeling done for this study.

Figure 1. Vicinity map.

Chapter 2: Background

Broadview is located in the northwest part of Seattle and the majority of the land use is single family residences. The area also includes multifamily low-rise, neighborhood commercial, and commercial zoning. Broadview became part of the City of Seattle on January 4, 1954. City Ordinance 82425, known as the annexation ordinance, states "[as of January 4, 1954 the annexed area] shall become and be a part of the City of Seattle subject to all the laws and ordinances thereof and thereafter in force."

Broadview has experienced two significant storm events in the last decade that resulted in several sewage backups in houses. The first storm event occurred on December 31, 1996 - January 1, 1997 where about 2.99 inches of precipitation occurred in a 24-hour period on top of moderate snow cover. The second storm event occurred on December 2-3, 2007; approximately 5 inches of rainfall occurred primarily on the second day. Backups prior to 1996 have occurred based on SPU claims data for the area.

During both of these major events, portions of the sanitary sewer received stormwater from inflow and infiltration, resulting in basement sewage flooding of private properties and maintenance hole overflows. Figure 2 shows typical inflow and infiltration sources. Excessive inflow and infiltration contributed to roadway flooding, impacts to the Piper's Creek drainage, and flooded private properties. In general, residences and businesses with plumbing fixtures below the closest upstream sanitary sewer maintenance hole rim are at most risk for sewer backups. The majority of homes that have experienced sewer backups have fixtures below the closest upstream sanitary sewer maintenance hole rim.

Seattle Public Utilities

Private Side Sewers & SPU Sewers are both Sources of Infiltration and Inflow (I/I)

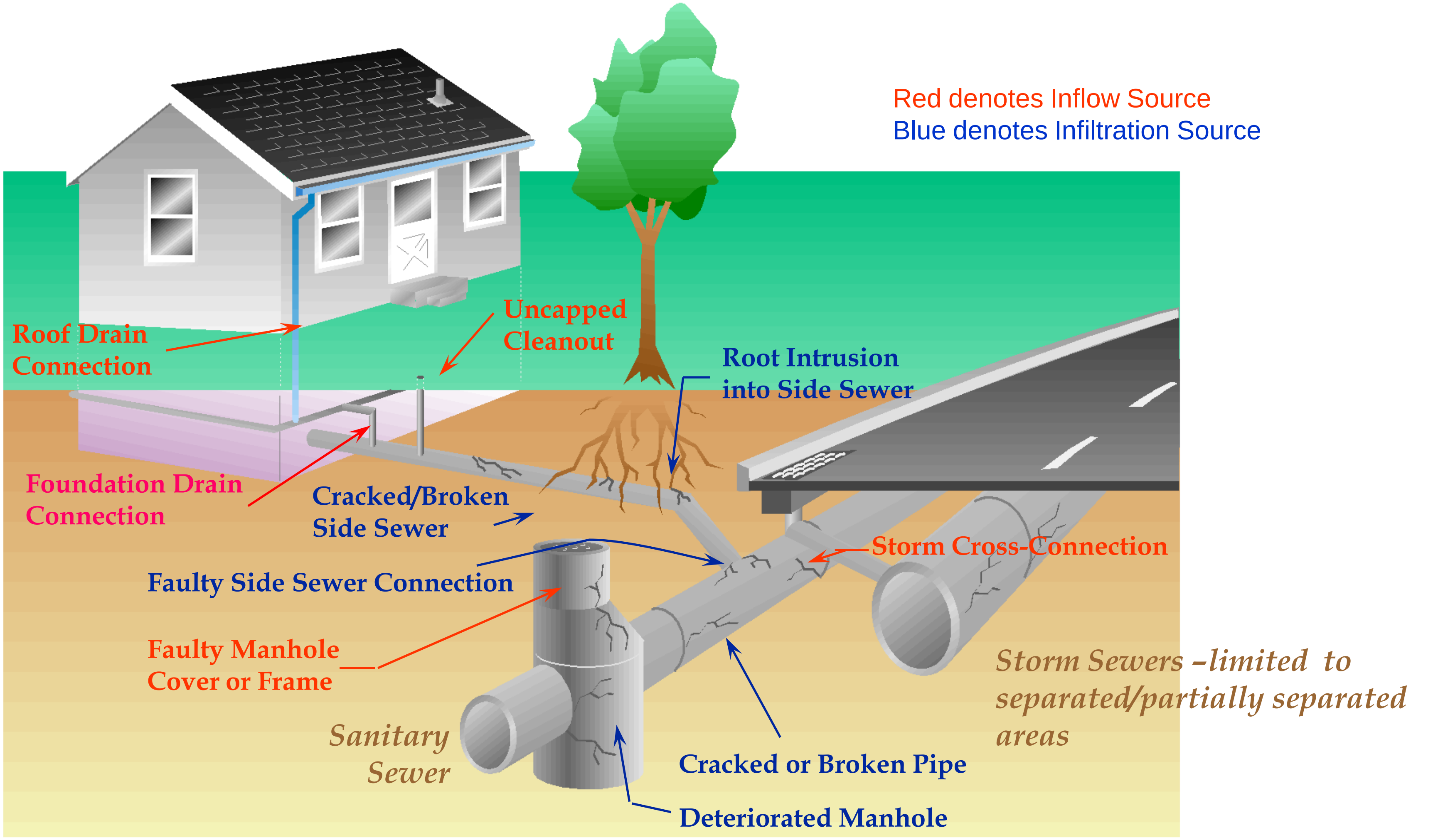

Figure 2. Inflow and infiltration sources.

Chapter 3: Existing Conditions

Broadview is served by a separate sanitary sewer system and a limited drainage system.

Drainage

The majority of stormwater in the Broadview area sheet flows off roadways into adjacent grass lined ditches. A portion of the stormwater infiltrates, although infiltration rates vary throughout the study area. Stormwater may also evaporate or enter the sanitary sewer through direct connections as inflow or through infiltration. Eventually, most of the remaining stormwater is delivered to the Pipers Creek drainage.

Wastewater Conveyance

Wastewater generated within the study area is from residential and light commercial sources with no known industrial wastewater contribution. It is collected in sewer mains owned and operated by SPU; however, the system was constructed in the 1950s prior to the area being annexed by Seattle. Wastewater is conveyed to the West Point Treatment Plant via the King County pipeline and Carkeek Park Pump Station located at the bottom of the Carkeek drainage. In case of high flows that cannot be conveyed by the pump station, the wastewater receives treatment prior to discharge to Puget Sound through the Carkeek CSO Outfall. Smoke testing was performed both as part of the 1998 Broadview Sewer Assessment and as part of this project in June 2008 to determine if there are significant drainage connections to the sanitary sewer. The results of smoke testing are discussed in later sections.

The majority of sanitary sewers in Broadview are between 6 and 12 inches in diameter. The sanitary sewers are concrete and were constructed in the 1950s. The majority of maintenance holes are brick and mortar. Figure 3 shows a sanitary sewer project constructed in 1998 that included replacement of sanitary sewer lines along 9th Avenue NW, NW 118th Street, 8th Avenue NW, and NW 120th Street. This project included a new mainline sanitary sewer and was constructed to alleviate sanitary sewer backups in the area of NW 120th Street and 7th Avenue NW. Figure 4 shows the same information in a large format and includes maintenance hole numbers.

Geology and Hydrology

Broadview and the surrounding area are situated on an extensive upland glacial plane called the Seattle Drift Plane (Liesch 1963). This geologic feature consists primarily of Quaternary glacial deposits resulting from the Vashon stage of the Fraser glaciation that occurred between 17,000 and 13,500 years ago. The glacial units in the Seattle area, including Broadview, are represented by four generally recognizable members (from oldest to youngest): Lawton Clay (glaciolacustrine deposit), Esperance Sand (advance outwash), Vashon till, and Vashon stratified ice-contact and recessional outwash deposits (Troost et al. 2005).

It is difficult to determine what impact the geology may have on infiltration and Green Stormwater Infrastructure. Typically infiltration tests are performed to verify actual infiltration rates for project sites. Infiltration testing to support the Venema Creek Natural Drainage System Project was performed in Broadview and was discussed in the July 5, 2006, Addendum to Venema Greengrid Natural Drainage Infiltration Conclusions and Recommendations Memorandum (SPU 2006). Figure 5 shows infiltration rates for the Venema Creek Project.

Groundwater in the Seattle area generally occurs in unconfined permeable zones within the recessional outwash sand/gravel deposits overlying glacial till and in confined zones within the advance outwash Esperance Sand underlying the till. Groundwater is primarily recharged by direct infiltration and seepage from precipitation and surface runoff. Based on surface topography, flow direction of shallow groundwater within Broadview is assumed to the west and southwest toward Pipers Creek and Puget Sound. The regional groundwater flow direction within the Esperance Sand advanced outwash generally is to the west toward Puget Sound. A more detailed discussion of the existing conditions in Broadview are included in the March, 2008 Problem Identification Technical Memorandum (Herrera 2008b).

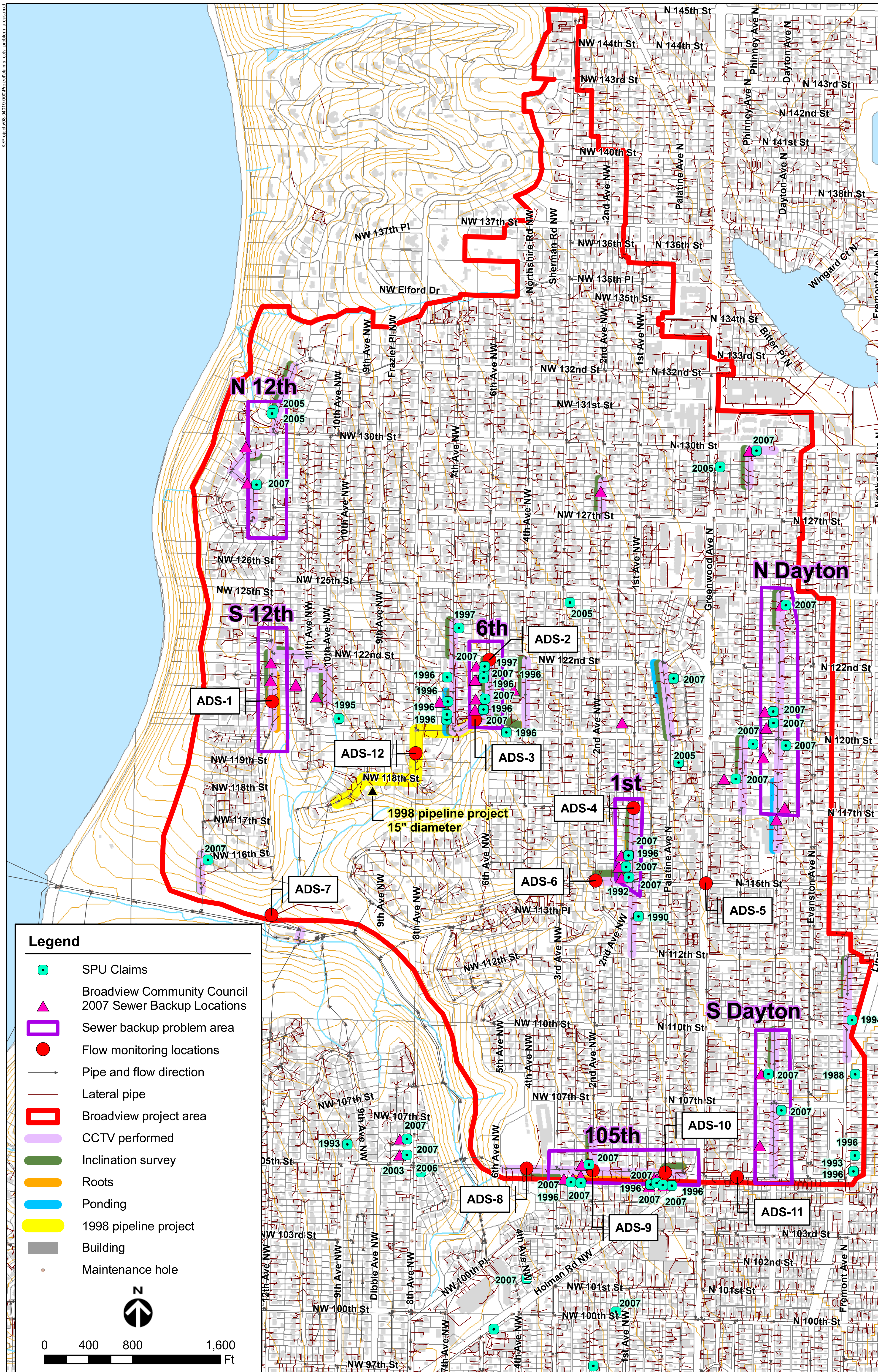

Figure 3. Claim locations, CCTV results, and problem focus areas.

Figure 4. Claim locations, CCTV results, and problem focus areas.

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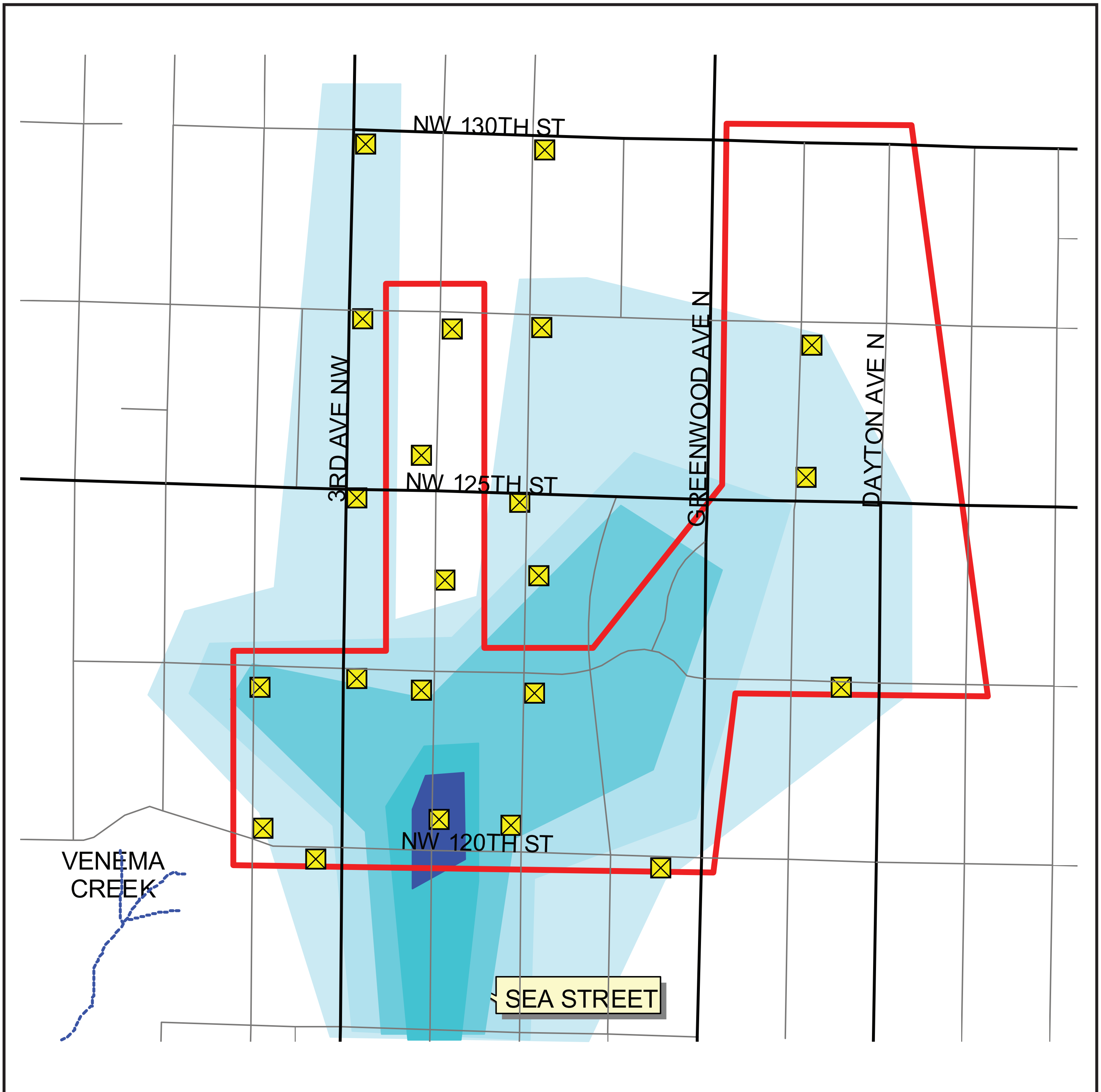

Legend

- Infiltration Test Locations
- >4 inches per hour
- 3 to 4 inches per hour
- 2 to 3 inches per hour
- 1 to 3 inches per hour
- 0.5 to 1 inches per hour
- Not Recommended

Figure 5.
Infiltration rates for Venema Creek Project.

N

0 300 600 1200

Approximate scale in feet

NAVD88 Datum

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Chapter 4: Alternatives Development

The existing system configuration, referred to as the "existing condition," and four alternatives, were analyzed as potential solutions to improve the performance of the sanitary sewer. The alternatives included either replacement of pipe or incremental reductions in inflow and infiltration. Backflow preventers were also investigated to reduce the frequency and magnitude of sewer backups. For purposes of discussion, "inflow" is defined as a direct connection of stormwater runoff to the sewer system. Typical examples of this include roof downspouts and area drains or leaky maintenance hole lids. "Infiltration" enters the sewer system when groundwater seeps into the system through cracked pipes or cracked maintenance holes or leaky pipe joints. The existing condition includes the existing pipe network in place during the monitoring period and represents the baseline for alternative comparison. Figures 3 and 4 show claim locations, CCTV results, and problem focus areas that are discussed in more detail below.

Modeling

Hydrologic and hydraulic modeling was used as the primary tool to analyze the existing sanitary sewer system and alternatives. Analysis was performed with the EPA-SWMM 5 modeling platform. The Broadview Sewer System Study Area Modeling Report (Herrera 2009) includes a detailed discussion of modeling objectives, data used, model calibration, model implementation, and an analysis of model results.

Data Collection

Many forms of data were gathered to better understand the history and existing conditions in Broadview. The data used includes flow monitoring, smoke testing, field observations and investigations, and discussions with the community. Members of the community conveyed information related to the general history of the basin including the timing, duration and extent of sanitary sewer flooding.

Flow Monitoring

Flow monitoring was performed to better understand and predict the behavior of the sanitary sewer. Twelve sites were monitored from September 18, 2008 to February 20, 2009. The data was analyzed and used as a basis to predict the behavior of the sanitary sewer during dry and wet weather periods. The largest storm recorded was the 12-hour 2-year storm on January 7, 2009. The hydrologic and hydraulic model is well calibrated to this event, but without calibration to larger events there remains uncertainty when extrapolating results to larger storm events. For this reason, additional monitors have been installed at critical locations as discussed in Chapter 7. Nonetheless, the calibrated model simulates surcharge at largely the same historic sewer backup locations for similar storm events.

Smoke Testing

The Broadview smoke testing analysis performed by SvR (SvR 2008), smoke testing performed during the 1998 (Herrera 1998) and the SPU downspout connectivity study (SPU 2009) were used to estimate the area of impervious surfaces directly connected to the sewer system. This analysis was used to determine connectivity incorporated in the EPA-SWMM 5 model and used to evaluate Alternative 2 – Inflow Reduction and Alternative 4 – Inflow and Infiltration Reduction.

The smoke testing performed in 2008 included an area of 406 acres having 230 connections. The area connected to the sanitary sewer totaled 4.38 acres. 95 of the connections were downspout connections from residences. There are 1,464 residences in the area tested resulting in a seven percent downspout connection rate. Other connections included private catch basins, uncapped lateral cleanouts, and other sources (see Table 1). However, smoke testing often underestimates the amount of connections and scale-up factors are often used and were used in this study to account for under catchment (SPU 2009). More details of the factors used are presented in the model alternatives section.

Table 1. Smoke testing results.

Summary	Total	% By Type of Connection	% of Total Residences
Downspouts	95	41%	7%
Ground/Other	66	29%	5%
Drain/Catch Basis	52	23%	4%
Faulty Cleanout	17	7%	1%
Total	230	–	16%

Community Involvement

SPU performed community outreach and held several public meetings during the course of the project. A significant goal of community involvement was to engage the public as stakeholders. A discussion of the history of sewer problems that homeowners have experienced was a key to identify areas of concern.

Representatives from the community referred to as the Broadview Task Force formed a subcommittee and served as spokespeople for Broadview. Several meetings were held with the Task Force to exchange information and ideas. To assist with analysis, the Broadview Task Force created a database of sewer backups for Broadview that included only sanitary sewer backup records for the December, 2007 event.

CCTV and O&M

SPU provided maintenance records and closed circuit television (CCTV) records. Additional CCTV work was performed as part of this project and included sections of sanitary sewer upstream and downstream of reported flooding locations. These records were used to assess the existing condition of the sanitary sewer and to adjust the model and to provide a general assessment of the sanitary sewer. Pipe sags were identified and the model was adjusted to duplicate the existing sanitary sewer geometry.

Maintenance logs were used to identify locations that received significant operation and maintenance. It was determined that Broadview generally required an average amount of operation and maintenance when compared to greater Seattle. Results of maintenance records analysis are presented in the Problem Identification Technical Memorandum (Herrera 2008b).

Field Investigation

Herrera conducted a site visit on August 13, 2008 to assess conditions of the known problem areas. As part of this effort and to evaluate conditions for flow meter installation, a general maintenance hole condition assessment was conducted. The assessment included visual observations only and the maintenance hole was not entered as part of the assessment. No significant rainfall had occurred within days of investigation. The majority of the maintenance holes were brick and mortar and were generally in fair condition and showed evidence of infiltration at several locations.

Claim Data

Claim data from 1988 through 2007 was used as a tool to identify historic sanitary sewer backup locations and provide a preliminary indication of areas with conveyance constraints. It was also used to validate modeling results.

Alternatives

Four alternatives were developed to improve the performance of Broadview sanitary sewer system.

- Alternative 1 includes pipe replacement
- Alternative 2 includes inflow reduction
- Alternative 3 includes infiltration reduction, and
- Alternative 4 includes both inflow and infiltration reduction.

Alternatives 1 thorough 4 are discussed in more detail below. Backflow preventers were also analyzed as a potential solution and are also discussed below.

Alternative 1

Alternative 1 includes select pipe replacement, as shown in Figure 6 for 1st Avenue NW Street and N and NW 115th Street and N and NW 105th Street. The pipe replacement alternatives were configured to reduce the frequency and magnitude of future backups near their locations and minimize downstream and upstream impacts for a variety of storm events. Another consideration was the opportunity for SPU to use streamlined contracting mechanisms for smaller contracts to accelerate improvements.

