REPORT

SITE ASSESSMENT AND MONITORING PLAN
LOWER GOLDSBOROUGH CREEK

Prepared for

Squaxin Island Tribe

10 SE Squaxin Lane

Shelton, Washington 98584

Prepared by

Anchor QEA, LLC

1605 Cornwall Avenue

Bellingham, Washington 98225

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LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
cfs	cubic feet per second
ESA	Endangered Species Act
Ev(c)	Eocene-aged bedrock
LiDAR	Light Detection and Ranging
LWD	large woody debris
mm	millimeters
NGVD 29	National Geodetic Vertical Datum of 1929
Qa	glaciation
Qapo	glacial outwash
Qc(k)	sedimentary bedrock
Qgd	glacial drift
Qgo	glacial outwash
Qgt	glacial till
RM	river miles
Shelton	City of Shelton
SIT	Squaxin Island Tribe
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WSDOT	Washington State Department of Transportation

1 INTRODUCTION AND SCOPE

Lower Goldsborough Creek is located within the City of Shelton (Shelton) and flows through the Simpson Lumber Mill into Oakland Bay. After a historic ferry dock structure at the mouth of Goldsborough Creek was removed, channel bed downcutting occurred downstream of the 1st Street Bridge. Grade controls were placed to prevent potential damage to exposed pipelines; however, continued downcutting has caused adverse hydraulic conditions adjacent to these grade control features for threatened salmonids migrating upstream.

An additional 14 miles of valuable habitat area were made available in the upper-basin following the 2001 removal of the Goldsborough Dam (USACE 1999). Goldsborough Creek supports five Endangered Species Act (ESA)-listed and priority fish species that pass through the lower reach:

- Fall Chinook (in the estuary only)
- Coho
- Fall chum
- Winter steelhead
- Sea run cutthroat trout

The Squaxin Island Tribe retained Anchor QEA, LLC, to evaluate current channel conditions in the lower reach in order to determine the anticipated geomorphic effects of removing one or both exposed pipelines from the channel bed. Removing the pipelines would allow the channel to adjust and re-establish natural channel grades and improve fish passage without implementing grade-control or non-native structures. There are concerns, however, that the channel adjustment may pose potential risks to existing infrastructure. Anchor QEA has also been retained through a separate contract to evaluate clean up and restoration in the harbor.

As a part of this scope of services, Anchor QEA performed the following activities:

- Site reconnaissance
- Survey data collection
- Current channel cross-section comparisons with past survey and as-built drawings
- Hydraulic modeling

- Sediment transport analyses to evaluate bedload sediment transport in the reach

The above information was analyzed and used to evaluate the likely risks and benefits of infrastructure removal both locally and upstream of the immediate project area.

2 BASIN AND SITE DESCRIPTION

Goldsborough Creek is located on the Olympic Peninsula of Washington State (Figure 1, attached). The creek drains into Oakland Bay at the west end of the Hammersley Inlet of the Puget Sound through Shelton. A majority of the watershed is forested, with large areas of the valley occupied by wetlands and riparian areas in the upper watershed. Both natural geologic controls and anthropogenic influences have shaped the present physical conditions and processes occurring within the basin.

2.1 Regional Geology

The geology of the Goldsborough Creek basin is largely the result of glacial processes that occurred during several periods of glaciation following the formation of Eocene-aged bedrock (Ev(c)). The volcanic bedrock underlies the surface glacial sediments and outcrops at a few locations within the watershed (Figure 2, attached). Glacial ice carved wide, steep-sided valleys into the bedrock, leaving behind terraces of striated glacial till (Qgt) and glacial drift (Qgd), and wide, flat glacial outwash (Qgo) valleys where sands and gravels were deposited as the ice receded. Pre-Fraser sedimentary bedrock and glacial outwash (Qc(k); Qapo) units are also present at the surface that consist of riverine or glacially deposited alluvium that was consolidated during the Fraser glaciation. Glacial compaction converted these sand and gravel deposits into relatively erosion-resistant units similar to sandstone or conglomerate. The most notable presence of these units is within the steep, entrenched section of Goldsborough Creek (river miles [RM] 2.5 to 7) and along the south valley walls of Coffee Creek and Lower Goldsborough Creek (RM 1.75 to 1). Recent alluvium deposited following glaciation (Qa) is also present within existing floodplains and streambeds.

2.2 Basin Geomorphology and Historical Context

Upstream of RM 8, the valley is a relatively flat, wide and dominated by marshes and wetlands. Downstream of approximately RM 7, downcutting into outwash deposits has occurred over the past several thousand years. Over time, the creek cut through the surrounding outwash and till until the bed elevation reached the consolidated pre-Fraser unit between RM 7 and 2.75 and RM 1.75 and 0.75. Elsewhere, the Qapo was not encountered. The resulting landscape downstream of RM 2.75 is a perched glacial outwash terrace currently occupied by the northern portion of Shelton.

In the mid-1800s, the basin was settled and infrastructure was constructed to support the logging industry, including railroads and grade control features such as dams and weirs. Vast areas of forest were logged and the logs transported via railroad and stream flow downstream to Shelton Harbor. In 1885, the creek was dammed to create a log storage pond near RM 2.5 at the site of a small natural waterfall. By the 1920s, the pond berm was rebuilt as the Goldsborough Dam and used to provide hydroelectricity to Shelton. Before it was removed, the dam actually consisted of four steps or separate drops that collectively dropped more than 35 vertical feet and 100 longitudinal feet; the largest vertical drop was 14 feet. The dam resulted in adverse geomorphic effects downstream, including incision and channelization that were exacerbated by bedload sediment being trapped behind the dam. Because the dam was also a fish passage barrier for threatened salmonids, stakeholders chose to remove the dam when its integrity was compromised during a 1996 flood event. The dam was completely removed in 2001, and the dam and former pond reach were replaced with a series of 3 dozen weirs that hold the channel grade, which was evened out by transporting deposited sediment from upstream of the dam to the incised downstream reach.

A longitudinal profile extracted from 2002 Light Detection and Ranging (LiDAR) bare-earth elevation data shows the major grade breaks throughout the channel from the mouth to the wetland section above RM 8 (Figure 3). Overall, the channel grade throughout RM 0 to 7 is relatively consistent (average of approximately 0.4%), except for the former dam section (average 2%) and a straight, incised section between RM 5.5 and 5.1 (average 1%).

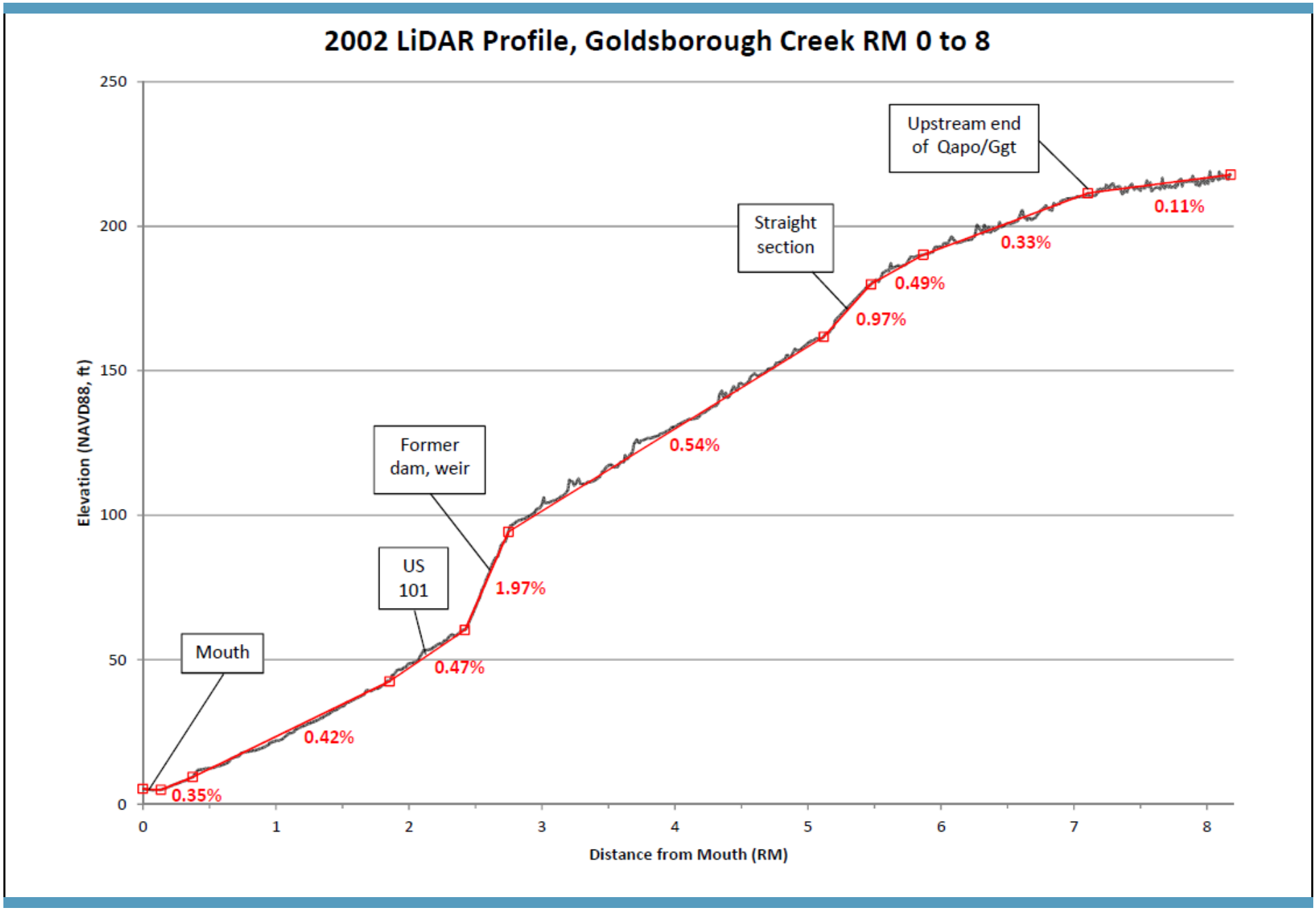
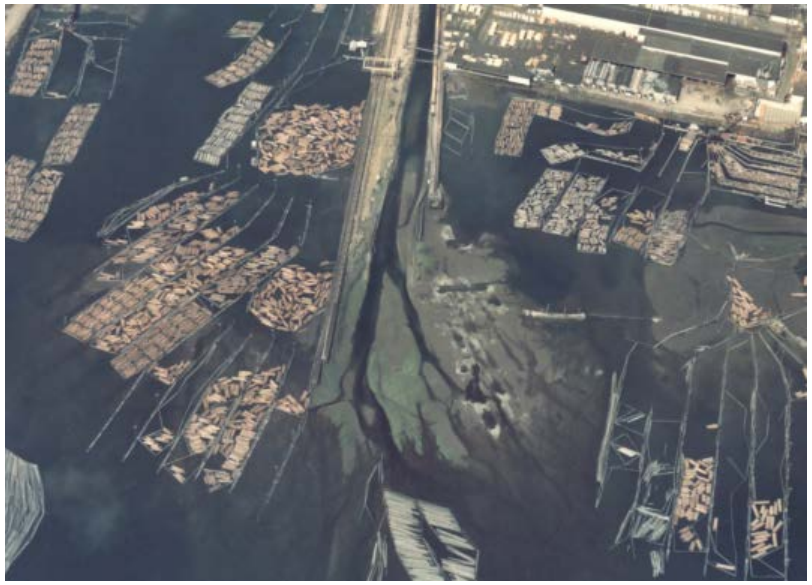


Figure 3
Longitudinal Profile Extracted from 2002 LiDAR, RM 0 to 8
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

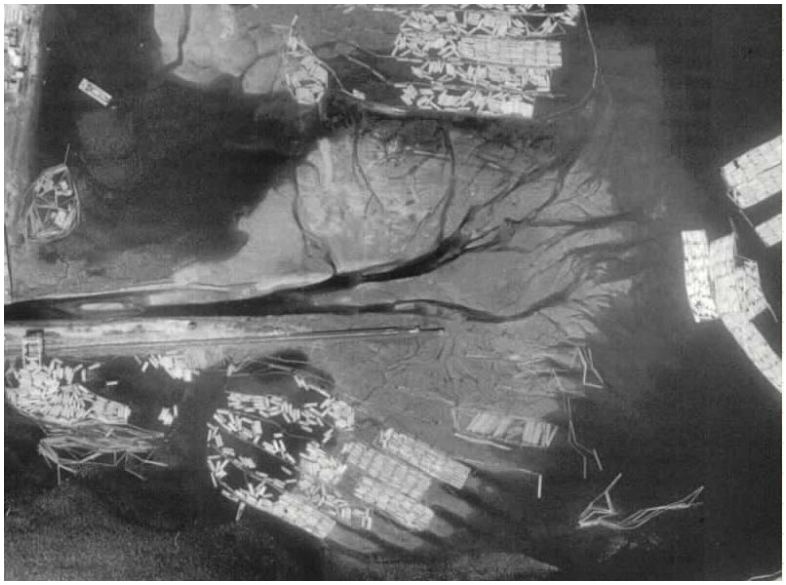
ANCHOR QEA

Anthropogenic impacts at the mouth of the creek in Shelton Harbor and at the Goldsborough Creek estuary have also influenced geomorphic processes. Over the course of the early to mid-20th century, industrial companies gradually filled and built upon the natural tidal flats and estuary area, channelizing the creek into a straight pathway flanked by steel walls and steep armored banks that extended the mouth of the creek further east towards the Hammersley Inset and out of the sheltered tide flats. In addition, hundreds of wood piles were installed throughout the harbor to be used for log storage. In the 1950s, the outlet of the stream protruded approximately 1,500 feet east from the edge of the developed industrial area, confined between a railroad ferry dock on the north (left) bank and a railroad spur on the south (right) bank. Sediment was regularly dredged from the harbor adjacent to the north railroad ferry dock to be used as fill. In approximately 1991, the ferry dock was removed by the U.S. Army Corps of Engineers (USACE). The south bank railroad spur remained in place. Figure 4 shows before and after photos of the ferry dock removal and the subsequent sediment deposition that occurred in the harbor; sedimentation likely increased as coarse sediment was able to pass the site of the former Goldsborough Dam after its 2001 removal.

After the railroad ferry dock was removed, the creek quickly migrated to the north into the dredged area that had been behind the dock embankment, creating an abrupt grade drop from the channel into the dredged area. This likely resulted in a quickly propagating headcut up the creek channel as the creek adjusted to its new base elevation, which resulted in channel incision in Lower Goldsborough Creek. The exposure of two buried pipelines and the undercutting of infrastructure is evidence of the downcutting of the channel bed. Photograph documentation of bed elevations relative to infrastructure is provided in Appendix B.



1977 (Washington State Coastal Atlas, Ecology)



1990 (USGS)

1992 (Washington State Coastal Atlas, Ecology)

2006 (Washington State Coastal Atlas, Ecology)

Figure 4
Comparison of Historic Aerial Photos at Mouth of Lower Goldsborough Creek
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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2.3 Project Site Description

The project site is located within Lower Goldsborough Creek from the mouth to the 1st Street crossing (Figure 5, attached). Limited survey was collected between 1st and 7th streets and a site reconnaissance was performed between 1st Street (Station 21+00) and West Cota Street (Station 61+00). Site reconnaissance upstream of 1st Street was performed by Anchor QEA staff on July 17, 2012, at a discharge of approximately 72 cubic feet per second (cfs; U.S. Geological Survey [USGS] gage #12076800).

2.3.1 1st Street Crossing to Mouth

(Note: Detailed photographic documentation is provided in Appendix A.)

Downstream of 1st Street, the Goldsborough Creek channel is straightened and confined to an approximately 50- to 80-foot cross-section. A majority of the banks are held by vertical corrugated steel and pile walls or armored with buried riprap between Stations 21+00 and 8+00 (Photograph 1). Two vehicle bridges, two railroad bridges, one footbridge, two exposed below-ground pipelines, and two overhead utility crossings are located through this section of the creek. Concrete abutments, piers, and armor rock protruding from the banks associated with this infrastructure creates local channel constriction points. Downstream of Station 8+00, the channel becomes wider and the banks are lined with large angular rock. Flows in the channel are tidally influenced from the mouth to the exposed pipeline crossing just downstream of 1st Street.

Photograph 1
Typical Channel Conditions Downstream of 1st Street, Looking Downstream Towards Pedestrian and Lower Vehicle Bridge

At the upper exposed pipeline near Station 21+00, large angular rock has been placed in the channel bed as a grade control to minimize exposure and potential damage to the pipe. Just upstream of the upper railroad bridge near Station 18+00, an approximately 40-linear-foot concrete mattress is located across the channel bottom. At both of these locations, significant plunge pools with approximately 3.5-foot vertical drops were observed on the downstream side of the grade control.

Bedload sediment was observed to be a mixture of sands, gravels, and cobbles within the surface layer. Local areas of deposition were observed, primarily in the lee of hydraulic obstructions such as the lower railroad bridge pier. Some areas of the channel contained an armor layer of gravel and small cobble. Downstream of the confined channel in the estuary, the tidal delta was composed of primarily fine sands with rounded gravels (Photograph 2). The south bank/railroad spur is armored with angular rock and extends approximately 1,450 feet downstream of Station 0 along the right bank.

Photograph 2
Sediment within the Estuary; Main Goldsborough Creek Outflow Channel and Right Bank Railroad Spur in Background

2.3.2 West Cota Street to 1st Street

(Note: Detailed photographic documentation is provided in Appendix B.)

Between approximately Stations 58+00 and 49+00, the right bank and portions of the toe of the left bank are lined with compacted, resistant sands and gravels in a fine matrix (Qapo). The channel is relatively straight and plane-bed throughout this section. Much of the left bank is a steep slope to the higher terrace above, which contains a residential area. The West Cota Street Bridge is a private bridge placed to service this residential area. Between Stations 60+00 and 55+00, the left bank contains very large (greater than 5-foot diameter) angular concrete chunks that line the bank. Some concrete chunks are located on the channel bed and force local scour pools. Evidence of bank erosion was observed through the channel as undercut banks and exposed tree roots. A number of residences were observed within close proximity to the left bank; however, no imminent risk to the structures was apparent. One significant gravel bar was observed along the left bank near Station 58+00, which contains a relatively well-distributed surface bedload layer of gravel and small cobble.

