Lower Coal Creek Flood Hazard Reduction Alternatives Analysis

Prepared for: City of Bellevue

Prepared by: Northwest Hydraulic Consultants, Seattle, WA

In association with: Tetra Tech, Seattle, WA

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KING COUNTY
FLOOD CONTROL
DISTRICT

City of Bellevue
WASHINGTON

Acknowledgements

Consultant team members instrumental in conducting this project and preparing this report include:

Name	Role	Affiliation
David M. Hartley, Principal Hydrologist, P.E. Ph.D.	Project Manager and primary author	NHC
Patty Dillon, Principal, P.E.	Hydrology	NHC
Vaughn Collins, Senior Engineer, P.E.	Stream Hydraulics	NHC
Peter Brooks, Engineer, P.E.	Geomorphology and Sedimentology	NHC
Courtney E Moore, Jr. Engineer	Data analysis, hydrology, and hydraulics	NHC
Madalyn Ohrt, GIS Specialist	Maps and graphics	NHC
Jerry Scheller, P.E.	Stormwater hydraulics and preliminary design lead	Tetra Tech
Greg Woloveke	Stormwater hydraulics, cost estimating	Tetra Tech
Bryan Thomasy	CAD	Tetra Tech
Greg Gaasland, P.E.	QA/QC	Tetra Tech
Robert Wheeler, P.E.	Lead Facilitator, Public Involvement	Triangle and Associates
Sarah Saviskas, Associate	Public Involvement Support	Triangle and Associates
Shanese Crosby, Associate	Public Involvement Support	Triangle and Associates
Benn Burke, Environmental Program Manager	Environmental Evaluation and Permitting	SWCA

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Executive Summary

The Newport Shores neighborhood is located on the alluvial fan of Coal Creek, where the channel gradient naturally declines as the creek approaches its delta at Lake Washington. This basic geographic reality has made the Newport Shores neighborhood in the vicinity of Coal Creek a naturally flood prone area. Additionally, historic coal mining activities and urbanization within the upstream Coal Creek watershed aggravated both flooding and sedimentation problems in the neighborhood. Since the 1990s, both the City of Bellevue and King County have implemented a comprehensive set of measures to reduce watershed sediment sources, trap and remove creek sediments, and reduce peak flows entering Newport Shores. These measures have proven highly effective at controlling sediment delivery to the neighborhood; however, flooding continues to be a problem in the neighborhood, with the most recent flood complaints occurring following a storm on August 13, 2014.

In recognition of ongoing flooding problems in Newport Shores, the King County Flood Control District and the City of Bellevue engaged an interdisciplinary team of experts to analyze flooding problems, seek input from Newport Shores Community, evaluate alternatives, and recommend a preferred project that provides up to 100-yr flood protection in Newport Shores. Based on these activities, it was concluded that to reduce flood risk in Newport Shores, distinct measures to manage both high creek flows (direct flooding) and storm drain backups (indirect flooding) are required. Evaluation of alternatives addressing these two flooding sources resulted in the following recommendations:

- To lower risk of direct creek flooding, replace 5 hydraulically restrictive culverts within Newport Shores.
- To lower risk of indirect flooding caused by backup of storm drains, redirect storm drains to flow to new outfalls on the Newport Shores Grand Canal and Lake Washington instead of to Coal Creek. Facilitate drainage efficiency by allowing stormwater to cross under the creek.

Replacement of culverts at Cascade Key, Upper Skagit Key, Glacier Key, Newport Key, and Lower Skagit Key should go forward to the design and construction phase as soon as is practicable and should include construction of creek crossing storm drain pipes (inverted siphons). Construction of recommended new storm drain outfalls will require from two to three new drainage easements which may involve an extended period of negotiations with property owners. Therefore, stormwater design, permitting, and construction activities will be required to adapt to the schedule and outcome of these negotiations.

In addition to the recommended culvert replacements and upgrades to the storm drain system, it is recommended that the City work with the Newport Shores Yacht Club (HOA) to develop “fact sheets” for streamside property owners that provide information about stewardship of their streamside property. The purpose of the fact sheets is to provide streamside property owners with vegetation management guidance and information on improving stream bank stability.

Table of Contents

List of Figures

List of Tables

Definition of Abbreviations

CCSP:	Coal Creek Stabilization Program
COB:	City of Bellevue
EIS:	Environmental Impact Statement
WSEL:	Water Surface Elevation
HWM:	High Water Mark

List of Appendices

1 Introduction

The Newport Shores neighborhood is located on the alluvial fan of Coal Creek, where the channel gradient naturally declines as the creek approaches its delta at Lake Washington. This basic geographic reality has made the Newport Shores neighborhood in the vicinity of Coal Creek a naturally flood prone area. Additionally, historic coal mining activities and urbanization within the upstream Coal Creek watershed aggravated both flooding and sedimentation problems in the neighborhood. Since the 1990s, both the City of Bellevue (COB) and King County have implemented a comprehensive set of measures to reduce watershed sediment sources, trap and remove creek sediments, and reduce flood peaks entering Newport Shores. These measures have proven highly effective at controlling sediment delivery to the neighborhood; however, flooding continues to be a problem in the neighborhood, with the most recent flood complaints occurring following a storm on August 13, 2014.

In recognition of ongoing flooding problems in Newport Shores, the City of Bellevue contracted a consultant team led by Northwest Hydraulic Consultants (NHC) to conduct a flood risk reduction alternatives analysis of lower Coal Creek. The objectives of the project may be summarized as follows:

- Determine the causal mechanisms of flooding in the Newport Shores neighborhood associated with Coal Creek
- Establish the level of flood risk with the existing hydrologic and sediment regime
- Develop, analyze, and recommend flood reduction alternatives that provide up to 100-yr flood protection in Newport Shores
- Support public involvement through mailings, neighborhood meetings, website materials
- Develop 15%-level design plans and cost estimates for the preferred alternative

This report documents the consultant team's pursuit of the project objectives. The following sections document the team's review of literature and data related to the Coal Creek watershed, flooding, and sedimentation in Newport Shores; analysis of existing conditions related to hydrology, stream hydraulics, sedimentation, and neighborhood drainage; development and comparison of flood risk reduction alternatives; and selection and detailing of a preferred alternative.

2 Literature and Data Review

A literature and data review was conducted to provide a firm foundation for technical evaluation of flood hazard reduction alternatives in Newport Shores. NHC collected and reviewed existing relevant documents and data in various forms requested from and provided by the City of Bellevue staff and by tapping NHC's own archives of Coal Creek-related materials. The resultant extensive collection of materials may be categorized as follows: electronic hydrologic timeseries data (precipitation, stream stages, and discharges), electronic spatial data (GIS maps and data layers), flood-related photos, hydrologic and hydraulic models (electronic), sediment data (grain size distributions, composition, and morphology), reports and technical memos, and miscellaneous archival materials. Materials within each of these categories were reviewed to determine relevance to the current project. Highlights of this review are summarized in Appendix A.

3 Flood Hydrology for Lower Coal Creek

Hydrologic analysis of Coal Creek was conducted to determine the probability of annual exceedance of peak annual discharge levels within the study area. The purpose of this analysis was to support hydraulic analysis to determine how frequently different flood levels can be expected to occur within the Newport Shores neighborhood.

Peak annual exceedance probabilities are also more commonly referred to as “flood frequencies,” “recurrence intervals,” or “average annual return periods” of discharges and are usually expressed graphically as a flood frequency curve or tabulated as standard recurrence intervals (e.g. 2-, 5-, 10-, 25-, 50-, 100-, 500-year) with corresponding discharges exceedance levels. When a sufficient length of record of measured discharges is available, a peak annual flow frequency curve can be estimated from the data; however, discharge record lengths for smaller streams are generally not sufficient to provide estimates of discharges corresponding to larger intervals (25-yr, 50-yr, 100-yr…) without undue extrapolation and resultant high levels of uncertainty. To overcome this deficiency, new or longer discharge records for such streams can be synthesized using a hydrologic model which translates historical rainfall and other meteorological inputs into discharges. This approach is predicated on the availability of a longer length of valid meteorological records for the stream basin of interest. This was indeed the case for the lower Coal Creek Study.

A continuous hydrologic model was used to simulate a long term record of creek flows, fit a peak annual flow frequency curve, and provide flood quantiles and hydrographs for both Coal Creek hydraulic modeling and modeling of the Newport Shores drainage system. The HSPF model previously used in the Coal Creek EIS study served as the basis for hydrologic modeling for this study. The EIS model, which was based on a basin model developed by NHC in 2004, was updated and calibrated for this work.

3.1 HSPF Model Updates

Subbasins delineated for the 2004 modeling remain unchanged through the current study and are shown in Figure 1. Stage-storage-discharge relationships (HSPF FTABLEs) are defined in the model to represent flow routing through detention facilities, pipe systems, and the stream channel network. FTABLEs representing detention facilities are based on information from facility plans; approximate FTABLEs for channel and pipe networks are based on flow length and slope information from GIS. For the current study, the only modification was to the FTABLE representing the I-405 detention pond. NHC modified the stage-discharge relationship for the I-405 pond based on updated HEC-RAS hydraulic modeling. The elevation-volume relationship, from City of Bellevue data, was not changed.

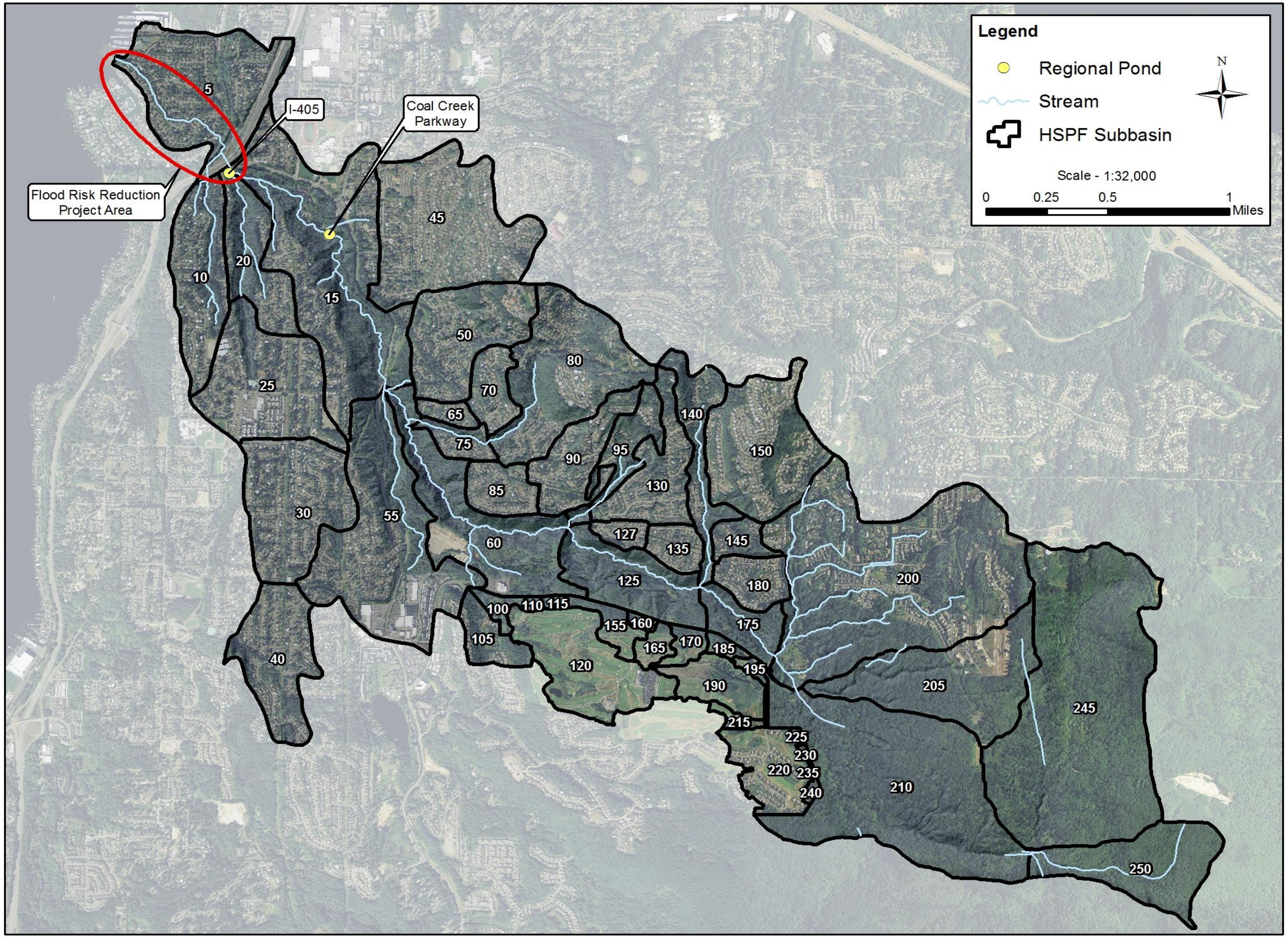

Figure 1. Coal Creek HSPF Model Subbasins

3.2 Model Calibration

NHC initially intended to calibrate the HSPF model to stage and flow records collected by the COB at the I-405 pond and downstream at Newport Key. However, NHC's review of the data provided by the COB showed a number of undocumented shifts in both stage records, apparently related to resetting the gauge level during site visits. Due to the uncertain and inconsistent quality of the COB records, these were not suitable for model calibration. In place of the current COB data, NHC used the flow record from King County's discontinued Coal Creek stream gage (06a) at Newport Key, operated between 2002 and 2005, and direct discharge measurements collected by King County, the USGS, and the COB at the same location between 2002 and 2013.

Initial model simulations produced flows that were consistently high, compared to observed base flows and storm flows. NHC reviewed mean annual precipitation mapping (prepared by the Oregon Climate Service) and compared it to mean annual totals for the two rain gauges used in the model—King County's Lower May Creek (37u) and Cougar Mountain (63y). Based on this comparison, the three precipitation multipliers were adjusted slightly from previous values, resulting in a slight net decrease in rainfall over the basin.

The most significant calibration adjustments were a basinwide reduction in effective impervious area (EIA) and adjustment of HSPF's deep groundwater parameter (DEEPFR), which adjusts the allocation of groundwater to deep or inactive groundwater that is lost from the system. The DEEPFR parameter for till and outwash soils was raised to 50 percent to get a good match to observed base flow volumes.

Storm peaks and volumes remained high after base flow was adjusted. The basinwide EIA fraction in the earlier models was 17 percent, which seemed high for a watershed that is dominated by single family residential land use and has large remaining undeveloped areas. To reduce impervious area contributions, EIA was reduced by 20 percent across the board. The converted EIA was distributed proportionally among the pervious land types in each subbasin. This adjustment significantly improved storm simulations. To better match response to small rainfall events, HSPF impervious land surface (IMPLND) parameters (LSUR and RETSC) were adjusted to attenuate impervious runoff response.

The resulting simulated hydrographs still tend to over-simulate many storm peaks and volumes compared to King County's observed record. However, King County reported that the channel was subject to scour and fill, which necessitated multiple rating curves (David Funke, pers. comm., 2013). This suggests that, while gage records are believed to be good overall, stage-discharge relationship could shift during an event, so storm flows are less reliable than in a static channel situation. For this reason, greater weight was given to the directly measured discharges. The model reproduces measured low flows quite well. Measured discharges during events are reasonably well simulated, though simulated hydrograph recessions tend to be slightly high, i.e. modeled flows are not decreasing as quickly as observed. Observed discharges for the very large December 2007 and moderately large January 2013 events, where discharge measurements were taken near the simulated peaks, are very well simulated. Additional calibration adjustments could likely improve modeling of hydrograph recessions, but were deemed unnecessary for this study based on the intended applications of the model.

Figure 2 compares simulated and observed flows from the calibrated model for selected periods. There is still a tendency for simulated storm flows to be high compared to the King County record, but adjustments to counter this tendency would reduce the large event peaks as well. Since this study is particularly interested in flooding events, better matching of the recent large events was considered more important. One explanation for high event flows could be the limited temporal variability of rainfall in the model. In reality, rainfall over the basin is often not uniform. However, the HSPF model has only two temporal patterns for precipitation (the two input rain gages). Thus, most (if not all) of the model area experiences rainfall—even peak intensities—at the same time in all storm events. This would tend to result in over-simulation of peaks in events where rainfall was more varied (especially common in fall and spring events in this area) and have less impact on events with more uniform rainfall patterns, such as December 2007.

3.3 Key Results

Model calibration generally decreased peak flows and overall flow volumes compared to the EIS model and previous studies. Table 1 compares computed flow frequency quantiles from the two studies for discharge from the I-405 pond, which accounts for most of the flow in lower Coal Creek. The current modeling produces peak flows up to 20 percent less than reported in the EIS study. Note that some of the difference in these values results from a different approach to fitting a flow frequency distribution. The 2006 study used single Log Pearson Type 3 (LP3) curve to fit the data, while the current study fits separate LP3 curves to flows above and below about 300 cfs, where the data clearly indicate a break in the curve due to storage effects from the I-405 pond. The curve derived from the current approach provides a much better fit to the simulated peak flow data (see Figure 3).

Table 1: Flow Frequency Comparison for Coal Creek at I-405

Return Interval	EIS Model Flow (cfs)	Current Model Flow (cfs)	Percent Difference (%)
2-year	274	242	-12
10-year	424	412	-3
25-year	498	455	-9
100-year	607	494	-19

The primary use of the HSPF model in this study was to provide flows for hydraulic, sediment, and drainage analyses. The HSPF model produced flow time series for I-405 pond inflows, the Newport Creek tributary, and local drainage area downstream of I-405 for use as inflows for unsteady HEC-RAS modeling. Peak flows determined from frequency analysis at key locations were also used for steady-state hydraulic modeling and sediment analysis. For drainage modeling, characteristic storm events were selected from the simulated local runoff (tributary area downstream of I-405) timeseries to represent 2-, 10-, 25-, and 100-year local storm events. Events were selected on the basis of flow frequency analysis at multiple durations from 15-minute to 6-hour flows. The selected events were those that most consistently matched the target recurrence interval over the range of durations, with preference to matching peaks at the shorter durations most relevant for conveyance system flooding. Event hydrographs for individual inflow locations in the Newport Keys SWMM model were scaled from the HSPF runoff time series based on tributary area

In addition to providing flow inputs for other modeling and analysis, the existing conditions HSPF model was used to characterize the effectiveness of the existing I-405 pond and outlet structure for flow control. Flood mitigation alternatives included modification of existing facilities to alter magnitude and timing of flows to Coal Creek. As shown in Table 2, the existing pond configuration provides no control of small to moderate storms (up through the two-year event) and modest peak flow reductions for larger storms. Since the current outlet structure provides only minor restriction to pond discharges, relatively little of the available storage is engaged in most events, resulting in minimal flow attenuation through the facility.

Table 2: I-405 Pond Flow Control Effectiveness

Return Interval	I-405 Pond Inflow (cfs)	Existing I-405 Pond Outflow(cfs)	Percent Difference (%)
1.01-year	112	112	0
2-year	226	226	0
5-year	357	347	-3
10-year	421	390	-7
25-year	484	428	-12
50-year	521	449	-14
100-year	552	464	-16
500-year	602	488	-19

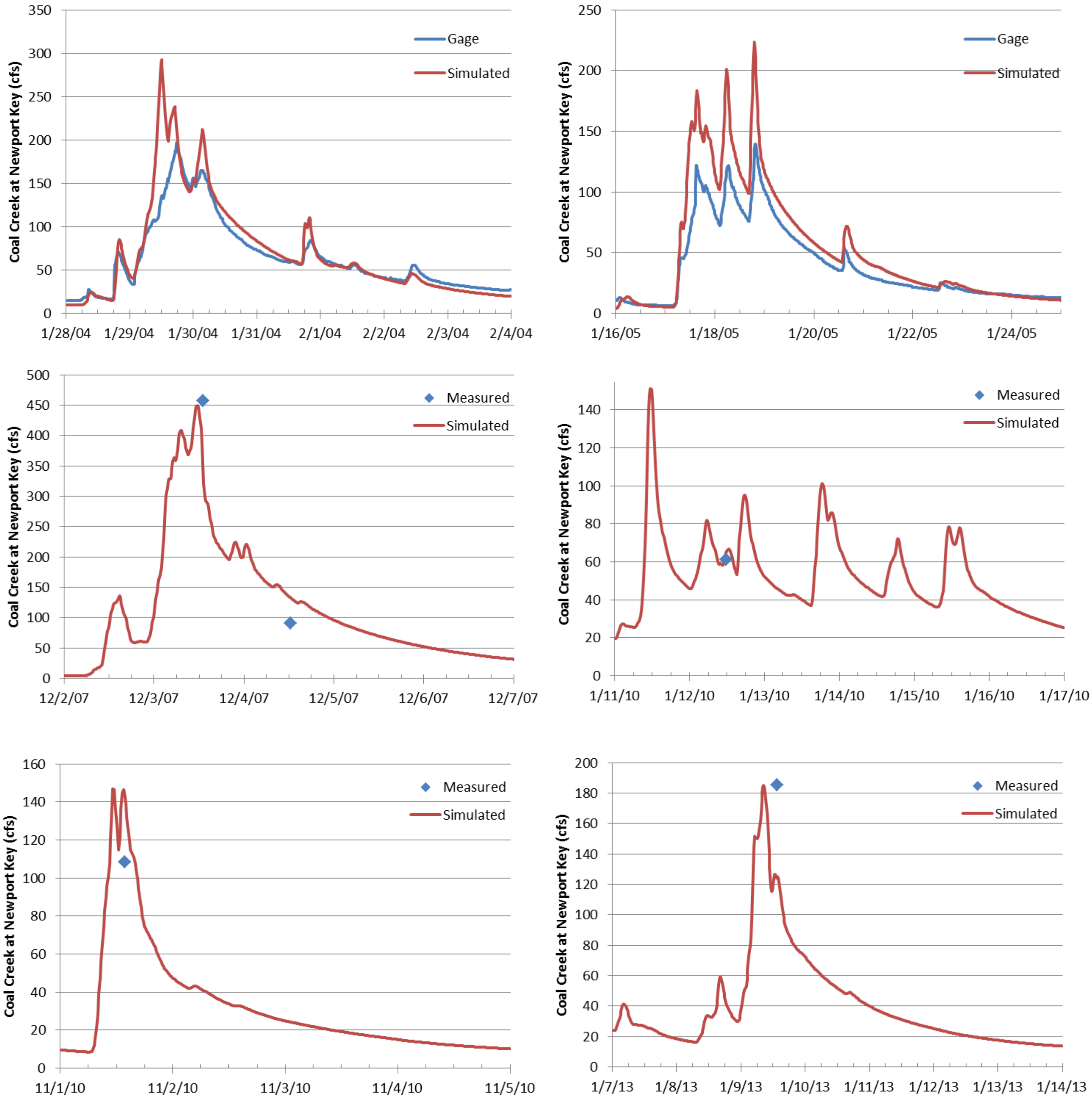

Figure 2. Comparison of HSPF-simulated and observed flows for selected storm events

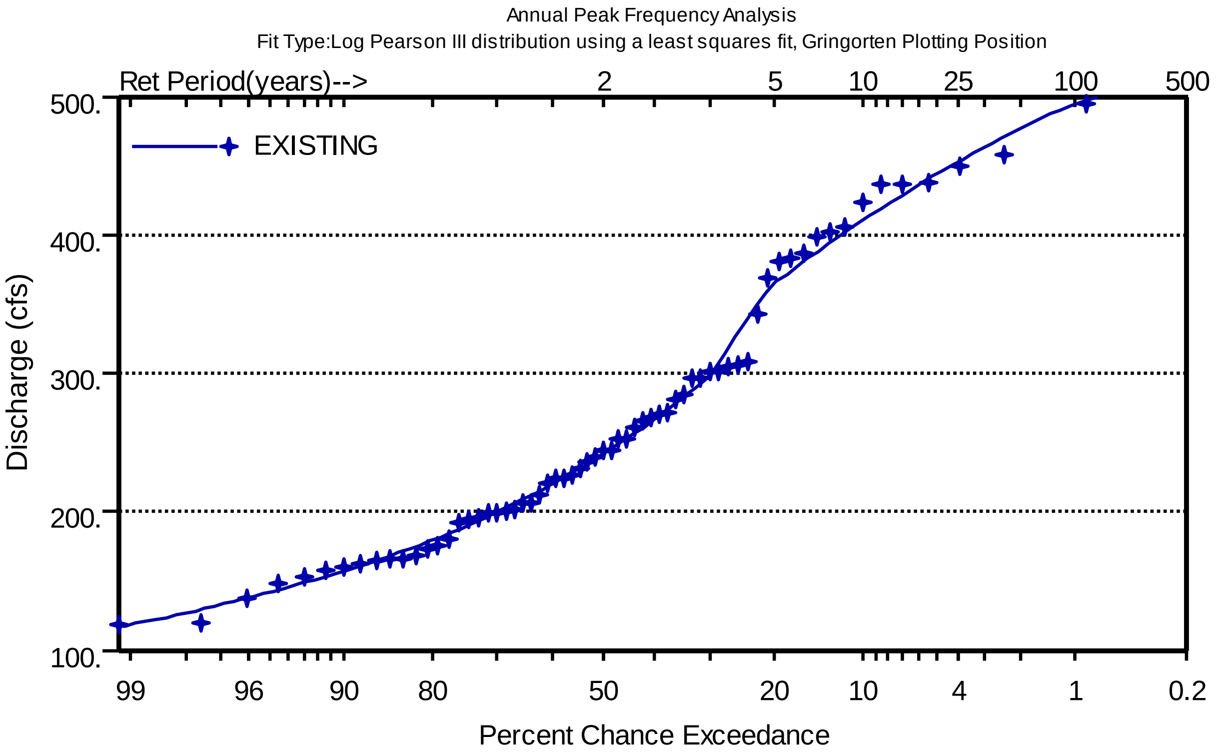

Figure 3. Flow frequency curve for Coal Creek at I-405

4 Stream Hydraulics

There have been multiple occurrences of flooding along Coal Creek in Newport Shores in recent decades. Hydraulic modeling and analysis of current conditions reveals the magnitude and frequency of discharges that are expected to cause flood damages along the creek, and shows the locations at highest risk of flooding. Additionally, it provides a tool to compare existing and past flood risk, as well as to evaluate the flood risk reduction effectiveness of alternative future projects.

NHC has utilized field observations, the City of Bellevue drainage complaints database and a stream hydraulics model for Coal Creek to detail existing conditions and their impact. The model makes predictive estimates of water surface elevation at various flows, supports analysis of the interaction of the stream with the stormwater system, and evaluates the effectiveness of potential creek flooding alternatives. The drainage complaint database was used as a check on the hydraulic model and to evaluate changes in flooding over time. Analysis was informed by the hydrologic modeling and sediment analysis described in Section 3 and Section 5 and integrated with drainage analysis in Section 6.

4.1.1 Hydraulic Modeling

4.1.1.1 *RAS model set-up and geometry*

A one-dimensional HEC-RAS steady state model was used to simulate existing conditions in Coal Creek. The model extends from the I-405 sediment detention pond to Lake Washington. The I-405 pond was represented in the HEC-RAS model with geometry and cross sections using LiDAR from the Puget Sound LiDAR consortium. The control structure representation used City of Bellevue as-built plans and survey elevations. Channel cross sections along Coal Creek from I-405 to Skagit Key were developed using COB channel survey data merged with an overbank digital elevation model. The COB survey also included culvert information, which was augmented with NHC field inspections and measurements. The channel below Lower Skagit Key was not surveyed; here data from the previous 2004 HEC-RAS model was used. Channel roughness was set based on field observations.

The Lake Washington water surface elevation used for the lower boundary conditions was set to 17.25 feet NAV88, a typical winter elevation. Model sensitivity testing indicates that changes in lake level within normal operating limits do not propagate upstream beyond the lower Skagit Key crossing.

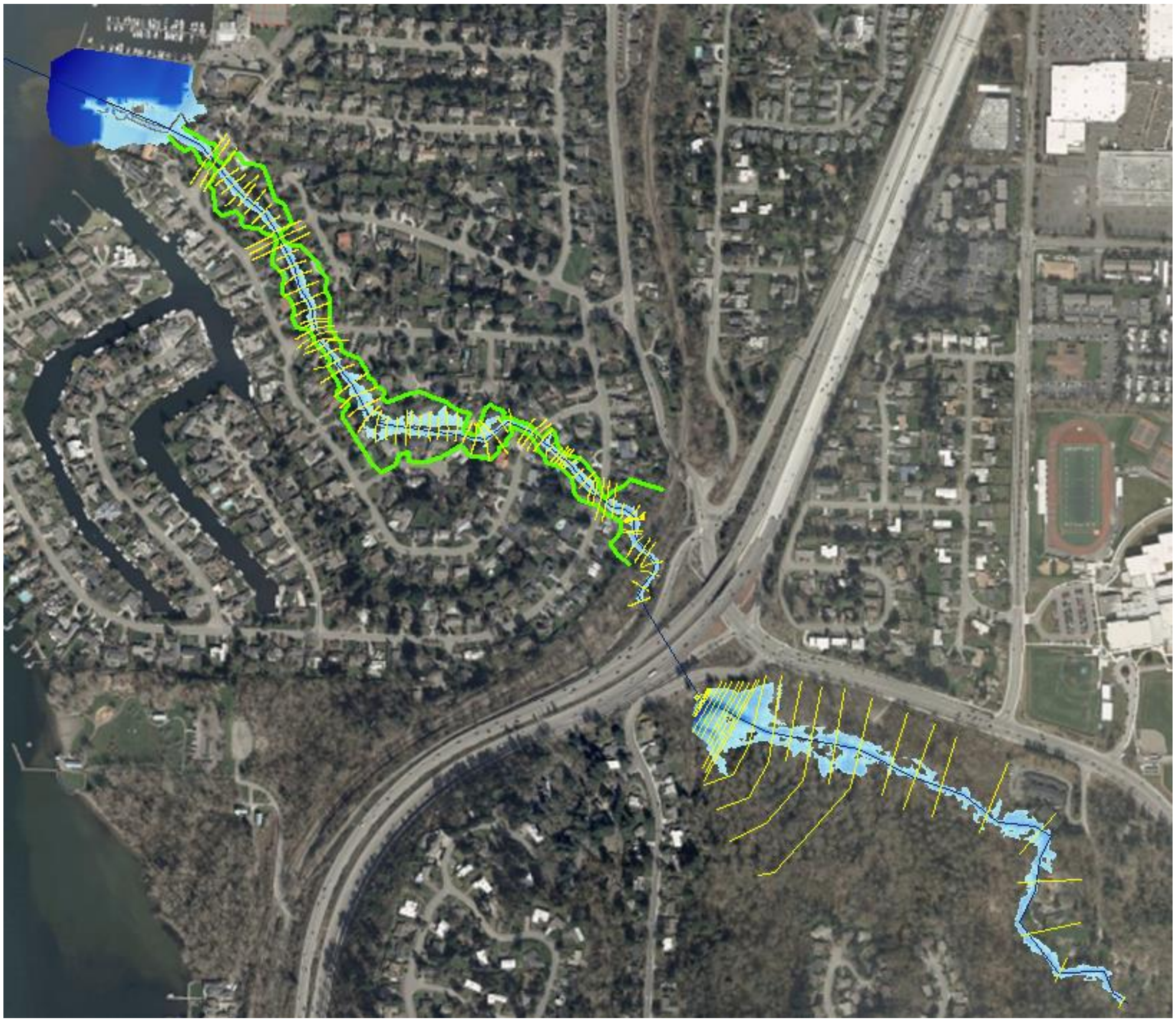

Figure 4. HEC-RAS Model Structure (Cross section lines are shown in yellow, green shows the spill line of water not returning to Coal Creek. Water level extent for the 2007 event is shown in blue, along with the stream centerline.)

4.1.1.2 *I-405 pond rating curve*

The hydraulic behavior of the existing detention pond at Interstate 405 was investigated in order to understand its current effectiveness, estimate downstream flows, and evaluate its potential for retrofit. Pond outflow is through a complex structure with multi-stage control elements. A HEC-RAS derived rating curve was established for the City of Bellevue by Entranco in the 2004. While the rating curve itself was available, the model was not. NHC developed a new pond rating curve based on HEC-RAS simulation results. The structure geometry used in the model was based on as-built plans. The curve was calibrated to water level photos, gage records and manual discharge measurements taken during the 2007 and 2010 floods. Culvert roughness values were set based on the most recent hydraulics literature for baffled culverts. Proper accounting for culvert roughness was important because over a certain range of flows, the culvert rather than the control structure controls the head discharge relationship of the I-405 pond. Figure 5 shows the 2004 rating curve and the updated curve used in this project. The various flood stage and discharge measurements noted in the figure enabled the development of calibration targets – these are shown as boxes and lines due to some uncertainty in each type of data source. Both the pond rating curve (blue) and structure bay rating curve (red) are shown and compared with high water observations. Also shown is the 2004 preferred rating curve (solid green) which was developed in HEC-RAS by estimating the roughness effect of the culvert baffles with a higher Manning n value of 0.035. In comparison, another approach taken in 2004 to represent the effect of the baffles was to partially block the culvert (dashed green line). This curve is more similar to the ones developed using observed data for this project. Note that all of the rating curves are similar up to a flow of about 300 cfs; above this flow the new rating curves are significantly higher than the preferred 2004 curve. The calibration data and the recent research on baffled culverts enabled the construction of the new and more accurate curve with a high degree of confidence.