All the locations evaluated included locations near 1st Avenue NW Street and N and NW 115th Street, 6th Avenue NW and 120th Street NW, 12th Avenue NW, N and NW 105th Street, and Dayton Avenue NW. The analyses showed that the sanitary sewer near 6th Avenue NW and 120th Street, 12th Avenue NW, and Dayton Avenue N do not have significantly lower capacity than the adjoining upstream or downstream pipes. These locations were not evaluated further under Alternative 1 for the following reasons:

- 6th Avenue NW
  - The model does not simulate pipe surcharge for this location until a storm approximately three times the 100-year event is passed through the system. The model underestimates inflow and infiltration (I/I). To better understand the system at this location additional monitoring is being conducted to quantify and (I/I).
- 12th Avenue NW
  - The model indicates capacity limitations for 12th Avenue NW from about NW 120th Street to near NW 130th Street for the 25- and 100-year events. This was too large an area to qualify for the smaller contracts mechanism. Pipe replacement was evaluated but not on the accelerated schedule since more time and design work (at more cost) would be required.
- Dayton Avenue N
  - The model indicates sufficient capacity backups occurred on December 3, 2007. A blockage in the pipe Additional monitoring is being conducted on Dayton to confirm the model results.

Alternative 2

Alternative 2 is flow reduction through removal of inflow. Three different scenarios (2.A, 2.B, and 2.C) described below were modeled to determine the quantity of inflow reduction required to reduce backups.

Smoke testing was used to establish and quantify the amount of inflow connected to the sanitary sewer. However, previous studies by SPU (SPU 2009) indicate that smoke testing underreports the number of connections. As a result, a 50 percent scale up factor to the SvR smoke test results were used to better represent the downspout connection rate.

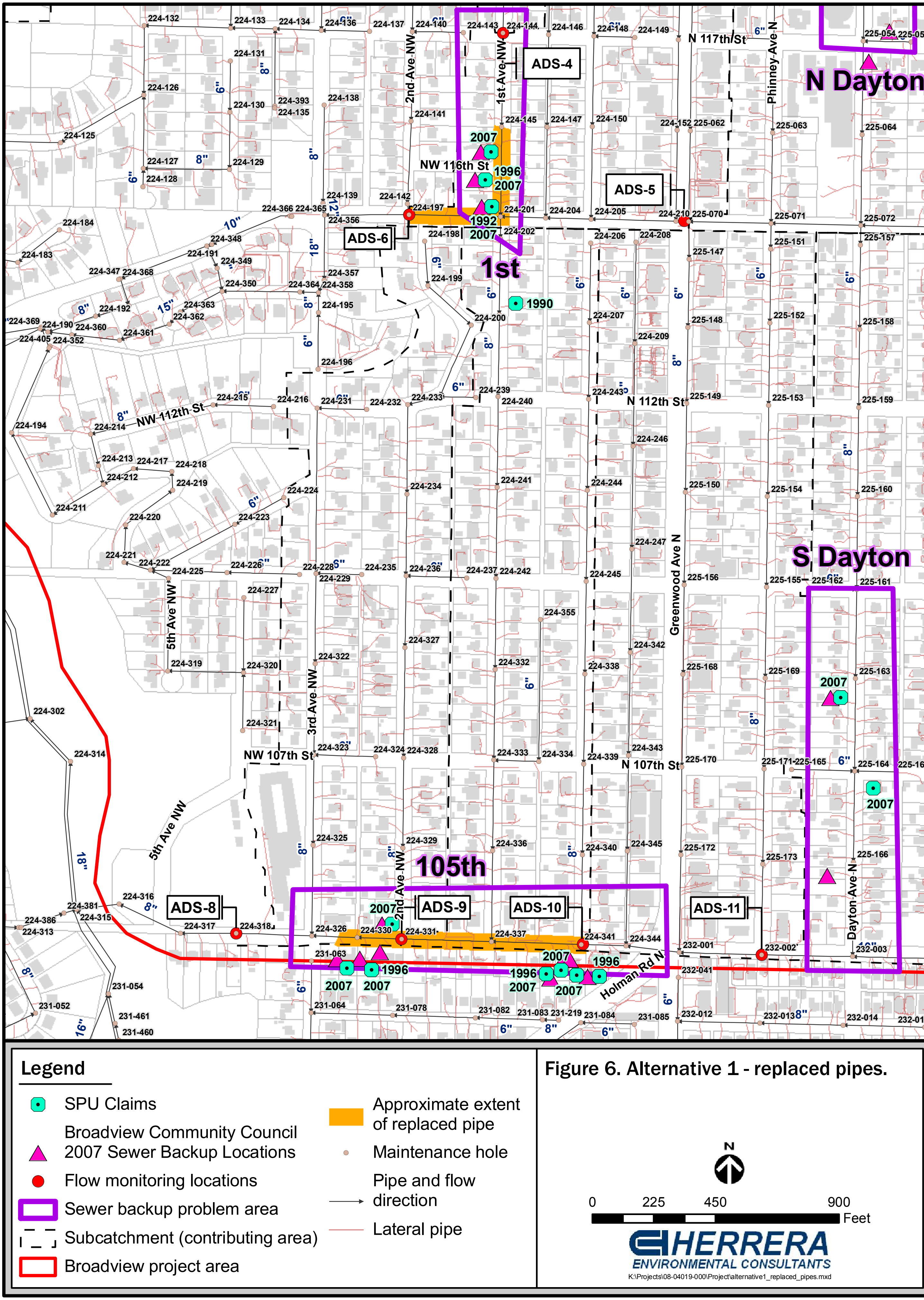


Figure 6. Alternative 1 - replaced pipes.

The hydrologic and hydraulic model is based on percent of total area connected and not as a percent of the total residences connected.

4.38 acres out of 406 acres tested positive during smoke testing for a direct connection of 1.1 percent of the area. Of the 230 connections found, 41 percent were downspouts (95 connections)[1]. The other connections were from private catch basins, cleanouts, and other lateral connections to the main line. Scaling the values up by a 50 percent results in 0.68 percent of the basin area being directly connected to the sewer system through downspout connections (1.1 percent of the area is connected × 41 percent of connections are downspouts × 1.50 scaling factor = 0.68 percent). Disconnecting all connected downspouts would result in reducing the fraction of rainfall entering the sanitary sewer from inflow[2] by 0.68 percent.

The following is a description of the assumed factors used to derive acreage of removed inflow:

- Smoke Test Scale Up Factor (150 percent) – Represents under catchment of connections confirmed by smoke testing

- Percent of Residences Participating (50 percent, 70 percent, & 100 percent) – Represents varying amount of residents that are willing to participate in a downspout disconnection program

- Percent of Residences Participating That Are Feasible (50 percent, 70 percent, & 100 percent) – Represents varying amount of residents that are willing to participate and are able to participate in a downspout disconnection program due to site constraints

- Alternatives 2.A and 2.B remove a percent of the connected roof area which is a fraction of the total connected area. Alternative 2.C was a theoretical scenario which would minimize inflow by removing all connected area to evaluate the limit of inflow reduction as a strategy. The percent inflow reduction calculations for Alternative 2.A through 2.C are presented in Table 2.

The description of Alternative 2.C does not include percentages of residences participating or residences participating that are feasible because it includes removal of all connected area. Disconnection of all stormwater connections was modeled to produce a theoretical boundary condition for analysis only, but is not a realistic option.

[1] It was assumed that each connection was equal to the roof area.
[2] This is the fast "R" value.

Table 2. Alternative 2 – inflow reduction summary.

Item	Alternative		
	2.A	2.B	2.C
Total Area	406	406	406
Total Acres Connected	4.38	4.38	4.38
Percent Downspouts	41%	41%	N/A
Smoke Test Scale Factor	150%	150%	150%
Percent of Residences Participating	40%	70%	100%
Percent of Residences Participating That Are Feasible	50%	70%	100%
Percent of Roof Area Removed	100%	100%	100%
Total Acres Removed	0.54	1.32	6.57
Percent of Area Removed	0.13%	0.33%	1.62%

Alternative 3

Alternative 3 is infiltration reduction. Infiltration, as described earlier, occurs when groundwater seeps into the sewer pipe through leaks in the gravity sewer system. Locations of historical sewer backups, previous infiltration reduction studies, and observed and modeled discharge in the sewer system were used to identify locations where a reduction in infiltration into the sewer system would lead directly to a reduction in the frequency and magnitude of potential future backups. As with Alternative 2, three different levels of infiltration reduction are modeled to give a range of the effectiveness of infiltration reduction strategies.

Alternatives 3.A, 3.B, and 3.C include a 20 percent, 40 percent, and 80 percent reduction in infiltration respectively. Information related to determining and applying these levels are presented below.

Realistic infiltration reduction levels were obtained from the 2004 King County Regional Infiltration and Inflow Control Program Study (King County, 2004). The King County report summarized the findings of 10 regional I/I control pilot programs. The greatest reduction in infiltration achieved was 87 percent in Skyway where the entire pipe system was replaced. Kent and Ronald also reported high infiltration reductions at 76 percent and 74 percent respectively, where all laterals and side sewers were replaced. Mercer Island achieved a 37 percent reduction by replacing mainlines, while North Shore obtained a 23 percent reduction through lining the existing maintenance holes. Two locations, Auburn and Redmond, replaced 11 percent and 36 percent of mainlines and found no measurable reduction in infiltration. From these studies, 20, 40, and 80 percent were used to represent the range of potential infiltration reductions in Broadview.

The Ronald basin is closest to Broadview and was constructed about the same time and of similar material and construction techniques. As a result, Ronald was used as a basis of realistic I/I removal rates in Broadview.

Inflow and infiltration reduction is included in the percent removal reported in Ronald of 74 percent. However, 11 out of 261 (4 percent) downspouts were disconnected representing inflow removal. Since the amount of downspout connections removed was relatively small, it was assumed that the majority of flow reduction was representative of infiltration. This may or not be the case and can only be verified by pilot testing. For purposes of modeling, this percent reduction was assumed to be an adequate approximation of inflow reduction in Broadview.

In the King County study, the entire pipeline from the mainline to residences or businesses is referred to as a lateral and side sewer depending on location with respect to right of way. For this study, this pipeline is referred to as a lateral.

Alternative 4

Alternative 4 is a combination of inflow and infiltration reduction and was developed to better determine if a combined inflow and infiltration reduction was a viable option. In the original modeling effort that included Alternatives 1 through 3, each of these alternatives was modeled separately, with no alternative that combined both inflow and infiltration reductions in a single model run. After reviewing the Broadview Sewer System Study Area—Modeling Report (Herrera 2009), SPU decided to conduct an additional model run for the subcatchment around 12th Avenue NW that combined both inflow and infiltration reduction in one alternative.

Alternative 4 includes the parameters illustrated in Table 3 for inflow and infiltration reductions. The inflow reduction assumptions reflect the most up to date assumptions from SPU and reflect the most recent project experience. The quantity of infiltration reduction is reflective of Alternative 3.B which includes a reduction of 40 percent.

Table 3. Alternative 4 – inflow and infiltration reduction summary.

	Alternative 4	
Item	Inflow	Infiltration
Total Area	141.5	
Total Acres Connected	1.97	
Percent Downspouts	1	
Smoke Test Scale Factor	110%	
Percent of Residences Participating	50%	
Percent of Residences Participating That Have Feasible Sites	20%	
Percent of Roof Area Removed	33%	
Total Acres Removed	0.072	
Percent of Area Removed	0.05%	
Infiltration Reduction		40%

Backflow Preventers

Backflow preventers are flap gate valves that are designed to shut when mainlines are surcharged. They are installed in laterals and used in new and existing construction when there is a risk of sewer backups at businesses or residences. They are required in some jurisdictions on all new commercial construction and on new, vulnerable, residential construction. They are also required and installed on existing residences or businesses after a sewer backup. There are several considerations to take into account when installing backflow preventers. Some of them include:

- Fixtures cannot be used until the surcharge has subsided.
- Backflow preventers require periodic maintenance
- Backflow preventer must be installed upstream of all downspout or area drains connected to the lateral.
- Quality of backflow preventers varies. Generally, a backflow preventer including a PVC or brass flap gate should be used. Backflow preventers with rubber flap gates should be avoided due to their inability to resist high head and vulnerability to rodent damage.

Backflow preventers can be used on their own or as part of other alternatives. Backflow preventers can also be used to provide an added level of security with other alternatives.

Modeling Objectives

The performance of the modeled alternatives was assessed with respect to surcharge as a surrogate for the risk of backups. When a sanitary sewer surcharges, the hydraulic grade line is not contained within the pipe. Most residences have basement elevations that are higher relative to the sewer line and it would take a significant depth of surcharge to cause a backup. However, some residences include basements lower than the nearest downstream maintenance hole rim elevation and may be vulnerable to flooding from surcharge. Because basement elevations were not generally available for the Broadview area, to be conservative it was assumed that any surcharge could put residences and businesses at risk for flooding.

The level of service was not directly addressed during alternatives evaluation. Instead, various storms were run thorough the model to determine level of service relative to cost.

Chapter 5: Alternative Analysis

Several alternatives were created to address sewer backups in Broadview as described above. They include; a model of the Existing Conditions. Alternative 1 –Pipe Replacement, Alternative 2 – Inflow Reduction, and Alternative 3 – Infiltration Reduction, and Alternative 4 – Inflow and Infiltration Reduction. Back flow preventers were also considered but the performance was not analyzed. Several focus areas were created from review of claims data and modeling output. The focus areas include locations that have encountered sewer backups and coincide with modeled conveyance problems. The focus areas include; 1st Avenue NW and N and NW 115th Street, N and NW 105th Street between Greenwood Avenue N and 3rd Avenue NW, 12th Avenue NW between NW 119th Street and NW 132nd Street, 6th Avenue NW and NW 120th Street, and Dayton Avenue N. The results of the alternatives are discussed for each focus areas in the section below.

Existing Conditions

The existing conditions model simulated pipe surcharge in roughly the same locations that have experienced sewer backups. Modeling showed a large portion of most focus areas surcharged during the 100-year events. Some of these locations such as 12th Avenue NW and 1st Avenue NW also surcharge during 2-year and 25-year events. A more detailed discussion of focus areas follows.

Downstream conditions were modeled as free flow due to extreme change in elevation and because modeling downstream system was very complex and not included in the scope of this project.

1st Avenue NW

Field inspection on August 13, 2008 found evidence of surcharge in maintenance hole 224-201 located downstream of surcharged residences. Maintenance hole 224-201 is located at the corner of 1st Avenue NW and N and NW 115th Street. Although the basement elevation of these residences has not been surveyed, a rough assessment in the field indicated that basement elevations are roughly the same or below the elevation of the level of surcharge found in the maintenance hole. Surcharge in basements would occur if basement elevations are even slightly below the surcharge elevation in the maintenance hole.

A Manning’s calculation of the free-flow capacity of the existing pipe network indicates capacity out of the maintenance hole lower than the capacity into the maintenance hole. Table 4 below shows that the existing capacity of the pipes into the maintenance hole is 5.03 cfs, while the capacity out of the maintenance hole is 3.25 cfs. The lower capacity out of the maintenance hole could contribute to surcharge if both pipes into the maintenance hole were flowing at their capacity.

Table 4. The Manning's capacity[a], January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for the pipe segments that connect to the maintenance hole at the corner of N and NW 115th Street and 1st Avenue NW.

Pipe Segment	Location	Capacity[a] (cfs)	1/7/2009 OBS Discharge (cfs)	100-Year MOD Discharge (cfs)	100-Year MOD Discharge as Percent of Capacity[a] (percent)
224-204 to 224-201 (Inflow to Maintenance hole)	Along N and NW 115th Street to the west of 1st Avenue NW	3.32	2.45	3.15	95
224-145 to 224-201 (Inflow to maintenance hole)	Along 1st Avenue NW to the north of N and NW 115th Street	1.71	0.45	0.95	56
224-201 to 224-197 (Outflow from maintenance hole)	Along N and NW 115th Street to the east of 1st Avenue NW	3.25	2.90	4.12	129

Note:

[a] Capacity calculations presented here are based on Manning's calculations of maximum free flow discharge based on roughness, slope, and pipe diameter. This capacity does not include the effects of pressure head on discharge.

Table 4 also shows the observed discharge in the pipe segments during the 1/7/2009 storm event, the 100-year modeled discharge, and the 100-year modeled discharge as a percent of capacity. The observed discharge during the January 7, 2009 storm, with a return interval of about 2 years, in pipe segment 224-201 to 224-197 (out of the maintenance hole) was 2.9 cfs. The capacity of the pipe is about 0.35 cfs higher at 3.25 cfs. The 100-year modeled discharge for this segment is 4.12 cfs, which is greater than Manning's capacity. The capacity calculations are based on the free flow Manning's calculation and do not include the effects of pressure head induced during surcharge. The calculations show that there is insufficient capacity for a storm between the observed 1/7/09 (2-year) and 100-year out of maintenance hole 224-201. Because of the existing capacity of the outlet, the maintenance hole and incoming sewer lines surcharge and lead to sewer backups in upstream residences.

Profile plots of the peak water surface elevation during the 2-, 25-, 100-year, and December 3, 2007 events are presented in Appendix B (Figures B-1 and B-2). The upstream maintenance hole in these plots is 224-144 located at the corner of 1st Avenue NW and NW 117th Street. The downstream maintenance hole is 224-197 located at the corner of 2nd Avenue NW and NW 115th Street. These plots show that maintenance hole 224-201 does not surcharge during the 2-year event but does surcharge in the 25- and 100-year events. As expected from the capacity calculations above, the under capacity segment from maintenance hole 224-201 to maintenance hole 224-197 causes the maintenance hole and pipe surcharge. The elevation of surcharge shown appears to be close to basement elevations, indicating that the cause of sewer backups at this location is likely from inadequate capacity in this segment of pipe.

N and NW 105th Street

The existing sewer line along N and NW 105th Street is a 10 inch diameter concrete pipe with 3 foot pipe segments. The capacity of the pipe segments through this area are presented in Table 5. Table 5 shows that segment 224-330 to 224-331 has a capacity less than the adjoining pipe. The observed discharge in the pipe segments during the 1/7/2009 storm event, the 100-year modeled discharge, and the 100-year modeled discharge as a percent of capacity are also shown in Table 5. The pipe segment with the lowest capacity is segment 224-331 to 224-330 and has a capacity lower than the 100-year modeled discharge which makes it function as a bottleneck in the system. The 100-year modeled discharge is 128 percent of the Manning's capacity in this pipe segment.

Table 5. The Manning's[a] capacity, January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for the pipe segments in the area of concern along N and NW 105th Street.

Pipe Segment	Location	Capacity[a] (cfs)	1/7/2009 OBS Discharge (cfs)	100-Year MOD Discharge (cfs)	100-Year MOD Discharge as Percent of Capacity[a] (percent)
224-341 to 224-337	N and NW 105th Street between Palatine Avenue and 1st Avenue NW	4.5	1.2	2.99	66
224-337 to 224-331	N and NW 105th Street between 1st and 2nd Avenue NW	6.2	n/a	3.47	56
224-331 to 224-330	N and NW 105th Street between 2nd Avenue NW and alley to the west	3.0	1.8	3.84	128
224-330 to 224-326	N and NW 105th Street between 3rd Avenue NW and alley to the east	5.7	n/a	3.91	69

Note:

[a] Capacity calculations presented here are based on Manning's calculations of maximum free flow discharge based on roughness, slope, and pipe diameter. This capacity does not include the effects of pressure head on discharge.

The location of this pipe segment with the lowest capacity is downstream of the residences at N 105th Street and 2nd Avenue NW that have experienced sewer backups. Field inspection confirmed the upstream maintenance hole in this segment surcharges. Additionally, photographs from the December 3, 2007 storm event show overtopping of the maintenance hole. The basement elevations of the residences that have sewer backups have not been surveyed. However, they appear to be at an elevation near the surcharge elevation for the 100-year event. Reducing surcharge of these pipe segments would likely reduce the likelihood of the sewer backing-up at residences immediately upstream of the surcharged maintenance hole.

Profile plots of the peak water surface elevation during the 2-, 25-, 100-year, and December 3, 2007 events are presented in Appendix B (Figures B-3 and B-4). Surcharge of the pipe system first occurs during the 100-year event Appendix B (Figure B-3) which approximately corresponds to the level of storm that caused sewer backups in December 1996.

Surcharge occurs in maintenance hole 224-326 and maintenance hole 224-331 during the 100-year storm. There have been no reports of sewer backups near maintenance hole 224-326. Basement elevations appear to be higher than the level of surcharge along this reach of NW 105th Street.

The surcharge at maintenance hole 224-331 corresponds with the sewer backup locations near 2nd Avenue NW and additional locations west on NW 105th Street. Modeling of the December 3, 2007 event shows that the pipe continues to surcharge east to an alley between Palentine Avenue N and Greenwood Avenue N. This eastern location corresponds to several locations of residences that experienced sewer backups during the December 1996 and December 2007 events.

12th Avenue NW

Modeling of existing conditions indicates that 12th Avenue NW from NW 117th Street to north of NW 130th Street surcharges during large storm events. However, SPU sewer backup claims include only two residences near NW 122nd Street, two residences near NW Blakely Court, and two residences north of NW 130th Street. The sewer backups at four residences occurred during the December 3, 2007 storm while the remaining residences experienced backups during a period of no rain.

Correspondence with neighbors indicates the number of residences that experienced backups during the December 3, 2007 event as well as during smaller events is greater than those indicated by SPU claims. One resident reported that maintenance hole 218-098 located at the corner of 12th Avenue NW and NW 130th Street regularly overflows. Additionally, most residences that have experienced sewer backups in this area have basement elevations lower than the rim of the nearest maintenance hole.

Table 6 below presents the observed discharge in the pipe segments during the January 7, 2009 storm event, the 100-year modeled discharge, and the 100-year modeled discharge as a percent of capacity for the sanitary sewer along 12th Avenue NW near the installed ADS flow meter. The capacity of the sanitary sewer is below the 100-year modeled discharge and below the observed discharge during the January 7, 2009 storm. The observed discharge may be greater than the Manning’s capacity due to pressure head associated with pipe surcharge.

Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figure B-5). Two maintenance holes (224-067 and 224-070) surcharge during the 2-year event, all the maintenance holes between 218-098 and 224-071 surcharge during the 25-year event, and all maintenance holes between 218-070 and 224-071 surcharge during the 100-year event.

Table 6. The Manning's[a] capacity, January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for the pipe segments in the area of concern along 12th Avenue NW.