Typical sediment load throughout the channel was similar to the bar observed at Station 58+00, with a few local areas containing large cobble riffles and steeper grades.

Between Stations 49+00 and 34+00, the channel is located through a low-sinuosity bend in the channel planform. The channel morphology is an alternating riffle-run pattern with forced pools at occasional large woody debris (LWD), large rocks, or debris in the channel. The banks are occasionally armored with armored rock, boulders, concrete blocks, or layers of poured concrete. Undercut banks and exposed root masses were observed throughout the channel where armoring was not present and along the poured concrete-armored banks downstream of the 7th Street Bridge. Large fallen trees observed near Stations 45+00 and 37+00 appeared to have fallen in the channel several years earlier. At the railroad crossing, the banks have been reinforced with large armored rocks.

Placement of quarry spalls adjacent to a residence just upstream of the 7th Street Bridge was further indication that an erosion concern exists (Photograph 3). In addition, it appears that armor rock placed adjacent to the 7th Street Bridge was intended to mitigate for erosion. Two gravel point bars near the railroad crossing and one mid-channel gravel bar near Station 34+00 were observed within this section of the channel. The mid-channel bar was vegetated with grasses and contained a minor amount of LWD, including one rootwad log. The surface bedload of the three gravel bars contained primarily gravel and small- to moderate-sized cobbles, with a progressively larger D_{50} and gradation of clast sizes moving downstream.

Photograph 3
Rock Placed along the Left Bank at a Residence Adjacent to the 7th Street Bridge

Downstream of Station 34+00, the riffle transitions into an approximately 1,300-foot section that is primarily a straight run to the 1st Street Bridge (Photograph 4). Some slightly deeper areas of the channel were observed; however, the thalweg is relatively undefined and deep pools or gravel bars were not observed. Portions of the banks are armored with angular rock, and bank undercutting was observed where armoring was not present. One small gravel bar was observed near Station 25+00 that contained primarily gravels with occasional small cobbles.

Photograph 4

Typical Channel Conditions between Stations 34+00 and 21+00

3 METHODOLOGY

This evaluation includes site reconnaissance and survey data collection to document existing conditions and to compare current survey data to past elevation measurements in 1998 and 2001, and in as-built drawings for infrastructure where available. These data provide the basis for a long-term monitoring plan that will allow detailed elevation comparison through Lower Goldsborough Creek through time. The long-term monitoring plan will help us to understand the state of recovery (degradation vs. aggradation) in the lower creek, as well as document the effects that pipeline removal may have on the creek.

Previous data collection appears to have been focused on the creek system in areas adjacent to the pipelines and little to no data were collected near the mouth or into the estuary. This data collection effort attempted to duplicate previous data collection locations and to extend data collection through the creek mouth and out into the estuary. Because of the level of confinement in the creek, we believe that the creek mouth and adjacent estuary area will be the first area to respond to either aggradation or degradation and, therefore, represents the best location to monitor and evaluate past, current, and future trends.

3.1 Site Reconnaissance

Site reconnaissance and survey data collection for existing conditions was performed on July 16 and 17, 2012. The following features were observed and documented where applicable:

- Bedload sediment size and distribution (qualitative)
- Bank erosion, including evidence of erosion or aggradation
- Presence of and potential risks to public and private infrastructure
- Other channel characteristics, including grade and planform controls and observed extent of tidal influence

3.2 Survey Data Collection

Survey sections from the 1st Street Bridge to approximately 125 feet upstream of the mouth of the creek were previously obtained by the USACE in 1998 and 2001. These data were translated into a HEC-RAS model to compare bed elevations and differing hydraulic

conditions. The surveys were not georeferenced to a standard horizontal datum; rather, a project datum was used and notes were made at each section about the relative location of the cross-section along the channel. Several intermediate sections were also interpolated for the purposes of the model—these sections are essentially averaged topographic values between two real survey sections.

As part of this scope, a majority of the existing survey sections were replicated to capture 2012 conditions and assist in evaluating changes to the channel bed elevation through time. Additional survey sections were added to help create a refined hydraulic model and to better capture potential bed elevation changes throughout the channel in the future. The survey was georeferenced to a national standard horizontal datum; Figure 6 (attached) displays collected survey points through the project area. Appendix C describes the details of the survey plan, including recommendations for replicating the survey in future years. Table 1 summarizes the existing and current surveys.

Table 1
Summary of Existing and Current Surveys in Lower Goldsborough Creek

Survey Year	No. of Sections	Horizontal Datum	Vertical Datum	Notes
1998	6	Local	NGVD 29	From just upstream of 1st Street Bridge to mouth
2001	6	Local	NGVD 29	From just upstream of 1st Street Bridge to mouth
2012	22	North American Datum of 1983, State Plane North Zone, feet	NAVD 88	Only profile data obtained upstream of approximately Station 21+50. Elevations converted to National Geodetic Vertical Datum of 1929 (NGVD 29) for comparison with older surveys.

Notes:
1998 and 2001 include additional cross-sections upstream of 1st Street but do not include continuous thalweg profile.
NGVD 29 = National Geodetic Vertical Datum of 1929
NAVD 88 = North American Vertical Datum of 1988

The duplicated survey sections and channel profile were compared through the lower reach where practical (Table 2). The relative bed elevations adjacent to the 1st Street Bridge from

as-built drawings provided by Washington State Department of Transportation (WSDOT) were also analyzed and compared to the observed 2012 existing conditions. Additional details regarding the 2012 survey plan, cross-sections, as-built comparisons, and other documentation are provided in Appendix D.

Table 2
Duplicated Survey Sections

Approximate Station	Section	Survey Years	Notes
7+55	2	1998, 2001, 2012	Upstream of lower overhead utility crossing
9+60	3	1998, 2012	Upstream of lower railroad crossing
15+55	4	1998, 2001, 2012	Upstream of upper vehicle bridge
17+85	5	1998, 2012	Upstream of upper railroad crossing; on top of concrete mattress
20+40	5.6	2001, 2012	Downstream of rocks
20+90	5.7	2001, 2012	Downstream of 1st Street Bridge
21+45	6	1998, 2012	Upstream of 1st Street Bridge

3.3 Hydrology and Hydraulic Modeling

Hydrology for Lower Goldsborough Creek was developed for peak flow events using USGS gage #1276500 (Goldsborough gage, near Shelton). The computed flows were then scaled using the USGS basin-scaling method. See Appendix E for a detailed explanation of the basin-scaling method. The hydrology obtained from the basin-scaling method was used in the model to evaluate sediment transport in Lower Goldsborough Creek.

Hydraulic model geometry was developed to simulate the existing hydraulic conditions within the Lower Goldsborough Reach. The upstream extent of the model is just upstream of the 1st Street Bridge, and the downstream extent is the mouth of Lower Goldsborough Creek. The model provided estimates of hydraulic conditions, including water surface elevations, flow velocities, and channel bed shear stress. These estimates were used to evaluate hydraulic and sediment transport parameters and develop a baseline for comparison with future surveys and models.

Additional cross-sections were needed in the vicinity of the large armor rock located just downstream of the 1st Street Bridge to simulate channel roughness and elevation drop. Cross-section 5.65 was duplicated and used for this purpose. See Appendix E for a detailed description of the method for simulating the roughness and elevation drop due to the large armor rock.

3.4 Sediment Transport Evaluation

The HEC-RAS existing conditions modeling results were used to obtain parameters for use in evaluating the sediment transport competency of the Lower Goldsborough Reach. Sediment transport calculations and analyses were performed to determine the critical grain size in the Lower Goldsborough reach under existing conditions. Refer to Appendix E for a discussion about critical grain sizes, equations used, and plots of results for differing hydraulic conditions.

4 RESULTS

4.1 Channel Grade and Bedload in the Lower Creek

4.1.1 Comparison of Surveyed Cross-sections

Eight cross-sections were duplicated over at least 2 years within the historic and recent survey record. These sections were overlaid and compared to estimate the change in bed elevation over time. However, because the historic survey was not tied into a known horizontal datum, the surveys could not be replicated at the exact stations linearly along the creek and, therefore, the resulting values are approximate. Table 3 summarizes the difference in minimum elevation at select cross-sections. See Appendix D for a detailed description of these results.

Table 3
Historic and Recent Survey Results, Difference in Minimum Elevation at Select Cross-sections (NGVD 29, feet)

Section	1998 to 2012	1998 to 2001	2001 to 2012	Note
1	-	-1.29	-	2012 not surveyed
2	-0.88	-0.73	-0.15	
3	+0.22	-	-	2001 not surveyed
4	-0.71	-0.05	-0.66	
5	-0.19	-	-	2001 not surveyed
5.6	-	-	-1.18	1998 not surveyed
5.7	-	-	-2.12	1998 not surveyed
6	-0.87	-	-	2001 not surveyed

Note:
NGVD 29 = National Geodetic Vertical Datum of 1929

The greatest change in bed elevation that has occurred since 2001 was observed on the downstream side of the large armor rock at the exposed pipeline (Section 5.7). Although a historical section was not surveyed on the downstream side of the concrete mattress, it can be assumed that this location was also one where significant bed scour occurred based on the 2012 survey, observed hydraulic conditions, and hydraulic model output (Appendix D, Figure D-2). Near the mouth (Station 0), it was noted that the minimum channel elevations downstream of the historical Section 1 were higher in elevation than the last survey in 2001.

This would suggest that the creek at the mouth may have aggraded since 2001; however, we have no specific data to confirm this.

4.1.2 Observations of Bridge Abutments and Infrastructure

During the field visit, observations of existing conditions at the bridge were noted and later compared with as-built drawings of the 1st Street Bridge provided to Anchor QEA by WSDOT. The channel material in the vicinity of the 1st Street Bridge appeared to be well graded with a mix of sands, gravels, and some cobbles. Underneath the 1st Street Bridge, sediment deposits were observed along the face of the left abutment, while the channel thalweg was located along the right abutment. The cross-section surveyed just upstream of the bridge confirms these conditions. The elevation at the toe of the left bank is approximately 4.7 feet National Geodetic Vertical Datum of 1929 (NGVD 29) and is approximately 3.5 feet NGVD 29 at the toe of the right bank.

As-built drawings of the 1st Street Bridge show the bed elevation, abutment elevation, and pile depths at the time of the bridge construction. The face of both the right and left bank abutments is shown as 1.8 feet NGVD 29, and the average depth of pilings for the left and right abutments are -14.7 feet NGVD 29 and -19.3 feet NGVD 29, respectively.

4.2 Hydraulic Model Results

The results of the HEC-RAS modeling show that high shear stresses are occurring just downstream of the 1st Street Bridge near the existing pipeline. This is likely because of confinement from the bridge and the abrupt drop in channel elevation.

During the 2012 survey collected on July 16 and 17, the flow in Goldsborough Creek at 7th Street was approximately 70 cfs. This flow was used to evaluate the accuracy of the model for flow conditions in the lower discharge range. Field observations of the water surface were compared to the calculated water surface in the model. The water surfaces were comparable and it was determined that the model was providing an accurate estimate of hydraulic conditions for those specific hydrologic conditions.

4.3 Sediment Transport Analysis

Complete results for the sediment transport analysis are provided in Appendix E. The results of the sediment transport analysis show that the largest critical grain sizes occur at the upstream end of the reach, just downstream of the 1st Street Bridge. At Section 5.7, located between the bridge and the gravity pipeline, the critical grain size is 284 millimeters (mm; 11.2 inches) for the 2-year return period. Large critical grain sizes are also seen at the large armor rock protecting the pipeline and the concrete apron just upstream of the dual railroad bridge. Section 5.6, located within the large armor rock, has a critical grain size of 169 mm (6.6 inches). Section 5, located on the concrete apron, has a critical grain size of 190 mm (7.5 inches) for the 2-year return period. Downstream of the concrete apron, the critical grain sizes for the 2-year return period are fairly consistent, varying between 34 mm (1.3 inches) and 64.5 mm (2.5 inches).

4.4 Geomorphic Reconnaissance Upstream of 1st Street Bridge

The following are key observations from the geomorphic field reconnaissance upstream of the 1st Street Bridge:

- Bedload grain size is small just upstream of the bridge and these materials are likely easily mobilized during high-flow conditions
- The channel is straight and plane-bed, with no bar deposits until approximately Station 34+00
- Additional gravel deposits were observed upstream of Station 34+00 and bars become more frequent further upstream
- The channel planform (i.e., horizontal position) is relatively fixed, although some limited channel migration was observed
- Bank armoring is sporadic throughout the reach
- Erosion-resistant compacted sands and gravel were observed between approximately Stations 47+00 and 58+00
- Evidence of bank undercutting was observed throughout the reach
- Pools, large woody debris, cover, and other habitat features valuable to salmonids were limited

4.5 Anticipated Future Conditions

The hydraulic model output, sediment transport calculations, survey comparison, and geomorphic assessment were used collectively to develop a conceptual model of expected future conditions within the lower creek channel should the exposed pipelines and associated concrete and armor rock be removed. Given the change in bed elevation that has occurred below 1st Street since the removal of the railroad ferry dock, it is clear that an adjustment to the channel grade as a result of pipeline removal is likely. The potential for headcut initiation and movement upstream through the finer grained sediments is present and there may be channel downcutting in the near proximity of the pipeline location. The sediment transport results indicate that, within a majority of the model extent, a particle with a D_{50} between approximately 30 and 60 mm is potentially mobile during a 2-year flood (Appendix E). This critical grain size meets or exceeds the observed D_{50} of bedload sediment entering the reach from upstream, which has resulted in armoring of the channel bed through much of the lower reach, and subsequent deposition at the mouth within the estuary. What this means is that any sediment that passes the 1st Street Bridge is highly mobile and likely quickly transported through the lower creek and into the estuary.

Since the pipeline was uncovered in 1996, the armor rock just downstream of 1st Street has been replaced more than once as the headcut travelled upstream and undermined the rock (John Konovsky, personal communications, 2012). It appears that, since approximately 2000, the headcut has not travelled upstream of the rock and concrete mattress grade controls. The plunging of water across the boulders to the channel on the downstream side has continued to erode the bed locally, where a lowering of approximately 1.25 feet has been observed since 2001 (Appendix D). At the concrete mattress, the channel bed drops approximately 3.5 feet from the top of the concrete to the plunge pool and rock on the downstream side.

Removing the two grade controls is expected to result in local adjustment of the grade at these locations and may have the potential to migrate upstream. However, the upstream extent of potential effects is uncertain. As described within the results of the field reconnaissance, relatively resistant glacially compacted alluvium is first observed near Station 47+00, upstream of 7th Street. This resistant unit is likely located along the banks and bed upstream to Railroad Avenue and the confluence with Coffee Creek (based on review of topography and geology data), creating a relatively uniform and stable channel profile with

an average grade around 0.45%. Figure 7 shows the average grade of the resistant bed section, as well as the average grade of the lower channel of approximately 0.37%. If the channel were to adjust its profile on a reach scale, it is unlikely that the downcutting would occur upstream of Station 47+00, where the resistant unit would likely inhibit incision.

The supply of coarse bedload material entering the reach from upstream will likely have some impact on reducing the effects of channel incision. Multiple gravel bars and evidence of mobile bedload material were observed upstream of 1st Street, indicating that sediment is being received from upstream and is moving through the reach (Appendix B). Recent deposition of similar-sized sand and gravel near the channel mouth and within the estuary was also observed (Appendix A).

If this sediment supply were not present, hydraulic energy would be expended on the bed and the likelihood of incision would be increased. We believe that an ample bedload supply is present and will continue to be supplied from upstream. Therefore, future channel aggradation is expected over the long term. It is likely that aggradation will first be detectable near the mouth of the creek and out into the estuary. Some gravel and cobble materials can be observed in this area now, and we expect a broader distribution and a coarsening of materials over time.

The continued growth of the delta in the estuary will contribute to reduced instream velocities and shear stress. Deposition of bedload in the estuary is apparent from observation of the delta in historic aerial photos, as well as from visual observation of recent sand and gravel deposits during field reconnaissance. The results of the survey comparison indicate that the channel bed downstream of approximately Station 15+50 (Section 4) has lowered less than a foot over time (Appendix D). The slowed rate of change is likely, in part, because of the effects of channel lengthening and sediment deposition at the mouth of the creek.