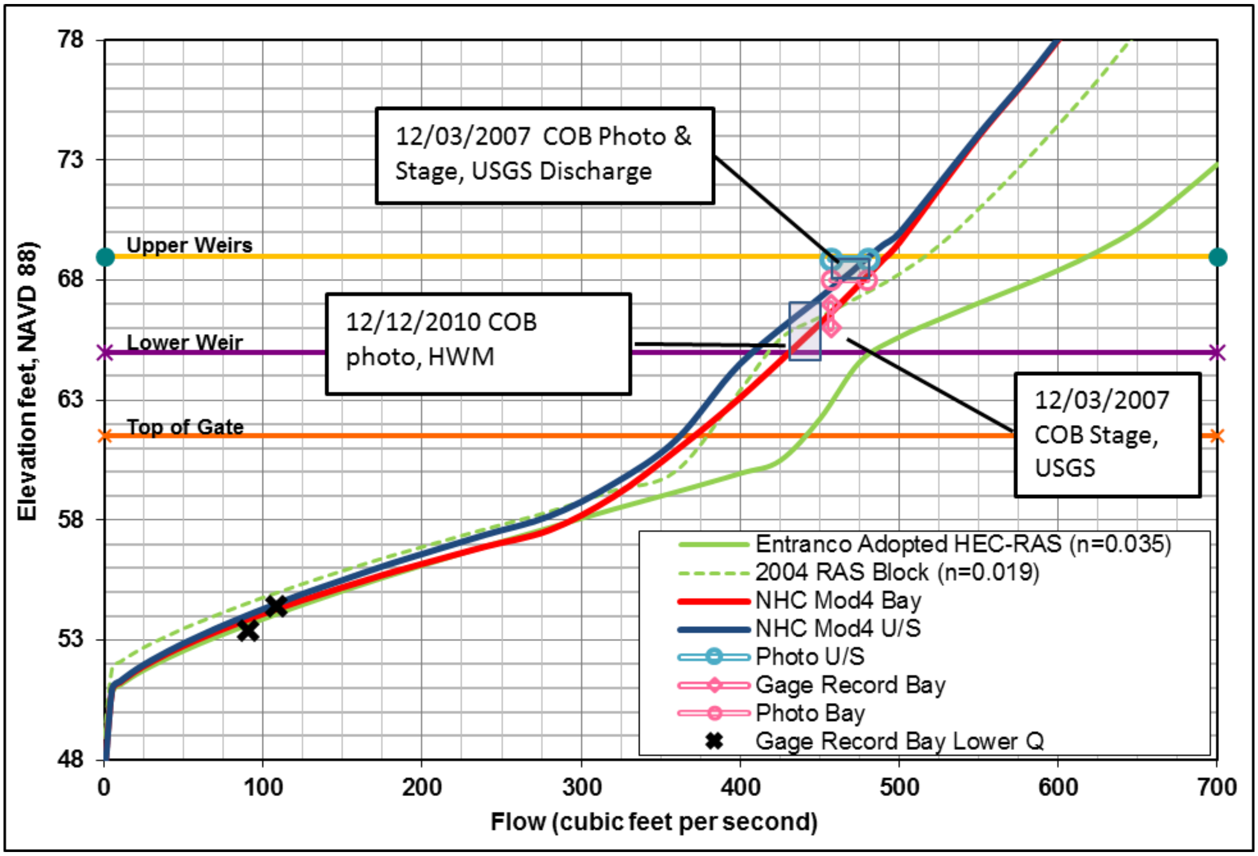

Figure 5. I-405 Pond Rating Curves

4.1.1.3 *Flow Data*

An HSPF model of the study reach's contributing basin was updated and rerun to compare with observed flows and provide flow frequencies for HEC-RAS. HSPF then provided a range of flows for use in the hydraulic model. HEC-RAS was run in steady state up to the 500 year return interval. Additionally, flows measured during documented flooding events and low flow periods were also considered for model calibration. These flows were chosen based on availability of high water marks, accuracy of the flow estimate and the range of flow. Three high flow events and one low flow event were used for water surface profile calibration, see Table 3. Using flows that correspond to a range of return intervals (1.4 – 125 year return interval) ensured that the model performs well over a wide range of conditions.

Table 3: Calibration Flow Events

Date	Flow Simulated (cfs)	Recurrence Interval (yrs)	Source	Notes
1996	450	80 year	Unknown	
2007	457	90-125 year	USGS	NHC estimated range of flow 457-480 cfs based on I-405 pond rating curve analysis
2010	440	25-50 year	NHC	NHC estimated range of flow 420-440 cfs based on I-405 pond rating curve analysis
2013	180	1.4 year	NHC	Direct Discharge Measurement at Glacier Key

4.1.1.4 *Calibration*

The final existing conditions HEC-RAS model was calibrated using the four flood events described above using three key parameters: channel and overbank roughness, culvert geometry and culvert sediment scour. Adjustment of the parameters within realistic limits was performed until simulated water surface profiles best matched observed high water marks and stage records.

4.1.1.4.1 *Channel and Overbank Roughness*

Field observations were taken along the length of the Coal Creek study reach and included information on locations of sediment sampling, bank instabilities and armoring, and current vegetation encroachment into the channel (Figure 6). Sediment sampling along the creek in the study area showed fairly uniform sediment sizes; this information was used for estimation of channel bed roughness. Vegetative encroachment is most prominent in three locations: Cascade to upper Skagit Key, Newport to lower Skagit Key, and downstream of upper Skagit Key. Several channel locations had overhanging logs and other vegetation that formed significant impediments to flow; bed roughness values were set higher at these cross sections to represent the average effect of encroachment within a reach. Overbank roughness was set based on bank armoring (such as riprap, crib walls, and bank protection) and vegetation type.

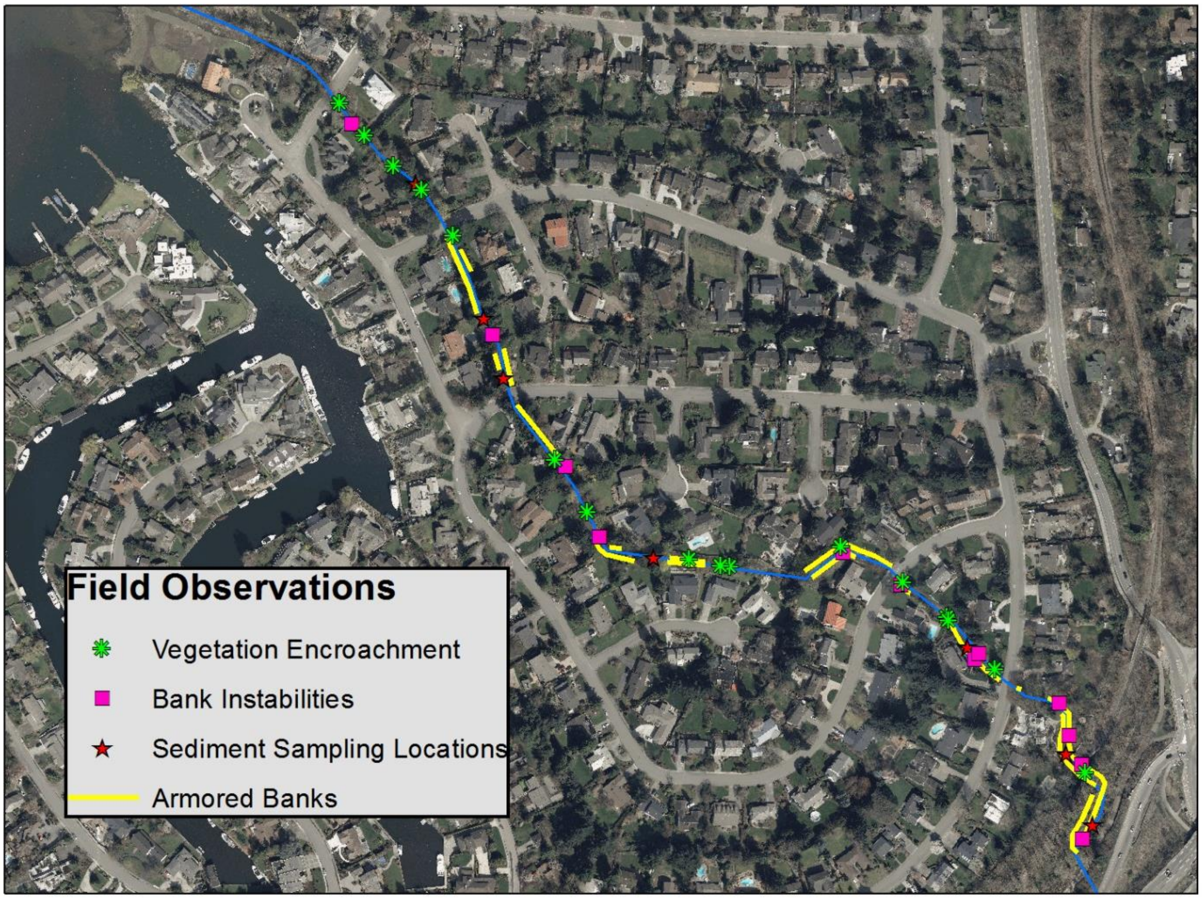

Figure 6. Summary of Field Observations

4.1.1.4.2 *Culvert Sediment Scour*

Culvert bed sediment scour assumptions were required in order to match modeled water surface elevations with observed water surface levels. During high flow events full bed scour in the lower three culverts (Glacier Key, Newport Key, and Lower Skagit Key) was assumed (the upper culverts do not contain any sediment). This is the same assumption required for calibration in previous modeling studies on Coal Creek. During simulations of the 2007 flooding event, if no culvert scour was assumed, modeling results predicted flood levels that were much higher than the observed high water marks measured after that event. These levels would have resulted in extensive roadway overtopping with localized flooding which did not occur during that storm event.

The "full scour assumption" was tested and validated by burying scour chains in the stream channel at Newport Key and lower Skagit Key. After a flow event of approximately 180 cfs, which frequently occurs, approximately 3.5 inches of scour was observed at Newport Key and approximately 2 inches of scour at lower Skagit Key. Within the hydraulic model, culverts were modeled as 'full' and 'scoured' with the velocity of flow through the culvert compared with critical velocity necessary for sediment movement. The threshold for significant scour was found to be between 160-280 cfs between Glacier and lower Skagit Key. This is consistent with the observed scour measurements and supports the assumption of full scour at higher flows.

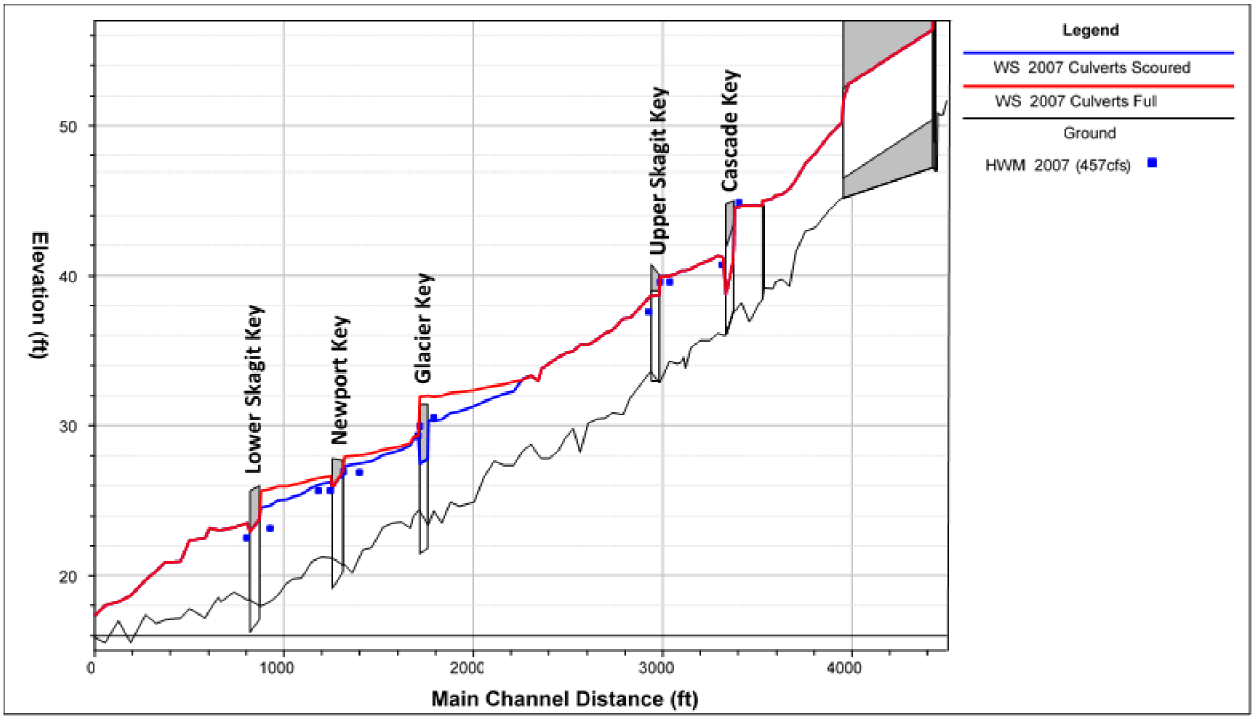

Figure 7. Effects of sediment scour assumptions on water surface profiles

4.1.1.4.3 *Culvert Geometry*

Representation of culvert geometry in HEC-RAS assumes a constant cross section, but the Cascade Key culvert was found to be taller at the downstream end than upstream end. In addition, there is no explicit way to add the hanging utilities that partially block the upper three culvert barrels. Culvert geometry, roughness and loss coefficients were modified to represent these factors and match observed high water marks.

4.1.1.4.4 *Calibration Results*

Calibrated water surface profiles are shown in Figure 8. Calibration was generally considered good except in the vicinity of the Lower Skagit Key crossing. Here the model over-simulates maximum water surface elevations. This is believed to be due to changes in the channel downstream that have increased conveyance capacity as opposed to poor representation of the culvert since the over-simulation occurs on both sides of the crossing. The model downstream of Skagit Key uses 2004 data, which implies that conveyance capacity between the road and the lake may have increased since that time. A summary of the high water mark accuracy is shown Figure 9. The average error for all events is less the 0.5 feet. The 1996 event has a small HWM dataset but simulates well using the 2013 model geometry and the reported flow of 450 cfs. Assuming the flow estimate is accurate (its source and methods are unknown), the good calibration implies similar conditions to the present existed in 1996.

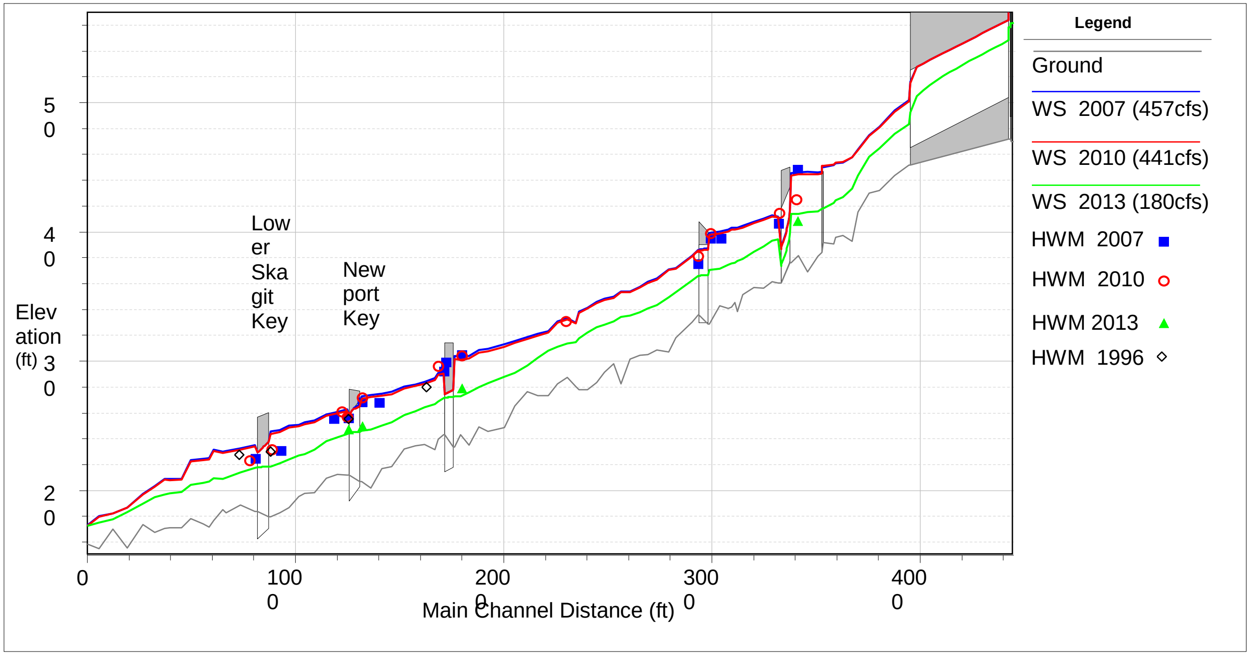

Figure 8. Observed High Water Marks and Calibration Water Surface Profiles

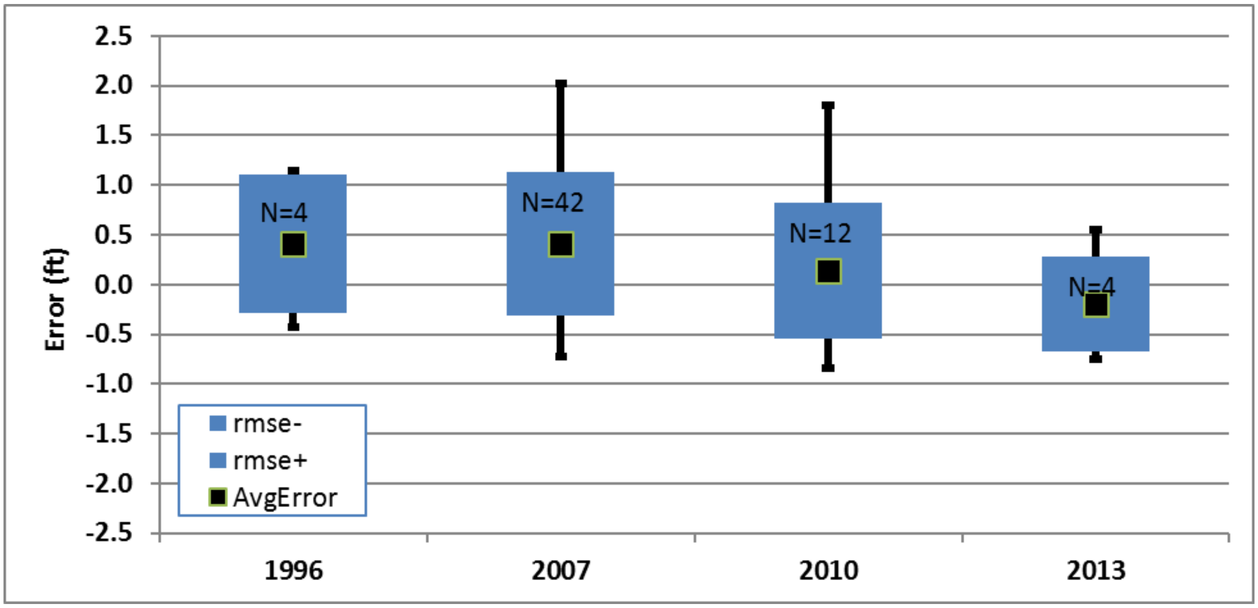

Figure 9. Calibration Accuracy

4.1.2 Existing Conditions

4.1.2.1 *Flooding Extents*

Predicted extents of flooding for the 2007 flood (25-35 year event) are shown Figure 4 and Figure 13. The 'spill lines' referred to in the figures indicate the topographic divide where floodwaters would flow away from the stream and through the community should they extend beyond the line. The figures show that even during the large 2007 event most of the flooding is predicted to remain well within the spill line limits. Flooding extents are closer to the spill lines in the upper reaches of the creek, and closest at the road crossings, where any road overtopping will tend to funnel flow down the roads away from the creek, as happened in 2007 at Cascade Key. The limited extents of flooding help to focus the development of alternatives on reducing flood risk for homes immediately adjacent to the stream and the road crossing; homes farther away are not at high risk of overland flow from the stream causing damages. It should be noted this conclusion only applies to stream-related flooding; flooding due to stormwater related problems can occur some distance from the stream and is described in Section 6.1.

4.1.2.2 *Effects of Culverts on Flood Levels*

Culverts in Newport Shores are undersized based on City of Bellevue conveyance standards. Their effect on stream flooding was investigated by removing them from the model (equivalent to replacement with larger culverts that do not cause any impact) and running the 2007 flood with a flow of 457 cfs. The results show all culverts cause upstream backwatering, the largest impact being over two feet at Cascade Key (Figure 10). This backwater effect results in an increased risk of road, yard and home flooding and these effects extend over most Coal Creek's length within Newport Shores.

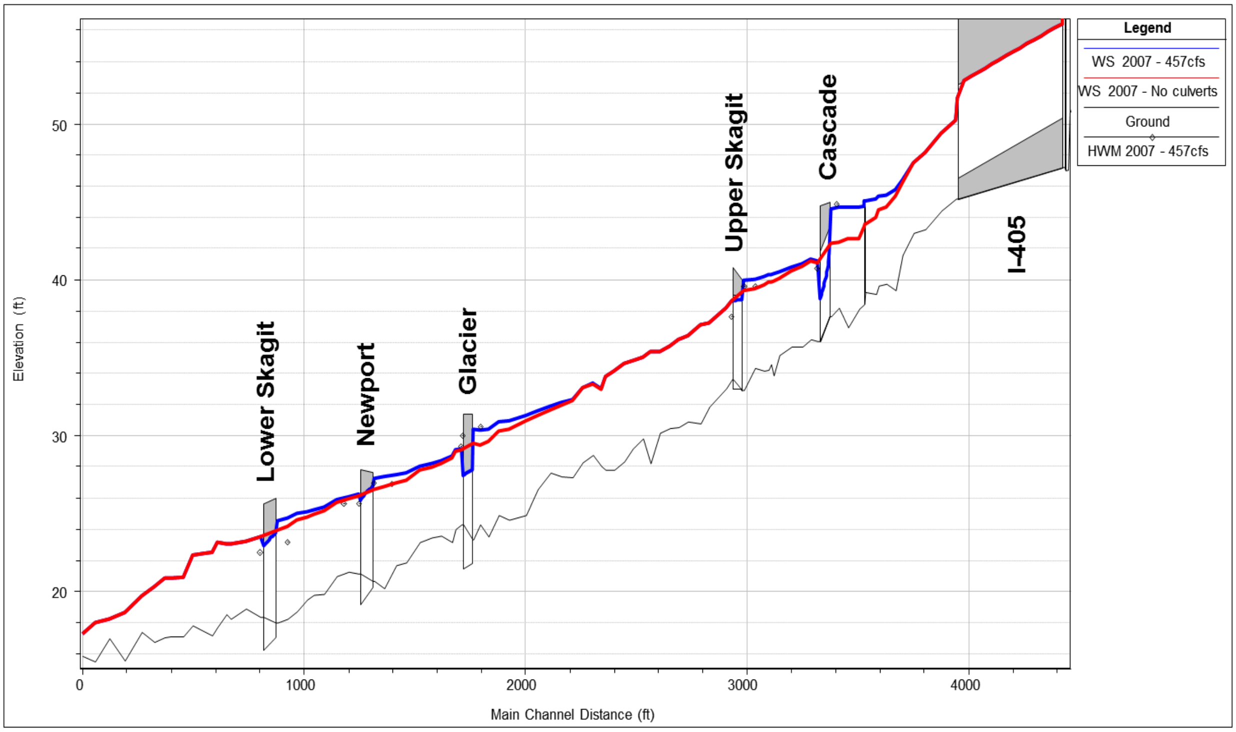

Figure 10. Backwater effects of culverts

4.1.2.3 *Effects of Vegetation and Debris on Flood Levels*

The effect of vegetation on flood levels was investigated through sensitivity testing of the model using the same 2007 flood of 457 cfs. Global changes to bank and bed roughness of plus and minus 20% from the calibrated values simulated to represent potential vegetation changes. This spans a range of potential channel bank conditions from thickly vegetated brushy banks to grassy banks. The test was somewhat conservative in that bed roughness was also changed, although that is controlled by sediment size which would not be expected to change with different vegetation on the banks. Changes to water surface elevations were relatively small for the range of roughness tested. As shown in Figure 11, a 20% increase (or decrease) in channel n-value results in an average increase (or decrease) change in water surface elevation of 0.3 feet. The reason for the this rather modest shift in elevation is that Coal Creek in Newport Shores is a relatively steep stream which makes it less sensitive to changes in n-value than a stream of lower gradient.

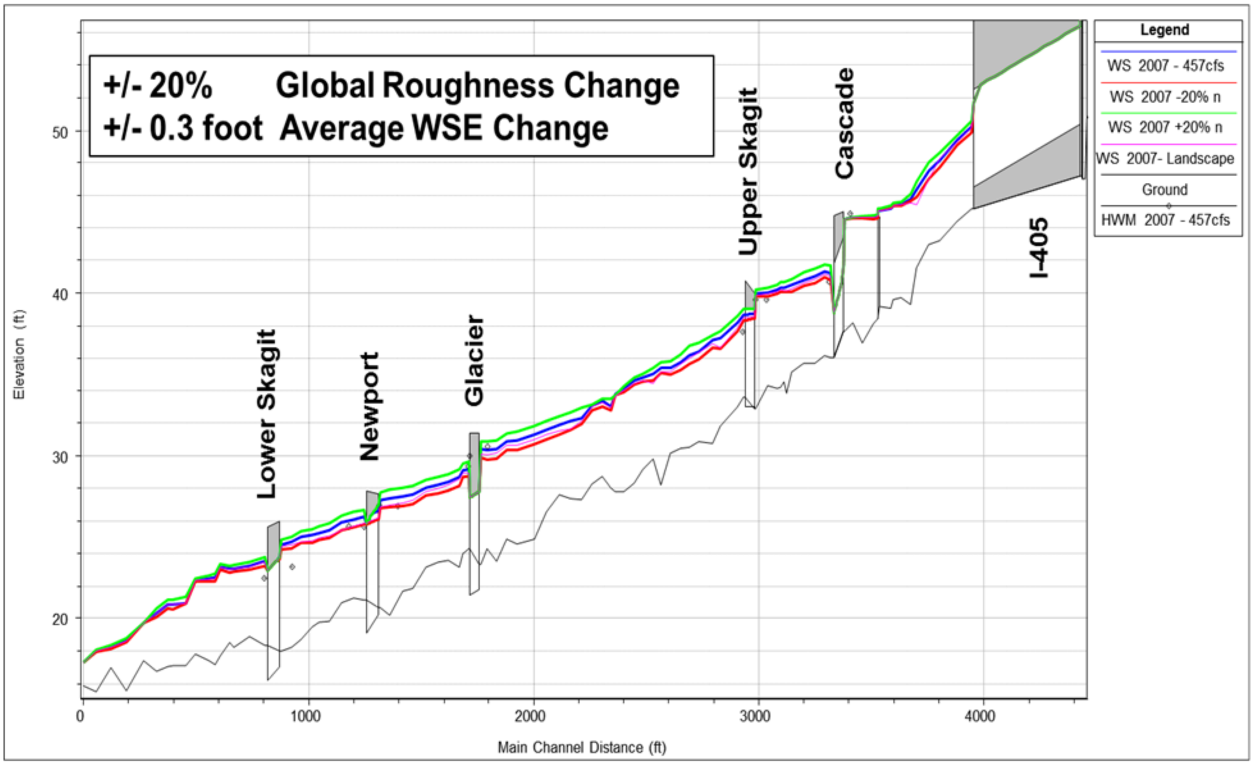

Figure 11. Effects of vegetation on flood level

Figure 12. Example of localized vegetation issue

It must be noted that the application of the HEC-RAS model only tests the sensitivity of flood levels to vegetation roughness that is evenly distributed on the bed and banks along the creek. While the results indicate that reach-scale effects of vegetation on flood levels appear to be minor, field observations identified multiple locations where individual trees were likely to partially block and impede flood flows. These are mapped in Figure 6 and an example is shown in Figure 12. Localized impacts (extending over one to two properties) are possible at these locations, including racking of debris from upstream, higher local flood levels, streambed scour, and bank undermining.

4.1.2.4 *Debris Risk*

The effects of debris on flood levels was not modeled but there is a potential to exacerbate flood damages when debris blockages occur. This happened in the 2007 flood when a log jammed the entrance of the Cascade Key culvert and resulted in floodwaters overtopping the roadway. Based on the field reconnaissance and past history, debris risk is highest at this location. Another high risk site is located upstream of Cascade Key at where remnant piers protrude from the channel bed under the railroad trestle. These piers form an effective debris trap that backs up water several feet high. Partial or complete release of this debris could lead to culvert blockage. The Cascade Key culvert is unique in that there are a series of parallel utility conduits overhanging the culvert mouth which are judged to further increase the risk of debris accumulation. Debris that passes the Cascade Key culvert or is generated from the banks downstream can also rack up at sites overhanging logs or at culverts further downstream. Debris blockage could also reduce the sediment scouring the culverts rely on for conveyance.

4.1.2.5 *Culvert Risk Ranking*

The five Coal Creek culverts in Newport Shores were ranked for risk based on a set of factors from the hydraulic modeling and field inspections. The risk ranking and criteria definitions are shown in Table 4; these factors may also be used in prioritizing potential culvert replacements.

Table 4: Culvert Risk Ranking

Location (upstream to downstream)	Free-board (ft)	Back-water Effect (ft)	Sensitivity to Flow (ft)	Sensitivity to Sediment (ft)	Comment	Rank
Cascade	0.6	2.2	0.4	0	Debris/Hanging Utilities/Large Backwater	1
Upper Skagit	0.7	0.7	0.3	0	Least Sensitive/clear of sediment	4
Glacier	0.5	0.9	0.5	1.6	Depends on sediment flushing/pressure flow/low freeboard	2
Newport	0.3	0.7	0.4	0.7	Lowest freeboard/depends on sediment flushing	3
Lower Skagit	2.7	0.6	0.4	1.2	Good freeboard/culvert crushed	5
Criteria Definitions:						
Freeboard: Distance in feet between 50-year water surface elevation and roadway.						
Backwater Effect: Increase in 50-year flood level upstream of culvert due to being undersized.						
Flow Sensitivity: Change in water level between a 20-year and 90-year flood. Higher sensitivity indicates higher risk of road flooding.						
Sediment Sensitivity: Change in 50-year water level if culverts do not fully scour sediment from bed.						

4.1.2.6 *Trends in Stream-Related Drainage Complaints*

The City of Bellevue provided NHC with a drainage complaint database starting in 1986, and continuing to the present day. The database provided a method to check model results against complaints from residents related to flooding. NHC catalogued drainage complaints, ranked their severity based on comments that detail flood damage and sorted them based on flooding event. Figure 13A summarizes the complaints plotted on the maximum monthly flow record from the HSPF model. Drainage complaint locations, severity and date are shown in Figure 13B. The number of complaints has decreased in both severity and number over time. Multiple creek flows in excess of levels that generated many complaints during the 1980s and early 1990s have occurred since that period, but have not generated nearly as many complaints. One potential explanation is the initiation of upstream sediment removal activities by the COB in 1994. This, along with extensive sediment source control work, has resulted in streambed lowering since the mid-1990s, (Figure 17) which would tend to increase channel conveyance locations in the 1990s and has addressed some of the other chronic roadway flooding areas with small scale projects. It is likely the net effect of these actions has resulted in the reduction in complaints. COB operations staff also indicated that numerous homeowners installed sump pumps and other individual projects such as floodwalls to reduce flooding. The COB constructed some berms in key locations in key locations in the 1990s and has addressed some of the other chronic roadway flooding areas with small scale projects. It is likely that the net effect of these actions has resulted in the reduction in complaints.

4.1.3 Existing Level of Service

The existing level of service for the road crossings of Coal Creek in Newport Shores is estimated at a 50- to 100- year flood event (440-460 cubic feet per second). This current system capacity assumes unobstructed and self-scouring culverts. Without the I-405 detention pond facility, the existing system would have only a 10- to 25-year event capacity.

4.1.4 Summary of Existing Conditions Findings

- Culverts are undersized by current city and state standards for conveyance and fish passage. This creates backwater effects over most of the reach. Debris entrapment risk is exacerbated by hanging utilities and relatively small culvert size. Freeboard is inadequate at all but the Lower Skagit Key culvert. Ideally, freeboard at each culvert is 1.0’. The lower three culverts depend on sediment flushing for conveyance, which is an uncertain process that should not be relied upon.

- Culverts can be ranked by risk. Cascade Key has the highest risk: it has the largest backwater, hanging utilities, an upstream debris source (located at the wooden trestle), a history of debris problems, and road flooding. Glacier Key ranks second: it depends on sediment flushing during floods, and has low freeboard. Newport Key, Upper Skagit Key, and Lower Skagit Key occupy the lowest three rankings.