Pipe Segment	Location	Capacity [a] (cfs)	1/7/2009 OBS Discharge (cfs)	100-Year MOD Discharge (cfs)	100-Year MOD Discharge as Percent of Capacity [a] (percent)
224-019– 224-025	12th Avenue NW south of NW 122nd Street	1.6	1.75	2.74	174
224-025 – 224-067	12th Avenue NW north of NW 120th Street	2.4	1.75	2.74	113
224-067 – 224-070	12th Avenue NW south of NW 120th Street	1.4	1.75	2.74	198
224-070 – 224-071	12th Avenue NW north of NW 119th Street	1.4	1.75	2.74	194

Note:

[a] Capacity calculations presented here are based on Manning's calculations of maximum free flow discharge based on roughness, slope, and pipe diameter. This capacity does not include the effects of pressure head on discharge.

6th Avenue NW

The existing conditions model did not simulate surcharge at 6th Avenue NW and NW 120th Street. It is assumed that the model did not simulate surcharge at this location because it under simulates infiltration. As described previously, the model was calibrated with a limited flow monitoring period that did not include any large storm events.

Several attempts were made to replicate surcharge at this location. A pipe sag was observed in CCTV tapes along 6th Avenue NW roughly between maintenance holes 224-042 and 224-104. The model was adjusted to include a sag node and the diameter of the pipe was reduced to account for sedimentation that likely occurs in a pipe sag. The model still did not surcharge at this location. Modelers were required to increase flow in the pipe segment to a quantity approximately three times the 100-year event to induce surcharge at this location. As a result, the model is not considered accurate for 6th Avenue NW. Model recalibration could correct this but would require flow data from large storm events. To better assess the local sewer basin behavior, a monitor was installed at 224-104 in November, 2009. Recent results seem to indicate infiltration is present at this location. See Chapter 7 – Summary for more details.

Peak water surface elevation profiles are not shown for 6th Avenue NW since the EPA-SWMM 5 model does not simulate any pipe surcharge at this location. However, the January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for the area near 6th Avenue NW and NW 120th Street are presented in Table 7.

Table 7. The Manning's capacity, January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for the area of concern near 6th Avenue NW and NW 120th Street.

Pipe Segment	Location	Capacity [a] (cfs)	1/7/2009 OBS Discharge (cfs)	100-Year MOD Discharge (cfs)	100-Year MOD Discharge as Percent of Capacity [a] (percent)
224-042 – 224-104 (IN)	Along 6th Avenue NW to the north of NW 120th Street	1.6	0.26	0.58	36
224-105 – 224-104 (IN)	Along NW 120th Street to the east of 6th Avenue NW	2.7	0.62	0.77	29
224-104 – 224-103 (OUT)	Along NW 120th Street to the west of 6th Avenue NW	3.5	0.88	1.38	39

Note:

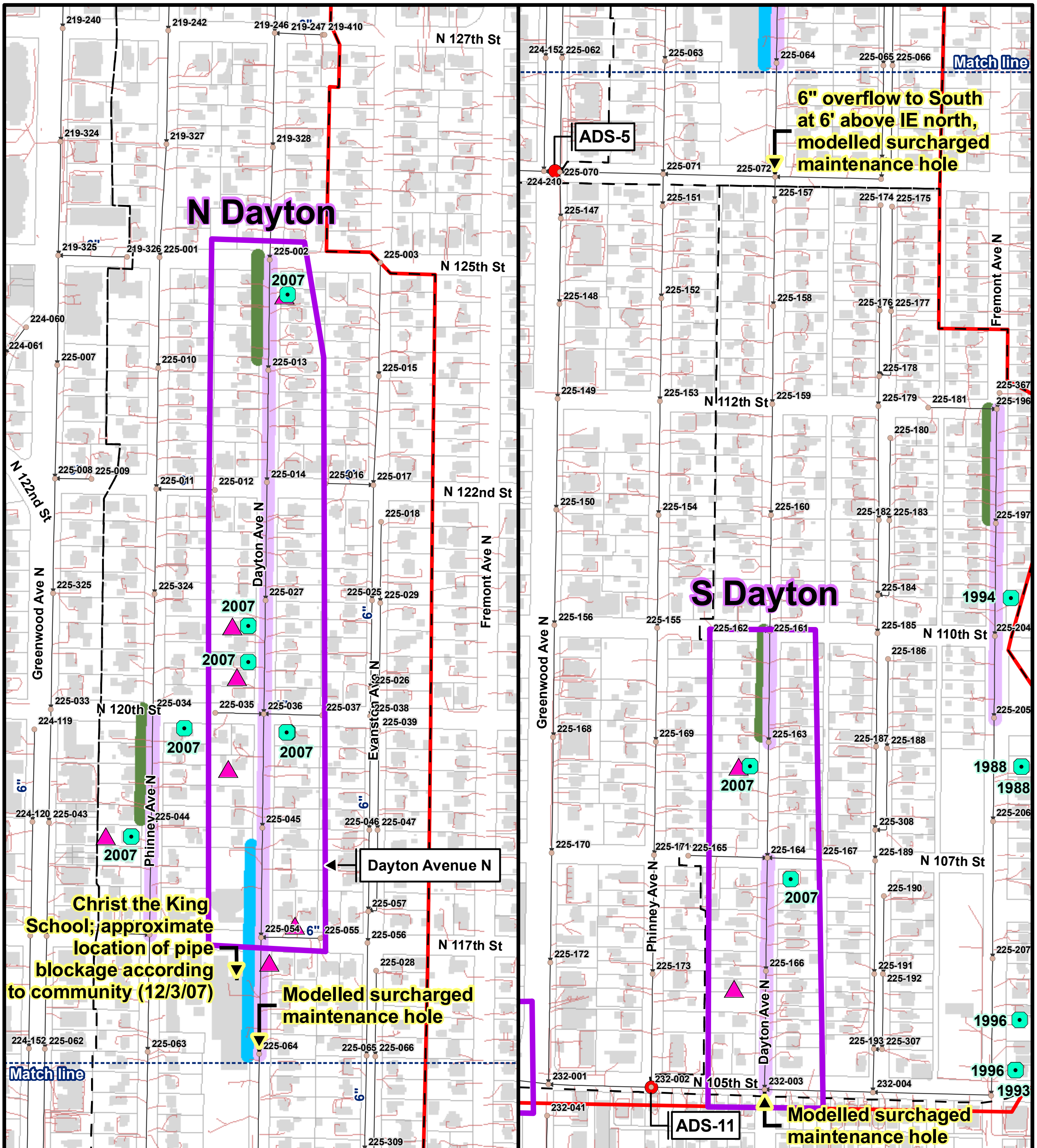
[a] Capacity calculations presented here are based on Manning's calculations of maximum free flow discharge based on roughness, slope, and pipe diameter. This capacity does not include the effects of pressure head on discharge.

Dayton Avenue N

A number of sewer backups were reported on Dayton Avenue N during the December 3, 2007 storm event. Most of these residences are clustered upstream of Christ the King School located on N 117th Street. There have been conflicting reports of a blockage in the sewer pipe at this location during this event. Three additional residences reported flooding further south near Dayton Avenue N and N 107th Street and are discussed at the end of this section.

Table 8 below presents the Manning's capacity, observed discharge during the 1/7/2009 storm event, 100-year modeled discharge, and the 100-year modeled discharge as a percent of capacity for the sanitary sewer on Dayton Avenue N south of N 120th Street and for the sanitary sewer on N 115th Street the east of Greenwood Avenue N. The Manning's capacity of the sanitary sewer on Dayton Avenue N exceeds the 100-year modeled discharge which could confirm the claim that there was a pipe blockage during the December 3, 2007 event. The downstream pipe segment on W 120th Street, however, has a capacity less than the 100-year modeled discharge.

The southern portion of Dayton Avenue N by N 105th Street shows surcharge in the existing condition model under the 100-year event to a depth of 1.5 feet. Although Dayton Avenue N north of N 115th Street appears to be hydraulically disconnected from Dayton Avenue N south of N 115th Street, an overflow outlet exists at 6 feet elevation in the maintenance hole at Dayton Avenue N and N 115th Street. It allows excess flow in maintenance hole 225-072 to continue south. Reducing surcharge on Dayton Avenue N north of N 115th Street may also reduce surcharge on Dayton Avenue N south of N 115th Street by not activating the overflow at maintenance hole 225-072. Figure 7 illustrates model results, claim locations, and hydraulic connectivity for this portion of Dayton Avenue N.



Legend

- SPU Claims
- Broadview Community Council 2007 Sewer Backup Locations
- Flow monitoring locations
- Sewer backup problem area
- Subcatchment (contributing area)
- Broadview project area
- CCTV performed
- Inclination survey
- Ponding
- Maintenance hole
- Pipe and flow direction
- Lateral pipe

Figure 7. Dayton Avenue NW - modeling results, claim locations, and hydraulic connectivity.

N

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Table 8. The Manning's[a] capacity, January 7, 2009 observed discharge, 100-year modeled discharge, and 100-year discharge as a percent of capacity for Dayton Avenue N south of N 120th Street and for N 120th Street to the east of Greenwood Avenue N.

Pipe Segment	Location	Capacity[a] (cfs)	1/7/2009 OBS Discharge (cfs)	100-Year MOD Discharge (cfs)	100-Year MOD Discharge as Percent of Capacity[a] (percent)
225-036– 225-045	Dayton Avenue N south of N 120th Street	1.6	n/a	0.7	44
225-071 – 225-070	N 115th Street east of Greenwood Avenue N	1.1	1.7	2.0	182

Note:

[a] Capacity calculations presented here are based on Manning's calculations of maximum free flow discharge based on roughness, slope, and pipe diameter. This capacity does not include the effects of pressure head on discharge.

Alternative 1 – Early Action Pipe Replacement

Output from the EPA-SWMM 5 model indicates sewer backup locations near 1st Avenue NW and N and NW 115th Street and N and NW 105th Street between Greenwood Avenue N and 3rd Avenue NW occur where segments of pipe have capacity lower than the 100-year modeled discharge. Upsizing a limited amount of pipe at these locations would significantly reduce the potential of sewer backups in the future as is modeled under Alternative 1. This alternative was initiated to take early action using available funding and contract mechanisms for smaller projects.

Alternative 1 eliminates surcharge up to the 100-year event at the area of concern at 1st Avenue NW and N and NW 115th Street and at N and NW 105th Street to the east of Greenwood Avenue N.

To eliminate surcharge for 12th Avenue NW, over 2,500 feet of 15-inch pipe would be required to address capacity limitations for the 100-year event. The potential size of such a pipe replacement would exceed the ability to evaluate and construct it as an "early action". In addition to cost considerations, it could cause impacts in the downstream pipe and/or at the Carkeek Pump Station which could contribute to combined sewer overflows (CSOs) at this location. For that reason pipe replacement on 12th Avenue NW. was not included in the Alternative 1 – Early Action Pipe Replacement Alternative. However, the results and cost of pipe replacement for 12th Avenue NW were evaluated and are presented in Chapter 6.

As discussed earlier, the model does not predict the behavior of 6th Avenue NW or Dayton Avenue N accurately so estimating the size and extent of pipe replacement is not currently possible. For that reason, additional monitoring is being conducted at these sites.

1st Avenue NW

The solution to reduce the potential for surcharge in maintenance hole 224-201 was obtained from increasing the diameter of the pipe segment 224-201 to 224-197 which conveys flow out of the maintenance hole. The existing pipe is 8 inches in diameter and has a capacity of 3.25 cfs. The proposed alternative replaces the pipe with a 12-inch pipe, increasing capacity to 9.6 cfs. Since segment 224-145 to 224-201 includes a sag, it was also replaced as part of the modeled alternative. Although Manning's calculations and modeling show segment 224-145 to 224-201 has sufficient capacity, a 12 inch pipe is proposed to replace the 8 inch pipe due to the pipe sag to provide added protection for an area prone to sewer backups. This increases the capacity of this segment to 4.84 cfs.

Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figure B-7). The model shows that maintenance hole 224-197 does not surcharge under the proposed alternative during the 2-year through 100-year events but does during the December 3, 2007 event shown in Appendix B (Figure B-8). Sewer backups at this location may have been caused by the surcharge of maintenance hole 224-197. Therefore, eliminating surcharge at this maintenance hole may reduce the likelihood of sewer backups near maintenance hole 224-201. Please note the model shows that replacing pipe as indicated above does not protect the system under the December 3, 2007 event.

Upsizing pipe segment 224-201 to 224-197 from 8-inch to 12-inch diameter results in a peak downstream flow increase of 0.48 cfs during the 100-year event. Additionally, the alternative does not increase surcharge in the downstream pipe for events up to and including the 100-year event. However, it causes surcharge that occurred in the existing pipe network at maintenance hole 224-201 during the December 3, 2007 to occur at the next maintenance hole downstream.

N and NW 105th Street

Upsizing pipe segment 224-331 to 224-330 from a 10 inch diameter pipe to a 15 inch diameter pipe will reduce the frequency and magnitude of surcharge in this section of pipe. The existing capacity of this pipe segment is 3.0 cfs. Upsizing the pipe increases the capacity to 8.8 cfs.

Table 5 shows that pipe segment 224-341 to 224-337 has adequate capacity for the modeled 100-year event. However, its capacity is lower than the adjoining pipes and it is located where sewer backups have occurred on multiple occasions. Because of this proximity to historical backups and having a lower capacity than surrounding pipes, the modeling done under this alternative also includes upsizing pipe segment 224-341 to 224-337 from 10 inch to 15 inch.

Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figures B-9) for Alternative 1. Appendix B (Figure B-10) shows the peak hydraulic grade line during the December 3, 2007 event (for Alternative 1. Modeling of existing conditions shows no surcharge during the 2- and 25-year events but does indicate surcharge in the 100-year and December 3, 2007 event. The proposed alternative eliminates surcharge west of 3rd Avenue N for events up to and including the December 3, 2007 event. The proposed alternative eliminates surcharge between maintenance hole 224-330 and maintenance hole 224-337 during the 100-year event and between maintenance hole 224-330 and maintenance hole 224-344 up to the December 3, 2007 event. This reach of pipe is where sewer backups occurred.

The downstream impacts associated with upsizing the two segments of pipe include a maximum increase in downstream surcharge of 0.03 feet during the 100-year event. Additionally, the peak flow increase in the downstream pipe is 0.02 cfs (4.04 cfs in existing conditions versus 4.06 cfs in Alternative 1) during the 100-year event. Since 1st Avenue NW and N and NW 105th Street are addressed in Alternative 1, they are not included in analysis or discussion of Alternatives 2 or 3.

12th Avenue NW

Although not assessed as an early action as discussed earlier, upsizing pipe segment 218-144 to 224-084 from a 10-inch diameter pipe to a 15-inch diameter pipe will reduce the frequency and magnitude of surcharge in this section. The existing capacity of this pipe segment is 1.4 cfs. Upsizing the pipe increases the capacity to 4.1 cfs.

Appendix B (Figure B-11) shows the peak water surface elevation along 12th Avenue NW for the 100-year design event for Alternative 1.

The peak flow increase in the downstream pipe is 0.9 cfs (2.8 cfs in existing conditions versus 3.7 cfs in alternative 1) during the 100-year event.

Alternative 2 – Inflow Reduction

Alternative 2 applies inflow reductions across the entire Broadview Basin, enabling review of the flow reductions anywhere in the study area. However, if one of the modeled scenarios were implemented, specific areas upstream of sewer backup locations would likely be targeted. Alternative 2 assumes that the Alternative 1 pipe replacement options are implemented for 1st Avenue NW and N and NW 105th Street.

The problem areas that exist after Alternative 1 is implemented include 12th Avenue NW, 6th Avenue NW between NW 120th Street and NW 122nd Street, Dayton Avenue N north of N and NW 105th Street and Dayton Avenue N north of N 115th Street. The Alternative 2 scenarios result in a decrease in the amount of surcharge at these locations the extent of which is further reduced with increased reductions in inflow. An increase in the reduction of inflow reduces the extent of surcharge on 12th Avenue NW. The surcharge remaining along NW 105th Street after implementation of Alternative 1 west of 3rd Avenue N is reduced in Alternative 2.A and eliminated in Alternatives 2.B and 2.C. The modeled surcharge at the corner of Dayton Avenue N and N 105th Street is eliminated in Alternative 2.A. The surcharge at Dayton Avenue N and

N 115th Street is progressively reduced in Alternatives 2.A through 2.C. More detailed information for each of the problem locations is presented in the sections below.

12th Avenue NW

Peak discharge from the 100-year event is presented below in Table 9 for the existing conditions and Alternative 2 scenarios for maintenance hole 224-071 located on 12th Avenue NW just north of NW 122nd Street. This segment of pipe is 10-inch concrete with a Manning's capacity of 1.4 cfs. The Manning's capacity is the highest discharge that can flow through the pipe without any pressure head. Surcharge of upstream pipe can force more water through and allow discharge in excess of the Manning's capacity. Column "Peak Discharge" indicates all discharge exceeds Manning's capacity. Alternative 2.C is the most aggressive inflow reduction scenario and results in a peak 100-year discharge 0.85 cfs greater than the Manning's pipe capacity. The percent reduction in peak flow is 2 percent, 4 percent, and 14 percent for Alternative 2.A, 2.B, and 2.C respectively. So, a reduction in inflow would not be sufficient to eliminate surcharge on 12th Avenue NW.

Table 9. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 224-071 for the existing conditions and Alternative 2 scenarios during the 100-year event with a capacity of 1.4 CFS.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	2.61	n/a
Alt 2.A	2.56	2
Alt 2.B	2.51	4
Alt 2.C	2.25	14

A 46 percent reduction in peak flow is required to limit discharge to the Manning's capacity. However, any reduction in inflow and peak flow will reduce the probability and/or extent of backups in the future.

Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figures B-12, B-13, and B-14) for Alternatives 2.A through 2.C.. A small amount of surcharge in maintenance hole 224-067 in the existing conditions, 2-year model still exists in Alternative 2.A and 2.B but is eliminated in Alternative 2.C. During the 25-year event, the existing conditions model simulates approximately 3,000 feet of surcharge from maintenance hole 218-098 to maintenance hole 224-071. Surcharge is progressively reduced in Alternatives 2.A, 2.B, and 2.C. In Alternative 2.C, a small amount of surcharge exists in maintenance holes 224-067 and 224-070. The surcharge associated with the 100-year event goes from maintenance holes 218-070 to 224-071 (~3,500 feet) in the existing conditions model. The surcharge in Alternative 2.A and 2.B scenarios begins 500 feet downstream. For Alternative 2.C, surcharge is decreased considerably, and is less than 1 foot in depth where it still exists. However, as noted in Chapter 4, Alternative 2.C is a theoretical boundary and is not considered achievable.

6th Avenue NW

As discussed earlier, the EPA-SWMM 5 model does not accurately simulate discharge during large return interval events at this location. Nonetheless, Table 10 below shows the reduction in peak discharge that is achieved with the Alternative 2 scenarios. The discharges shown are for maintenance hole 224-104 located at the corner of 6th Avenue NW and NW 120th Street. A detailed discussion is not provided for this table because it is believed the discharge numbers presented are not representative of actual conditions in the pipe system.

Table 10. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 224-104 for the existing conditions and Alternative 2 scenarios during the 100-year event.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	1.38	n/a
Alt 2.A	1.33	3
Alt 2.B	1.26	8
Alt 2.C	0.81	41

Dayton Avenue N

Although the existing conditions model does not simulate pipe surcharge sewer backup locations on Dayton Avenue N north of N 120th Street during either the 100-year or December 3, 2007 events, it does predict surcharge about two blocks south, where the sanitary sewer on Dayton Avenue N heads west.

A small amount of surcharge is present in the 2-year simulation at maintenance holes 225-071 and 225-072 in the existing conditions model. The same maintenance holes surcharge during the 2-year event in Alternatives 2.A and 2.B but to a lesser extent. Surcharge at both maintenance holes is eliminated in the 2-year event in Alternative 2.C. The existing conditions model predicts surcharge in the same maintenance holes during the 25-year event with maintenance hole 225-072 surcharges to a depth of approximately 5 feet. Alternative 2.A shows a negligible decrease in surcharge, while Alternative 2.B predicts a reduction in surcharge by approximately 1 foot in both maintenance holes that currently surcharge. During the 100-year event, the existing conditions model surcharges at maintenance hole 225-064 and also surcharges in maintenance hole 225-072 to the elevation of the overflow outlet at 6 feet above the bottom of the maintenance hole. The Alternative 2.A model under the 100-year event has peak surcharge to essentially the same depth as the existing conditions model. The surcharge depth in the Alternative 2.B model is only slightly less than in Alternative 2.A, however by Alternative 2.C there is a significant decrease in surcharge.

Table 11 below shows the peak discharge at maintenance hole 225-070 located at the intersection of N 115th Street and Greenwood Avenue N for existing conditions and Alternative 2.A, 2.B, and 2.C. For comparison, the Manning's capacity for the 8 inch pipe is 1.1 cfs which is lower than the modeled peak discharge associated with the 100-year event. This peak discharge above the Manning's capacity shows the effects of pipe surcharge and pressure head on the discharge. The reduction in peak discharge associated with Alternatives 2.A, 2.B, and 2.C are 0 percent, 0 percent, and 12 percent, respectively. Although these reductions in peak discharge may seem erroneous, the existing conditions, Alternative 2.A, and Alternative 2.B all have the same discharge because the upstream surcharge is up to the 6 foot overflow elevation. In Alternative 2.C, the flow is reduced because of the drop in water surface elevation indicated in the profile plots.

Table 11. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 225-070 for the existing conditions and Alternative 2 scenarios during the 100-year event with a capacity of 1.1 CFS.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	1.99	n/a
Alt 2.A	1.98	0
Alt 2.B	2.00	0
Alt 2.C	1.74	12

Water surface profiles are not shown for this location due to no modeled surcharge. Table 12 presents the peak discharge at maintenance hole 225-036 at the intersection of N 120th Street and Dayton Avenue N for the existing conditions and Alternatives 2.A, 2.B, and 2.C. For comparison, the Manning's capacity for the 8 inch pipe is 1.6 cfs which is greater than the peak modeled discharge associated with the 100-year event. This peak discharge below the Manning's capacity supports the claim of a blockage existing in the pipe network during the December 3, 2007 event. This may also indicate an under-simulation of I/I in the model, but that is believed to be less likely due to model calibrating and validating well at this location. The reduction in peak discharge associated with Alternatives 2.A, 2.B, and 2.C are 2 percent, 7 percent, and 31 percent, respectively. Although these reductions in peak discharge are not required here since they are already under the pipe capacity, they do benefit the system capacity by removing flow. This would help reduce the likelihood of sewer backups at locations where the pipe may be at or near capacity near maintenance holes 225-064, 225-072, and 232-003.