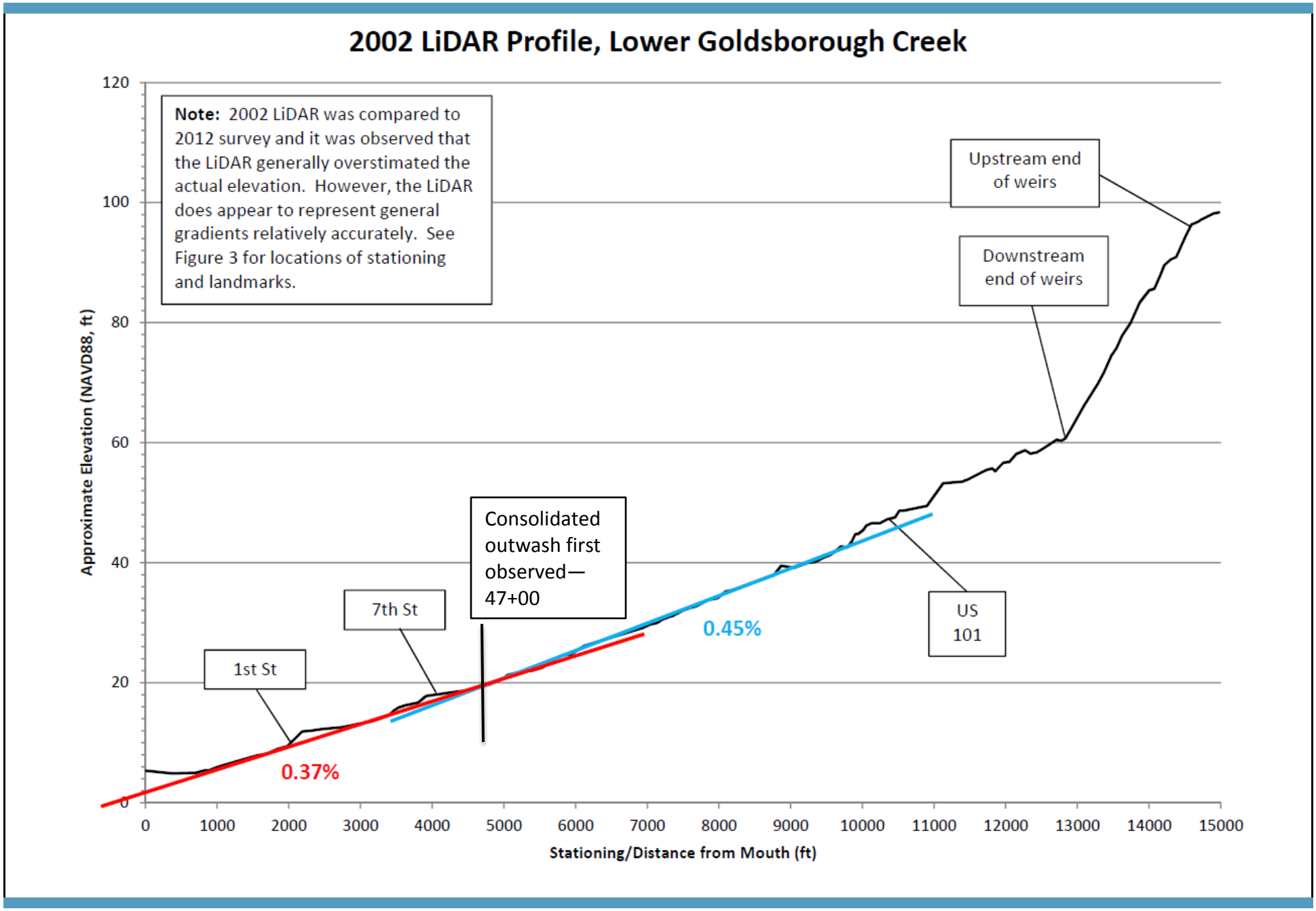


Figure 7
Potential Future Channel Adjustment in Lower Goldsborough Creek
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

ANCHOR QEA

4.5.1 Implications to Existing Infrastructure

As documented in Appendix A, multiple private bridges are located within the reach on the Simpson Timber Company property downstream of 1st Street. Upstream of 1st Street, major infrastructure includes one public and one private bridge crossing, a private rail crossing, municipal stormwater infrastructure, and private residences built adjacent to the creek (Appendix B). As shown in Figure 7, the potential extent of a headcut projected on a longitudinal profile intersects the average grade of the relatively stable and steeper reach just upstream of the 7th Street Bridge.

We conducted further evaluations of survey data and predicted slopes after channel adjustment to help understand the likely risks to the 1st Street Bridge after the existing pipelines and associated large rock are removed. The as-built drawings indicate that the face (base elevation) of the abutment is at approximately 1.8 feet NGVD 29. Two predicted channel slopes were evaluated and projected upstream to the bridge location. The projected slopes represent a likely grade adjustment under typical hydrologic conditions and a worst case scenario that may be expected if an extremely large flood event occurred in the first year after removal (Appendix D). The grade line estimate of the predicted bed adjustment under typical hydrologic conditions projects up to the bridge location near elevation 2.6 feet NGVD 29. Considering the more conservative estimated grade (worst case), the projected bed elevation at the bridge is 1.2 feet. The conservative estimate shows that the concrete of the abutment has the potential of being undermined; however, the piles are embedded at a sufficient depth (approximately 16 to 20 feet below grade) to protect the bridge against failure due to downcutting in the channel.

5 NEXT STEPS

We recognize that the Squaxin Island Tribe (SIT) is interested in removing the pipelines and associated large rock in the creek and in restoring the estuary and adjacent aquatic lands. Studies are currently underway to evaluate contamination cleanup and restoration in Oakland Bay and areas near to the mouth of the creek. It is important to note that care should be taken to ensure that cleanup efforts do not have temporary or longer term effects on the estuary or mouth of the creek. Specifically, the grade of the creek bed through the estuary/mud flats should not be lowered during or after cleanup and restoration activities. Furthermore, habitat benefits from restoration actions will be improved if the grade of previously dredged areas is increased in elevation to better reflect pre-dredging site conditions.

When considering pipeline removal and estuary restoration, several potential pathways forward could be chosen:

1. Monitoring to confirm existing trend—aggradation versus degradation
2. Cleanup and restoration of the estuary and adjacent aquatic lands first
3. Remove the pipelines in phases and monitor response between phases
4. Remove both pipelines in conjunction and monitor response

Monitoring to confirm existing trend would involve waiting 1 to 3 years or until the system has experienced one to three large flood events where sediment transport from the upper basin is certain. This would likely result in changed conditions at the mouth and the ability to document change. If the trend was aggradational, then the likelihood that pipeline removal would lead to infrastructure risk would be low. However, if the trend was still degradation (still incising) then restoration in the estuary would be recommended before removing the pipelines.

Cleanup and restoration of the estuary before pipeline removal would delay the pipeline removal and allow for specific restoration treatments to be placed that would maximize habitat benefit and help route and sort sediments currently stored upstream of 1st Street. Restoration treatments could include placing large wood or cobbles that would help hold grades and promote additional sediment retention near the mouth of the creek.

Removing the pipelines in phases would allow for monitoring of the channel response associated with the first removal. Under this scenario, we recommend removing the upstream pipeline first and allowing sediment currently stored upstream to transport through to the estuary. This will likely result in a lowering of the channel grade upstream of 1st Street for several hundred feet. Depending on the observed channel response, the downstream pipeline could be removed the following year or postponed until a suitable channel response has been observed.

Removing both pipelines in the same year adds an element of risk since the response of the channel is deterministically uncertain. While the worst case estimate of predicted bed elevations at the 1st Street Bridge suggests that there is little risk of total bridge failure, it is possible that temporary conditions could be worse than presented if headcuts associated with each pipeline removal combine at the bridge location. We believe this is unlikely and would be short lived if it did occur; however, it is a possible outcome.

The selected pathway forward will likely be a group decision among stakeholders. One potential choice that would likely meet stakeholder needs while limiting risks would be to implement some restoration treatments near the creek mouth, monitor the response to confirm that the creek and estuary are in a recovery tract (aggrading), remove the upstream pipeline and monitor the response, and remove the downstream pipeline and monitor the overall success of the project.

6 LIMITATIONS

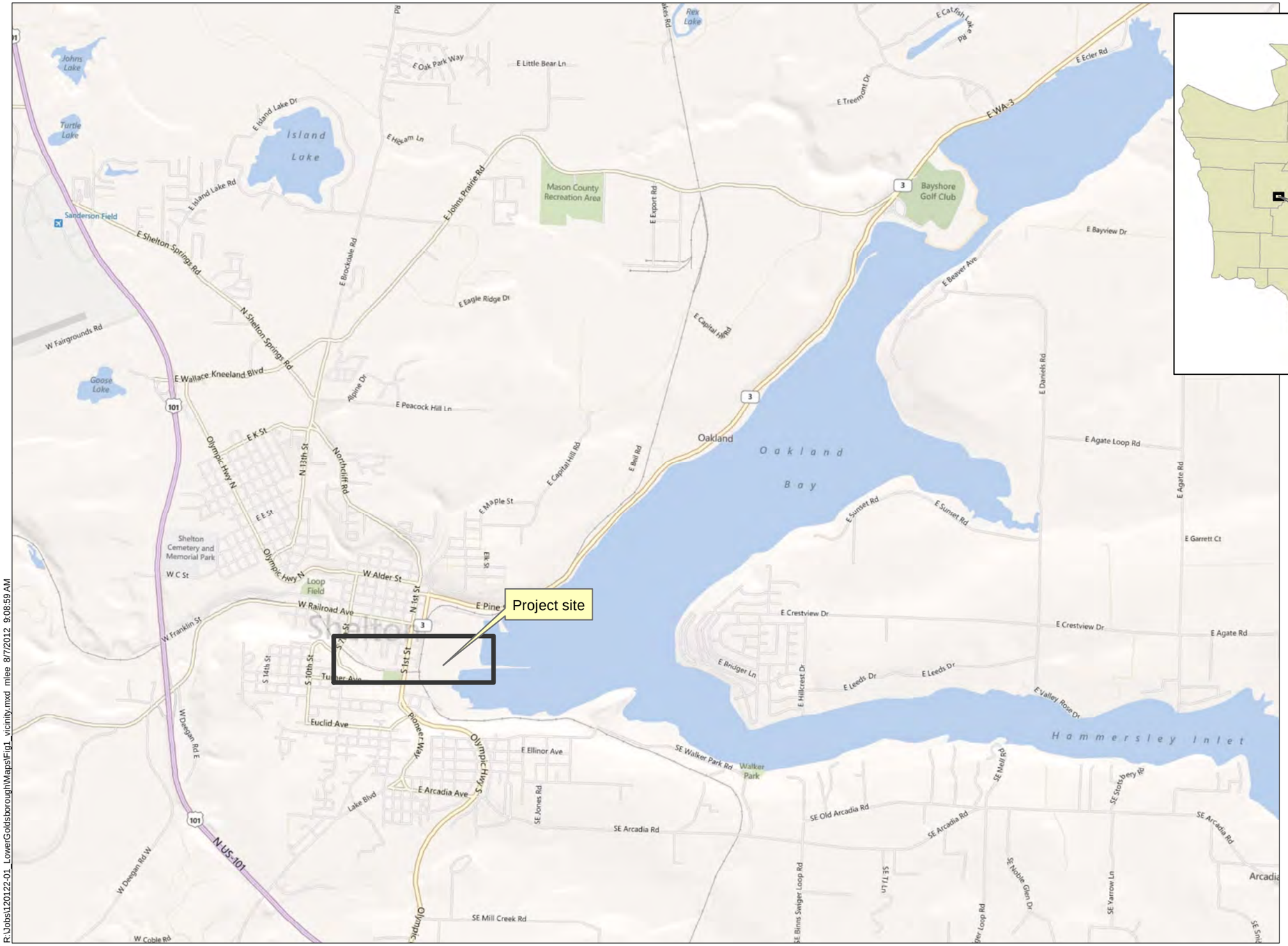
We have prepared this report for use by the SIT to evaluate geomorphic conditions in Lower Goldsborough Creek and to monitor morphological changes in the creek over time. The information presented in this report is based on available data and limited site reconnaissance at the time of report development. Conditions within the study reach may change both spatially and with time, and additional scientific data may become available. Significant changes in site conditions or the available information may require re-evaluation. Within the limitations of scope, schedule, and budget, our services have been executed in accordance with generally accepted scientific and engineering practices in this area at the time this report was prepared.

7 REFERENCES

Konovsky, J., 2012. Personal communication to Tracy Drury.

USACE (U.S. Army Corps of Engineers), 1999. *Goldsborough Creek Section 206 Restoration Project: Ecosystem Restoration Report and Environmental Assessment.* U.S. Army Corps of Engineers, Seattle District Hydraulics and Hydrology Section. July 1999.

FIGURES



NOTES:
Bing road map shown.

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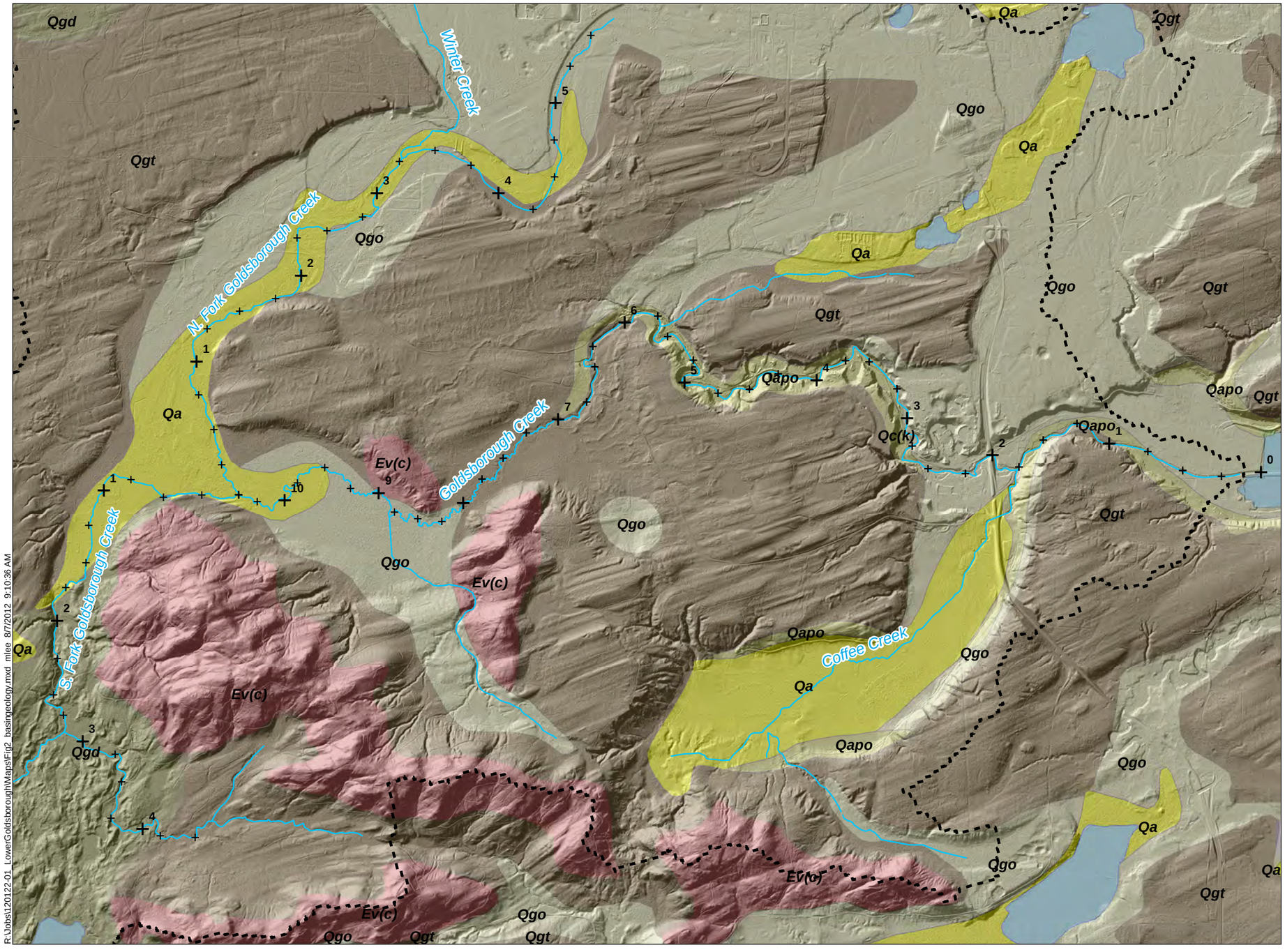
ANCHOR QEA

Figure 1
Vicinity Map
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe



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LEGEND

- River Miles (RM)
- Streams
- Approximate Watershed Boundary

Geologic Units

- Qa - alluvium, recent
- Qgo glacial advance outwash, Fraser-age
- Qgt - glacial till, Fraser-age
- Qga - glacial advance outwash, Fraser-age
- Qgd - glacial drift, Fraser-age
- Qapo and Qc(k) - glacial outwash (compacted), pre-Fraser age
- Ev(c) - volanic rocks/deposits, Eocene-age
- Water

NOTES:
WA DNR 1:100,000 scale geologic mapping and 2002 LiDAR hillshade shown. Watershed boundary may be inaccurate in relatively flat valleys and plateau areas.

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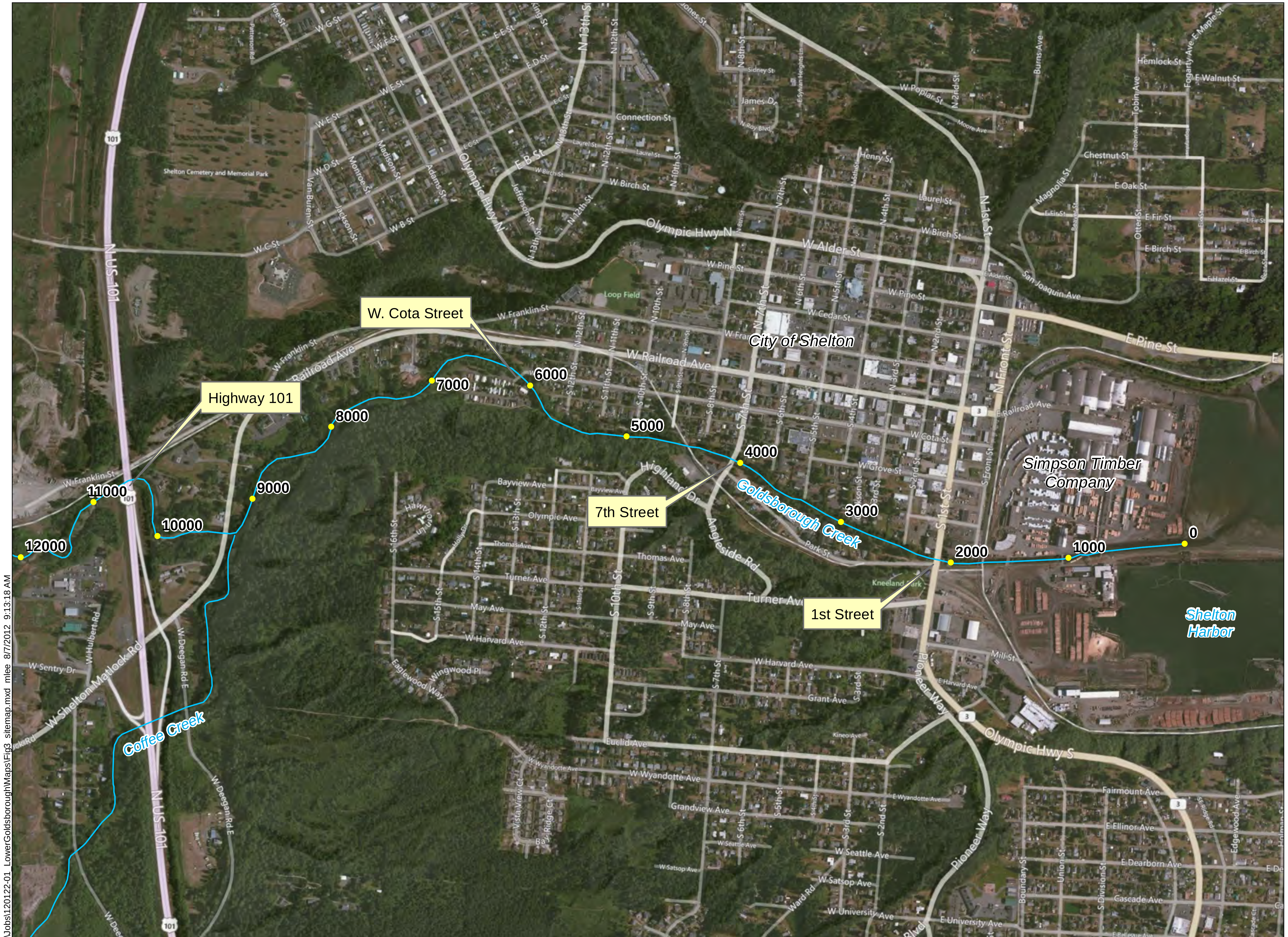
Figure 2
Goldsborough Creek Basin Surface Geologic Units
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe



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LEGEND

- Station points (1000 ft)
- Streams

NOTES:
Bing aerial and road map, and 2002 LiDAR hillshade shown.

