Preliminary Design Report

Squalicum Creek Weir and Baker Creek Crossing
Fish Passage Project
Bellingham, Washington

for
City of Bellingham

April 28, 2022

GeoEngineers
Earth Science + Technology

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File No. 0356-178-00

April 28, 2022

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Table of Contents

1.0 INTRODUCTION 1

1.1. Site Location 1
1.2. Fish Passage Barrier and Aquatic Species Description 1

2.0 PROJECT VISION, GOALS AND OBJECTIVE 2

2.1. Vision 2
2.2. Habitat Restoration Goals 3
2.3. Project Objectives 3

3.0 EXISTING CONDITIONS 3

3.1. Geology 3
3.2. Watershed Conditions 3
3.3. Site Description 4
3.4. Site Reconnaissance and Site Survey 4
3.5. Site History and Constraints 4
3.6. Channel Geomorphology 5
3.7. Fish Use 6
3.7.1. Documented Fish Use 6
3.7.2. Upstream and Downstream Fish Barriers 7
3.8. Hydrology 8

4.0 PRELIMINARY DESIGN ALTERNATIVES 9

4.1. Selection Criteria 9
4.2. Alternatives 10
4.3. Preferred Alternative 13
4.3.1. Cost Effectiveness and Biological Benefit 13

5.0 DESIGN CONSIDERATIONS AND PRELIMINARY ANALYSES 14

5.1. Design Criteria 14
5.1.1. Proposed Alignment 14
5.1.2. Proposed Profile 14
5.1.3. Proposed Section 14
5.1.4. Hydraulic Opening and Length 15
5.2. Hydraulic Modeling 15
5.3. Structure Design 17
5.3.1. Design Methodology 17
5.3.2. Structure Type 17
5.3.3. Freeboard 18
5.3.4. Roadway Design 18
5.3.5. Utilities 19
5.4. Streambed Design 19
5.4.1. Existing Bed Material 19
5.4.2. Proposed Bed Material 19
5.4.3. Streambed Complexity 20
5.5. Climate Change Considerations 21

6.0 PERMITTING AND STAKEHOLDER CONSULTATION 21
6.1. Stakeholder Coordination 21
6.2. Permits 22
7.0 CONCLUSIONS AND RECOMMENDATIONS 22
8.0 LIMITATIONS 22
9.0 REFERENCES 23

FIGURES

Figure 1. Vicinity Map
Figure 2. Watershed Map
Figure 3. Long Profile

APPENDICES

Appendix A. Site Assessment Photos
Figure A-1. Existing Weir – Looking Upstream
Figure A-2. Baker Creek Culvert Inlet
Figure A-3. Existing BNSF Railroad and Racked Wood – Looking Downstream
Figure A-4. Squalicum Creek–Looking Downstream from approximately 350 upstream of confluence
Figure A-5. Baker Creek–Looking Upstream from above the Railroad
Figure A-6. Squalicum Creek–Looking Downstream from approximately 100 downstream of confluence
Figure A-7. Squalicum Creek–Looking Downstream from approximately 50 downstream of confluence
Figure A-8. BNSF Railroad West of the Project Site
Appendix B. Preliminary Design Drawings
Sheets 1 through 5. Squalicum Creek
Sheets 6 though 10. Baker Creek Crossing at Squalicum Parkway
Appendix C. Hydraulic Model Results
Figure C-1. Squalicum Creek and Baker Creek Existing Conditions Hydraulic Model Plan View
Figure C-2. Squalicum Creek and Baker Creek Proposed Conditions Hydraulic Model Plan View
Figure C-3. Baker Creek and Squalicum Creek Existing Profile
Figure C-4. Squalicum Creek Existing Profile
Figure C-5. Baker Creek and Squalicum Creek Proposed Profile
Figure C-6. Squalicum Creek Proposed Profile
Figure C-7. Squalicum Creek Existing Conditions Tabular Results
Figure C-8. Baker Creek Existing Conditions Tabular Results
Figure C-9. Squalicum Creek Proposed Design Tabular Results
Figure C-10. Baker Creek Proposed Design Tabular Results
Figure C-11. Natural Conditions Tabular Results
Appendix D. Preliminary Geotechnical Considerations Memorandum
Appendix E. Value Engineering Report

1.0 INTRODUCTION

The City of Bellingham (COB) is proposing to submit a grant application to the Brian Abbott Fish Barrier Removal Board (FBRB) to correct two fish passage barriers by removing a barrier weir on Squalicum Creek and correcting an existing culvert crossing on Baker Creek at Squalicum Way. The weir on Squalicum Creek (Appendix A, A-1) is a fish passage barrier that limits access to spawning and rearing habitat for anadromous salmonids, including steelhead (*Oncorhynchus mykiss*), Chinook (*O. tshawytscha*), Chum (*O. keta*) and Coho (*O. kisutch*) Salmon; Bull Trout (*Salvelinus confluentus*), Sea-run cutthroat (*O. clarkii*) and resident trout (*O. mykiss*) within Squalicum Creek. The undersize culvert on Baker Creek at the confluence with Squalicum Creek just upstream from the weir is identified by the Washington Department of Fish and Wildlife (WDFW) (WDFW 2021) as having the same species as the Squalicum Creek weir site, with the exception of Chinook Salmon.

While the weir on Squalicum Creek restricts passage, it simultaneously supports fish passage through the upstream Baker Creek crossing by backwatering the culvert. At the time of the site visit, the presence of the weir was maintaining a water surface elevation 6 inches higher than the bottom of the Baker Creek culvert outlet, which improves fish passage through the culvert for some species, but is not sufficient to meet minimum depth standards based on Water Crossing Design Guideline (WCDG) standards (Barnard, et al. 2013). The project described in this design report proposes to remove the weir, replace the Baker Creek culvert with a WCDG-compliant bridge, and regrade the channel to accommodate a more natural slope through the Baker Creek crossing. The existing Baker Creek crossing (Appendix A, A-2), which outfalls directly into Squalicum Creek, consists of two, four-sided 5-foot by 5-foot concrete box culverts, one of which was retrofitted with baffles, that will be replaced with a single bottomless crossing structure, fully restoring fish passage at both sites. In addition, removing the weir and replacing the crossing structure on Baker Creek, through Squalicum Way, will enhance fish habitat by removing man-made hydraulic controls and allowing for natural stream channel and habitat-forming processes in both Squalicum and Baker Creeks.

1.1. Site Location

Squalicum Creek flows southwest from Squalicum Lake through the city of Bellingham and into Bellingham Bay. The project site is located in the city of Bellingham, in Whatcom County Section 24 of Township 38 North and Range 2 East of the Willamette Meridian and within Water Resource Inventory Area (WRIA) 1 (Nooksack). The roadway, Squalicum Way, is owned and maintained by the COB. Similarly, COB holds a contiguous roadway easement across several parcels on the southeast side of Squalicum Way adjacent to this crossing. One of the adjacent parcels, located southwest of and including the project crossing, is owned outright by the COB. The approximate site location is shown on the vicinity map (Figure 1). Baker Creek flows north to south under Squalicum Way to its confluence with Squalicum Creek, just downstream of the structure. Property on the north side of Squalicum Way is owned by Burlington Northern Santa Fe (BNSF) and includes an inoperable railroad that has been excavated, decommissioned, and undermined by natural stream processes in various locations east and west of the Squalicum Way crossing (Appendix A, A-3, A-8). The railroad will not be impacted with the proposed design.

1.2. Fish Passage Barrier and Aquatic Species Description

Squalicum Creek in the project area contains documented habitat for steelhead, Chinook Salmon, Coho Salmon, Cutthroat Trout, and Chum Salmon and presumed habitat for resident trout and Bull Trout (NWIFC WDFW 2022). Documented habitat for Bull Trout is located in Squalicum Creek approximately 4,400 feet downstream of the project site; however, Bull trout are considered absent or very rare, as last documented occurrence was of one sub-adult in 1970 (NWIFC WDFW 2022). In 1999, WDFW surveyors identified multiple reaches in the upper Squalicum Creek watershed as either “Excellent” or “Good” steelhead spawning habitat (Klacan 2013). Bull Trout, Puget Sound Chinook Salmon, and Puget Sound steelhead are identified as threatened and subject to compliance with the Endangered Species Act (ESA) in the Puget Sound and its tributaries. Squalicum Creek and Baker Creek are mapped as designated Critical Habitat for steelhead (NOAA 2022).

The WDFW has identified the weir as a fish passage barrier (WDFW Site ID 602273), while the Baker Creek crossing is not currently identified in the WDFW database as a barrier based on a retrofit completed in 2005 (WDFW 2021). Upstream of the weir, there is an estimated 5,285 linear feet (LF) of habitat gain in Squalicum Creek upstream to a recently completed project at I-5, above which there is over 114,261 LF of habitat gain. Upstream of the Baker Creek crossing there is an estimated 120,384 LF of habitat in Baker Creek (WDFW 2021). Although the Baker Creek crossing through Squalicum Way is considered passable by WDFW (WDFW 2021), that determination is based on the backwater effect from the weir and installation of baffles on the floor of the crossing structure. Observations of flow conditions during GeoEngineers’ site visit indicated that the crossing may present a water depth barrier during low flow conditions, which are not considered as part of the barrier determination (WDFW 2019); however, the retrofit using baffles and the weir are hydraulic design approach to addressing fish passage and are not the preferred approach by WDFW and Tribes. In addition, the crossing has a smooth concrete bottom and lacks streambed sediment through the crossing limiting steam channel features that support fish passage and degrades habitat through the crossing (Barnard, et al. 2013).

2.0 PROJECT VISION, GOALS AND OBJECTIVE

The COB is proposing to address two fish passage structures. First is the fish passage barrier weir on Squalicum Creek downstream of the confluence with Baker Creek. The existing fish passage barrier limits access to spawning and rearing habitat for anadromous salmonids, including threatened steelhead within Squalicum and Baker Creek. Second is removal and replacement of the existing upstream culvert on Baker Creek conveying flow through Squalicum Way to the confluence with Squalicum Creek. This second structure was identified during the feasibility analysis due to the weir’s influence on the passability of this Baker Creek structure. The existing culvert will be replaced with a fish passable crossing structure. Additionally, this project will enhance stream habitat by installing large woody material (LWM), providing floodplain benches and installing native plants. GeoEngineers worked collaboratively with the COB to develop and evaluate alternatives for providing fish passage at the Squalicum Creek weir. We prepared conceptual alternatives and completed WDFW’s FBRB Barrier Correction Analysis Form (GeoEngineers 2022).

2.1. Vision

Restore accessibility to approximately 120,000 LF of available habitat for key species within the Squalicum Creek watershed and improve access to approximately 120,384 LF of available habitat (WDFW 2021) for key species within Baker Creek watershed, consistent with the Bellingham Comprehensive Plan, and Washington State Department of Fish and Wildlife Brian Abbott Fish Barrier Removal Board guidance.

2.2. Habitat Restoration Goals

Removal of the weir and restoration of natural channel grade and geometry with natural wood, rock and streambed sediment will enhance habitat at the site, provide access to an estimated 120,000 LF of upstream habitat in Squalicum Creek and restore natural channel processes. Replacement of the Baker Creek crossing and restoration of channel grade and geometry using natural rock, wood and streambed sediment will enhance habitat at the site, improve access to an estimated 120,384 LF of upstream habitat in Baker Creek (WDFW 2021) and restore natural channel process that benefit the confluence of Baker Creek with Squalicum Creek. Restoration is intended to support and further the benefits of projects previously completed by the COB on Squalicum Creek (see Section 3.5).

2.3. Project Objectives

Project objectives include determination of feasible alternatives for the modification or removal of the identified fish passage barrier on Squalicum Creek and selection of a preferred alternative based on performance related to selection criteria. Design alternatives, selection criteria and the preferred alternative are presented in Section 4.0.

Appendix B contains preliminary design drawings and draft special provisions that detail a restoration action and removal of the weir on Squalicum Creek. The preliminary design drawings and special provisions are intended to restore a natural channel morphology through the reach occupied by the weir and in Baker Creek at Squalicum Parkway to the greatest extent practicable, while allowing for balanced bed load transport. The preliminary design drawings and draft special provisions considered and accommodated passage of all life stages of the key species noted in Section 1.2.

3.0 EXISTING CONDITIONS

3.1. Geology

The geology in this area is mainly a reflection of past glacial activity. The headwaters and upper reaches of Squalicum Creek flow within a glacial meltwater channel that transitions to a large fossil delta near Cornwall Park consisting of outwash sand and gravel from the Sumas Stade of the Fraser Glaciation (Kovanen, Haugerud and Easterbrook 2020). The meltwater channel was carved into the landscape within the Everson Glaciomarine Drift (Bellingham Drift of (Easterbrook 1976)), a geologic unit consisting of pebbly sandy silt and pebbly clay. From Cornwall Park downstream, Squalicum Creek has incised into the fossil delta and underlying Everson Glaciomarine Drift as it flows to Bellingham Bay. Additional information regarding geology, geohazards and preliminary geotechnical investigations can be found in Appendix D.

3.2. Watershed Conditions

Squalicum Creek originates east of Bellingham, approximately 2.5 miles east of the Nooksack River delta in the Cascade foothills (Figure 2). Major tributaries include Spring Creek, Baker Creek, Toad Creek and McCormick Creek. Squalicum Creek flows through primarily residential and commercial areas before entering Bellingham Bay. The Squalicum Creek watershed, at the project site, is approximately 13.2 square miles with a maximum and minimum elevation of 1,550 feet and 62 feet, respectively (USGS 2022). The proposed project site is in the lower reaches of the creek, approximately 1.5 miles upstream from where Squalicum Creek enters Bellingham Bay and just downstream from the confluence with Baker Creek.

Baker Creek has a slightly smaller watershed of 9.4 square miles that originates approximately 4.5 miles east of the confluence with Squalicum Creek. The Baker Creek watershed has similar land cover and usage characteristics as Squalicum Creek, flowing through primarily residential and commercial areas. The maximum and minimum basin elevations are 552 and 76 feet, respectively (USGS 2022).

3.3. Site Description

Squalicum Creek generally flows from the northeast to the southwest through the project reach adjacent to Squalicum Way. The project barrier on Squalicum Creek consists of an approximately 29-foot-long and 2-foot-tall concrete weir that is characterized as a partial fish passage barrier by WDFW with 33 percent fish passability due to water surface drop (WDFW 2021). The weir structure is approximately 2 feet high at the bottom of the notch and 2.5 feet at the weir crest. Upstream of the weir, Squalicum Creek is mostly straight, geomorphically confined and artificially constrained between Squalicum Way and the left valley wall (Appendix A, A-4). Narrow, intermittent floodplains are observed upstream that are approximately 2 to 4 feet above the channel bed.

Baker Creek is a tributary to Squalicum Creek just upstream of the existing weir. The confluence location is immediately downstream of a double-barrel, 5-foot by 5-foot box culvert that conveys Baker Creek under Squalicum Way from north to south. The double-barrel box culvert is identified as a corrected barrier per WDFW assessment. Upstream of the culvert, Baker Creek is artificially constrained on the right bank and has a narrow floodplain approximately 1 to 3 feet above the channel bed on the left bank (Appendix A, A-5). The concrete weir on Squalicum Creek backwaters Squalicum and Baker Creeks, maintaining a water surface elevation that is slightly higher than the Baker Creek culvert outlet and creating a pool that is approximately 50 feet wide and 5 feet deep at the Baker Creek-Squalicum Creek confluence. Downstream of the weir, the Squalicum Creek channel is straight and flows southwest for approximately 300 feet, moving away from Squalicum Way, with a high terrace along the right bank between the creek and Squalicum Way (Appendix A, A-6). The creek is located within an area of suburban residential development.

3.4. Site Reconnaissance and Site Survey

GeoEngineers conducted two field-based site assessments. The first was on March 1, 2022 and the second was March 24, 2022. We collected bankfull width measurements, a Wolman pebble count, documentation of riparian vegetation and fish habitat, documentation of channel morphologic conditions and general site observations. The assessment included the reach approximately 400 feet upstream and 400 feet downstream of the weir crossing on Squalicum Creek and approximately 200 feet upstream of the Baker Creek crossing through Squalicum Way. Survey was collected by PACE and delivered to GeoEngineers on March 14, 2022. Survey included six cross sections on Squalicum Creek, extending approximately 200 feet upstream of the weir and 200 feet downstream. Additional information was collected at the inlet and outlet of the Baker Creek culvert and survey of the thalweg extended 130 feet upstream of the culvert inlet.

3.5. Site History and Constraints

Multiple restoration projects have been completed by the COB and Washington State Department of Transportation (WSDOT) on Squalicum Creek upstream and downstream of the project site. Downstream, COB and the Nooksack Salmon Enhancement Association (NSEA) have been working together since 2004 to restore riparian areas along Squalicum Creek. COB also completed off-channel rearing habitat expansion with the creation of the Willow Spring project in 2010 and 2018. Upstream, the COB completed a series of large-scale restoration projects on Squalicum Creek from 2015 to 2020, including rerouting the creek around Sunset Pond, reactivating historic channel alignments, replacing a culvert (WDFW barrier 990435) on Squalicum Parkway and restoring a portion of Bug Lake to a forested wetland (City of Bellingham 2022). WSDOT corrected WDFW barrier 991036, conveying Squalicum Creek under I-5, replacing two circular culverts with an inverted, three-sided fish passable culvert. Two barriers remain between the restoration project completed by the COB and the weir on Squalicum Creek, one of which is a natural barrier. The other barrier is less than a half mile upstream, conveys Squalicum Creek under Meridian Street and is 67 percent passable (WDFW, Washington State Fish Passage 2021). Downstream of the weir, the COB completed Willow Spring, a project in 2018 that restored a gravel pit, airport and concrete plant to off channel habitat connected to Squalicum Creek (City of Bellingham 2022). Finally, the COB, Port of Bellingham, WDFW, and BNSF are coordinating on a feasibility for addressing the three fish passage barriers at the Squalicum Creek estuary (991104, 991079 and 602275). The entities are coordinating on a design grant application intended for submittal in June 2022.

Squalicum Way is a truck route providing access to the Port of Bellingham. Construction of the preferred alternative should consider transportation impacts. Underground utilities including a gravity sanitary sewer and a natural gas pipeline were observed on the north side of Squalicum Way near the inlet of the Baker Creek culvert. Survey of the utilities was not available, however based on discussions with COB they are not expected to have substantial construction implications.

3.6. Channel Geomorphology

Squalicum Creek is a single-thread, straight to meandering creek in the vicinity of the project. The creek is naturally confined due to incision and is also constrained by the Squalicum Parkway truck route. Discontinuous floodplains, approximately 20 to 30 feet wide, exist on either side of the stream within 200 to 300 feet upstream of the project. The average bankfull width is 30 feet. The local gradient upstream of the weir is approximately 1.5 percent based on the 2013 COB LiDAR data (Figure 3). This gradient is a deviation from the overall average slope of Squalicum Creek between Meridian and the culvert downstream that conveys the creek under Squalicum Parkway, which is approximately 0.9 percent.

The bedform is characterized by pool-riffle morphology. Riffles are short and steep and controlled by large cobbles to small boulder sized material that is highly angular and resembles riprap. It is possible this material is failed bank protection from Squalicum Way or was installed during construction of the weir. Pools were typically near 100 feet long and up to 4 feet deep upstream of the weir on Squalicum Creek at the time of our field assessments. Squalicum Creek turns and flows southwest, just upstream from the weir and a wide pool has formed at the confluence of Squalicum Creek and Baker Creek above the weir. For a distance of approximately 100 feet upstream from the weir, the right bank is lined with riprap and the left bank is characterized by steep, near vertical banks, some that are undercut and border residential properties.

Based on COB 2013 LiDAR data, the gradient downstream of the weir is 1.5 percent for approximately 150 feet before transitioning to approximately 0.5 percent (Figure 3) where several large meanders have formed. The channel in the first 225 feet downstream of the weir is confined by terraces with a narrow floodplain bench present along the left bank. The meandering section downstream of there is moderately confined with a wider floodplain that is slightly higher than the channel bed. Bedform in these downstream reaches is pool-riffle. Sediment appears slightly finer than upstream with a mix of sand, gravel and cobble but fewer boulders. The larger material is angular, as was observed upstream, and appears to have accumulated to form riffles. Pools are not well developed in the first 225 feet downstream and appear more as glides within the pool-riffle sequences. Pools were better developed in the meandering reach further downstream.

Baker Creek upstream of the Squalicum Parkway crossing, has downcut into the glacial fossil delta. Subsequent widening at the new base level produced a narrow floodplain along the left bank. The channel is geomorphically confined and constrained by the culverts at Squalicum Parkway and Birchwood Avenue. According to the 2013 LiDAR data, the reach of Baker Creek between the culverts has a gradient that is similar to the local gradient of Squalicum Creek within the project bounds (Figure 3). The reach is short, approximately 225 feet long, but appears to have a pool-riffle bedform. A large scour pool exists at the outlet of the Birchwood Avenue culvert that gives way to a steep riffle upstream of the railroad trestle piers and Squalicum Parkway culvert. Sediment consists of predominantly small cobbles and very coarse gravel. Two large 2- to-3-foot-diameter logs are currently racked against the piers and have caused or exacerbated deposition behind it.

3.7. Fish Use

3.7.1. Documented Fish Use

Fish distribution information was gathered from the Statewide Washington Integrated Fish Distribution (SWIFD) managed by WDFW and the Northwest Indian Fisheries Commission(NWIFC WDFW 2022) and WDFW Barrier Inventory and Assessment (WDFW 2021) and fish studies conducted by the City of Bellingham.

Squalicum Creek in the project area contains documented habitat for steelhead, Chinook Salmon, Coho Salmon, Cutthroat Trout, resident trout and Chum Salmon and presumed habitat for Bull Trout (NWIFC WDFW 2022). Documented habitat for Bull Trout is located in Squalicum Creek approximately 4,400 feet downstream of the project site (NWIFC WDFW 2022). Table 1 below summarizes fish presence within Squalicum Creek at the project location.

TABLE 1: NATIVE FISH SPECIES POTENTIALLY PRESENT WITHIN THE PROJECT AREA

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Coho Salmon	Documented	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Species of Concern – Puget Sound
Steelhead Trout	Documented	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Threatened – Puget Sound DPS
Cutthroat Trout	Documented	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Not warranted
Resident trout	Documented	Barrier Inventory Report Assessment (Washington Department of Fish and Wildlife 2021) City of Bellingham Fish Studies (Bellingham n.d.)	Not warranted

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Chum Salmon	Documented	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Not warranted
Chinook Salmon	Documented	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Threatened – Puget Sound ESU
Bull Trout	Presumed*	Statewide Washington Integrated Fish Distribution Commission (Northwest Indian Fisheries Commission and Washington Department of Fish and Wildlife 2022)	Threatened – Pacific Region

Notes: *Bull trout absent or very rare, last documented occurrence of one sub-adult in 1970.

Areas immediately upstream of the project site provide limited spawning habitat due the large size of substrate along riffles and the large amount of angular rock intermixed with the streambed sediment. However, this reach provides some rearing habitat due to sufficient shade, cover, pools and channel complexity and restoration projects upstream provide excellent spawning and rearing habitat for various salmonids species, in addition to quality natural habitat farther upstream. Several well shaded pools and low-velocity channel margins provide potential resting habitat for migrating adult salmonids and rearing habitat for juveniles in the project area. Limited large woody material is present within the reach immediately upstream. Riparian vegetation in the project area consists primarily of Himalayan blackberry (*Rubus armeniacus*), reed canary grass (*Phalaris arundinacea*), and red osier dogwood (*Cornus sericea*), with an overstory of red alder (*Alnus rubra*) with a few western red cedar (*Thuja plicata*). The forested canopy covers approximately 75 percent of the channel while shrubs shade approximately 40 percent of the channel.