Table 12. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 225-036 for the existing conditions and Alternative 2 scenarios during the 100-year event with a capacity of 1.6 CFS.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	0.73	n/a
Alt 2.A	0.72	2
Alt 2.B	0.68	7
Alt 2.C	0.50	31

Alternative 3 – Infiltration Reduction

Alternative 3 applies the infiltration reductions across the entire Broadview Basin, enabling review of flow reduction anywhere in the study area. However, if one of these scenarios were implemented, it would likely be targeted to the specific drainage areas upstream of sewer backup locations. Reducing infiltration as much as possible is beneficial because it reduces the volume of rainwater conveyed to the West Point Wastewater Treatment Plant and would reduce the likelihood of CSO events. However, reducing infiltration downstream of backup locations will not help reduce the likelihood of sewer backups in the future unless backups resulted from downstream controls. Regardless, basin wide results are presented as well as in-depth results for the locations where infiltration reduction can potentially reduce the occurrence of future sewer backups.

The Alternative 1 pipe replacement options eliminates surcharge up to the 100-year event at both 1st Avenue NW and N and NW 115th Street as well as on N and NW 105th Street between 3rd Avenue NW and Greenwood Avenue N. The problem areas that exist after the Alternative 1 solution are 12th Avenue NW, 6th Avenue NW between NW 120th Street and NW 122nd Street, Dayton Avenue N north of N 105th Street and Dayton Avenue N north of N 115th Street. Alternative 3 scenarios result in a progressive decrease in the amount of locations that are susceptible to surcharge. Along 12th Avenue NW, each increasing level of infiltration reduction results in fewer maintenance holes surcharge locations for a given event.

Alternative 3 infiltration reduction scenarios are more effective at reducing pipe surcharge than the Alternative 2 inflow reduction scenarios on 12th Avenue NW. On N and NW 105th Street, the surcharge that remains in the Alternative 1 model west of 3rd Avenue N is reduced in Alternative 3.A and eliminated in Alternatives B and C. The modeled surcharge at the corner of Dayton Avenue N and N 105th Street is eliminated in Alternative 3.A, while the surcharge at Dayton Avenue N and N 115th Street remains in Alternative 3.A and 3.B and is eliminated in Alternative 3.C. More detailed information for each of the problem locations is presented discussed below.

12th Avenue NW

Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figures B-19, B-20, and B-21) for Alternative 3.A through 3.C. During the 2-year event, maintenance holes 224-067 and 224-070 surcharge a small amount in Alternative 3.A and 3.B, but none by Alternative 3.C. The 25-year event shows approximately 3,000 feet of (maintenance hole 218-098 to maintenance hole 224-071) surcharge in the existing conditions scenario. Alternatives 3.A and 3.B have the same surcharge extent but at a slightly lower depth.

In Alternative 3.C, surcharge is reduced to maintenance holes 218-143 and 218-192 near the outlet of NW Blakely Court and between NW 122nd Street and NW 119th Street. The existing conditions model shows pipe surcharge during the 100-year event from NW 132nd Street to

NW 119th Street. In Alternative 3.A, surcharge is reduced and extends to NW 130th Street. The extent of surcharge is the same in Alternative 3.B but the depth of surcharge is reduced further. In Alternative 3.C, the pipe flows full on 12th Avenue NW with surcharge around NW Blakely Court in maintenance holes 218-143 and 218-144 and between NW 122nd Street and NW 119th Street in maintenance holes 224-019 to 224-071.

Peak discharges from the 100-year event are presented below in Table 13 for the existing conditions and Alternative 3 scenarios. The discharges given are for discharge into maintenance hole 224-071 (located on 12th Avenue NW just north of NW 122nd Street). This segment of pipe is 10-inch concrete with a Manning's capacity is 1.4 cfs. The Manning's capacity is the highest discharge that can flow through the pipe without any pressure head behind it. Surcharge of upstream pipe can force more water through and allow discharge in excess of the Manning's free flow capacity.

Table 13. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 224-071 for the baseline and Alternative 3 scenarios during the 100-year event with a capacity of 1.4 CFS.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (%)
Existing Conditions	2.61	n/a
Alt 3.A	2.54	2
Alt 3.B	2.43	7
Alt 3.C	2.33	11

Although a 46 percent reduction in peak flow is required to limit discharge to the Manning's capacity of the pipe, any reduction in infiltration and peak flow will reduce the probability and/or extent of future backups.

The "Peak Discharge" column indicates that all discharge exceed Manning's capacity. The existing conditions scenario includes a peak discharge 1.2 cfs in excess of Manning's capacity. Alternative 3.C, which includes the greatest amount of infiltration reduction, still has a peak 100-year discharge 0.93 cfs greater than Manning's capacity. The percentage reductions in peak flow are 2 percent, 7 percent, and 11 percent in scenarios A through C respectively.

6th Avenue NW

Although several residences along 6th Avenue NW between NW 120th Street and NW 122nd Street experienced sewer backups, the EPA-SWMM 5 model does not predict surcharge on 6th Avenue NW. As discussed earlier, it is believed that excessive infiltration in large storm events could be the cause of excessive flow resulting in sewer backups. Due to the relatively dry flow monitoring and calibration period, the excessive infiltration that likely occurs during large storm events is not simulated in the model.

Table 14 below shows the reduction in peak flows that are achieved with the Alternative 3 scenarios. The discharges shown are for maintenance hole 224-104 which is at the corner of 6th Avenue NW and NW 120th Street. A detailed discussion is not provided for Table 14 because the discharge numbers presented are not believed to be representative of what occurs in the actual pipe system. A monitor at maintenance hole 224-104 was installed in November, 2009. Early results appear to indicate infiltration at this location. This is discussed in more detail in Chapter 7.

Table 14. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 224-104 for the baseline and Alternative 3 scenarios during the 100-year event.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	1.38	n/a
Alt 3.A	1.32	4
Alt 3.B	1.25	9
Alt 3.C	1.13	18

Dayton Avenue N

Alternative 1’s water surface profile between the intersection of Dayton Avenue N and N 117th (maintenance hole 225-054) and the intersection of Greenwood Avenue N and N 115th Street (maintenance hole 225-070) is shown in Appendix B (Figure B-22). Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in Appendix B (Figures B-23, B-24, and B-25) for Alternative 3.A through 3.C.

In the existing conditions model, a small amount of surcharge is present in the 2-year simulation at maintenance holes 225-071 and 225-072. The same maintenance holes surcharge during the 2-year event in Alternatives 3.A, 3.B, and 3.C but not as deep. Under the existing conditions model, during the 25-year event, the same two maintenance holes surcharge with maintenance hole 225-072 surcharge approximately 5 feet deep. Alternative 3.A and 3.B show progressive 1 foot reductions in surcharge in both maintenance holes. During the 100-year event, the existing conditions model surcharges at maintenance hole 225-064 and in maintenance hole 225-072 to depth equal to the overflow outlet at 6 feet. Alternative 3.A includes surcharge similar to the existing conditions model during the 100-year event. The surcharge depth in Alternative 3.B is slightly less than in Alternative 3.A, while surcharge in the Alternative 3.C decreases about 1 foot to an elevation of 5 feet in maintenance hole 225-072 and 3 feet in maintenance hole 225-071.

Table 15 below shows the peak discharge at maintenance hole 225-070 at the intersection of N 115th Street and Greenwood Avenue N for the existing conditions and Alternative 3.A, 3.B, and 3.C. For comparison, the Manning’s capacity for the 8 inch pipe is 1.1 cfs which is lower than the modeled peak discharge associated with the 100-year event. This peak discharge above the Manning’s capacity shows the effects of pipe surcharge. The reduction in peak discharge associated with Alternatives 3.A, 3.B, and 3.C are -1.1 percent, 0.1 percent, and 7 percent, respectively. The reduction in peak discharge is first realized in Alternative 3.C when surcharge drops below the elevation of the overflow in maintenance hole 224-071.

Table 15. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 225-070 with a capacity of 1.1 cfs for the existing conditions and Alternative 3 scenarios during the 100-year event.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	1.99	n/a
Alt 3.A	2.01	-1.1
Alt 3.B	1.99	0.1
Alt 3.C	1.85	7.1

Table 16 below shows the peak discharge at maintenance hole 225-036 at the intersection of N 120th Street and Dayton Avenue N for the baseline and Alternatives 3.A, 3.B, and 3.C for the 100-year event. For comparison, the Manning's capacity for the 8 inch pipe is 1.6 cfs which is greater than the peak modeled discharge associated with the 100-year event. Profiles of the hydraulic grade line are not shown for this area because the model does not simulate any pipe surcharge.

Table 16. Peak discharge (CFS) and reduction in peak discharge (percent) at maintenance hole 225-036 with a capacity of 1.6 cfs for the baseline and Alternative 3 scenarios during the 100-year event.

Model Run	Peak Discharge (cfs)	Reduction in Peak Discharge (percent)
Existing Conditions	0.73	n/a
Alt 3.A	0.69	5
Alt 3.B	0.66	10
Alt 3.C	0.58	20

Alternative 4 – Inflow and Infiltration Reduction

Alternative 4 combines reductions in inflow and infiltration. It was applied to 12th Avenue NW to assess whether such an option could significantly improve capacity at potentially lower cost. Because of the limitations to the model as discussed earlier, Alternative 4 was not used to analyze 6th Avenue NW and Dayton Avenue N.

12th Avenue NW

Alternative 4 reduces the extent, depth, and duration of surcharge on 12th Avenue NW. Profile plots of the peak water surface elevation during the 2-, 25-, and 100-year events are presented in

Appendix B (Figures B-26, B-27, and B-28). They include a portion of the sanitary sewer from the corner of 12th Avenue NW and NW 132nd Street (MH 218-070) at the north portion of 12th Avenue NW downstream to 12th Avenue NW and NW 119th Street (MH 224-074).

Appendix B (Figure B-5) shows the maximum water surface elevations in the sanitary sewer line on 12th Avenue NW under existing conditions. Three sections of pipe near MH 224-067, MH 224-019, and between MH 218-191 and MH 218-143 surcharge in the 2-year event, although the depth of surcharge is only slightly greater than the pipe diameter. For the 25-year event, approximately 3,200 feet of pipe surcharges from MH 218-096 to MH 224-074. The maximum surcharge depth is approximately 2.5 feet at MH 218-144, MH 218-143, MH 224-019, and MH 224-067. During the 100-year event, approximately 3,600 feet of pipe surcharges from MH 218-070 to MH 22-074. The extent and depth of surcharge has increased with a maximum surcharge depth of 7 feet.

Although Alternative 4 does not eliminate all surcharge, it is effective at reducing the extent, depth, and duration of surcharge. Reductions in these parameters could have direct impacts on the number of homes that may experience sewer backups during a given storm event. Table 17 below provides a summary of output from the two scenarios and compares the length of pipe and the maximum depth of surcharge for existing conditions and Alternative 4. Alternative 4 results in a shorter length, depth, and duration of surcharge when compared to existing conditions. It should be noted that most of this effect is due to reductions in infiltration since the reduction of inflow was relatively low.

Table 17. Summary of length, depth, and duration of surcharge along 12th Avenue NW during the 2-year, 25-year, and 100-year events for the I/I Reduction and Existing Conditions model simulations.

	Existing Conditions			I/I Reduction		
Return Interval	Length (ft.)	Max Depth (ft)	Duration (hr.)	Length (ft.)	Max Depth (ft)	Duration (hr.)
2-year	735	0.95	0.25	150	0.7	0
25-year	3175	3.6	16	2100	2.7	2
100-year	3600	5.3	19	3450	3.8	9

A newer version of SWMM 5 was applied to Alternative 4 with water surface elevations that are slightly higher than those simulated in the initial modeling. Regardless, the additional reduction in inflow associated with Alternative 4 reduces the probability and severity of surcharge events.

Chapter 6: Cost Estimates

Cost estimates for alternatives 1, 2 and 4 include a 2.35 or 2.65 construction multiplier to produce a total project cost unless indicated otherwise and are included in Appendix C.[3] Alternative 3 assumes work is performed by homeowners and includes no total project cost multiplier. Construction costs are based on SPU Unit Cost Report – January 2007 or Broadview homeowner testimony.

Alternative 1

Alternative 1 includes replacement of sanitary sewer pipe within a paved roadway along 1st Avenue NW and N and NW 105th Street. At the time of this document, N and NW 105th Street and 1st Avenue NW were constructed and actual project construction costs are presented in addition to an estimate of soft costs added to construction cost to estimate total project cost. Also included are costs for 12th Avenue NW with a 2.65 total project cost multiplier.

Excavation, installation, and surface restoration are included in the estimate of the construction costs are presented in Table 18.

Table 18. Alternative 1 – pipe replacement.

						Construction Cost	Total Project Cost
Location	Segment	Length (ft)	Existing Diameter (in)	New Diameter (in)	Storm	Open Cut	Open Cut
1st Ave NW	224-201_224-201	508	8	12	100-year	$222,300	$422,300
NW 105th St	224-330_224-341	891	10	15	100-year	$525,100	$825,100
12th Avenue NW	224-071 _224-019	2550	10	15	100-year	$777,200	$2,061,100

General Notes:

Upsize segment 224-201 to 224-197 from 8" to 12". Sag in segment 224-145_224-201 is in downstream 40' of pipe.

Storm level of service indicates amount of flow that new pipe can convey without significant downstream impacts.

Costs based on January 2007 SPU Unit Costs and other sources. No escalation applied for inflation.

A 20% contingency and 10% sales tax are included for 12th Avenue NW. Total project costs presented for 12th Avenue NW include a 2.65 multiplier.

Total project costs presented for 1st Avenue NW and N 105th Street are actual project construction costs plus an estimate of soft costs to arrive at a total project cost, and include additional surface restoration when compared to 12th Avenue NW (7/26/10 phone conversation with SPU).

No pipeline replacement costs are presented for Dayton Avenue N or 6th Avenue NW since the model does not correlate well with observed backups. Additional monitoring is on-going at these

[3] Multiplier provided by SPU.

locations to further calibrate the model. For locations presented in Alternative 1, the range of Total Project Cost depending on location is $422K to $2.1M.

Alternative 2

Alternative 2 includes installation of rain gardens to reduce inflow to the sanitary sewer. Also required are improvements to the stormwater conveyance system including ditches and culverts. The costs presented below reflect Alternative 2.A since this was considered to be close to the most likely achievable option and include construction costs and total project cost associated with rain garden and ditch and culvert improvements. These costs are presented in Tables 19 and 20.

Several factors are included in the number of residences able to utilize rain gardens including topography, land use, soil conditions, participation, and experience in other basins. The total amount of residential participation based on assumptions derived early in the project are shown in Table 2 under Alternative 2.A and serve as the basis of the cost estimates. The assumptions used to determine the total residential participation were refined for Alternative 4 for 12th Avenue NW. As a result, the costs associated with inflow reduction resulting from residential participation are revised and presented in the Alternative 4 discussion.

For Alternative 2, range of Total Project Cost depending on location is $292K to $639K.

Alternative 3

Alternative 3 includes installation of new laterals by homeowners to reduce infiltrations to the sanitary sewer. As a result a 2.65 multiplier is not used to escalate construction costs. The costs presented represent construction costs associated with lateral replacement and are based on the assumptions listed in Table 21. There are several methods of lateral replacement including pipe bursting, lining, grouting, or chemical sealing. Open cut was the assumed method of replacement used to generate cost estimates. Alternative 3.C includes replacement of all laterals within each basin and was used as the basis for cost estimating.

As discussed earlier, King County conducted an I/I study where several alternatives for I/I reduction were pilot tested. In Ronald, just north of Broadview in the City of Shoreline, I/I reductions as high as 74 percent were realized from replacing all laterals and side sewers (King County, 2004). As discussed earlier, even though inflow reduction was included in this percent by removal of a small percent (4 percent) of downspouts, this percent reduction was assumed adequate to approximate infiltration reduction in Broadview since the majority of flow reduction is likely associated with infiltration. King County refers to the lateral serving residences and business as lateral and side sewers depending on which side of the right of way they are located. For the purposes of this report, the entire pipe serving residences and businesses is referred to as the lateral and is included in costs presented in Table 21 and 22.

Table 19. Alternative 2 – inflow reduction.

	Rain Garden					Ditch and Culvert			
Location	Number of Connected Residences	Rate of Participation	Feasibility	Total %	Cost	Basin Length (ft)	Ditch Length (ft)	Cost	Assumptions
12th Avenue NW	40	40%	50%	30%	$96,000	3,900	585	$72,600	Assume 15 percent of basin length will require new ditch conveyance and one new 12 inch culvert per block (~400 ft)
				Subtotal	$96,000		Subtotal	$72,600	
				Subtotal Project Cost	$254,400		Subtotal Project Cost	$192,400	
							Total Project Cost	**$446,800**	
6th Avenue NW	18	40%	50%	30%	$43,200	3,600	540	$67,000	Assume 15 percent of basin length will require new ditch conveyance and one new 12 inch culvert per block (~400 ft)
				Subtotal	$43,200		Subtotal	$67,000	
				Subtotal Project Cost	$114,500		Subtotal Project Cost	$177,600	
							Total Project Cost	**$292,100**	
Dayton Avenue N	50	40%	50%	30%	$120,000	6,500	975	$121,000	Assume 15 percent of basin length will require new ditch conveyance and one new 12 inch culvert per block (~400 ft). All connected residences included in rain garden totals.
				Subtotal	$120,000		Subtotal	$121,000	
				Subtotal Project Cost	$318,000		Subtotal Project Cost	$320,700	
							Total Project Cost	**$638,700**	

General Notes:

150%	Smoke testing scale up factor
2000	Average Broadview residence roof area, sf (estimate)
100%	Percent of roof area connected
$4.00	Cost for rain gardens per sf of roof area served (Ref 1)
$124.04	Ditch Cost for Broadview, lf (Ref 2)
$155.07	Culvert Cost for Broadview, lf (Ref 2)
50	Average culvert length, lf
15%	Average length of basin requiring new ditch
400	Average length of block

SPU Reference Documents (1) 7/22/10 email from SPU
(2) Ditch & Culvert cost.xls (provided by SPU)

Total Project Cost includes a 2.55 multiplier provided by SPU
A 20% escalation of construction and 10% sales tax are included.

Table 20. Alternative 2 – inflow reduction summary.

Location	Inflow Total Project Cost
12th Avenue NW	$446,800
6th Avenue NW	$292,100
Dayton Avenue N	$638,700

Table 21. Alternative 3 – infiltration reduction.

Location	Number of Blocks	Lateral Replacement Number of Laterals	Lateral Replacement Total Project Cost	Assumptions
12th Avenue NW	20	220	$2,200,000	Assume 11 residences per block.
		Subtotal	$2,200,000	
		Total Project Cost	$2,860,000	
6th Avenue NW	6	66	$660,000	Assume 11 residences per block.
		Subtotal	$660,000	
		Total Project Cost	$858,000	
Dayton Avenue N	10	110	$1,100,000	Assume 11 residences per block.
		Subtotal	$1,100,000	
		Total Project Cost	$1,430,000	

General Notes:
$10,000 Average lateral cost provided by residence owner testimony
11 Number of laterals per block
A 20% escalation of construction and 10% sales tax are included.

Table 22. Alternative 3 – infiltration reduction summary.

Location	Infiltration Total Project Cost
12th Avenue NW	$2,860,000
6th Avenue NW	$ 858,000
Dayton Avenue N	$1,430,000

As stated above, Alternative 3 includes the cost of individual homeowner open trench replacement of laterals at $10,000 per home. This cost could be significantly reduced if many homes were bundled under on construction contract or by replacing laterals by pipe bursting or rehabilitating laterals with slip lining or pipe sealing. For Alternative 3, the range of Total Project Cost depending on location is $858K to $2.9M.

Alternative 4

Alternative 4 includes implementation of inflow and infiltration reductions utilizing methods defined under an updated inflow reduction reflected in Table 3 and Alternative 3.B which corresponds to a 40 percent reduction in infiltration.

Alternative 4 includes rain gardens, new ditch and culverts, and replacement of laterals using open cut methods. Alternative 4 includes inflow reduction at five homes due to basin constraints. For these five locations, significant improvements to stormwater infrastructure are required resulting in significant addition cost with relatively low flow reduction contribution from only five homes.

It was assumed that 53 percent of laterals would need to be replaced to achieve a 40 percent reduction in infiltration. This was based on the ratio of percent infiltration reduction to percent of lateral replaced reflective of results achieved in Ronald where about a 75 percent reduction in infiltration was achieved by replacing 100 percent of laterals. The costs associated with Alternative 4 are presented in Table 23.

Table 23. Alternative 4 – inflow and infiltration reduction

Lateral Replacement			Rain Garden		Ditch and Culvert			
Number of Blocks	Number of Laterals	Construction Cost	Removable Connected Residences	Total	Basin Length (ft)	Ditch Length (ft)	Ditch	Culvert
20	117	$1,515,800	5	$40,000	3900	585	$72,600	$75,600
	Subtotal	$1,515,800	Subtotal	$40,000		Subtotal	$72,600	$75,600
							Total Project Cost	**$2,014,600**

General Notes:
$10,000 Average lateral cost provided by residence owner testimony
11 Number of laterals per block
40% Infiltration reduction goal
53% Number of laterals replaces to meet infiltration reduction goal
2000 Average Broadview residence roof area, sf (estimate)
$4 Cost for rain gardens per sf of roof area served (Ref 1)
$124.04 Ditch Cost for Broadview, lf (Ref 2)
$155.07 Culvert Cost for Broadview, lf (Ref 2)
50 Average culvert length, lf
15% Average length of basin requiring new ditch
400 Average length of block
SPU Reference Documents (1) 7/22/10 email from SPU
(2) Ditch & Culvert cost.xls (provided by SPU)
(3) Removal Connected residences determined by SPU
Total Project Cost includes a 2.65 multiplier provided by SPU not applied to laterals.
A 20% escalation of construction and 10% sales tax are included.

As with Alternative 3, the cost of individual homeowner opens trench replacement of laterals at about $10,000 per home was assumed for lateral replacement costs. This cost could be significantly reduced if many homes were bundled under on construction contract or by replacing laterals by pipe bursting or rehabilitating laterals with slip lining or pipe sealing.

For Alternative 4, the Total Project Cost is $2.0M.

Backflow Preventers

The costs presented below represent construction costs associated with installation of backflow preventers and are based on the assumptions listed in Table 24. This alternative assumes that all residences that have submitted claims for sewer backups in the past receive backflow preventers. It also includes an increase in the amount of backflow preventers required based on an assumed percentage of residences that did not report claims.

Table 24. Backflow preventers.

	Backflow Preventer			
Location	Number of residences With Claims	Number of residences Without Claims	Total Project Cost	Assumptions
12th Avenue NW	10	5	$105,000	Total number of residences based on claims records plus under reporting of 50%. Includes only 1996 and newer claims
		Subtotal	$105,000	
		Total Project Cost	$136,500	
6th Avenue NW	5	3	$56,000	Total number of residences based on claims records plus under reporting of 50%. Includes only 1996 and newer claims
		Subtotal	$56,000	
		Total Project Cost	$72,800	
Dayton Avenue N	10	5	$105,000	Total number of residences based on claims records plus under reporting of 50%. Includes only 1996 and newer claims
		Subtotal	$105,000	
		Total Project Cost	$136,500	

General Notes
50% Percent of additional residences that did not submit a claim
$ 7,000 Average backflow preventer cost from residence owner testimony
A 20% escalation of construction and 10% sales tax are included.