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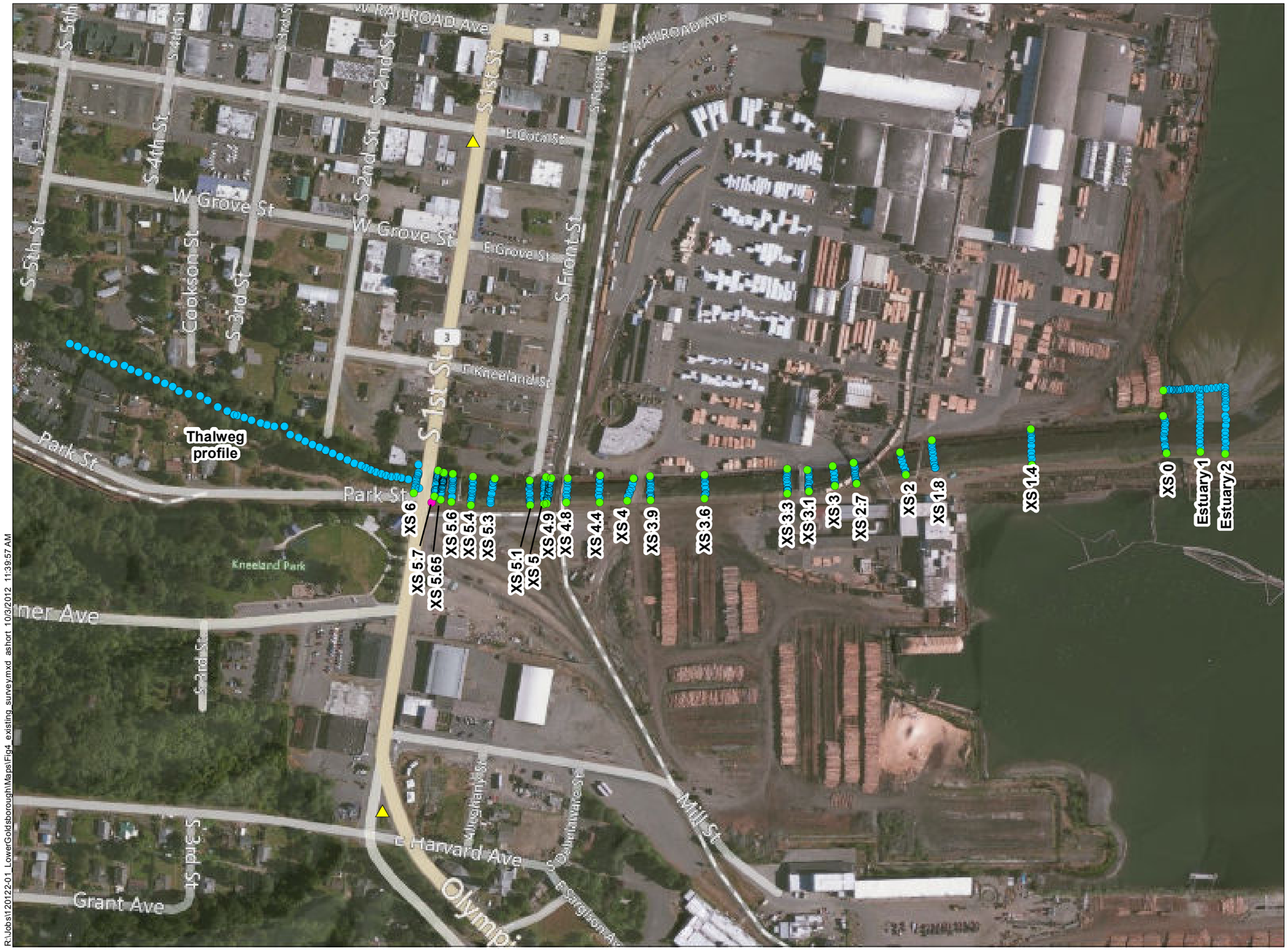
ANCHOR QEA

Figure 5
Lower Goldsborough Creek Project Site Map
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe



LEGEND

- 2012 Survey Points
- Project Control Point
- Hub
- Monument

NOTES:
Survey includes ground elevations as well as infrastructure (e.g., abutments, walls, piers). Bing aerial and road map, and 2002 LiDAR hillshade shown.

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Figure 6
2012 Survey Points and Cross-Sections
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

APPENDIX A
PHOTOGRAPH ATTACHMENT
LOWER GOLDSBOROUGH CREEK BELOW 1ST STREET

Notes: Stations referenced herein are approximate (see Figure 3 of main report). Photos are presented from upstream (the crossing at 1st Street) to the mouth. Reconnaissance was conducted on July 17, 2012 between 2:00 pm and 4:00 pm. Estimated average discharge at the nearest gage (above the 7th Street bridge) during this time was 72 cubic feet per second.

Photograph 1

Station 21+00, Small Gravel Bar Adjacent to Left Abutment of 1st Street Bridge

Photograph 2

Station 21+00, Underneath 1st Street Bridge Looking Upstream

Photograph 3

Large Angular Rock Placed at Exposed Pipe, Standing on 1st Street Bridge Looking Downstream

Photograph 4

Station 17+50 at Upper Dual Railroad Bridge

Photograph 5

Station 15+00, Upper Vehicle/Pedestrian Bridge Looking at Right Bank

Photograph 6

Station 15+00, Exposed Backfill Rock Behind Wooden Abutment/Pier Bank Underneath Upper Vehicle/Pedestrian Bridge

Photograph 7

Station 12+00, Looking Downstream Towards Pedestrian and Lower Vehicle Bridge

Photograph 8

Station 11+00, Exposed Wooden Pilings Beneath Concrete Piers Just Upstream of Lower Vehicle Bridge

Photograph 9
Station 10+50, Right Abutment/Piers at Lower Vehicle Bridge, Adjacent to Gravel Deposit

Photograph 10
Station 9+50, Right Side Abutment of Lower Railroad Bridge

Photograph 11

Station 9+00, Downstream Side of Middle Pier of Lower Railroad Bridge

Photograph 12

Station 8+50, Wooden Pilings Downstream of Lower Railroad Bridge

Photograph 13

The Channel at the Mouth from Station 0, Looking Upstream

Photograph 14

Sand Deposits Along Right Bank Railroad Spur at Mouth, Looking Downstream

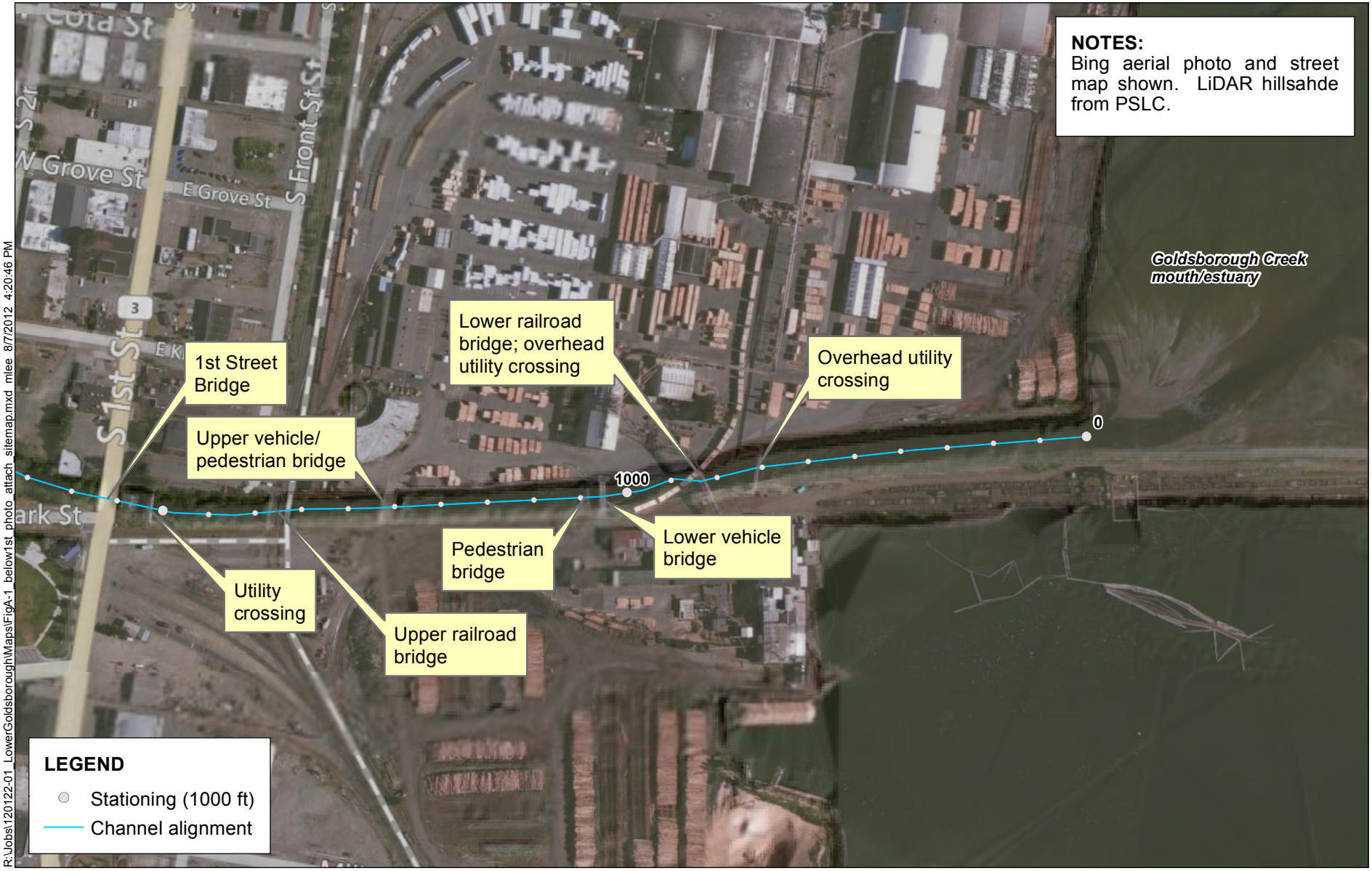
Photograph 15

Sand Deposits Along Right Bank Railroad Spur at Mouth, Looking Upstream

Photograph 16

Estuary Conditions at Low Tide, Looking Southeast

FIGURES



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Feet
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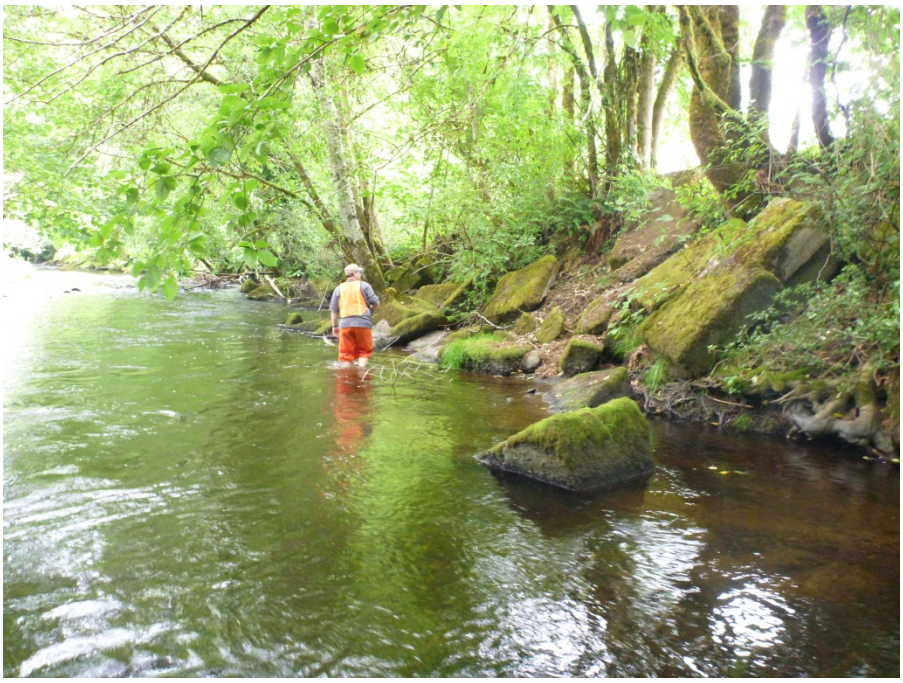
Figure A-1
Site Map of Lower Goldsborough Creek Reconaissance Area
Appendix A, Lower Goldsborough Site Assessment and Monitoring Plan
Squaxin Island Tribe

APPENDIX B
PHOTOGRAPH ATTACHMENT
LOWER GOLDSBOROUGH CREEK ABOVE 1ST STREET

Notes: Stations referenced herein are approximate. Photos are presented from upstream (West Cota Street) to Downstream (crossing at 1st Street). Reconnaissance conducted on July 17, 2012 between 2:00 pm and 4:00 pm. Estimated average discharge at the nearest gage (above the 7th Street bridge) during this time was 72 cubic feet per second.

Photograph 1

Station 59+50, Looking Downstream Near W. Cota Street Crossing



Photograph 2

Station 58+50, Looking Upstream at Armored Left Bank

Photograph 3

Station 58+00, Looking Upstream at Left Bank Gravel Bar

Photograph 4

Station 58+00, Typical Sediment Distribution of Bedload Surface Layer

Photograph 5

Station 55+00, Looking Upstream at Typical Channel Conditions Between Stations 48+00 and 56+00

Photograph 6

Typical Bed Composition, Right Bank and Portions of Left Bank Between Stations 58+00 and 49+00

Photograph 7

Station 51+00, Exposed Roots Along Left Bank; Residence in Background

Photograph 8

Station 49+00, Looking Upstream at Straight Channel Section;

Exposed Roots Along Left Bank and Residence in Background

Photograph 9

Near Station 50+00, Looking Downstream Towards Railroad Crossing

Photograph 10

Near Station 49+00, Compacted Sand and Gravels Typically Observed Within the Channel Upstream of this Location

Photograph 11

Gravel Bar on Right Bank at Station 48+00, Looking Upstream

Photograph 12

Station 47+00 Typical Sediment Distribution of Bedload Surface Layer

Photograph 13

Station 45+00 Gravel Bar and LWD in Channel at Railroad Crossing, Looking Upstream

Photograph 14

Station 45+00 Typical Sediment Distribution of Bedload Surface Layer

Photograph 15
Channel Conditions Between Railroad Crossing and Seventh Street (in background), Near Station 45+00, Looking Downstream

Photograph 16
Station 41+00, Rock Armor Placed Adjacent to Residences to Address Bank Erosion Occurring Near 7th Street Crossing, Looking Downstream

Photograph 17

Concrete Blocks Placed Beneath the 7th Street Crossing, Station 41+00, Looking Upstream

Photograph 18

Station 40+00, Undercutting Beneath Poured Concrete Bank Armoring Along the Left Bank Downstream of the 7th Street Crossing

Photograph 19

Station 39+00, Fallen Logs Forcing Scour Pools in the Channel, Looking Downstream; Residential Properties (Armored Bank) and 6th Street Park in Background

Photograph 20

Station 38+50, Bank Armoring Adjacent to Residences along the Left Bank, Looking Upstream

Photograph 21

Station 33+50, Mid-channel Gravel Bar and LWD, Looking Upstream

Photograph 22

Station 33+50 Typical Sediment Distribution of Bedload Surface Layer

Photograph 23

Station 33+00, Looking Downstream from the Mid-channel Gravel Bar in Photograph 22

Photograph 24

Station 30+00, Apartment Buildings Adjacent to the Right Bank;

Undercutting Observed at Toe of Bank

Photograph 25

Station 27+00, Undercutting Along Right Bank Adjacent to Residence

Photograph 26

Typical Sediment Distribution of Bedload Surface Layer, Small Gravel Bar near Station 25+00

Photograph 27

Station 24+00, Looking Downstream Towards 1st Street Bridge (in Background)

Photograph 28

Station 22+00, Bank Undercutting along the Left Bank Upstream of 1st Street Bridge

Photograph 29

Station 21+00, Looking Downstream From Beneath 1st Street Bridge Towards Shelton Harbor; Large Placed Rocks in Channel at Exposed Pipeline Crossing in Background