- Assuming no partial blockages and scoured barrels at culverts, flood flows are generally confined within and adjacent to the stream corridor: there is little spillover or uncontained flow risk in most of reach. The degree of confinement increases in the downstream reaches. The greatest spillover risk occurs at the road crossings.

- Flood levels are not very sensitive to bank vegetation on a reachwide scale; however, there are localized areas where vegetation may cause local scour, backwater effects, and streambed aggradation.

- Stream-related drainage complaints have decreased in severity and number since 1990. Recent complaints tend to be focused near the upper end of the study area. The 2007 and 2010 flows were very large, but few complaints were on record in the COB's database. This reduction in complaints during more recent high flows is attributed to upstream sediment management, construction of berms and individual homeowner actions such as sump pump installations.

- The existing system provides around a 50-100 year conveyance capacity; however, this depends on no debris blockage and full sediment scouring. There is insufficient freeboard to provide a safety factor against debris blockage or failure to fully scour sediment, which could lead to roadway flooding at lesser flows. The system can be thought of as lacking the resilience or factor of safety current engineering standards would seek to maintain the existing level of service even with debris.

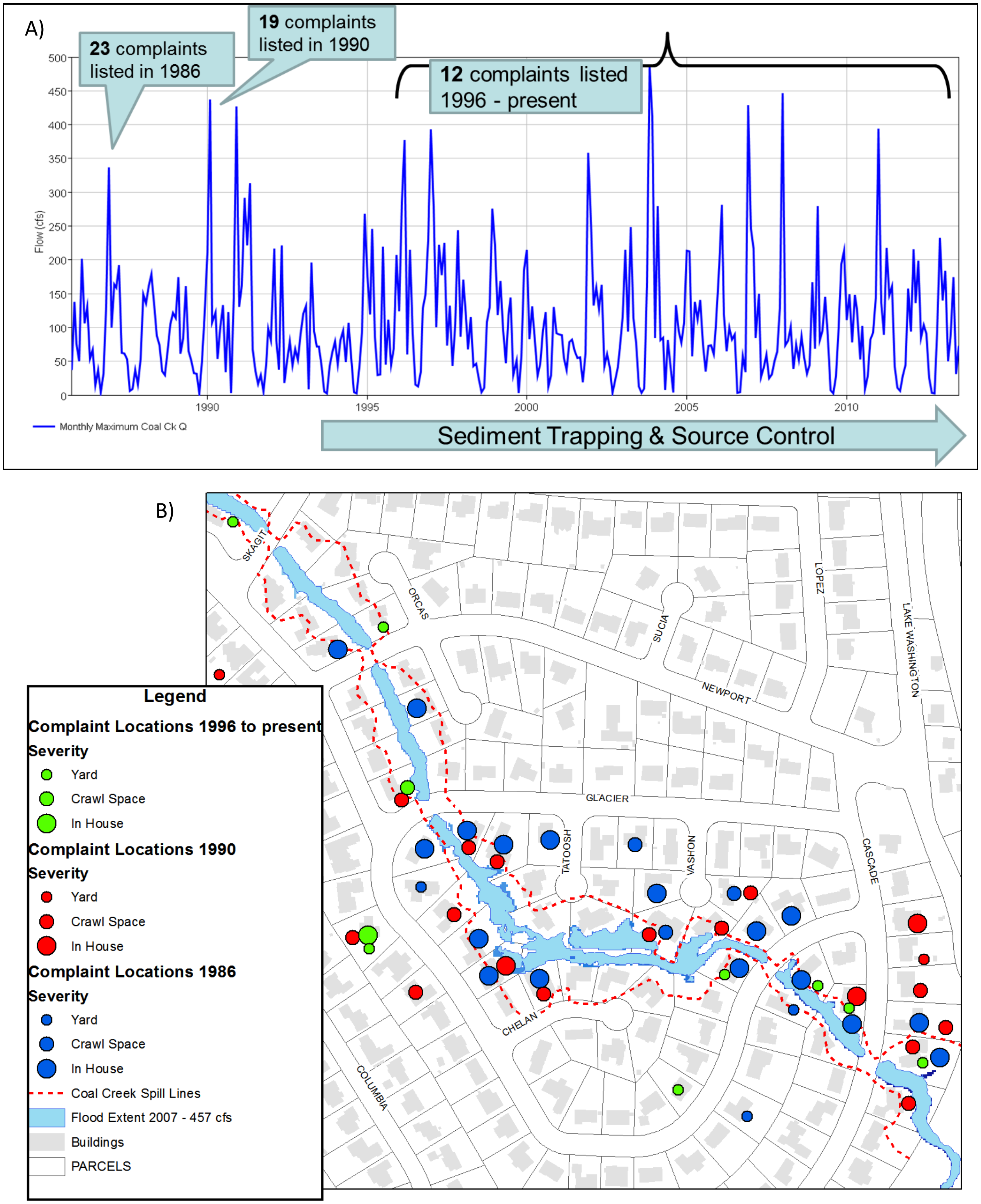

Figure 13. Flood history and trends in stream flooding related drainage complaints

5 Sedimentation Analysis

Sedimentation on Coal Creek has long been recognized as a factor contributing to flooding within the Newport Shores Community (CCBP, 1987). To address this issue the COB and King County have implemented upstream sediment management measures consisting of multiple slope and channel stabilization projects, as well as the construction and maintenance of three sediment collection facilities (Tetra Tech, 2006). However, since being implemented, the impact of sediment management on the lower Coal Creek system has not been assessed or fully understood.

The analysis considers past and existing sediment loading, patterns, and transport with the ultimate goal of determining the influence of sedimentation on flood risk within the Newport Shores Community. Furthermore, an understanding of the current sediment regime informs the selection of possible future flood alleviation measures. Historic channel survey data, maintenance records, field data collection, and current hydraulic modeling are utilized. Methods, analysis, and conclusions are presented in the following sections.

5.1 Methods and Data

Sedimentation processes and patterns on lower Coal Creek were evaluated from the reach to local scale utilizing a combination of historic and recently collected data. Reach scale processes considered both sediment loading from upstream of I-405, and downstream patterns of sediment deposition and erosion within the Newport Shores Community. Reach analyses primarily relied upon historic data; although, recently collected field data were also used. At the local scale, bed mobility and culvert scour were evaluated using collected field data and hydraulic modeling (see Section 4.1.1). The following sections describe the methods and data used to perform the sedimentation analyses at both the reach and local scales.

5.1.1 Reach Scale Sedimentation

Sediment loading into the Newport Shores Community was evaluated using sedimentation pond maintenance records provided by the COB as discussed and documented in Appendix A, Sections A.6 and A.7. These records provide annual accounts of sediment volumes removed from the I-405, Anna's Pond, and the Coal Creek Parkway facilities from 1995 to 2013. Records were compared with previously estimated sediment loading rates and used to evaluate the long term effect of sediment removals on downstream channel aggradation within the Newport Shores Community.

Sedimentation within the Newport Shores Community was evaluated using the channel centerline profile data discussed in Appendix A. The COB surveyed the reach from Lake Washington to upstream of Cascade Key seven times between 1985 and 2013. Comparison between successive profiles indicates regions of bed level change through processes of sediment deposition and erosion. Volumetric estimates of net sediment erosion or deposition between successive profiles were then calculated by multiplying the measured change in bed level by channel bottom width and the distance between survey points. Channel bottom widths were estimated based on sub-reach averaged values, with sub-reaches defined by culvert crossings.

Existing reach conditions were directly observed through a field assessment conducted by NHC during the summer of 2013. A stream walk was performed, extending from I-405 to the lower Skagit Key crossing, to characterize overall channel condition, inventory bank stability, and assess the encroachment by vegetation into the channel. Seven sediment samples were also collected to characterize the variation of surface sediment composition along the reach. A pebble count sampling methodology was employed that consisted of measuring approximately 100 particles randomly in selected areas. In general, samples were collected on riffle crests to be consistent between sites. Furthermore, samples were collected away from road crossings to minimize possible backwater influences on surface sediment composition.

5.1.2 Local Scale Sedimentation

At the local scale, the analysis was conducted primarily to understand how scour and sediment transport at existing culvert crossings affect conveyance and flood capacity. The three downstream culvert crossings in the Newport Shores Community (Glacier, Newport, and lower Skagit) all contain sediment deposits within the barrels of the structures; the two upstream culvert crossings (Cascade and upper Skagit) are predominantly clear with exposed concrete bottoms. Calibration of a previously developed hydraulic model to observed high water marks indicated that scour of the lower three culvert occurred during high flow events (NHC, 1996). However, this modeling result was never verified. To provide verification as well as data on typical scours depths, two scour chains were installed at the upstream faces of Newport Key and lower Skagit Key. Figure 14 shows a diagram of a typical scour chain apparatus and installation. The scour chain apparatus generally consist of a long thin cable attached to an anchor, with buoyant balls threaded onto the cable. Installation involves placing the apparatus into a metal pipe, driving the pipe and apparatus into the streambed, then removing the pipe leaving the anchor, cable, and balls buried within the substrate. When competent flows and scour occurs, the balls are exposed and slide up the tag end of the cable. Depth of scour is then estimated by summing the number of balls exposed and multiplying by their diameter. The scour chains were installed on December 28, 2012, and used to monitor scour during a single moderate flow event that occurred in early January 2013.

5.2 Analysis

5.2.1 Upstream Sediment Loading

Figure 15 plots the volumes of material removed from sedimentation ponds annually at the three facilities along Coal Creek. Beginning in 1995, 400 cubic yards of sediment was removed from the I-405 facility immediately upstream of the Newport Shores Community. In 1997, the Coal Creek Parkway facility, located 1.3 miles upstream of I-405, came online. The first year of substantial sediment removal occurred in 1999, with removal of sediment from both ponds totaling approximately 2,480 cubic yards. In the following two years, no sediment removals were performed presumably because of little hydrologic activity and sediment deposition within the ponds. From 2002 to 2013, annual removal resumed with between 500 and 3,600 cubic yards excavated each year. During this period, in 2011, an additional offline sediment trapping facility known as Anna's Pond was constructed 0.5 miles upstream of I-405. On average, between 1995 and 2013, approximately 1,600 cubic yards of sediment was removed annually from Coal Creek. To put this volume in perspective, 1,600 cubic yards is nearly half the estimated annual load of 3,600 cubic yards delivered to the Coal Creek delta in Lake Washington (CCBP, 1987). A reduction of this magnitude is likely to have perceptible impacts to downstream sediment deposition within the Newport Shores Community.

Considering the episodic nature of sediment transport and limits on travel distance, it can be expected that impacts of upstream removal would take time to become perceptible downstream. Removal of sediment at the I-405 facility would likely have an immediate impact on delivery of material into the Newport Shores Community, but impacts from removals at the Coal Creek Parkway and Anna's Pond facilities, both located further upstream, would take time to have an influence in the project reach. This time delay can be estimated using sediment travel distance relationships developed for gravel bedded streams. For example, Beechie (2001) estimates a sediment particle's travel distance during a given year as approximately 20 times the bankfull width. Assuming a bankfull channel width, between Coal Creek Parkway and I-405, of 30 feet, an estimate of travel distance would be 600 feet per year. This suggests that it would take 12 to 13 years for the influence of sediment removals at the Coal Creek Parkway to Reach Newport Shores. Considering that the Coal Creek Parkway facility has been operating for 18 years as of the end of 2014, it is reasonable to believe it is currently reducing the volume of sediment delivered to the I-405 pond as well as downstream in Newport Shores. The comparable lag time for Anna's Pond is approximately 5 years and it has been in operation for only 3 years as of the end of 2014.

5.2.2 Channel Profiles

Figure 16 compares longitudinal profiles of channel centerline elevations along lower Coal Creek within the Newport Shores Community. The earliest profile was obtained from the original 1977 FEMA Flood Insurance Study (FIS) and provides a reasonable estimate of the lower Coal Creek bed shortly after final construction in the mid-1970s. However, it should be noted that FEMA profiles typically report thalweg elevations, rather than channel centerline. In addition, three of the seven profiles surveyed by the COB between 1985 and 2013 are shown (February 1987, March 2000, and August 2013). Comparison of these profiles clearly illustrates sedimentation patterns along lower Coal Creek over the last 26 years.

In the 10 year period between 1977 and 1987, persistent channel aggradation resulting from sediment deposition was observed in the reach between Upper Skagit Key and Glacier Key, with a net increase in bed levels in the central portion of 1 to 2 feet. In the reaches immediately upstream and downstream, alternating episodes of sediment erosion and deposition were observed, but overall magnitude of bed level change was generally less than 1 foot. Three large floods (greater than 300 cfs) occurred during this period (Dec 1980, Feb 1984, and Dec 1986), and presumably delivered a significant amount of sediment to the reach. A cursory evaluation of the impacts of this sedimentation on flood levels was conducted by modifying the existing condition HEC-RAS model, presented in Section 4.1.2.1, with 1987 bed levels. Findings indicated that raising the bed to 1987 levels between the upper Skagit Key crossing and Glacier Key, would result in 100-year flood levels being increased by 0.5 to 1.0 feet.

In the summer of 1987, the COB dredged approximately 720 cubic yards of sediment from the channel between upper Skagit Key and Glacier Key. The dredging was conducted as part of flood a reduction project and coincided with the construction of berms on either side of the channel. Between 1987 and 1991, sediment deposition had refilled much of this reach. To address this aggradation, the COB re-dredged approximately 280 cubic yards of material from the reach in 1991 (COB, 1990). By 1994, minor sediment deposition and channel aggradation was observed along the downstream half of lower Coal Creek to just upstream of Glacier Key. Reduced sedimentation between 1991 and 1994 were likely due to hydrologic inactivity as no major flow events (greater than 300 cfs) occurred during this period.

In February 1996, a major flood event occurred on Coal Creek; however, the magnitude of change to bed profile did not reflect this. While minor sediment deposition occurred along the lower 1,700 feet of the reach, significant channel aggradation between the Glacier Key and upper Skagit Key crossings, like that observed between 1985 and 1987, did not occur (Figure 16). This lack of significant aggradation during the 1996 event may have been the result of the sediment removal that commenced the previous year at the I-405 facility.

By 2000, a pattern of localized downstream aggradation and upstream degradation along lower Coal Creek became established. In part, this observation may be based on the higher resolution of the channel survey conducted by the COB in 2000. Channel centerline points were surveyed at a spacing of 50 feet, rather than 100 feet like previous surveys, thus specific channel features such as riffle crests and pool bottoms would be visible. Regardless, the overall trend of downstream aggradation and upstream degradation is apparent. The 2013 profile, surveyed at a similar resolution to that in 2000, indicates reach-wide degradation along the entirety of lower Coal Creek within the Newport Shores Community (Figure 16).

5.2.3 Sediment Storage in Newport Shores

Figure 17 plots changes in sediment storage volume within lower Coal Creek were computed using the surveyed bed profiles just discussed. Volumes were averaged by the number of years between consecutive surveys to provide annualized values. Positive values indicate sediment deposition (channel aggradation) within the reach while negative values represent sediment erosion (channel degradation). Sediment volumes dredged from the reach by the COB in 1987 and 1991 were accounted for in the computation. Between 1985 and 1996, net aggradation, ranging from approximately 150 to 450 cubic yards per year, was observed within the project reach. Conversely, in the period from 1996 to 2013, net degradation was observed. This period coincides with the commencement of upstream sediment removal first at I-405, and later at Coal Creek Parkway and Anna's Pond facilities. These findings suggest that current channel and sediment management activities being conducted by the COB are effectively controlling existing sediment input into the Newport Shores Community.

5.2.4 Field Assessment

Figure 6 shows bank conditions along lower Coal Creek as well as locations of vegetative encroachment and sediment sampling sites. Much of the reach is armored by rockeries or crib walls located along the banks immediately adjacent to the channel. Bank instabilities were observed at several locations throughout the reach, but overall they appear to be relatively minor and isolated. In the vicinity of Cascade Key and upper Skagit Key, several of the instabilities were associated with failing bank armoring. Regardless, immediate threats to structures or substantial property loss were not observed.

Vegetative encroachment into the channel was also observed at several locations along the reach. Encroachment varied from overhanging branches to relatively mature deciduous trees leaning, or growing within the channel. The latter were observed primarily in the sub-reaches bounded by Cascade Key and upper Skagit Key, and by Newport Key and lower Skagit Key. Although significant sediment deposition or bank instability were not associated with the observed vegetative encroachment, debris racking on this vegetation during high flows could exacerbate flood conditions.

Figure 18 shows grain size distribution curves for the seven surface samples collected by NHC in 2013 along lower Coal Creek. Characteristic grain sizes for each sample are provided in Table 5. Results indicate that the surface bed material along lower Coal Creek is uniformly graded and composed of coarse gravel and cobbles forming a distinct armor layer. Evidence of significant downstream fining was not observed as material remained relatively uniform and coarse from upstream to downstream. A significant sand component was not observed in the surface composition, although visual inspection of the underlying substrate did include sand sized material. Measurement of bed material thickness was attempted with a metal probing rod, but a distinct break in bed composition was not found.

Overall, there was very little evidence of recent transport or deposition, thus suggesting the channel is stable. One exception was the sample collected at Station 11+22 on what appeared to be a recently active depositional 'lobe' immediately downstream of Glacier Key. This deposit of uniform material likely formed as medium sized gravel transported through the Glacier Key settled out in the rapidly widened channel downstream. This, however, was an isolated observation and does not conflict with the general conclusion that lower Coal Creek has degraded, become armored, and stabilized.

Table 5: Characteristic Surface Particle Diameters

			Characteristic Particle Diameter (mm)				
Reach	**Station**	**Description**	D_{10}	D_{16}	D_{50}	D_{84}	D_{90}
1	5+82	Riffle Crest	18	23	51	81	88
2	9+62	Riffle Crest	20	24	45	80	88
2	11+22	Depositional Lobe	19	24	40	63	76
3	17+42	Riffle Crest	11	17	36	70	87
4	26+45	Riffle Crest	18	24	56	99	115
5	30+50	Riffle Crest	19	25	53	89	105
5	32+75	Riffle Crest u/s of RR trestle	24	28	47	73	83

5.2.5 Culvert Scour

Evaluation of localized scour at lower Skagit, Newport, and Glacier Keys, i.e. those with substantial sediment deposits currently in the barrels, was conducted using a combination of methods. Scour chains installed at the upstream faces of lower Skagit and Newport Keys indicated that flows less than a 2-year recurrence interval are competent to initiate scour. The only event monitored, occurring in early January 2013, had an estimated discharge of approximately 180 cfs, and resulted in approximately 0.3 and 0.2 feet of scour at Newport and Lower Skagit Keys, respectively. This small amount of scour at a moderate discharge establishes a lower threshold for bed movement.

Evaluation of scour at higher discharges utilized the HEC-RAS model presented in Section 4.1.1. The HEC-RAS model was primarily developed to evaluate flood levels and assumed that culvert barrels were clear of sediment. To evaluate scour, however, model geometry was modified at the lower Skagit, Newport, and Glacier Key culverts to reflect culvert barrels “filled” to levels observed during the 2013 channel survey. Computed barrel velocities with culverts “clear” and “full” were then compared with critical scour velocities and depths estimated using Neill’s Competent Velocity Method outlined in FHWA (2007). Using typical median (D50) particle diameters observed along the reach, results indicated that significant scour (greater than 1 foot in depth) would occur at a discharge of 160 cfs at Glacier Key, and 280 cfs at lower Skagit and Newport Keys. The lower threshold discharge at Cascade Key results from the increased constriction created by the 10-foot wide by 6-foot tall opening. Although this is a simplified analysis that does not take into account the complex hydraulics through culverts, it does suggest that the assumption of culverts being fully scoured during substantial flood events (300-400 cfs) is valid.

5.3 Discussion and Conclusion

Results of the sedimentation analysis indicate that lower Coal Creek is benefiting from current channel stabilization and sediment management practices further upstream. Prior to these practices being implemented, significant amounts of sediment were being transported downstream and depositing within the Newport Shores Community and the adjoining delta at Lake Washington. Peak sedimentation within the channel occurred in the mid-1980’s, with cursory estimates of increased flood levels due to sediment aggradation being on the order of 0.5 to 1 foot between Glacier and Upper Skagit Keys. These conditions led the COB to perform dredging of the central portion of the reach in 1987 and 1991. However, these measures only addressed the sedimentation problem locally and temporarily.

In the early 1990’s, upstream sediment management activities were initiated (TetraTech, 2006). These included slope and channel stabilization measures to control sediment sources, as well as the eventual construction of three separate sedimentation ponds along the lower 1.3 miles of Coal Creek. Findings of this analysis indicate that these measures, particularly the interception and removal of sediment at the ponds, have resulted in the effective control of sediment delivered to the Newport Shores Community. The average removal volume is on the order of 45% of the previously estimated total annual load to the delta. Although still less than half, this percentage likely represents a large proportion of gravel bedload material that historically deposited within the channel of lower Coal Creek. Channel profile evolution over time shows net degradation along lower Coal Creek since sediment removals began, thus supports this observation. Maximum decreases in bed level are most pronounced between Glacier and upper Skagit Key, where degradation of 1 to 2 feet has been observed since 1987. Furthermore, the current armored condition of the bed suggests that the channel has degraded and stabilized. Under current conditions, the threat of armor layer destabilization and channel degradation is minimal. Assuming no significant changes to hydrologic regime along lower Coal Creek (e.g. increased flow permitted through the I-405 pond) the bed is expected to remain stable in the future; however, modifications to existing hydraulic controls along the reach (e.g. culvert replacements) may warrant further evaluation of channel stability.

Localized sediment transport analyses at the culverts indicate that they do scour at competent events to accommodate discharge, thus increased flood levels are more a function of the hydraulic constriction created by the structures itself, rather than sediment deposition within the barrels.

Although existing sedimentation on lower Coal Creek no longer appears to be an issue with regards to flood risk, it should still be considered when evaluating possible flood alleviation measures. Changes to reach hydraulics, following culvert replacement(s) for example, may introduce localized increases to transport capacity. If culvert replacements are included as part of a preferred flood risk reduction project, the design phase should address any changes in sediment transport and bank stability so that appropriate measures can be incorporated into the design that prevent any negative impacts along the creek.

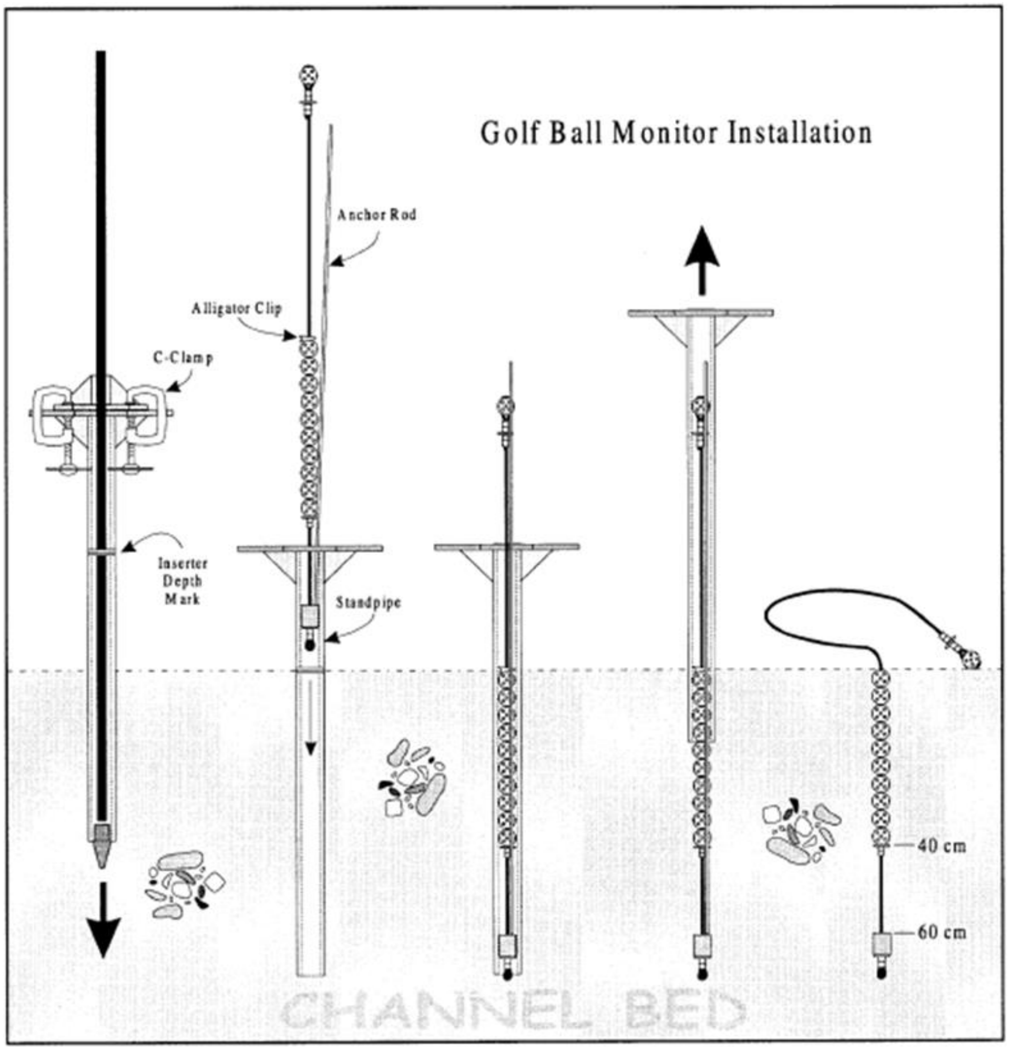

Figure 14. Typical scour chain apparatus and diagram of installation (after Schuett-Hames et al, 1999)

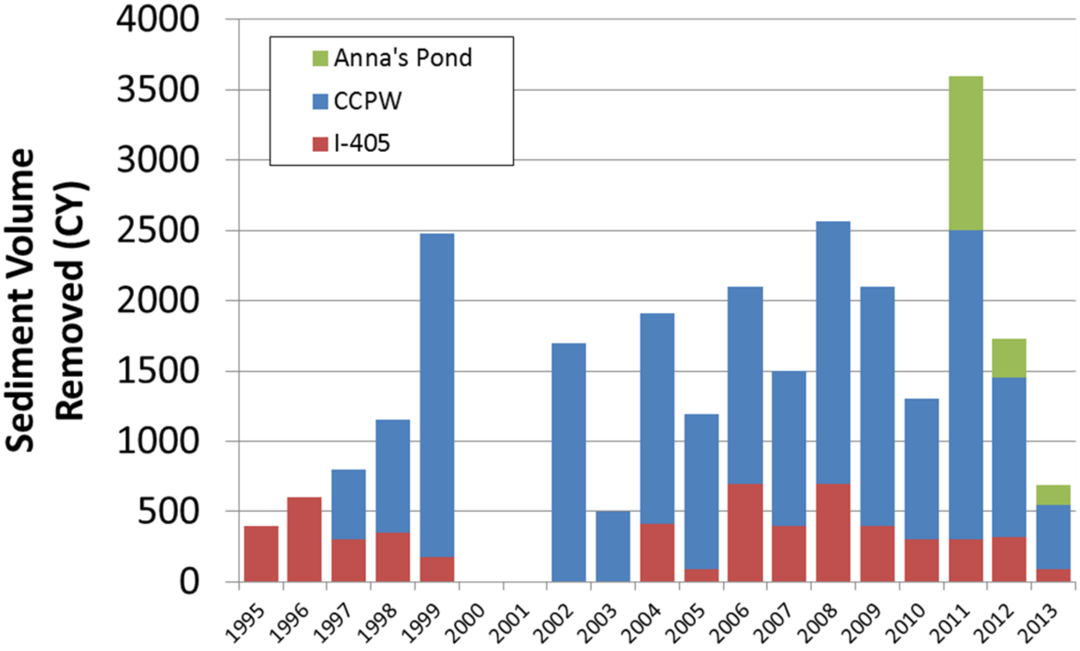

Figure 15. Volumes of material annually removed from sedimentation pond at three facilities along Coal Creek (City of Bellevue)

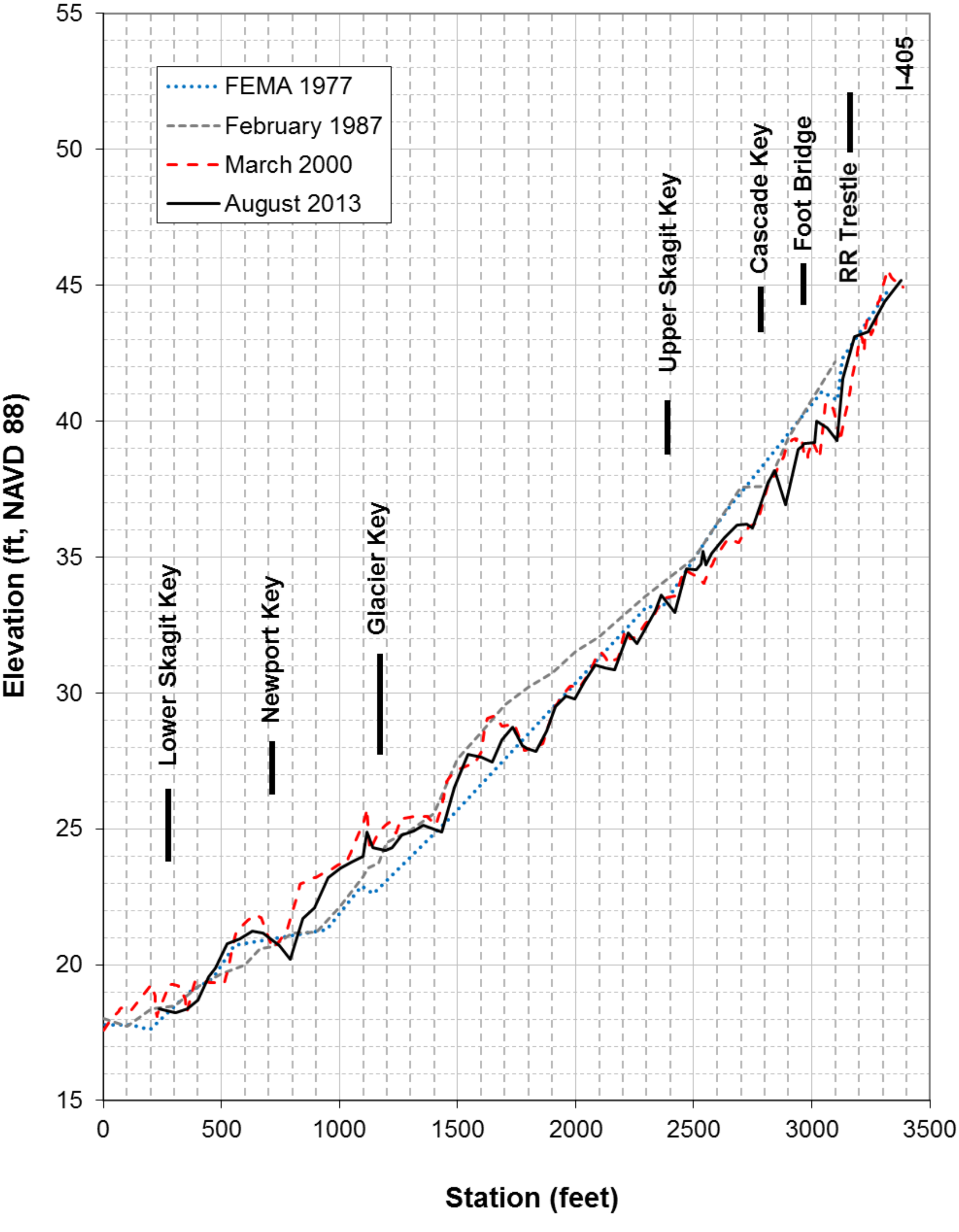

Figure 16. Comparison of longitudinal bed profiles of lower Coal Creek: circa 1977 (FEMA), February 1987, March 2000, and August 2013 (City of Bellevue)

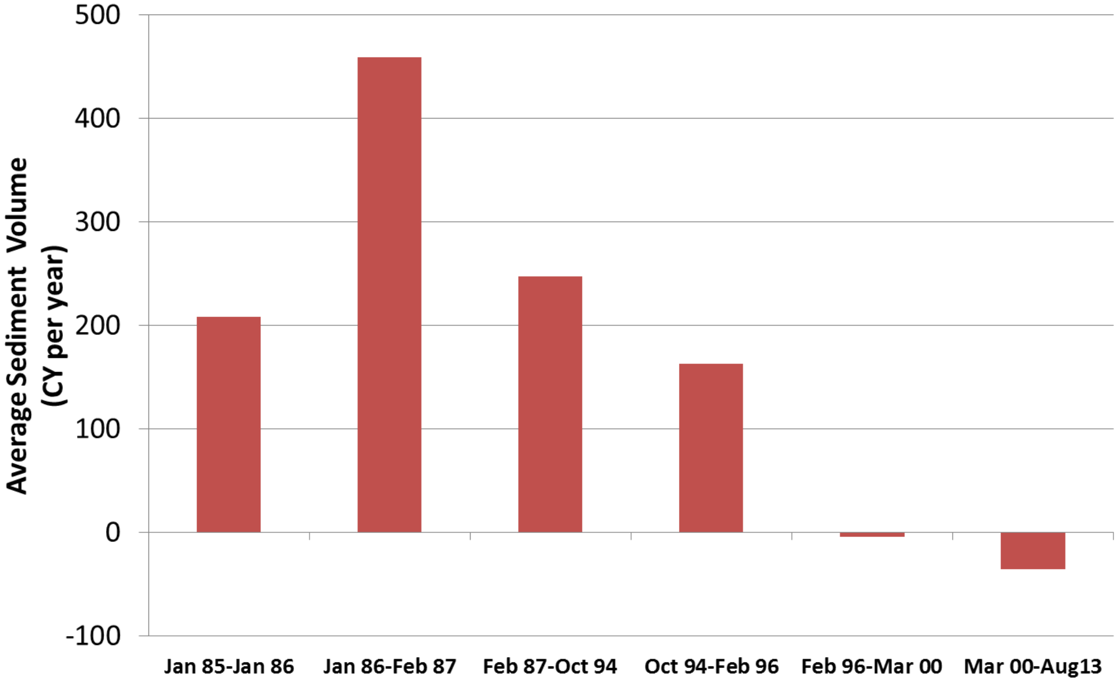

Figure 17. Changes in sediment storage volume within lower Coal Creek

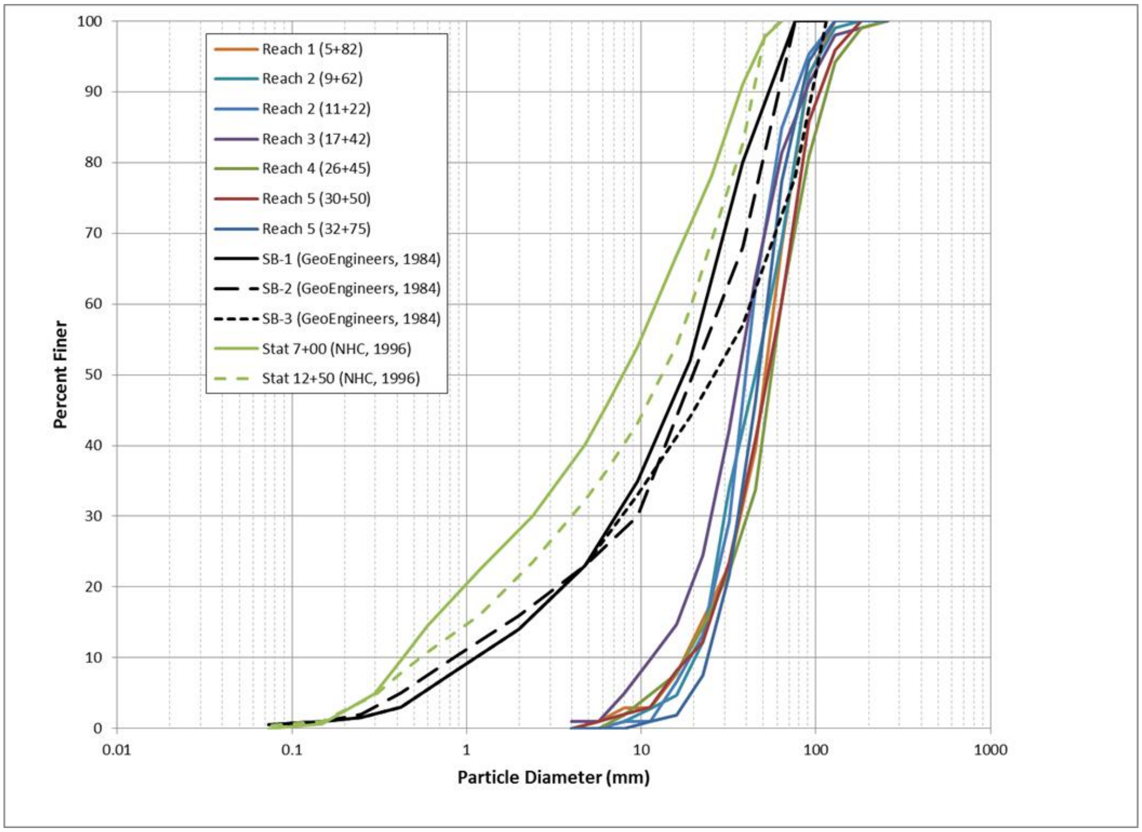

Figure 18. Grain size distributions of surface material and past subsurface samples (GeoEngineers, 1984 and NHC, 1996)

6 Drainage Analysis

Hydraulic analysis was performed on the Newport Shores storm drain system in the project area to identify deficiencies in the existing conveyance system during low flow and bankfull events in Coal Creek. The drainage analysis also provided a basis for developing integrated solutions to flooding that address the interaction of storm system backups with high creek levels and stream sedimentation.