For Backflow Preventers, the Total Project Cost ranges from $73K to $137K as indicated in Tables 24 and 25.

Table 25. Backflow preventers summary.

Location	Backflow Preventer Total Project Cost
12th Avenue NW	$136,500
6th Avenue NW	$72,800
Dayton Avenue N	$136,500

Backflow preventers can be utilized in Broadview to protect residences and businesses at a relatively low cost when compared to Alternatives 1 through 4.

Chapter 7: Summary

The Broadview sanitary sewer system was investigated to improve the performance of the sanitary sewer system. Many sources of information were gathered to assess the history and performance of the system including smoke testing to assess inflow, CCTV inspections of pipes to assess condition, claim and maintenance records and information gathered from residents to assess historical problems. Additionally, flow in the sewer was monitored and the system was modeled to predict the pipe network's existing behavior and develop alternatives to improve the performance of the sanitary sewer system. Flow monitoring was performed at 12 sites from September 19, 2008 through February 20, 2009. Through this review five areas were identified that had a history of repeated backup problems that formed the focus of analysis.

Four alternatives were analyzed for their effectiveness to improve the performance of the sanitary sewer system.

Alternative 1 is a pipe replacement solution targeted to 1st Avenue NW and N and NW 115th Street and N and NW 105th Street between Greenwood Avenue N and 3rd Avenue NW. Additional locations were also analyzed but were not implemented as part of Alternative 1 either because the estimated cost exceeded the contracting limits for early action (12th Avenue NW) or because the systems behavior was not adequately replicated by the model (6th Avenue NW, Dayton Avenue N.) The alternative of pipe replacement was still analyzed for 12th Avenue NW to compare with other alternatives in terms of cost and effectiveness. Alternative 2 included three separate reductions of inflow of stormwater to the system. Alternative 2.A assumes a 20 percent reduction in connected downspouts, Alternative 2.B assumes a 50 percent reduction, and Alternative 2.C assumes a 100 percent removal of the total connected area analyzed as a boundary condition only. The total connected area includes downspouts, area drains, and all other inflow connections. Alternative 2.C is a hypothetical alternative only since it is not feasible to remove all direct stormwater connection to the sanitary sewer. Alternative 3 includes three levels of infiltration reduction. Alternative 3.A assumes a 20 percent reduction in infiltration, Alternative 3.B assumes a 40 percent reduction, and Alternative 3.C assumes an 80 percent reduction. These three alternatives were analyzed separately and were not combined.

Alternative 4 includes a combination of inflow reduction and infiltration removal. Alternative 4 was analyzed for 12th Avenue NW.

Pipe replacement included in Alternative 1 early actions have been constructed for both N and NW 105th Street and 1st Avenue NW. Locations analyzed under Alternatives 2, 3, and 4 include the remaining problem areas located at 12th Avenue NW, 6th Avenue NW, and Dayton Avenue N. A summary of results and recommended actions is provided below for each of these areas.

1st Avenue NW and N and NW 115th Street

Pipe replacement included in Alternative 1 eliminates sewer backups for this location during a 100-year event. The existing conditions model simulates pipe surcharge at the corner of

1st Avenue NW and NW 115th. Surcharge under existing conditions occurs in events as small as the 25-year storm. This corresponds with reported sewer backups. Analysis of Alternative 1 shows no surcharge at this location up to and including the 100-year event. However it should be noted that surcharge simulated at 1st Avenue NW and N and NW 115th Street during the much larger December 3, 2007 event transmits downstream to 2nd Avenue NW and NW 115th Street. As a result, the piped solution for this location does not protect the entire system under all storms.

A section of sanitary sewer was replaced during the course of this project based on modeling results. The total cost for the 1st Avenue NW and N and NW 105th Street sanitary sewer improvements was $749K.

N and NW 105th Street between Greenwood Avenue N and 3rd Avenue NW

The existing conditions model simulates pipe surcharge during the 100-year event which corresponds well with reported backups. The existing conditions model also simulates an additional reach of pipe surcharge under the December 3, 2007 event which also corresponds with reported sewer backups during this storm. The Alternative 1 pipe replacement solution eliminates surcharge in these segments for events up to and including the December 3, 2007 event. There is no significant increase in downstream surcharge along NW 105th Street due to the pipe replacement option, but the potential for downstream surcharge still exists. This does not mean that backups would result. From a windshield survey, connections in the blocks west of 3rd Avenue NW include few low basements. In addition, no backups have been reported for this reach of NW 105th Street.

A section of sanitary sewer was replaced during the course of this project based on modeling results. The total cost for the 1st Avenue NW and N and NW 105th Street sanitary sewer improvements was $749K.

12th Avenue NW

The existing conditions model simulates approximately 3,500 feet of pipe surcharge along 12th Avenue NW. In addition, multiple segments of pipe have a manning’s capacity below the modeled 100-year discharge. Replacing the existing 10-inch with 15-inch diameter pipe will eliminate surcharge up to the 100 year event. However, pipe replacement would increase flow in downstream pipelines by about 1.0-cfs for the 100-year event. Scenarios A and B in both Alternatives 2 and 3 reduce the length of pipe that surcharges by approximately 500 feet. Alternative 3.C is slightly more effective than Alternative 2.C but it still does not eliminate surcharge completely. Alternative 4 also decreases the length of surcharged pipe. Additionally, Alternatives 2, 3, and 4 have higher costs when compared to Alternative 1. This is because of limited existing collection and conveyance systems for storm water and the cost of replacing laterals. There are also site considerations such as steep slopes that restrict the appropriate location for onsite natural systems.

Alternative 4 decreases the extent, depth, and duration of surcharge when compared to the existing conditions. A direct comparison between Alternative 2, 3, and 4 is difficult due to slight differences in hydraulic grade line predictions resulting from different model build. For a discussion of model builds, refer the Alternative 4 discussion in Chapter 5.

Additional monitoring will aid in assessing the existing conditions and if implemented, the performance of improvements for 12th Avenue NW. A flow monitor was installed on maintenance hole 224-025 to assist this effort.

Alternative 4 shows that for 12th Avenue NW, little additional benefit is realized by inflow reduction and requires a significant amount of improvements to the storm water infrastructure at a significant cost. If the costs of lateral replacement could be reduced, infiltration reductions could be a cost effective solution. Also, lateral replacement has shown to be the most effective way to reduce infiltration in Ronald Wastewater Sewer District located in Shoreline, Washington.

A business case will be developed for 12th Avenue NW that compares the cost and benefits of all or portions of Alternatives 1 through 4 and backflow preventers for this area.

6th Avenue NW and NW 120th Street

The model does not accurately simulate discharge at this location for return intervals greater or equal to the 100-year event. Inflow is predicted well by the existing model but infiltration is not. Excessive infiltration appears to be present during large storm events. The percentage of rainfall that becomes inflow remains relatively constant regardless of storm size because the area directly connected is relatively constant. However, infiltration can increase dramatically as storm size increases.

A pilot study to reduce infiltration could be performed at this location. One approach could be to assess infiltration reduction technologies, apply the most suitable and cost effective solution, and then measure compare pre and post flows. Continued flow monitoring will enable a performance assessment of infiltration mitigation measures.

Infiltration testing is also an option. However, from a presentation by CHS Engineers, quantifying infiltration is a labor intensive effort with results that are difficult to measure. Because of this, a more practical industry standard practice is to monitor flows prior to improvements, perform improvements, and measure performance with additional flow monitoring.

To better evaluate conditions in the system, a flow monitor was installed at maintenance hole 224-104.

Dayton Avenue N and N 105th Street

The existing model indicated surcharge at two locations on Dayton Avenue N. The location furthest south located at N 105th Street and Dayton Avenue N only surcharges during the 100-year event. All of the Alternative 2 and 3 scenarios eliminate surcharge at this location in events up to and including the 100-year event. The piped system along Dayton Avenue N is hydraulically connected at maintenance hole 225-072. Normally all flow from the northern portion of Dayton Avenue N is directed west along N 115th Street. When there is approximately six feet of surcharge in maintenance hole 225-072, an 6-inch overflow is triggered allowing a portion of flow from the northern part of the basin to continue south along Dayton Avenue N to N 105th Street. This occurs during high flow events. The southern portion of Dayton Avenue N appears to experience surcharge only when this overflow is triggered where excess flow from the northern part of the basin is directed south.

Dayton Avenue N and N 115th Street

The sanitary sewer near N 115th Street and Dayton Avenue N surcharges in the existing model. However, the location of surcharge is located two blocks downstream of historic sewer backups. The location of reported sewer backup during the December 3, 2007 event was immediately north of Christ the King School on N 117th Street. Reports were conveyed from the public of a pipe blockage during the December 3, 2007 storm. The model shows sufficient capacity near N 117th Street but predicts surcharge a few blocks downstream near N 115th Street. The modeled surcharge near N 115th Street is progressively reduced in the Alternative 2 scenarios but not eliminated.

Surcharge is also progressively reduced in the Alternative 3 scenarios and is completely eliminated in Alternative 3.C. There is a discrepancy between the location of the observed sewer backups and the location of the modeled pipe surcharge that could be due to the blockage mentioned above.

To better evaluate the conditions in the system, a flow monitor was installed in maintenance hole 225-064.

Basin Approach

To improve performance of Broadview's sanitary sewer system, infiltration and inflow (I/I) should be reduced as much as possible. The sanitary sewer has capacity to accommodate wastewater flows. However, high rates of inflow and infiltration exceed the system's capacity. A multipronged approach to address sewer backups should be employed. I/I reductions should be addressed on a sanitary sewer basin scale and require a thorough assessment of applicable technology. Opportunities to reduce I/I may also exist on smaller neighborhood or street scale. Several locations exist where roadway drainage enters depressed driveway catch basins connected to the sanitary sewer during large storm events. A handful of these have been identified through informal discussions with homeowners mostly along 12th Avenue NW and may be remedied by installation of a rolled asphalt curb.

Backflow preventers could protect particularly vulnerable residences or residences that have flooded in the past. Only high quality valves should be installed and require regular maintenance. SPU is examining their existing policy on backflow preventers to see if it should be modified to encourage their use in vulnerable areas.

A longer term solution would be an inflow reduction program to assess applicability of green infrastructure to remove inflow from the sanitary sewer as well as to improve storm water quality and reduce peak flow in downstream creeks. However, such a program will not be possible in every sewer sub-basin for various reasons such as steep bluffs or other geographic constraints.

Infiltration reduction should also be addressed. From King County studies in The Ronald Sewer District located north of Broadview in Shoreline, the most significant reductions in infiltration were obtained from replacement of laterals. The existing condition of laterals can be assessed using various techniques as described earlier in this report. If warranted, replacement of laterals could be performed as part of an I/I pilot study.

Additional monitors have been installed at 6th Avenue NW and NW 120th Street, 12th Avenue NW, and Dayton Avenue N to better understand flow inputs to more accurately predict the behavior of the sanitary sewer and support future I/I reduction efforts.

If stormwater were removed from the sanitary sewer through natural drainage systems such as the proposed Venema project, the sanitary sewer would receive less flow and the likelihood of sewer overflows would be reduced. The proposed Venema Natural Drainage System Project would potentially improve sewer capacity in Dayton Avenue N near N 120th Street where 75 percent of the contributing drainage area is within the project area, and 1st Avenue NW and N and NW 115th Street where 50 percent of the contributing area is within the Venema project area.

A continuation of regular maintenance is recommended for all areas of Broadview. In addition, proactive and reactive maintenance should be used to manage existing and new maintenance and performance problems.

Table 26 summarizes the conclusions for the sub-basins in Broadview and shows the costs and benefits estimated for each option as well as the assumptions made and potential range of values.

Table 26. Broadview Summary.

Costs

Alternative	Problem Area: 12th Avenue NW	NW 105th St	1st Avenue NW	6th Avenue NW	Dayton Avenue N	Notes
Alternative 1 - Pipe Replacement	$2,061,100	$1,234,000	$522,500	N/A	N/A	105th and 1st include Engineer's estimate and not the actual cost of construction. No pipe replacement estimates were performed for 6th or Dayton. 6th has high infiltration and pipe replacement is inappropriate. Dayton only floods to an extent that triggers claims during 500-year events.
Alternative 2 - Inflow Reduction	$446,800	N/A	N/A	$292,100	$638,700	
Alternative 3 - Infiltration Reduction	$2,860,000	N/A	N/A	$858,000	$1,430,000	
Alternative 4 - Inflow and Infiltration Reduction	$2,014,600	N/A	N/A	N/A	N/A	
Backflow Preventers	$136,500	N/A	N/A	$72,800	$136,500	

Level of Service (year)

Alternative	Problem Area: 12th Avenue NW	NW 105th St	1st Avenue NW	6th Avenue NW	Dayton Avenue N	Notes
Alternative 1 - Pipe Replacement	100	100	100	N/A	N/A	Pipe replacement options were sized to convey the maximum storm with no significant downstream impacts. This generally resulted in a 100-year design.
Alternative 2 - Inflow Reduction	2	N/A	N/A	N/A	2	Inflow is reduced by about 30% and results in conveyance of a 2-year storm.
Alternative 3 - Infiltration Reduction	2	N/A	N/A	N/A	<2	Infiltration is reduced by about 80% (based on King County study in Ronald) and surcharge is eliminated for the 2-year storm (for 12th Avenue NW) or to a level less than the 2-year (for Dayton Avenue NW shown as <2).
Alternative 4 - Inflow and Infiltration Reduction	<2	N/A	N/A	N/A	N/A	Alternative 4 produces similar results as Alternative 2 and 3 for 12th Avenue NW.
Backflow Preventers	500+	N/A	N/A	500+	500+	Backflow valves protect sewage from entering home through lateral for virtually any storm event. 500+ year interval indicated is the maximum storm interval analyzed. Valves do NOT guarantee sewage overtopping maintenance holes will not travel overland and enter home.

References

Herrera. 2008. Broadview Sewer Assessment, Seattle Public Utilities. Herrera Environmental Consultants, Inc., Seattle, Washington. April 1998.

Herrera. 2008b. Problem Identification Technical Memorandum. Herrera Environmental Consultants, Inc., Seattle, Washington. September 2008.

Herrera. 2009. Broadview Sewer System Study Area Modeling Report. Herrera Environmental Consultants, Inc., Seattle, Washington. December 2009.

King County. 2004. Pilot Project Report, Executive Summary, Regional Infiltration and Inflow Control Program, King County. October, 2004.

Liesch, Bruce A., Charles E. Price, and Kenneth L. Walters. 1963. Geology and Ground-Water Resources of Northwestern King County, Washington. Water Supply Bulletin No. 20. U.S. Geological Survey, Ground Water Branch and Washington State Division of Water Resources, Olympia, Washington.

SPU. 2006. Addendum to Venema Greengrid Natural Drainage Infiltration Conclusions and Recommendations Memorandum. Seattle Public Utilities. July 5, 2006.

SPU. 2009. Determining Connectivity of Downspouts to the Combined Sewer, Draft. Seattle Public Utilities. June 4, 2009.

SPU. 2009. Microsoft Excel Spreadsheet, Ditch & Culvert cost.xls, sheet 1.

SvR. 2008. Broadview Neighborhood Inflow Assessment, Memorandum #12. SvR Design Company. August 28, 2008.

Troost, Kathy Goetz, Derek B. Booth, Aeron P. Wisher, and Scott A. Shimel. 2005. The Geologic Map of Seattle – A Progress Report. U.S. Geological Survey Open-File Report 2005-1242. Available online from the USGS website: http://geomaps.wr.usgs.gov/pacnw/100sea.html.

U.S. Army Corps of Engineers, Seattle District, 1997. Post event report: winter storm of 1996-97 Federal Disaster DR 1159 Western Washington Summary. Prepared for the Federal Emergency Management Agency, Region X.

APPENDIX A

Cost Estimates

Alternative 1). Increase pipe diameter in segments MH 224-014 TO 224-071

ASSUMPTIONS/QUANTITIES

AVERAGE PATCH WIDTH	12	FT	ASSUME TRENCH WIDTH REPLACEMENT
AVERAGE SANITARY SEWER DEPTH	10	FT	BASED ON MAIN REPLACEMENT
PAVEMENT THICKNESS	3	IN	BASED ON STANDARD PLAN 401
PAVEMENT BASE COURSE THICKNESS	6	IN	BASED ON STANDARD PLAN 401
REPLACE PAVEMENT	2,550	LF	ASSUME PAVEMENT LENGTH EQUALS PIPE LENGTH
REPLACE PIPE	2,550	LF	
MANHOLE	13	EA	
LATERAL CONNECTION	33	EA	
PIPE DIAMETER	15	IN	

SECTION	BID ITEM DESCRIPTION	UNIT	UNIT COST	QUANTITY	TOTAL	ASSUMPTIONS
OPEN TRENCH						
SECTION 1-10 TEMPORARY TRAFFIC CONTROL						
110005	MAINTENANCE AND PROTECTION OF TRAFFIC CON INCLUDING FLAGGING, MIN. BID = $ (City Jobs)	LS	7000.00	1	$ 7,000	
110010	MAINTENANCE AND PROTECTION OF TRAFFIC CON (INCLUDING FLAGGING) (Fed Jobs)	LS	0.00			
110020	TRAFFIC CONTROL LABOR (PEACE OFFICERS)	HR	60.00			
110030	CONSTRUCTION SIGNS CLASS A	SF	25.00	108	$ 2,700	
				SUBTOTAL	**$ 9,700**	
SECTION 2-02 REMOVAL OF STRUCTURES AND OBSTRUCTIONS						
202045	REMOVE PAVEMENT { QTY >= 1000 }	SY	16.00		$ -	ALL EXISTING PAVEMENT REPLACED
	{ 200 <= QTY < 1000 }		22.00	3,400	$ 74,800	
	{ QTY < 200 }		34.00	-	$ -	
202355	REMOVE MANHOLE	EA	650.00	13	$ 8,288	REMOVE ALL EXISTING MANHOLES
202750	SAW ASPHALT CONCRETE FULL DEPTH	LF	4.00	5,100	$ 20,400	ASSUME ONLY ONE SIDE OF EXCAVATION TO BE SAW CUT
	{ 200 <= QTY < 1000 }		22.00		$ -	
	{ QTY < 200 }		34.00		$ -	
202190	REMOVE PIPE	LF	18.00	2,550	$ 45,900	ALL EXISTING PIPE REMOVED
				SUBTOTAL	**$ 149,388**	
SECTION 4-01 MINERAL AGGREGATES						
401002	MINERAL AGGREGATE, TYPE 2 { QTY >= 2000 }	TN	30.00		$ -	
	{ 200 <= QTY < 2000 }		32.00		$ -	ASSUME 6 IN THICK BASE COURSE. NO EXISTING REUSE
	{ QTY < 200 }		45.00	1,037	$ 46,665	
401209	MINERAL AGGREGATE, TYPE 9	CY	48.00	71	$ 3,400	18 IN BASE FOR MANHOLES
				SUBTOTAL	**$ 50,065**	
SECTION 5-04 ASPHALT CONCRETE PAVEMENT						
504045	PAVEMENT, HMA (CL 1/2 IN)	TN	120.00	680	$ 81,600	ASSUME 3 IN THICK CLASS A
				SUBTOTAL	**$ 81,600**	
SECTION 7-17 STORM DRAINS AND SANITARY SEWERS						
705200	MANHOLE, TYPE 200A	EA	3400.00	13	$ 43,350	NO EXISTING MANHOLE SALVAGED
717015	BEDDING, CL B, 15 IN PIPE	LF	14.00	2,550	$ 35,700	REPLACES 6 IN PIPE
717716	PIPE, PSS, CONC REINF C76 CL IV, 15 IN	LF	80.00	2,550	$ 204,000	REPLACES 6 IN PIPE
717990	TELEVISION INSPECTION	LF	4.00	2,550	$ 10,200	TV INSPECT ALL NEW PIPE
717S01	TEMPORARY BYPASS	EACH	1.00	50,000	$ 50,000	ENGINEER'S ESTIMATE BASED ON SIMILAR KING COUNTY PROJECT
717900	SAFETY SYST. FOR TRENCH EXCAV, MIN BID = $.8(	SF	1.20	26,679	$ 32,015	
				SUBTOTAL	**$ 375,265**	
SECTION 8-01 EROSION CONTROL						
801005	TEMPORARY EROSION & SEDIMENT CONTROL, MII	LS	7500	1	$ 7,500	ENGINEER'S ESTIMATE BASED ON SIMILAR KING COUNTY PROJECT
				SUBTOTAL	**$ 7,500**	
SECTION 8-22 PAVEMENT MARKING						
822004	PAVEMENT MARKING, PAINT, 4 IN STRIPE	{ QTY >= 5,(	0.20	-	$ -	

		{ 500 <= QTY < 5,000	0.45		$	-
		{ QTY < 500 }	1.50		$	-
				SUBTOTAL	**$**	**-**
LATERAL CONNECTION						
	LATERAL CONNECTION	EA	1000.00	33	$	33,000
					$	**33,000**
				SUBTOTAL	**$**	**706,518**
109005	MOBILIZATION (10%)				$	70,652
	DESIGN CONTINGENCY (20%)					
	TAX (10%)					
				TOTAL		**777,170**

WBS	Code:	Sub:	Activity:	Comments	Percentage:	Cost Summary:	Hard Costs:
P2	**X**		**CIP Development:**				
P2.1	50		Determine Candidate I	Labor costs	0.00%	$0	
P2.3	60		Develop Details & Adj	Labor costs	3.00%	$23,315	
P2.5	70		Analze Financial Data	Labor costs	4.00%	$31,087	
Project Development Phase Sub-Total:					**7.00%**	**$54,402**	**$0**
P3	**Y**		**Project Development:**				
P3.1	0		Service Request/Agre	Labor costs	0.50%	$3,886	
P3.2	80		Develop Project Idea &	Labor costs	0.00%	$0	
P3.3	100		Preparation and Prese	Labor costs	3.00%	$23,315	
P2.5	90		Set Up Project Numbe	Labor costs	1.00%	$7,772	
Project Development Phase Sub-Total:					**3.50%**	**$34,973**	**$0**
1	**Z**		**Preliminary Engineering:**				
1.1	0		Service Request/Agre	Labor costs	0.50%	$3,886	
1.3	110		Identify Existing Condi	Labor costs	3.00%	$23,315	
			In-House Design Su	Labor costs	5.00%	$38,858	
			Basemaps	Non-Labor	5.00%	$38,858	
			Materials Lab Services		2.00%	$15,543	
1.4	120		Develop Alternatives		10.00%	$77,717	
1.5	130		Prep PE Report		5.00%	$38,858	
1.6	140		Review PE Report		1.00%	$7,772	
1.7	150		Finalize PE		2.00%	$15,543	
1.8	100		Prepare and Present PDP No. 2		1.00%	$7,772	
Preliminary Engineering Phase Sub-Total:					**34.50%**	**$268,123**	**$0**
	D		**Design (D)**				
	0		Service Request/Agre	Labor costs	0.50%	$3,886	
	230		Develop 30% Design		10.00%	$77,717	
	231		Circulate & Review 30% Design		0.50%	$3,886	
	260		Develop 60% Design		10.00%	$77,717	
	432		Permit/Regulatory Compliance		1.00%	$7,772	
	433		Permit Fees		1.00%	$7,772	$7,772
			Federal			$0	
			Army Corp of Engineers			$0	
			Fish and Wildlife			$0	
			State			$0	
			WADOT			$0	
			DOE			$0	