The area immediately downstream of the weir provides both rearing and spawning habitat with sufficient shade, cover, channel complexity, and appropriately sized streambed material to support many species and life history stages of salmonids and other aquatic species. Gravels and cobbles within appropriate size ranges for spawning were observed, including on riffle crests in areas with presumably suitable flow during spawning seasons. There is limited large woody material downstream of the weir within Squalicum Creek. Riparian vegetation consisted primarily of Himalayan blackberry, English ivy (*Hedera helixa*), and Osoberry (*Oemleria cerasiformis*) with an overstory of red alder, western red cedar and Douglas fir (*Pseudotsuga menziesii*). Since 2004 the COB and NSEA have been working to restore the riparian areas along Squalicum Creek, having completed an extensive riparian restoration project that includes the right bank of Squalicum Creek adjacent to the project.

3.7.2. Upstream and Downstream Fish Barriers

Multiple corrected and uncorrected fish passage barriers are located on Squalicum Creek both upstream and downstream of the project location. Table 2 below summarizes the uncorrected barriers.

Numerous restoration projects within the Squalicum Creek watershed have been completed by WSDOT, and the COB since 2010 (City of Bellingham 2022) (see Section 3.5). The preferred alternative for this project is intended to support previous work completed on Squalicum Creek and enhance fish habitat within the watershed. Two barriers remain between the restoration project completed by the COB and the weir on Squalicum Creek, one of which is a natural barrier. The other barrier conveys Squalicum Creek under Meridian Street and is 67 percent passable. Additional barriers within the Squalicum watershed are listed in Table 2.

TABLE 2: UNCORRECTED FISH PASSAGE BARRIERS

WDFW Barrier ID	Feature Type	Approximate Distance from Project Crossing (ft)	Approximate Distance from Bellingham Bay (ft)	Percent Passability
990014	Culvert and fishway	31,817 Upstream	39,881	33
920649	Dam	1,992 Upstream	10,056	67
01.0552 2.00	Culvert and fishway	1,480 Upstream	9,544	67
01.0552 1.80	Culvert retrofitted with Fishway	50 Upstream	9,014	Unknown*
602273	Weir	0	8,064	33
920646	Culvert and fishway	1,803 Downstream	6,261	Unknown
991105	Culvert and fishway	4,654 Downstream	3,410	33
811121	Culvert and fishway	5,127 Downstream	2,937	67
991104	Culvert	7,759 Downstream	305	Unknown**
991079	Culvert	8,003 Downstream	61	Unknown**
602275	Culvert	8,064 Downstream	0	Unknown**

Notes: *Based on site assessment by project team, crossing is a barrier during low flows.

**Currently in a feasibility analysis, COB, Port of Bellingham, WDFW and BNSF are coordinating on design grant application for submittal in June 2022.

3.8. Hydrology

The 2-, 100-, and 500-year peak flows were calculated for Baker Creek and Squalicum Creek at the project crossing. A gauge on Squalicum Creek maintained by the COB (City of Bellingham 2021), approximately 4,000 feet downstream of the project site, was used for the analysis. HEC-SSP version 2.2 (USACE 2019) was used to perform a flood frequency analysis on Squalicum Creek at the gauge location based on Bulletin 17C methods (Cohn, et al. 2019). The flows from the analysis of the gauge location were then transposed to the project location by scaling the flows by basin area as recommended by the USGS (Mastin, et al. 2016). The gauge basin area is approximately 22.9 square miles compared to the 22.6 square mile project area basin (USGS 2022).

The Squalicum Creek peak flows at the gauge location were calculated using the record of annual peak flows from COB gauge. This gauge reports 16 peak flows between the years of 2005 and 2021. Estimation of the skewness coefficient is necessary for a Bulletin 17C analysis (USACE, HEC-SSP Statistical Software Package User's Manual 2019). The weighted skew option was used, which combines the station skew coefficient and regional skew coefficient to form a better estimate of skew (Mastin, et al. 2016). For this analysis, the regional skew is -0.07, the standard error of the regional skew is 0.424, and the mean square error of the regional skew is 0.18 (Mastin, et al. 2016). Table 3 lists the 2-, 100-, and 500-year flows for Squalicum Creek at COB Gauge and the flows transposed to the project location. The project location flows are used as input values in the hydraulic model described in Section 6.3. A ratio of basin size was used to determine flows on Baker Creek at the Squalicum Way crossing and on Squalicum Creek upstream of the confluence with Baker Creek. Squalicum Creek contributes 58 percent of the combined watershed with a basin of 13.2 square miles. Baker Creek contributes 42 percent of the watershed area with a basin area of 9.4 square miles.

To evaluate the effects climate change may have on flows in Baker and Squalicum Creek, the WDFW's Culverts and Climate Change web application was used to estimate the projected future ("2080s") increase in the 100-year flow. The 2080s refers to the range of years between 2070 and 2099. Methods are described in a paper published in 2017 (Wilhere, et al. 2017). The tool predicts that the mean percent increase in flows during a 100-year storm event in the 2080s is 9.2 percent. The 2080s predicted 100-year flow is reported in Table 3.

TABLE 3: PEAK FLOWS AT THE PROJECT SITE

Recurrence Interval	Squalicum Creek at COB Gauge (cfs)	Squalicum Creek at Weir (cfs)	Squalicum Creek Upstream of the Confluence (cfs)	Baker Creek at Squalicum Way (cfs)
2-Year	761	752	440	312
100-Year	3,476	3,435	2,009	1,426
500-Year	4,923	4,864	2,845	2,020
2080 100-Year	3,796	3,751	2,194	1,557

4.0 PRELIMINARY DESIGN ALTERNATIVES

4.1. Selection Criteria

GeoEngineers, in cooperation with KPFF and the COB, developed evaluation criteria to select a preferred design alternative. The preferred alternative was selected using a multi criteria decision analysis (MCDA) table. Eleven criteria were outlined and evaluated for each alternative by the design team. A weight of 1 to 5 was assigned to each criterion with higher scores correlating to higher priority criteria by the COB. The eleven criteria were then assigned a score of 1 to 10 for each alternative by GeoEngineers with higher scores correlating to more favorable project impacts and lower scores correlating to less favorable impacts. The criteria weight and score were multiplied and summed. Results of the MCDA analysis are presented in Section 4.3 and the Barrier Correction form (GeoEngineers 2022). The alternative with the highest total summed score was selected as the preferred alternative. The selection criteria are presented in Table 4 below.

TABLE 4: DESIGN ALTERNATIVES SELECTION CRITERIA

Evaluation Criteria	Description	Weight
Construction Cost	Relative construction cost. Includes: Excavation quantity, dewatering time, delivery, ease of installation, streambed material, import/backfill quantity & depth. Lower overall costs are more favorable.	3
Traffic Control/Traffic Impacts	Includes: roadway restoration limits, dewatering time, community access. Alternatives that have quicker constructability and schedules are more favorable.	2
Easements & ROW Acquisition	Alternatives that do not require permanent acquisition of additional right-of-way are less impactful and more favorable. Temporary construction easements are not problematic	4
Environmental Considerations	Potential effects may impact potential project mitigation. Environmental considerations also include impacts from: excavation quantity, roadway restoration limits, dewatering time. Fewer environmental considerations are more favorable.	3
Geomorphic Considerations	This criterion evaluates how well the design allows for natural channel process to occur post construction and if the design is compatible with natural geomorphic conditions. Alternatives that support natural channel processes and are compatible with natural geomorphic conditions are preferred.	5
Project Schedule	The project schedule takes design, permitting, bid, construction, and closing tasks into account. Includes: dewatering time, delivery, ease of installation. Alternatives that require less time to complete the overall tasks are more favorable.	2
Maintenance	This will evaluate the level of effort for maintaining the structure post-construction. The structure that requires less maintenance are more favorable.	5
Habitat Benefits	This measures the relative opportunity to create new habitat and improve existing habitat for aquatic and terrestrial species. Larger project area may increase the opportunity for habitat creation and restoration and project constraints may decrease the potential habitat benefits. Alternatives that return the channel to more natural conditions are more favorable.	5
Fish Passage	This criterion evaluates the how well the design provides for fish passage during all flows and ability to maintain design conditions in perpetuity. Alternatives that provide fish passage and have the potential to provide fish passage long term are more favorable.	5
Future Compatibility	This measures the compatibility of the project with future construction and restoration efforts. Compatibility with existing projects and potential future projects are more favorable.	3
Utility Conflicts	This evaluates if the project will require utilities to be relocated or if construction will be impacted by existing utilities. Alternatives that do not require utility relocation or consideration are more favorable.	2

4.2. Alternatives

GeoEngineers developed three conceptual stream channel action alternatives based on project goals, objectives, the site assessment, hydrology and the selection criteria. The alternatives vary in complexity and disturbance area. Each of the three alternatives can be designed to meet the project goal regarding fish passage barrier removal. Alternatives 1 and 2 can be constructed to provide continuous vehicular traffic conveyance without a detour during construction. Alternative 3 will require temporary roadway modifications within the right of way to provide continuous vehicular traffic conveyance. Abandonment of the existing barriers was considered prior to the three alternatives described below; however, it was determined to be infeasible due to the importance of Squalicum Way as a means of transportation and as a truck route. The three alternatives, including design elements, benefits and limitations are described below:

Alternative 1: Remove (abandon) weir only and regrade the stream channel using engineered channel stability elements such as a roughened rock ramp

Alternative Elements:

- Remove existing weir and associated bank armoring.
- Grade channel and banks approximately 60 feet upstream, use engineered grade control structures built from boulders and large wood to maintain water surface elevation at outlet of Baker Creek and protect pool habitat.
- Grade channel approximately 180 feet downstream.
- Roughened rock channel geometry built from boulders and cobbles, with resting pools intermixed.
- Stable channel design elements to maintain slope long-term and prevent channel degradation that could create a fish passage barrier at Baker Creek outlet

Alternative Benefits:

- Weir is removed from stream channel.
- Smaller project footprint compared to alternatives 2 and 3.
- Squalicum Way not impacted and minimal impacts to traffic during construction.

Alternative Limitations:

- Must maintain water surface elevation at Baker Creek crossing to maintain fish passage while maintaining the channel profile to prevent increase in flooding/bank erosion on adjacent private properties.
- Channel slope and morphology will not align with upstream and downstream and require grade controls and engineered bank transitions to prevent channel degradation.

Alternative 2: Create a split flow channel

Alternative Elements:

- Construct new 500- to 600-foot-long channel along right floodplain with channel slope that aligns with reach slope.
- Abandon the weir in place and restore old mainstem of Squalicum creek upstream and downstream as a roughened side channel that is active during high flows.

Alternative Benefits:

- Geomorphically aligns with reach conditions.
- Increase in amount and quality of stream channel habitat, including side channel habitat that is lacking in lower Squalicum Creek.
- Water surface elevation at Baker Creek crossing is maintained by weir and channel height.
- Squalicum Way not impacted or would be minimally impacted by construction.
- Reduces stream flows along a section of steep eroding bank and allows stream to access floodplain.

Alternative Limitations:

- Must engineer water surface elevation control using natural stream channel features (LWM, boulders, stream banks) to maintain fish passage at Baker Creek crossing.

Alternative 3: Remove (abandon) weir, restore Squalicum Creek and additionally replace Baker Creek crossing with a conveyance structure

Alternative Elements:

- Remove the existing weir and associated bank armoring.
- Replace the Baker Creek crossing with a structure that has an approximate minimum hydraulic opening of 38 feet.
- Regrade Squalicum Creek within project areas to create more gradual transition that allows for channel to naturally regrade.
- Add channel and habitat complexity elements throughout graded channels, including protecting or recreating pool habitat at the confluence with Baker Creek.

Alternative Benefits:

- Allows for restoration of more natural channel process in Squalicum Creek and Baker Creek.
- Improves fish passage into Baker Creek during all flows.
- Removes existing barrier (weir) and improves fish passage on Squalicum Creek.
- Reduces flooding risk to adjacent landowners by lowering Squalicum Creek profile.
- Gradual slope transition along Squalicum Creek.
- Restores continuity of riffle-pool morphology through reach.

Alternative Limitations:

- BNSF railroad trestle will stay in place. Requires temporary construction easement from BNSF.
- Squalicum Way, an important truck route, will be impacted during construction of Baker Creek crossing.
- Requires assessment of Baker Creek upstream of Squalicum Way to support geomorphic and hydraulic compatibility with the Birchwood Avenue crossing.

4.3. Preferred Alternative

The project team compared the three proposed channel modification alternatives to the project goals, objectives and selection criteria. Each alternative was scored using the selection criteria described in Section 4.1 and the weights determined by the COB. Alternative 3 was selected as the preferred design with a total score of 254 compared to Alternative 1 and 2 scores of 187 and 240, respectively (GeoEngineers 2022). A value-based engineering assessment was also conducted on the three alternatives by Whitewolf Engineering Services (Appendix E). The value engineering assessment results agreed with the MCDA approach described in Section 4.1.

Alternative 3 was selected because it meets the project goal of removing the current fish passage barrier while also allowing for natural stream channel and habitat-forming processes that will sustain fish passage and habitat. In fact, it will completely remove (abandon) the weir and will also replace the Baker Creek culvert through Squalicum Way with a larger, fish passable structure at a grade consistent with Squalicum Creek – correcting two fish passage problems in one project. This channel restoration concept best addresses the identified selection criteria, specifically regarding fluvial geomorphic, fish passage, habitat benefits and maintenance considerations. Alternative 3 restores more natural geomorphic processes on Baker Creek through Squalicum Way, eliminating the risk of the existing Baker Creek culvert becoming perched with the removal of the existing weir. Restoring geomorphic processes and replacing the Baker Creek culvert, generates greater habitat benefits and fish passage at all flows, as compared to Alternatives 1 and 2. Additionally, Alternative 3 removes the need for potential future projects by completely removing the weir, and fully correcting the Baker Creek crossing.

The COB has communicated a preference to prevent permanent impacts to the BNSF railroad upstream of the Baker Creek culvert through Squalicum Way. GeoEngineers' design, described in Section 4.3.1, includes measures to reduce impacts to the BNSF railroad upstream of Squalicum Way.

4.3.1. Cost Effectiveness and Biological Benefit

The evaluation criteria developed to select a preferred design alternative using a MCDA approach included eleven criteria related to a variety of project components representing project costs, geomorphic and biological benefit. The separate value engineering assessment also considered criteria representing project costs, geomorphic processes and biological benefits as key attributes to alternative selection (Appendix E). Weighing the biological and geomorphic benefits against the relative cost was extensively considered during the Team's alternative analysis and selection process. Selecting weir removal and replacement of the existing Baker Creek crossing through Squalicum Way as the preferred alternative increases the overall price of the project compared to Alternatives 1 and 2, however the selected alternative provided the greatest, most comprehensive, and sustainable biological and geomorphic benefits with the replacement of the Baker Creek crossing. The proposed alternative reduces the number of potential barriers with the removal of the weir and upsizing of the Baker Creek crossing. Unique to Alternative 3, this design allows for natural geomorphic processes including the transport of streambed materials and woody debris through the Baker Creek crossing and on Squalicum Creek. Natural channel processes including sediment and woody debris transport reduces potential maintenance costs and is intended to maintain fish passage long term.

5.0 DESIGN CONSIDERATIONS AND PRELIMINARY ANALYSES

5.1. Design Criteria

The design has been developed in accordance with the WDFW WCDG and WSDOT Hydraulics Manual (HM) (Barnard, et al. 2013, Washington State Department of Transportation 2019). The design considers the 100-year storm event and incorporates climate change impacts (see Section 5.5).

The WCDG (Barnard, et al. 2013) present two bridge methodologies for designing a crossing: confined bridge design and unconfined bridge design. The method is determined by the value of the Floodplain Utilization Ratio (FUR). The FUR is defined as the flood-prone width (FPW) divided by the bankfull width (BFW). The FPW is the water surface width at twice the bankfull depth, or the width at the 100-year flood water surface elevation. A FUR under 3.0 is considered a confined channel and above 3.0 is considered unconfined (Barnard, et al. 2013).

For the preliminary design analysis, the FUR was calculated from the existing conditions hydraulic model results, approximately 50 and 96 feet upstream of the existing crossing and was determined to be greater than 3, indicating an unconfined channel at the crossing location. For unconfined bridge design, the velocity ratio between the proposed and natural conditions should not exceed 1.1. The velocity ratio is taken as the average channel velocities at the crossing location for the proposed and natural conditions. A natural conditions hydraulic model was developed for the Squalicum Way crossing as required for unconfined crossings (Washington State Department of Transportation 2019) (see Section 5.2). The natural conditions model is intended to represent the hydraulic conditions of Baker Creek if the Squalicum Way road fill were removed entirely. The ratio between the natural and proposed conditions crossing velocity is used in sizing the proposed minimum hydraulic opening width (Washington State Department of Transportation 2019). The proposed design meets unconfined bridge crossing criteria described in the WCDG and HM (see Section 5.2).

5.1.1. Proposed Alignment

The channel alignment was not changed as part of the proposed design. Using the existing alignment for the proposed design will reduce the cost associated with earthwork and prevent additional impacts to adjacent private properties. The existing alignment is shown in Appendix B.

5.1.2. Proposed Profile

The proposed profile ties in just upstream of the existing Squalicum Way crossing of Baker Creek and approximately 75 feet downstream of the existing weir, resulting in a total grading length of 225 feet. Tie in locations were chosen to create a 0.9 percent grade consistent with the long profile slope (Figure 3) and prevent permanent disturbance of the BNSF railroad. The surveyed slope in the 170 feet upstream of the confluence on Squalicum Creek has a slope of approximately 1 percent. The design grade smooths the slope transition between Baker Creek and Squalicum Creek through the weir location. The existing and proposed profile is shown in Appendix B.

5.1.3. Proposed Section

Two sections were used in the proposed channel design; one for Baker Creek and the second for the combined Baker and Squalicum Creek downstream of Squalicum Way. Channel planform and shape were informed by topographic data upstream of Squalicum Way on Baker Creek and downstream of the weir on Squalicum Creek.

The Baker Creek section targets a 30-foot top of bank to top of bank width. Channel geometry includes a channel cross section with a 20-foot bottom width, and 2:1 (horizontal to vertical) side slopes. The proposed channel depth is 3.5 feet. A 5-foot floodplain bench at a 10H:1V slope is included on both sides of the channel before it ties into existing grade at a 2H:1V side slope. This section extends from the confluence with Squalicum Creek, through the Squalicum Way crossing to the upstream grading limits on Baker Creek.

The Squalicum Creek section targets a 30-foot top of bank to top of bank width. Channel geometry includes a channel cross section with a 16-foot bottom width. A 2:1 side slope creates a channel depth of 3.9 feet. A 25-foot floodplain bench at a 20H:1V slope is included on the right side of the channel section before it ties into existing grade at a 2H:1V side slope. The channel left side slope continues at a 2:1 to tie into the existing grade. This section is maintained from the confluence with Squalicum Creek to the downstream grading limits. A bench was included on the right bank and not the left to allow for overbank flow while minimizing risk to properties on the left bank.

The natural conditions model used the Baker Creek design section modified to have benches extending 100 feet to represent undeveloped conditions. Natural Conditions model results and associated velocity ratios are described in Section 5.2.

5.1.4. Hydraulic Opening and Length

The minimum required hydraulic opening was calculated using Equation 3.2 of the WCDG (Barnard, et al. 2013), rounded up to the nearest whole foot. Equation 3.2, shown below, calculates a minimum hydraulic opening of 38 feet for the Baker Creek crossing through Squalicum Way:

Equation 3.2: Minimum Hydraulic Opening Width = $(1.2\times30) + 2 = 38$ feet (rounded up to nearest foot)

A minimum hydraulic opening width of 40 feet was determined to be necessary to include 5-foot channel benches on either side of the bankfull channel, maintain a velocity ratio of 1.1 or less (see Section 5.2), and allow for natural channel and habitat-forming processes to occur. The proposed crossing length, measured along the proposed channel thalweg, is approximately 80 feet. The length perpendicular to the roadway is approximately 65 feet.

5.2. Hydraulic Modeling

GeoEngineers developed existing and proposed conditions hydraulic models for the Baker Creek culvert at Squalicum Way and the Squalicum Creek weir, using the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center – River Analysis System (HEC-RAS) version 6.1.0 hydraulic modeling program (USACE 2021). The model includes approximately 420 feet of the Squalicum Creek channel, and 200 feet of Baker Creek including the double barrel 5-foot by 5-foot box culvert crossing (Appendix C, Hydraulic Model Results, Figure C-1). The model extends approximately 250 feet downstream of the confluence. The existing surface was developed with survey information provided by PACE on March 18, 2022, and COB LiDAR collected in 2013 (City of Bellingham 2013).

The model was run using a steady state regime, utilizing normal depth as the downstream boundary condition for both the existing and proposed conditions models. Flow data described in Section 3.8 was used at the upstream boundary. Manning's n values for the channel and floodplain were assigned based on field visit observations completed by GeoEngineers on February 24, 2022, utilizing the U. S. Department of Agriculture (USDA) roughness tool (Yochum 2018). The Manning's n values were updated for the proposed conditions model based on grading limits and design characteristics.

The existing surface was modified to reflect the proposed profile and sections described in Section 5.1. A structure with a hydraulic opening of 40 feet was modeled as a bridge. Model parameters, roughness values and flow values were kept consistent with the existing conditions model. Model results were extracted upstream of Squalicum Way on Baker Creek, downstream of Squalicum Way at the confluence of Squalicum Creek and Baker Creek, downstream of the weir and upstream of the confluence on Squalicum Creek. Table 5 and Table 6 present existing and proposed conditions hydraulic model results.

TABLE 5: EXISTING CONDITIONS MODEL RESULTS

Location	Maximum Depth (FT)		Velocity (FT/S)		WSEL (NAVD88)		
Peak Flow Recurrence Interval	2-Year	100-Year	2-Year	100-Year	2-Year	100-Year	2080 100-year
Upstream Baker	3.4	10.9	3.4	10.9	64.4	71.9	72.1
Upstream Squalicum	3.2	8.7	3.2	8.7	62.8	68.3	69.0
Through Crossing	4.4	*N/A	6.9	9.8	64.3	71.8	N/A
Downstream of Confluence	5.4	10.6	4.3	8.2	62.7	67.9	68.3
Downstream of Weir	3.8	8.8	5.6	9.7	60.5	65.5	65.8

Notes: *Flow overtops Squalicum Way at the 100-year event

TABLE 6: PROPOSED CONDITIONS MODEL RESULTS

Location	Maximum Depth (FT)		Velocity (FT/S)		WSEL (NAVD88)		
Peak Flow Recurrence Interval	2-Year	100-Year	2-Year	100-Year	2-Year	100-Year	2080 100-year
Upstream Baker	2.6	7.6	6.8	5.0	63.7	68.7	69.1
Upstream Squalicum	4.1	7.4	5.4	11.3	63.7	67.0	67.5
Through Crossing	5.2	10.2	2.5	4.3	63.2	68.4	68.9
Downstream of Confluence	4.6	8.9	6.8	12.0	62.3	66.5	66.9
Downstream on Squalicum	4.0	8.3	7.8	12.2	60.8	65.1	65.5

The existing road surface elevation of Squalicum Way through the project area is approximately 67.5 feet at the road centerline. The existing conditions 100-year event on Baker Creek overtops the roadway and Squalicum Creek's water surface elevation at the confluence is within a foot of the roadway elevation. Water depth over the road is approximately 2 feet at the 100-year event. At the 2-year event the model predicts backwater upstream of Squalicum Way in Baker Creek. The proposed conditions 100-year water surface elevation through Squalicum Way with a 40-foot-wide hydraulic opening is 68.3 feet, approximately 3.4 feet below the existing conditions water surface elevation, and approximately 0.2 feet lower than the existing roadway. Maximum depths and water surface elevations at the 100-year and 2080 100-year event are reduced at all cross sections under the proposed conditions. In the existing conditions, velocities are lower in the downstream reach and upstream on Squalicum Creek than through the proposed crossing. In the proposed conditions, velocities increase upstream and downstream of the confluence on Squalicum Creek and are reduced through the Baker Creek crossing. Velocity increases, upstream on Baker Creek and Squalicum Creek at the 100-year event, are due to a reduction in backwater due to the removal of the Squalicum Creek weir and upsizing of the crossing structure.