6.1 Drainage Related Problems

Frequent flooding in the Newport Shores neighborhood has generated numerous complaints to the COB over the years. Many of the flooding problems are directly related to overbank flooding in Coal Creek; however, a subset of reported problems identify road and property flooding some distance away from the creek in areas served by the storm drainage system. Flooding problems in the storm drainage system were identified from a review of the flood records recorded in the MAXIMO database and by COB maintenance staff. Figure 19 maps drainage complaints in the Newport Shores neighborhood.

The timing of the drainage complaints in the Newport Shores area was compared to flow rates estimated by the hydrologic model and most were found to correspond to elevated flows, at or near bankfull conditions in Coal Creek (see Figure 13a). Based on this review, it is concluded that flooding in the storm drain system is primarily due to high flow depths in Coal Creek rather than capacity restrictions in the storm drain pipe network. However, there are exceptions to this finding at three locations:

- Flooding reported in late December 2007 at Glacier Key is likely due to an obstructed outfall to the creek. Sediment deposition in the creek has been noted as a problem during low flow conditions at the Glacier Key crossing. The 2009 complaint (a bankfull event) at this location identified sediment as a contributor to flooding.

- Flooding was also reported at the east end of Tulalip Key in August 2007. Rainfall records from the Coal Creek rain gage indicate about 0.5 inches of rain fell that day. This volume of rainfall is not large enough to generate street flooding although locally intense rainfall may have been responsible for the flooding. If that was the case, limited capacity of the street inlets, rather than conveyance capacity of the storm drain system, may have been the source of flooding.

- Flooding at a third location, Skagit Key at Lopez Key, coincided with a bankfull flow condition in Coal Creek, but the cause of flooding is probably due to snow blocking inlets during the large snow fall event rather than conditions in the creek or storm drain capacity issues. The December 1996 event was a very large rain-on-snow event and is known to have caused significant flooding problems throughout the region. No other complaints were recorded for this location.

In addition to the obstructed Glacier Key outfall described above, sediment deposition occurs at two downstream outfall locations at Newport and Skagit Keys. During low flow events, the obstructed outfall would prevent the storm drain system from freely discharging stormwater to the creek and surface flooding would occur. During high flow events, higher stream energy would mobilize the sediment blocking the outfalls reducing the obstruction at the outfall. As the flow in the creek recedes, stream energy drops and sediment is re-deposited at the outfall.

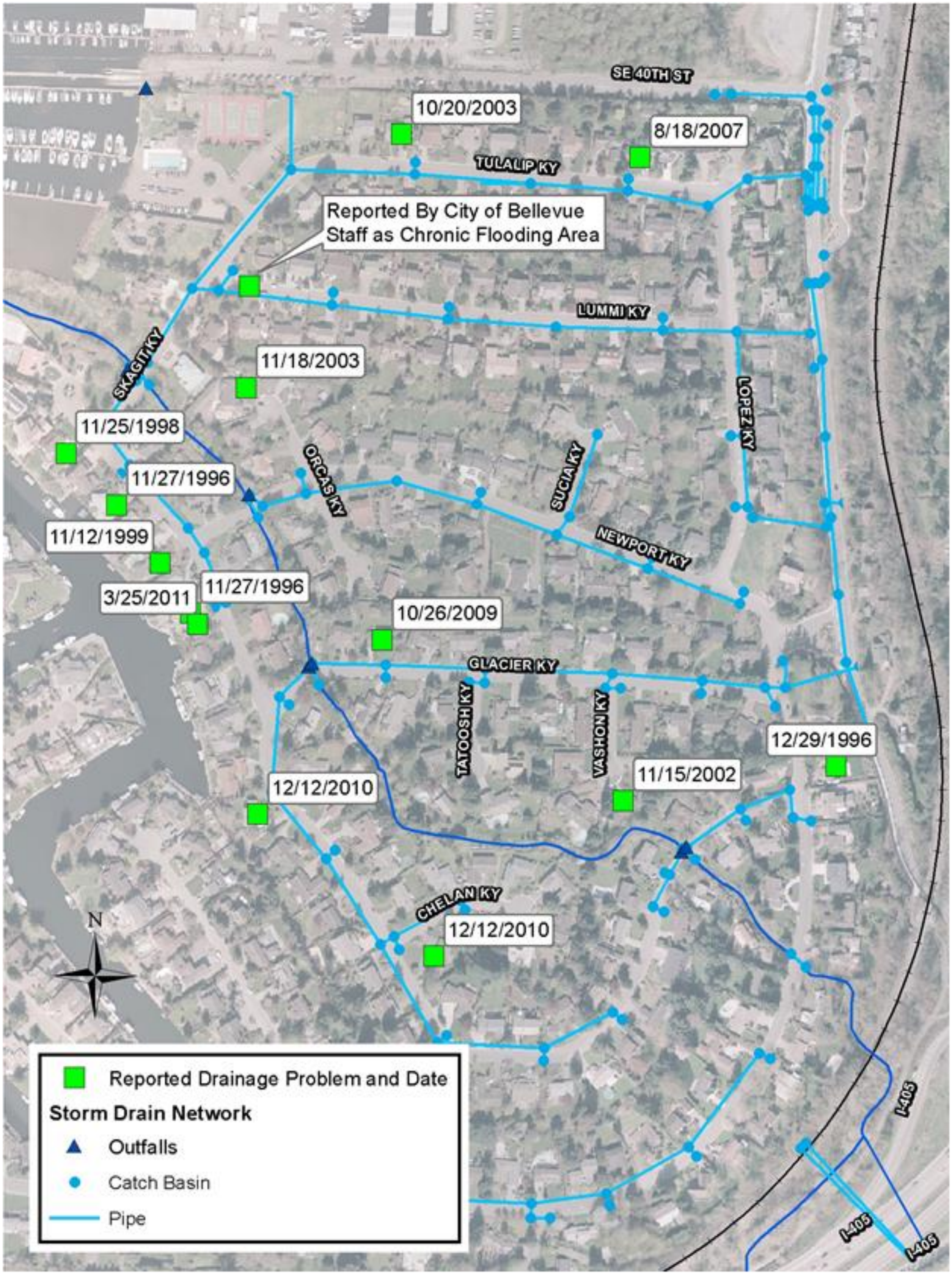

Figure 19. Drainage Related Problems Reported for the Newport Shores Neighborhood

6.2 Model Scenarios

Four design events and two tailwater conditions were analyzed to evaluate the range of conditions under which the capacity of the local storm drainage system in the Newport Shores neighborhood might be exceeded. Design flow events included the 2-, 10-, 25-, and 100-year runoff events. Each design event was analyzed for two different tailwater conditions – low flow and nominal bankfull. The low flow condition assumed free discharge at the storm drain outfalls to Coal Creek. The bankfull condition assumed tailwater at the creek outfalls was equal to the 2-year water surface elevation.

6.3 Existing Storm Drain System

Stormwater runoff in the Newport Shores neighborhood is collected in a curb and gutter system and conveyed through a pipe storm drain system to outfalls to Coal Creek located at all creek road crossings except Cascade Key. The storm drain network within the project area serves properties along Tulalip Key, Lummi Key, Newport Key, Glacier Key, Skagit Key and Lopez Key and includes an overflow from Tulalip Key to the SE 40th Street system and its outfall at Lake Washington in addition to the four outfall points along Coal Creek. The project area and SWMM5 (EPA, 2011) model extents are shown in Figure 20.

EPA developed SWMM to simulate surface water runoff and hydraulics for urban storm and sewer collection systems. Pipe characteristics are assigned to SWMM5 conduits, which are linked to model junctions representing inlets, catch basins, and outfalls. Stormwater flow inputs can either be calculated within SWMM or developed using an independent method and input to SWMM5 model junctions. In this project, input hydrographs for storm events were developed from outputs of the previously described HSPF basin hydrology model (see Section 3.3).

6.3.1 Data Sources and Verification

The primary data source used to create SWMM5 representation of the Newport Shores drainage system were obtained from the MAXIMO database created and maintained by the City of Bellevue. Data elements for conduits include pipe diameter, upstream and downstream invert elevations, pipe material, and conduit length. Catch basin features were obtained from the Maximo database and include bottom invert and RIM elevations. Manning's roughness coefficients for pipes were based on pipe material assuming fair condition.

The catch basin rim elevations provided in the MAXIMO database were compared to elevation data extracted from a digital elevation model (DEM) data as a check on the accuracy of the MAXIMO data. Discrepancies between the two data sets were noted in the Lummi Key area so additional field survey was performed to verify the MAXIMO data. As a result of this survey, the rim elevations in question were found to be low and were adjusted based on the field survey. The storm drain pipe inverts along Lummi Key and Tulalip Key were also verified with measure-down data and adjusted as needed.

6.3.2 Model Construction

The SWMM network was developed from the MAXIMO database. Catch basins characteristics were imported into the SWMM5 model as junctions with the junction ID assignment based on the maintenance number documented in the MAXIMO database. Subsequently, conduits were imported into the SWMM5 model using the catch basin maintenance number referenced to the upstream and downstream pipe ends. For example, conduit '1000_2000' represents a pipe extending between upstream node 1000 and downstream node 2000. Missing RIM elevations were supplemented with intersecting DEM elevations when necessary. Missing pipe elevations are supplemented by interpolating between known connecting pipe slope and catch basin inverts (assuming a 1-foot sump).

The SWMM5 model of the Newport Shores drainage system included pipe conduits representing over 17,000 feet of 8-inch through 24-inch diameter pipe and junctions representing 200 catch basins and inlets.

It should be noted that SWMM5 models developed for this study are planning level models. Planning level models are typically developed at a coarser scale than design models and are useful for estimating system flow rates, identifying potential problem areas, and sizing infrastructure improvements for cost estimating purposes. Some, but not all data sources were confirmed during the analysis so care should be taken in interpreting the results. If the findings from this analysis are used for design, model development should be critically reviewed to be sure the assumptions used are applicable and that appropriate safety factors are incorporated into the design process. No calibration was performed for this analysis.

6.3.3 Subbasin Delineation and Inflow Assignment

Drainage subbasin areas tributary to each of the storm drain systems were delineated based on the drainage basin identification in the COB's storm drainage GIS database, pipe network, topographic mapping, and limited field verification of drainage pathways.

Inflow hydrographs were obtained from the HSPF analysis for the 2-, 10-, 25-, and 100-year design flood events. The runoff time-series for the Newport Shores subbasin (subbasin 05) was exported from the HSPF model developed for the Coal Creek watershed (Section 3.3). At 177 acres, HSPF Subbasin 05 is much larger than the drainage subbasins developed for the SWMM model so scale factors were developed to apportion the runoff from Subbasin 05 to discrete junctions in the drainage network.

The scale-factor used to assign inflow at individual junctions was based on the ratio of the subbasin area to the HSPF Subbasin 05 area. Scaled inflows were evenly distributed to the SWMM5 junctions located in the respective drainage subbasin. Figure 20 shows the drainage subbasin delineation and flow input points. Table 6 documents the scale-factors used for each subbasin.

Table 6: Inflow Scale Factor for SWMM5 Subbasins

Subbasin	Area (Acres)	Scale Factor
SE 40th Street	8.8	0.049
Lake Washington Blvd.	4.7	0.026
Tulalip Key	11.5	0.064
Lummi Key	14.9	0.083
Newport Key	17.1	0.095
Lower Skagit Key	4.5	0.025
Glacier Key West	11.2	0.062
Glacier Key East	12.1	0.067
Upper Skagit Key West	1.3	0.007
Upper Skagit Key East	5.3	0.290
Cascade Key	13.3	0.074

6.3.4 Design Storm Events

Design event runoff hydrographs were extracted from the HSPF time-series data to represent the 2-, 10-, 25-, and 100-year peak flow condition. The SWMM model was run for a minimum of 24-hours to capture the full volume of inflow occurring during a storm event. Table 7 documents the recurrence interval and date associated with each design event. Derivation of design flow events is described in Section 3.3.

Table 7: Design Storm Events

Recurrence Interval	Date
2 Year	12/19/1953
10 Year	06/17/1964
25 Year	03/03/1950
100 Year	06/05/1995

6.3.5 Boundary Condition

Two alternative boundary conditions were assumed for the outfalls represented by the SWMM model one with creek tailwater and one without. For the tailwater (or high creek flow) condition, Lake Washington and Coal Creek water surface elevations were used as fixed-elevation boundary conditions for all pipe outfalls in the SWMM model. For pipe systems that outfall to Coal Creek, the estimated 2-year water surface elevation at each of the road crossings in Coal Creek were extracted from the HEC-RAS hydraulic model (see Section 4.1.1). The boundary condition for Lake Washington outfalls was based on the daily average water surface elevation. Table 8 shows the fixed tailwater elevations used at each outfall. For the low creek flow condition, the Coal Creek outfalls were assumed to discharge freely.

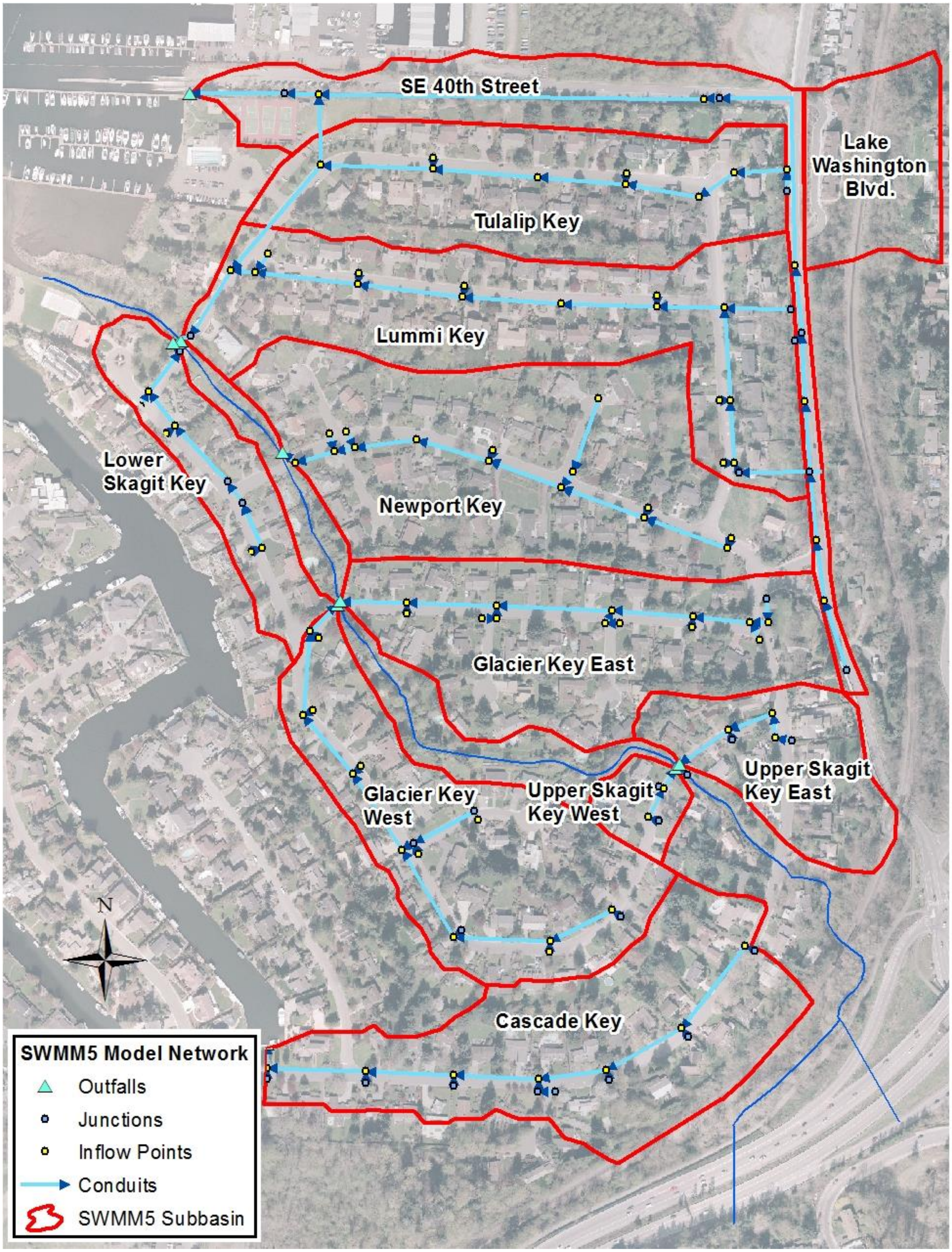

Figure 20. SWMM5 Subbasin and Model Schematic

Table 8: Fixed-Elevation Boundary Condition for the Bankfull Flood Conditions Tailwater Modeling Scenario

Subbasin	Receiving Water	Tailwater Elevation (feet NAVD 1988)
SE 140th Street	Lake Washington	18.05
Lower Skagit Key Outfall East	Coal Creek	22.16
Lower Skagit Key Outfall West	Coal Creek	22.16
Newport Key	Coal Creek	24.85
Glacier Key Outfall East	Coal Creek	27.65
Glacier Key Outfall West	Coal Creek	27.65
Upper Skagit Key East	Coal Creek	37.49
Upper Skagit Key West	Coal Creek	37.49
Cascade Key	Lake Washington	18.05

6.4 Modeling Results

Design event inflow runoff hydrographs listed in Table 7 were routed through the SWMM5 hydraulic model of the Newport Shores drainage system to estimate peak flows in conduits and maximum water surface elevation at junctions. The results of the hydraulic analysis were used to evaluate the performance of the stormwater conveyance system, identify flood problem areas, and capacity limitations that exist in the storm drain network. SWMM5 output was queried for two conditions, “at-risk” and “flood”, with “at-risk” defined as nodes where peak water levels were within 0.5 feet of the street surface, and “flood” defined as where overflow to the street was predicted. Flooding was assumed to occur where the SWMM5 model simulated the water surface elevation to be higher than the rim elevation. The “at-risk” condition recognizes uncertainties in modeling results associated with its idealized representation of the drainage system.

Modeling results showed that when water levels are low in the creek, the existing storm drain system in Newport Shores has adequate capacity to convey up to the 100-year design event without flooding at any location. However, it must be emphasized again that this level of service would only be achievable if the existing storm drain outfalls to Coal Creek are neither backwatered by high creek levels, nor impeded by sediment or debris blockages. With the more conservative, and actually more realistic, boundary condition assumption of bankfull conditions in the creek, the SWMM5 model indicates either flooding or near flooding conditions at 19 locations in a 100 year event, and potential problems at several locations for events as frequent as 1 in 2 years. These potential flooding sites are summarized in Table 9 and depicted spatially in Figure 21 and 22. As indicated, if creek flow is high, the SWMM5 model indicates “at-risk” conditions for the 2- and 10-year design events at locations along Skagit Key, Tulalip Key, and Lummi Key. Clearly, results indicated that the coincidence of high creek water and local storm runoff within Newport Shores are jointly responsible for compromising the capacity of the storm drain system and causing flooding. Additionally, it should be noted that storm drain flooding may occur during more localized rain storms affecting Newport Shores, even if creek levels are low and storm drain outfalls are partially or completely blocked by sediment or debris.

With the bankfull creek tailwater condition, the water surface elevation was predicted to be within 0.5 feet of the rim at Skagit Key near Glacier Key, additional locations along Skagit Key, Tulalip Key, and Lummi Key. For the 100-year event, surface flooding is widespread throughout the study area.

A comparison of the model results to the reported drainage complaints shows a general correspondence between observed and predicted flooding locations. The model was predicted flooding on lower Skagit Key (near Newport Key), Lummi Key near Skagit Key, and Tulalip Key for the 2-year event under bankfull conditions. For the more frequent events, tailwater in Coal Creek is the primary cause of flooding at these locations rather than capacity limits caused by insufficient pipe size. Based on the hydrologic analysis, drainage complaints on Skagit Key seem to occur for creek flow events exceeding the 2-year level. The SWMM5 analysis predicted additional flooding at Upper Skagit Key near Glacier and Chelan Keys starting with the 10-year event. Drainage complaints for this area corresponded to larger storm events closer to the design event used in the SWMM5 analysis. Flooding was also predicted on Newport Key and Glacier Key east of the Coal Creek in the vicinity of recorded drainage complaints.

Event peak flows were nearly identical for each tailwater condition except at the Lower Skagit Key east outfall. When flood levels rise high enough in a junction located at the intersection of Tulalip Key and Skagit Key, they overflow to a pipe and ditch system along SE 40th Street. Modeling scenarios with the free discharge tailwater at the Coal Creek outfalls indicated that this overflow was not active. However, with a bankfull tailwater condition in Coal Creek, the water surface elevation at Lower Skagit Key was high enough to engage the relief pipe and divert some flow northward to the SE 40th Street system.

Table 9: Drainage Problems Identified from SWMM5 Modeling – Bankfull Conditions

Structure Location	Drainage System Subbasin[a]	Minimum Design Event with Depth with 0.5 foot of Rim	Minimum Design Event with Flooding
21 Tulalip Key	Tulalip Key	2-year[b]	--
5 Tulalip Key	Tulalip Key	25-year	--
70 Skagit Key at Lummi Key	Lummi Key	2-year[b]	100-Year
33 Lummi Key	Lummi Key	100-Year	100-Year
5 Lummi Key	Lummi Key	100-Year	100-Year
66 Skagit Key	Skagit Key	2-year[b]	100-Year
65 Skagit Key	Skagit Key	10-year	--
53 Skagit Key	Skagit Key	100-Year	--
20 Sucia Key	Newport Key	100-Year	--
45 Orcas Key at Newport Key	Newport Key	100-Year	--
37 Newport Key	Newport Key	100-Year	--
44 Glacier Key	Glacier Key East	100-Year	--
43 Skagit Key	Glacier Key West	10-Year	100-Year
39 Skagit Key	Glacier Key West	100-Year	100-Year
42 Skagit Key	Glacier Key West	100-Year	--

[a] See Figure 20

[b] Flooding at 2-year event due to backwater from Coal Creek.

6.5 Conclusions

The storm drain system has capacity to convey the 100-year design storm during low flow periods in Coal Creek. However, the system is surcharged during this event. Any reported flooding in the Glacier Key and Newport Key systems during low flow conditions in Coal Creek is likely due to sediment deposition in Coal Creek obstructing discharge from storm drain outfalls. The SWMM5 models of the storm drainage system did not consider sediment deposition at the outfalls.

Street flooding on Skagit Key near Newport Key and the Lummi and Skagit Key intersection, and Tulalip Key near Skagit Key is due to high tailwater in the creek during bankfull flow conditions. Flooding is exacerbated during large rainfall events.

Street flooding on Skagit Key near Glacier and Chelan Keys, Glacier Key east of Coal Creek, and Newport Key is due to a combination of high tailwater in Coal Creek during a bankfull condition and undersized storm drainage system. Sediment deposition at these outfalls to Coal Creek would also contribute to flooding at these locations.

Extensive flooding occurs throughout the Newport Shore neighborhood during the 100-year storm event and bankfull conditions in Coal Creek.

High tailwater in Coal Creek during bankfull flow conditions, especially in the downstream reaches, would limit the effectiveness of drainage solutions based solely on upsizing pipes (increasing conveyance capacity). However, this type of improvement may be effective if creek solutions to reduce overbank flooding also lower tailwater at the outfalls. The most effective drainage solution for solving flooding problems in the Newport Shores neighborhood would involve relocating outfalls from Coal Creek to Lake Washington where water levels fluctuate seasonally and are not dependent on local storm events.

A second higher-level outfall pipe could also improve conveyance at locations where sediment deposition in the creek obstructs free discharge from the storm drain outfalls during low flow in Coal Creek. Storm drain outfalls affected by sediment deposition are found at Lower Skagit Key, Newport Key, and Glacier Key.

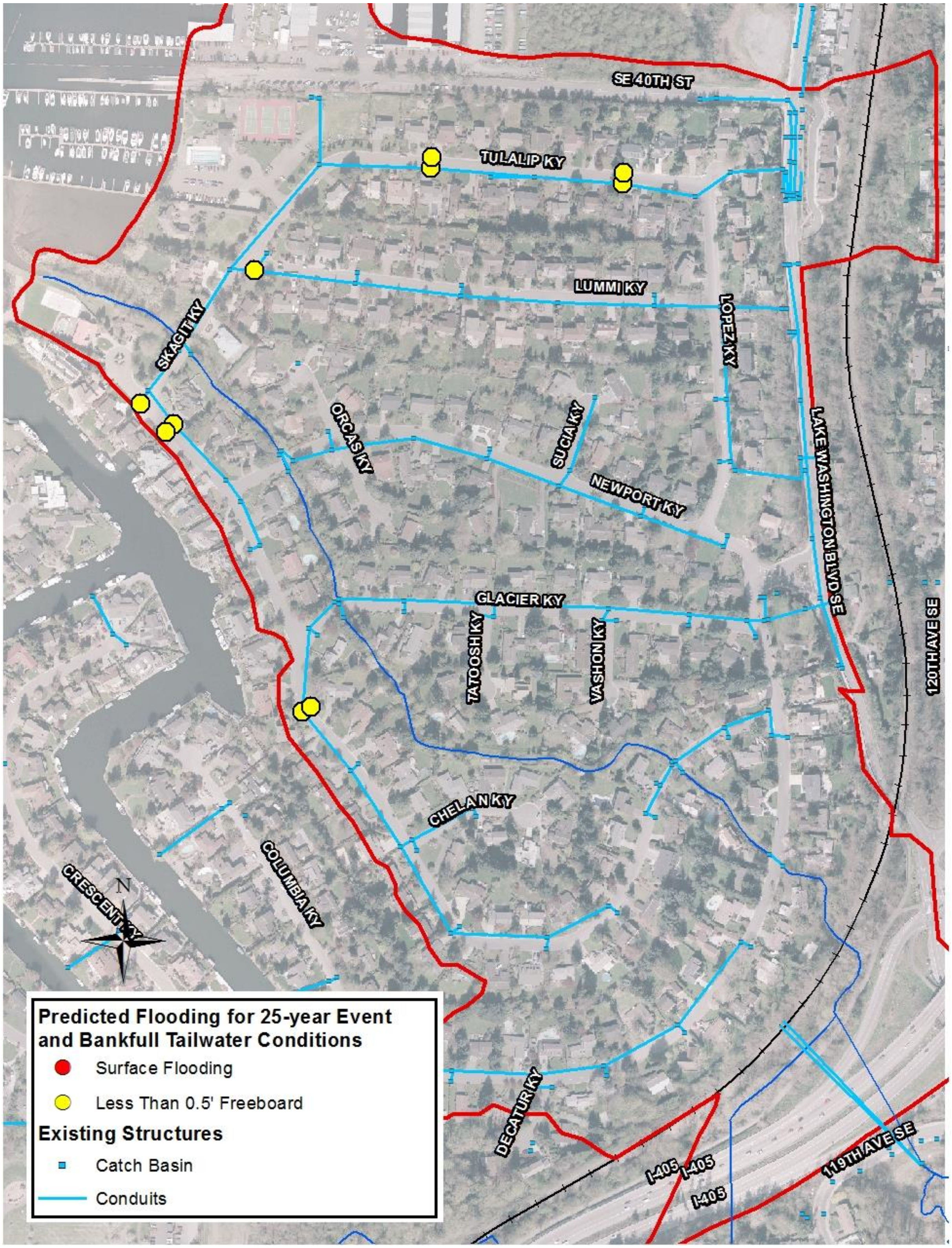

Figure 21. 25-Year Flooding Locations Simulated by the SWMM5 Model

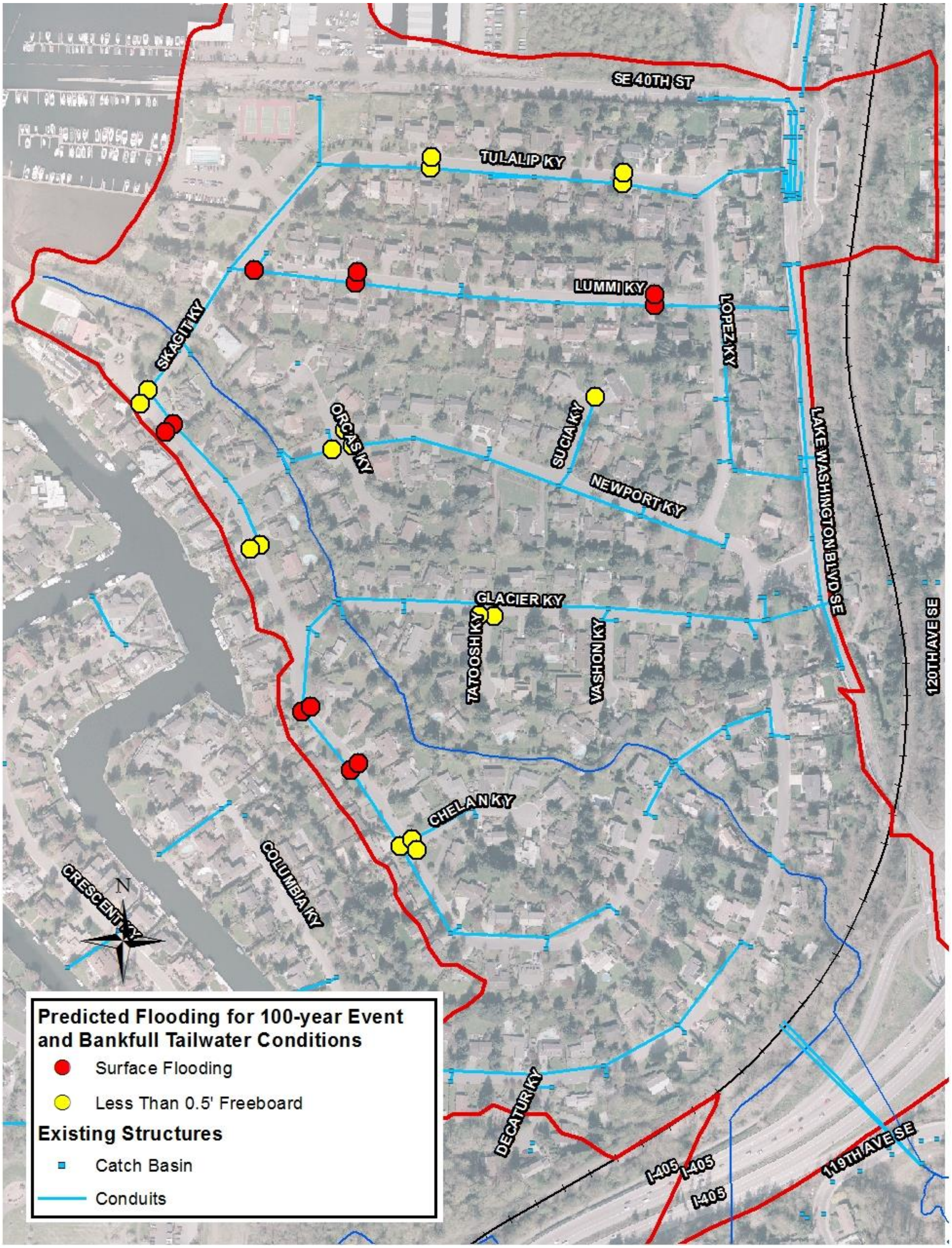

Figure 22. 100-Year Flooding Locations Simulated by the SWMM5 Model

7 Flood Reduction Alternatives Analysis

The alternatives analysis to select a flood risk reduction project for lower Coal Creek was based on a multi-stage screening process that applied increasing resolution to both project definition and project evaluation to arrive at a recommended project and pre-design. This process took advantage of knowledge, expertise, and input from four primary sources:

1. Documents and data related to past flooding and drainage problems in the Newport Shores neighborhood
2. Data collection, analysis, modeling, and expertise of the consultant team
3. Expertise of City of Bellevue staff with long experience in Newport Shores flooding and drainage problems as well as the City's surface water management policies
4. Input from the Newport Shores community via the Newport Shores Homeowners Association and Neighborhood Forums

7.1 Project Alternative Filter Step 1- Design Charrette

The initial step in the alternatives analysis phase was to create a wide list of flood hazard reduction measures or components and exclude those components judged to be infeasible or ineffective. A design charrette or workshop with key City of Bellevue staff and consultant team representatives was the primary mechanism for filtering the initial list of alternatives and giving direction to succeeding steps in the alternative analysis process. The charrette took place on January 9, 2014. Participating COB staff contributed experience with storm water management policy, engineering, operations and maintenance, and stream ecology plus decades long involvement with and knowledge of the history of flooding and drainage problems within the Newport Shores neighborhood. A list of charrette participants is provided in Appendix C of this report. The consultant team contributed extensive experience in flood and drainage analysis, permitting, and problem solving along with results of an existing conditions analysis providing an up-to-date assessment of lower Coal Creek hydrology, channel hydraulics, sediment processes, drainage capacity and flood risk from either creek flow or backup of the drainage system.