		Local:		$0	
		DPD		$0	
		Parks		$0	
		Street Use		$0	
434		Value Engineering	1.50%	$11,658	
261		Circulate & Review 60% Design	0.50%	$3,886	
290		Develop 90% Design	15.00%	$116,575	
100		AMC Prep & Presentation	0.00%	$0	
291		Circulate & Review 90% Design	0.50%	$3,886	
299		Finalize Design	1.00%	$7,772	
		Specification and Cost Estimating	3.00%	$23,315	
310		CSD Circulation Labor costs	1.00%	$7,772	
320		Prep for Advertisement	0.25%	$1,943	
330		Contractor Selection Process	0.25%	$1,943	
Design Phase Sub-Total:			**46.00%**	**$357,498**	**$7,772**
C		**Construction:**	**Allowance:**	**$777,170**	
0		Service Request/Agre Labor costs	0.00%	$0	
430		Acquisition Hard Costs	1.00%	$7,772	$7,772
438		Purchase Assets & Resources	1.00%	$7,772	$7,772
340		Preparation for Constr Labor costs	1.00%	$7,772	
300		Payments forContractor	108.90%	$846,338	$846,338
350		Original Contract Labor	19.00%	$147,662	
##		Construction Survey	1.00%	$7,772	$7,772
##		Geotech Services	1.00%	$7,772	$7,772
370		Testing and Commissioning	1.00%	$7,772	
380		Develop and Resolve Punch List	2.00%	$15,543	
C80		SPU Operations Activi Defined by	0.80%	$6,217	$6,217
	C80	Construct WM & Appurtenances		$0	
	C81	WM Connections		$0	
	C82	Temporary WMs and Services		$0	
	C83	Cut/Cap/Plug/Remove		$0	
	C84	Water Service Work		$0	
	C85	Service Transfer/Adjustment		$0	
	C86	Service Kills		$0	
	C87	Hydrant/Valve Adjustment		$0	
	C88	Other Water Ops Connection		$0	
	C90	Construct WM % Appurtenances		$0	
	C95	WQ Inspection		$0	
Construction Phase Sub-Total:			**136.70%**	**$1,062,391**	**$883,642**

4	**F**	**Close-Out:**				
4.1	390	Close-Out Activities/Pc	Labor costs	4.00%	$31,087	
	301	Payment for Landscap	Labor cost	3.00%	$23,315	
	436	Investigate Accidents & Claims		1.00%	$7,772	
	437	Public Disclosure Requests		1.00%	$7,772	
4.2		Contingency/Change Orders/Savi		20.00%	$155,434	*$155,434*
	Close-Out Phase Sub-Total:			**29.00%**	**$225,379**	**$155,434**
		Other Agency Specific Work Packages				
	442	City Levied Fees: DEA Contract C		2.00%	$15,543	
	490	Parks Support		1.00%	$7,772	*$7,772*
	491	SCL Support		1.00%	$7,772	*$7,772*
	492	SDOT Support		1.00%	$7,772	*$7,772*
	493	Other Department Support:				
		1% Art Contribution'		1.00%	$7,772	
		Fleet and Facilities		1.00%	$7,772	
		Seattle Design Commission		1.00%	$7,772	
Other Agency Work Packages Sub-Total:				**6.00%**	**$46,630**	**$23,315**
		Staff Specific Work Packages				
	410	Perform Real Estate Services		1.00%	$7,772	
	411	Communications Support		1.00%	$7,772	
	412	Operations Support (Project Deliv		1.00%	$7,772	
	413	Grants & Contracts Support		1.00%	$7,772	
	414	Management Support		1.00%	$7,772	
	415	Administrative Support		1.00%	$7,772	
	416	Finance Support (CM and DOE Lc		1.00%	$7,772	
	417	SPU Conservation Activities		1.00%	$7,772	
	418	Security Program Support		1.00%	$7,772	
		Sales tax		10.00%	$77,717	
Staff Specific Work Package Sub-Total:				**19.00%**	**$147,662**	**$0**
		Totals:		**265.20%**	**$2,061,054**	**$1,062,391**
						51.546%
Adjusted Escalation Cost Year 2:				2.65%	**$2,115,713**	**50.214%**
Adjusted Escalation Cost Year 3:				2.65%	**$2,171,821**	**48.917%**
Adjusted Escalation Cost Year 4:				2.65%	**$2,229,418**	**47.653%**

APPENDIX B

Sanitary Sewer Profiles

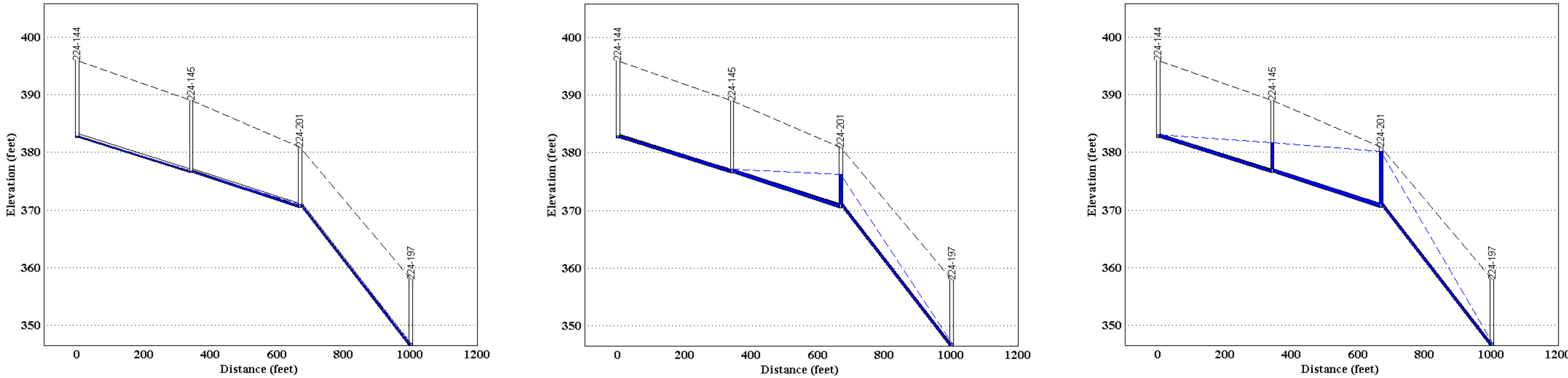


Figure B-1. Water surface elevation profiles on 1st Avenue NW and N 115th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under existing conditions.

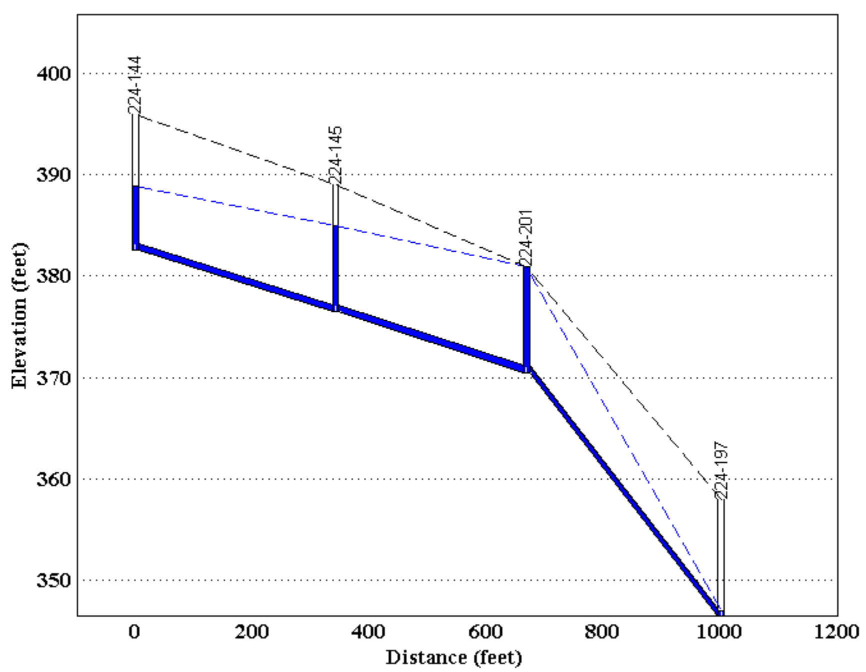


Figure B-2. Water surface elevation profile on 1st Avenue NW and N 115th Street for the December 3, 2007 storm under existing conditions.

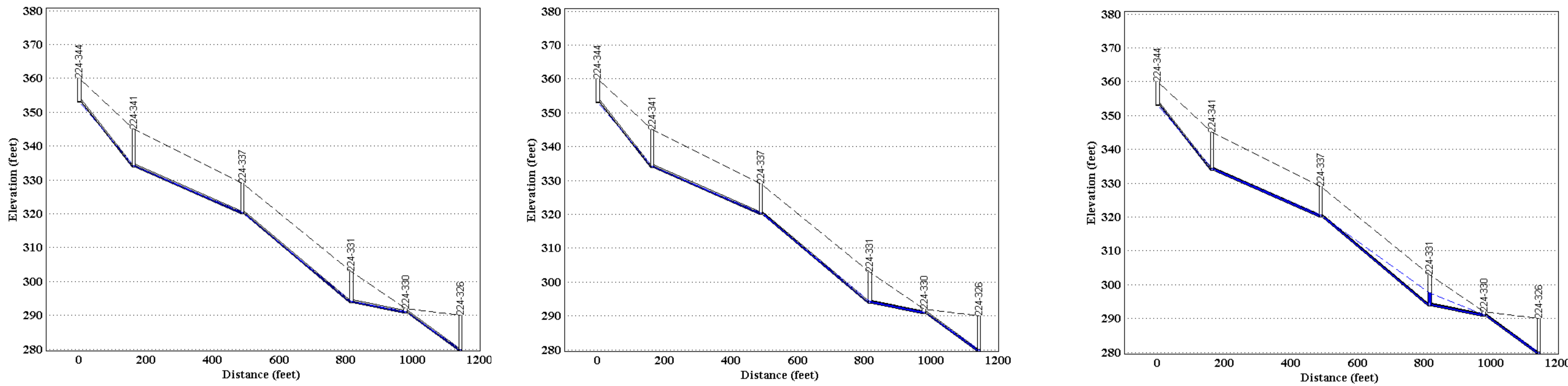


Figure B-3. Water surface elevation profiles on N 105th Street between Greenwood Avenue N and 3rd Avenue NW for the 2-year (left), 25-year (middle), and 100-year (right) storms under existing conditions.

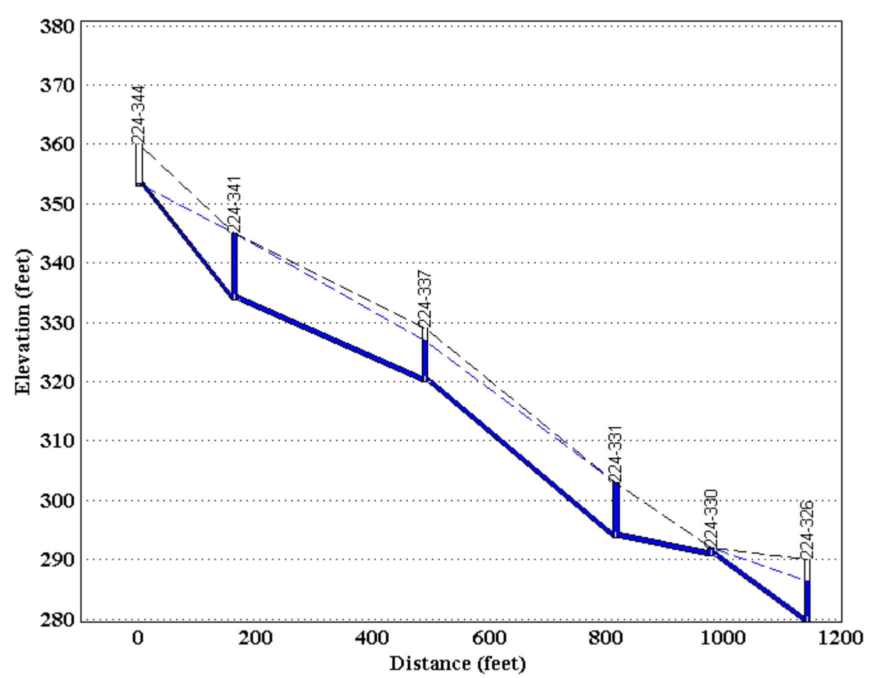


Figure B-4. Water surface elevation profile on N 105th Street between Greenwood Avenue N and 3rd Avenue NW for the December 3, 2007 storm under existing conditions.

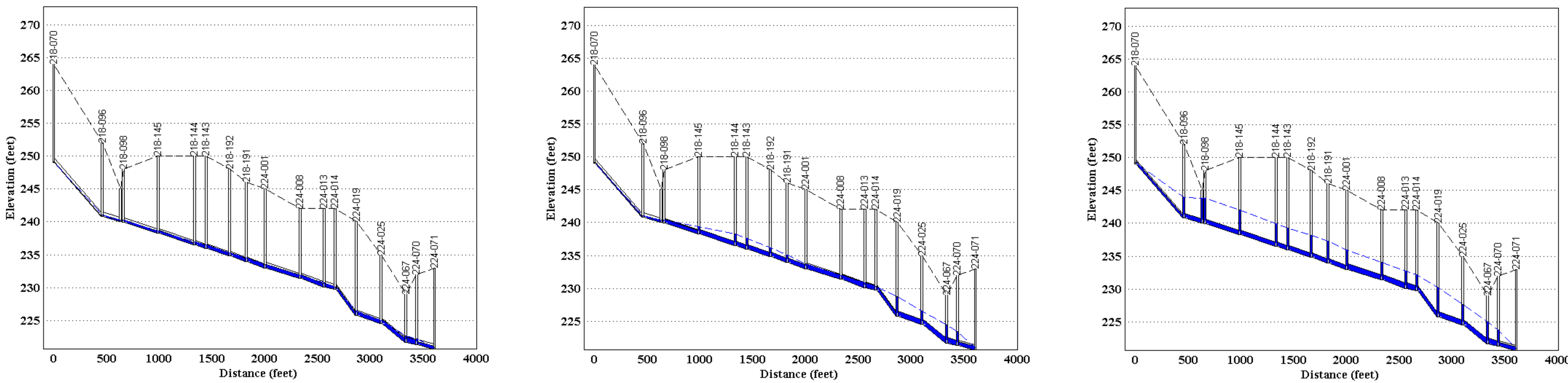


Figure B-5. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under existing conditions.

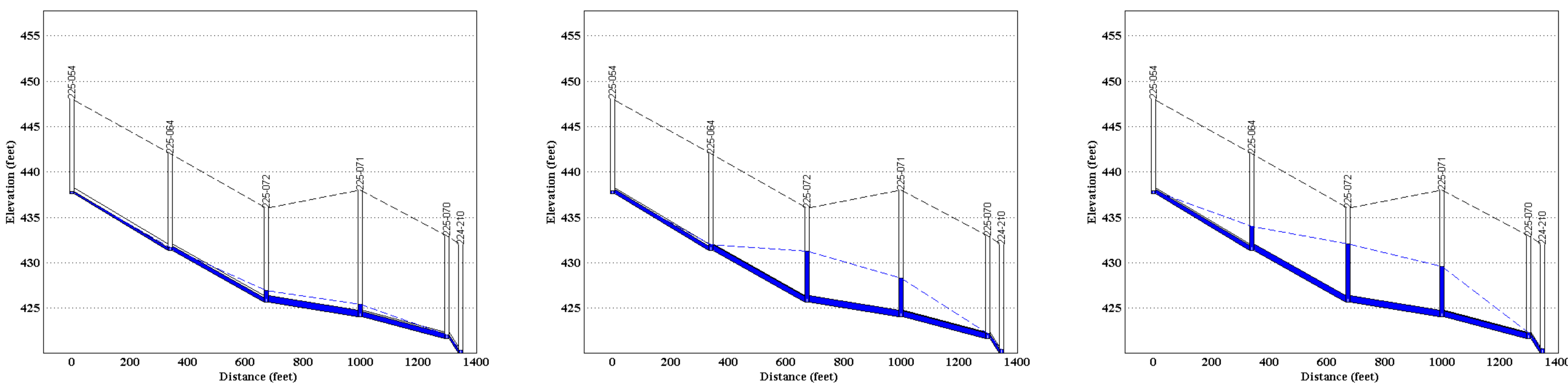


Figure B-6. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under existing conditions.

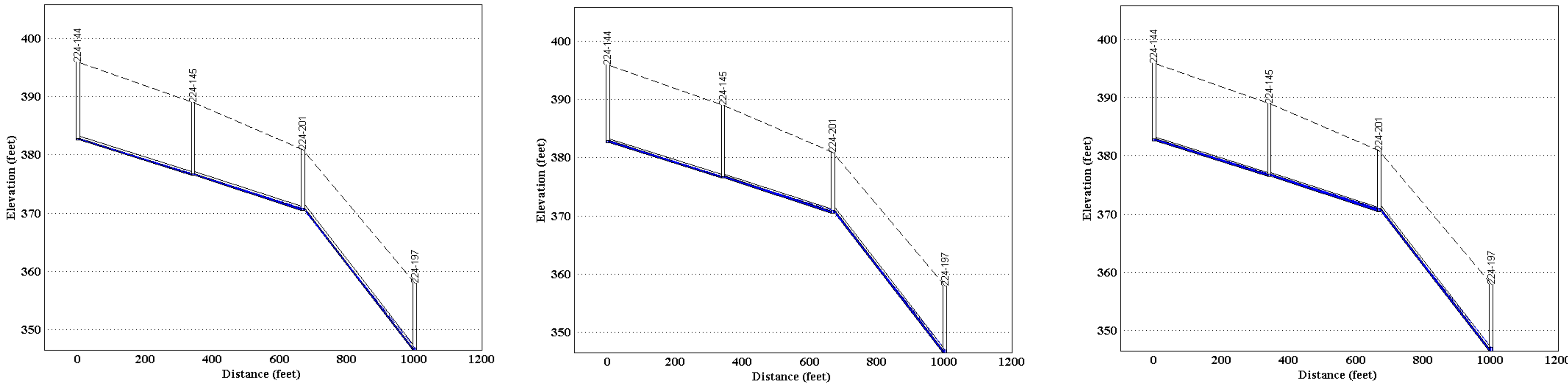


Figure B-7. Water surface elevation profiles on 1st Avenue NW and N 115th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 1.

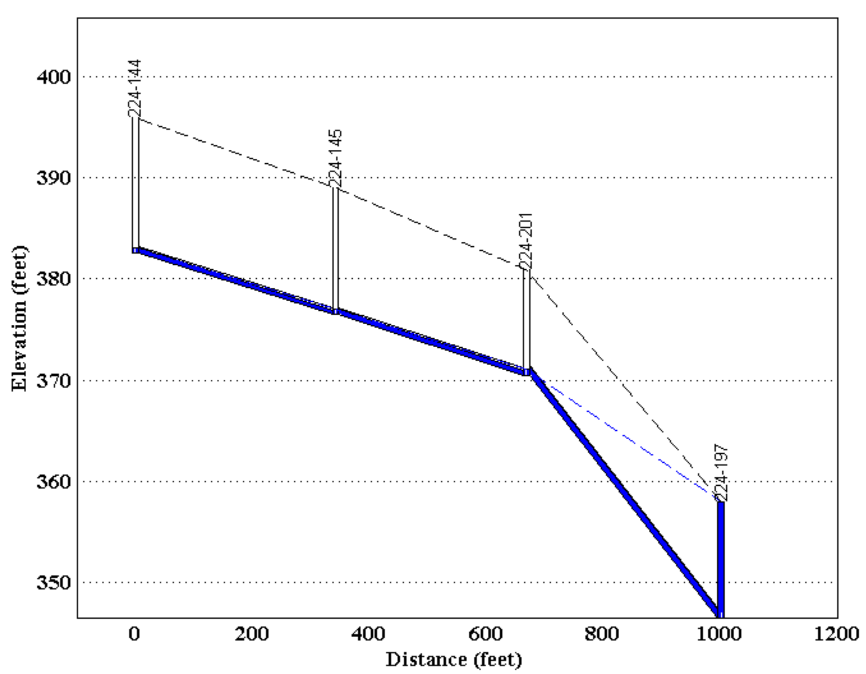


Figure B-8. Water surface elevation profiles on 1st Avenue NW and N 115th Street for the December 3, 2007 storm under Alternative 1.

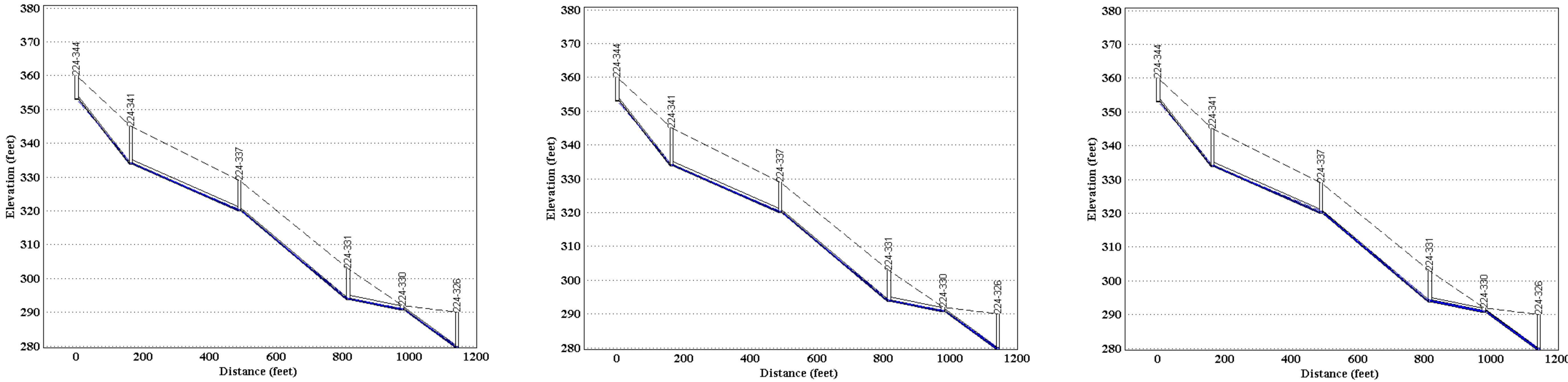


Figure B-9. Water surface elevation profiles on N 105th Street between Greenwood Avenue N and 3rd Avenue NW for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 1.