The Hydraulics Manual states that for an unconfined system, velocity ratios through the structure and directly upstream of the crossing, if roadway fill were to be removed, shall not exceed 1.1 when rounded to the nearest tenth (Washington State Department of Transportation 2019). The 100-year natural conditions modeled velocity is 4.5 feet per second yielding a velocity ratio of 1.0 at the 100-year event.

5.3. Structure Design

5.3.1. Design Methodology

The structural design criteria for the bridge is based on the following design standards:

- WSDOT Bridge Design Manual M23-50.20 (September 2020)
- AASHTO LRFD Bridge Design Specifications, Customary U.S. Units, 9th Ed. (2020)

5.3.2. Structure Type

Concrete superstructures generally have lower long-term operation and maintenance costs when compared to steel superstructures, which typically require painting every 20 to 30 years. Use of pre-cast concrete superstructure elements will allow for conventional construction techniques and will help to reduce construction time.

Further geotechnical investigation is required to finalize the substructure foundation type (Appendix D). Initial information indicates that shallow spread footings may not be feasible. Nearby subsurface explorations completed within the local geologic unit indicate that the site is underlain by soft to medium stiff clay. Depending on the selected bridge span and proposed foundation loads, we anticipate that bridge abutments will likely need deep foundation support to mitigate against excessive settlement over the lifetime of the structure. Our experience with similar projects in this geologic unit indicates that driven piles could be a viable option for foundation support. If deeper explorations indicate that the soils at the site are more competent than anticipated, there may be an opportunity to consider a lower cost shallow foundation alternative, however, careful consideration should be given to long term foundation settlement.

Two main considerations when selecting bridge superstructure type were the maximum allowable skew angle of the abutments and total bridge superstructure depth relative to water surface elevations and allowable freeboard.

A pre-cast, prestressed concrete voided slab girder superstructure with a cast-in-place concrete deck is the preferred alternative for this site. The following geometry was used:

- 40-foot minimum hydraulic opening width;
- 20-degree skew angle of the abutments;
- 50-foot bridge length (inlet to outlet);
- 50-foot bridge span, measured parallel to the roadway. Span length is limited by voided slab capacity and constructability; and
- 30-inch-thick voided slab girders with a 6-inch-thick topping slab, for a total superstructure depth of 3 feet.

The major advantage of the voided slab bridge is that it has the shallowest superstructure depth. This helps achieve minimum freeboard requirements while mitigating impacts that would result from raising the existing roadway grade.

Slab girder superstructures also require less formwork than traditional girder and deck bridges. This will eliminate or significantly reduce the amount of access the contractor requires in the channel and will potentially shorten the construction time for the bridge.

5.3.3. Freeboard

The City of Bellingham has requested the proposed design accommodate 1 foot of freeboard above the 100-year flow event. The crossing upstream of Squalicum Way conveying Baker Creek through Birchwood Avenue is a 10-foot box culvert and is expected to limit debris and material conveyed to Squalicum Parkway by Baker Creek. One foot of freeboard is not anticipated to create additional risk to the Squalicum Parkway crossing with the existing limited crossing capacity of Birchwood Avenue. Squalicum Parkway is a truck route and the City of Bellingham conducts maintenance to ensure conveyance capacity through Squalicum Parkway. The proposed 100-year water surface elevation in Baker Creek at the Squalicum Way crossing is 68.3 feet, approximately 0.2 feet lower than the existing road deck. The existing road has an approximate minimum elevation of 68.5 feet based on LiDAR. A recommended road deck and structure thickness of 3 feet requires the road elevation to be increased by 6.5 feet to accommodate 1 foot of freeboard.

5.3.4. Roadway Design

Squalicum Parkway has a functional classification of Minor Arterial with approximately 5,300 vehicles per day (a high percentage of which is truck traffic) based on the 2018 City of Bellingham Traffic Volume reports. It is posted for 35 mph and is a designated bike route. City of Bellingham standards would suggest that the roadway section be based on standard drawing ST-132 with sidewalks; however, Squalicum Parkway in this location is not identified for pedestrian upgrades in the City’s Pedestrian Master Plan and, therefore, it is proposed to maintain the existing roadway section of two 16-foot travel lanes with 6.75-foot shoulders. A total width of 45.5 feet is proposed to provide a bridge that is economical for this location. The existing ROW is 80 feet wide and abuts BNSF right of way on the north side.

The roadway profile will raise approximately 6.5 feet above existing grade and the extents of roadway work sufficient to provide adequate sight distance for the posted speed of 35 mph.

5.3.5. Utilities

Utilities present at this location include a gravity sanitary sewer and a natural gas pipeline. The gas line is owned by Cascade Natural Gas. Specifics of its size and depth are not known at this time but the relocation costs will be borne by the utility owner.

The sanitary sewer is an 18-inch concrete pipe with a structure depth of 3.8 feet below the finished grade per City GIS information. The proposed concept is to Install wetwell/drywell lift station on the upstream side of the bridge. A forcemain will be supported on the side of the precast slab girder bridge and discharge to a new manhole on the west side of the bridge, connecting to the existing sewer.

5.4. Streambed Design

5.4.1. Existing Bed Material

One pebble count was collected by GeoEngineers to characterize the existing channel sediment upstream of Squalicum Way on Baker Creek. The pebble count was collected between approximately 90 and 110 feet upstream of Squalicum Way. Results are shown in Table 7. Existing sediment throughout Baker Creek and Squalicum Creek largely consists of small gravels to cobble. Angular rock was observed in Squalicum Creek, and finer sediment was observed beginning approximately 50 feet downstream of the weir. No pebble count was collected on Squalicum Creek due to high flow conditions. Sediment on Squalicum Creek throughout the project reach is expected to be impacted by grade control structures such as the weir and proximity to the roadway and not representative of an undisturbed setting.

TABLE 7: EXISTING BAKER CREEK SEDIMENT GRADATION

Recurrence Interval	Baker Creek
D_{16}	0.7
D_{50}	1.9
D_{84}	3.2
D_{95}	4.6
D_{100}	40.3

5.4.2. Proposed Bed Material

Proposed streambed gradation for Squalicum Creek will be determined at later stages of the design but is anticipated to be similar to results from Baker Creek. Streambed sediment per WSDOT Standard Specifications will be appropriately sized for the proposed Baker Creek channel design and be reflective of existing site conditions if deemed appropriate by stability calculations. Two feet minimum of streambed material is anticipated to be placed through the graded reach.

Meander bars will be placed throughout the graded reach under the proposed bridge to promote channel sinuosity and habitat complexity. Large wood is not proposed within the crossing structure and is not recommended with the limited crossing freeboard. Meander bar spacing and size will be determined at later stages of the design process.

5.4.3. Streambed Complexity

Large woody material (LWM) structures will be constructed in specific locations throughout the project reach to develop channel complexity and improve bank stability. Large woody material will enhance habitat during all flows, developing channel complexity, providing cover, and improving overall habitat diversity through the project reach. WSDOT provided guidance and analysis tools for LWM quantities consistent with *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State* (Fox and Bolton 2007) were used to inform proposed LWM placement.

The LWM proposed for this project is expected to meet or exceed three metrics representing the 75th percentile quantities observed by Fox and Bolton (Fox and Bolton 2007). These metrics include:

- Key piece density (count/foot of stream), each key piece must meet minimum volume requirements (cubic yard) excluding rootwad
- Total pieces (per foot of stream)
- Total wood volume (cubic yard/foot of stream)

The 75th percentile quantities for the metrics described above were used as targets for the proposed LWM design. The minimum volume of LWM required for each metric is based on the total creek reconstruction length of 225 feet. The targets are determined by habitat zone and bankfull width class. Squalicum Creek is in the Western Washington habitat zone (Fox and Bolton 2007) and has a BFW of 30 feet.

The key piece density requirement for Western Washington streams with bankfull widths between 0 and 33 feet is 0.0335 key piece per foot of stream. Based on 225 feet of reconstructed stream length, 8 key pieces would be required to meet 75th percentile criteria. For streams with bankfull widths between 17 and 33 feet, key pieces must meet a minimum volume of 3.28 cubic yards, not including the rootwad.

The total number of LWM pieces required for Western Washington streams with bankfull widths between 21 and 98 feet is 0.1921 piece per foot of stream reconstruction. Based on 225 feet of reconstructed stream length, 43 LWM pieces would be required to meet 75th percentile criteria.

The total wood volume required for Western Washington streams with bankfull widths between 0 and 98 feet is 0.3946 cubic yard per foot of stream reconstruction. Based on 225 feet of reconstructed stream length, a total wood volume of 88.8 cubic yards, not including the rootwads, would be required to meet 75th percentile criteria.

The proposed design shown in Appendix B meets the 75th percentile quantities for number of key pieces, total number of LWM pieces, and total wood volume. The design proposes 21 key pieces, compared to the 8 key pieces required by Fox and Bolton. Additional key pieces are proposed to meet the total number of pieces requirement. Each key piece in the proposed design meets the minimum volume of 3.28 cubic yards. Key pieces will be installed outside the crossing structure. An additional 22 LWM pieces are proposed to exceed the total minimum number outlined by Fox and Bolton (2007). Overall, the proposed 107.3 cubic yards in the design exceeds the minimum total wood volume of 88.8 cubic yards. Proposed log type dimensions and structure details will be completed at later phase of the design.

The proposed design is preliminary and based on the current alignment and project footprint for the stream. The LWM design will change with any design component variation. LWM structures will interact with all flows, support creation and maintenance of aquatic habitat diversity, induce pool development, promote sediment sorting, and increase hydraulic roughness through the channel alignment.

As part of the large wood design an existing western red cedar (*Thuja plicata*) will be incorporated into the design (see Appendix A, A-7). Additional habitat features such as boulders and meander bars will be evaluated at later design stages. The combination of large wood and boulders allows natural development of channel complexity with pools, riffles, and cover to support a wide, diverse range of fish habitat (Wildlife 2010).

5.5. Climate Change Considerations

The proposed design addresses the predicted effects of climate change and is anticipated to be climate resilient under future conditions. To evaluate the effects that climate change may have on Squalicum and Baker Creek, the WDFW's Culverts and Climate Change web application was used to estimate the projected future ("2080s") increase in the 100-year flow (see Section 3.8). The tool predicts that the mean percent change in the 100-year flood in the 2080s for Squalicum and Baker Creek at the confluence is 9.2 percent. The 2080 increase in flow was modeled using proposed site conditions (see Section 5.2). The change in WSE at the upstream proposed bridge face between the 100-year event and 2080 100-year event is 0.4 feet (Table 6), and is less than the 1 foot of freeboard (see Section 5.3.3). The 2080 100-year flow is not anticipated to notably impact inundation extents compared to the 100-year flow.

The proposed channel complexity elements including large wood, small and mobile woody material and meander bars will increase available aquatic habitat. The proposed project includes 43 pieces of large woody material meeting the 75th percentile targets for Fox and Bolton (see Section 5.4.3). The large wood will encourage sediment sorting, promote flow diversity, encourage the development of pools, and provide cover for anadromous salmonids. Providing low velocity holding areas for fish will become increasing important with projected increasing flows due to climate change and the potential for additional urbanization in the watershed. The addition of LWM and planting of native vegetation will provide shade and cover for instream aquatic organisms. Shaded areas will be essential to provide lower temperature areas for aquatic organisms. The proposed design will help maintain habitat connectivity under changing climate conditions by allowing natural stream channel processes to occur. A low flow channel thalweg will be constructed under the direction of a water resources engineer to connect habitat features to facilitate habitat connectivity during low flows. By installing LWM and restoring natural stream channel processes, the proposed design is facilitating species to naturally adapt to changing environmental conditions associated with climate change.

6.0 PERMITTING AND STAKEHOLDER CONSULTATION

6.1. Stakeholder Coordination

The project was prioritized in part due to the COB's coordination with Nooksack Indian Tribe and the Tribe's interest in addressing this lower mainstem barrier. The City of Bellingham discussed the Squalicum weir with the WRIA 1 Salmon Staff Team's culvert sub-committee, including members from local governments, tribes, non-profits, and WSDOT. As a result, the WRIA 1 Management Team and WSDOT both provided letters of support for submittal to the Brian Abbott FBRB. On March 3rd, the project team met with Joel

Ingram of WDFW on site to review existing conditions, confirm BFW measurements and coordinate on design details. The BFW width of 30 feet was confirmed during the site visit for use in designing the project. Between January and April of 2022, the project team was also in contact with adjacent landowners and project partners (City of Bellingham Parks and Recreation Department and NSEA) to inform them of and request feedback on the proposed project.

6.2. Permits

The project fits within the requirements of WDFW's Fish Enhancement Streamlined Permit pathway for state and local permitting. Proposed activities will result in discharge of fill within Waters of the United States and as such will trigger federal permitting, including ESA consultation and a Clean Water Act Section 401 and 404 permit. The work is consistent with the requirements of a Nationwide Permit for Habitat Enhancement and is consistent with programmatic ESA consultation for salmon habitat and fish passage projects.

7.0 CONCLUSIONS AND RECOMMENDATIONS

GeoEngineers developed three conceptual stream channel alternatives based on project goals, objectives, the site assessment, hydrology and the selection criteria. The three alternatives were evaluated by an interdisciplinary design team using both a MCDA and value engineering. Results from the alternatives analysis determined that Alternative 3, replacing the Baker Creek crossing at Squalicum Way with a bridge and removal of the weir on Squalicum Creek is the preferred alternative (GeoEngineers 2022). A preliminary hydraulic design was developed for Alternative 3 and hydraulic modeling was conducted to inform preliminary bridge design efforts. Initial channel complexity design has been completed and aims to improve habitat quality in the vicinity of the project site.

The proposed preliminary design will facilitate fish passage, improve aquatic and terrestrial habitat at the project site, promote natural channel processes and provide access to approximately 58,478 LF of habitat gain above the weir on Squalicum Creek and 120,384 LF upstream of Squalicum Way on Baker Creek. The proposed project will be part of a continued effort to improve Squalicum Creek fish habitat and promote watershed restoration.

The outlined design for Alternative 3 is preliminary and refinement to design elements including but not limited to grading, hydraulic opening, large wood design, streambed material, and structure design are anticipated at future design stages.

8.0 LIMITATIONS

We have prepared this Preliminary Design for COB and for review by regulatory agencies for the Squalicum Creek weir located in Bellingham, Washington, as illustrated in the Preliminary Design Drawings in Appendix A. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the disciplines of stream and river habitat enhancement, stabilization and restoration design engineering in this area at the time this revised report was prepared. The conclusions, recommendations and opinions presented in this report are based on our professional knowledge, judgement, and experience. No warranty, express or implied, applies to our services and this report.

Any electronic form, facsimile or hard copy of the original document (email, text, table and/or figure), if provided, and any attachments should be considered a copy of the original document. The original document is stored by Geoengineers, Inc. and will serve as the official document of record.

9.0 REFERENCES

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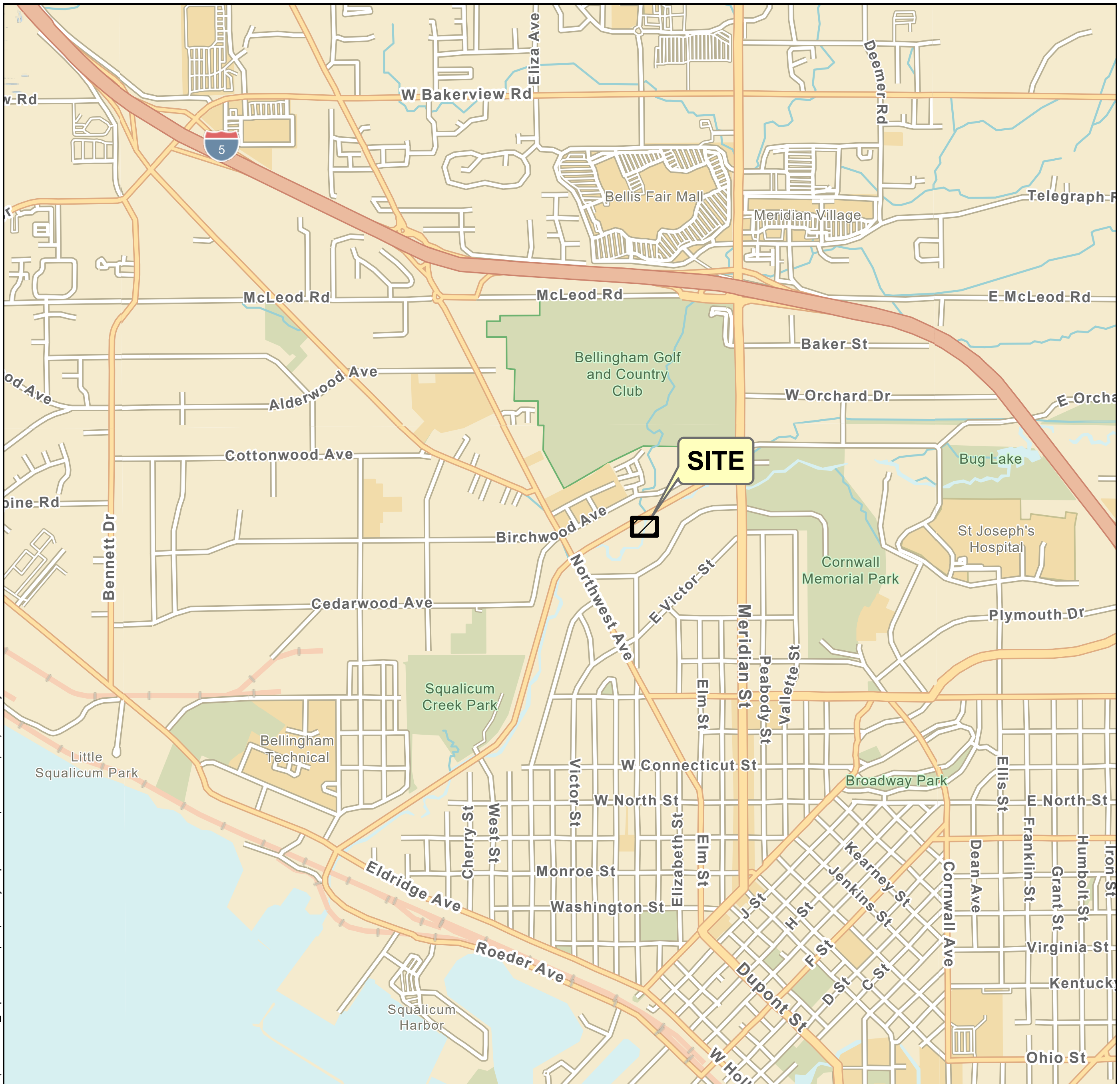
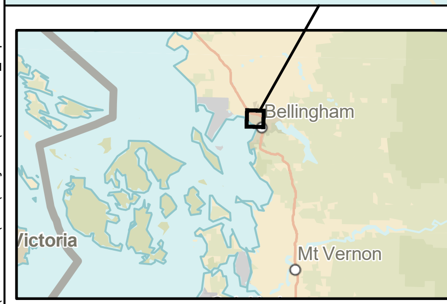
FIGURES





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Feet

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: ESRI

Projection: NAD 1983 UTM Zone 10N

Vicinity Map

Squalicum Creek Weir Fish Passage Project
Bellingham, Washington

GEOENGINEERS

Figure 1

\\geoengineers.com\WAN\Projects\0\0356178\GIS\Projects\0356178_Squalicum.aprx\VicinityMap Date Exported: 03/22/22 by lbaldwin

Legend

- Project Location
- Streams (National Hydrography Dataset)
- Watershed

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Notes:

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Data Source: Aerial imagery from Whatcom County (2019)

Projection: WGS 1984 Web Mercator Auxiliary Sphere

Watershed

Squalicum Creek Weir Fish Passage Project
Bellingham, Washington

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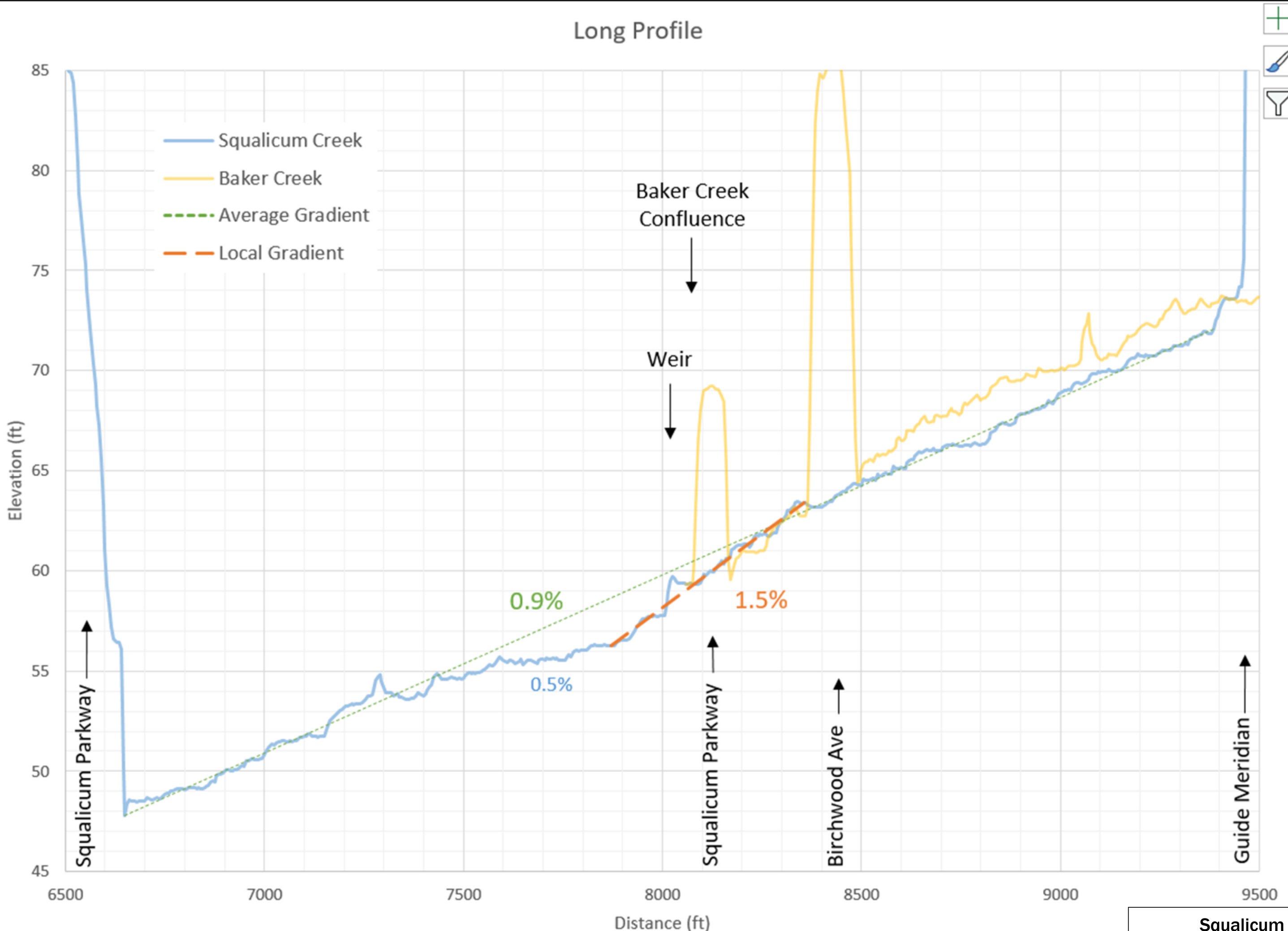
Figure 2

\\geoengineers.com\WAN\Projects\0\0356178\GIS\Projects\0356178_Squalicum\0356178_Squalicum.aprx\0356178_Squalicum Date Exported: 04/08/22 by lbaldwin



Data Source: City of Bellingham LiDAR 2013

Squalicum Creek and Baker Creek Long Profile	
Squalicum Creek Weir Fish Passage Project Bellingham, Washington	
GeoEngineers	Figure 3

00356-178-00 Date Exported: 04/13/22

APPENDICES

Appendix A
Site Assessment Photos

00356-178-00 Date Created: 04/07/22

Notes:
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Existing Weir – Looking Upstream