FIGURES

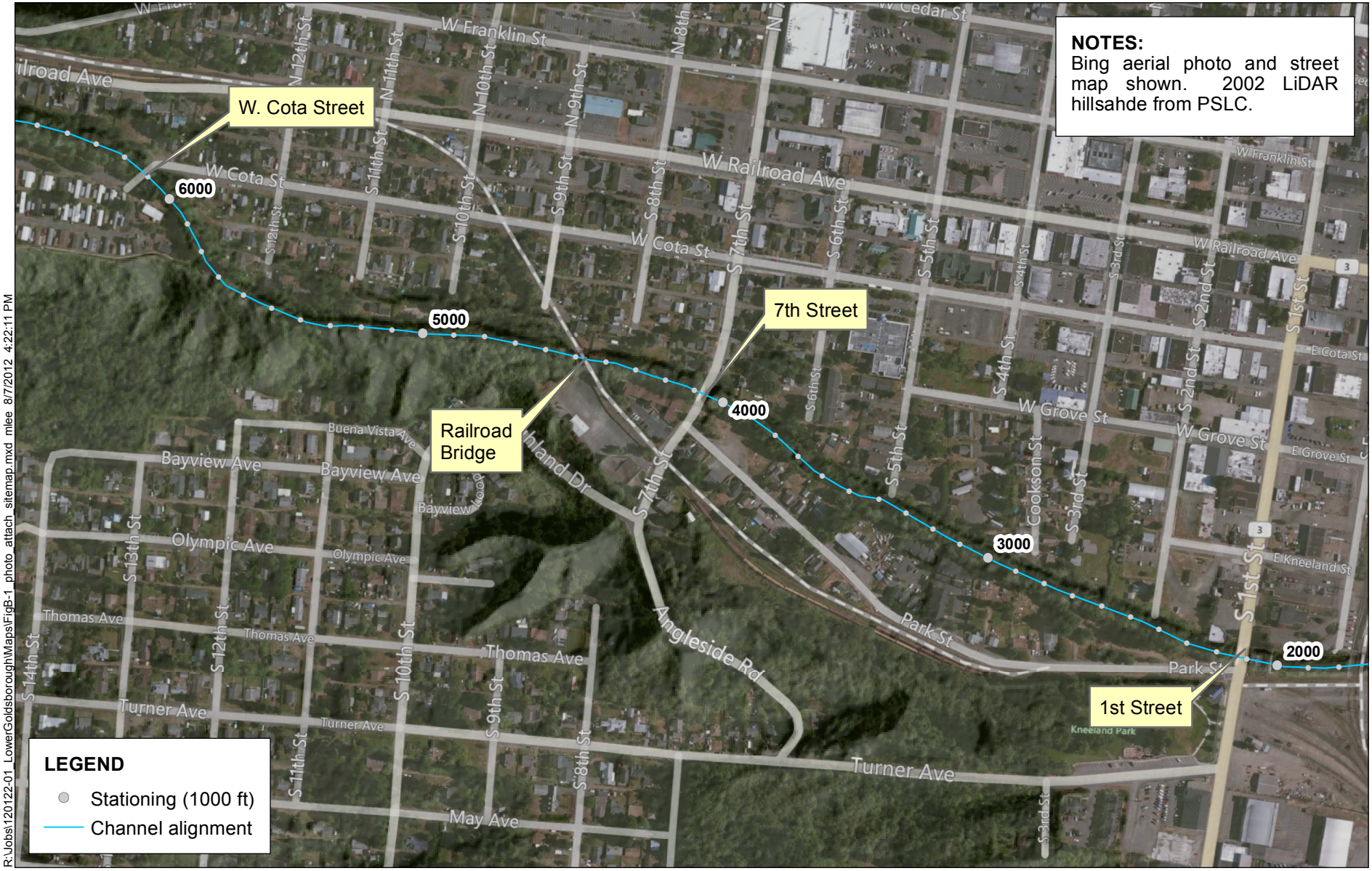


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Figure B-1
Site Map of Lower Goldsborough Creek Reconaissance Area
Appendix B, Lower Goldsborough Site Assessment and Monitoring Plan
Squaxin Island Tribe

APPENDIX C
SURVEY PLAN

C.1 INTRODUCTION

As part of the sediment monitoring program, Anchor QEA performed a survey of Lower Goldsborough Creek from just upstream of the 1st Street Bridge to the mouth of the creek. Historical sections were located from surveys performed in 1998 and 2001 by the U. S. Army Corps of Engineers (USACE) and were resurveyed to compare the channel bed over time. Additional sections were taken in the estuary to provide a baseline for future monitoring. A thalweg profile upstream of the 1st Street Bridge was also collected as part of the survey.

C.2 HISTORIC SURVEYS

In 1998 and 2001, the USACE obtained survey cross-sections from the 1st Street Bridge to approximately 125 feet upstream of the mouth of the creek. The data were translated into a Hydraulic Engineering Center-River Analysis (HEC-RAS) model to compare bed elevations and differing hydraulic conditions. The surveys were not georeferenced to a standard horizontal datum; rather, a project datum was used and notes were made at each section about the relative location of the cross-section along the channel. Several intermediate cross-sections were also interpolated for the purposes of the model – these cross-sections are essentially averaged topographic values between two real survey cross-sections.

C.3 2012 SURVEY

Survey data was collected by Anchor QEA on July 16 and 17, 2012 in Lower Goldsborough Creek from just upstream of the 1st Street Bridge to the mouth of the creek. A majority of the existing survey cross-sections were replicated for 2012 conditions. Additional cross-sections were added to create a refined hydraulic model and to capture potential bed elevation changes in the future.

Two Washington State Department of Transportation (WSDOT) monuments were located and used as benchmarks to tie into a real-world coordinate system (Table C-1). An existing control point next to the utility box on the southeast end of the 1st Street Bridge was shot and primarily used as a common backsight location in staking out other control points. All project control points are shown in Table C-2 and Figure C-1. These monuments and control points can be used in future monitoring efforts to locate surveyed cross-sections.

Table C-1
WSDOT Monument Locations

WSDOT Monument ID	Northing (USFt)	Easting (USFt)	Elevation (NAD 83)	Location
3206	695731.364	994257.126	16.926	Southwest quadrant of the intersection of State Route 3 and Cota Street, south edge of wheelchair ramp
3205	693833.730	993993.950	36.152	Westerly curb of landscaped traffic island at the intersection of State Route 3 and Harvard Street and Pioneer Way

Note:
USFt = NAD 83 Feet Washington State Plane Zone South

Table C-2
Project Control Points

Control Point ID	Northing (USFt)	Easting (USFt)	Elevation (NAD 83)	Elevation (NGVD 29)
100	694706.4366	994137.3051	17.97	14.52
101	694703.9607	994156.5694	17.89	14.44
102	694707.3234	994454.1023	16.61	13.17
103	694698.6524	994303.3567	16.39	12.94

Control Point ID	Northing (USFt)	Easting (USFt)	Elevation (NAD 83)	Elevation (NGVD 29)
104	694710.2066	994689.6354	16.56	13.12
105	694727.8844	995110.0869	15.85	12.40
106	694822.3366	995380.3654	15.88	12.43
107	694797.1113	995561.8498	11.58	8.14
108	694958.7105	996384.8801	1.93	-1.52
109	694750.3169	994090.2037	14.67	11.22

Note:
USFt = NAD 83 Feet Washington State Plane Zone South

Once control points were shot and recorded in the instrument, approximate locations of historical cross-sections were determined by descriptions and reach lengths from surveys. A hub was pounded into the ground with a PK nail and on the left and right top banks of the channel at the cross-section locations. Starting from the hub, cross-sections were surveyed perpendicular to the direction of flow. Shots were taken along the bank, toe, and within the channel. This process was continued at each defined cross-section until reaching the mouth of Lower Goldsborough Creek.

After reaching the mouth, control point 108 was shot on driftwood with a PK nail located in the center of the estuary. The instrument was then set up on that control point to shoot the points in the estuary. A hub was pounded into the ground on the northerly armored bank in the estuary to align the east-west alignment, and two L-shaped cross-sections were surveyed. The north-south alignment of cross-section Estuary 1 was lined up with the western support beam of the Simpson crane, while the north-south alignment of Estuary 2 was lined up with control point 108. Hubs were placed at the southern end of both L-shaped cross-sections. The instrument was then moved back to control point 100 and a control point was set to shoot the thalweg profile upstream of the 1st Street Bridge.

The instrument was setup at control point 109, which was an existing PK nail located on a large rock in the riprap next to the creek. A thalweg profile was taken upstream of the 1st Street Bridge. Survey points were taken approximately every 15 to 20 feet along the channel to just downstream of the gravel bar located at station 34+00.

C.4 FUTURE SURVEY PLAN

Future monitoring of Lower Goldsborough Creek will help in determining the impacts to the channel grade due to the removal of the gravity pipeline. The survey conducted in 2012 was tied into a real world coordinate system so that the defined cross-sections can be resurveyed in the future and have exact data comparisons. The 2012 survey should serve as a baseline for future comparison of the channel grade.

The 2012 survey data can be exported to a total station survey instrument prior to going out in the field to resurvey the cross-sections. Once in the field, the locations of cross-sections can be staked out using the northing and easting of the hubs. Cross-sections can then be taken perpendicular to flow along the bank, toe, and within the channel. The data can then be compared with past surveys to determine the condition of the channel bed; additionally, a visual photograph comparison can be used.

The photographs in Appendix A/Photograph Attachment Below 1st Street can be used as a guide for visually comparing channel bed elevations at piers and bridge abutments. As part of the future survey, photographs should be taken at approximately the same locations as the 2012 photographs. This can provide a rough estimate of changes to the channel bed.

FIGURES

LEGEND

- Control Point
- Monument

NOTES:
Bing aerial and road map, and 2002 LiDAR hillshade shown.

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Figure C-1
2012 Survey Monuments and Control Points
Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

APPENDIX D
COMPARISON OF RECENT AND HISTORIC CHANNEL SURVEYS

1 COMPARSION OF CROSS-SECTIONS

The following figures and tables display overlaid cross-section survey data of all sections between 1st Street and the Goldsborough Creek mouth that were duplicated over at least two separate survey years. The spatial accuracy of the correlated 1971 to 2001 sections is unknown as these survey locations were not tied into a known horizontal datum. The locations of the duplicated cross-sections during the 2012 survey effort were positioned according to the descriptive notes and reach lengths provided in the U.S. Army Corps of Engineers (USACE) 1998 and 2002 survey and HEC-RAS hydraulic model. Therefore, some cross-sections may be several feet upstream or downstream from the original location; some error is inherent in these results. Upon comparison of the results and best professional judgment, for the purposes of this evaluation it is assumed that the surveyed cross-sections are in similar locations throughout the survey years. The sources of the survey data are shown in Table D-1.

Table D-1
Survey Data Sources

Survey Year	Collected By	Study
1971	USACE	City of Shelton Flood Insurance Study (1983)
1998	USACE	Hydraulic Assessment (1999)
2001	USACE	Hydraulic Assessment (2001)
2012	Anchor QEA	See Appendix A

Notes: A dash symbol indicates no survey were obtained during that year.

The survey results were translated into a relative stationing to allow the cross-sections and channel profile to be overlaid across the survey years; these plots are shown in Figures D-1a and D-1b. Table 2 compares the minimum channel elevations at each duplicated section for the years 1971 through 2012 where applicable.

Table D-2
Minimum Elevation of Duplicated Survey Cross-sections (feet)

Section	Approx. Station	Location	Minimum Channel Elev. (NGVD 29, feet)				Difference in Channel Elev. (feet)					
			1971 (FIS)	1998 (USACE)	2001 (USACE)	2012 (AQ)	1971 – 2012	1971 – 1998	1971 – 2001	1998 – 2001	1998 – 2012	2001 – 2012
Estuary 2	-160	L-shaped section, downstream of mouth on delta	-	-	-	0.13	-	-	-	-	-	-
Estuary 1	-90	L-shaped section, downstream of mouth on delta; at crane	-	-	-	0.54	-	-	-	-	-	-
0	0	Downstream extent of armored banks at mouth	-	-	-	0.03	-	-	-	-	-	-
1	130	Approx. 130 feet from mouth	-0.5	-2.96	-4.25	-	-	-2.46	-3.75	-1.29	-	-
1.4	390	Approx. halfway between overhead utility crossing and mouth	-	-	-	-2.48	-	-	-	-	-	-
1.8	680	Just downtream of overhead utility crossing	-	-	-	-1.52	-	-	-	-	-	-
2	760	Just upstream of overhead utility crossing	1.1	-0.47	-1.2	-1.35	-2.45	-1.57	-2.3	-0.73	-0.88	-0.15
2.7	900	Just upstream of lower railroad bridge pier	-	-	-	-1.61	-	-	-	-	-	-
3	960	Halfway between lower vehicle and lower railroad bridge pier	2.5	-1.07	-	-0.85	-3.35	-3.57	-	-	0.22	-
3.1	1030	Just downtream of lower vehicle bridge	-	-	-	-1.63	-	-	-	-	-	-
3.3	1100	Just upstream of lower vehicle bridge and pedestrian walkway	-	-	-	-0.05	-	-	-	-	-	-
3.6	1320	Approx. halfway between upper and lower vehicle bridges	-	-	-	-0.02	-	-	-	-	-	-
3.9	1480	Just downstream of upper vehicle bridge	-	-	-	-0.24	-	-	-	-	-	-
4	1530	Just upstream of upper vehicle bridge	3.9	1.41	1.36	0.7	-3.2	-2.49	-2.54	-	-0.71	-
4.4	1620	Approx. halfway between upper railroad and upper vehicle bridge	-	-	-	0.43	-	-	-	-	-	-
4.8	1710	Just downstream of upper railroad bridge	-	-	-	0.01	-	-	-	-	-	-
4.9	1770	Just upstream of upper railroad bridge on downstream side of concrete mattress (plunge pool).	-	-	-	-0.78	-	-	-	-	-	-
5	1780	Just upstream of upper railroad bridge atop concrete mattress.	4.7	2.37	-	2.56	-2.14	-2.33	-	-	0.19	-
5.1	1820	Upstream of upper railroad bridge on upstream side of concrete mattress.	-	-	-	2.14	-	-	-	-	-	-
5.3	1930	Approx. halfway between 1st Street and upper railroad bridges.	-	-	-	2.69	-	-	-	-	-	-
5.4	1990	Just downstream of raised pipeline crossing.	-	-	-	2.69	-	-	-	-	-	-
5.6	2040	Just upstream of raised pipeline crossing on downstream side of rocks.	-	-	2.21	1.03	-	-	-	-	-	-1.18
5.65	2070	Downstream side of rocks (plunge pool).	-	-	-	2.82	-	-		-	-	-
5.7	2090	Just downstream of 1st Street Bridge on upstream side of rocks.	-	-	5.6	4.52	-	-	-	-	-	-1.08
6	2150	Just upstream of 1st Street Bridge *(note: 2001 bed elevation was adjusted in model from 1998 section)*	5.5	4.25	-	3.38	-2.12	-1.25	-	-	-0.87	-

Notes: A dash symbol indicates no survey were obtained during that year.

Table D-3 summarizes the greatest amount of elevation change at each section between 1971 and 2012. Note that some sections do not contain data over all four years. The greatest change over this time period occurred between the upper railroad crossing (Section 5) and near the mouth (Section 1).

Table D-3
Elevation Change at Minimum Elevation Point, All Survey Years (feet)

Section	Difference (feet)
1	-3.75
2	-2.45
3	-3.35
4	-3.20
5	-2.14
5.6	-
5.7	-
6	-2.12

Table D-4 summarizes the elevation change at each section over the three recent survey years between 1998 and 2012. Only two sections were repeated across these three datasets, which limits the ability to observe trends in downcutting or aggradation between the survey years and in different areas of the channel. At Section 2, the rate of downcutting slowed between 2001 and 2012. At Section 4, the rate of downcutting increased between 2001 and 2012. However, the results at both locations are within the error of the cross-section positioning.

Table D-4
Difference in Minimum Elevation Point, Selected Survey Years (feet)

Section	1998 to 2012	1998 to 2001	2001 to 2012	Note
1	-	-1.29	-	2012 not surveyed
2	-0.88	-0.73	-0.15	
3	+0.22	-	-	2001 not surveyed
4	-0.71	-0.05	-0.66	
5	-0.19	-	-	2001 not surveyed
5.6	-	-	-1.18	1998 not surveyed
5.7	-	-	-2.12	1998 not surveyed
6	-0.87	-	-	2001 not surveyed

Notes: A dash symbol indicates no survey data were obtained during that year.

The overall results of this comparison are inconclusive because the 2012 cross-sections could not be positioned at the same locations as those in historic surveys. As discussed in Appendix E, future surveys should be horizontally positioned to the same datum and positioned between the hubs set during the recent survey collection. Future years of survey in these locations will yield the best conclusions regarding bed elevation change over time.

2 COMPARISON OF AS-BUILT AND SURVEY DATA

A comparison of as-built drawing to the survey data collected in 2012 was used to evaluate possible infrastructure impacts associated with removing the pipeline and large angular rock. The 1st Street Bridge as-built drawing, as seen in Figure D-2, shows that the elevation of the face of the abutment is 16.5 feet below the top of the railing. The vertical datum of this drawing is unknown, but a monument located on the northwest railing states that the elevation is 18.343 feet National Geodectic Vertical Datum of 1929 (NGVD 29). Subtracting 16.5 feet from the elevation of the monument on the top of the railing gives the elevation of the face of the abutment as approximately 1.8 feet NGVD 29. To analyze impacts of a grade adjustment to the 1st Street Bridge, the longitudinal profile shown in Figure D-3 was used to estimate the adjusted elevation of the channel bed at the face of the abutment.

Two slopes were projected from the mouth to the 1st Street Bridge to estimate two possible adjusted elevations of the channel bed at the face of the abutment. The section surveyed at the mouth of the river, Section 0, could be considered stable since it has adjusted to the removal of the railroad ferry dock, and will likely not be significantly affected by what adjustments occur upstream. Since this section is considered a stable section, the two slopes were projected from Section 0 to just upstream of the 1st Street Bridge. A conservative estimate of the possible channel bed adjustment was determined by projecting a slope from Section 0 using low points of Sections 3.6 and 5.6. A less conservative slope was projected by ignoring the low points of Sections 4.9 and 5.6 since these low points were created by high energy at the large angular rock and concrete apron. The longitudinal profile and projected slopes are shown in Figure D-2.

The conservative estimate of the projected slope of the bed adjustment is approximately 0.22%, giving a predicted bed elevation at the 1st Street Bridge of approximately 1.2 feet NGVD 29. The less conservative estimate of the projected slope of the bed adjustment is approximately 0.29%, giving a predicted bed elevation at the 1st Street Bridge of approximately 2.6 feet NGVD 29. Given the abutment elevation of 1.8 feet NGVD 29, the abutment could be undercut if the channel adjusts to the conservative slope. The abutment would not be undercut if the channel adjusts to the less conservative slope. The average pile elevation of the south abutment is -19.3 feet, while the north pilings have an average elevation of -14.7 feet.