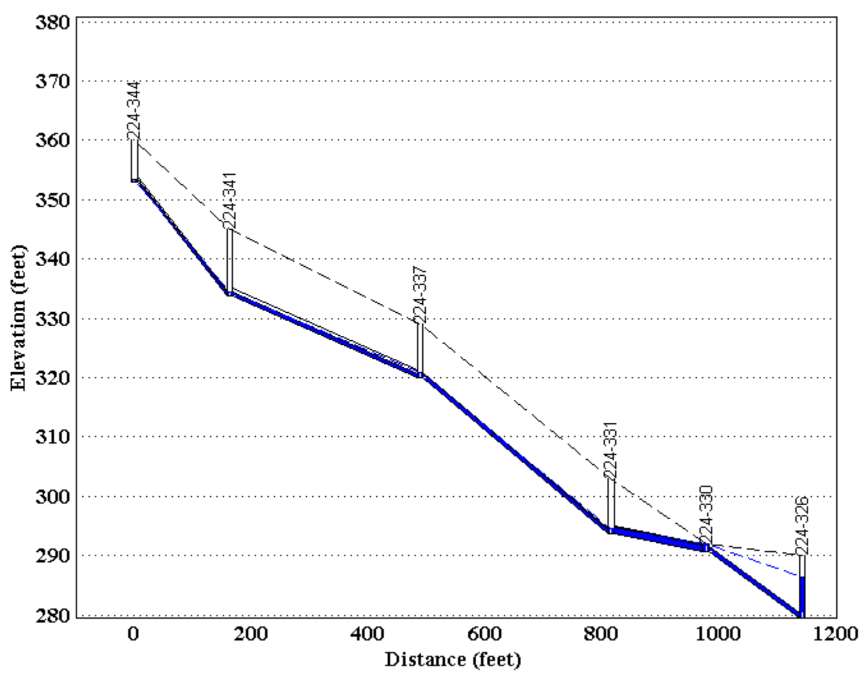


Figure B-10. Water surface elevation profile on N 105th Street between Greenwood Avenue N and 3rd Avenue NW for the December 3, 2007 storm under Alternative 1.

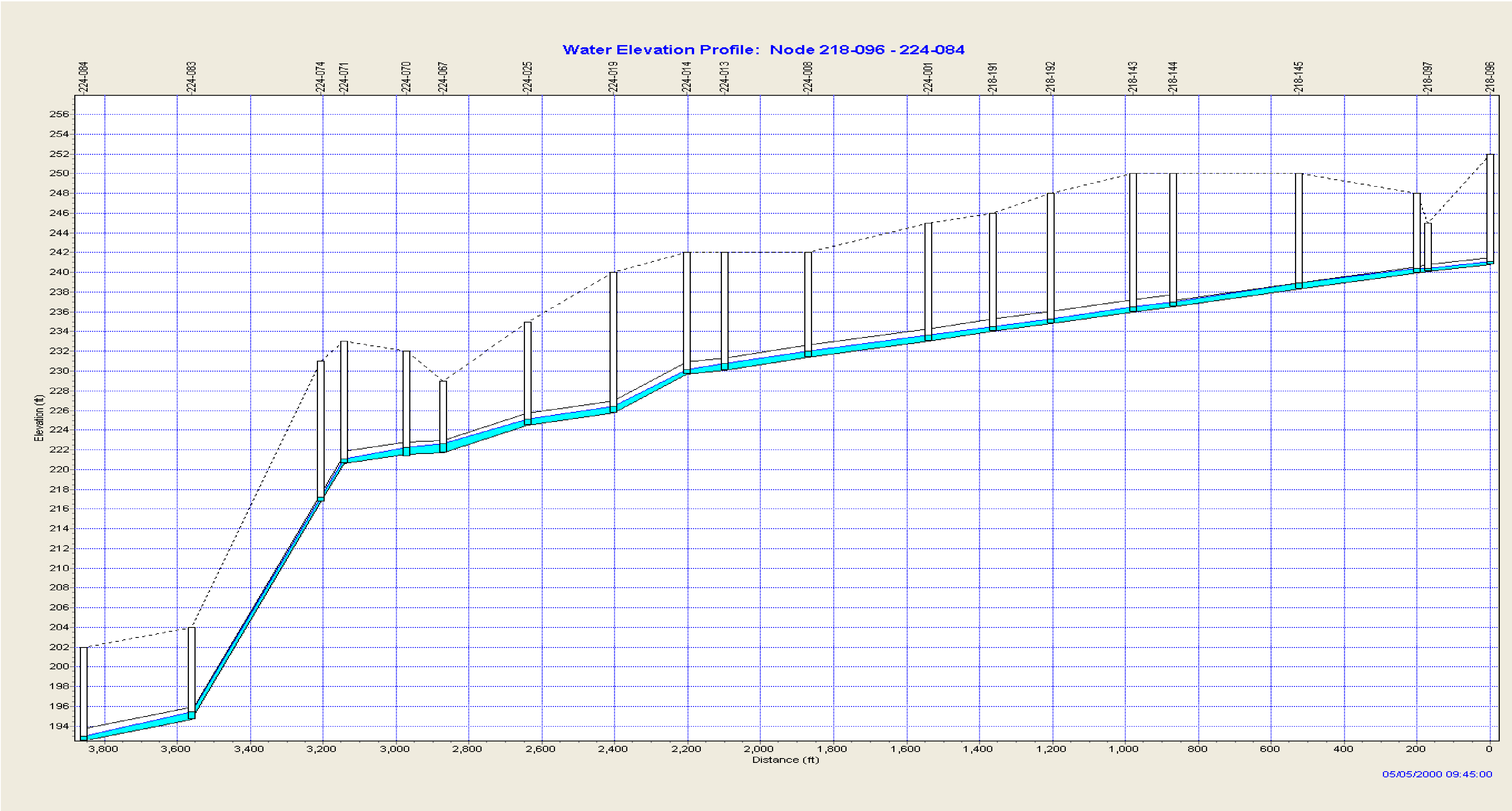


Figure B-11. Water Surface profile on 12th Avenue NW for the 100-year under Alternative 1.

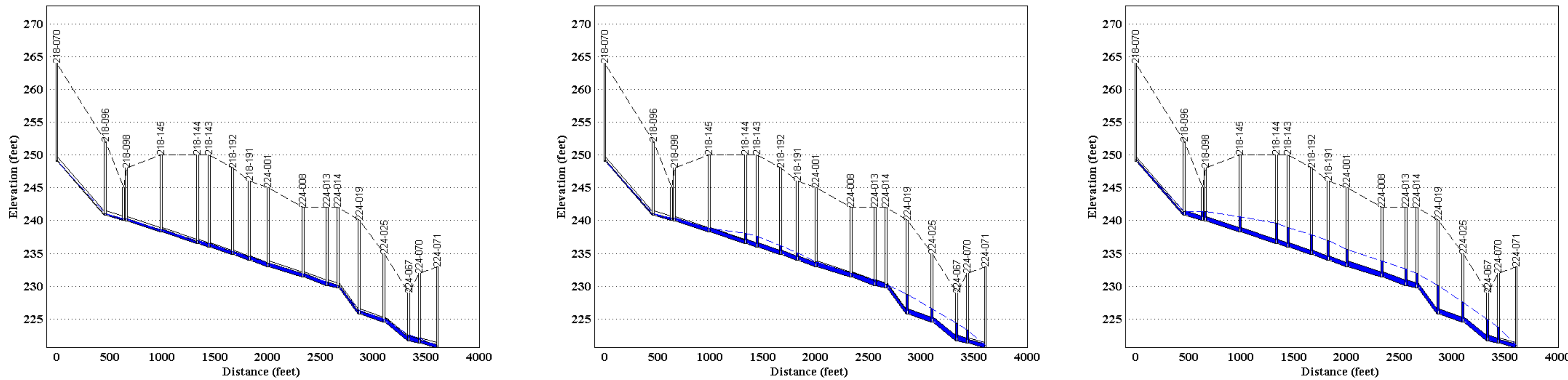


Figure B-12. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.A.

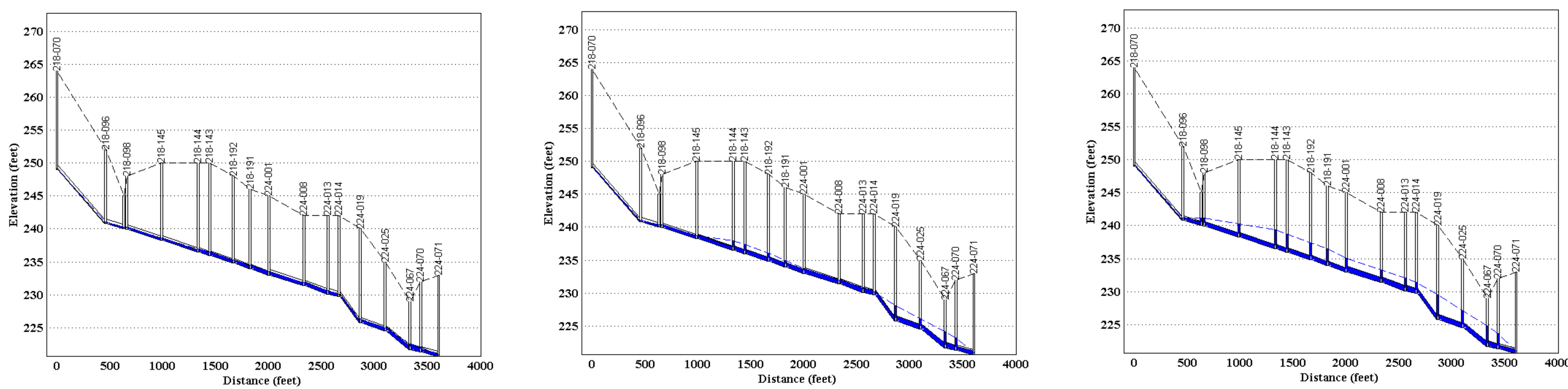


Figure B-13. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.B.

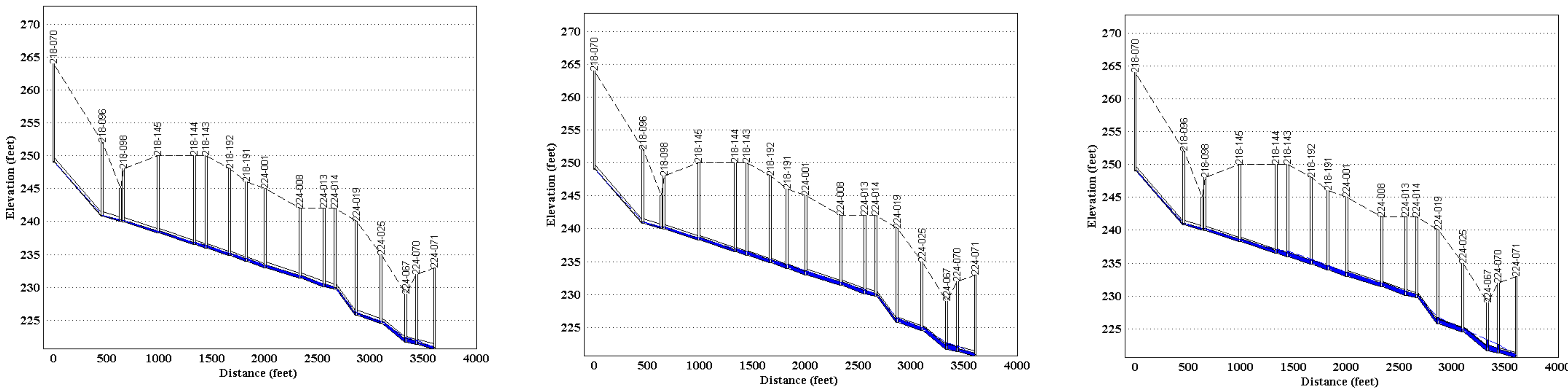


Figure B-14. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.C.

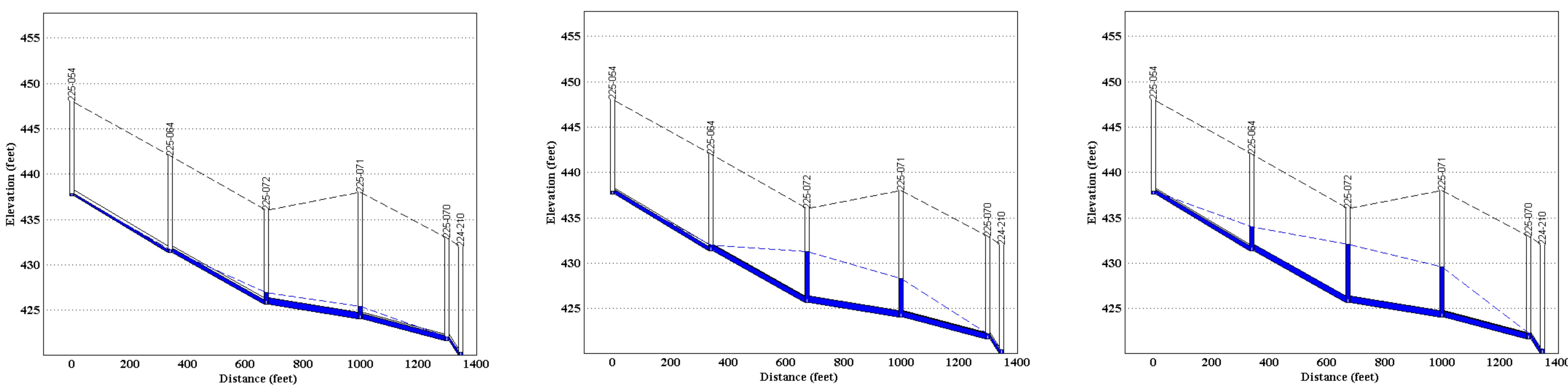


Figure B-15. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 1.

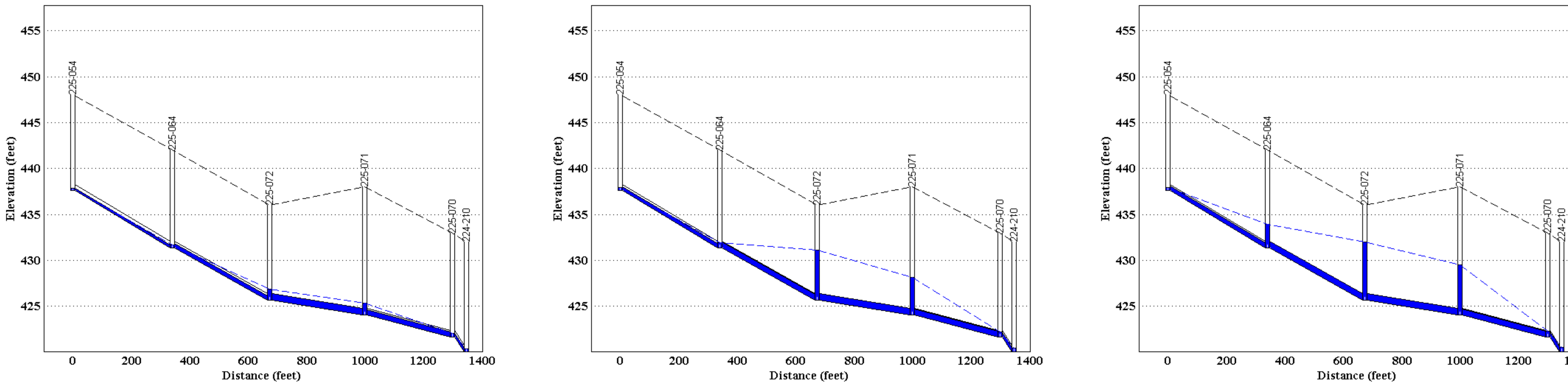


Figure B-16. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.A.

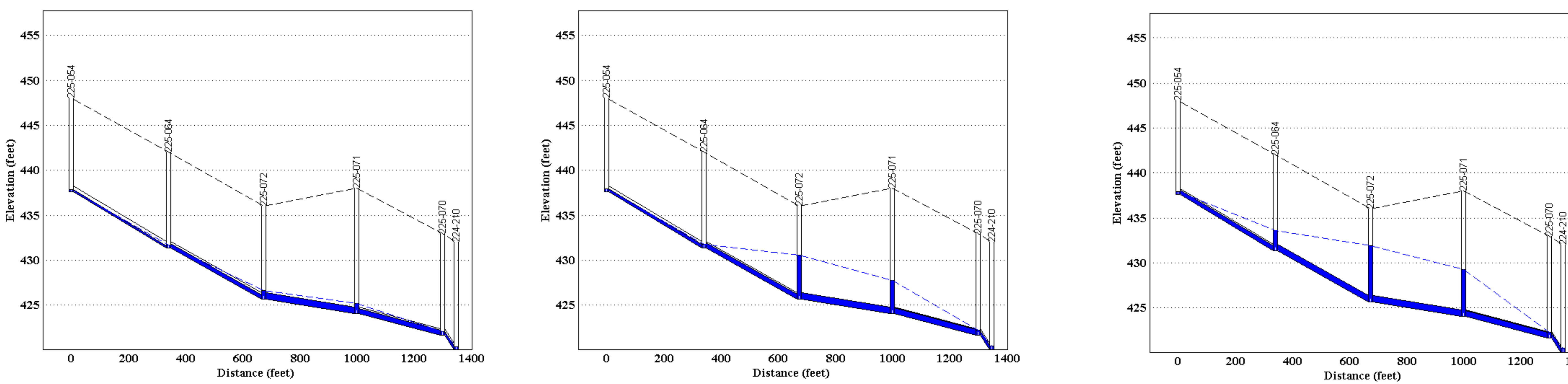


Figure B-17. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.B.

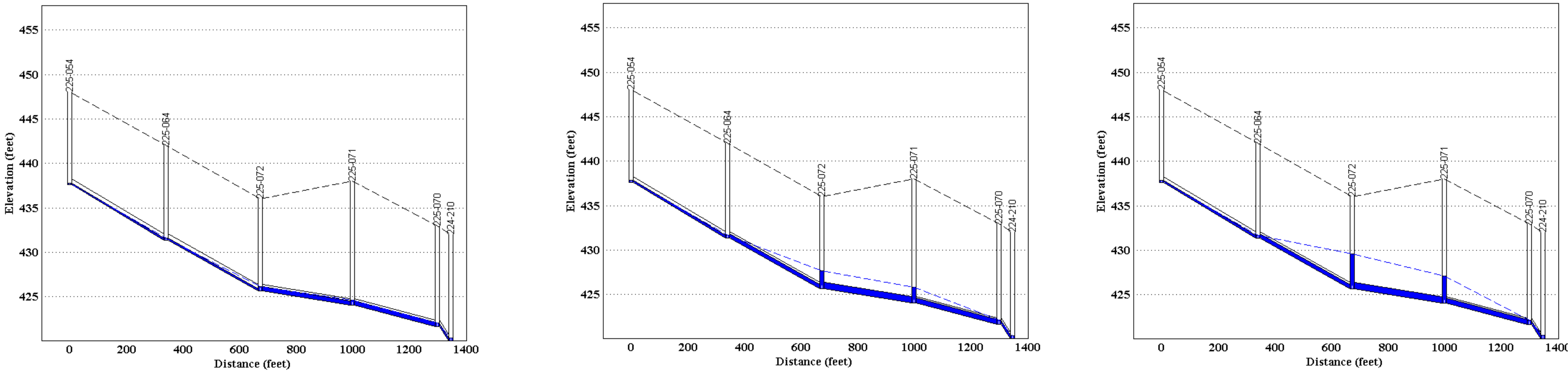


Figure B-18. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 2.C.

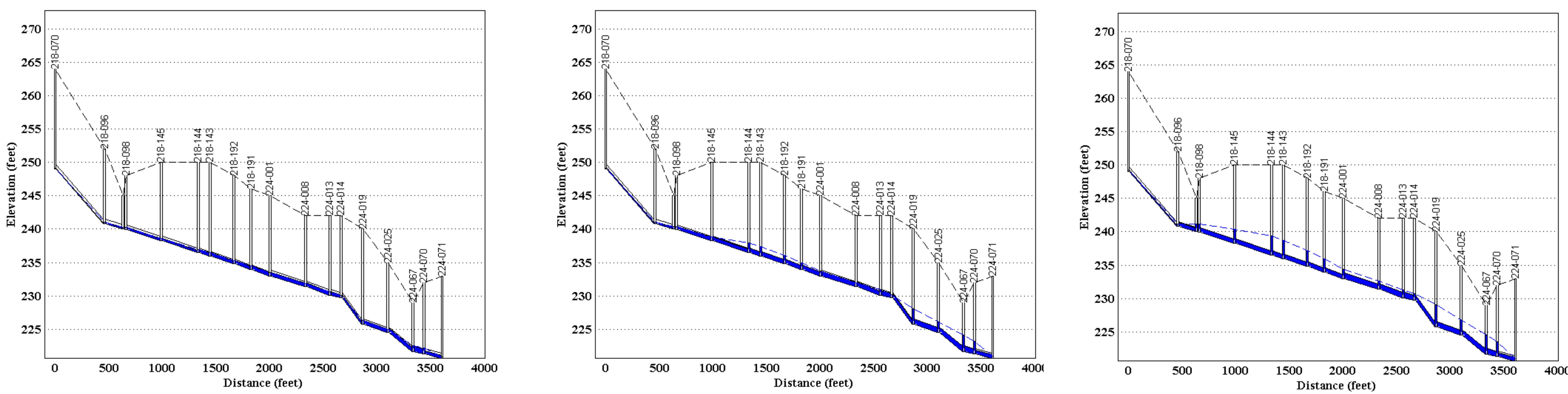


Figure B-19. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.A.