Squalicum Creek
Bellingham, Washington

GeoEngineers

A - 1

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Baker Creek Culvert Inlet

Squalicum Creek
Bellingham, Washington

GeoEngineers

A - 2

00356-178-00 Date Created: 04/07/22

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Existing BNSF Railroad and Racked Wood – Looking Downstream

Squalicum Creek
Bellingham, Washington

GeoEngineers

A - 3

00356-178-00 Date Created: 04/07/22

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00356-178-00 Date Created: 04/07/22

Squalicum Creek–Looking Downstream from approximately 350 upstream of confluence

Squalicum Creek
Bellingham, Washington

GeoEngineers

A - 4

Baker Creek–Looking Upstream from above the Railroad

Squalicum Creek
Bellingham, Washington

GeoEngineers

A - 5

Notes:
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Squalicum Creek–Looking Downstream from approximately 100 downstream of confluence

Squalicum Creek
Bellingham, Washington

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A - 6

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Squalicum Creek–Looking Downstream from approximately 50 downstream of confluence

Squalicum Creek
Bellingham, Washington

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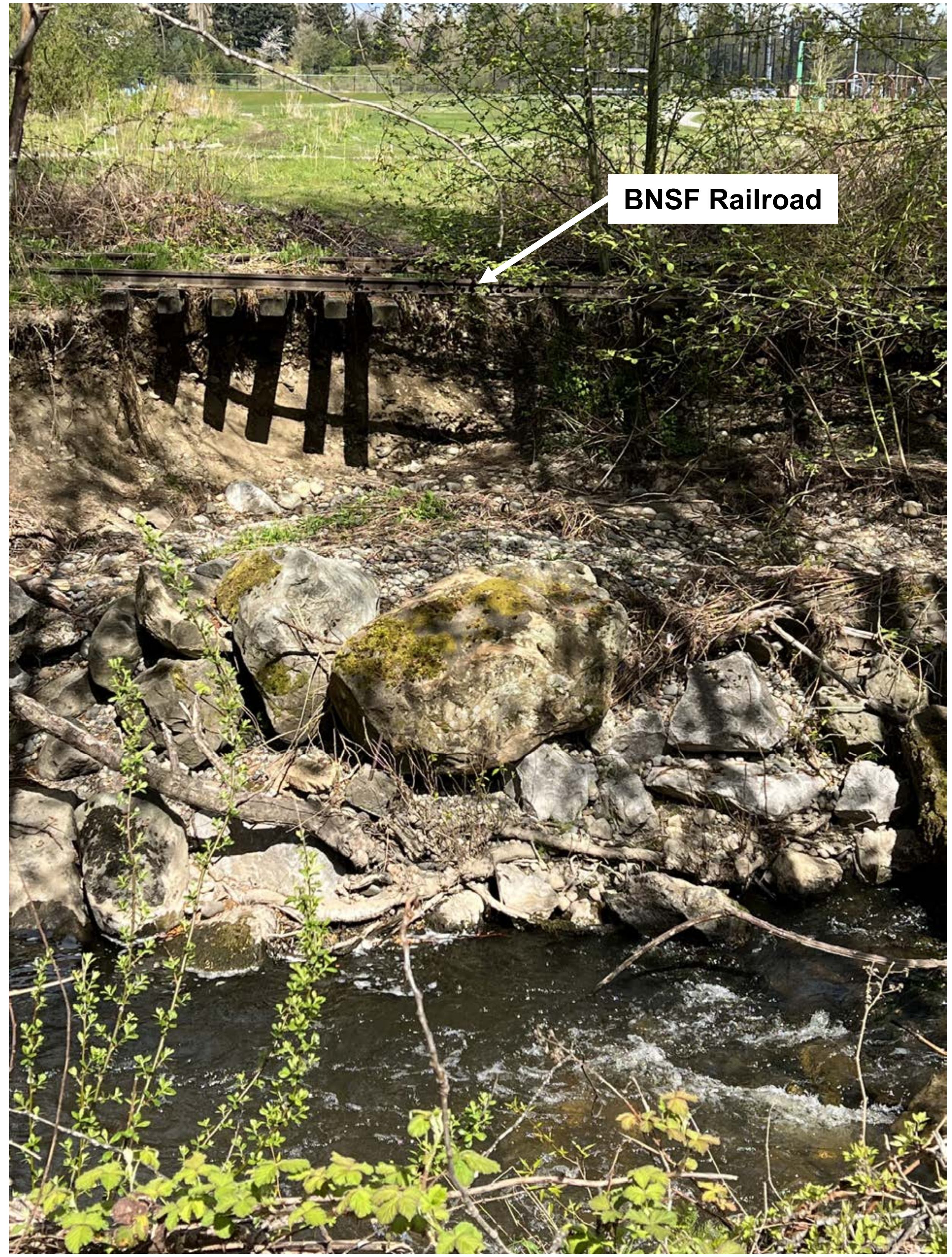
A - 7

00356-178-00 Date Created: 04/07/22



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BNSF Railroad West of the Project Site

Squalicum Creek
Bellingham, Washington

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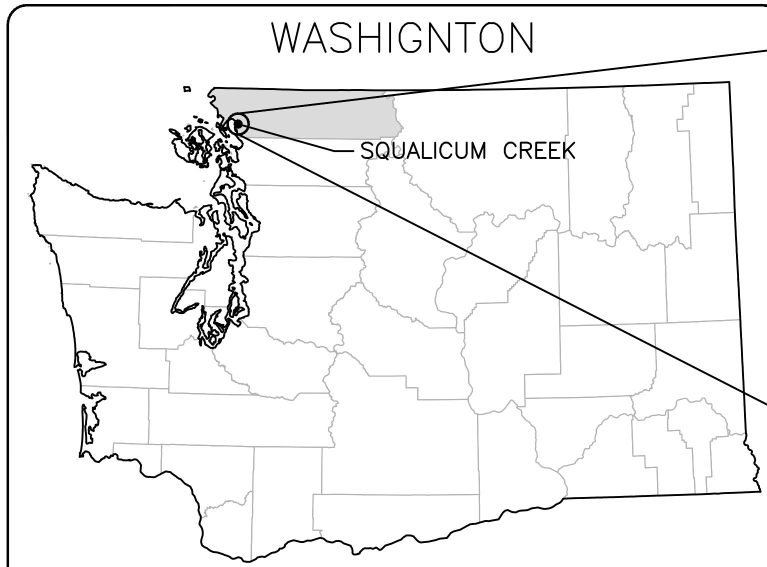
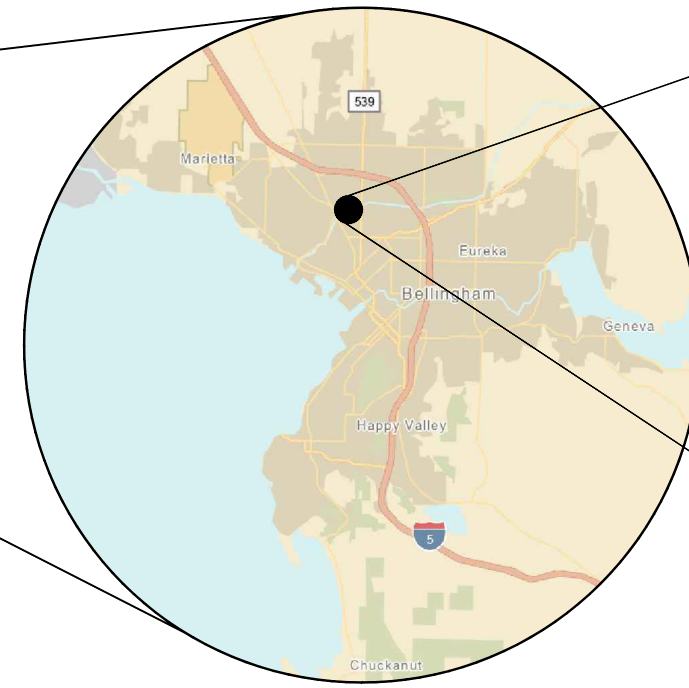
A - 8

APPENDIX B
Preliminary Design Drawings

STREAM RESTORATION
SQUALICUM CREEK
CITY OF BELLINGHAM, WASHINGTON
PRELIMINARY DESIGN



PROJECT LOCATION
CITY OF BELLINGHAM, WASHINGTON



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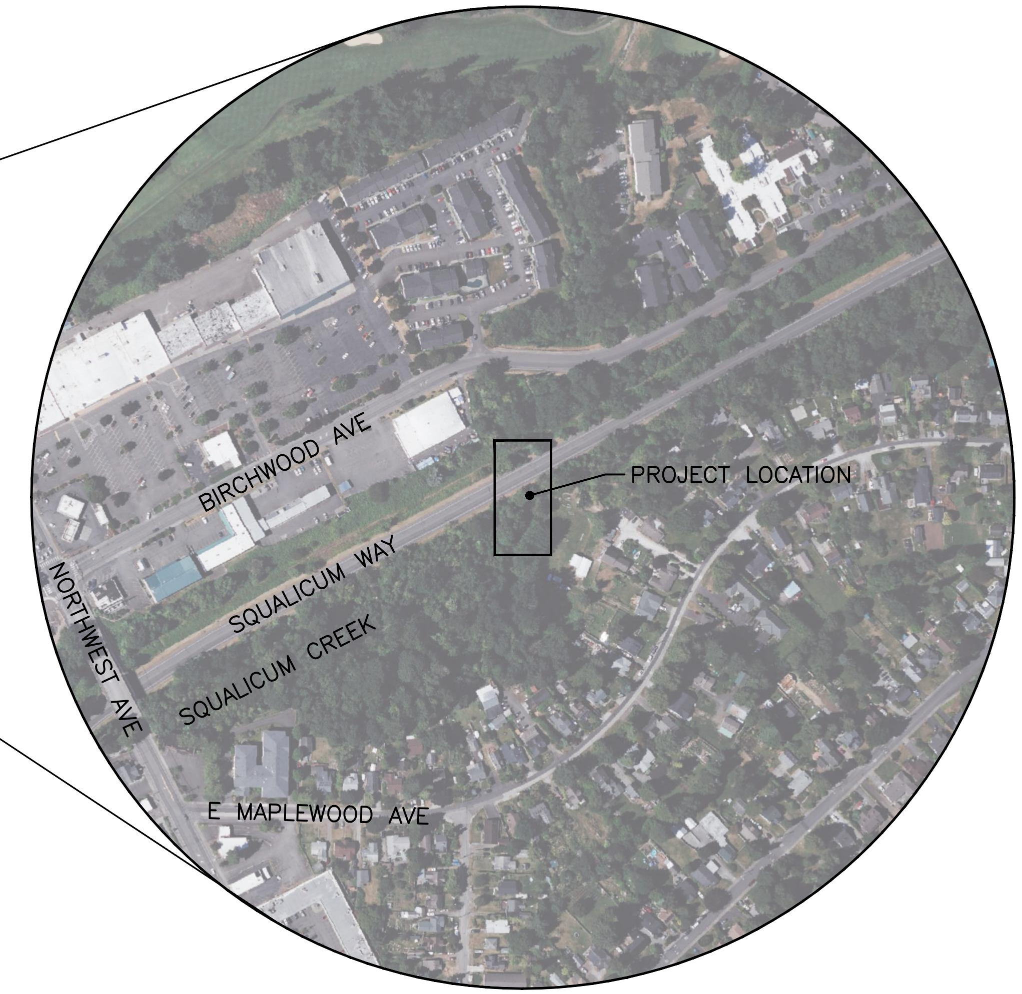

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SHEET INDEX:

1	COVER
2	EXISTING CONDITIONS ACCESS, AND STAGING
3	PROPOSED PLAN VIEW
4	PROFILE AND SECTION
5	LWM TYPICAL DETAILS
6	ROADWAY PLAN AND PROFILE
7	ROADWAY PLAN AND PROFILE CONT.
8	ROADWAY TYPICAL SECTION
9	PLAN AND ELEVATION – SLAB GIRDER
10	TYPICAL SECTION – SLAB GIRDER

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SQUALICUM CREEK
COVER SHEET

SHEET 1 OF 10

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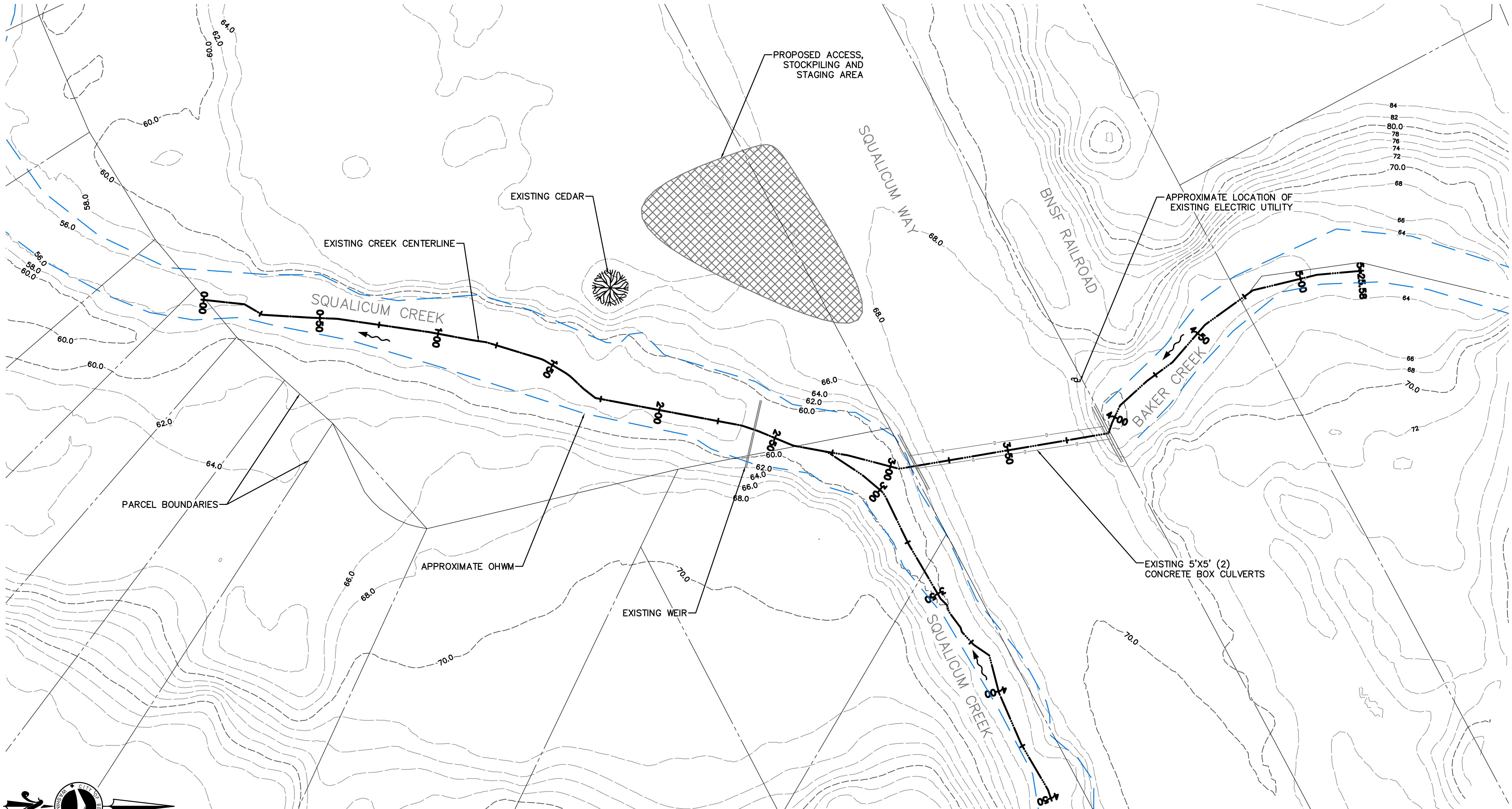

LEGEND

- EXISTING GRADE MAJOR CONTOUR
- EXISTING GRADE MINOR CONTOUR
- STOCKPILE AND STAGING AREA
- ORDINARY HIGH WATER MARK (OHWM)
- PARCEL BOUNDARY

NOTES:

1. ACCESS VIA SQUALICUM WAY
2. OHWM LINEWORK IS APPROXIMATE BASED ON 2013 LIDAR AND SITE OBSERVATIONS

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SQUALICUM CREEK
EXISTING CONDITIONS ACCESS, AND STAGING

SHEET 2 OF 10

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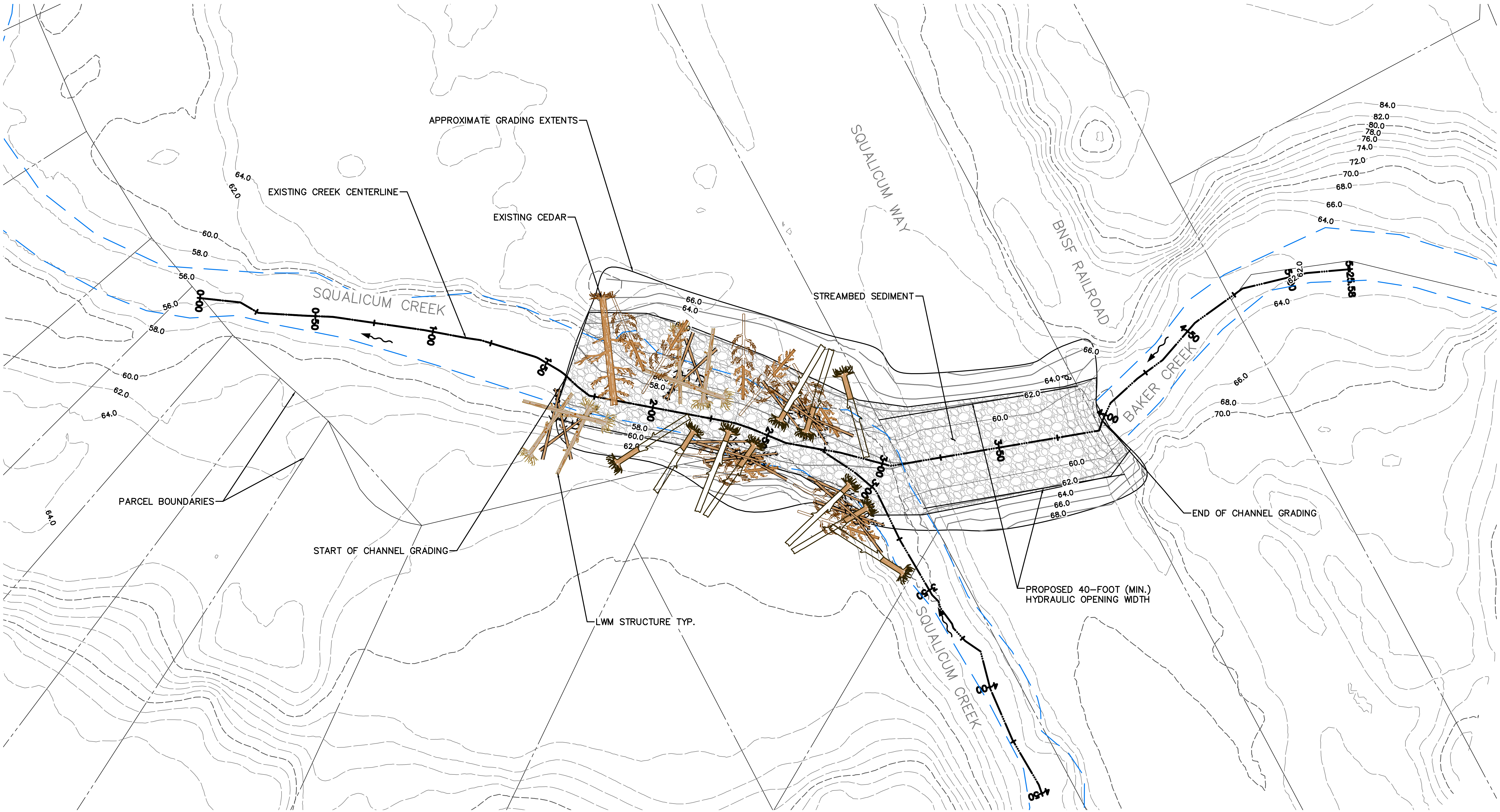

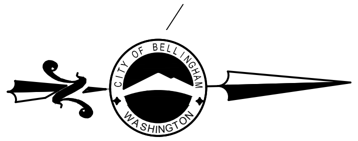

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SCALE HORIZONTAL SCALE FEET

LEGEND

- EXISTING GRADE MAJOR CONTOUR
- EXISTING GRADE MINOR CONTOUR
- PROPOSED GRADE MAJOR CONTOUR
- PROPOSED GRADE MINOR CONTOUR
- GRADING EXTENTS
- PARCEL BOUNDARY

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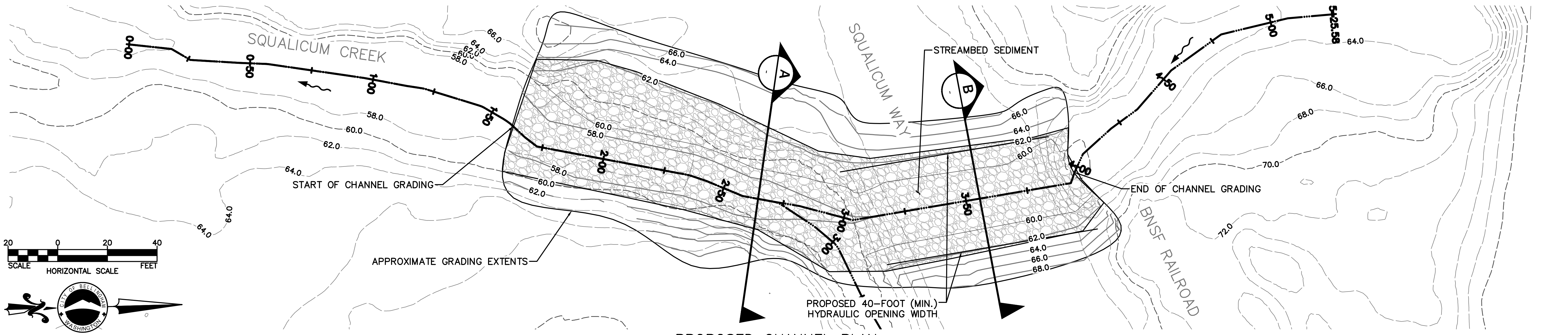
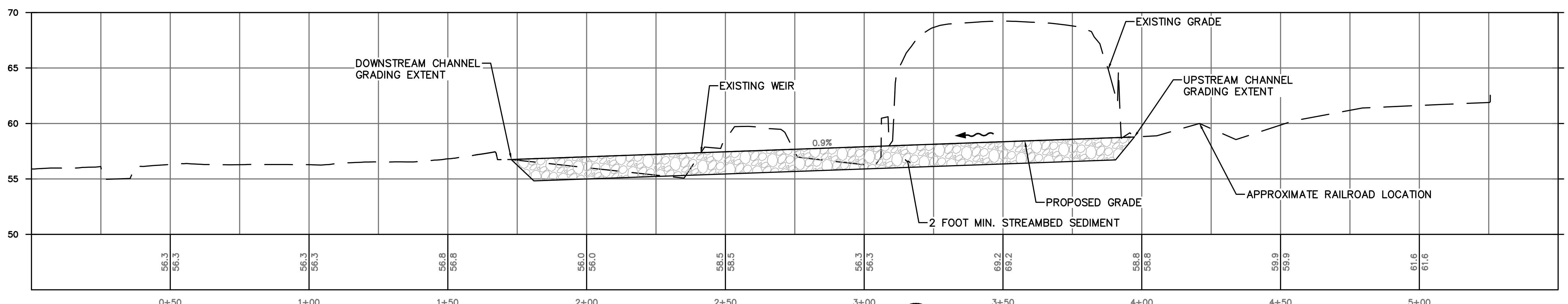
SQUALICUM CREEK
PROPOSED PLAN VIEW