FIGURES

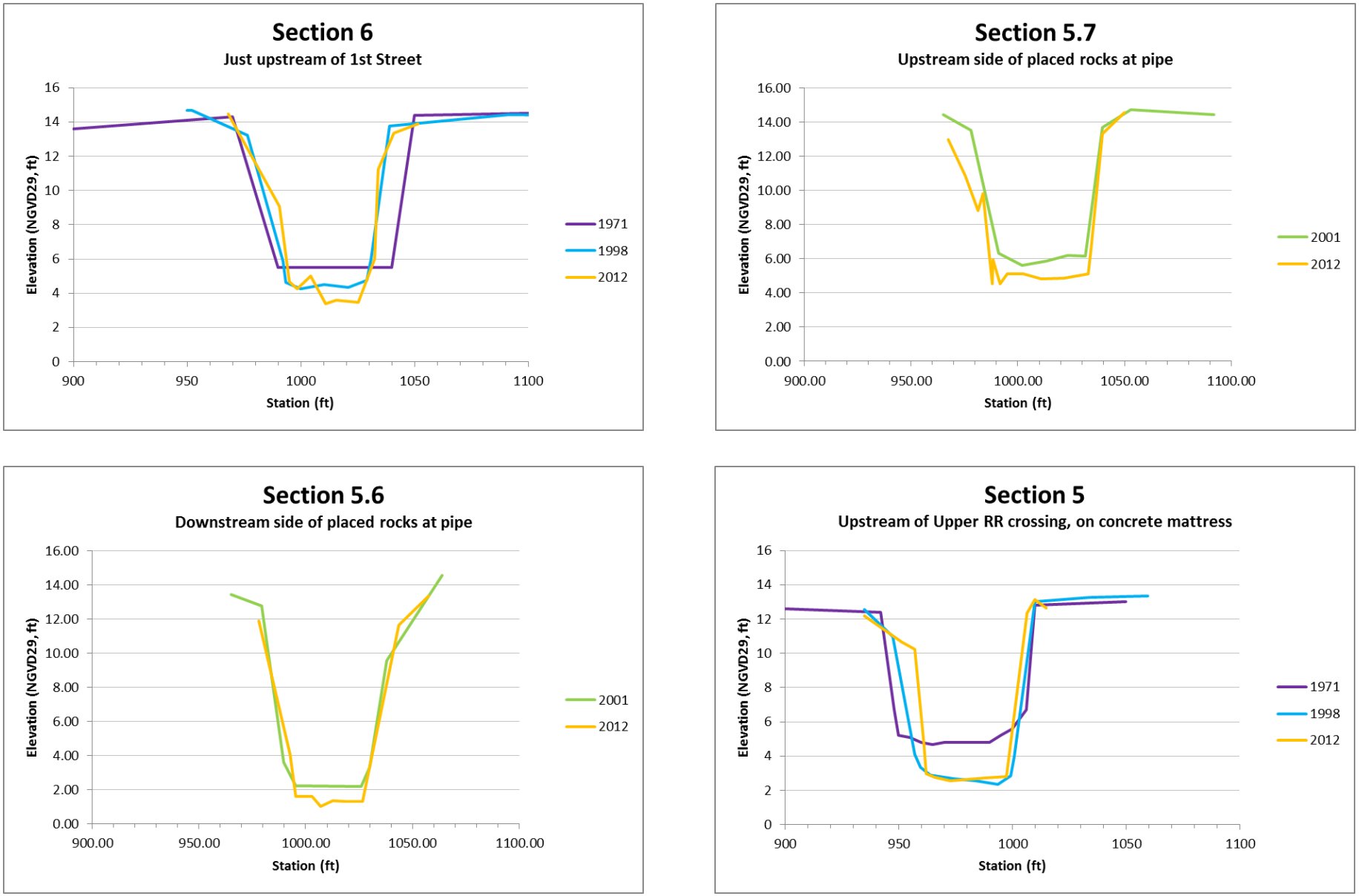

Figure D-1a
Comparison of Duplicated Survey Cross-Sections
Appendix D, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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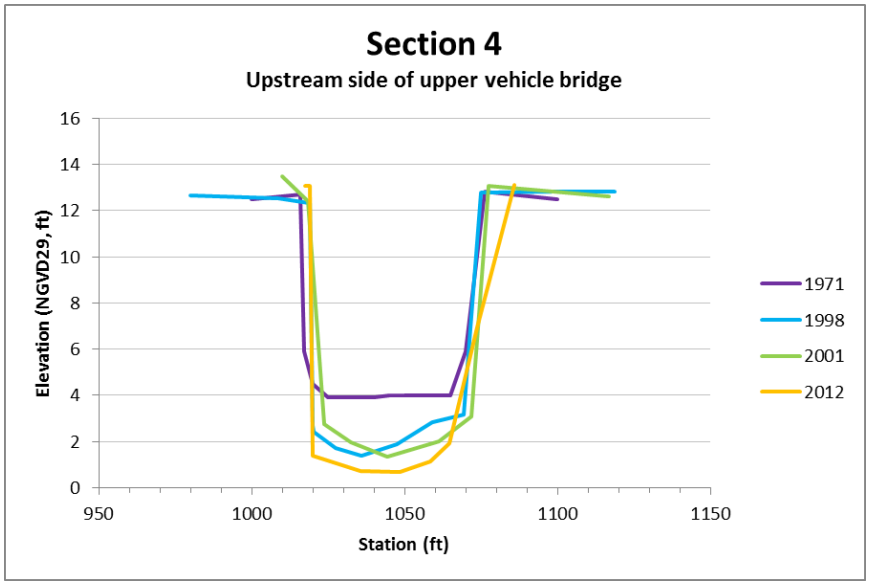

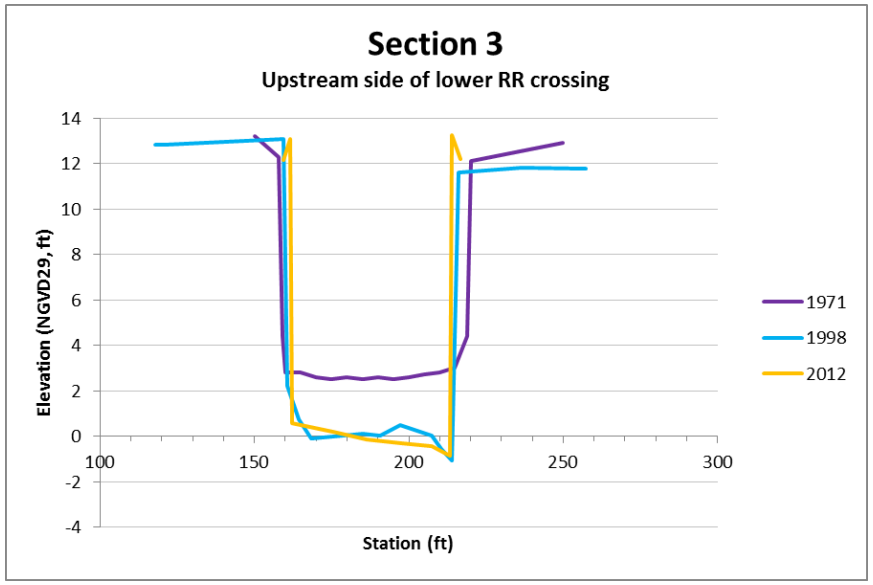

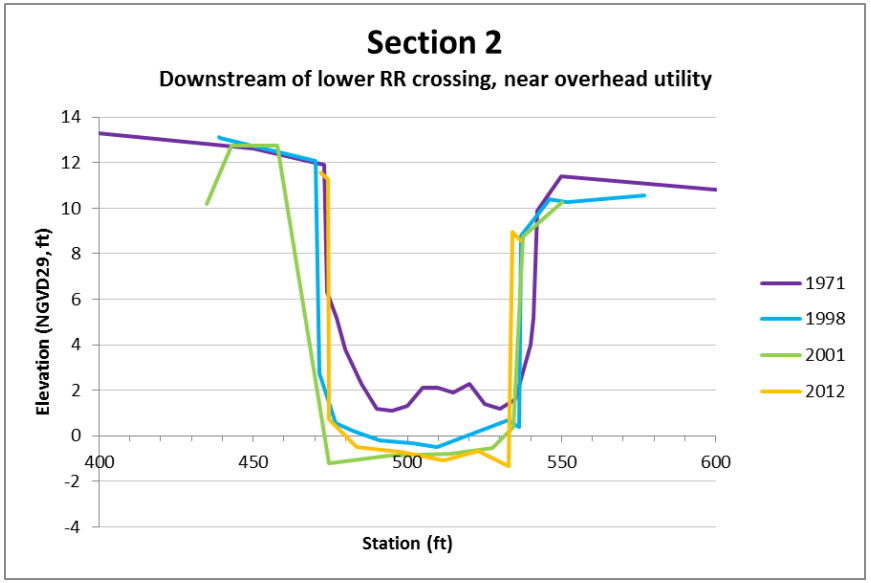

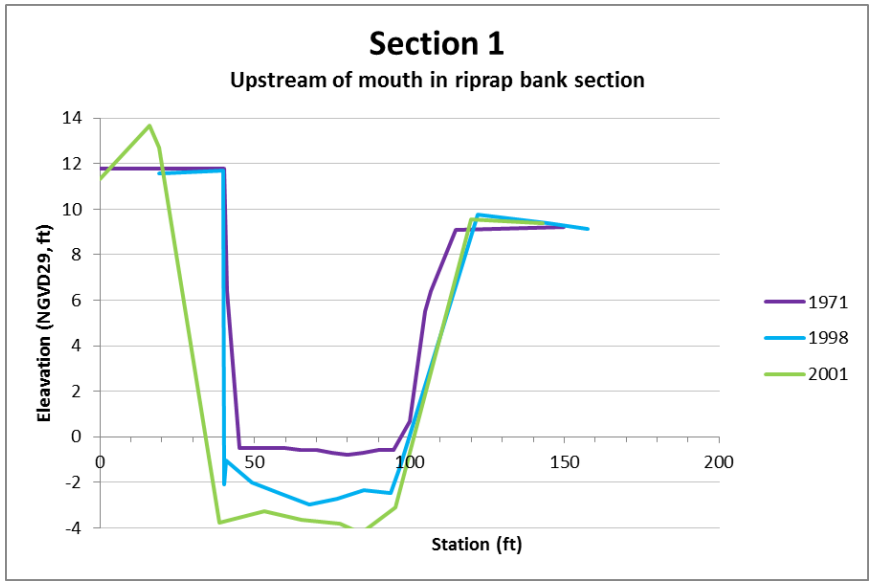

Figure D-1b
Comparison of Duplicated Survey Cross-Sections
Appendix D, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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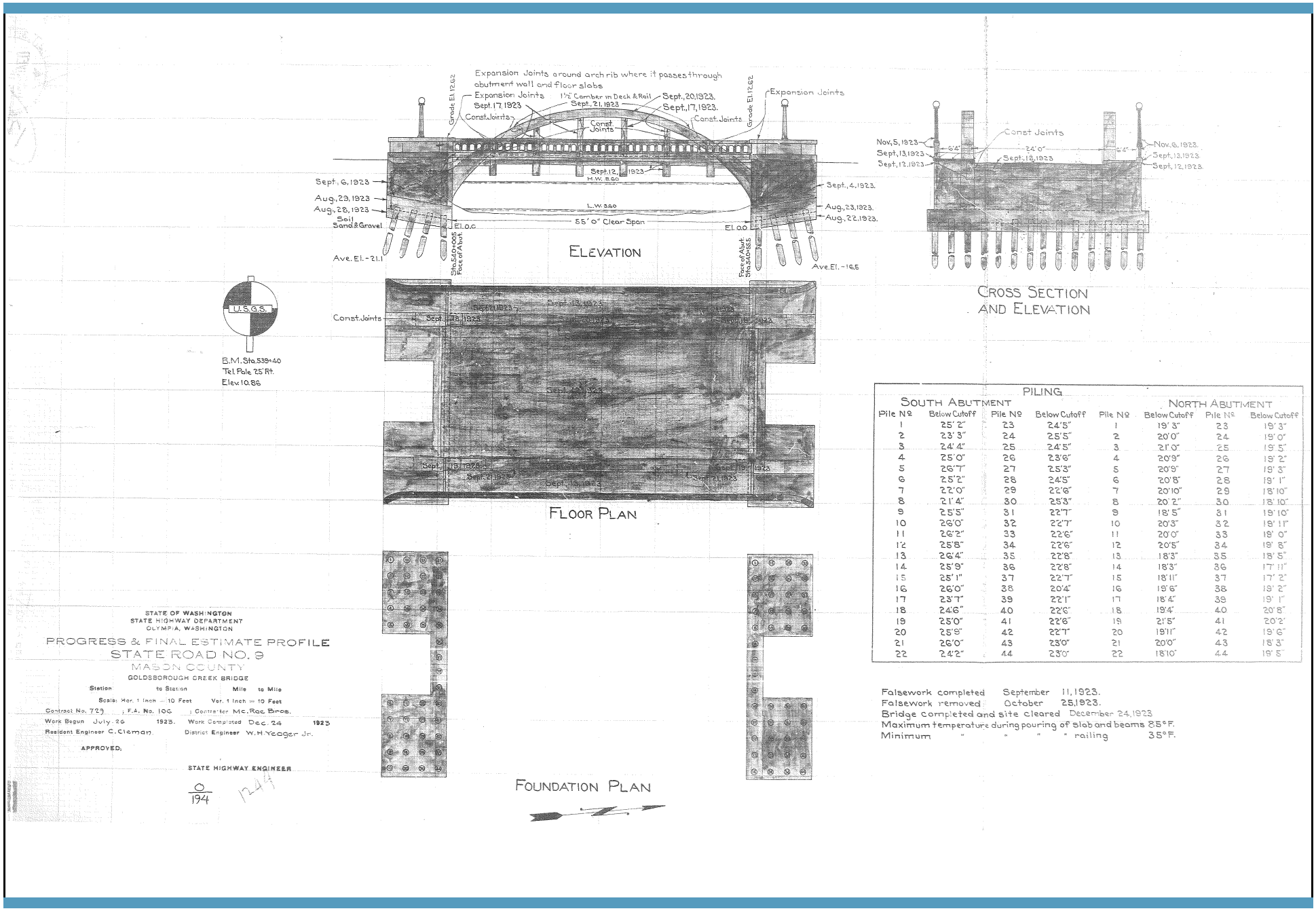

PILING

South Abutment				North Abutment			
Pile Nº	Below Cutoff	Pile Nº	Below Cutoff	Pile Nº	Below Cutoff	Pile Nº	Below Cutoff
1	25' 2"	23	24'5"	1	19' 3"	23	19' 3"
2	23' 3"	24	25'5"	2	20'0"	24	19' 0"
3	24' 4"	25	24'5"	3	21'0"	25	19' 5"
4	25'0"	26	23'6"	4	20'9"	26	19' 2"
5	26'7"	27	25'3"	5	20'9"	27	19' 3"
6	25'2"	28	24'5"	6	20'8"	28	19' 1"
7	22'0"	29	22'6"	7	20'10"	29	18'10"
8	21' 4"	30	25'3"	8	20' 2"	30	18'10"
9	25'5"	31	22'7"	9	18' 5"	31	19'10"
10	26'0"	32	22'7"	10	20'3"	32	19' 11"
11	26'2"	33	22'6"	11	20'0"	33	18' 0"
12	25'8"	34	22'6"	12	20'5"	34	19' 8"
13	26'4"	35	22'8"	13	18'3"	35	18' 5"
14	25'9"	36	22'8"	14	18'3"	36	17' 11"
15	25' 1"	37	22'7"	15	18'11"	37	17' 2"
16	26'0"	38	20'4"	16	19'6"	38	19' 2"
17	23'7"	39	22'1"	17	18'4"	39	19' 1"
18	24'6"	40	22'6"	18	19'4"	40	20'8"
19	25'0"	41	22'6"	19	21'5"	41	20'2"
20	25'5"	42	22'7"	20	19'11"	42	19'6"
21	26'0"	43	23'0"	21	20'0"	43	18' 3"
22	24'2"	44	23'0"	22	18'10"	44	19' 5"

Falsework completed September 11, 1923.
Falsework removed October 25, 1923.
Bridge completed and site cleared December 24, 1923
Maximum temperature during pouring of slab and beams 85°F.
Minimum " " " " railing 35°F.