During the first half of the all-day charrette, the consultant team presented a summary of existing conditions (documented in earlier sections of this report) in order to establish a common technical understanding of the status of the creek and storm drain systems. In the second half of the meeting, the assembled group discussed an initial list of alternative flood risk reduction measures (Table 10) with a view toward applying its collective knowledge and expertise to winnowing unpromising measures and potentially adding additional measures for later evaluation and comparison. In discussing the list of measures shown in the first column of Table 10, the group qualitatively considered a range of criteria including flood risk reduction effectiveness, permitability, environmental benefit, community acceptance, and consistency with COB policy; however, no attempt was made to rank the listed measures. The second column of Table 10 provides a summary of which measures the charrette participants agreed should be eliminated and which ones were worth taking forward to the next stage in the selection process. In conclusion, the design charrette group directed the consultant team and the COB's project manager to combine measures appropriate into flood risk reduction alternatives and to continue the alternative filtering process based on increasingly detailed and quantitative applications of the criteria discussed above.

Table 10: Charrette-based Screening of Flood Risk Reduction Measures

Measures Considered by Charrette	Summary of Charrette Consensus
A. Creek Conveyance/Channel Measures	
1. Newport Shores Culvert Replacement(s)	Considered promising by the group. Continue to evaluate.
2. Newport Shores Vegetation Management	Modeling shows this would not be generally effective as flood risk reduction measure. Might be useful as supplemental practice from time to time when and where large vegetation blocks the channel.
3. Selective Bank Stabilization and Berm Enhancement	Effectiveness questionable. Continue to evaluate.
4. Dredging	Additional measure added by Charrette for further consultant consideration.
5. Channel Widening	Additional measure added by Charrette for further consultant consideration.
B. Creek Storage Measures	
1. I-405 Control Structure Redesign	Considered promising by the group. Continue to evaluate.
2. I-405 Excavation for Increased Flood Storage	Eliminated. Not considered effective based on analysis and experience. Additional available flood storage not significant.
3. I-405 Excavation and/or control for Increased Sediment Trapping	Continue to evaluate.
4. Buyout and New Off-Channel Sediment Pond in Newport Shores	Eliminated. Questionable effectiveness, high community impact. Sediment accumulation in Newport Shores arrested by upstream management.
C. Creek Bypass Measures	
1. From I-405 pond or creek upstream of RR Grade to Cascade Key and west to existing lagoon outfall between Columbia Key and Crescent Key	Concern regarding lagoon sedimentation at outfall. Continue to evaluate.
2. From I-405 pond or creek upstream of RR Grade North along Lake WA Blvd to I-90 and west to lake (per WSDOT)	Eliminated. Not considered viable or effective for flood risk reduction. Would require a very large pipe to be effective.
D. Newport Shores Drainage Measures	

1. New outfalls to lake on west side of Coal Creek at or near Lower Skagit Key and/or Glacier Key	Considered promising by the group. Continue to evaluate.
2. Same as 1) above with possible inverted siphons[1] to connect drainage networks on the east side of the creek to the west side of the creek	Additional measure added by Charrette for further consultant consideration
3. Up-Size Lummi Key Drains	Considered promising by the group. Continue to evaluate.
4. Up-Size Glacier Key Drains	Considered promising by the group. Continue to evaluate.
5. Re-Engineer Existing Coal Creek Outfalls to manage sediment deposition	Considered promising by the group. Continue to evaluate.
6. Replace pipeline at Lummi and Skagit Keys and new outfall at NYC	Considered promising by the group. Continue to evaluate.
7. Replace pipeline at Lummi Key, Skagit Key and SE 40th Street bypass	Considered promising by the group. Continue to evaluate.
8. Infiltration Vaults/Pond(s)	Eliminated. Not considered viable due to high water table within Newport Shores.
9. Detention Pond/Vault with Pumped Discharge or discharge by gravity	Eliminated. Pumping considered impractical, gravity discharge preferred, but not practical.
[1] Inverted siphon is a term used to describe a structure that enables a pipe to cross a stream or another utility line by going underneath the conflicting conduit at a safe distance. In this case the inverted siphon is achieved with a drop-manhole on the right bank, a short section of pipe beneath the creek bed that flows under pressure, and another manhole on the left bank with a rise to allow continued free surface, gravity flow.	

7.2 Project Alternative Screening Step 2- Flood Reduction Effectiveness

In the next stage of the screening process, flood risk reduction alternatives composed of measures listed in the previous section that were not explicitly eliminated in the charrette were evaluated and ranked using the scheme summarized in Table 11. At this stage of the process, some measures listed in Table 10 were combined together for evaluation- notably, measures D1 and D2 were combined, and D3 through D7 plus D9 were combined. Scoring of each “alternative” using this scheme were based on the knowledge gained from the existing conditions study and the collective experience of the consultant team members and COB’ project manager.

A summary of total scores for the alternatives is shown in Table 12 and the full scoring details are shown in Appendix D. Note that alternatives primarily aimed at reducing risk of creek flooding were ranked separately from the two alternatives aimed primarily at reducing risk of storm drain backups.

Table 11: Scoring Method for Alternative Screening

Scoring Method for Alternative Screening			
Criterion	**Range of Possible Scores**	**Relative Weight of Criterion**	**Comment**
Flood Risk Reduction Effectiveness-Creek Flooding	**-2 to +2**	4	Considered most critical criterion at this stage of process
Flood Risk Reduction Effectiveness-Local Drainage	**-2 to +2**	3	
Consistency with COB Policy	**-2 to +2**	3	
Community Acceptance	**-2 to +2**	2	
Constructability	**-2 to +2**	2	
Environmental Benefit	**-2 to +2**	1	
Permitability	**-2 to +2**	1	
Robustness/Long Term Benefit Potential	**-2 to +2**	1	
Property Acquisition Requirement	**-2 to 0**	1	Ranges from property (-2) purchase to easement acquisition (-1) to no property rights required (0)
Capital Cost	**-2 to +2**	1	
O&M Cost	**-2 to +2**	1	
Unknowns and Level of Study Required	**-2 to +2**	0.5	Higher scores for lower uncertainty
Coordination Required	**-2 to +2**	0.5	Higher scores for less required coordination
Opportunity for Cost Share/Cooperation	0 to 2	0.5	

Table 12: Scoring Flood Risk Reduction Measure or Combination

Scoring Flood Risk Reduction Measure Or Combination	Total Score
CREEK FLOOD RISK REDUCTION MEASURES	
Newport Shores Culvert Replacements	**29.3**
I-405 Control Structure Redesign and Flood Storage Enhancement	**27.3**
I-405 Pond Excavation/Control for Increased Sediment Trapping	**16.5**
Berm Enhancement	**14.5**
Channel Widening	**11.5**
Creek Bypass (upstream of Newport Shores or at I-405 west to existing lagoon outfall between Columbia and Crescent along Cascade).	**10.8**
Channel Dredging	**10.5**
STORM DRAINAGE FLOOD REDUCTION SOLUTIONS	
Storage and Upsizing Pipes (NO NEW OUTFALLS CREEK OR X-INGS). Upsize selected pipes along Lummi and Glacier, re-engineer creek outfalls to shield them from sediment deposition and also add possible ROW storage for stormwater.	**23.0**
Inverted Siphons and Additional Outfalls. (UP TO 2 outfalls to lagoon west of Glacier and Lwr Skagit x-ing, and to Lake Washington near Lummi-Skagit intersection. Up to 3 inverted siphon crossings of creek at Glacier, Newport, and Lwr Skagit).	**23.0**

7.2.1 Creek Flood Risk Alternative Scoring Results

As indicated in Table 12, **Newport Shores Culvert Replacements** and enhanced **I-405 Control Structure Redesign and Flood Storage Enhancement** both were scored distinctly higher than other alternatives. Both of these measures were judged to have potentially significant flood reduction benefits. In the case of culvert replacements, existing condition analysis indicates that hydraulic restriction at the existing culverts causes substantial increases in flood elevations. Furthermore, restrictive culverts increase risk of debris blockage. Culvert replacements also received consistently high scores for most other criteria since they offer an opportunity for upgrading to WDFW-approved, fish passable designs, reduce maintenance costs, and meeting COB conveyance standards policy. Re-engineering of the I-405 control structure with resultant increase in flood storage volume has the potential to significantly lower flood discharges and water surface elevations within Newport Shores providing more freeboard and reducing flood risk along the entire length of the stream in Newport Shores. It also ranks consistently high for the other criteria except for environmental benefit and permitability which have lower scores.

All other creek flood risk reduction measures are considerably lower in score. For example, **I-405 Pond Excavation/Control for Increased Sediment Trapping** scored more than 10 points lower than the two top alternatives. This is mainly due to lower performance in reducing flood risk, as well as more difficulty in permitting, lower environmental benefit, and higher maintenance cost. As was explained in earlier sections of this report, sediment storage within Newport Shores is already declining, largely because of watershed erosion control and sediment removal at the three existing facilities. In theory, trapping more sediment at I-405 could accelerate overall channel deepening between I-405 and Lake Washington with a resultant reduction in flood levels; however, it is uncertain what additional flood risk reduction benefit this would provide above the sediment trapping capacity provided by the three existing ponds. Furthermore, the acceleration of channel deepening will not address the hydraulic constriction and associated with the undersized box culverts at Cascade Key, Upper Skagit Key, and Glacier Key.

Berm Enhancement also falls short in flood risk reduction performance. This alternative would not alleviate constrictions and overtopping risk at the existing Newport Shores culverts. **Channel Widening** has similar hydraulic limitations to berm enhancement, but would be more challenging to permit, and less acceptable to creek-side residents because of the likely need to re-grade portions of backyards bordering the creek. **Channel Dredging** has similar hydraulic limitations to other alternatives, is contrary to COB policy, and would be very difficult to permit.

The flood risk reduction effectiveness of the **Creek Bypass** alternative would depend on the size of the bypass pipe and the intake location. For example, a 48-inch diameter high flow bypass line could reduce peak discharges in Coal Creek within Newport Shores by more than 100 cfs. While a pipeline of this size ranks well for flood risk reduction it falls short with respect to community acceptance, permitting, and environmental benefit criteria. Such a pipeline would likely transport large concentrations of wash load (fine sediment) to the head of the Newport Shores Grand Canal located between Columbia Key and Crescent Key. Turbidity and sedimentation at the outfall would be a concern to the City, the neighborhood, and environmental permitting agencies due to potential negative impacts on water quality, habitat, navigation, and aesthetics. Such a bypass would also be likely to require purchase of easements and possibly a home buyout to reach the Cascade Key right-of-way.

Based on the scoring of seven creek flood reduction alternatives carried forward from the design charrette, it was determined to further detail and compare the two alternative projects for reducing risk of Creek Flooding in Newport Shores, **Newport Shores Culvert Replacements** and **I-405 Control Structure Redesign and Flood Storage Enhancement**.

7.2.2 Drainage Flood Risk Reduction Alternative Scoring Results

Two alternative concepts were ranked for reducing the risk of flooding by local stormwater runoff, **Storage and Upsizing Pipes** and **Inverted Siphons and Additional Outfalls**. As indicated in the existing conditions assessment, storm drainage capacity in Newport shores is limited by both backwater from high creek flows and sediment blockage of outfalls. The **Inverted Siphons and Additional Outfalls** would solve this problem by switching the outfall locations from the creek to Lake Washington. This alternative would also incorporate inverted siphons that conduct drainage from the northeast side of the creek across the creek, thus improving drainage for the entire area served by existing Glacier Key, Newport Key, and Lower Skagit Key outfalls. The **Storage and Upsizing Pipes** alternative would re-engineer the existing outfalls to Coal Creek to alleviate sediment blockage, upsize selected pipes and possibly add some stormwater storage capacity in the right-of-way to reduce peak flow. As indicated by the scores in Table 12, these two concepts were rated roughly equally at this stage; therefore, it was decided to use more detailed analysis to refine and compare both of these options in order to select a preferred alternative for reduction of storm drain flood risk.

7.3 Detailed Analysis of Shortlisted Alternatives

This section documents the flood risk reduction benefits of four shortlisted alternatives, two that target reduction in creek flood risk, and two that target reduction in local flooding of the Newport Shores storm drain system. Each of these alternatives is described in more detail and their respective flood risk reduction benefits are analyzed using the Coal Creek HEC-RAS backwater model or the Newport Shores drainage system SWMM model. At this stage of the project selection process, each alternative was analyzed independently of the others and not in combination. However, it must be acknowledged that the shortlisted creek alternatives could be combined for additive risk reduction benefits, and that lowered flood levels in the creek can also improve storm drain performance.

7.3.1 Creek Flooding Risk Reduction Alternatives

Two creek flooding risk reduction alternatives were analyzed using the HSPF hydrologic model and the HEC-RAS hydraulic model; 1) **I-405 Control Structure Redesign and Flood Storage Enhancement** which reduces peak flows by providing additional flood storage, and 2) **Newport Shores Culvert Replacements** which would upgrade the five road crossings in the Newport Shores neighborhood with larger, fish-friendly culverts that would eliminate backwater.

A further detailing of these alternatives and the analysis of their flood reduction performance are provided in the sections that follow.

7.3.1.1 *I-405 Control Structure Redesign and Flood Storage Enhancement*

This alternative would modifying the I-405 pond outlet control structure in order to more fully utilize available natural valley storage, thereby reducing downstream peak flows. This would be accomplished by further reducing the low level outlet opening from the existing cross-sectional area of 46 square feet to 12 square feet and eliminating the existing overflow weir. Additionally, two variants of the alternative were considered, one which would raise the emergency overflow level of the structure by 5 feet and another by 10 feet. In both variants, the emergency overflow capacity would remain the same as under current conditions. Ten feet is the maximum increase in the height of the structure that can be accommodated while allowing sufficient freeboard to protect roads and structures adjacent to the pond. The restricted opening forces higher operating water levels in the pond, which allows access to significantly greater valley storage than under existing conditions. As part of the project, the fill around the structure will need to be raised a commensurate amount to allow continued equipment access. This may require new retaining walls.

There is a fair amount of permitting, design, and operational uncertainty associated with this alternative that would need to be considered in the next phase of the Lower Coal Creek Flood Risk Reduction Project. Key areas requiring evaluations include:

- Metro sewer trunk line: Changes in duration and depth of flooding over the existing metro trunk line will need to be evaluated and potential retrofits designed to ensure continued function with adequate factors of safety.
- Dam Safety: Increasing the maximum water level in the pond may trigger state dam safety requirements requiring evaluation of the I-405 embankment that forms the impoundment.
- Hillslope stability. Both maximum water levels and the range of fluctuation will change with either variant of the alternative: risks to valley wall stability will need to be evaluated to ensure new landslides or sediment sources are not created.
- Debris Management: The floating log boom and debris rack currently in use at the pond has proved to be fairly effective in preventing debris problems within the structure. The proposed alternative will decrease the orifice size, potentially increasing the risk of blockage. The top spillway structure has never had significant overtopping, but this will change with the proposed alternative. Debris control structure design will be an important requirement, as will ensuring

good equipment access to remove debris. It is possible that a sliding lift gate may be desired in order to enhance debris management options.

The costs for the five-foot and ten-foot options are estimated to be around $980,000. It is not clear at this time whether there are constraints or thresholds that may limit the amount of rise or create large incremental cost increases with increasing structure height.

7.3.1.2 *I-405 Control Structure Redesign and Flood Storage Enhancement Benefits*

The five-foot and ten-foot variants of this alternative reduce peak flows entering the Newport Shores neighborhood by around 15% and 30%, respectively, across most large floods. This results in water level reductions throughout lower Coal Creek of around 0.5 and 1.0 feet, respectively. These reduced levels occur consistently along lower Coal Creek, benefiting all stream-side property owners equally and lowering water levels and backwater effects at culverts. On the negative side, the risk of debris blockage at culvert entrances is not significantly reduced because the culverts remain undersized. Also, water levels would not be reduced sufficiently to prevent backwater of the existing storm drain system and street flooding in a 100-yr event even if storm drain outfalls were not blocked by sediment.

7.3.1.3 *Newport Shores Culvert Replacements*

This alternative consists of replacing the five lower Coal Creek culverts in Newport Shores with new culverts. The culverts would be significantly larger and would be designed to meet Washington State fish passage criteria. For analysis purposes, 16-foot wide concrete box culverts countersunk to allow a natural sediment bed were assumed. As part of any culvert replacement, utility lines that currently traverse the barrel of existing culverts would be relocated outside of the culvert opening. At a minimum, it is assumed the existing stormwater culvert outfalls that are currently buried in sediment would be re-engineered to include higher outfalls. It is likely some work would be required on private properties up and downstream to provide engineered culvert approaches and exits. It is generally preferred to completely shut the crossing down during construction for efficiency, but this will not be possible in the case of the Cascade Key crossing because there is no alternative access to residences located to the south and west on Cascade Key, Columbia Key, and Crescent Key. It is likely full replacement would be accomplished over two years in order to minimize traffic and construction impacts and meet the short in-water construction window allowed for Lake Washington tributaries. The cost estimates for individual culvert replacements range from $720,000 to $890,000, with a total cost of $4,150,000.

7.3.1.4 *Culvert Replacement Benefits*

The alternative would remove the backwater effects exerted by the current culverts, thereby increasing conveyance capacity, reducing debris entrapment risks, increasing road freeboard, and meeting state fish passage criteria. The reduction in flood levels would vary by culvert, with maximum reductions at the upstream face of each culvert and benefits tapering off upstream. Figure 23 shows the reduction in water surface elevation that could be achieved with culvert replacement in the 100-year flood. The reductions due to the two I-405 pond variants are also shown for comparison.

While this alternative has been presented as a group, the culverts all create essentially independent backwaters and have varying levels of risk in their current condition. The five culvert replacements could be easily prioritized and phased, or could be combined with other alternatives. Culvert replacement is unlikely to independently provide significant improvement of backwater flood risk in the stormwater system, especially for outfalls located on the downstream side of culvert entrances where there is no reduction in creek flood level.

7.3.1.5 *Comparison of I-405 Modification and Culvert Replacement Flood Risk Reduction Benefits*

Table 13 and Figure 23 provide numerical and graphical comparisons of the flood risk reduction benefits of the two variants of the I-405 alternative and the Newport Shores culvert replacement alternative. These can be summarized as follows:

- Culvert replacement has the greatest benefit in reducing the 100-year flood level on the upstream side of Cascade Key crossing; at the other culverts, reductions are similar between the culvert replacement and the 5-foot variant of the I-405 alternative. At the other four crossings, the ten-foot I-405 alternative variant provides greater reductions (Table 13).
- The culvert replacement alternative does not reduce flood levels immediately downstream of the culverts, whereas both I-405 alternative variants do (Table 13). Reduced creek flood levels may provide some reduction in storm drain flood risk; however, even the ten-foot I-405 variant will not eliminate storm drain flooding.
- The I-405 alternative provides flood level reductions more uniformly along the entire length of Coal Creek in Newport Shores, whereas the culvert replacement alternative only lowers flood levels where they are caused by culvert backwater (Table 13, Table 14, and Figure 23).
- The I-405 alternative reduces the risk of debris entrapment at the crossings to some degree, but does not address the undersized culverts, hanging utilities, reliance on sediment flushing for conveyance, and sediment-blocked stormwater outfalls.

Table 13: Change in 100-year Flood Water Surface Elevation from Existing Conditions (feet)

	Culvert Replacement		I-405 with 5 ft Rise		I-405 with 10 ft Rise	
Culvert	US[1]	DS[1]	US	DS	US	DS
Cascade Key	-2.3	-0.1	-0.7	-0.4	-1.5	-0.7
Upper Skagit Key	-0.7	0.0	-0.6	-0.4	-1.3	-0.9
Glacier Key	-1.0	-0.1	-0.9	-0.5	-1.8	-1.0
Newport Key	-0.8	-0.1	-0.8	-0.5	-1.5	-0.9
Lower Skagit Key	-0.7	0.0	-0.8	-0.4	-1.5	-0.8

[1] US = upstream side of culvert, DS = downstream side of culvert

Table 14: Percent of Lower Coal Creek Reach with 100-year flood level reduction

Water Surface Reduction (ft)	Culvert Replacement	I-405- 5 ft Rise	I-405- 10 ft Rise
>0.00	99%	100%	100%
>0.25	44%	92%	96%
>0.50	28%	53%	90%
>1.00	10%	0%	54%
> 1.5	5%	0%	14%

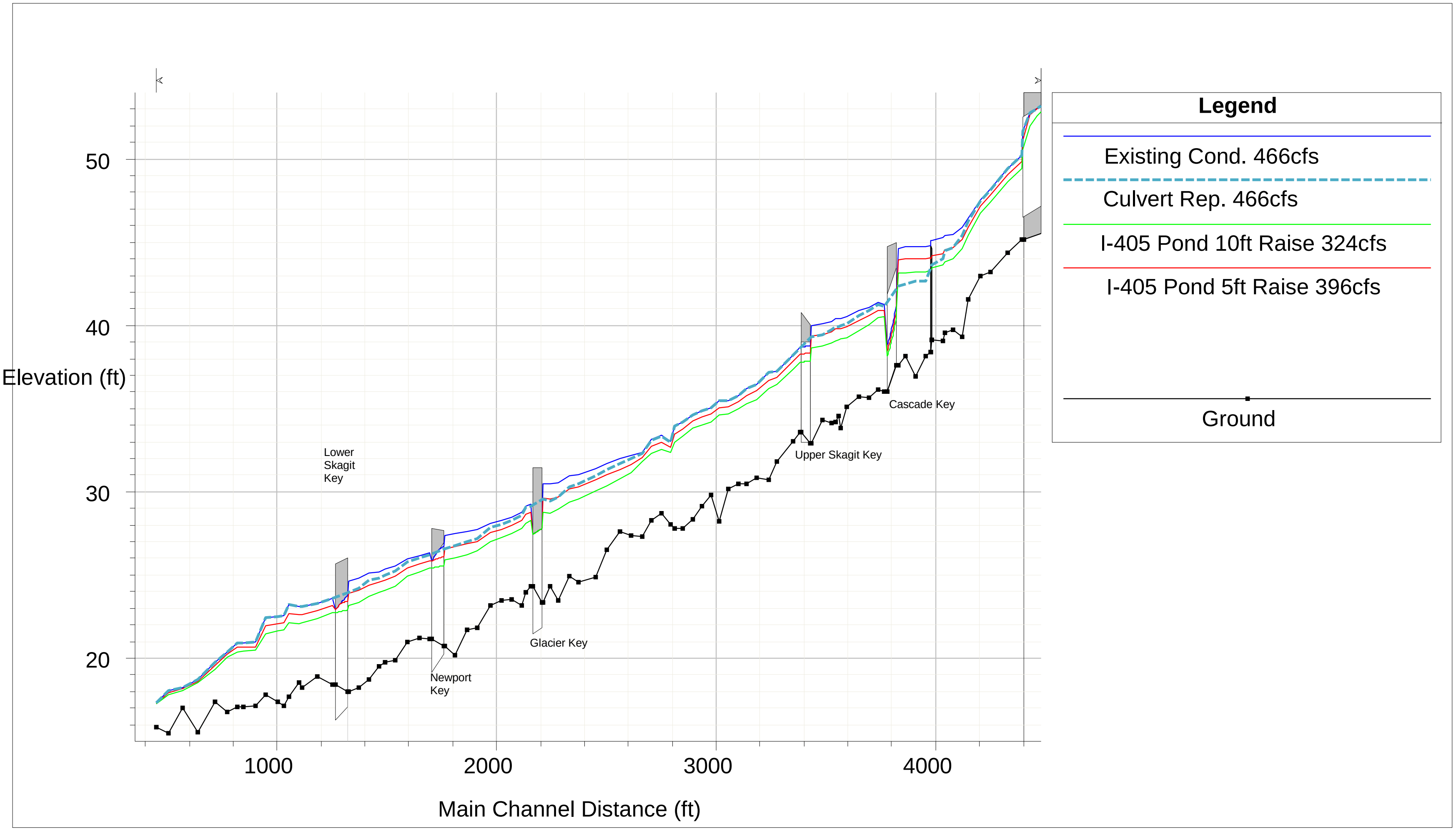

Figure 23. Flood Profiles for Stream Flood Risk Reduction Alternatives

7.3.2 Storm Drain Flood Reduction Alternatives

Two alternatives were developed to reduce flooding associated with storm drain surcharging and overflows in the portion of the Newport Shores neighborhood that discharges stormwater water to lower Coal Creek. As shown in Figure 19, this area is approximately bounded by Tulalip Key on the north, Lake Washington Blvd. on the east, and Skagit Key on the south and west.

The two drainage alternatives were each tested with 100-yr design inflow events and two different water level conditions at their respective storm drain outfalls. The Conveyance Improvement Alternative was tested with 2-yr recurrence intervals stream levels and 10-yr recurrence interval levels in Coal Creek. The second alternative abandons existing creek outfalls in favor of newly constructed outfalls to Lake Washington. This proposed alternative was tested with two lake levels, a conservatively high level for the winter, and an extremely high lake level equivalent to the highest recorded summer levels (18.75 NAVD88).

7.3.2.1 *Conveyance Improvement Alternative*

The conveyance improvement alternative will reduce flooding by replacing the existing storm drain system with larger diameter pipes where conveyance is restricted. Approximately 1,100 feet of pipe is proposed for replacement. High-level overflow pipes will be installed at the Lower Skagit Key and the Newport Key outfalls to Coal Creek to allow for flood relief during periods when sediment is blocking the existing outfall. Additional system-wide improvements are described below:

Lower Skagit Key Outfall East

- Replace 23 feet of 18-inch outfall pipe with 24-inch pipe.
- Install 23 feet of 24-inch new overflow pipe 4 feet higher than existing outfall.
- Replace 220 feet of 18-inch pipe on Skagit Key with 24-inch pipe.
- Replace 68 feet of 12-inch pipe on Lummi Key with 18-inch pipe.
- Planning level construction cost estimated to be $332,000.

Lower Skagit Key Outfall West

- Install 22 feet of 12-inch overflow pipe 3 feet higher than the existing outfall invert.
- Planning level construction cost estimated to be $8,000.

Newport Key

- Replace 42 feet of 12-inch outfall pipe with 18-inch pipe.
- Install 42 feet of 24-inch new overflow pipe 3.5 higher than existing outfall.
- Replace 115 feet of 18-inch pipe with 24-inch pipe.
- Planning level construction cost estimated to be $133,000.

Glacier Key

- Replace 188 feet of 12-inch pipe on Glacier Key with 18-inch pipe.
- Replace 348 feet of 12-inch pipe on Skagit Key with 18-inch pipe.
- Planning level construction cost estimated to be $233,000.

Figure 24 details the location of proposed replacement pipes for this alternative and also displays the locations where the model predicts stormwater overflows (red dots) or near-flooding conditions (yellow dots) for the 100-yr design storm and relatively mild high water conditions in Coal Creek corresponding to a 2-yr water level. As indicated by the figure, flooding is eliminated in the drain that runs along the southeastern portion of Skagit Key and discharges at the Glacier Key crossing. The peak rate of overflow to the SE 40th Street system does not change for the 100-year design event. Overall predicted flooding only occurs at one location indicated by two closely spaced red dots in the vicinity of 61 Skagit Key southwest of the lower Skagit Key creek crossing. This is compared with a total six overflow locations under existing conditions, three on Skagit Key and three on Lummi Key. However, incipient flooding conditions (as indicated by simulated water surfaces within 0.5 feet of street level) persist at multiple locations on Skagit Key, Tulalip Key, Lummi Key and Sucia Key. If flows in Coal Creek are at a 10-yr level during the 100-yr runoff event in Newport Shores, then extensive storm drain back-ups and associated street flooding are expected to occur throughout the neighborhood as shown in Figure 25.

The planning level project cost for this alternative is estimated to be $1,013,000. Planning cost includes construction cost (with 30% contingency), engineering and administration, and construction management. Cost estimates are documented in Appendix E.

Underground detention pipes were also considered as part of the Conveyance Improvement Alternative but were found to be ineffective for most areas due to the relatively high tailwater elevation in Coal Creek compared to the elevation of the storm drainage system and limited depth of cover at catch basins and inlets. The exception is upper Skagit Key between Glacier and Crescent Key where the storm drain and roadway are sufficiently high enough to install a detention pipe. However, preliminary estimates of the pipe size showed that the detention option would not provide a more cost effective solution when compared to simply replacing the existing storm drain system (as outlined above) nor would it provide better performance in meeting level of service goals.

7.3.2.2 *Three Outfall/Two Inverted Siphon Alternative*

The inverted siphon alternative will utilize a siphon configuration to convey storm flow under pressure below the Coal Creek culvert crossings to up to three new outfalls to Lake Washington. As noted earlier, the inverted siphon is a structure that enables storm drainage to flow under Coal Creek. It consists of a drop-manhole on the right bank, a short section of pipe beneath the creek bed, and another manhole on the left bank in which water rises to an outlet that allows continued free surface, gravity flow toward proposed new outfalls. Two such siphons and three outfalls are proposed for this scenario. Additionally, about 1,820 feet of pipe is proposed for replacement with 12- to 18-inch pipe. The siphon configuration will need to be determined during the design phase. Pipe replacement is proposed in the following locations:

Skagit Key

- Install 220 feet of 18-inch pipe outfall to Lake Washington.
- Replace 615 feet 18-inch pipe on Skagit Key with 18-inch pipe to provide positive slope to proposed outfall.
- Replace 220 feet of 18-inch pipe on Skagit Key with 12-inch pipe to provide positive slope to proposed outfall.
- Planning level construction cost estimated to be $447,000.