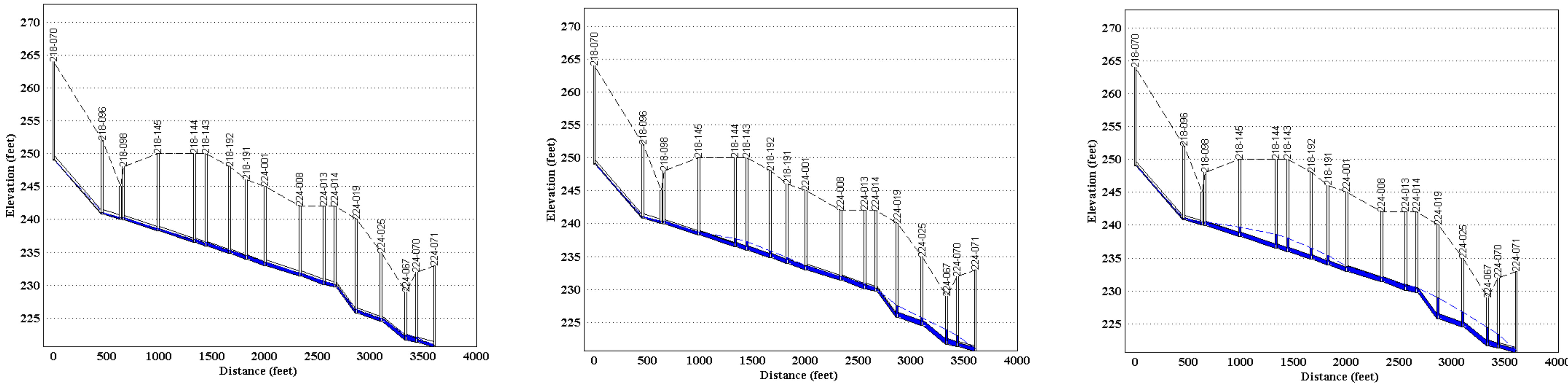


Figure B-20. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.B.

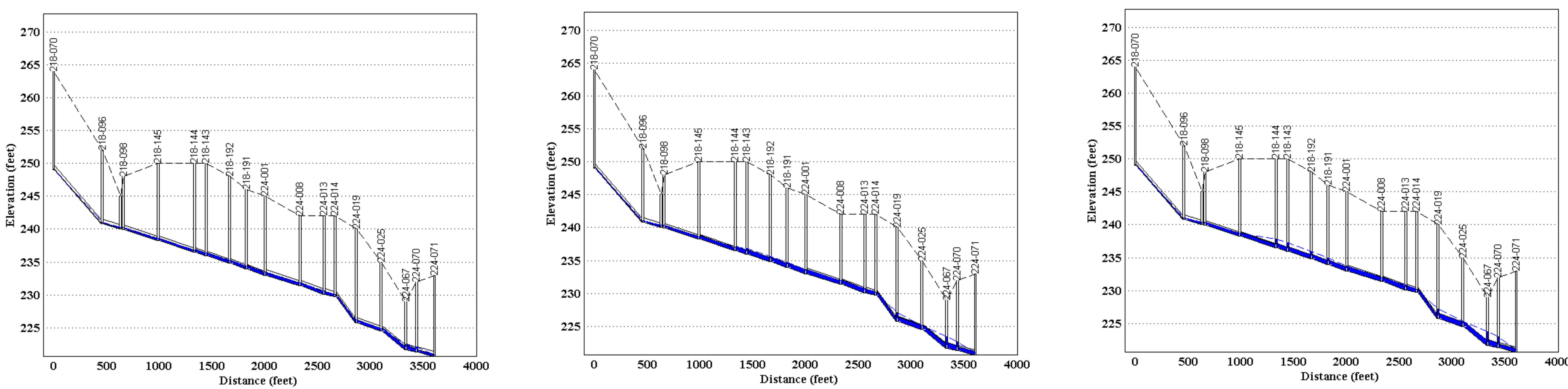


Figure B-21. Water surface elevation profiles on 12th Avenue NW between NW 132nd Street and NW 119th Street for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.C.

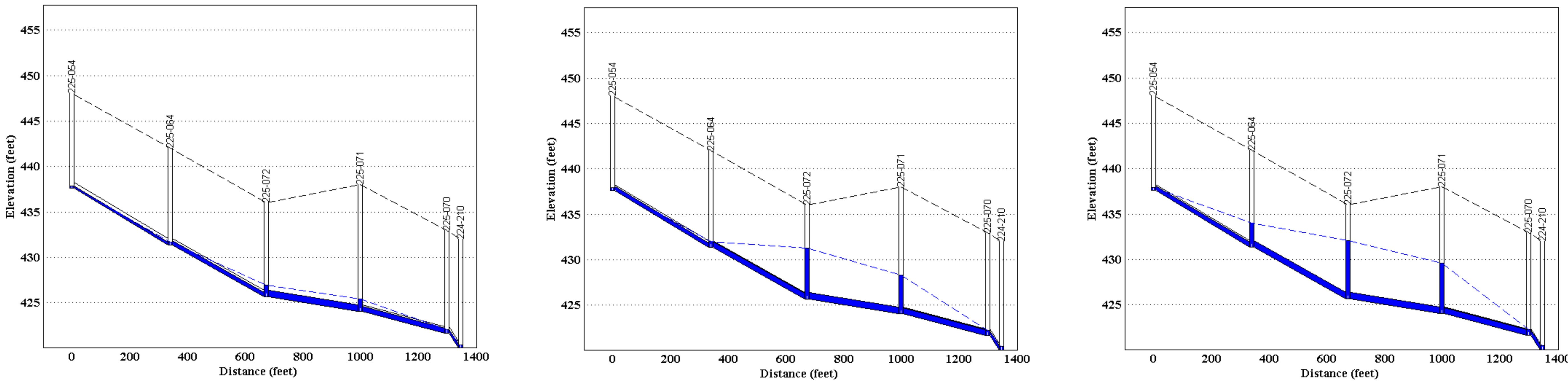


Figure B-22. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 1.

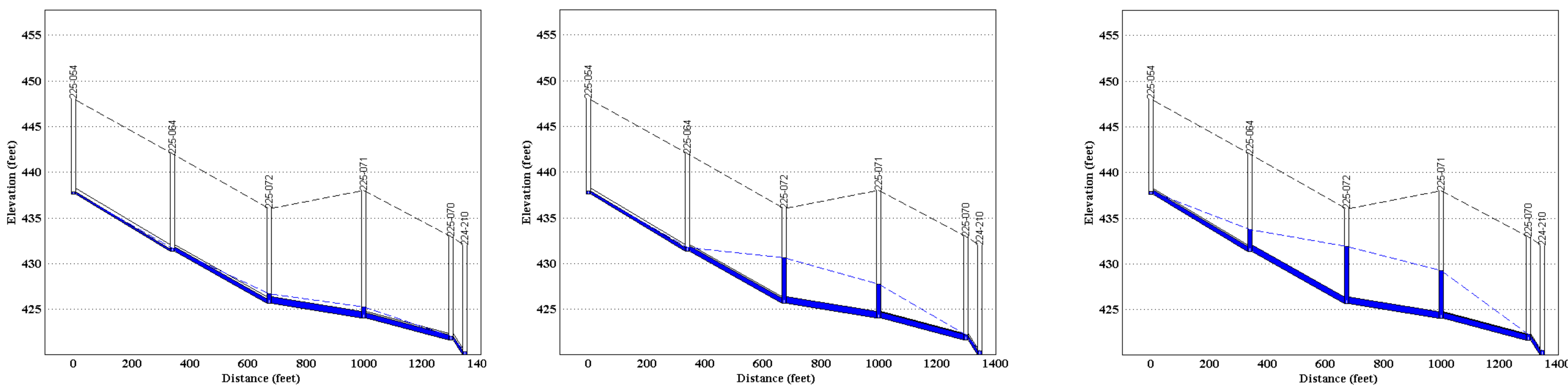


Figure B-23. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.A.

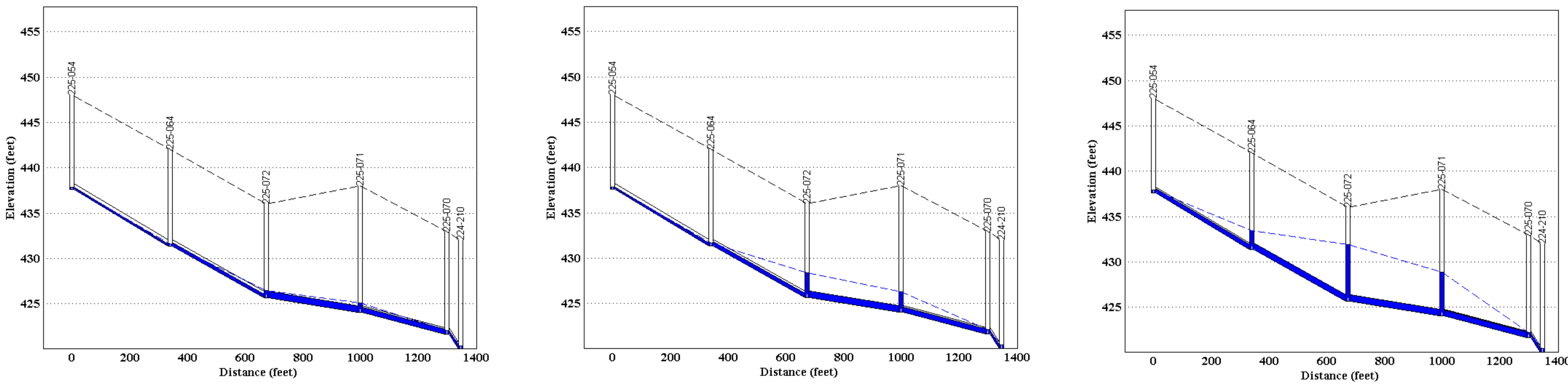


Figure B-24. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.B

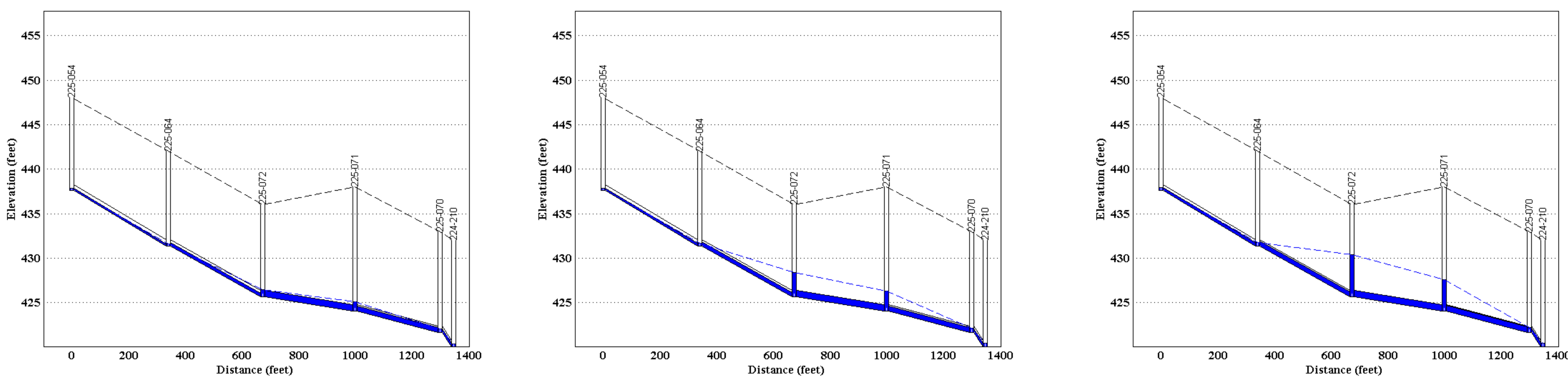
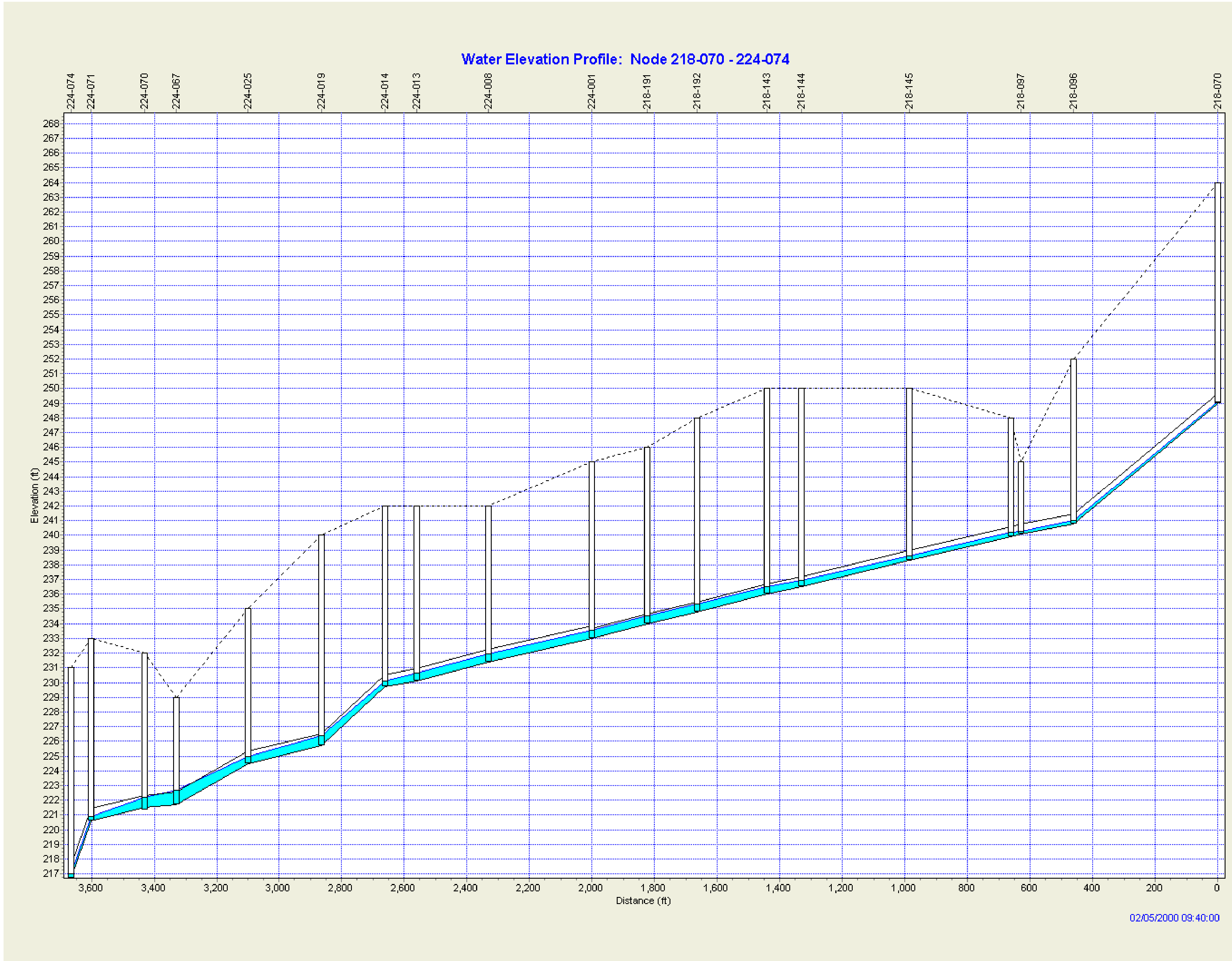


Figure B-25. Water surface elevation profiles on Dayton Avenue N for the 2-year (left), 25-year (middle), and 100-year (right) storms under Alternative 3.C.



FigureC-26. Water surface elevation profiles on 12th Avenue NW for the 2-year storm under Alternative 4.

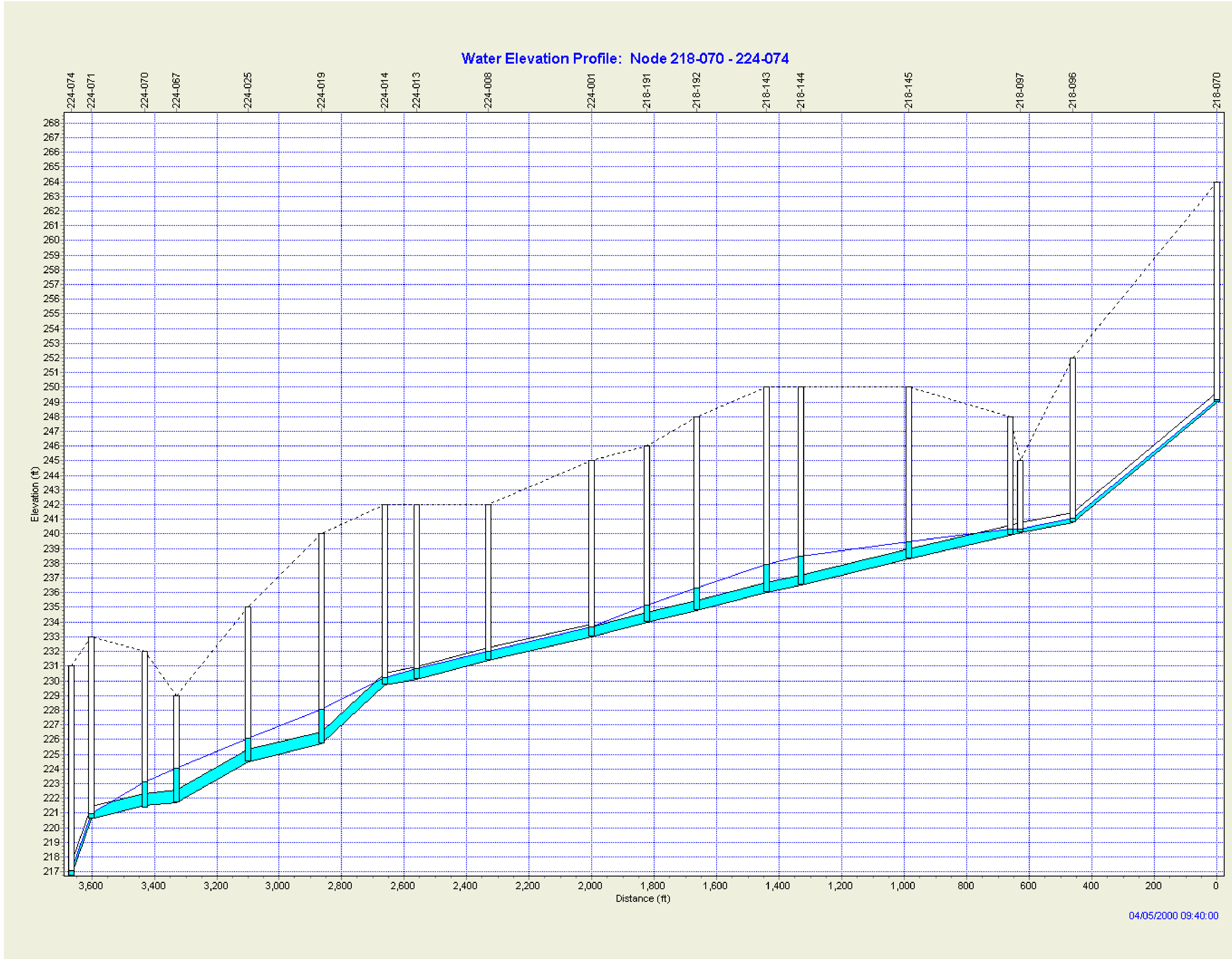


Figure B-27. Water surface elevation profiles on 12th Avenue NW for the 25-year storm under Alternative 4.

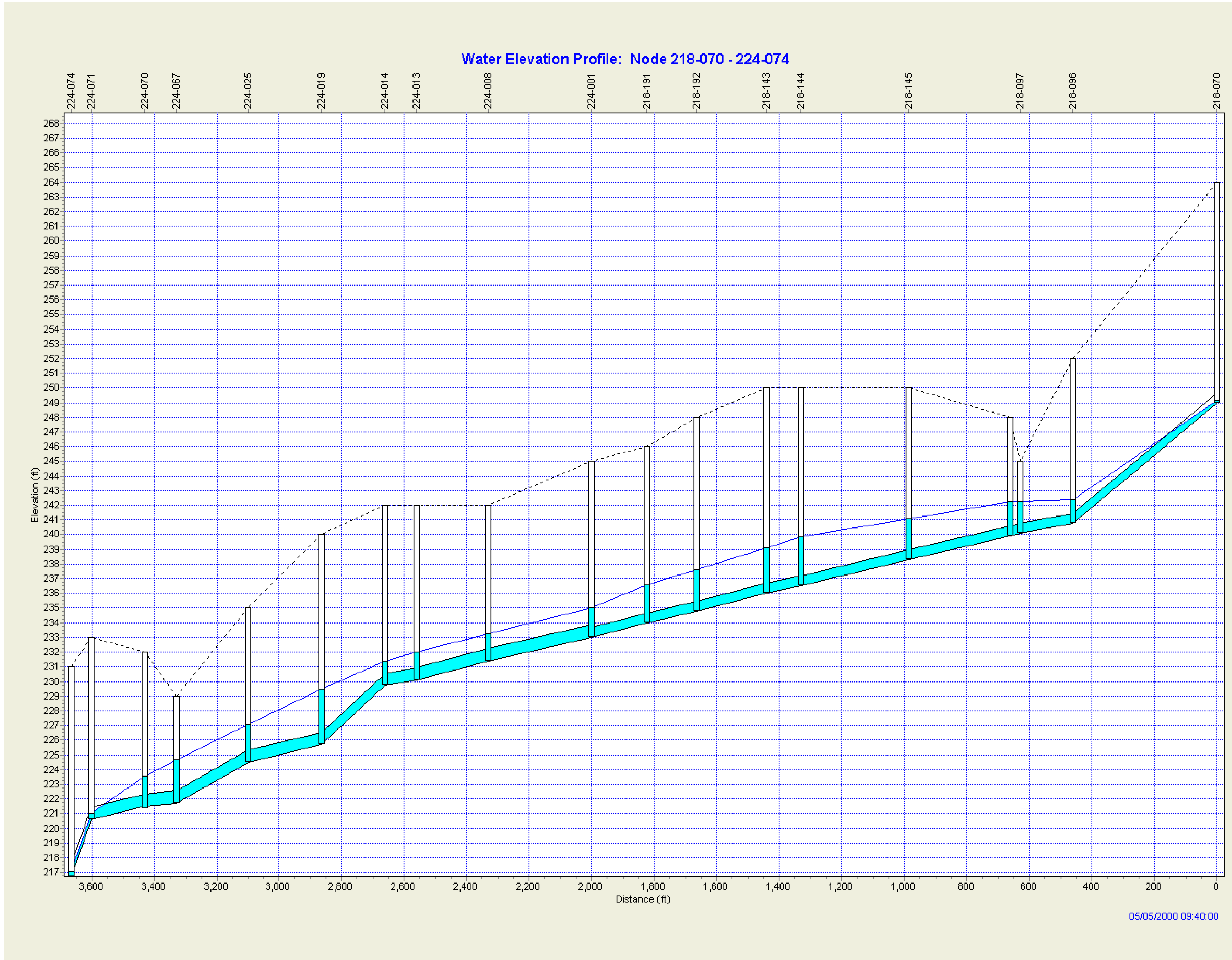


Figure B-28. Water surface elevation profiles on 12th Avenue NW for the 100-year storm under Alternative 4.