Figure D-2
As-built Drawing of 1st Street Bridge
Appendix D, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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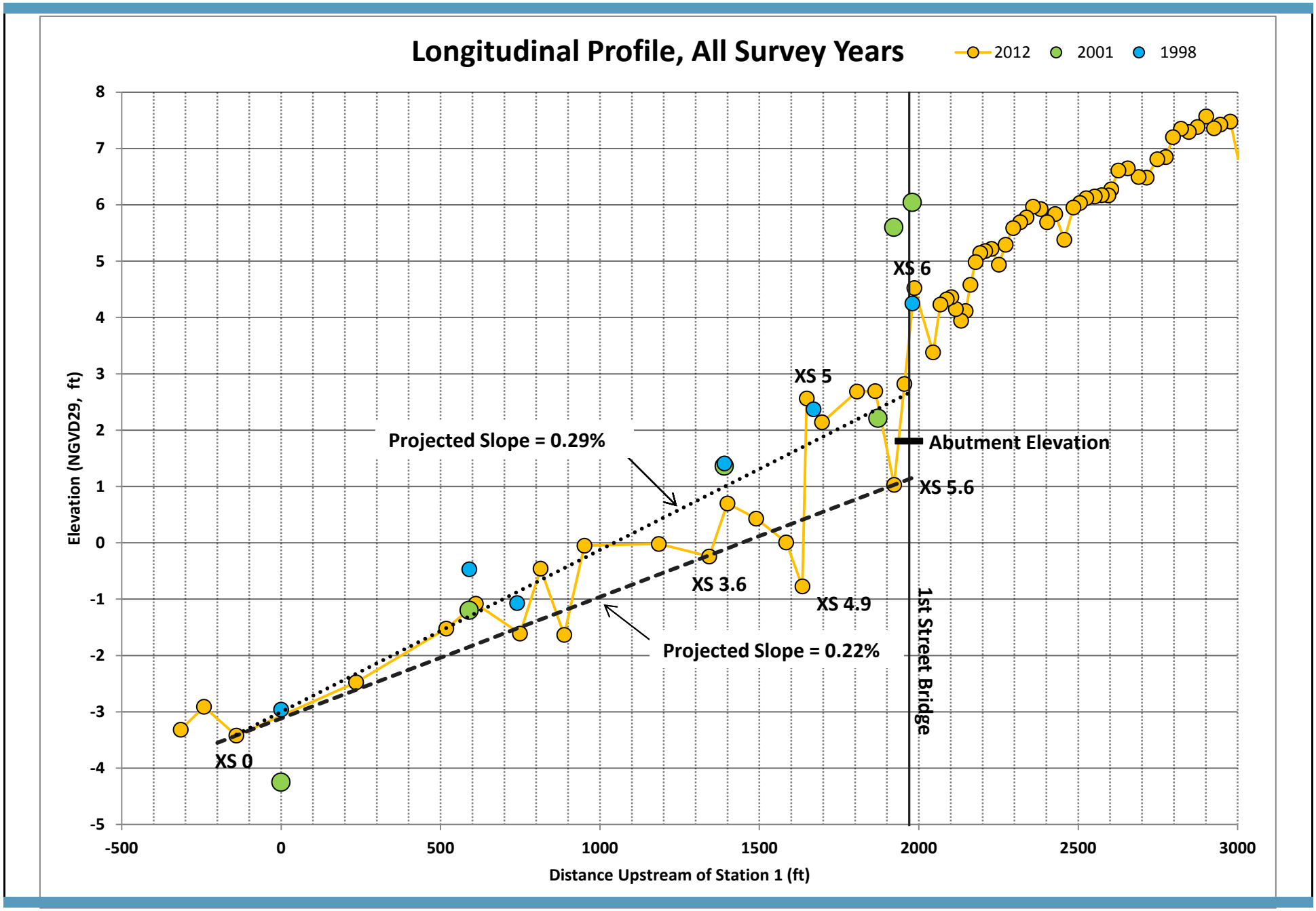

Figure D-3
Comparison of Surveyed Longitudinal Profiles (1998 to 2012)
Appendix D, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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APPENDIX E
HYDRAULIC AND SEDIMENT TRANSPORT EVALUATION

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LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
1-D	one dimensional
cfs	cubic feet per second
D50	median sediment grain size by mass
HEC-RAS	Hydraulic Engineering Center – River Analysis System
kg/m3	kilograms per cubic meter
m	meter
mm	millimeters
m/s2	meters per second squared
N/m2	Newton per square meter
USGS	U.S. Geological Survey

E.1 HYDRAULIC MODEL DEVELOPMENT

A reach-based, one-dimensional (1-D) Hydraulic Engineering Center-River Analysis System (HEC-RAS) hydraulic model (Brunner 2010a, 2010b) was developed for the Lower Goldsborough Reach to provide estimates of hydraulic conditions for existing conditions based on the survey performed by Anchor QEA on July 16 and 17, 2012. The model was run for the hydrology presented in Section E.1.1 to provide a thorough understanding of hydraulic conditions over a wide range of discharges.

E.1.1 Model Hydrology

Hydrology for the Lower Goldsborough Reach was developed for peak flow events (floods). The Lower Goldsborough Reach is located downstream of U.S. Geological Survey (USGS) Gage No. 12076800 (Goldsborough Creek above 7th Street at Shelton, Washington). This gage only has five years of data, so a peak flow frequency analysis (WRC 1981) was performed on historical USGS Gage No. 12076500 (Goldsborough Creek near Shelton), which has been discontinued. USGS Gage No. 12076500 has 27 years of record (1952 to 1979). The results of the peak flow frequency analysis were then scaled using the USGS basin scaling method (USGS 2001) as shown in equation E-1.

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^x \qquad \text{(E-1)}$$

where:

Q_u = the peak discharge, in cubic feet per second (cfs), at the ungaged site for a specific interval

Q_g = the weighted peak discharge, in cfs, at the gaged site for a specific interval

A_u = the contributing drainage area, in square miles, at the ungaged site

A_g = the contributing drainage area, in square miles, at the gaged site

x = the exponent for the region in which both sites are located (0.98 for Region 2)

The basin scaling method is valid when the ungaged site is within 50% and 150% of the gaged site. The basin area of USGS Gage No. 12076500 is 39.3 square miles, and the basin area of the Lower Goldsborough reach is approximately 60.4 square miles. The Lower

Goldsborough drainage area is 153% of the gaged drainage area. While this falls outside the limits of the basin scaling equation, the flows computed using the equation appear to be representative of the Goldsborough Creek watershed based on engineering judgment.

The results of the peak flow frequency analysis and basin scaling for all return periods performed on USGS Gage No. 12706500 are presented in Table E-1.

Table E-1
Peak Flow Frequency Analysis and Basin Scaling Results for USGS Gage No. 12706500

Return Period (years)	Flow at Station 12076500 Goldsborough Creek near Shelton (cfs)	Flow at Lower Goldsborough (cfs)
1	287	437
2	806	1228
10	1294	1972
25	1529	2330
50	1700	2591
100	1867	2845

E.1.2 Hydraulic Model Geometry

Hydraulic model geometry was developed to simulate the existing hydraulic conditions within the Lower Goldsborough Reach. The upstream extent of the model is just upstream of the 1st Street Bridge, and the downstream extent is the mouth of Lower Goldsborough Creek. The model provided estimates of hydraulic conditions, including water surface elevations, flow velocities, and channel bed shear stress. These estimates were used to develop a baseline for comparison with future surveys and models.

The HEC-RAS cross-section station elevation data was taken from the survey performed by Anchor QEA on July 16 and 17, 2012 (refer to Appendix C for survey plan). To georeference the cross-sections in the model, the survey points were traced to get transects in ESRI ArcGIS®, exported using HEC-GeoRAS (Ackerman 2011), and imported into the 1-D HEC-RAS model. Channel and floodplain Manning's n-value (roughness values) used in the 1998 and 2001 HEC-RAS models were used for the 2012 conditions model. The Manning's n-

value used for the channel is 0.04 in the entire reach except for a few locations. The n-value at the section just upstream of the 1st Street Bridge is 0.055, and the n-values from the downstream edge of the bridge through the line of rocks is 0.065. The Manning's n-value for overbank areas is 0.05 for the entire reach.

The cross-section located at the upstream edge of the 1st Street Bridge (cross-section 6) was duplicated upstream and the elevation adjusted based on the surveyed thalweg profile. This was done to allow the upstream extent of the model to be extended past the survey limit, which helped to smooth out the model at cross-section 6. The line of rocks located just downstream of the 1st Street Bridge were surveyed by Anchor QEA (cross-section 5.65). To represent the channel roughness and elevation drop within the riprap, additional model cross-sections were needed downstream of surveyed cross-section 5.65. Two duplicate cross-sections of 5.65 were created, one placed 5 feet downstream (cross-section 5.63) and one placed 6 feet downstream (cross-section 5.62) of cross-section 5.65. The station-elevation data of cross-section 5.63 was not modified. The elevation drop within the riprap was represented by lowering the elevation within the channel 2 feet in cross-section 5.62.

Downstream of the rock structure, the survey station-elevation data was not modified and no cross-sections were duplicated. Throughout the entire model, the bank stations in the cross-sections were placed at the toe of the slope so that an accurate representation of the shear stresses and other sediment transport parameters could be obtained.

E.2 SEDIMENT TRANSPORT ANALYSIS

The sediment mobility and transport competency within the Lower Goldsborough Reach area was calculated using the results of the HEC-RAS 1-D hydraulic model and applicable sediment mobility formulas. The critical grain size was calculated and evaluated for existing conditions.

E.2.1 Observed Average Grain Sizes

A field reconnaissance was performed upstream of the 1st Street Bridge. Multiple gravel bars were observed between approximately Stations 34+00 and 58+00 that appeared to be representative of typical bedload grain size distribution in Lower Goldsborough Creek. Figures E-1 through E-3 display a 1-inch grid approximately overlaid on a reference scale. The estimated D_{50} in the observed reach was between ½ to 1½ inches or about 13 to 38 millimeters (mm). The coarsest D_{50} was observed at the mid-channel gravel bar near Station 34+00 (see Appendix B).

E.2.2 Sediment Transport Methodology

To evaluate sediment transport competency in Lower Goldsborough Creek for existing conditions, the threshold sediment grain size was compared to the observed sediment grain size distribution. The results of the transport calculations were used to evaluate potential geomorphological changes to the stream.

E.2.2.1 Threshold Sediment Grain Size

The threshold (or critical) sediment grain size is the grain size that is just mobile under given hydraulic forces. This analysis used the dimensionless critical shear stress concept (Shields 1936) to define the mobility threshold for sediment grains exposed to the force of flowing water. The approach uses the following relationship between critical grain size (D_c) and critical dimensionless shear stress (τ^*_c):

$$\tau^*{}_c = \frac{\tau}{(\rho_s - \rho) g D_c} \qquad \text{(E-2)}$$

where:

τ^*_c	=	critical dimensionless shear stress
τ	=	bed shear stress (Newton per square meter [N/m^2])
ρ_s	=	sediment grain density (kilograms per cubic meter [kg/m^3])
ρ	=	water density (kg/m^3)
g	=	gravitational acceleration (meters per second squared [m/s^2])
D_c	=	critical grain size (meter [m])

For this evaluation, a critical dimensionless shear stress (τ^*_c) of 0.050 was used. This value is valid for critical grain sizes in the cobble-size range (Fischenich 2001).

The results of the threshold sediment grain size calculations were used to evaluate the existing conditions and potential geomorphological changes to the channel. Results from calculations were compared with the observed bedload grain size distribution for evaluation.

E.2.3 Sediment Transport Results and Analysis

To analyze the potential geomorphological changes in the channel, the critical grain size was calculated for all return periods. The results of these analyses are shown in Figures E-4 to E-9 and Table E-2.

The following analysis of the sediment transport results will concentrate on the 2-year return period. The 2-year return period is considered to be channel forming, and it can be assumed that active bedload transport is occurring throughout the reach. As seen in Figure E-5, the largest critical grain sizes are seen at the upstream end of the Lower Goldsborough Reach. The maximum critical grain size for the reach is 284 mm (11.2 inches) at cross-section 5.7 (Station 20+76) just downstream of the 1st Street Bridge. This cross-section is between the edge of the bridge and the buried pipeline just upstream of the riprap. Higher shear stresses are occurring across the channel bed before plunging over the riprap, resulting in a larger critical grain size. Large critical grain sizes can also be seen at the cross-sections through the riprap structure.

There is a concrete apron located at cross-section 5, just upstream of the dual railroad bridge. Modeling results show that the water surface reaches critical depth at this location. This results in high shear stress across the channel bed and a large critical grain size. For the 2-year flow, the critical grain size at cross-section 5 (Station 17+65) is 190 mm (7.5 inches). Field observations showed that the concrete apron was free of sediment, which verifies the sediment transport results.

Downstream of the concrete apron, the critical grain sizes for the 2-year return period are fairly consistent, varying between 34 mm (1.3 inches) and 64.5 mm (2.5 inches).

Table E-2

Critical Grain Size, $\tau^*_c = 0.05$

Project Stationing	HEC-RAS Stationing	1-year RP (mm)	2-year RP (mm)	10-year RP (mm)	25-year RP (mm)	50-year RP (mm)	100-year RP (mm)
0	0.0	24	43	64	63	67	71
379	1.0	28	50	72	70	75	78
659	1.8	21	41	62	62	67	72
747	2.0	25	48	73	74	79	85
886	2.7	18	39	61	62	67	72
946	3.0	35	64	97	98	105	113
1018	3.1	17	36	56	57	61	66
1079	3.3	31	57	84	84	90	96
1312	3.6	25	55	86	88	95	102
1467	3.9	21	45	70	71	77	82
1521	4.0	26	51	76	75	80	85
1609	4.4	29	56	85	85	91	96
1703	4.8	16	35	55	56	60	64
1754	4.9	13	34	57	59	65	70
1766	5.0	122	190	256	247	260	269
1808	5.1	26	48	70	68	72	75
1915	5.3	29	46	62	59	62	64
1973	5.4	33	63	88	85	89	91
2029	5.6	29	76	119	119	127	134
2052	5.6	34	82	125	125	132	139
2053	5.6	148	169	209	195	200	204
2058	5.7	121	161	203	190	196	201
2077	5.7	275	284	317	282	281	278
2131	6.0	44	112	177	179	191	200

Note:
RP = return period

E.3 REFERENCES

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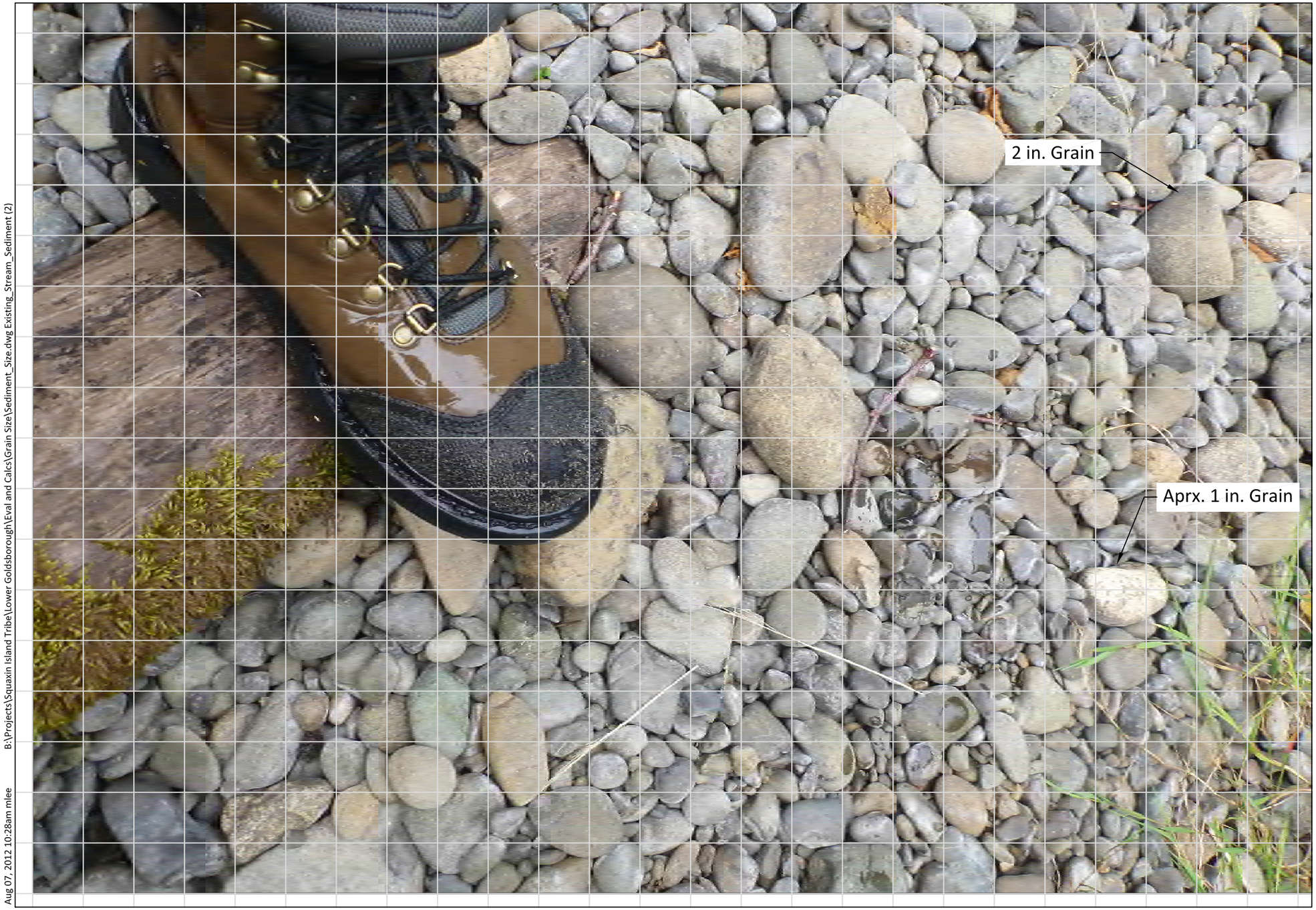
FIGURES



SOURCE: Drawing prepared from photograph of existing streambed sediment in Lower Goldsborough Creek (07/17/2012).

NOTES:
Photograph scale determined by shoe dimensions used for reference.
Grid overlay is 1 inch squares.

Aug 07, 2012 10:28am mlee B:\Projects\Squaxin Island Tribe\Lower Goldsborough\Eval and Calcs\Grain Size\Sediment_Size.dwg Existing_Stream_Sediment (2)

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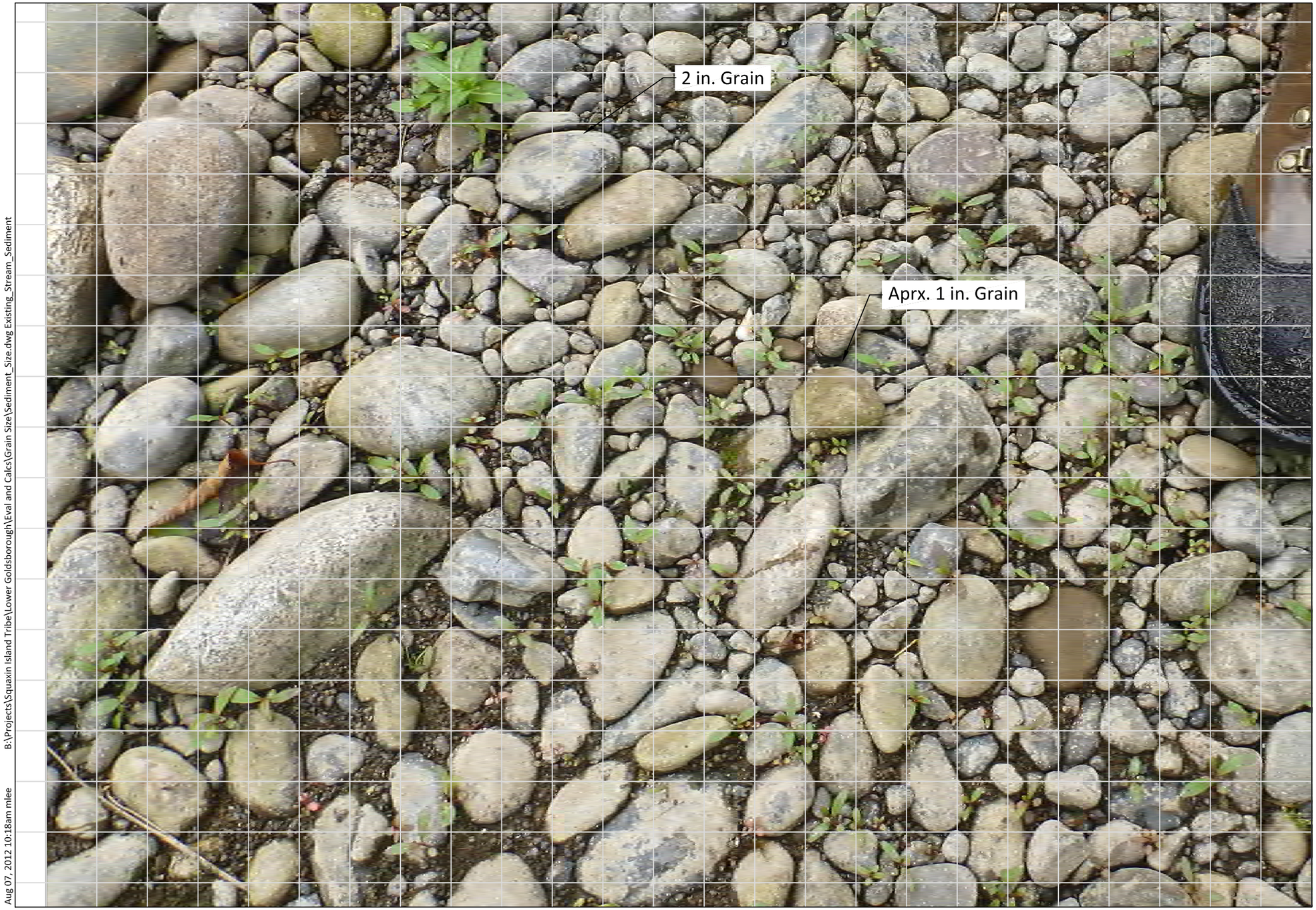
Figure E-1
Existing Stream Sediment, Near Station 5800
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe



SOURCE: Drawing prepared from photograph of existing streambed sediment in Lower Goldsborough Creek (07/17/2012).