SHEET 3 OF 10

CONTACT PERSON: ______________________ , PROJECT ENGINEER AT 778-7900

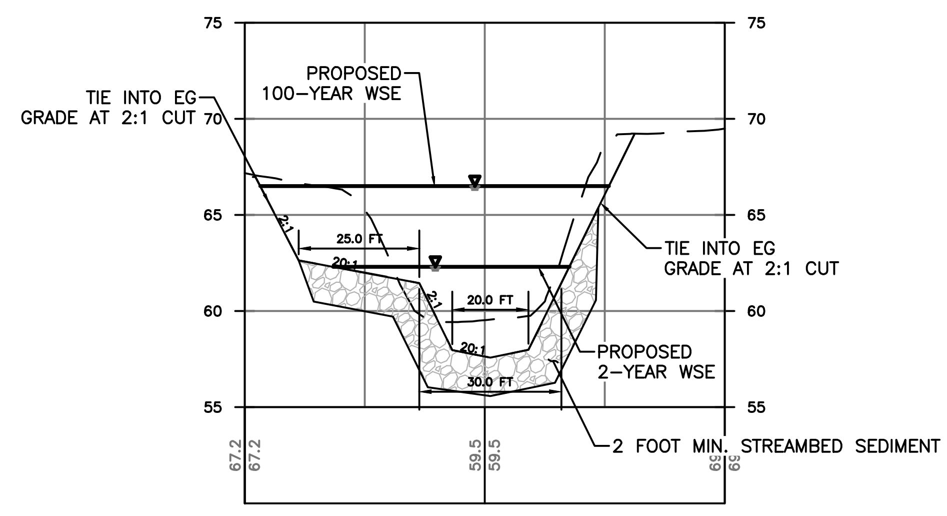


PROPOSED CHANNEL PLAN



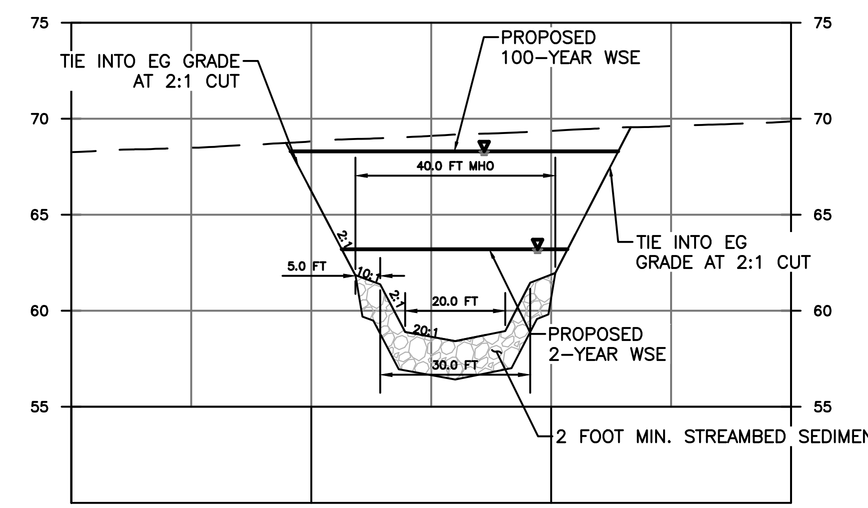
Squalicum and Baker Creek Profile (- / 4)

SCALE: 1"=20' (4X VERT EXAG)



Squalicum Creek Section (A / 4)

SCALE: 1"=20' (4X VERT EXAG)



Baker Creek Section (B / 4)

SCALE: 1"=20' 1"=20' (4X VERT EXAG) 4

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SQUALICUM CREEK
PROFILE AND SECTION

SHEET 4 OF 10

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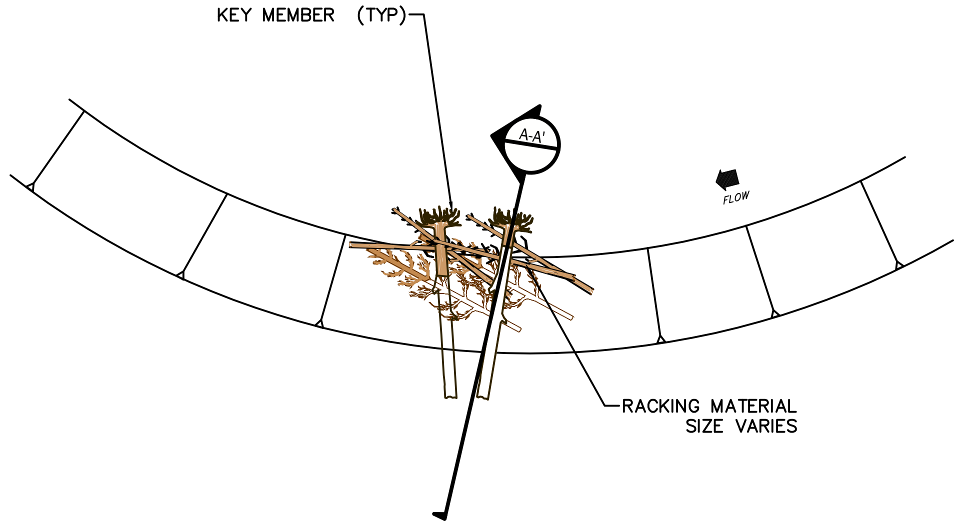
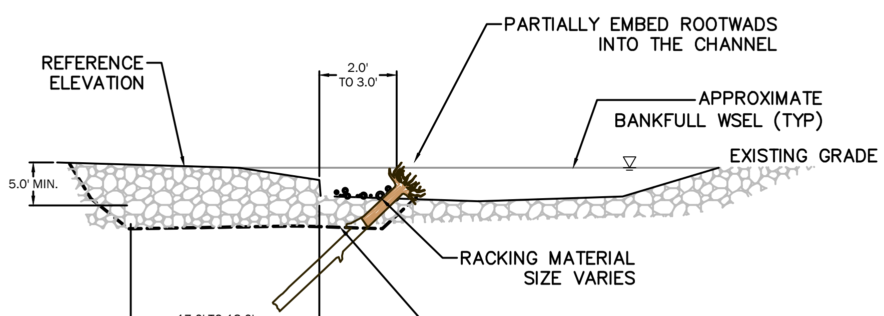


PLAN VIEW

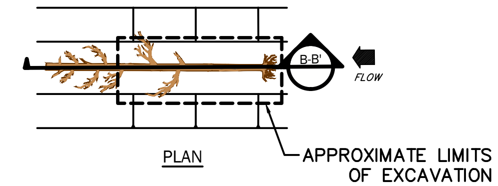
NOTES:
PURPOSE:
- INCREASES POOL DEPTH.
- SLOWS LATERAL MIGRATION.
- PREVENTS BANK EROSION.

DESIGN SPECIFICS:
- TOP OF ROOTWAD SHOULD NOT EXTEND MORE THAN ½–FT ABOVE TOP OF BANK. (BANKFULL)
- MEMBERS SHALL EXTEND BELOW CALCULATED SCOUR DEPTH. SCOUR DEPTH WILL BE DETERMINED AT LATER PROJECT PHASE.
- INSTALL RACKING MEMBERS AND VEGETATION AMONG ROOT WADS WHILE INSTALLING ROOT WADS.
- IRRIGATE VEGETATION AS REQUIRED.
- DIMENSIONS AND STABILITY DETERMINED AT FINAL DESIGN.

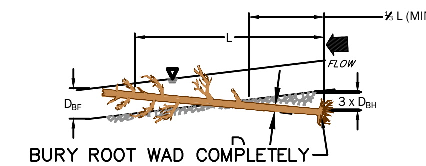


SECTION A-A'

BANK ROOTWADS (1)



PLAN

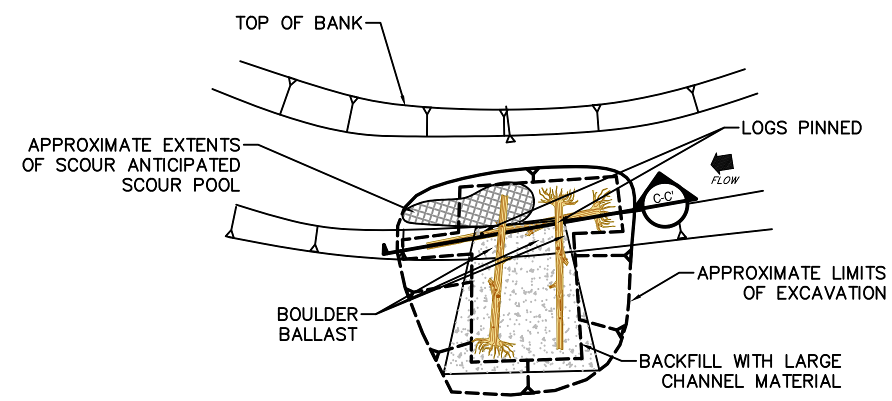


PROFILE B-B'

NOTES:
PURPOSE:
- SLOWS STREAM VELOCITY.
- CREATES DIVERSE FISH HABITAT.
- ENCOURAGES SEDIMENT SORTING.
- CREATES FLOODPLAIN ROUGHNESS

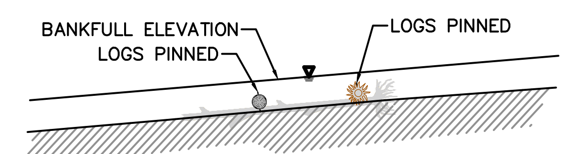
DESIGN SPECIFICS:
- TREE LENGTH (L) AND DIAMETER (D) MAY VARY.
- LOGS MAY BE PARALLEL OR ANGLED TO FLOW.
- TREES WITH BRANCHES AND/OR MULTIPLE TRUNKS PREFERRED.
- DIMENSIONS AND STABILITY DETERMINED AT FINAL DESIGN.

BURIED SNAG (2)



PLAN

PURPOSE:
- CREATES LATER SCOUR POOL.
- PROMOTES GRAVEL BAR FORMATION.
- CREATES DIVERSE FISH HABITAT.
- PROVIDES COVER.



PROFILE C-C'

DESIGN SPECIFICS:
- PLACE AS INDICATED ON HABITAT PLANS.
- PLACE ROOT WAD ON OR IN STREAM BED.
- TREES WITH BRANCHES OR MULTIPLE TRUNKS PREFERRED.
- DIMENSIONS AND STABILITY DETERMINED AT FINAL DESIGN.

LONGITUDINAL HABITAT LOGS (3)

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SCALE HORIZONTAL SCALE FEET

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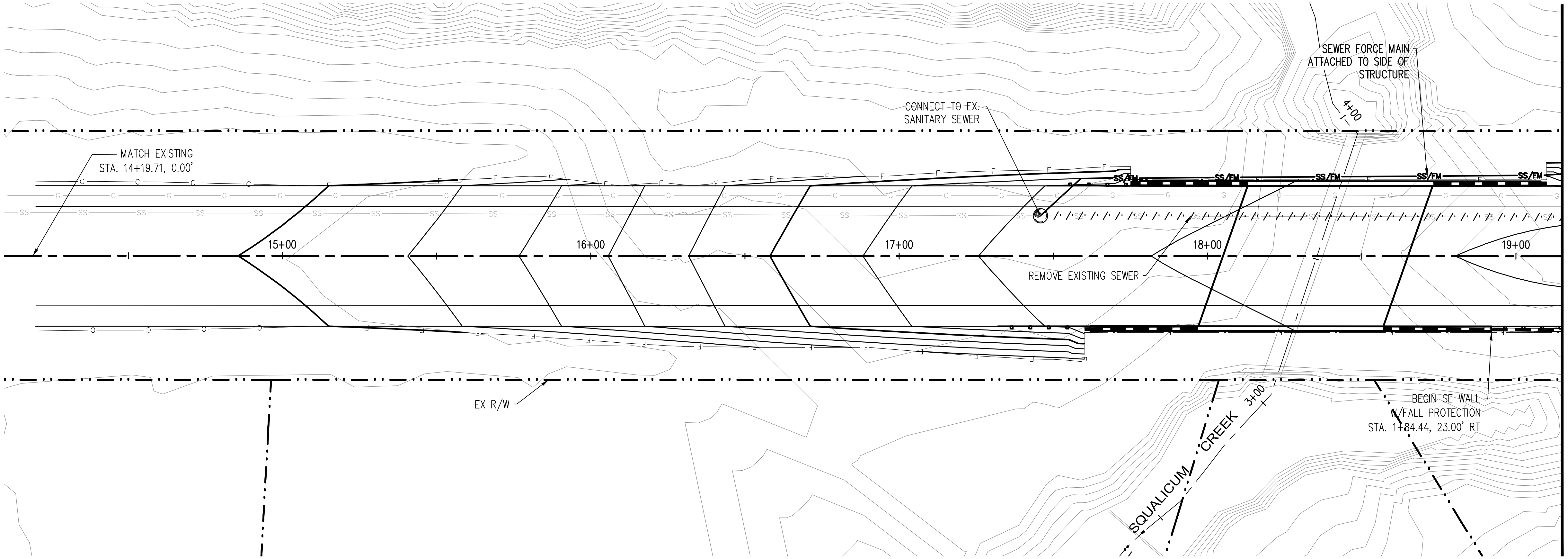
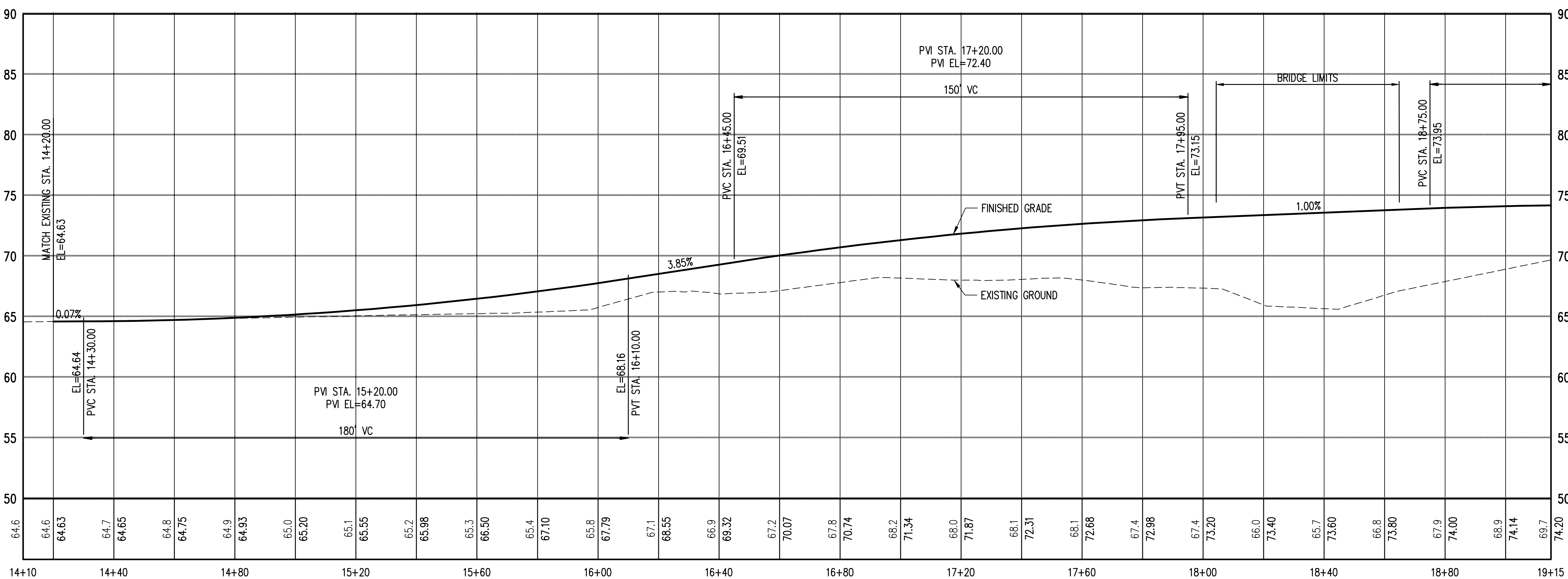
SQUALICUM CREEK
LWM TYPICAL DETAILS

SHEET 5 OF 10

CONTACT PERSON: ______________________ , PROJECT ENGINEER AT 778-7900

SEC.24, T.38N, R.2E.





SCALE IN FEET
HORIZONTAL SCALE: 1 inch = 20 ft.

SCALE IN FEET
VERTICAL SCALE: 1 inch = 10 ft.

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811 Know what's **below**. **Call** before you dig.
Determina lo que esta **bajo tierra**. **Llama** antes de excavar.

RP01

Z:\2200001-2209999\2200143 Padden Creek Fish Passage\CADD\Design\PADN-CRK_RP-SQCRK.dwg

Apr 27, 2022 – 9:55am MasonT

Date	No	Revision	By
	4		
	3		
	2		
	1		

PROJECT ENGINEER PDS
DESIGNED/DRAWN MLT
INSPECTOR INS.

DIRECTOR PUBLIC WORKS DIR.
CITY ENGINEER ENG.
ASSISTANT DIRECTOR DIR.

CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION

SCALE
Horiz. AS NOTED
Vert. AS NOTED

DATUM
NAD 83/98
NAVD 88

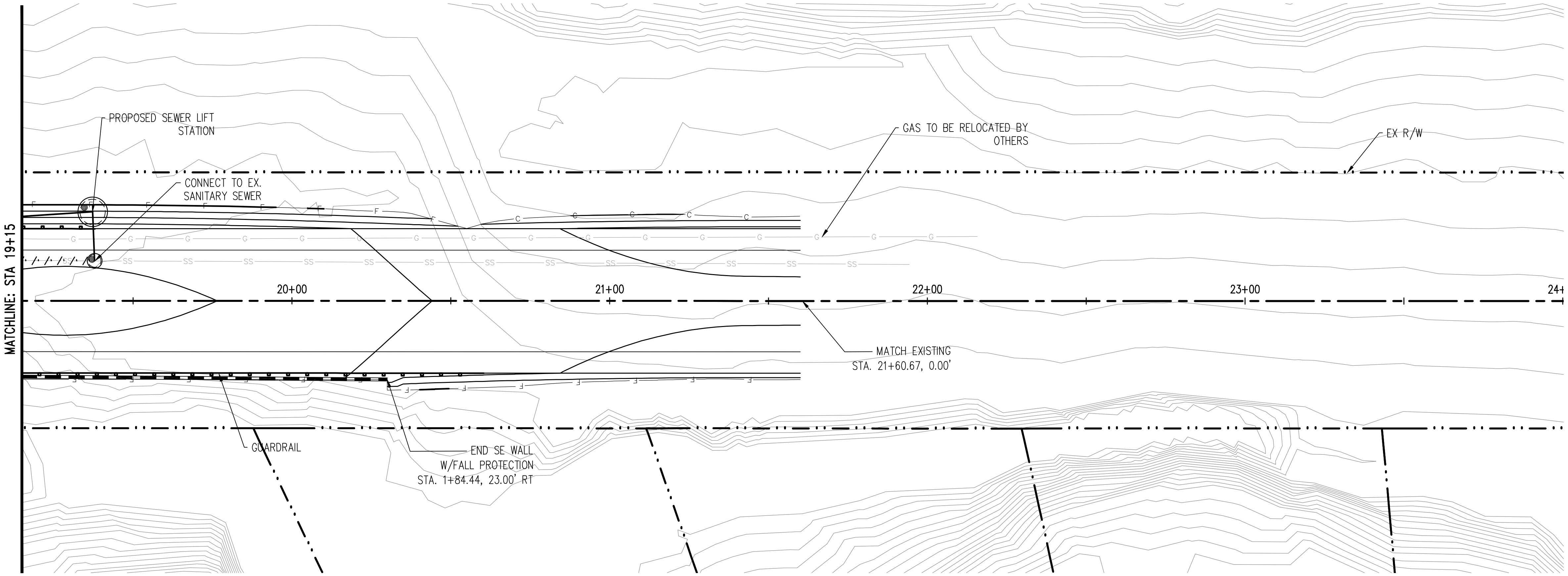
Job. No. PROJECT
Date DATE
Field Bk. FIELDBOOK

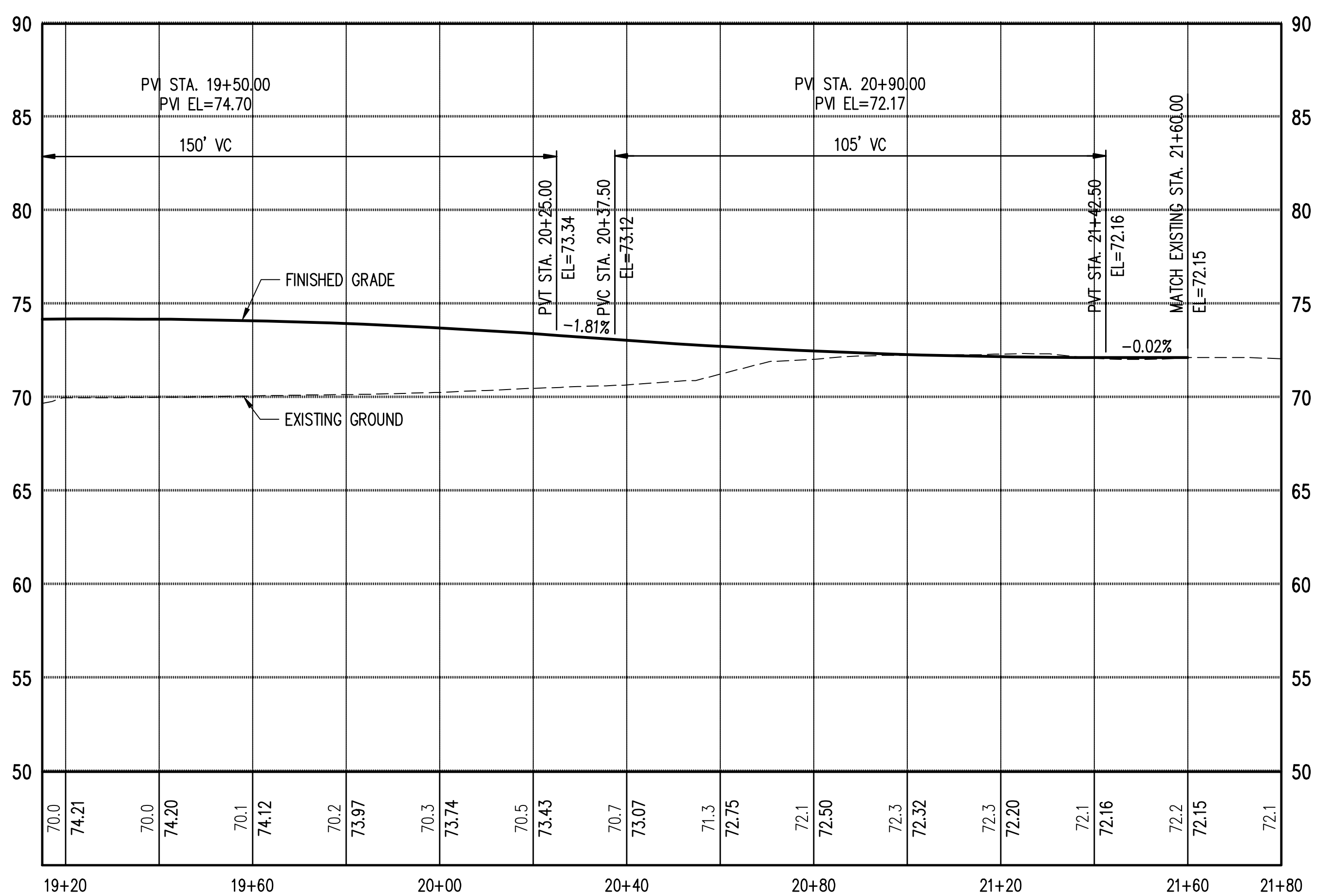
SQUALICUM CREEK
ROADWAY PLAN AND PROFILE

SHEET 6 OF 10

CONTACT PERSON: ______________ , PROJECT ENGINEER AT 778-7900

SEC.24, T.38N, R.2E.