Newport Key

- Install 220 feet of 18-inch pipe outfall to Lake Washington.

- Replace 340 feet of 12-inch pipe on Skagit Key with 18-inch pipe.
- Install 150 feet of 18-inch pipe to connect Newport and Skagit Key downstream of siphon.
- Install 50 feet of 12-inch pipe for siphon under Newport Key.
- Replace 115 feet of 18-inch pipe on Newport Key with 18-inch to match the higher elevation of adjacent pipe to allow positive flow.
- Planning level construction cost estimated to be $356,000.

Glacier Key

- Install 160 feet of 18-inch pipe outfall to Lake Washington.
- Replace 240 feet of 12 inch pipe on Skagit Key with 18-inch pipe.
- Install 50 feet of 12-inch pipe for siphon under Glacier Key.
- Replace 295 feet of 12-inch pipe on Glacier Key with 12-inch pipe to match the higher profile elevation of adjacent pipe to allow positive flow.
- Planning level construction cost estimated to be $270,000.

This alternative may require water quality treatment for the three new outfalls. Basic TSS treatment could be provided by an underground vault or large manhole structure with one or more filter-media units installed to remove TSS and other pollutants. These systems need to be located far enough upstream from the outfalls to Lake Washington to allow sufficient head for their operation. For example, systems could be located at mid-block on Tulalip Key, Lummi Key near Skagit Key, Skagit Key near Newport Key, and Skagit Key between Crescent and Glacier Keys. High tailwater conditions (relative to the pipeline profile) in the lower Skagit Key drainage system between Newport Key and Lummi Key do not allow siting inline treatment systems. For these areas, catch basin insert or filter box units would be used to capture and treat stormwater runoff at street level where it enters the storm drain system.

As shown in Figure 26, the Inverted Siphon alternative eliminates surface flooding at all locations for up to the 100-year design event with at least 0.5 feet of freeboard during higher fall-winter lake levels. In the extremely unlikely event (much less than 1% annual probability of occurrence) that a 100-yr storm event occurs during the late spring or summer when lake levels are at the maximum recorded level of 18.75 feet NAV88, flooding is predicted at only one location on Lummi Key as shown in Figure 27 It should be noted; however, that even this isolated and rare instance of flooding could likely be eliminated by upsizing selected pipes connected to the proposed marina outfall. The overflow to the SE 40th Street system would be made obsolete by this alternative.

The planning level project cost for the Inverted Siphon alternative is estimated to be $1,765,000. Planning cost includes construction cost (with 30% contingency), engineering and administration, and construction management. Cost estimates are documented in the in Appendix E. With the addition of water quality treatment, the cost for this alternative would increase by approximately $250,000 to $2,015,000.

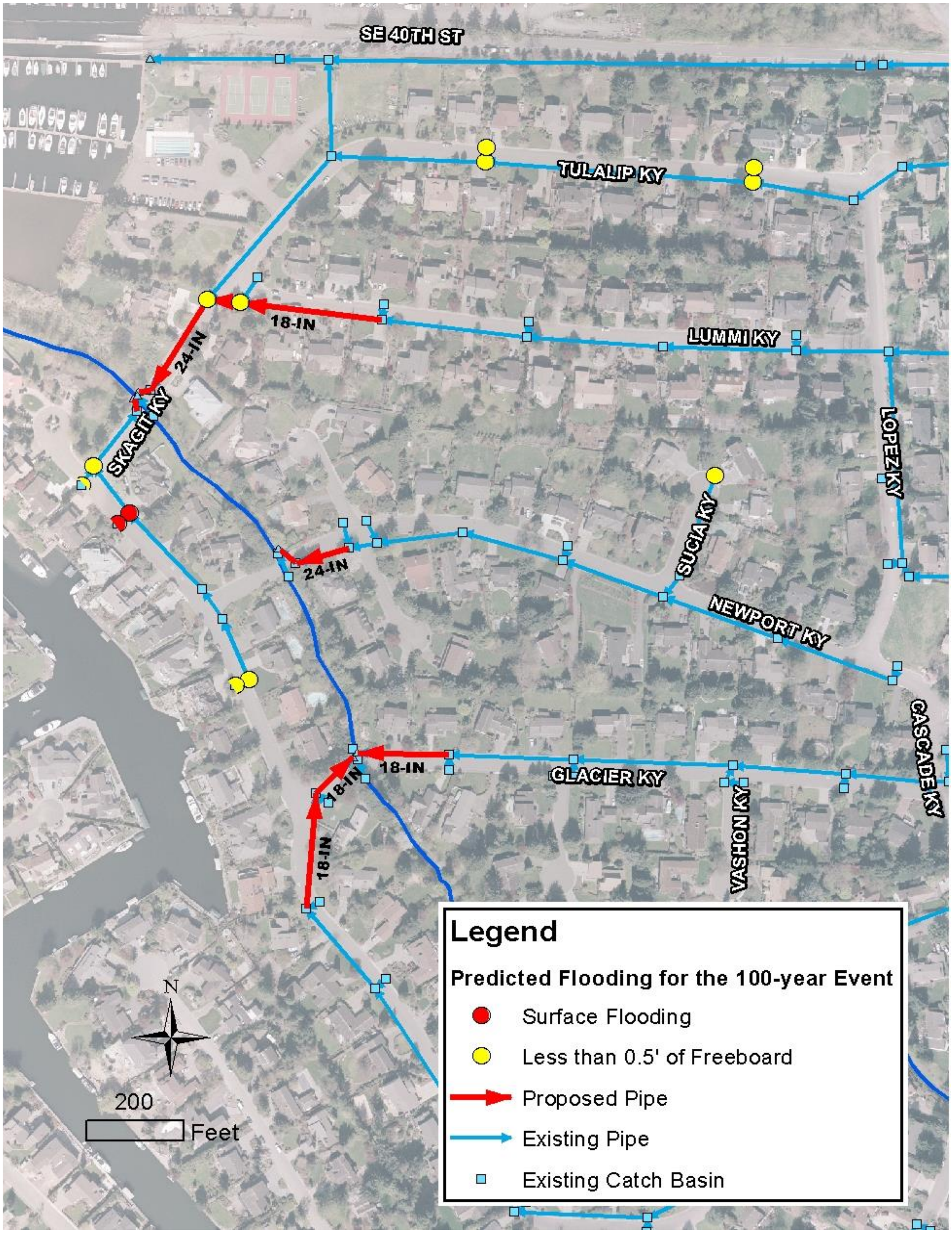

Figure 24. Conveyance Improvement Alternative, 100-yr storm drain inflow with 2-yr Coal Creek water level

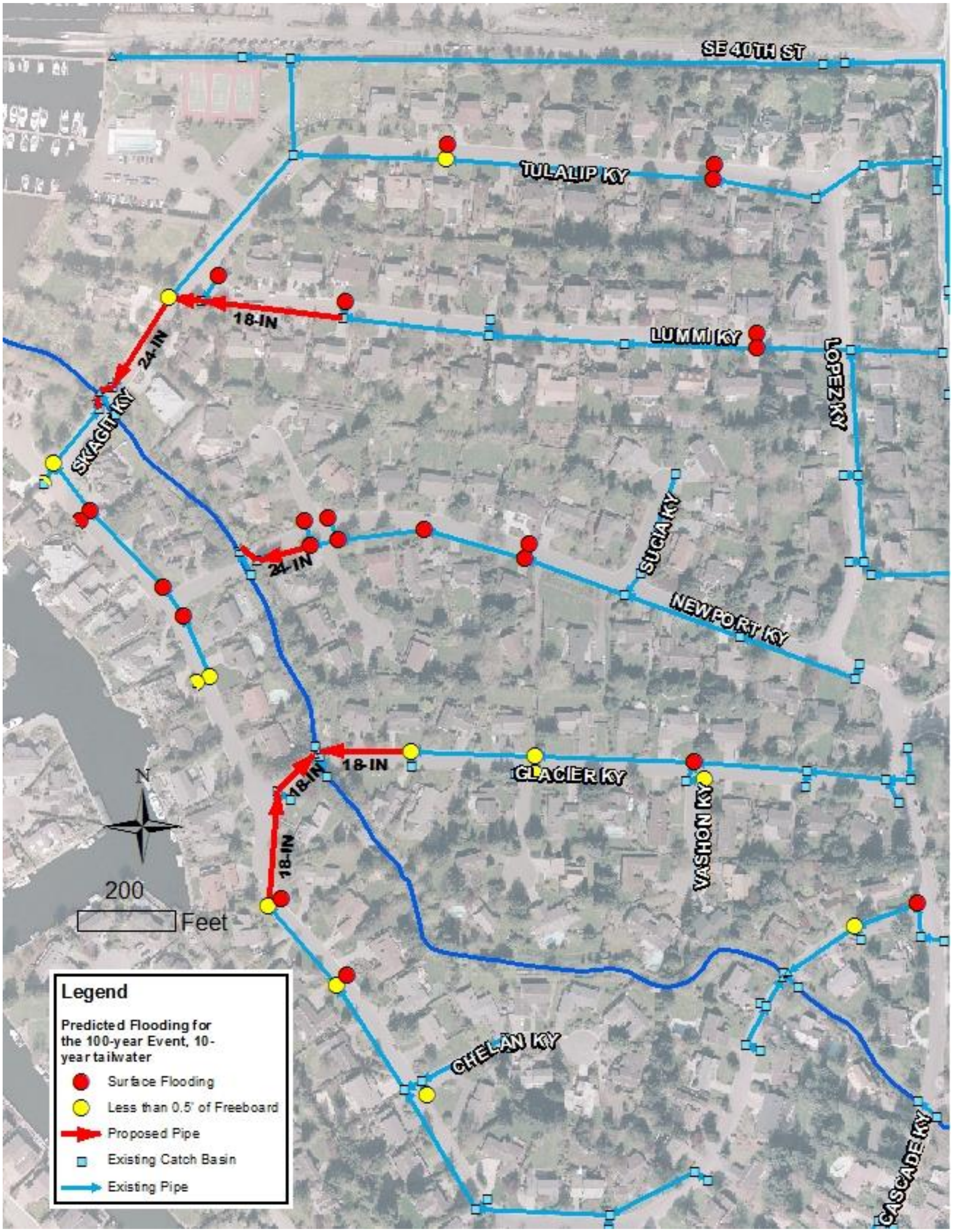

Figure 25. Conveyance Improvement Alternative, 100-yr storm drain inflow with 10-yr Coal Creek water level

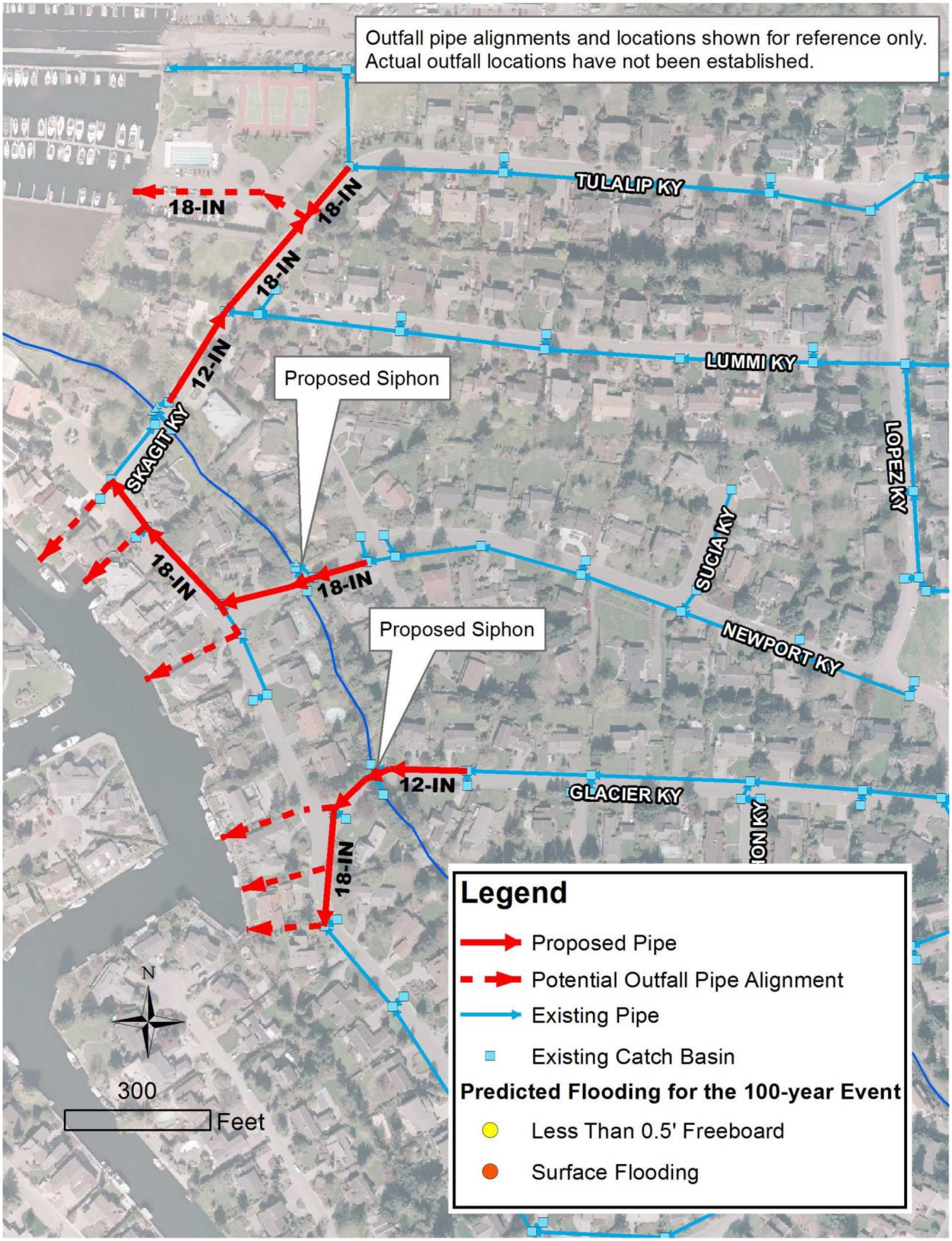

Figure 26. Three-Outfall Siphon Alternative with maximum fall-winter lake level (18.05 feet NAV88)

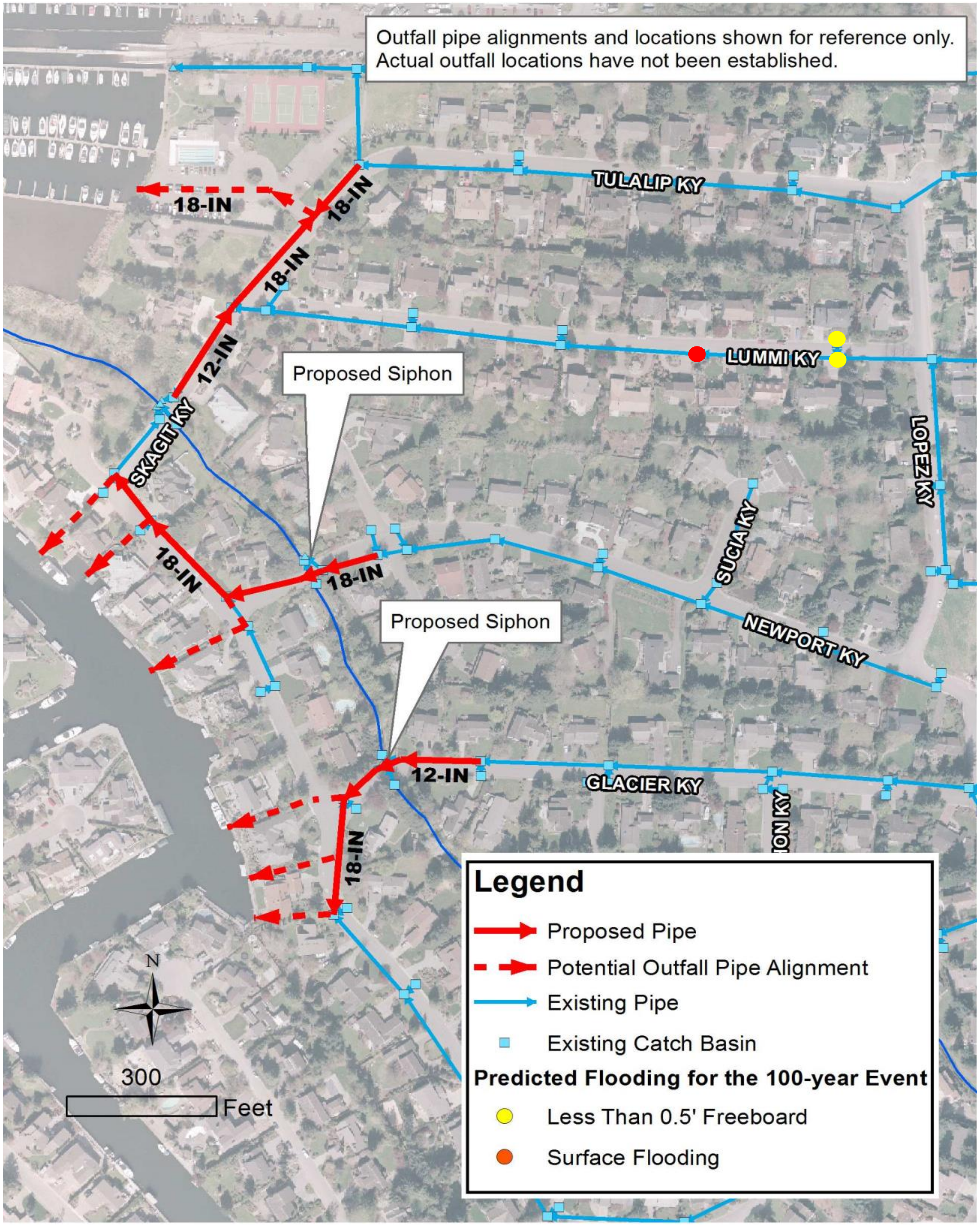

Figure 27. Three-Outfall Inverted Siphon Alternative with maximum spring-summer lake level (18.75 feet NAV88)

7.3.2.3 *Comparison of Drainage Benefits for Conveyance and Siphon Alternatives*

With the exception of incipient flooding (<0.5 feet of freeboard) at one site on Lummi Key near the intersection with Lopez Key, the alternative that includes siphons and new outfalls provides 100-year level of service for the drainage system within Newport Shores. In contrast the conveyance alternative continues to show storm drain flooding near 61 Skagit Key and incipient flooding at six additional locations spread across the drainage system that currently outfalls to Coal Creek.

7.4 Final Comparison and Scoring of Project Alternatives

Separate comparisons are made between the two shortlisted creek flood reduction projects and the two shortlisted storm drain improvement projects to arrive at a recommended project that consists of one creek alternative and one storm drain alternative. The criteria used to rate and compare the projects are described below. For each criterion, a numerical score ranging from 0 to 3 is assigned to each project based on a narrative assessment of relevant project characteristics. Final project scoring is based on a summation across all criteria that applies weighting factors to each criterion as described below.

Flood Risk Reduction- this rating is based on an interpretation of modeled flood risk reduction performance as analyzed in previous sections. Weight = 3.

Project Risk and Uncertainty- this criterion assesses the complexity of project engineering, need for additional study and coordination, uncertainty of project costs, as well as risks associated with project operations and potential malfunctions. Weight = 2.

Environmental Benefit- this rating is based on an assessment of opportunities to improve riparian and fish habitat. Weight = 1.

Permitability- this is based on difficulty in obtaining permits including the potential for delays associated with design modifications or negotiation mitigation measures. Weight = 1.

Project Modularity- this criterion rates flexibility to phase and ease in scheduling project construction. Weight = 1.

Neighborhood Impact and Acceptance- this criterion assesses impact on the neighborhood during project construction as well as perceptions and preferences expressed by residents during public meetings. Weight = 1.

Cost- this criterion assigns a score based on differences in estimated project cost. Weight = 1.

7.4.1 Final Comparison and Ranking of Creek Flood Reduction Alternatives

7.4.1.1 *Flood Risk Reduction Performance*

As shown in Figure 23 and Table 13, culvert replacements are most effective at reducing flood levels immediately upstream of the five road crossings in Newport Shores and the theoretical benefit of each replacement dissipates with upstream distance until it dies out at the next upstream road crossing. However, it should also be noted that new culverts will have a larger opening and provide much less opportunity for debris to collect at the upstream face of the culvert. In comparison, modification of the I-405 outlet structure would reduce the 100-yr discharge and provide more consistent reduction in the 100-year water surface elevation throughout the Newport Shores neighborhood. While both project alternatives provide significant flood hazard reduction benefits, the I-405 modification is judged to be superior for this criterion and is rated a 3 while the culvert replacements are rated 1.5.

Flood Risk Reduction Score	
Culvert Replacements	I-405 Outlet Modification
1.5	3

7.4.1.2 *Project Risk and Uncertainty*

Risk and uncertainty associated with the design and construction of culvert replacements is relatively low. Designs are based on well-defined standards and procedures, costs are generally well known, and construction experience with this type of project is extensive. The presence of utilities within some of the Newport Shores culverts and the need for their relocation, as well as the need to maintain appropriate access and traffic flow during construction are minor additional challenges associated with this alternative; therefore, culvert replacements are rated a relatively high score of 2 for this criterion. In comparison, there are several aspects of risk and uncertainty that would need to be resolved in the design and construction of I-405 modification as documented in previous sections of this report. These include the need to coordinate with King County and potentially design counter-measures to mitigate the impact of higher water levels on the sewer trunk line crossing of Coal Creek, the potential need for dam safety analysis, geotechnical studies, and additional design features to assure slope stability and pond safety including the installation of monitoring systems and emergency spillway gates to prevent overtopping. Additionally, WSDOT is considering replacement of the I-405 culvert with a bridge as part the I-405 widening project, which could impact design features, project costs, and schedule. These multiple factors render the I-405 outlet modification alternative relatively high in risk and uncertainty. Therefore, it is assigned a score of zero.

Project Risk and Uncertainty	
Culvert Replacements	I-405 Outlet Modification
2	0

7.4.1.3 *Environmental Benefit*

Culvert replacements provide an opportunity to install “stream simulation” fish-passable culverts that meet WDFW criteria. Additionally, replacements also generally incorporate enhancements to riparian habitat on both the upstream and downstream sides of the culvert. Modification of the I-405 outlet structure is not considered to provide an environmental benefit.

Environmental Benefit Score	
Culvert Replacements	I-405 Outlet Modification
3	0

7.4.1.4 *Permitability*

Replacement of older, hydraulically restrictive, culverts with fish-friendly designs have become fairly routine and generally have the support of both tribal and state fisheries co-managers. Ease of permitting is relatively high and scores a 3. Modification of the I-405 structure will increase both peaks and durations of water surfaces within the inline storage area with likely impacts to existing riparian wetlands. Additionally, permit reviewers have not been favorably disposed toward inline flood storage or sediment ponds as evidenced by COB's recent experience with Anna's Pond facility which was originally proposed as an inline sediment trap and had to be re-designed as an off-channel facility. The I-405 facility is, therefore, scored 1 indicating a comparatively difficult project to permit.

Permitability	
Culvert Replacements	I-405 Outlet Modification
3	1

7.4.1.5 *Project Modularity*

The culvert replacement alternative is inherently modular with the ability to replace a subset of the five culverts in successive construction seasons. It is scored 3 for modularity. The I-405 outlet modification alternative is less modular. While it would be possible to do an initial project with a five foot increase in structure height followed at some future point by another rise in structure height to up to ten feet, there would be significant additional costs related to changing the elevation of access for maintenance and operations, as well as relocating electrical, monitoring and control features. Therefore, it is assigned a score of zero.

Project Modularity	
Culvert Replacements	I-405 Outlet Modification
3	0

7.4.1.6 *Neighborhood Impact and Acceptance*

Culvert replacements will involve some inconvenience to Newport Shores residents. At least one resident expressed a concern that construction of new culverts would disrupt normal traffic and access to some homes in the neighborhood. Construction of the I-405 outlet modification would have much less direct impact on day-to-day life in the neighborhood; however, neighbors who prioritize Coal Creek aquatic habitat, may take issue with the alteration I-405 pond hydroperiod and its potential impact on fish habitat and riparian wetlands.

Neighborhood Impact and Acceptance	
Culvert Replacements	I-405 Outlet Modification
1	2

7.4.1.7 *Project Cost*

The preliminary cost estimate for replacement of all five Newport Shores culverts is approximately $4.2M dollars compared with approximately $1.0M for the I-405 outlet modification. This is a large difference in cost, but it should be noted that it is based on an assumption that all five culverts would be replaced. On this basis, the culvert replacement alternative is assigned a score of "1" compared to a score of "2" for the I-405 outlet modification.

Project Cost	
Culvert Replacements	I-405 Outlet Modification
1	2

7.4.1.8 *Total Score*

Application of scores with respective weighting factors results in the following total score:

		Un-Weighted Scores		Weighted Scores	
Criterion	Weight	Culvert Replacements	I-405 Outlet Modification	Culvert Replacements	I-405 Outlet Modification
Flood Risk Reduction	3	1.5	3	4.5	9
Project Risk and Uncertainty	2	2	0	4	0
Environmental Benefit	1	3	0	3	0
Permitability	1	3	1	3	1
Modularity	1	3	0	3	0
Neighborhood Impact & Acceptance	1	1	2	1	2
Project Cost	1	1	2	1	2
Total Relative Score				19.5	14.0

7.4.2 Final Comparison and Ranking of Storm Drain Flood Reduction Alternatives

7.4.2.1 *Flood Risk Reduction Performance*

Under existing conditions, incipient storm drain flooding is predicted to occur at multiple locations within Newport Shores on Skagit Key, Tulalip Key, and Lummi Key at a frequency greater than one in twenty five years under an assumption of clear pipes and Coal Creek water levels associated with a 2-yr peak flow. While the conveyance alternative reduces the frequency to less than one in 25-year; during a 100-year runoff event, street flooding is predicted at a sag point near 61 Skagit Key, and incipient flooding (less than 0.5 feet of freeboard) is predicted at a half dozen other locations. Furthermore, if the 100-yr local runoff coincides with a Coal Creek water surface level that is equal or greater than the 10-yr level (not an unlikely coincidence), predicted flooding is widespread throughout the Newport Shores neighborhood.

The Inverted Siphon alternative allows drainage to cross the creek at Glacier and Newport Skagit Key to connect to two proposed outfalls to the Grand Canal. Additionally, Lummi Key and Tulalip Key drainage is improved by a third proposed outfall in the Newport Yacht Club marina. This alternative would virtually eliminate flooding up to a 100-year runoff event for lake levels occurring during the fall and winter. In the unlikely coincidence of a 100-year runoff event with the maximum summer Lake Washington level of record 18.75 NAV88, flooding is predicted at a single location on Lummi Key; however, this could likely be relieved by increasing selected pipe sizes. Based on these results, the conveyance alternative is assigned a score of 1 and the siphon alternative is assigned a score of 3.

Flood Risk Reduction Performance	
Conveyance	Inverted Siphons and New Outfalls
1	3

7.4.2.2 *Project Risk and Uncertainty*

The conveyance alternative primarily involves upsizing selected drain pipes and improving the design of existing storm outfalls to Coal Creek. Engineering and cost analysis of this alternative is generally straightforward. Operational risks of this alternative are associated with the concurrence of high creek levels with Newport Shores peak storm runoff and resultant blockage of drainage; however, this shortcoming has already been accounted for above by the flood risk reduction performance rating. By comparison, the siphon alternative requires acquisition of a stormwater right-of-way across existing residential properties and the yacht club to access the lake at the Grand Canal and marina. However, there is some flexibility in the alignment of proposed outfalls, number of inverted siphons, and even in their number of new outfalls. This flexibility is reflected in this alternative's modularity rating below. Primarily, on the basis of the need for acquisition of outfall easements, the siphon alternative is rated a 1 and the conveyance alternative is rated a 3 (low risk/uncertainty) for this criterion.

Project Risk and Uncertainty	
Conveyance	Inverted Siphons and New Outfalls
3	1

7.4.2.3 *Environmental Benefit*

The conveyance alternative does not include any environmental benefit. It is rated zero for this criterion. The siphon alternative includes basic water quality treatment prior to discharge into Lake Washington at the Grand Canal. This is judged to provide an environmental benefit to both the lake and the creek and is assigned a rating of 2.

Environmental Benefit Score	
Conveyance	Inverted Siphons and New Outfalls
0	2

7.4.2.4 *Permitability*

Compared to the conveyance alternative, the siphon alternative appears to involve a somewhat more complex permitting process due to the need to cross the creek with the inverted siphons, and introduce two new outfalls into Lake Washington. Based on these considerations, the conveyance alternative is assigned a maximum score of 3 and the siphon alternative is assigned a value of 1.

Permitability	
Conveyance	Inverted Siphons and New Outfalls
3	1

7.4.2.5 *Project Modularity*

Both projects involve work activities at pipe replacements and work at multiple outfalls. Each can be phased and coordinated with culvert replacement work. However, given that the siphon alternative can achieve significantly better flood risk reduction performance under multiple configurations of outfall location, number of siphons, and number of outfalls, it is rated a 3 compared to a 2 for the conveyance alternative.

Project Modularity	
Conveyance	Inverted Siphons and New Outfalls
2	3

7.4.2.6 *Neighborhood Impact and Acceptance*

The siphon alternative presents an additional challenge with regard to neighborhood impact and acceptance compared to the conveyance alternative, because of the need to traverse residential property and introduce stormwater outfalls to the Grand Canal. The degree of neighborhood acceptance of this alternative depends on the ability to effectively communicate its superior flood risk reduction performance, water quality, and environmental advantages to the Newport Shores community. Additionally, chances of neighborhood rejection of the siphon alternative would depend on the success in securing the necessary right-of-way for each new outfall through negotiation with property owners. If right-of-way could be secured for each of the proposed outfalls, resistance to the siphon alternative could be partially or completely neutralized. The improved conveyance alternative offers only marginal flood risk reduction benefit and it's presumed that neighborhood acceptance of this alternative would not be well received. On the basis of these considerations, the conveyance alternative is ranked a 1 and the siphon alternative is ranked a 2.

Neighborhood Impact and Acceptance	
Conveyance	Inverted Siphons and New Outfalls
1	2

7.4.2.7 *Project Cost*

The siphon alternative is estimated to cost approximately $1.6M. This includes the cost of basic water quality treatment, but does not include any cost associated with right-of-way acquisition for the new outfalls. By comparison the conveyance alternative is estimated to cost approximately $1.0M. On this basis, a score of 1 is assigned to the siphon alternative and a score of 3 is assigned to the conveyance alternative.

Project Cost	
Conveyance	Inverted Siphons and New Outfalls
3	1

7.4.2.8 *Total Score*

Application of scores with respective weighting factors results in the following total score:

		Un-Weighted Scores		Weighted Scores	
Criterion	Weight	Conveyance	Inverted Siphons and New Outfalls	Conveyance	Inverted Siphons and New Outfalls
Flood Risk Reduction	3	1	3	3	9
Project Risk and Uncertainty	2	3	1	6	2
Environmental Benefit	1	0	2	0	2
Permitability	1	3	1	3	1
Modularity	1	2	3	2	3
Neighborhood Impact & Acceptance	1	1	2	1	2
Project Cost	1	3	1	3	1
Total Relative Score				18	20

The Inverted Siphon alternative significantly outperforms the conveyance alternative in reducing the risk of storm drain flooding; however, its total score considering all factors is only 2 points greater than that of the conveyance alternative. This is largely due to the need to acquire easements to cross private, residential, and community-owned property to allow for new storm drain outfalls to Lake Washington. This affects project uncertainty, permitting difficulty, and neighborhood acceptance ratings. If a drainage easement can be secured for even one of the three proposed new outfalls this alternative should be pursued. If this is not possible, then the conveyance alternative could be considered; however, this alternative's flood risk reduction performance is limited by reliance on existing outfalls to Coal Creek and the likelihood of backwater flooding during storms. If new outfalls cannot be constructed, additional drainage improvements should be considered to assure that storm drain overflows remain in the street and do not enter adjacent yards and residences. This may include raising sidewalks or curbs, or by demonstrating through a refined storm drain model and analysis that includes street and side walk geometry that private property flooding will not occur as a result of overflows during a 100-yr event.

7.5 Summary and Recommendations

Large storms in the Coal Creek basin cause creek levels to rise and are responsible for two related, mechanisms of flooding in the Newport Shores neighborhood. Direct flooding occurs when the creek rises high enough to escape its banks and flows across residential parcels or within the street system. This direct flooding is often aggravated by restrictive culverts which may be partially occluded by debris that has accumulated at the culvert entrances. Even when the creek does not rise high enough to cause direct flooding, indirect flooding may occur when a severe storm produces local runoff in the Newport Shores storm drain network which currently relies on outfalls to the creek to drain local stormwater runoff. To reduce flood risk in Newport Shores requires distinct measures be taken to manage both types of flooding.