SCALE IN FEET
HORIZONTAL SCALE: 1 inch = 20 ft.
0 20 40 60

SCALE IN FEET
VERTICAL SCALE: 1 inch = 10 ft.
0 10 20 30

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RP02

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ENGINEERING DIVISION

SCALE
Horiz. AS NOTED
Vert. AS NOTED

DATUM
NAD 83/98
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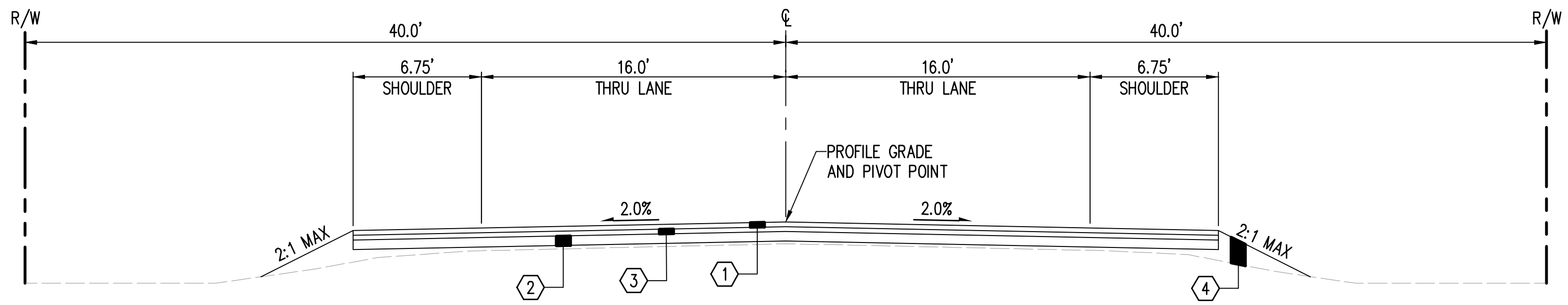
Job. No. PROJECT
Date DATE
Field Bk. FIELDBOOK

SQUALICUM CREEK
ROADWAY PLAN AND PROFILE

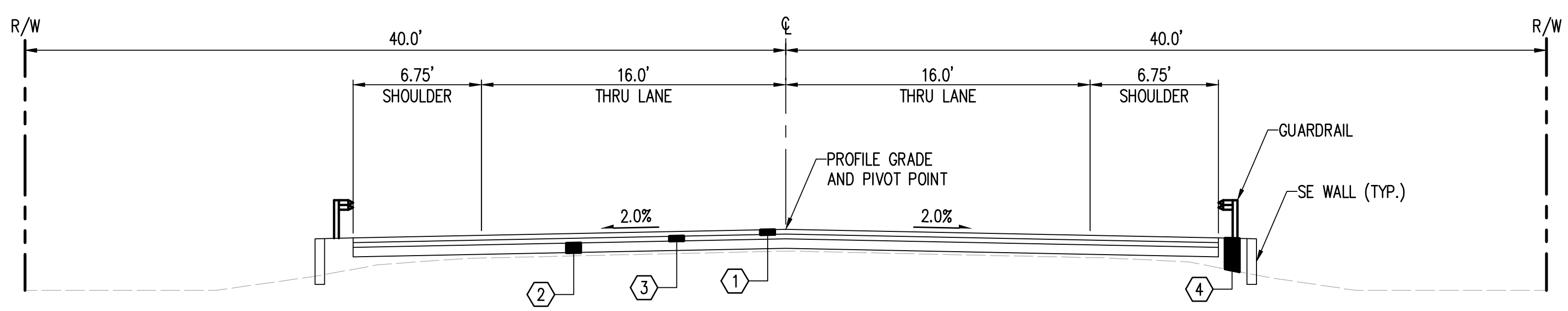
SHEET 7 OF 10

CONTACT PERSON: ________________ , PROJECT ENGINEER AT 778-7900

Apr 27, 2022 – 9:55am MasonT Z:\2200001-2209999\2200143 Padden Creek Fish Passage\CADD\Design\PADN-CRK_RP-SQCRK.dwg



TYPICAL ROADWAY SECTION
NTS
STA XX+XX TO STA XX+XX



TYPICAL ROADWAY SECTION
NTS
STA XX+XX TO STA XX+XX

GENERAL NOTES:

1. ALL MATERIAL AND WORKMANSHIP SHALL CONFORM TO THE PROVISIONS OF APWA "STANDARD SPECIFICATIONS" AND SHALL CONFORM TO THE REQUIREMENTS OF THE CITY ENGINEER.

CONSTRUCTION NOTES:

1. WMA CL 1/2-IN PG 58H-22
2. CRUSHED SURFACING BASE COURSE
3. ASPHALT TREATED BASE
4. GRAVEL BORROW

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TS01

Date	No	Revision	By
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	1		

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CITY OF BELLINGHAM, WASHINGTON
PUBLIC WORKS DEPARTMENT
ENGINEERING DIVISION

SCALE
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Vert. AS NOTED

DATUM
NAD 83/98
NAVD 88

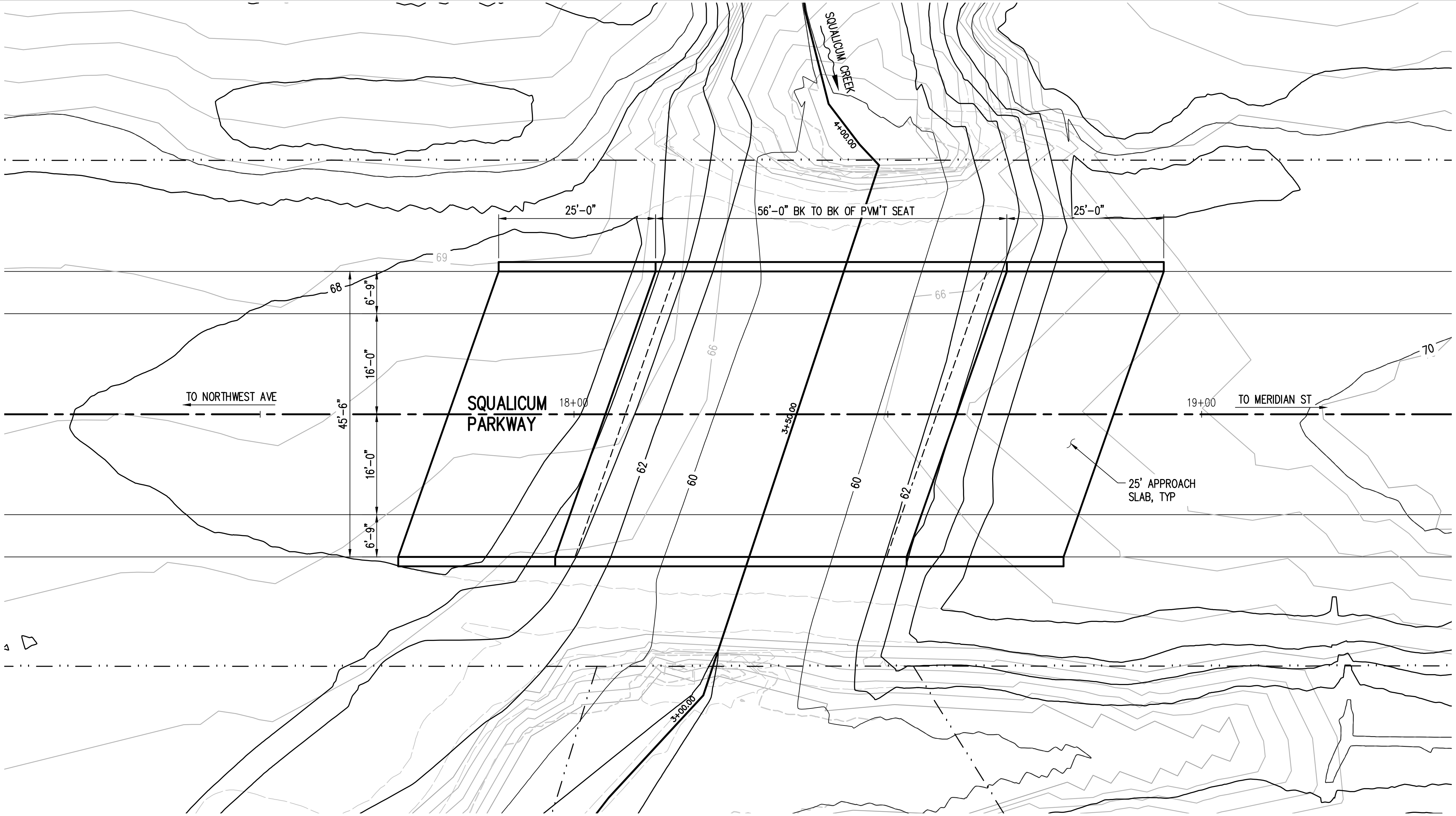
Job. No. PROJECT
Date DATE
Field Bk. FIELDBOOK

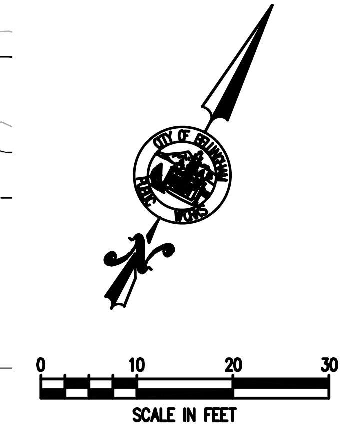
SQUALICUM CREEK
ROADWAY TYPICAL SECTION

SHEET 8 OF 10

CONTACT PERSON: ______________________, PROJECT ENGINEER AT 778-7900

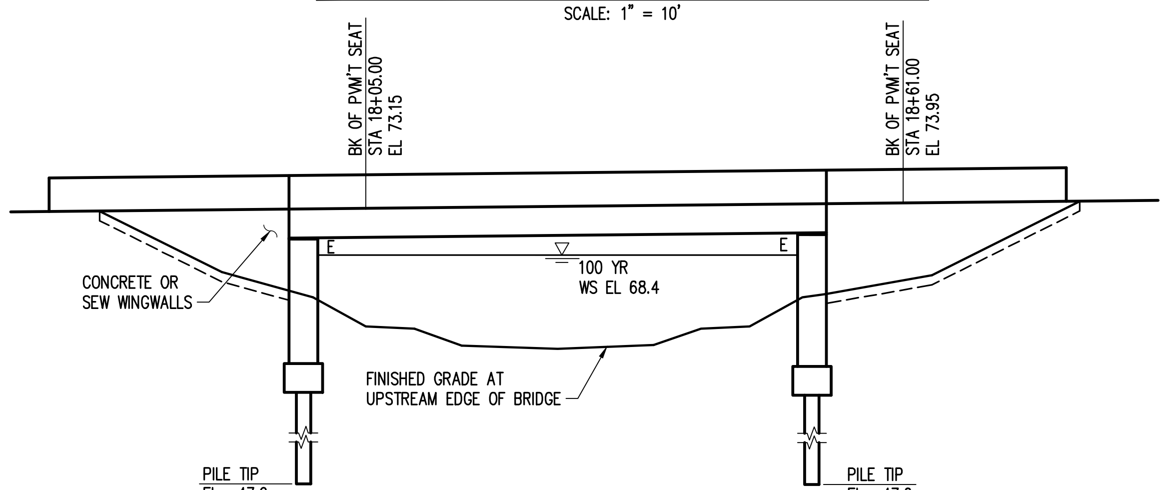
Apr 27, 2022 - 9:55am MasonT Z:\2200001-2209999\2200143 Padden Creek Fish Passage\CADD\Design\PADN-CRK_TS-SQCRK.dwg





SQUALICUM CREEK – BRIDGE PLAN

SCALE: 1" = 10'



SQUALICUM CREEK – BRIDGE ELEVATION

SCALE: 1" = 10'

CONCEPT DRAWING - NOT FOR CONSTRUCTION

V:\2200143 (Padden Creek Fish Passage)\02_Design (v2019)\PC-BR – S4.1B – SQUAL-CONCEPT-ALT1.dwg

Apr 27, 2022 – 1:27pm   tauniep

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Vert. AS NOTED

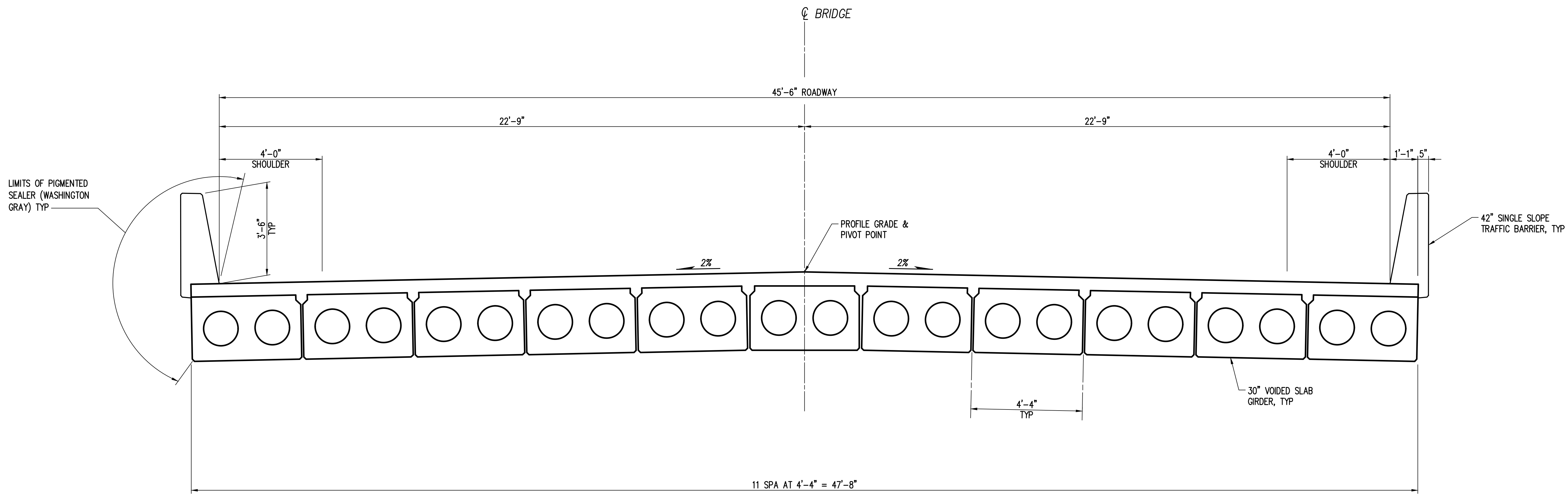
DATUM
NAD 83/98
NAVD 88

Job. No. PROJECT
Date DATE
Field Bk. FIELDBOOK

SQUALICUM CREEK
PLAN AND ELEVATION - SLAB GIRDER

SHEET 9 OF 10

CONTACT PERSON: ____________________, PROJECT ENGINEER AT 778-7900



SQUALICUM CREEK – TYPICAL SECTION

SCALE: 1/2" = 1'-0"

CONCEPT DRAWING - NOT FOR CONSTRUCTION

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S4.2A

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SCALE
Horiz. AS NOTED
Vert. AS NOTED

DATUM
NAD 83/98
NAVD 88

Job. No. PROJECT
Date DATE
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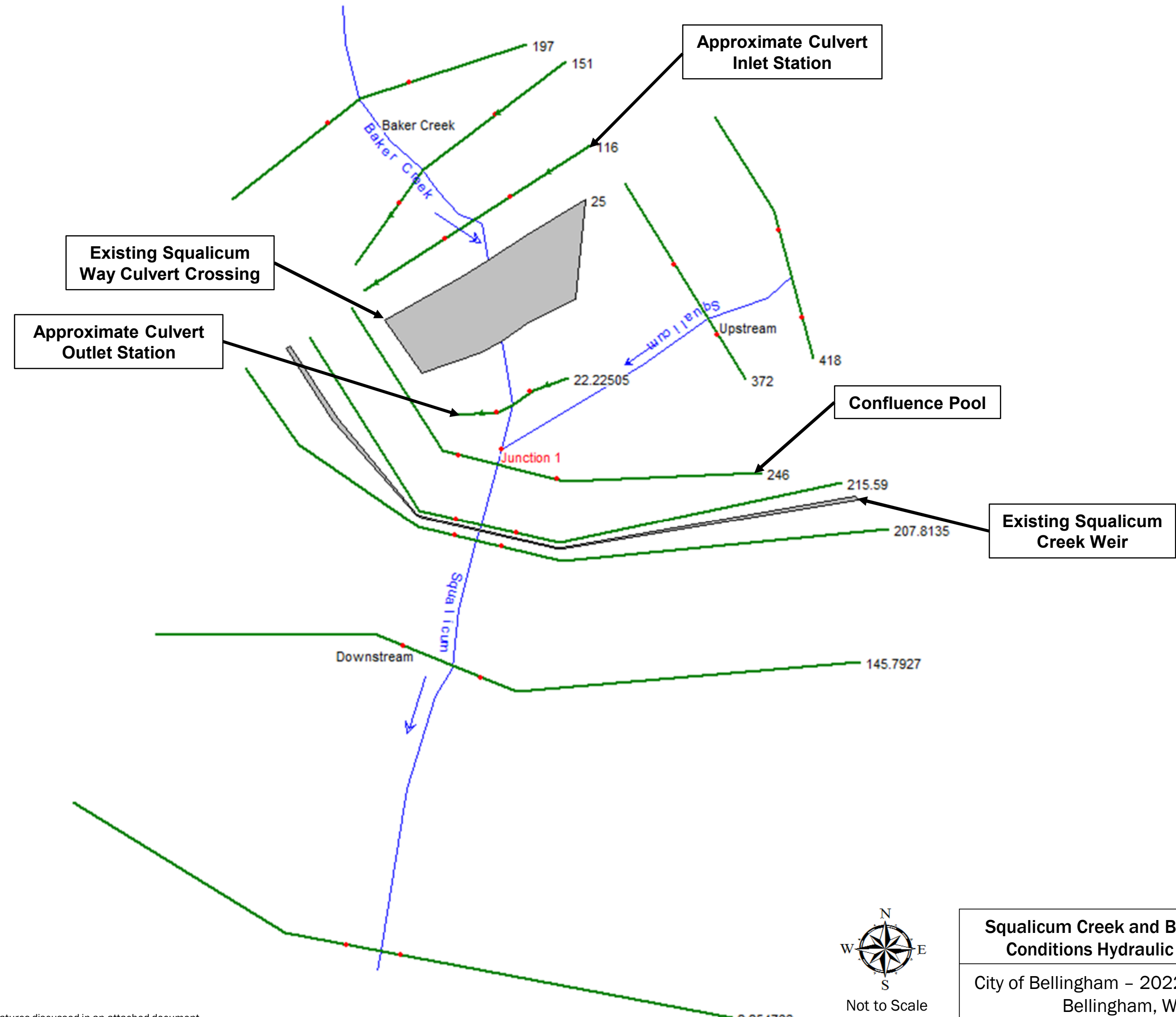
SQUALICUM CREEK
TYPICAL SECTION - SLAB GIRDER

SHEET 10 OF 10

CONTACT PERSON: ______________________ , PROJECT ENGINEER AT 778-7900

APPENDIX C
Hydraulic Model Results



Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: HEC-RAS version 6.1

Squalicum Creek and Baker Creek Existing Conditions Hydraulic Model Plan View

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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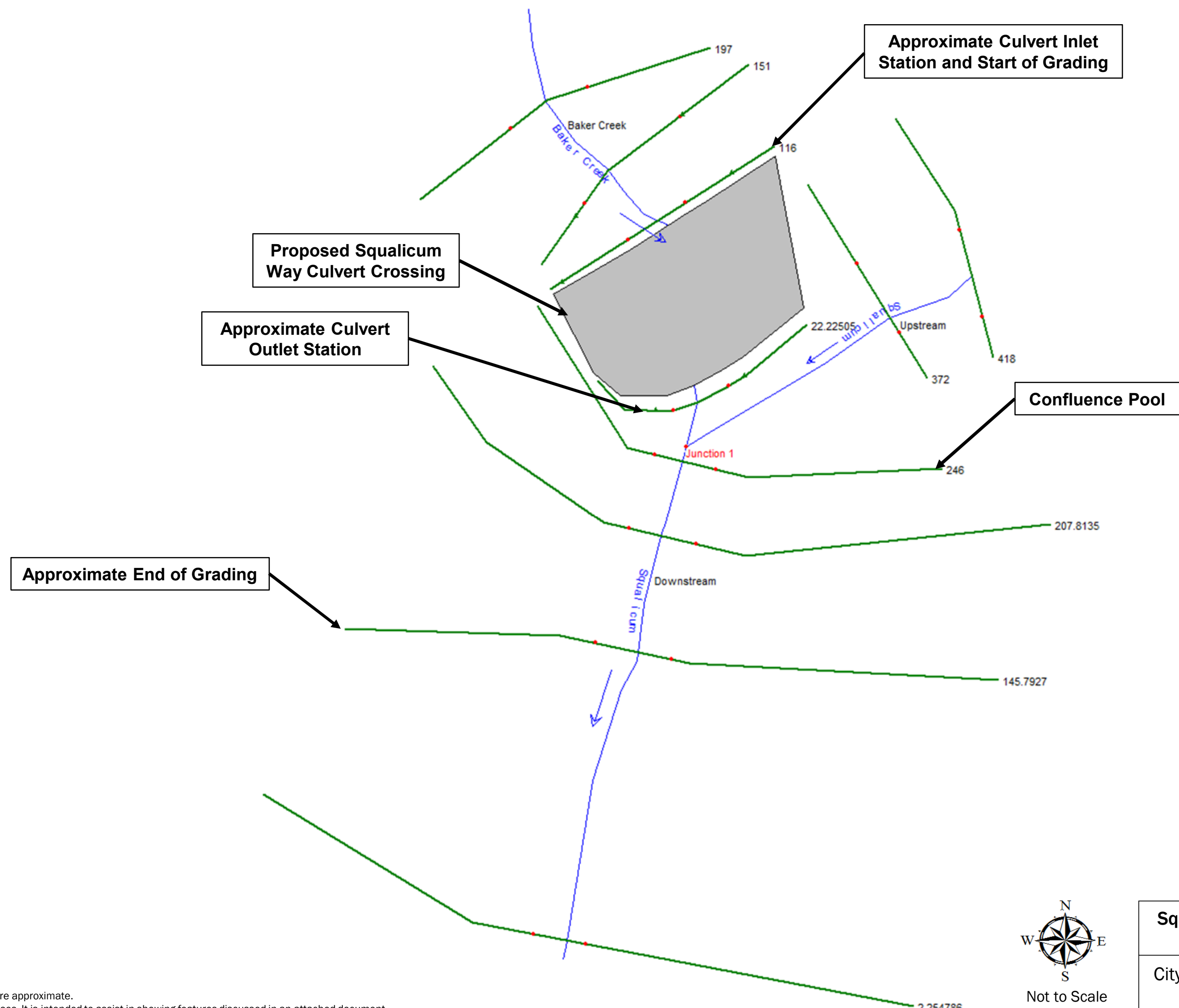
C-1

00356-178-00 Date Exported: 04/12/22



Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: HEC-RAS version 6.1

Squalicum Creek and Baker Creek Proposed Conditions Hydraulic Model Plan View

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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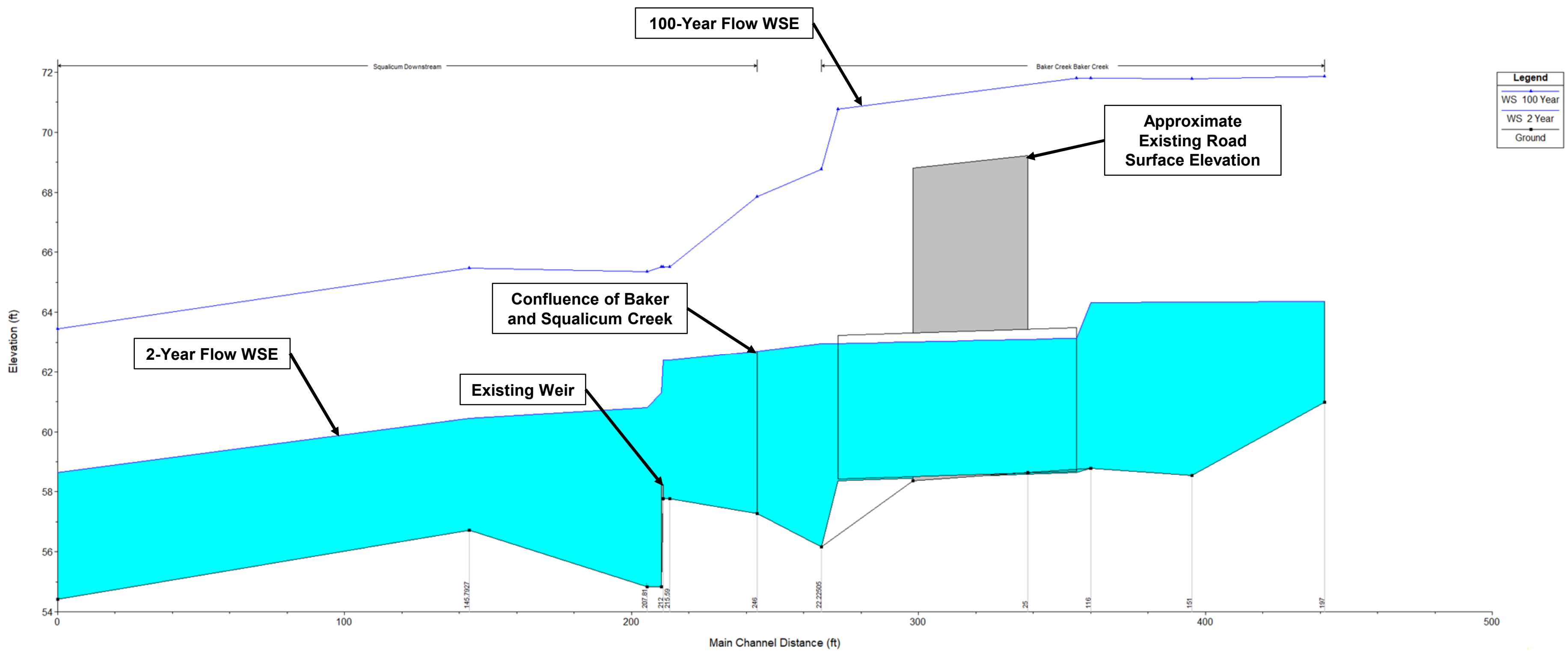
C-2

00356-178-00 Date Exported: 04/12/22



N W E S

Not to Scale

Notes:

1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: HEC-RAS version 6.1

Baker Creek and Squalicum Creek Existing Profile	
City of Bellingham – 2022-2025 Fish Passage Bellingham, Washington	
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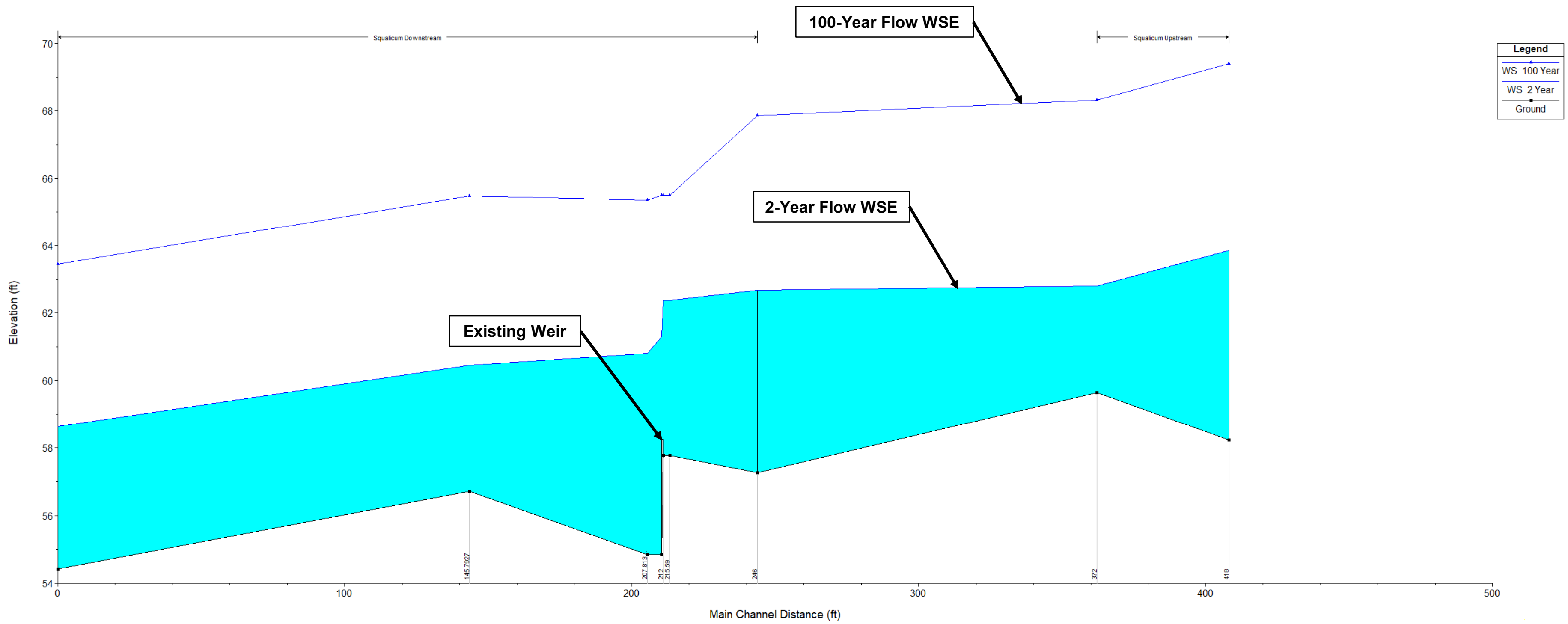
00356-178-00 Date Exported: 04/12/22



Notes:
1. The locations of all features shown are approximate.
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Data Source: HEC-RAS version 6.1

Not to Scale

Squalicum Creek Existing Profile

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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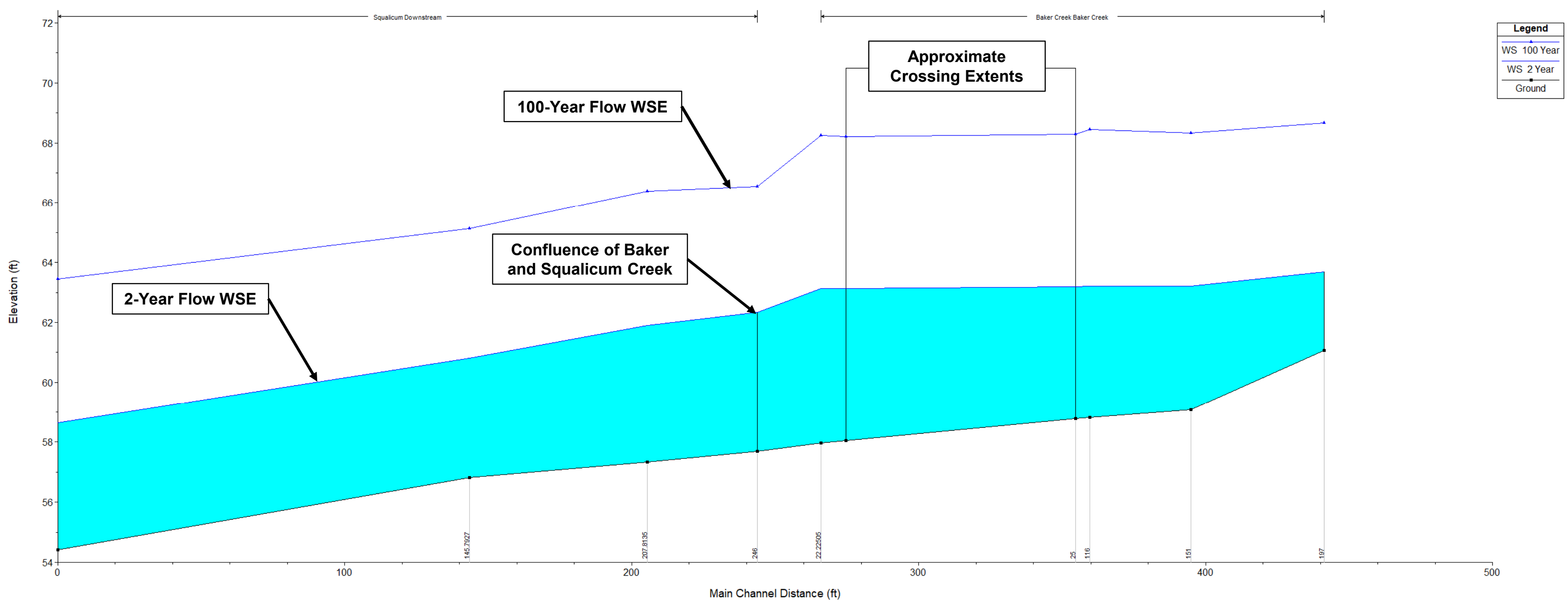
00356-178-00 Date Exported: 04/12/22



N
W
E
S
Not to Scale

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: HEC-RAS version 6.1

Baker Creek and Squalicum Creek Proposed Profile

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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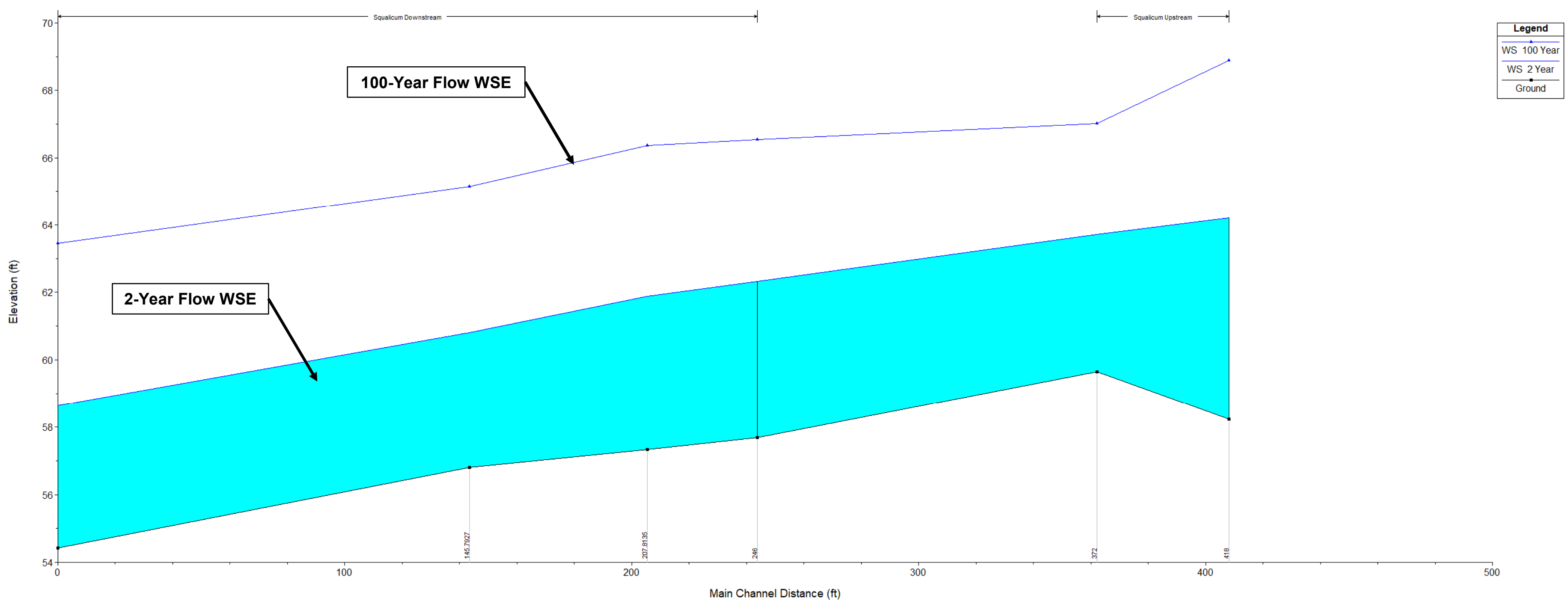
00356-178-00 Date Exported: 04/12/22



N
W
E
S
Not to Scale

Squalicum Creek Proposed Profile

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Data Source: HEC-RAS version 6.1

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Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	Vel Chnl	Flow Area	Top Width	Max Chl Dpth
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)
Upstream	418	2 Year	440.0	58.2	63.9	64.1	3.5	125.8	31.7	5.6
Upstream	418	100 Year	2009.0	58.2	69.4	69.9	5.9	340.0	49.3	11.2
Upstream	372	2 Year	440.0	59.6	62.8	63.7	7.6	57.8	24.2	3.2
Upstream	372	100 Year	2009.0	59.6	68.3	69.6	9.2	228.3	40.5	8.7
Downstream	246	2 Year	752.0	57.3	62.7	63.0	4.3	174.9	40.3	5.4
Downstream	246	100 Year	3435.0	57.3	67.9	68.9	8.2	448.7	86.9	10.6
Downstream	216	2 Year	752.0	57.8	62.4	62.9	5.6	146.9	38.7	4.6
Downstream	216	100 Year	3435.0	57.8	65.5	68.5	14.3	301.2	67.4	7.7
Downstream	212		Inl Struct							
Downstream	208	2 Year	752.0	54.8	60.8	61.3	5.9	150.4	39.1	6.0
Downstream	208	100 Year	3435.0	54.8	65.4	67.6	12.9	370.8	66.1	10.5
Downstream	146	2 Year	752.0	56.7	60.5	61.0	5.6	137.1	46.8	3.8
Downstream	146	100 Year	3435.0	56.7	65.5	66.9	9.7	406.8	61.2	8.8
Downstream	2	2 Year	752.0	54.4	58.7	59.6	7.8	100.3	31.6	4.2
Downstream	2	100 Year	3435.0	54.4	63.5	65.6	12.9	388.1	109.7	9.0

Squalicum Creek 2- and 100-Year Hydraulic Model Results

Reach	River Sta	Profile	W.S. Elev	Q Total	Q Weir	Min El Weir Flow	Weir Avg Depth	Weir Max Depth	Wr Top Wdth
			(ft)	(cfs)	(cfs)	(ft)	(ft)	(ft)	(ft)
Downstream	212	2 Year	62.4	752.0	752.0	58.3	3.6	4.6	40.2
Downstream	212	100 Year	65.5	3435.0	3435.0	58.3	3.3	10.2	171.6

Squalicum Creek 2- and 100-Year Weir Results

Data Source: HEC-RAS version 6.1

Squalicum Creek Existing Conditions Tabular Results

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	Vel Chnl	Flow Area	Top Width	Max Chl Dpth
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)
Baker Creek	197	2 Year	312.0	61.0	64.4	64.7	4.4	71.6	37.3	3.4
Baker Creek	197	100 Year	1426.0	61.0	71.9	72.0	2.8	627.0	107.3	10.9
Baker Creek	151	2 Year	312.0	58.5	64.3	64.4	2.5	125.8	30.8	5.8
Baker Creek	151	100 Year	1426.0	58.5	71.8	71.9	3.0	469.3	100.9	13.2
Baker Creek	116	2 Year	312.0	58.8	64.3	64.4	2.2	143.2	39.4	5.5
Baker Creek	116	100 Year	1426.0	58.8	71.8	71.9	2.7	659.9	102.6	13.0
Baker Creek	25		Culvert							
Baker Creek	22	2 Year	312.0	56.2	63.0	63.0	2.3	159.0	45.6	6.8
Baker Creek	22	100 Year	1426.0	56.2	68.8	69.0	4.5	364.7	60.8	12.6

Baker Creek 2- and 100-Year Hydraulic Model Results

Reach	River Sta		Profile	Culv Inv El Dn	Culv Inv El Up	Culv Vel DS	Culv Vel US	Q Culv	W.S. US.
				(ft)	(ft)	(ft/s)	(ft/s)	(cfs)	(ft)
Baker Creek	25	Culvert #1	2 Year	58.4	58.7	6.8	6.9	312.0	64.3
Baker Creek	25	Culvert #1	100 Year	58.4	58.7	9.8	9.8	1426.0	71.8

Baker Creek 2- and 100-Year Culvert Results

Data Source: HEC-RAS version 6.1

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Baker Creek Existing Conditions Tabular Results

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	Vel Chnl	Flow Area	Top Width	Max Chl Dpth
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)
Upstream	418	2 Year	440.0	58.2	64.2	64.4	3.2	137.2	32.5	6.0
Upstream	418	100 Year	2009.0	58.2	68.9	69.5	6.4	316.7	44.4	10.7
Upstream	372	2 Year	440.0	59.6	63.7	64.2	5.4	81.2	27.1	4.1
Upstream	372	100 Year	2009.0	59.6	67.0	69.0	11.3	179.4	34.6	7.4
Downstream	246	2 Year	752.0	57.7	62.3	63.1	6.8	116.0	47.9	4.6
Downstream	246	100 Year	3435.0	57.7	66.5	68.4	12.0	373.5	69.0	8.9
Downstream	208	2 Year	752.0	57.3	61.9	62.7	7.0	110.6	45.7	4.6
Downstream	208	100 Year	3435.0	57.3	66.4	68.0	11.0	403.6	78.0	9.0
Downstream	146	2 Year	752.0	56.8	60.8	61.7	7.8	99.8	45.3	4.0
Downstream	146	100 Year	3435.0	56.8	65.1	67.3	12.2	337.9	65.1	8.3
Downstream	2	2 Year	752.0	54.4	58.7	59.6	7.8	100.3	31.6	4.2
Downstream	2	100 Year	3435.0	54.4	63.5	65.6	12.9	388.1	109.7	9.0

Squalicum Creek 2- and 100-Year Hydraulic Model Results

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Data Source: HEC-RAS version 6.1

Squalicum Creek Proposed Design Tabular Results

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	Vel Chnl	Flow Area	Top Width	Max Chl Dpth
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)
Baker Creek	197	2 Year	312.0	61.1	63.7	64.4	6.8	46.2	32.7	2.6
Baker Creek	197	100 Year	1426.0	61.1	68.7	69.0	5.0	326.3	77.4	7.6
Baker Creek	151	2 Year	312.0	59.1	63.2	63.5	4.0	77.8	26.2	4.1
Baker Creek	151	100 Year	1426.0	59.1	68.3	68.8	5.5	258.6	45.5	9.3
Baker Creek	116	2 Year	312.0	58.8	63.2	63.3	2.6	126.1	42.4	4.4
Baker Creek	116	100 Year	1426.0	58.8	68.4	68.7	4.0	424.4	74.0	9.6
Baker Creek	25		Bridge							
Baker Creek	22	2 Year	312.0	58.0	63.1	63.2	2.0	177.6	64.0	5.2
Baker Creek	22	100 Year	1426.0	58.0	68.3	68.4	3.7	421.0	110.3	10.3

Baker Creek 2- and 100-Year Hydraulic Model Results

Reach	River Sta	Profile	BR Open Vel	Q Bridge	W.S. US.	Delta WS
			(ft/s)	(cfs)	(ft)	(ft)
Baker Creek	25	2 Year	2.5	312.0	63.2	0.1
Baker Creek	25	100 Year	4.3	1426.0	68.4	0.2

Baker Creek 2- and 100-Year Bridge Results

Data Source: HEC-RAS version 6.1

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Baker Creek Proposed Design Tabular Results

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

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River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	Vel Chnl	Flow Area	Top Width	Max Chl Dpth
				(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)
Squalicum	Upstream	418	2 Year	440.0	58.2	63.9	64.1	3.5	125.7	31.7	5.6
Squalicum	Upstream	418	100 Year	2009.0	58.2	69.7	70.2	5.7	355.5	57.8	11.5
Squalicum	Upstream	372	2 Year	440.0	59.6	62.8	63.7	7.8	56.4	24.0	3.1
Squalicum	Upstream	372	100 Year	2009.0	59.6	68.8	69.9	8.5	248.2	42.6	9.2
Squalicum	Downstream	246	2 Year	752.0	57.7	62.5	63.1	6.5	119.6	41.8	4.8
Squalicum	Downstream	246	100 Year	3435.0	57.7	67.3	68.9	11.2	410.1	71.6	9.6
Squalicum	Downstream	208	2 Year	752.0	57.3	62.2	62.8	6.4	119.7	42.4	4.8
Squalicum	Downstream	208	100 Year	3435.0	57.3	66.9	68.6	11.1	438.5	111.5	9.6
Squalicum	Downstream	146	2 Year	752.0	56.8	60.8	62.0	8.8	85.9	31.2	4.0
Squalicum	Downstream	146	100 Year	3435.0	56.8	65.1	67.8	13.9	322.0	68.4	8.3
Squalicum	Downstream	2	2 Year	752.0	54.4	58.7	59.6	7.8	100.3	31.6	4.2
Squalicum	Downstream	2	100 Year	3435.0	54.4	63.5	65.6	12.9	388.1	109.7	9.0
Baker Creek	Baker Creek	197	2 Year	312.0	61.1	63.7	64.4	6.8	45.7	32.6	2.6
Baker Creek	Baker Creek	197	100 Year	1426.0	61.1	69.2	69.4	4.5	364.8	79.3	8.1
Baker Creek	Baker Creek	151	2 Year	312.0	59.1	63.2	63.4	4.1	77.1	26.1	4.1
Baker Creek	Baker Creek	151	100 Year	1426.0	59.1	68.9	69.3	5.0	284.2	47.4	9.8
Baker Creek	Baker Creek	116	2 Year	312.0	58.8	63.1	63.3	3.1	127.6	73.6	4.3
Baker Creek	Baker Creek	116	100 Year	1426.0	58.8	69.1	69.2	2.0	1076.5	200.9	10.3
Baker Creek	Baker Creek	66	2 Year	312.0	58.3	63.1	63.2	2.2	180.2	98.9	4.8
Baker Creek	Baker Creek	66	100 Year	1426.0	58.3	69.1	69.1	1.6	1225.4	195.0	10.8
Baker Creek	Baker Creek	36	2 Year	312.0	58.1	63.1	63.1	2.0	205.7	107.9	5.0
Baker Creek	Baker Creek	36	100 Year	1426.0	58.1	69.1	69.1	1.6	1292.7	199.5	11.0

Natural Conditions 2- and 100-Year Hydraulic Model Results

Data Source: HEC-RAS version 6.1

Natural Conditions Tabular Results

City of Bellingham – 2022-2025 Fish Passage
Bellingham, Washington

GeoEngineers

C-11

APPENDIX D

Preliminary Geotechnical Considerations Memorandum

GEOENGINEERS

Memorandum

554 West Bakerview Road, Bellingham, WA 98226, Telephone: 360.922.5094, Fax: 360.647.5044 www.geoengineers.com

To:	Sara Brooke Benjamin – City of Bellingham
From:	Andrew Strahler, EIT and Sean W. Cool, PE
Date:	April 21, 2022
File:	0356-178-00
Subject:	Squalicum Creek Weir and Baker Creek Crossing Fish Passage Project Preliminary Geotechnical Considerations

INTRODUCTION AND PROJECT UNDERSTANDING

This memorandum presents the results of our preliminary geotechnical engineering services associated with the Squalicum Creek Weir and Baker Creek Crossing Fish Passage Project. Our services are provided in accordance with our amended agreement with the City of Bellingham (COB).

We understand that the COB intends to remove a fish passage barrier near the confluence of Squalicum Creek and Baker Creek, where Squalicum Way crosses Baker Creek between Cornwall Park and Squalicum Park in Bellingham, Washington. An existing weir structure is located in the channel below Squalicum Way. Based on the results of an alternatives analysis, the COB has selected a bridge option as the preferred structure type at this crossing location to mitigate fish passage barriers for both structures. The bridge span will be slightly affected by the skew of the crossing and has not been determined at this time but is expected to be in excess of 40 feet. Our review and reconnaissance, summarized in this memorandum, are intended to provide the design team with a preliminary understanding of known or apparent geologic conditions and preliminary geotechnical design criteria and recommendations for preliminary conceptual design and cost estimating of bridge option.