7.5.1 Creek Flood Risk Reduction

To lower flood risk from direct Creek flooding, an initial screening and ranking of several options determined that the two most promising alternatives involved either peak flow reduction through modification of the I-405 pond outlet structure with resultant increases in flood storage, or conveyance improvement within Newport Shores through replacement of existing culverts that meet current hydraulic and fish passage standards. While hydrologic and hydraulic modeling demonstrated that modification of the I-405 control structure to increase flood storage could theoretically provide a larger flood risk reduction benefit in Newport Shore, this alternative fell short due to considerations of engineering uncertainty, coordination, environmental benefit, and permitting difficulty. Therefore replacement of culvert replacement alternative was found to be the more viable option.

7.5.2 Supplemental Recommendation Related to Creek Flood Risk Reduction

Field observations by the technical team noted that there are several locations along Coal Creek where trees or other obstructions are encroaching on the creek. These obstructions can locally affect channel capacity, aggravate both debris blockages and channel erosion, and increase local flood risk. Stream-side homeowners also raised a range of concerns related to a lack of clarity regarding responsibility and permitting of stream side vegetation management. In order to address these concerns, it is recommended that the City work with the Newport Shores Yacht Club (HOA) to develop “fact sheets” for streamside property owners that provide information about stewardship of their streamside property. Specific to the Newport Shores reach of Coal Creek, it is recommended that the City continue public outreach efforts to disseminate stewardship principals discussed in the fact sheets. Fact sheet objectives would include establishing a clear statement of roles and responsibilities with respect to vegetation management, clarifying permitable and non-permitable activities, providing guidance on permitting procedures, recommending a list of suitable plant species for re-plantings. The “fact sheets” should both address the needs of Coal Creek streamside owners and be a tool to promote a common, long-range, understanding for stream-side stewardship throughout the City.

7.5.3 Storm Drain Flood Risk Reduction

Two alternatives were considered to reduce street flooding and potential for associated flooding of private property within Newport Shores. One relied on upsizing pipes and improving existing creek outfalls to minimize clogging by sediment, and the other which combined upsizing of selected pipes, with replacement of Coal Creek storm outfalls with more direct piped connections to Lake Washington. Each alternative was analyzed using EPA-SWMM with a range of boundary conditions to reflect water levels in the creek. The second alternative that replaces creek outfalls requires installation of inverted siphons to allow right bank storm flow to cross under the creek and reach new outfalls on the Grand Canal. Hydraulic modeling results clearly demonstrated that upsizing pipes alone would not significantly reduce the risk of storm drain flooding when Coal Creek is experiencing 10-year or larger floods. In contrast, with the inverted siphons and new outfalls, 100-yr level of service is achieved. These results clearly demonstrated the superiority of the inverted siphon-outfall alternative; however, to implement this alternative, up to three new drainage easements will be required. Nevertheless, this alternative is recommended as the preferred approach to address storm drain flooding. Two of these easements would cross residential property adjacent to the Grand Canal. For each of these outfalls, multiple, viable alternative parcels have been identified.

7.5.4 Phasing Implementation of Recommended Combined Alternative

While the flood reduction benefits of the proposed additional stormwater outfalls is quite clear, as a practical matter, the requirement of securing easements to cross private property may require an extended period of negotiations to accomplish. In contrast, improvements within the existing road right-of-way including the recommended culvert replacements and stream crossings with inverted siphons for the drainage system are not subject to this potential delay. Therefore, it is recommended that the replacement of culverts at Cascade Key, upper Skagit Key, Glacier Key, Newport Key, and lower Skagit Key go forward to the design and construction phase as soon as is practicable. Additionally, it is recommended that three inverted siphons at Glacier Key, Newport Key, and Lower Skagit Key crossings also go forward to the design and construction phase as these drainage system improvements must cross under the new culverts. This will facilitate the eventual comprehensive improvement of the drainage system once outfall easements have been secured.

8 References

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Appendix A

Highlights of Literature and Data Review

A.1 Time Series Data

Relevant time series data consist of continuous records of meteorological parameters (precipitation and potential evapotranspiration), stream stages, and detention pond levels. These data were instrumental in the updating and calibration of both the hydrologic model of the entire Coal Creek basin and the hydraulic model of the study areas which extended from the I-405 pond downstream to the mouth of Coal Creek at Lake Washington.

A.1.1 Meteorological Data

In 2004, NHC assembled a continuous long term hourly precipitation and daily pan evaporation record for the period WY 1949 through March 8, 2004. The data sources for these records included more recent King County precipitation records, long term NWS hourly precipitation record at Landsburg, non-winter, and daily pan evaporation data at Puyallup which had been filled and extended using temperature-based equations and monthly average values. King County began collecting continuous 15-minute precipitation totals in May Valley (KC 37U) in water year 1991 and on Cougar Mountain (KC 63Y) in WY 1997. These data were loaded into a WDM file to support HSPF modeling of the Coal Creek basin. In addition to the King County rain gage sites, there is also a City of Bellevue rain gage at the I-405 detention facility. With some gaps, hourly precipitation has been collected at this site from water year 1996 to present.

A.1.2 Stage and Water Elevation Data

Two relevant datasets include stream stage data for Coal Creek at the Newport Key crossing and water surface elevations in the I-405 detention pond.

A.1.3 Newport Key Coal Creek Stages

Stream stage data and direct measurements of discharge have been collected by the City of Bellevue in Lower Coal Creek on the downstream side of the Newport Key crossing during May-September, 2004 and intermittently from May 2008 to present. The data are contained in multiple EXCEL files organized by calendar year with one tab per month. Two stream rating curves derived from two periods of direct measurement (1989-1990 and 2011-2013) are available to convert stream stages to discharges. The two sets of measurements have zero discharge stages that differ by about 1.0 ft; however, by correcting recorded stages by subtracting the zero discharge stage for each set, the relationships of corrected stage to discharge estimated by the two periods are reasonably consistent over a range from near zero discharge to 250 cfs.

A.1.4 I-405 Pond Elevations

The water elevation record from the I-405 detention pond consists of hourly minimum, maximum, and average stages (correction factor converting stage to elevation is 49.0 feet NAVD 88) in the I-405 pond for two periods WY 1989-WY1998 and April 2, 2007 through WY 2012. The CCSP EIS (Tetra Tech, 2006) reports an updated elevation-storage-discharge curve for this facility based on a COB reassessment of pond bathymetry and a HEC-RAS backwater analysis through the pond control structure that was performed by Entranco (2004). However, since there is only a small amount of local inflow and no significant storage between the I-405 site and the Coal Creek stream gage site near Newport Key, the two records can be used as a checked against each other.

A.1.5 Relevance of Data

These two stage-elevation datasets provide useful checks on each other because the local inflow between the two sites is small and hydraulic storage is also minimal downstream of the I-405 crossing. In combination, these records allow checking and updating the HSPF model used for the EIS (see below) model as well as recalibration of the HEC-RAS model. Additionally, the Lake Washington elevation record is available for download from the USGS and could be used to set a downstream boundary condition for backwater analysis during specific floods or seasons

A.2 Past Geomorphic and Sediment Transport Analyses

A.2.1 Delta Morphology

The first assessment of Coal Creek delta morphology was performed circa 1984, as part of the Coal Creek Basin Plan (King County and City of Bellevue, 1986). Channel alignment, planform morphology, and areal delta growth were evaluated using aerial photos dating from 1936 to 1980. Delta depth was estimated through field probing of deposited sediment and delta volume was calculated using these data. An average sediment delivery rate to the delta was calculated then compared to total sediment loads derived from grain size data, suspended sediment, discharge measurements. This analysis showed that during the mid-1980s, the Newport Hills tributary was delivering a disproportionately high sediment load.

In 1997, delta and channel sedimentation was revisited using updated aerial photography, grain size analysis, and hydraulic model data (Spearman Engineering, 1997). The upstream reach of Coal Creek above the Coal Creek Parkway was subdivided for the purpose of identifying approximate locations of primary and secondary sources of material. Average current and future sediment delivery rates to the delta were estimated to estimate reductions in sediment delivery to the delta associated with operation of the Coal Creek Parkway and I-405 sedimentation ponds, two structures that were built to capture excess sediment.

In 2003-2004, NHC performed a re-evaluation of sedimentation in the Coal Creek delta and channel. The re-evaluation included updated analyses of areal and volumetric delta growth using aerial photo and bathymetric data collected in 1997 and 2003. Upstream a sub-reach analysis was conducted to apportion sediment delivery among bank erosion, stream incision, and channel storage sources.

A.2.2 Delta Morphology Relevance

Understanding of past delta morphology provides valuable information on variations in the rates of historic sediment delivery, as well as changes in the composition of deposited material. These data support evaluation of the long term pattern of sedimentation that is needed to assess the durability of flood hazard reduction alternatives over time.

A.2.3 Channel Bed Profile Data

The earliest available channel profile of lower Coal Creek is from a FEMA flood profile of the reach circa 1977. Subsequently, the City of Bellevue has surveyed profiles through the Newport Shores neighborhood seven times between 1985 and 2000. The profile surveyed in July 1991 only includes the reach from Glacier Key to Upper Skagit Key. In addition, the channel excavation line between Glacier Key and Upper Skagit Key, presumably from the 1987 and 1991 dredging projects, is also available. Table A1 summarizes currently available channel profile data, source, and format.

Table A1: Summary of Available Coal Creek Profile Data

Date	Source	Format
1977	**FEMA**	**Hard copy, digitized**
January 1985	**City of Bellevue**	**AutoCAD**
January 1986	**City of Bellevue**	**AutoCAD**
February 1987	**City of Bellevue**	**AutoCAD**

July 1991 - partial	**City of Bellevue**	**AutoCAD**
October 1994	**City of Bellevue**	**AutoCAD**
February 1996	**City of Bellevue**	**AutoCAD**
March 2000	**City of Bellevue**	**AutoCAD**

A.2.4 Channel Profile Data Relevance

Historic channel profile data provides information on the characteristics of sediment transport and deposition within the Newport Shores neighborhood. In particular, they provide insight on past rates of loading, correlations with flood events, and impacts of past management activities (e.g. dredging). The historic profiles listed in Table A1 were augmented with a detailed channel survey conducted by COB in August, 2013 to support this project.

A.2.5 Sediment Sampling

The earliest bed material samples collected on Coal Creek are those documented in the Coal Creek Basin Plan (1986). Three bulk samples of the top six inches of streambed material were collected in the channel reach within the Newport Shores Neighborhood. An additional eleven samples were collected on the top six inches of the active Coal Creek delta. Individual grain size distribution curves were reported for the three samples taken in the upstream channel. The eleven delta samples were reported as a range with only the maximum, minimum, and mean grain size distribution curves.

Between February 27-28, 1987, core (bulk) samples of bed material were collected at six locations along lower Coal Creek and reported in a Hydraulic Project Application (HPA) prepared by the City of Bellevue (COB, 1990). The HPA was prepared for the proposed 1991 dredging of the Coal Creek channel. Core samples were collected at depths up to three feet at irregular intervals spread between lower and upper Skagit Key crossings. Tabular grain size distributions for each sample were presented; although, standard size classes were not employed and material coarser than 50 mm were lumped as a single fraction.

In 1996, NHC collected four bulk sediment samples along the lower channel and delta of Coal Creek (NHC, 1996). Two samples were collected in the channel, one 50 feet upstream of Glacier Key and one at the upstream face of Newport Key. The remaining two samples on the delta were collected at the head (Station -3+50) and just downstream of the delta bar (Station -4+50). For all samples, grain size distributions were given both graphical (curve) and tabular format.

In 2003, NHC collected nine bulk samples from the Coal Creek delta and nine bulk samples from the upstream channel from I-405 to the Coal Creek Parkway Sedimentation Pond. Samples were sieved in a laboratory to provide grain size distributions in both graphical and tabular format. In addition to obtaining grain size distributions for the delta sediment, sediment lithology, based on specific gravity tests, was evaluated to differentiate between native substrate and that from mine waste. A single pebble count was also performed at the mouth of the Newport Hills Tributary to obtain surface gradation at the site.

Additional bed material samples have been collected on Coal Creek, but they have limited relevance to the current analysis. In 1984, five test pit samples were collected at the upstream Cinder Mine site (Hart-Crowser, 1984). Between 1996 and 1997, a monitoring project was conducted just downstream of Coal Creek Parkway to evaluate impacts associated with the recently constructed sedimentation pond (Johnson et al, 1997). Sediment sampling for this project consisted of pebble counts conducted at 18 cross-sections in March 1996, November 1996, and May 1997. In 2000, a single bulk sample was collected at the I-405 facility (CH2M Hill, 2000).

A.2.6 Sediment Sampling Relevance

Previously collected sediment samples were used as a baseline to evaluate recent spatial and temporal changes in channel bed material composition along lower Coal Creek. These data, together with five pebble counts collected as part of this study were used to gain insight into historic and current sediment composition and transport conditions in Newport Shores.

A.2.7 Sediment Maintenance

The City of Bellevue provided NHC with annual maintenance records for the three existing sedimentation ponds on Coal Creek (email comm., 5/8/2013). Records begin in 1995 at the I-405 facility, and in 1997 at the Coal Creek Parkway facility. The record for the recently constructed off-line pond located between Coal Creek Parkway and I-405 on 125th Ave SE, referred to by the COB as "Anna's Pond", begins in 2010. Table A2 summarizes the volumes of sediment removed each year at the three facilities. Years with blank entries following inauguration of each of these facilities indicate that insufficient sediment was collected to make removal worthwhile. Formal records of the composition of the material excavated from the ponds is not kept by the COB, but based on anecdotal information provided by COB staff, the material is 50% fine to sandy sediment, 25% small to medium gravel, and 25% vegetative debris, on average.

A.2.8 Sediment Maintenance Relevance

Maintenance records provide information on recent changes to upstream sediment budget of Coal Creek and can be correlated with conditions observed downstream in Newport Shores and the delta at Lake Washington.

Table A2: Coal Creek Sedimentation Pond Maintenance Record

	Volume of Sediment and Debris Excavated (cubic yards)		
Year	**Coal Creek Parkway**	**Anna's Pond**	**I-405**
1995	Facility not yet constructed/on line.	Facility not yet constructed/on line.	400
1996			600
1997	500		300
1998	800		350
1999	2,300		180
2000	Insufficient material to warrant removal		Insufficient material to warrant removal
2001			
2002	1,700		
2003	500		
2004	1,500		410
2005	1,100		90
2006	1,400		700
2007	1,100		400
2008	1,865		700
2009	1,700		400
2010	1,000		300
2011	2,200	1,100	300
2012	1,134	276	320
Total	*18,799*	*1,376*	*5,450*

A.2.9 Sediment Maintenance Data Needs

Grain size sampling or possibly just visual inspection of material removed in 2013 could be valuable to understanding the composition of material being captured at each facility.

A.3 Spatial (GIS) Data

NHC has collected an inventory of GIS data consisting of shapefiles, imagery, topography, and basemaps. The City of Bellevue provided shapefiles for water, storm, and sewer features in the project area. Additionally, the COB provided high resolution (0.3 inch raster) orthoimagery to augment USDA-sourced coarser imagery in NHC's GIS library. Topographic data consists of the 2010 Puget Sound LiDAR Consortium 6' raster data set and a higher resolution TIN with ±1.0 foot accuracy suitable for 1' rasterization provided by the COB. Additional coverages including hydrography, parcels, and roads were sourced from King County's GIS library. These GIS datasets will be used in analyzing and documenting existing flood conditions as well as flood risk reduction alternatives.

A.4 Digital Photos

A set of digital photos taken during flood conditions on December 3, 2007 and December 12, 2010 were provided to NHC for review. This set of photos has been augmented by photos taken by NHC in the wet season of 2012-2013; however, peak flows did not exceed bankfull conditions during these more recent events. Using a selection of these photos, NHC created an ArcGIS map (.mxd file) of photo points and an Excel database that includes file pathnames for photos taken at mapped points. A user can click on the points in GIS and obtain a pop up image of the photo. The excel database also includes a timestamp and interpretation of the stream, drainage, or flooding condition or mechanism depicted in the photo. Readme directions are included in map folders in order to allow for the addition or editing of the mapping files. This GIS-linked photo archive is provided in a digital appendix (See Appendix B of this report for further information).

The photos collection allows for a spatial and visual representation of flooding conditions in Coal Creek. This directory also illustrates problem locations, as well as locations where more photos are needed. A qualitative analysis of flooding conditions allows us to evaluate hydraulic models.

A.5 Hydrologic and Hydraulic Models

A.5.1 HSPF Hydrologic Model

An HSPF hydrologic model was used to analyze flood flows and develop design discharges for lower Coal Creek within the Newport Shores neighborhood. This section describes the history of the model and the updates that were made during the current project.

A.5.1.1 *Original Basin Plan Model*

The original Coal Creek Basin HSPF model was created to support the Coal Creek Basin Plan (King County and City of Bellevue, 1986) circa 1984. The model was calibrated using mean daily data from the old USGS site 12119700 located above the confluence with the Newport Hills Tributary. The calibration model was set up to reflect 1965 land use conditions consistent with the USGS period of record at the time (1/64-9/68). It used two pervious land use hydrologic response units (HRUs) for grass and forest and only a single soil representing till and bed rock. At that time, the basin upstream of the gage site was almost completely tree-covered with less than 3% total impervious area, mainly associated with paved roads. After calibration, the model land use was updated to reflect 1983 development conditions (>10% total impervious area) for production runs and model validation to hourly data at Metro flow measurement sites. Calibration results for monthly discharges were typically within 5% of recorded values. Additionally, 75% of 16 mean daily peaks exceeding 75 cfs were matched within 50% of measured values, and simulated peak daily values appeared to be largely unbiased; i.e. the number and magnitude of overestimates was in balance with the number and magnitude of underestimates. These calibration results indicate that the basin plan model provided accurate estimates of monthly mean discharge, only fair estimates of the largest daily means, and was of unknown accuracy in the estimation of hourly, or shorter time step peak flows. The relatively large peak daily error compared to monthly error suggests that the rainfall data used to drive the model were not of sufficient accuracy or spatial resolution. Note that no precipitation data were collected within the basin during the calibration period. Therefore, it was necessary to transpose data from Seatac Airport based on correlation analysis with short term rainfall records in closer proximity to the Coal Creek basin. This approach was used to derive a multiplier of 1.25 which was assumed to apply uniformly to the entire basin during calibration runs.

The Basin Plan documents did not report statistics or graphical comparisons for model verification; however, they indicate that the model fit to hourly flow records in the mid-1980s was not as good as the fit during calibration.

A.5.1.2 *HSPF Model Update for Sustainable Flood Damage Prevention*

In 1996 as part of the Sustainable Flood Damage Prevention Plan for The Skagit Key Reach of Coal Creek (Spearman Engineering, 1997), NHC updated the basin plan model to include development of residential housing on 464 acres of land that had previously been predominantly forested at the time of the basin plan. Additionally two detention facilities at I-405 and Coal Creek Parkway which had come on line were included in the model and the basin plan's transposed Seatac precipitation record was extended for water years 1989 through 1996 using King County's 37U May Creek gage located at Coal Creek Parkway with no multiplier.

In 2004, NHC made major revisions to the 1996 model including:

- Re-delineation of subbasins based on GIS datasets for topography and drainage.
- Updating of land use delineations using 2001 aerial photographs.
- Re-mapping of HRUs to subbasins using GIS overlay of land use, surficial geology, and slope.
- Incorporation of an additional higher elevation King County rain gage record at Cougar Mountain (63Y) and backward extension of input data using transposition of a disaggregated 15-minute record at Landsburg.
- Development of elevation bands for applying precipitation using contours published by the Oregon Climate Service.
- Explicit representation of numerous existing smaller detention basins with additional FTABLES.
- Adoption of USGS Regional Parameters for all HRUs.

As part of the Coal Creek Stabilization Program EIS work (Tetra Tech, 2006), NHC's 2004 model was further updated as follows:

- The flow routing table for the I-405/Coal Creek Detention/Retention facility was revised to incorporate backwater effects at high flows (Entranco, 2004).
- Flow routing tables, based on as-built and construction drawings, were revised to simulate detention facilities serving two subbasins in the Forest Hills (Subbasin 50; Group Four, Inc. 1976) and Summit (Subbasin 135) neighborhoods.

- The stream routing reach connections upstream of Coal Creek Parkway were revised to reflect the existing storm drain collection system.

A.5.2 HSPF Model Relevance and Use in Lower Coal Creek Flood Hazard Alternatives Analysis

The HSPF model was instrumental in determining the recurrence interval of discharges analyzed in the HEC-RAS model used to assess existing and future flood conditions in Newport Shores. Additionally, the HSPF model provided inflow hydrographs to the SWMM5 model of the Newport Shores stormwater drainage system. As part of this project, the EIS version of the model was updated and re-calibrated with the latest available data. Further details of the model updates and applications are documented in later sections of this report.

A.6 Reports, Memos, and Miscellaneous Archival Materials

The consultant team reviewed reports, correspondence, plan sets, and other documents related to the history of flooding and past flood mitigation projects along Coal Creek in the Newport Shores neighborhood. The City provided these materials to NHC in both electronic and hardcopy form. Hardcopy documents consisted of correspondence, neighborhood surveys, memos, plan sets, bid documents, and sketches. COB also transmitted some reports, technical memos, and correspondence in electronic form. In addition to the COB's archival materials, NHC reviewed materials in its own archives related to hydrology, hydraulics, erosion, and sedimentation in the Coal Creek basin. The following sections summarize all of the major technical reports starting with the 1987 Coal Creek Basin Plan, but cite only the most significant of the numerous technical memos, correspondence, and miscellaneous archival material.

A.6.1 Coal Creek Basin Plan and Technical Appendices (1987)

The Coal Creek Basin Plan and Final Environmental Impact Statement with Technical Appendix (1987) reflect early awareness on the part of King County and the City of Bellevue regarding the impact of urbanization on flooding, erosion, sedimentation, and environmental damage in the Coal Creek Basin. Basin Plan technical field and analytical work on urbanization and its effects on stormwater, hydrology, basin erosion, and sedimentation was initiated several years prior to the large storm event of January 18, 1986 which caused significant flood damage in Newport Shores. This technical work provided the basis for a comprehensive set of basin management recommendations including a $4.2M capital program consisting of projects along the mainstem of Coal Creek as follows:

- Cinder Mine Off Channel Regional Detention Pond
- Upper Main Channel Stabilization
- Detention Storage at Coal Creek Parkway
- Sedimentation Pond at Coal Creek Parkway
- Fitting I-405 with a control structure to create a detention pond
- Construction of 3-ft high berms between Upper Skagit Key and Glacier Key on 580 feet of right bank and 200 feet of left bank, and gully erosion control projects in the Newport Hills area
- Concrete stormwater bypass line to cut-off drainage to 4 eroding ravines
- 3 shorter ravine tightlines
- Newport Hills Drainage Pipe and Detention Pond
- Lower Newport Hills Channel Stabilization

Additionally a Citizen Study Group also recommended a dredging project to remove the entire accumulation of Coal Creek delta material since 1950; however, this project was not supported by City of Bellevue or King County staff.

As noted in 1997 by Spearman Engineering (see below), with the exception of the Newport Hills Drainage Pipe and Detention Pond project, all staff-recommended projects of the Basin Plan had been substantially completed by COB and King County by the mid-1990s.

Technical Appendices include documentation of data collection and analysis as follows:

- Mapping and discussion of erosion prone areas and landslide prone areas in the basin
- Coal Creek delta history, volumes, sedimentation rates, grain size distribution, and sedimentation. Coal Creek diverted to present mouth in 1958 after initiation of residential development in Newport Shores
- GeoEngineers estimated sediment deposition on delta at 89,000 cubic yards (cy) from 1958 through 1983, or 3600 cy/year (based on probing and sediment removal records). Sediment sampling indicated that only a small fraction of delta deposits within six inches of the top surface were larger than coarse sand (i.e. gravel or larger) in 1983. The fraction is reported by GeoEngineers reports "…It appears that gravel-sized particles account for less than 10 percent of the post-1958 sediment at the mouth of Coal Creek…;" however, a graph of the mean sediment distribution from GeoEngineers' eleven samples indicates that the gravel fraction is approximately 13%. Coal Creek stream bed sampling indicated little fine (sand, silt, clay) material, therefore, it was concluded that all of the sand and finer material is transported as suspended sediment to the delta and makes up 87% of the total load of sediment delivered there.
- GeoEngineers also found that 60% of the delta is composed of fine sand and that eroding Esperance Sand deposits in the Newport Hills area are a primary source of this fine material.
- Suspended sediment sampling indicated that the bulk of suspended sediment originated in the Newport Hills Tributary which was estimated to be delivering 6.6K to 12.3K cy in 1983 or 60% more sediment than Coal Creek upstream of the Newport Hills tributary confluence. Newport Hills tributary erosion (and sediment load) was estimated at more than 200 times the estimated average background rate since deglaciation.

A.6.2 Coal Creek Flooding and Sedimentation Study (NHC, 1996)

This report documents a preliminary assessment of flooding and sedimentation on Coal Creek, from Glacier Key to Lake Washington, initiated following the February 1996 flood event. A hydraulic model that included the Glacier, Newport, and Lower Skagit Key crossings was developed based on COB's February, 1996 survey data covering the delta and channel. Four sediment samples were collected on the delta and in the upstream channel. A preliminary assessment of flood control measures including channel and delta dredging and levee construction were evaluated.

The hydraulic model was calibrated to the February, 1996 event which produced an estimated peak of discharge of 450 cfs downstream of I-405. Based on the observation that overtopping did not occur at any Newport Shores road crossing during the event, it was concluded that the culverts were fully open when the peak discharge occurred and that sediment deposition occurred on the receding limb.

Findings showed that dredging below the lower Skagit Key crossing would provide limited benefit upstream. More substantial dredging throughout the study reach (Glacier Key to Lake Washington) would be necessary to lower flood levels; however, maintaining adequate opening areas at the two bottomless downstream culverts (Newport Key and lower Skagit Key) may provide a similar benefit. It was pointed out in this study that continuous aggradation appears to be occurring downstream of lower Skagit Key and additional survey data would be necessary to define high channel elevations in this reach.

A.6.3 Sustainable Flood Damage Prevention Plan for Skagit Key Reach of Coal Creek (Spearman Engineering, 1997)

This study is focused on the lower portion of Coal Creek in Newport Shores, from the lower Skagit Key crossing to Lake Washington. The document provides an overview of the Basin Plan (1987); and updated hydrologic, hydraulic, and sediment transport analyses conducted by NHC. A problem statement is formulated with criteria for evaluation; and presentation of several alternatives. Measures included no action, delta dredging, high flow by-pass, levee construction, channel design and maintenance, culvert replacement, and upstream sediment facilities. Findings indicate problems in delta vicinity are ultimately controlled by conditions in the upper basin. The plan recommends incremental approach with construction of a local levee and adoption of a flood control alternative (doesn't specify which one), ongoing monitoring and investigations, and coordination with other agencies and community groups to address overall basin problems.

Hydrology

Part of the work documented in the Spearman Report includes NHC's update of the 1987 Basin Plan HSPF model and reanalysis of flood frequencies downstream of the I-405 detention and sedimentation pond which came on line in the mid-1990s. This analysis also determined that the I-405 pond provides moderate peak flow reduction of approximately 10%-15% over a range of peak annual recurrence intervals between 10 and 100 years.

Hydraulics

Hydraulic analysis discussed in the report was based on NHC's earlier 1996 work and limited to the reach from Newport Key downstream to the delta. NHC determined that sediment aggradation downstream of Lower Skagit Key has a strong impact on flood levels in this reach, decreases between Lower Skagit Key and Newport Key, and becomes negligible upstream of this crossing. It was concluded that dredging would have a limited benefit that would be confined to the reach downstream of Skagit Key. The analysis also evaluated the impacts of future aggradation downstream of Lower Skagit Key.

Sediment Transport Analysis

For purposes of sediment transport analysis, Coal Creek was divided into five major reaches. NHC determined the primary source of sediment transported by Coal Creek to the delta was from streambank and ravine slopes upstream of the Coal Creek Parkway crossing. In contrast, the earlier basin plan studies of the 1980s had identified ravine erosion in the Newport Hills tributary subbasin as the primary sediment source; however projects to control this sediment source had been completed by the mid-1990s.

The average rate of sediment delivery to the Coal Creek delta was estimated at 5,000 cy/year prior to inauguration of the I-405 and Coal Creek Parkway sedimentation facilities. It was projected that this average rate would be reduced to 3,100 cy/year with these two facilities in operation.

A.6.4 Coal Creek Stabilization Program Final Environmental Impact Statement (2006)

This is a programmatic EIS document for a suite of measures within the natural area of Coal Creek basin between I-405 and Lakemont Blvd. The stated objective is to control erosion and sedimentation, reduce flooding, and improve water quality. Evaluation of two basic alternatives for erosion and sediment control is described: 1) Source control with an emphasis on slope, stream bank, and stream bed stabilization plus one sedimentation pond; 2) In-stream control emphasizing construction of new sediment ponds, expanding existing ones, and adding detention storage for flood control. Alternative 1 (source control) was selected due to cost, performance, and environmental benefits relative to the alternatives.

In addition to fulfilling SEPA EIS requirements, the document provides a very useful review of historic basin conditions including early mining and residential development, flooding and sediment problems. As well, the EIS reviews stormwater regulations, past stormwater projects, data collection, and studies of hydrologic, hydraulic, and geomorphic conditions both upstream of I-405 and downstream in the Newport Shores neighborhood.

Of particular interest, Appendix C of the EIS provides a summary and review of sediment budgets and sediment transport rates from past studies and compares the sediment retention and yield reduction benefits of the alternatives.

A.6.5 Miscellaneous Archival Materials

Miscellaneous archival materials consist of memoranda, maps, photos, bid documents and other materials in both hardcopy and electronic format provided to NHC by the City of Bellevue as well as a similar range of materials and formats in NHC's archives. These items are too numerous to review in detail here; therefore, only the most relevant ones are highlighted.

A.6.5.1 *City of Bellevue Master Drainage Plan (KCM-WRE/YTO, 1976)*

This high-level master drainage plan report enumerates existing and anticipated future drainage problems throughout the basins that intersected the City of Bellevue's incorporated areas in the mid-1970s. While the plan's preferred alternative for handling an estimated 80% increase in peak flow associated with future basin urbanization is distributed detention facilities, the plan also considered a competing alternative to reduce Newport Shores flooding that included a 400 cfs capacity, 84-inch high flow bypass from the upstream side of I-405 to the head end of the canal between Columbia Key and Crescent Key via Cascade Key.

A.6.5.2 *Newport Shores Storm Evaluation Questionnaire Responses, 1986*

This COB archival material consists of some fifty individual hardcopy responses from Newport Shores homeowners regarding damage to their property caused by the January, 1986 flood event. Several responses allude to drainage and problems of high groundwater that flooded crawl spaces.

A.6.5.3 *Manila Folder Related to January 1986 Flood Damage*

This includes multiple items of interest such as a memo dated March 12, 1986 from Lloyd Warren, Assistant Director of the COB Storm and Surface Water Utility that describes types of damage associated with the January 1986 flood event and also characterizes discharge rate and frequency as 450-500 cfs and 50-year recurrence. Three types of damage are noted, 1) silt deposition in peoples yards and swimming pools, 2) creek flood water in some crawl spaces and in living space of three homes, 3) drainage backup due to high water in the creek. Another item is a letter from KCM consulting engineers to Warren dated February 6, 1986 that includes recommendations for "emergency measures" including sediment removal, temporary berms near houses most affected, and results of a stream walk damage survey. Another item is a line printer output of damage assessment by name and address for the January 1986 flood, which appears to be a compilation of homeowner survey results.

A.6.5.4 *Coal Creek Basin Plan Reevaluation*

This is a Power Point (PPT) format electronic file in the NHC archives. The slide show summarizes a geomorphic assessment of delta sedimentation and evaluation of upstream sediment sources. Rates of delta growth were estimated based on analysis of aerial photos from 1960 to 1997 and topographic surveys conducted in 1997 and 2003. Based on sampling in November, 2003, the composition of top foot of delta was estimated based on nine samples as 11% silt, 52% sand, and 37% gravel. This composition is more coarse than what was determined by GeoEngineers in 1983, when they estimated the composition to be 20% silt, 70% sand, and 10% gravel based on eleven, 6-inch deep samples.

The assessment included field-based evaluation of channel reaches along Coal Creek both upstream and downstream of Coal Creek Parkway. Visual inspections, measurements of eroded, stored, and incised sediment volumes, and sediment sampling were used to develop a sediment budget. Findings indicated average delivery of sediment to the delta between 1958 and 2003 was 3,000 cy/year (600 cy less than GeoEngineers estimate for 1958-1983). Sediment from bank erosion and stream incision was observed to be occurring both upstream and downstream of Coal Creek Parkway, but in-channel storage was mostly downstream of this crossing.

Delta profile analysis comparing 1990, 1997, and 2003-4 transects indicated delta growth for the southern, central, and northern portions between 1990 and 1997, but overall shrinkage between 1997 and 2003-4. During this later period, the southern topset (top surface) and foreset (sloping delta front), actually retreated upstream of the 1990 positions. This was not evident in the central region where changes between 1990 and 1997 were slight except for some minor deposition in part of the topset. In the northern region, there was moderate foreset recession with minimal change to the topset length or height.

Based on the specific gravity of sediments, NHC estimated coal mine waste to be 27% to 29% of sampled sediment on the surface of the delta.

No formal report was generated documenting these studies which were made in support of litigation related to flooding in Newport Shores.