SITE INFORMATION

GeoEngineers reviewed available geologic maps and light detection and ranging (LiDAR) data for the project vicinity and reviewed previous site explorations within the project vicinity. Additionally, a GeoEngineers representative visited the site on April 13, 2022 to complete a site reconnaissance and observe existing site conditions. We have also reviewed the Preliminary Topographic Survey and Preliminary Cross Section Survey completed by PACE in March of 2022.

SITE CONDITIONS

Surface Conditions

The existing culvert crossing at Squalicum Way and Baker Creek is accessible by Squalicum Way, an asphalt concrete surfaced roadway located approximately ½-mile south of Interstate 5 (I-5) in Bellingham, Washington. The existing crossing consists of an 85-feet-long by 5-feet-wide double box concrete culvert that extends under Squalicum Way at an approximate skew angle of 18 degrees. An abandoned timber pile supported railroad crossing is present approximately 20 feet upstream of the culvert inlet. The Baker Creek culvert inlet contains an approximately 26-foot-long, 6-foot-tall, near vertical headwall structure that runs parallel to the existing roadway. Side slopes around and above the headwall structure are relatively gentle and contain approximately

6-foot-tall 1.5H:1V to 2H:1V (horizontal to vertical)-slopes that traverse from the existing road grade to the creek bank. No significant erosion or steep banks are present within the vicinity of culvert inlet; however, several incised banks are present just upstream of the abandoned railroad crossing.

The culvert outlet occurs at the confluence of Baker Creek and Squalicum Creeks. A similar 6-foot-tall, near vertical 26-foot-long concrete headwall is present that also generally runs parallel to and supports Squalicum Way. The roadway embankment and creek banks near the downstream headwall structure are generally steeper and transition to slopes on the order of near vertical to 1.25H:1V. Cobbles and boulders were observed in the exposed embankment side slopes and in and along the creek channel. We did not observe exposed bedrock during our site visit.

The Squalicum Way roadway at this crossing consists of two, 15-foot-wide lanes with approximately 5-foot-wide shoulders on both sides. The site is located within an area of suburban mixed residential and commercial development.

Geologic Conditions

The Baker Creek crossing area is mapped as glaciomarine drift (Q_{gdme}) of the Everson Stade. A contact with Sumas Outwash (Q_{gos}) is mapped immediately to the north and approximately 200 feet to the south of the site (Lapen 2000). Artificial fill is not mapped in the project vicinity but was likely placed historically at the project site to achieve Squalicum Way embankment grade. Undifferentiated glacial drift typically comprises soft to very stiff silt and clay, and medium dense to very dense sand and gravel with variable silt and clay content, and scattered cobbles and boulders. The Sumas Outwash consists of advance and recessional sand, gravel, and cobbles that were deposited by meltwater streams flowing from the glacier. The melting water and sediment formed an outwash plain. We interpret that the Squalicum Creek channel has incised partially or completely through the outwash deposits exposing the underlying glaciomarine drift in places near the channel elevation in the project vicinity.

Interpreted Subsurface Conditions/Reconnaissance

GeoEngineers completed a preliminary site reconnaissance visit on April 13, 2022 to observe and document exposed soil conditions in addition to performing shallow surficial explorations at the project site. Several shallow hand probe explorations were completed in and around the project site with a general focus on areas around the culvert inlet and outlet. Based on a review of observations completed during our preliminary site reconnaissance and boring logs from nearby geotechnical explorations we anticipate that subsurface conditions at the site will generally consist of the following soil units:

- **Existing Fill.** Observed portions of the soils within the existing roadway prism were interpreted to be composed of fill soils. The exposed fill soils generally consisted of medium dense to dense silty fine to coarse sand with gravel. Fill soils may locally include cobbles and boulders or other debris.
- **Alluvial Deposits.** Although not mapped in the project area, portions of the soils within the existing creek and deposited on the creek banks consisted of recently deposited alluvial soils. Exposed alluvial soils typically consisted of loose fine to coarse sand with variable silt content and soft silt with sand and gravel, and some cobbles. The depth of alluvial soils could not be precisely determined, however based on our experience, we anticipate this layer could extend to about 3 or 4 feet below existing creek grades.

- **Sumas Outwash (Q_{gos}).** An approximately 5- to 10-foot-thick layer of native glacial outwash was exposed overlying the glacial drift deposits along the Squalicum Creek bank side slopes at the time of our site reconnaissance visit. The outwash unit generally consists of relatively thin, discontinuous layers of medium dense, fine to coarse gravel and sand with gravel layers with variable silt and cobble content. These soils are anticipated to have relatively high hydraulic conductivity properties. Shallow groundwater is expected, near the existing creek channel elevation or slightly higher, in the adjacent fill and alluvial soils.
- **Glaciomarine Drift Deposits (Q_{gdme}).** Based on review of borings in nearby explorations and our on-site observations, we anticipate that glaciomarine drift deposits underly the fill and alluvial soils. These deposits in the project vicinity typically consist of very soft to medium stiff silt and clay with variable sand and gravel content and scattered cobbles or boulders. The upper portion of this unit can be stiff, and stiffer layers can be encountered at depth. Some layers and lenses of silty sand and non-plastic sandy silt are also encountered within this unit. This unit is generally considered compressible and could result in long-term settlement of structures that apply new loads. Given the variable consistency usually encountered in the undifferentiated glacial drift unit, these soils may actually represent multiple periods of glaciation, with some partial consolidation due to ice-contact loading in the stiffer layers.
- **Older Glacial Deposits and Bedrock.** The soils profile in the project vicinity may include layers of older glacial outwash and glaciomarine drift of various densities/consistencies. At times these layers are medium dense to dense or stiff to hard. Chuckanut Formation sandstone bedrock likely underlies the site at depth but is not expected within the depth of excavation.

PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

Based on our preliminary review of available site information, site reconnaissance, and shallow surficial explorations, we anticipate that the proposed bridge structure has the potential to be adequately supported by soils at the project site. Depending on the desired structure span and resulting foundation loads, we anticipate that bearing support will likely consist of deeper driven piles but could include drilled shaft supported abutments. We recommend that additional deeper explorations be performed at the project site to facilitate more in-depth foundation design analyses. If glacial drift soils at the site are more competent than anticipated, there may be an opportunity to evaluate shallow foundations as a less costly foundation option. The following sections detail the results of our preliminary site reconnaissance and additional preliminary recommendations.

Because site specific subsurface information is not available, we are providing a foundation options discussion for both deep foundation and shallow foundations. We recommend preliminary design of the bridge and cost estimate include deep foundations, and evaluation of an opportunity to reduce costs with an alternate shallow foundation system after completing the site-specific explorations.

Subsurface Explorations

It is our understanding that the proposed crossing structure will likely consist of a concrete slab or girder bridge supported on either deep pile foundation or shallow foundations. Regardless of the foundation type, deeper subsurface explorations are recommended to develop a better understanding of subsurface soil and groundwater conditions within the glaciomarine drift and alluvial soils, and to determine if soft or liquefiable soils are present underlying the site. The subsurface exploration program should be developed in conjunction with development of proposed bridge foundation option(s) and the anticipated extent of earthwork.

Geologic Hazards

The COB requires a geologically hazardous area site assessment be completed for the proposed project in accordance with Bellingham Municipal Code (BMC) 16.55.430 regarding potential geologically hazardous areas. The proposed project will be located within the required minimum setbacks from an erosion hazard as defined in the BMC. The methods of designating specific hazard areas are presented in the BMC and are briefly discussed below.

Erosion Hazard

Erosion hazard areas are designated in the BMC using the U.S. Department of Agriculture (USDA) Natural Resource Conservation (NRC) Web Soil Survey (WSS). The project site is mapped in the “Bellingham Silty Clay Loam” and a contact with “Kickerville-Urban Land Complex” unit is mapped to the south and north. Both units are rated as “slight” and this description is generally consistent with our observations on site, and we consider it to be generally applicable to the project area.

If disturbed, the sandy and silty fill and alluvial soils have a high susceptibility to erosion. Surface water should be prevented from flowing across disturbed areas and not directed toward the slopes during construction. Temporary erosion control measures should be used during construction depending on the weather, location, soil type, and other factors. Temporary erosion protection (e.g., straw, plastic, or rolled erosion control products [RECPs]) may be necessary to reduce sediment transport until vegetation is established or permanent surfacing applied. Appropriate best management practices (BMPs) should be incorporated into the temporary erosion and sediment control plan by the civil engineer. All finished slopes should be protected and/or vegetated before the rainy season. Provided that proper grading practices are used and BMPs incorporated into the grading plans, we conclude that the erosion hazard will be adequately mitigated during site development.

Landslide Hazard

The BMC defines a landslide area as any area with a slope of 40 percent or steeper and over 10 feet high. The generalized topography near the crossing is the flatter base of a creek meander valley with moderately steep side slopes away from the proposed crossing area. The project site is not mapped as having a high landslide potential in the above referenced COB Geologic Hazard Areas Map Folio. Creek bank slopes were generally greater than 40 percent slope but generally less than the 10-foot height specified in the BMC. However, several slopes on the downstream creek banks within vicinity observed during our site reconnaissance exhibited indications of recent shallow surficial landslides as the result of erosional processes. Therefore, the area in the immediate vicinity of the proposed project is not subject to the landslide hazard areas as designated by the BMC but the potential upstream and downstream impacts to slope stability should be considered in design.

Seismic Hazard

Seismic hazard areas include areas that are subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement, soil liquefaction or surface faulting. The site is mapped in an identified seismic hazard area as designated by the BMC; additional seismic design considerations are discussed below.

Coal Mine Hazard

The site is not located in a coal mine hazard area however, a contact with a mapped mine hazard area is located approximately 0.15 miles to the west based on our review of the COB Geologic Hazard Areas Map Folio and our previous experience.

Seismic Considerations

Seismicity

The site is located within the Puget Sound region, which is seismically active. Seismicity in this region is attributed primarily to the interaction between the Pacific, Juan de Fuca, and North American plates. Design practice in Puget Sound and building codes consider the local seismic conditions including local known faults in the design of structures.

Fault Hazards

No known faults are located in the site vicinity. The nearest known fault shown in maps by the Washington State Department of Natural Resources (DNR) and United States Geological Survey (USGS) is an unnamed fault located approximately 10 miles southwest of the project site. It is our opinion that the mapped faults do not present a significant risk of ground rupture at the project site.

Seismic Zone and LRFD Parameters

We understand that the 2017 version of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) manual will be used for design of site structures. The design earthquake has a 7 percent probability exceedance in 75 years (i.e., a 1,000-year recurrence interval). For preliminary planning, we anticipate that the project site will classify as Site Class E based on our knowledge and interpretation of the expected 100-foot soil profile. The site may classify as Site Class D if glacial drift soils in this unit are more competent than anticipated, based on future site-specific explorations. We have provided soil parameters for both conditions in Tables 1 and Table 2 below. If necessary for preliminary design, we recommend the seismic parameters presented in Table 1 be used based on the seismic data provided in the LRFD manual.

TABLE 1. SPECTRAL RESPONSE ACCELERATIONS (SRAs) FOR SITE CLASS E

SRA and Site Coefficients	PGA	Short Period	1 Second Period
Mapped SRA	PGA = 0.307	S_S = 0.689	S_1 = 0.229
Site Coefficients	F_{pga} = 1.179	F_a = 1.323	F_v = 3.083
Design SRA	A_s = 0.362	S_{DS} = 0.911	S_{D1} = 0.707

Note: Site Class D Description: Soft soil (N < 15).

TABLE 2. SPECTRAL RESPONSE ACCELERATIONS (SRAs) FOR SITE CLASS D

SRA and Site Coefficients	PGA	Short Period	1 Second Period
Mapped SRA	PGA = 0.307	S_S = 0.689	S_1 = 0.229
Site Coefficients	F_{pga} = 1.193	F_a = 1.249	F_v = 1.941
Design SRA	A_s = 0.366	S_{DS} = 0.860	S_{D1} = 0.445

Note: Site Class D Description: Soft soil (15 < N < 50).

Liquefaction Potential

Liquefaction is a phenomenon where soils experience a rapid loss of internal strength as a consequence of strong ground shaking. Ground settlement, lateral spreading and/or sand boils may result from liquefaction. Infrastructure supported on liquefied soils could suffer settlement or lateral movement that could be severely damaging. Conditions favorable to liquefaction occur in loose to medium dense, clean to moderately silty sand that is below the groundwater level. Dense soils/bedrock or soils that exhibit cohesion are generally considered not susceptible to liquefaction.

Our preliminary site explorations did not extend to sufficient depth to complete a liquefaction analysis at the site. Based on our experience with these geologic soil units and nearby projects within this project's vicinity, we anticipate that alluvial soils with moderate to high susceptibility to liquefaction may be present through the entire depth of this shallow soil unit. We anticipate these soils will likely be removed during foundation construction. We anticipate that the glaciomarine drift soils, because of their typically clayey composition will have a low susceptibility to liquefaction and not be significant for design. Mitigation, if required based on subsequent explorations, can consist of pile supporting the structure or designing the structure to accommodate the potential movement.

Bridge Type and Foundation Options

In our opinion, based on the available preliminary geotechnical information, a number of bridge and foundation options can be considered depending on desired height, span, stream hydraulics, scour potential and other considerations. We understand that a bridge is the preferred structure type and could likely be supported on deep foundations extending into the underlying glaciomarine drift, possible older glacial deposits, or bedrock if present. Additional deeper explorations will help evaluate appropriate foundation support options at the project site. If deeper explorations indicate that glacial soils in the project area are better than anticipated, spread footing foundations could be included as an alternative.

Deep Foundations

Abutments supported on friction or end bearing piles are recommended for preliminary planning and design for foundation support for the proposed crossing structure. A driven pile, or possible shaft foundation, will support the proposed structure over soft compressible soils, if present underlying the site. Pile foundations can also reduce the anticipated total and differential settlements to tolerable levels for design, if needed, likely to 1-inch or less for the options discussed below. Selection of the appropriate type and available capacity of any piles is inherently dependent on deeper subsurface explorations at the site and will be further evaluated after deeper subsurface explorations are completed. However, based on our experience with soils in the mapped geologic unit and projects completed within the project vicinity, we anticipate that deep foundation support would consist of driven friction or end-bearing piles or possible drilled shafts if suitable soils are present.

Driven Piles

Many of the bridges in Bellingham and Whatcom County are supported on driven piles gaining their strength from friction in the clay soils or by end-bearing in dense soils or bedrock, if present. Driven pipe piles (open- or closed-ended) and H-piles have been used successfully in Bellingham. Allowable pile capacity will depend on pile size, length and bearing soils/rock, but could range from 50 kips to greater than 250 kips.

Drilled Shafts

Drilled shafts may also provide a suitable deep foundation, especially if bedrock is encountered at a relatively shallow depth and have the potential to provide high axial and lateral resistance. Drilled shafts at 4-foot diameter socketed into bedrock could be designed in excess of 500 kips axial capacity and are currently being designed for another local Bellingham bridge project. Casing would likely be required during installation of the shafts.

Shallow Foundations

If additional deeper explorations indicate that the glacial drift soils are more competent than anticipated, medium stiff or stiffer, then shallow foundations may be considered as a viable option and should be supported on native undifferentiated glacial drift deposits, or on structural fill extending to these soils. A minimum thickness of granular structural fill, on the order of 18- to 24-inches thick, may be required to protect the subgrade and provide uniform support of the foundation over the fine-grained native soils. Shallow alluvial soils may require removal below foundations. If footings are supported on compacted structural fill, the fill zone should extend laterally beyond the edges of the footing a distance equal to the final fill height.

If site explorations indicate subgrade soils are medium stiff or stiffer, then we anticipate that shallow spread footing foundations embedded at least 2 feet below scour elevation and having a minimum width of 3 feet can be designed assuming a relatively low allowable soil bearing pressure on the order of 1,500 pounds per square foot (psf). This allowable soil bearing value assumes a submerged condition could occur and applies to the total of dead and long-term live loads and may be increased by up to one-third for wind or seismic loads.

Settlement potential, both total and differential, should be evaluated considering site-specific soil exploration data, foundation type, shape, and structural loading conditions, and may control the design from a service-limit design. A shallow foundation may need to accommodate several inches of post-construction settlement depending on the final soil profile. As noted, some additional post-seismic settlement may occur depending on the soil profile encountered in the explorations.

Dewatering and Drainage

We anticipate that static ground water conditions will be near the elevation of the existing creek channel. Groundwater seepage from perched zones may also be encountered above the high groundwater elevation. Permeable sand and gravel “pockets” may be present within site soils sidewalls of the planned excavation and may become unstable when excavated; therefore, dewatering will be necessary to maintain a stable and dry subgrade for foundation construction.

The groundwater level should be lowered to an elevation that will maintain a stable excavation during construction, which will depend upon the dewatering method, the size of the excavation and other factors. Commonly, this can be achieved if groundwater level is lowered to about 2 feet below the bottom of the excavation. The level of effort required for dewatering will depend on the time of year during which construction is accomplished and the extent to which the creek flow is diverted around the excavation. Lowest groundwater elevations and inflow rates should be expected between June and October, with higher levels outside of this period. We expect dewatering efforts will be greater for shallow foundations that require deeper excavation below scour elevations.

Drainage systems should be constructed to collect water and prevent the buildup of hydrostatic pressure against abutment retaining walls and wing walls. Alternatively, the walls and foundation elements should be designed for hydrostatic pressure.

Earthwork

We anticipate earthwork related to removing existing embankments and/or aligning, raising, or lowering the roadway to match a new bridge profile can be completed with conventional earthmoving equipment. We anticipate that portions of the near surface, on-site fill and alluvial soils may be suitable for reuse as structural fill during periods of dry weather, provided selected screening of cobbles and boulders and/or spreading of cobbles throughout embankment fill can be accomplished. Underlying undifferentiated glacial drift soils are anticipated to consist primarily of fine-grained clay and silt, are moisture sensitive, and will likely have natural moisture content at above the anticipated optimum moisture content for compaction. Soils within this unit may require significant moisture conditioning (drying) and additional effort in order to meet the specified compaction criteria during dry weather conditions and will not be suitable for reuse during wet weather. We do not recommend reuse of on-site native glaciomarine drift soils where 95 percent compaction is necessary, such as immediately under pavement areas and as retaining wall backfill. Imported gravel borrow will provide more reliable earthwork fill and compaction and will provide in improved stable working surface during a wide range of weather conditions. Detailed earthwork recommendations should be developed in conjunction with information developed from subsurface explorations.

Temporary Shoring

At the time of this memorandum, it is our understanding that temporary shoring is not planned for this project. Based on discussions with the project design team, we understand that the design of the structure is not finalized and is currently on-going. If temporary shoring is required to facilitate construction of the selected design alternative, we will provide design recommendations and update this section accordingly.

Temporary and Permanent Slopes

For preliminary design purposes, we recommend that temporary cut slopes be constructed no steeper than 1.5H:1V, permanent cut and fill slopes be constructed no steeper than 2H:1V. To reduce the potential for erosion, newly constructed slopes should be planted or hydroseeded shortly after completion of grading. Until the vegetation is established, some sloughing and raveling of the slopes should be expected. Temporary covering, such as clear heavy plastic sheeting, jute fabric, loose straw or geotextile matting should be used to protect the slopes during periods of rainfall and/or when vegetation cannot be established. Slopes exposed to open channel water flow will require additional protection such as riprap armoring and may require flatter slope inclinations. Design of open channel slopes should consider hydraulic conditions and scour potential.

Since the contractor has control of the construction operations, the contractor should be made responsible for the stability of temporary cut slopes, as well as the safety of the excavations. All shoring and temporary slopes must conform to applicable local, state, and federal safety regulations.

LIMITATIONS

We have prepared this memorandum for the exclusive use by the City of Bellingham and the design team for the Squalicum Creek Weir and Baker Creek Crossing Fish Passage project located in Bellingham, Washington.

No site-specific subsurface explorations were completed for this preliminary, alternatives study phase of work, but will be required prior to final design.

Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this memorandum was prepared. No warranty or other conditions express or implied, should be understood.

AWS:SWC:leh

APPENDIX E
Value Engineering Report

Whitewolf Engineering Services

whitewolfengineeringservices@gmail.com

3224 Bay Road, Ferndale, WA 98248

MEMO

4/15/22

To:	Mark Stamey, Geo Engineers
From:	Ravyn Whitewolf, P.E., VMA
CC:	John Monahan
Subject:	Value Engineering Alternative Analysis – Squalicum at Baker Creek

Whitewolf Engineering Services was hired to perform an independent value engineering (VE) analysis to validate the preferred alternative for addressing fish passage at this location. The value methodology tools used in this analysis follow the principles SAVE International,® the global voice of value and the recognized authority on the Value Methodology. This systematic and structured approach is used for improving projects, products, processes, services, and organizations to better refine goals, mitigate risk, optimize designs, save money, and improve performance.

Ravyn Whitewolf, who is certified in the VE methodology, led a VE workshop on March 21, 2022, with city staff and the GeoEngineers design team. At the workshop, key project "functions," as identified by the project team, were reviewed, analyzed, and classified to identify the root criteria by which to evaluate the specific project alternatives. This was then followed by a facilitated exercise to establish and rank performance measures utilizing the "function analysis" results to score the different alternatives. The resulting performance matrix, represented here in Figure 1, shows the results of the analysis. Because this process was conducted independently, the performance criteria outlined in this report is different than the evaluation criteria created by the design team. This report is not intended to evaluate the technical merits of the design alternatives.

The Squalicum crossing at Baker Creek is located on Squalicum Parkway (AKA "The Truck Route") across from Squalicum Creek Park. The project would remove the existing fish barrier (a weir structure that is approximately 2-feet high) with a crossing improvement that would be fully fish passable. The location is challenged by the railroad right-of-way, proximity to Baker Creek which outfalls to Squalicum Creek), and the lack of alternative access to the waterfront industrial area for heavy trucks. These were all taken into account during the study.

The GeoEngineers interdisciplinary design team with the City of Bellingham identified 3 alternatives to address the goals of the project:

- Alternative 1: Remove Weir and regrade
- Alternative 2: Create a Split Flow Channel
- Alternative 3: Remove weir, restore Squalicum Creek and replace Baker Creek crossing with a conveyance structure.

When applied to the technical score established by the design team, the VE-derived performance matrix resulted in the selection of Alternative 3, with a final score of 72.2/100, compared with 66.3 and 44.4 for alternatives 2 and 1 respectively.

Whitewolf Engineering Services

Squalicum Location

City of Bellingham

ATTRIBUTES WEIGHTING

03/21/22

Attribute

	Attribute	B	C	D	E	F	G	H	I	J	K	Importance Count	Importance Weight
A	Low Cost	B3	C3	D3	E2	F1	G3	H3	I3	J2	K3	0	0.0%
B	Natural restoration of fish population	B	B3	B3	B2	B3	B3	B3	B2	B3	B3	28	20.1%
C	Addresses Climate Change		C	C2	C3	C2	C3	C3	I2	C3	C3	22	15.8%
D	Minimize Maintenance (future)			D	D3	D2	D3	D2	I2	D2	K1	15	10.8%
E	Constructability				E	E2	G1	E3	I3	J1	K2	7	5.0%
F	Forward compatibility					F	F2	F3	I3	F2	K2	8	5.8%
G	Minimize roadway impacts						G	G2	I3	J3	K3	6	4.3%
H	Minimize Environmental Impact							H	I3	J3	K3	3	2.2%
I	Geomorphic Considerations								I	I3	K2	22	15.8%
J	Property Acquisition									J	J2	11	7.9%
K	Reduce risk to adjacent property										K	17	12.2%
												139	100%

1 - Low Certainty

2 - Neutral

3 - High Certainty

Enter alpha priority selection, followed by numeric level of certainty, e.g. B2

Figure 1

Whitewolf Engineering Services (WES) appreciates the opportunity to work with the GeoEngineers team on this important project evaluation. If there are any questions or more information is needed, please don't hesitate to contact us.

GeoEngineers