A.6.5.5 *File Folder of Assorted Memos and Other Materials Related to Lower Coal Creek, 1987*

This is a file folder in the COB archive containing both internal and external COB correspondence during 1987 related to the 1987 Coal Creek Drainage Improvement Project. Of particular interest is a March, 16 1987 letter from KCM to Denny Vidmar of COB comparing discharge capacity of “minimum” and “maximum” dredge options. It states that removal of 400 cy of sediment would raise bankfull discharge from 100 to 160, while 1200 cy raises bankfull discharge to 300 cfs. The file also includes a right-of-entry form for construction that outlines responsibilities of homeowners related to maintenance of constructed improvements and release of COB from maintenance obligations and performance warranty.

A.6.5.6 *Coal Creek Drainage Improvement Project Draft Bid Documents and Plan Set, May, 1987*

This plan set includes a channel dredge, habitat features (pools), bank protection, and berms along Coal Creek in Newport Shores. With the exception of the dredge, the improvements extend from a point 200’ upstream of Cascade Key to the upstream side of Newport Key. The dredge is a relatively minor cost option and is confined to a sediment wedge downstream of Glacier Key Culvert tapering to zero at Skagit Key.

A.6.5.7 *I-405 Drainage Detention/Sedimentation Facility, July 1987*

This comb-bound set of draft bid documents appears to be for the I-405 flow control structure, but does not include a full plan set. An appendix contains a geotechnical report that describes pre-existing road and highway embankments, box culvert, and utilities. Also included are plans showing the location of the existing Metro 78” RCP East Side Interceptor crossing of Coal Creek.

A.7 Time Line of Selected Events

A time line of events that are closely associated with flooding and sedimentation conditions along Coal Creek in Newport Shores has been assembled. The time line begins with the final plat of Newport Shores in 1972 and ends in December, 2010. Event types include peak flows, completion of basin flood and sediment storage facilities, completion of sediment source control projects, completion of dredging and channel improvement projects in Newport Shores, and maintenance of basin sediment storage facilities by sediment removal.

Table A3: Timeline of Selected Events (Period: 1972 -2012)

🟨 **Final Newport Shores Plat**
🟥 **Channel Dredging/Sediment Capture Facility Project**
🟧 **Sediment Source Control Project**
🟦 **High Flow Event**
🟫 **Sediment Removal from Facilities**

Event	TYPE	Date	Description
Newport Shores Plat Submittal		1/1/1972	3rd and Final Platting of Newport Shores Lots
Final Creek Re-Alignment		1/1/1974	per GeoEngineers in Coal Creek Basin Plan Appendix, lower 800 feet of Creek moved 50-100 feet north
High Flow	High Flow	1/18/1986	Severe Flood, Erosion, and Sedimentation Event
Lower Coal Creek Improvement Project	Channel Dredging	8/1/1987	Berms, Bank Protection, Dredging between
High Flow	High Flow	1/9/1990	Creek overflow, erosion, sedimentation (~10-YEAR FLOW)
Possible High Flow	High Flow	11/24/1990	(~10 year event)
Newport Shores Creek Dredging	Channel Dredging	9/1/1991	
Newport Hills Outfall Improvements	Sediment Source Control Project	9/1/1993	COB and KC stabilized 7 outfalls to eliminate ravine erosion and sediment delivery. This took place in the early 1990s.
Newport Hills Tributary Channel Stabilization	Sediment Source Control Project	9/1/1994	Series of measures to control sediment delivery from Newport Hills tributary including tightlining, channel regrading and slope stabilization. Completed over a period of years by KC and COB from 1983 to 1994
I-405 Detention/Sedimentation Facility	Sediment Pond Project	9/1/1994	Actual date facility came on line is uncertain, EIS only give year. , 400 cu yds of sediment storage capacity
I-405 Detention/Sedimentation Facility	Flow Control Storage Project	9/1/1994	Actual date facility came on line is uncertain, EIS only give year. , 400 cu yds of sediment storage capacity
I-405 Detention/Sedimentation Facility	Maintenance	8/1/1995	400 cy
Cinder Mine Hillslope Stabilization	Sediment Source Control Project	9/1/1995	South bank of Coal Creek in Cinder Mine area, constructed by KC, now owned and operated by COB
Cinder Mine Bed Grade Controls	Sediment Source Control Project	9/1/1995	Rock Stabilization of sediment in Coal Creek from 1995 debris flow. Owned/maintained by COB
High Flow	High Flow	2/9/1996	(crawl space and yard flooding)
I-405 Detention/Sedimentation Facility	Maintenance	8/1/1996	600 cy
Cinder Mine Bed Grade Controls	Sediment Source Control Project	9/1/1996	Rock Stabilization of sediment in Coal Creek from 1995 debris flow. Owned/maintained by COB
Coal Creek Parkway Sedimentation Basin	Sediment Pond Project	9/1/1996	Built by COB upstream of detention pond, 2. ac-ft of storage
Coal Creek Parkway Detention Pond	Flow Control Storage Project	9/1/1996	Build by KC upstream of Coal Creek Parkway, now owned and operated by COB, 1500 cu yd capacity
I-405 Detention/Sedimentation Facility	Maintenance	8/1/1997	300 cy

al **Final Newport Shores Plat**
🟥 **Channel Dredging/Bank Stabilization/Restoration Project**
🟧 **Sediment Source Control Project**
🟦 **High Flow Event**
🟫 **Sediment Removal from Facilities**

Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/1997	500 cy
Cinder Mine Bed Grade Controls	Sediment Source Control Project	9/1/1997	Rock Stabilization of sediment in Coal Creek from 1995 debris flow. Owned/maintained by COB
High Flow	High Flow	12/31/1996	(yard flooding)
I-405 Detention/Sedimentation Facility	Maintenance	8/1/1998	350 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/1998	800 cy
I-405 Detention/Sedimentation Facility	Maintenance	8/1/1999	180 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/1999	2300 cy
High Flow	High Flow	11/14/2001	Moderate flood, right bank downstream of Upper Skagit Key Crossing, Stage of ~60 in I405 pond,375 cfs discharge
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2002	1700 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2003	500 cy
High Flow	High Flow	10/20/2003	Street flooding reported, but may be drainage related
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2004	410 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2004	1500 cy
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2005	90 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2005	1100 cy
Coal Creek Hillside Pipe Outfall Repair	Sediment Source Control Project	8/30/2005	Repair of eroding outfalls in the middle reach of Coal Creek
Coal Creek Stream Stabilization - Phase 1	Sediment Source Control Project	8/30/2005	Grade control and bank stabilization using logs and stream boulders on the middle reach of Coal Creek
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2006	700 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2006	1400 cy
Middle Reach Stream Stabilization - Phase 2	Sediment Source Control Project	9/30/2006	1700 feet of bank stabilization and grade control between I-405 and Coal Creek Pkwy Crossing
Overbank Stormwater Outfall Improvements	Sediment Source Control Project	9/30/2006	Grade control and hillslope stabilization structures for nine storm drain outfalls to Coal Creek - City of Bellevue sites
Coal Creek Stormwater Outfall Repairs	Sediment Source Control Project	9/30/2006	Upper Reach/Cinder Mine Areas, erosion suppression in tributary ravines through tightlines and energy dissipation (6 sites) - King County sites
High Flow	High Flow	11/6/2006	No damage reported
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2007	400 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2007	1100 cy

🟨 Fi **Final Newport Shores Plat**

🟥 **Channel Dredging/Bank Stabilization/Restoration Project**

🟧 **Sediment Source Control Project**

🟦 **High Flow Event**

🟫 **Sediment Removal from Facilities**

Newport Creek Stream Channel Improvements	Sediment Source Control Project	8/30/2007	Grade control and bank stabilization using log habitat structures on Newport Creek above confluece with Coal Creek
High Flow	High Flow	12/3/2007	Stage of 67.5 in I405 pond, 550 cfs discharge, sand bags deployed in neighborhood to protect yards and homes, model predicts 5-10 year peak at 465 cfs
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2008	700 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2008	1865 cy
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2009	400 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2009	1700 cy
High Flow	High Flow	1/8/2009	I-405 Stage of 60.5, indicating discharge of approximately 380 (~5 year flood) cfs from pond at 12 AM
Coal Creek Upper Reach Stabilization and Grade Control Project	Sediment Source Control Project	9/30/2009	Landslide, bank erosion, and bed grade control using engineered rock and wood structures, left bank of upper Coal Creek downstream of Lakemont Blvd Crossing between RM 4 and RM 5
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2010	300 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2010	1000 cy
High Flow	High Flow	12/12/2010	Storm drain blockage and backyard flooding
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2011	300 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2011	2200 cy
Off-Channel Sedimentation Facility	Maintenance	8/1/2011	1100 cy
Middle Coal Creek Off-Channel Sedimentation Facility	Sediment Pond Project	9/1/2010	1500 cy capacity
I-405 Detention/Sedimentation Facility	Maintenance	8/1/2012	320 cy
Coal Creek Parkway Sedimentation Basin	Maintenance	8/1/2012	1134 cy
Off-Channel Sedimentation Facility	Maintenance	8/1/2012	276 cy

Appendix B

Digital Photo Archive of Coal Creek Flooding

A digital appendix of lower Coal Creek flood photos was transmitted electronically to the City of Bellevue's project manager, Mr. Brian Ward. The digital appendix consists of the following files:

- A point shapefile of mapped photos: **Photo_Locations.shp**
- An Excel database containing filepath names for mapped photos: **2000106_photoDirectory.xlsx**
- A read me file with instructions on how to link the shapefile to the photos: **200106_README.txt**
- A **photos** folder holding jpeg files of historic flooding

Appendix C

List of Design Charrette Participants

Name	Affiliation	Telephone
Brian Ward	City of Bellevue	425-452-5206
Brian Krause	City of Bellevue	425-452-6992
Bruce Jensen	City of Bellevue	425-452-7240
Kit Paulsen	City of Bellevue	425-452-4861
Paul Bucich	City of Bellevue	425-452-4596
Scott Taylor	City of Bellevue	425-452-4108
Mark Cross	City of Bellevue	425-452-6938
Don McQuilliams	City of Bellevue	425-452-7865
David Hartley	NHC	206-241-6000
Peter Brooks	NHC	206-241-6000
Vaughn Collins	NHC	206-241-6000
Jerry Scheller	Tetra Tech	206-883-9414
Benn Burke	SWCA	206-781-1909
Shanese Crosby	Triangle Associates	206-583-0655

Appendix D

Scoring of Flood Risk Reduction Measures

INITIAL SCREENING OF FLOOD RISK REDUCTION MEASURES

FLOOD RISK REDUCTION MEASURE	Flood Risk Reduction Effectiveness-Local Drainage	Flood Risk Reduction Effectiveness-Creek Flooding	Comments
	(H,M,L)	(H,M,L)	
Creek Conveyance/Channel Solutions			
Newport Shores Culvert Replacements	L	H	
Newport Shores Vegetation Management	L	L	Eliminated. Modeling shows vegetation is not a systematic limiting factor on flood conveyance in Newport Shores.
Berm Enhancement	M	L	
Channel Dredging	M	M	
Channel Widening	L	M	
Creek Storage Solutions			
I-405 Control Structure Redesign	L	H	
I-405 Excavation for Increased Flood Storage	L	L	Eliminated. Additional available storage from excavation is insignificant.
I-405 Excavation and/or control for Increased Sediment Trapping			Eliminated. Additional sediment removal upstream of N.S. not effective.
Buyout and New Off-Channel Sediment Pond in Newport Shores	L	L	Eliminated. Additional sediment removal within N.S. not effective.
Creek Bypass Solutions			
Upstream of Newport Shores or at I-405 west to existing lagoon outfall between Columbia and Crescent along Cascade	L	M	
From I-405 north along Lake WA Blvd to I-90 and west to lake (per WSDOT)	L	L	Eliminated from further ranking. Insufficient gradient and capacity for long distance of bypass, would require very large diameter pipe.
Newport Shores Drainage Solutions			
INVERTED SIPHONS AND LAGOON OUTFALLS. Add 2 outfalls to lagoon nr Glacier and Lwr Skagit x-ing, and 3 inverted siphon crossings of creek at Glacier, Newport, and Lwr Skagit)	H	L	
STORAGE AND UPSIZING PIPES (NO NEW OUTFALLS CREEK OR X-INGS). Upsize selected pipes along Lummi and Glacier, re-engineer creek outfalls for sediment management, add ROW storage for stormwater.	M	L	

RANKING OF FLOOD RISK REDUCTION ALTERNATIVES

FLOOD RISK REDUCTION MEASURE	**Flood Risk Reduction Effectiveness-Creek Flooding**	**Flood Risk Reduction Effectiveness-Local Drainage**	**Consistency with COB Policy**	**Community Acceptance**	**Constructability**	**Environmental Benefit**	**Permitability**	**Robustness/Long Term Benefit Potential**	**Property Acquisition Requirement (-2 to 0)**	**Capital Cost**	**O&M Cost**	**Unknowns and Level of Study Required**	**Coordination Required**	**Opportunity for Cost Share/Cooperation (0 to 2)**	**Total Score**
Weighting as shown in this row. Ranking of criteria goes from -2 to 2, unless as otherwise noted	**4**	**3**	**3**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**0.5**	**0.5**	**0.5**	
CREEK FLOOD RISK REDUCTION SOLUTIONS															
Newport Shores Culvert Replacement	2	-0.5	2	2	2	1.5	1.5	2	0	-1	2	2	2	0	**20.5**
I-405 Control Structure Redesign and Flood Storage Enhancement	2	0.25	2	2	2	0	0	2	0	-1	2	2	2	1	**20.3**
Berm Enhancement	1	-0.5	1	1	2	0	1	2	-1	1	0	2	2	0	**12.5**
Creek Bypass (upstream of Newport Shores or at I405 west to existing lagoon outfall between Columbia and Crescent along Cascade)	1	0.25	1	0	2	-1	-1	2	1	0	-1	-1	2	1	**8.8**
Channel Dredging	1	0.5	-2	1	2	-2	-2	0	0	2	2	-1	2	0	**2.0**
Channel Widening	0.5	0	2	-1	2	2	0	0	-1	0	0	-1	2	0	**9.5**
STORM DRAINAGE FLOOD REDUCTION SOLUTIONS															
STORAGE AND UPSIZING PIPES (NO NEW OUTFALLS CREEK OR X-INGS). Upsize selected pipes along Lummi and Glacier, re-engineer creek outfalls for sediment management, add ROW storage for stormwater.	0	1	2	1	2	0	2	2	0	1	1	2	2	0	**23.0**
INVERTED SIPHONS AND ADDITIONAL OUTFALLS. (UP TO 2 outfalls to lagoon west of Glacier and Lwr Skagit x-ing, and to Lake Washington near Lummi-Skagit intersection. Up to 3 inverted siphon crossings of creek at Glacier, Newport, and Lwr Skagit)	0	2	2	1.5	2	0	1	2	-1	0	0	2	2	0	**23.0**

Appendix E

Cost Estimate Details

PLANNING LEVEL CONSTRUCTION COST OPINION

PROJECT: **I-405 Structure Modification**
DESCRIPTION: **Modify structure at I-405.**
BASIN/SUBBASIN: **Lower Coal Creek**

BY: **GW**
CHECKED BY: **GMS**
DATE: **19-May-14**

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 20,000	$ 20,000
ROADWAY EXCAVATION INCL. HAUL	20	CY	$ 100	$ 2,000
GRAVEL BORROW INCL. HAUL	3450	TN	$ 10	$ 34,500
MECHANICALLY STABILIZED WALL:	3050	SF	$ 30	$ 91,500
GRAVEL BASE	68	TN	$ 15	$ 1,100
ACCESS ROAD ENTRANCE MODIFICATIONS	1	LS	$ 5,000	$ 5,000
I-405 STRUCTURE MODIFICATION	1	EA	$ 30,000	$ 30,000
INTERCEPTOR TRANSITION STRUCTURE ACCESS MOD.	1	LS	$ 20,000	$ 20,000
SEWER TRUNK MANHOLE MODIFICATION	9	LS	$ 8,000	$ 72,000
HAZELWOOD TUNNEL BUOYANCY MODIFICATION	1	LS	$ 60,000	$ 60,000
COAL CREEK SEWER TRUNK BUOYANCY/COUNTERMEASURES	1	LS	$ 7,200	$ 7,200
NEWPORT HILL TRUNK BUOYANCY/COUNTERMEASURES	1	LS	$ 9,200	$ 9,200
FLOW METER STATION W/ POWER & TELEMETRY	1	LS	$ 10,000	$ 10,000
			Subtotal	$ 362,500
EROSION & SEDIMENTATION CONTROL	10%			$ 36,250
SITE RESTORATION	5%			$ 18,125
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 18,125
			Subtotal	$ 435,000
CONTINGENCY	50%			$ 217,500
			Construction Subtotal (Rounded)	$ 653,000
STATE SALES TAX	9.5%			$ 62,035
ENGRG/LEGAL/ADMIN > $250K CONST	30%			$ 195,900
CONSTRUCTION MANAGEMENT	10%			$ 65,300
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 976,000**

Notes:

1. The above cost opinion is in 2014 dollars & doesn't include future escalation, financing, land acquisition, or O&M costs.

2. The order-of-magnitude cost opinion has been prepared for guidance in project evaluation from the information available at the time of preparation and for assumptions stated. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope and schedule, and other variable factors. As a result, the final project costs will vary from those presented above. Because of these factors, funding needs for individual projects must be scrutinized prior to establishing the final project budgets.

PLANNING LEVEL CONSTRUCTION COST OPINION
LOWER COAL CREEK FLOOD HAZARD REDUCTION PROJECT

PROJECT: Lower Skagit Key Culvert Replacement

DESCRIPTION: 20'x10' Precast Box Culvert

BASIN/SUBBASIN: Lower Coal Creek

BY: GW

CHECKED BY: GG

DATE: 3-Mar-14

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
PREPARATION				
CLEARING AND GRUBBING	1,000	SF	$ 2	$ 2,000
ROADWAY EXCAVATION INCL. HAUL	30	CY	$ 100	$ 3,000
STRUCTURE EXCAVATION CLASS B, INCLUDING HAUL	735	CY	$ 25	$ 18,375
GRAVEL BORROW INCL. HAUL	245	TN	$ 15	$ 3,675
SHORING OR EXTRA EXCAVATION CL. B	1	LS	$ 15,000	$ 15,000
UNSUITABLE FOUNDATION EXCAVATION INCL. HAUL	25	CY	$ 50	$ 1,250
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 25,000	$ 25,000
UTILITY RELOCATION	1	LS	$ 35,000	$ 35,000
STREAM				
STREAMBED GRAVEL	200	CY	$ 130	$ 26,000
STREAMBED SEDIMENT	60	CY	$ 70	$ 4,200
STREAMBED BOULDER (2-MAN)	190	EA	$ 100	$ 19,000
QUARRY SPALLS	35	TN	$ 50	$ 1,750
LOG WITH ROOTWAD	4	EA	$ 1,500	$ 6,000
CONSTRUCTION GEOTEXTILE FOR SEPARATION	170	SY	$ 5	$ 850
DRAINAGE				
CATCH BASIN TYPE 2, 48-IN DIAM	2	EA	$ 3,000	$ 6,000
12-INCH DIAM CPE	60	LF	$ 50	$ 3,000
PRECAST 3-SIDED BOX CULVERT (20'x10') W/ FOOTINGS, HEADWALL & WINGWALL	1	LS	$ 210,000	$ 210,000
SURFACING				
CEMENT CONCRETE SIDEWALK	35	SY	$ 60	$ 2,100
CRUSHED SURFACING TOP COURSE	45	TN	$ 60	$ 2,700
COMMERCIAL HMA CL. 1/2 IN. PG 64-22	25	TN	$ 175	$ 4,375
CEMENT CONC. TRAFFIC CURB AND GUTTER	55	LF	$ 40	$ 2,213
			Subtotal	$ 391,488
DEWATERING	10%			$ 39,149
EROSION & SEDIMENTATION CONTROL	5%			$ 19,574
TRAFFIC CONTROL	3%			$ 11,745
SITE RESTORATION	7%			$ 27,404
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 19,574
			Subtotal	$ 508,935
CONTINGENCY	30%			$ 152,680
			Construction Subtotal (Rounded)	$ 662,000
STATE SALES TAX	9.5%			$ 62,890
ENGINEERING > $250K CONST	25%			$ 165,500
CONSTRUCTION MANAGEMENT	15%			$ 99,300
PERMITTING	8%			$ 52,960
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 1,043,000**

Notes:

1. The above cost opinion is in 2014 dollars & doesn't include future escalation, financing, land acquisition, or O&M costs.
2. The order-of-magnitude cost opinion has been prepared for guidance in project evaluation from the information available at the time of preparation and for assumptions stated. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope and schedule, and other variable factors. As a result, the final project costs will vary from those presented above. Because of these factors, funding needs for individual projects must be scrutinized prior to establishing the final project budgets.

PLANNING LEVEL CONSTRUCTION COST OPINION
LOWER COAL CREEK FLOOD HAZARD REDUCTION PROJECT

PROJECT: Newport Key Culvert Replacement
DESCRIPTION: 20'x9' Precast Box Culvert w/Siphon
BASIN/SUBBASIN: Lower Coal Creek

BY: GW
CHECKED BY: GG
DATE: 3-Mar-14

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
PREPARATION				
CLEARING AND GRUBBING	1,000	SF	$ 2	$ 2,000
ROADWAY EXCAVATION INCL. HAUL	30	CY	$ 100	$ 3,000
STRUCTURE EXCAVATION CLASS B, INCLUDING HAUL	680	CY	$ 25	$ 17,000
GRAVEL BORROW INCL. HAUL	225	TN	$ 15	$ 3,375
SHORING OR EXTRA EXCAVATION CL. B	1	LS	$ 15,000	$ 15,000
UNSUITABLE FOUNDATION EXCAVATION INCL. HAUL	25	CY	$ 50	$ 1,250
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 25,000	$ 25,000
UTILITY RELOCATION	1	LS	$ 35,000	$ 35,000
STREAM				
STREAMBED GRAVEL	200	CY	$ 130	$ 26,000
STREAMBED SEDIMENT	60	CY	$ 70	$ 4,200
STREAMBED BOULDER (2-MAN)	190	EA	$ 100	$ 19,000
QUARRY SPALLS	35	TN	$ 50	$ 1,750
LOG WITH ROOTWAD	4	EA	$ 1,500	$ 6,000
CONSTRUCTION GEOTEXTILE FOR SEPARATION	170	SY	$ 5	$ 850
DRAINAGE				
PRECAST 3-SIDED BOX CULVERT (20'x9') W/ FOOTINGS, HEADWALL & WINGWALL	1	EA	$ 208,000	$ 208,000
STORM DRAIN SIPHON	1	LS	$ 37,000	$ 37,000
SURFACING				
CEMENT CONCRETE SIDEWALK	35	SY	$ 60	$ 2,100
CRUSHED SURFACING TOP COURSE	45	TN	$ 60	$ 2,700
COMMERCIAL HMA CL. 1/2 IN. PG 64-22	25	TN	$ 175	$ 4,375
CEMENT CONC. TRAFFIC CURB AND GUTTER	55	LF	$ 40	$ 2,213
			Subtotal	$ 415,813
DEWATERING	10%			$ 41,581
EROSION & SEDIMENTATION CONTROL	5%			$ 20,791
TRAFFIC CONTROL	3%			$ 12,474
SITE RESTORATION	7%			$ 29,107
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 20,791
			Subtotal	$ 540,557
CONTINGENCY	30%			$ 162,167
			Construction Subtotal (Rounded)	$ 703,000
STATE SALES TAX	9.5%			$ 66,785
ENGINEERING > $250K CONST	25%			$ 175,750
CONSTRUCTION MANAGEMENT	15%			$ 105,450
PERMITTING	8%			$ 56,240
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 1,107,000**

Notes:

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2. The order-of-magnitude cost opinion has been prepared for guidance in project evaluation from the information available at the time of preparation and for assumptions stated. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope and schedule, and other variable factors. As a result, the final project costs will vary from those presented above. Because of these factors, funding needs for individual projects must be scrutinized prior to establishing the final project budgets.

PLANNING LEVEL CONSTRUCTION COST OPINION
LOWER COAL CREEK FLOOD HAZARD REDUCTION PROJECT

PROJECT: Glacier Key Culvert Replacement
DESCRIPTION: 24'x10' Precast Box Culvert w/Siphon
BASIN/SUBBASIN: Lower Coal Creek

BY: GW
CHECKED BY: GG
DATE: 3-Mar-14

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
PREPARATION				
CLEARING AND GRUBBING	1,000	SF	$ 2	$ 2,000
ROADWAY EXCAVATION INCL. HAUL	30	CY	$ 100	$ 3,000
STRUCTURE EXCAVATION CLASS B, INCLUDING HAUL	690	CY	$ 25	$ 17,250
GRAVEL BORROW INCL. HAUL	195	TN	$ 15	$ 2,925
SHORING OR EXTRA EXCAVATION CL. B	1	LS	$ 15,000	$ 15,000
UNSUITABLE FOUNDATION EXCAVATION INCL. HAUL	25	CY	$ 50	$ 1,250
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 25,000	$ 25,000
UTILITY RELOCATION	1	LS	$ 35,000	$ 35,000
STREAM				
STREAMBED GRAVEL	195	CY	$ 130	$ 25,350
STREAMBED SEDIMENT	60	CY	$ 70	$ 4,200
STREAMBED BOULDER (2-MAN)	160	EA	$ 100	$ 16,000
QUARRY SPALLS	35	TN	$ 50	$ 1,750
LOG WITH ROOTWAD	4	EA	$ 1,500	$ 6,000
CONSTRUCTION GEOTEXTILE FOR SEPARATION	160	SY	$ 5	$ 800
DRAINAGE				
PRECAST 3-SIDED BOX CULVERT (24x10') W/ FOOTINGS, HEADWALL & WINGWALL	1	EA	$ 235,000	$ 235,000
STORM DRAIN SIPHON	1	LS	$ 37,000	$ 37,000
SURFACING				
CEMENT CONCRETE SIDEWALK	40	SY	$ 60	$ 2,400
CRUSHED SURFACING TOP COURSE	40	TN	$ 60	$ 2,400
COMMERCIAL HMA CL. 1/2 IN. PG 64-22	25	TN	$ 175	$ 4,375
CEMENT CONC. TRAFFIC CURB AND GUTTER	65	LF	$ 40	$ 2,600
			Subtotal	$ 439,300
DEWATERING	10%			$ 43,930
EROSION & SEDIMENTATION CONTROL	5%			$ 21,965
TRAFFIC CONTROL	3%			$ 13,179
SITE RESTORATION	7%			$ 30,751
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 21,965
			Subtotal	$ 571,090
CONTINGENCY	30%			$ 171,327
			Construction Subtotal (Rounded)	$ 742,000
STATE SALES TAX	9.5%			$ 70,490
ENGINEERING > $250K CONST	25%			$ 185,500
CONSTRUCTION MANAGEMENT	15%			$ 111,300
PERMITTING	8%			$ 59,360
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 1,169,000**

Notes:

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PLANNING LEVEL CONSTRUCTION COST OPINION
LOWER COAL CREEK FLOOD HAZARD REDUCTION PROJECT

PROJECT: Upper Skagit Key Culvert Replacement
DESCRIPTION: 16'x10' Precast Box Culvert
BASIN/SUBBASIN: Lower Coal Creek

BY: GW
CHECKED BY: GG
DATE: 3-Mar-14

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
PREPARATION				
CLEARING AND GRUBBING	1,000	SF	$ 2	$ 2,000
ROADWAY EXCAVATION INCL. HAUL	20	CY	$ 100	$ 1,972
STRUCTURE EXCAVATION CLASS B, INCLUDING HAUL	475	CY	$ 25	$ 11,875
GRAVEL BORROW INCL. HAUL	190	TN	$ 15	$ 2,850
SHORING OR EXTRA EXCAVATION CL. B	1	LS	$ 15,000	$ 15,000
UNSUITABLE FOUNDATION EXCAVATION INCL. HAUL	20	CY	$ 50	$ 1,000
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 25,000	$ 25,000
UTILITY RELOCATION	1	LS	$ 35,000	$ 35,000
STREAM				
STREAMBED GRAVEL	135	CY	$ 130	$ 17,550
STREAMBED SEDIMENT	40	CY	$ 70	$ 2,800
STREAMBED BOULDER (2-MAN)	160	EA	$ 100	$ 16,000
QUARRY SPALLS	25	TN	$ 50	$ 1,250
LOG WITH ROOTWAD	4	EA	$ 1,500	$ 6,000
CONSTRUCTION GEOTEXTILE FOR SEPARATION	120	SY	$ 5	$ 600
DRAINAGE				
CATCH BASIN TYPE 2, 48-IN DIAM	2	EA	$ 3,000	$ 6,000
12-INCH DIAM CPE	40	LF	$ 50	$ 2,000
PRECAST 3-SIDED BOX CULVERT (16'x10') W/ FOOTINGS, HEADWALL & WINGWALL	1	EA	$ 190,000	$ 190,000
SURFACING				
CEMENT CONCRETE SIDEWALK	30	SY	$ 35	$ 1,050
CRUSHED SURFACING TOP COURSE	35	TN	$ 60	$ 2,100
COMMERCIAL HMA CL. 1/2 IN. PG 64-22	20	TN	$ 175	$ 3,500
CEMENT CONC. TRAFFIC CURB AND GUTTER	50	LF	$ 40	$ 2,000
			Subtotal	$ 345,547
DEWATERING	10%			$ 34,555
EROSION & SEDIMENTATION CONTROL	5%			$ 17,277
TRAFFIC CONTROL	3%			$ 10,366
SITE RESTORATION	7%			$ 24,188
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 17,277
			Subtotal	$ 449,211
CONTINGENCY	30%			$ 134,763
			Construction Subtotal (Rounded)	$ 584,000
STATE SALES TAX	9.5%			$ 55,480
ENGINEERING > $250K CONST	25%			$ 146,000
CONSTRUCTION MANAGEMENT	15%			$ 87,600
PERMITTING	8%			$ 46,720
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 920,000**

Notes:

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PLANNING LEVEL CONSTRUCTION COST OPINION
LOWER COAL CREEK FLOOD HAZARD REDUCTION PROJECT

PROJECT: Cascade Box Culvert
DESCRIPTION: 24'x10' Precast Box Culvert
BASIN/SUBBASIN: Lower Coal Creek

BY: GW
CHECKED BY: GG
DATE: 3-Mar-14

BID ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
PREPARATION				
CLEARING AND GRUBBING	1,000	SF	$ 2	$ 2,000
ROADWAY EXCAVATION INCL. HAUL	30	CY	$ 100	$ 3,000
STRUCTURE EXCAVATION CLASS B, INCLUDING HAUL	825	CY	$ 25	$ 20,625
GRAVEL BORROW INCL. HAUL	235	TN	$ 15	$ 3,525
SHORING OR EXTRA EXCAVATION CL. B	1	LS	$ 15,000	$ 15,000
UNSUITABLE FOUNDATION EXCAVATION INCL. HAUL	25	CY	$ 50	$ 1,250
TEMPORARY STREAM BYPASS AND FISH PASSAGE	1	LS	$ 25,000	$ 25,000
UTILITY RELOCATION	1	LS	$ 35,000	$ 35,000
STREAM				
STREAMBED GRAVEL	135	CY	$ 130	$ 17,550
STREAMBED SEDIMENT	40	CY	$ 70	$ 2,812
STREAMBED BOULDER (2-MAN)	25	EA	$ 100	$ 2,500
QUARRY SPALLS	35	TN	$ 50	$ 1,759
LOG WITH ROOTWAD	4	EA	$ 1,500	$ 6,000
CONSTRUCTION GEOTEXTILE FOR SEPARATION	180	SY	$ 5	$ 900
DRAINAGE				
PRECAST 3-SIDED BOX CULVERT (24' x 10') W/ FOOTINGS, HEADWALL & WINGWALL	1	LS	$ 240,000	$ 240,000
CONNECTION TO EXISTING PIPE	2	EA	$ 1,000	$ 2,000
SURFACING				
CEMENT CONCRETE SIDEWALK	40	SY	$ 60	$ 2,400
CRUSHED SURFACING TOP COURSE	60	TN	$ 60	$ 3,600
COMMERCIAL HMA CL. 1/2 IN. PG 64-22	40	TN	$ 175	$ 7,000
CEMENT CONC. TRAFFIC CURB AND GUTTER	65	LF	$ 40	$ 2,600
			Subtotal	$ 394,521
DEWATERING	10%			$ 39,452
EROSION & SEDIMENTATION CONTROL	5%			$ 19,726
TRAFFIC CONTROL	3%			$ 11,836
SITE RESTORATION	7%			$ 27,616
MOBILIZATION (GENERAL REQUIREMENT)	5%			$ 19,726
			Subtotal	$ 512,877
CONTINGENCY	30%			$ 153,863
			Construction Subtotal (Rounded)	$ 667,000
STATE SALES TAX	9.5%			$ 63,365
ENGINEERING > $250K CONST	25%			$ 166,750
CONSTRUCTION MANAGEMENT	15%			$ 100,050
PERMITTING	8%			$ 53,360
2014 Dollars			**Total Estimated Project Cost (Rounded)**	**$ 1,051,000**

Notes:

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