NOTES:
Photograph scale determined by shoe dimensions used for reference.
Grid overlay is 1 inch squares.

0 2
Scale in Inches

Aug 07, 2012 10:18am mlee B:\Projects\Squaxin Island Tribe\Lower Goldsborough\Eval and Calcs\Grain Size\Sediment_Size.dwg Existing_Stream_Sediment

ANCHOR QEA

Figure E-2
Existing Stream Sediment, Near Station 4500
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

SOURCE: Drawing prepared from photograph of existing streambed sediment in Lower Goldsborough Creek (07/17/2012).

NOTES:
Photograph scale determined by shoe dimensions used for reference.
Grid overlay is 1 inch squares.

0 2
Scale in Inches

Aug 07, 2012 10:38am mlee B:\Projects\Squaxin Island Tribe\Lower Goldsborough\Eval and Calcs\Grain Size\Sediment_Size.dwg Existing_Stream_Sediment (3)

ANCHOR QEA

Figure E-3
Existing Stream Sediment, Near Station 3350
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

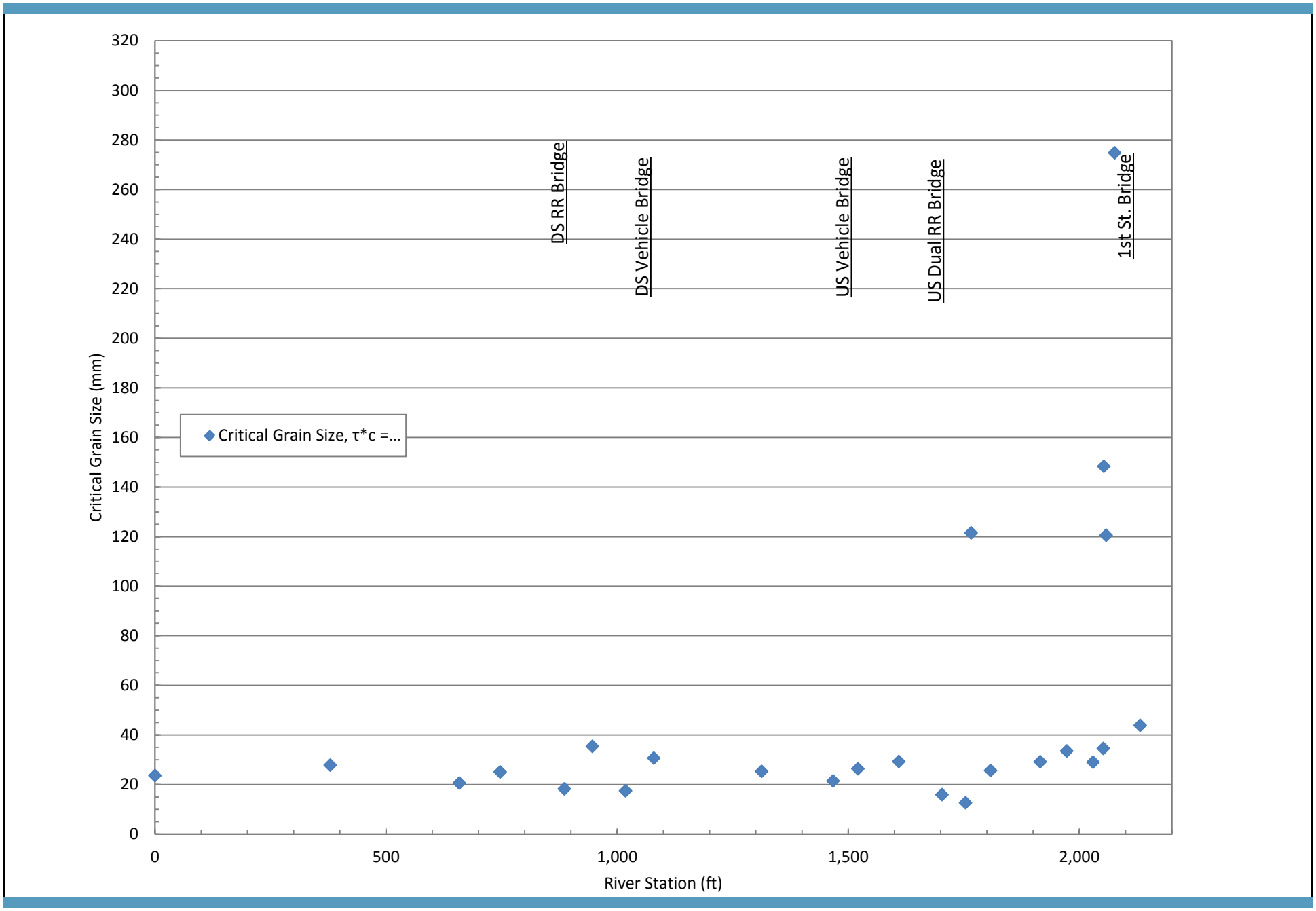


Figure E-4
Critical Grain Size for a 1-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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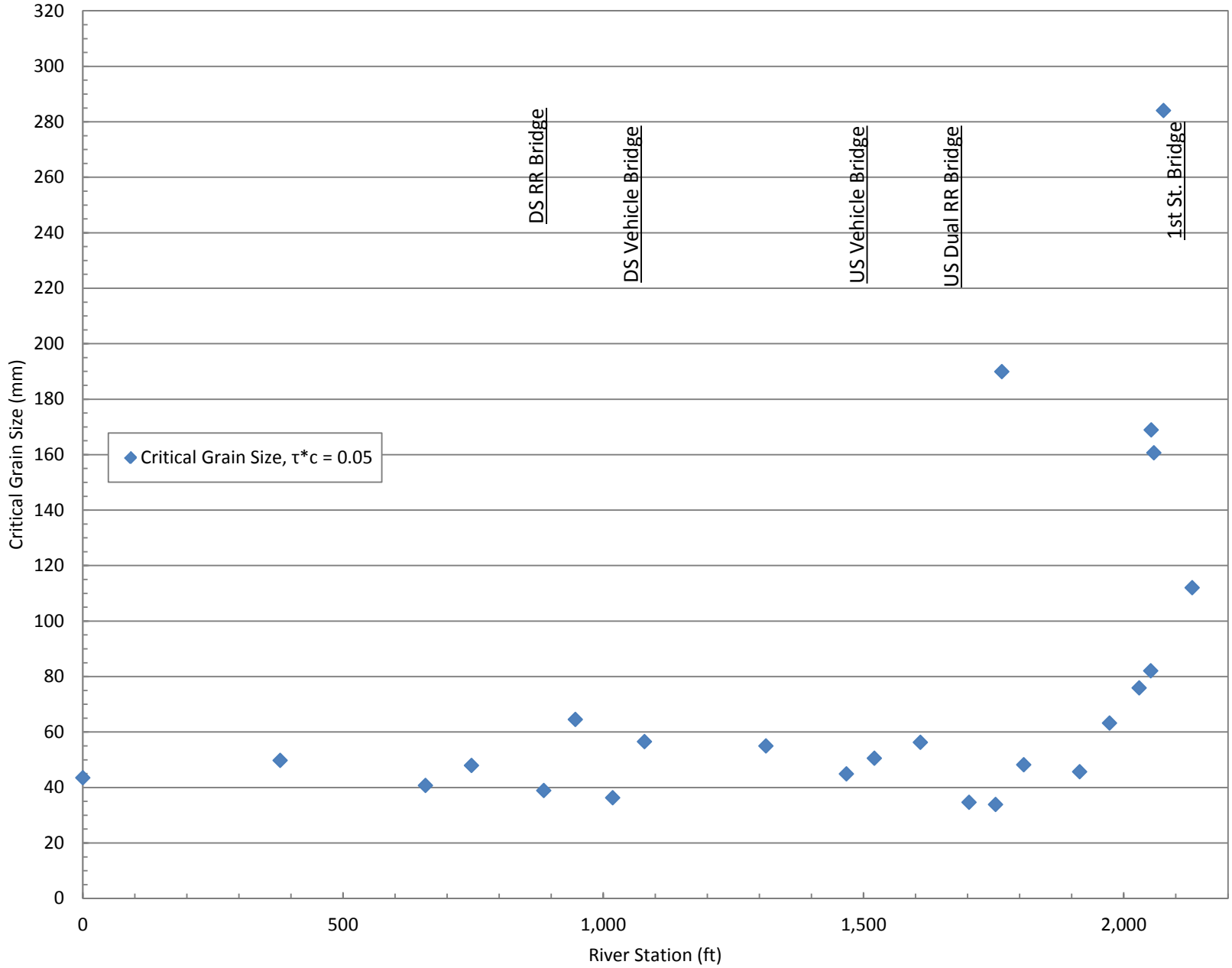

Figure E-5
Critical Grain Size for a 2-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

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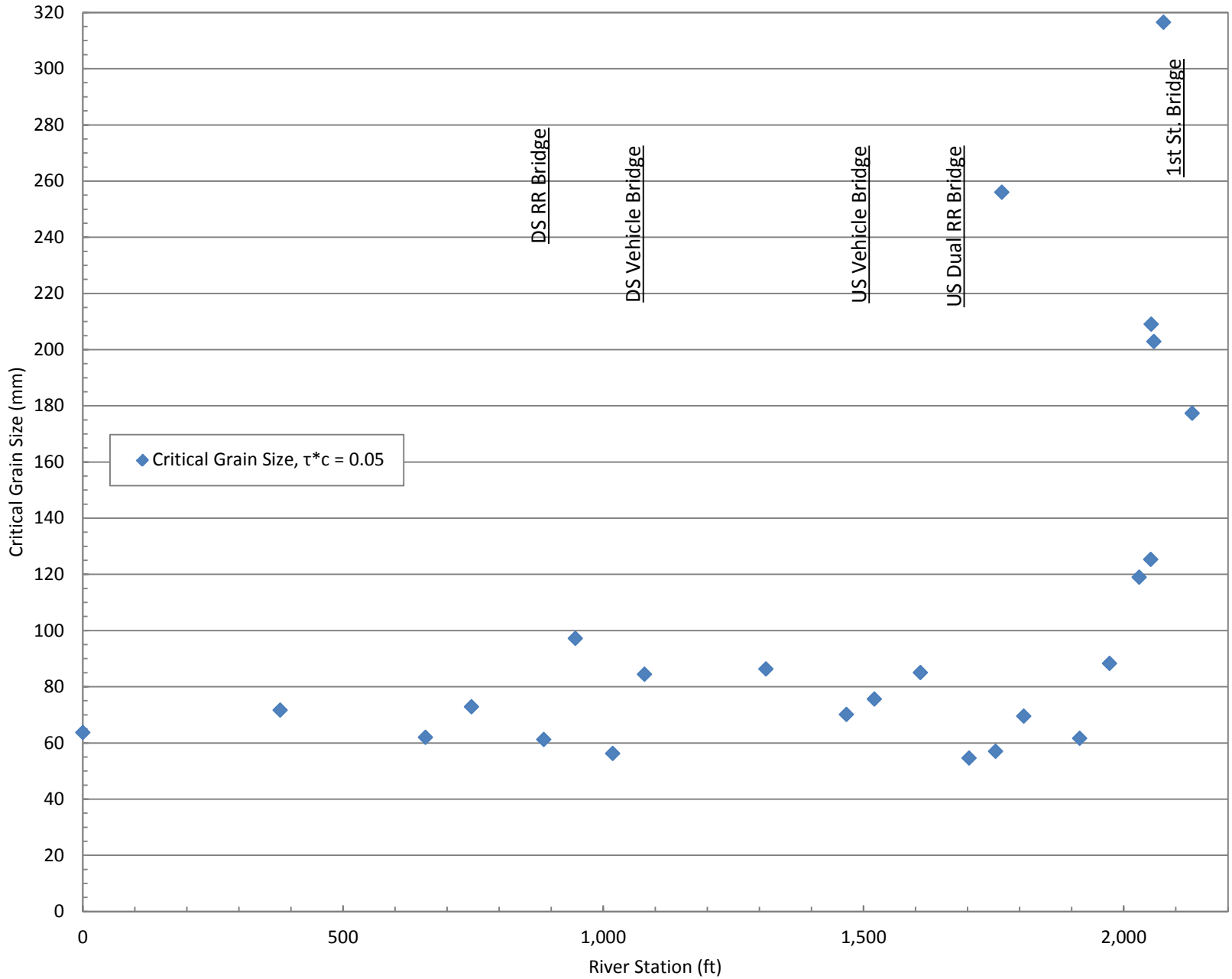

Figure E-6
Critical Grain Size for a 10-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

ANCHOR QEA

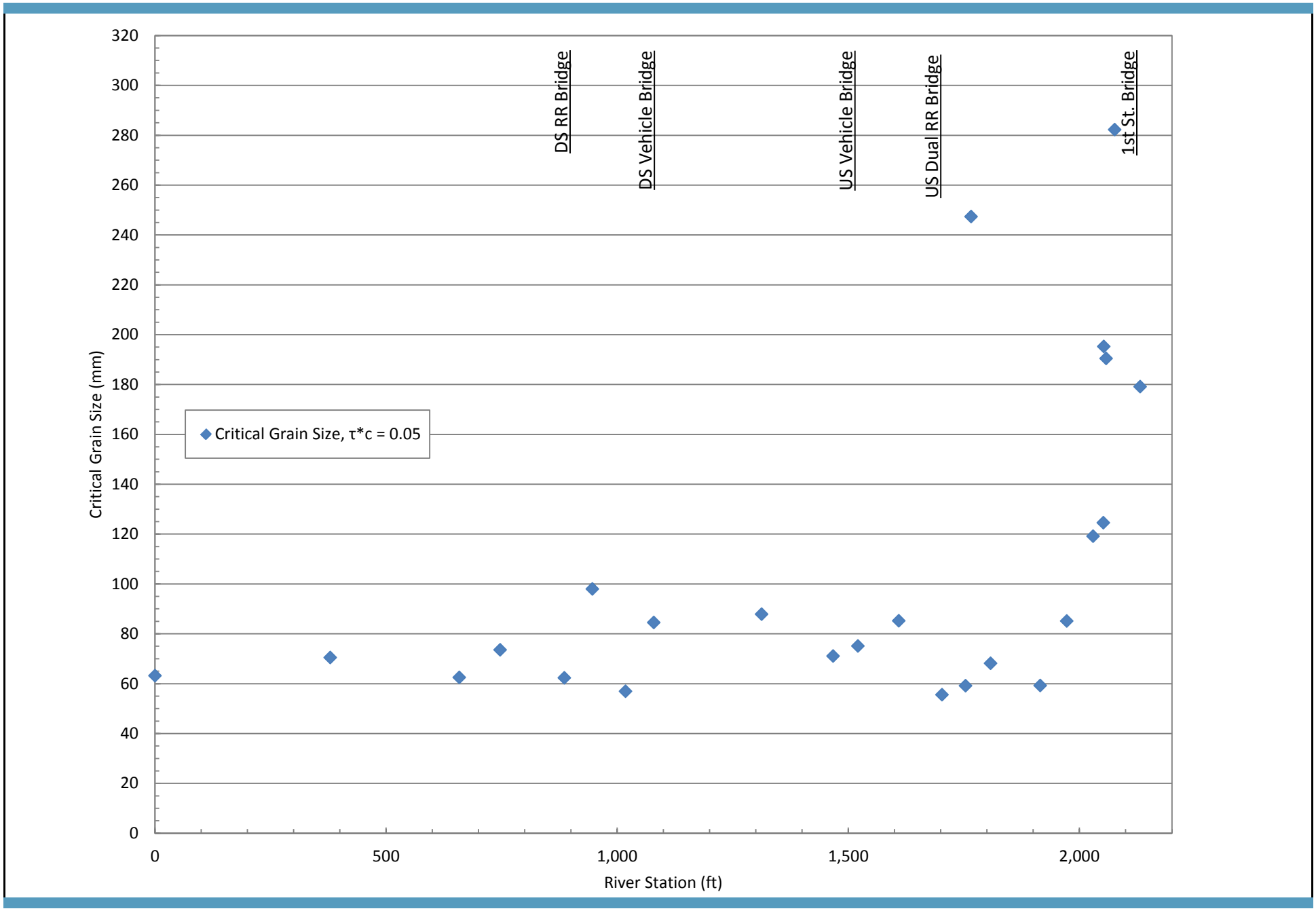

Figure E-7
Critical Grain Size for a 25-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

ANCHOR QEA

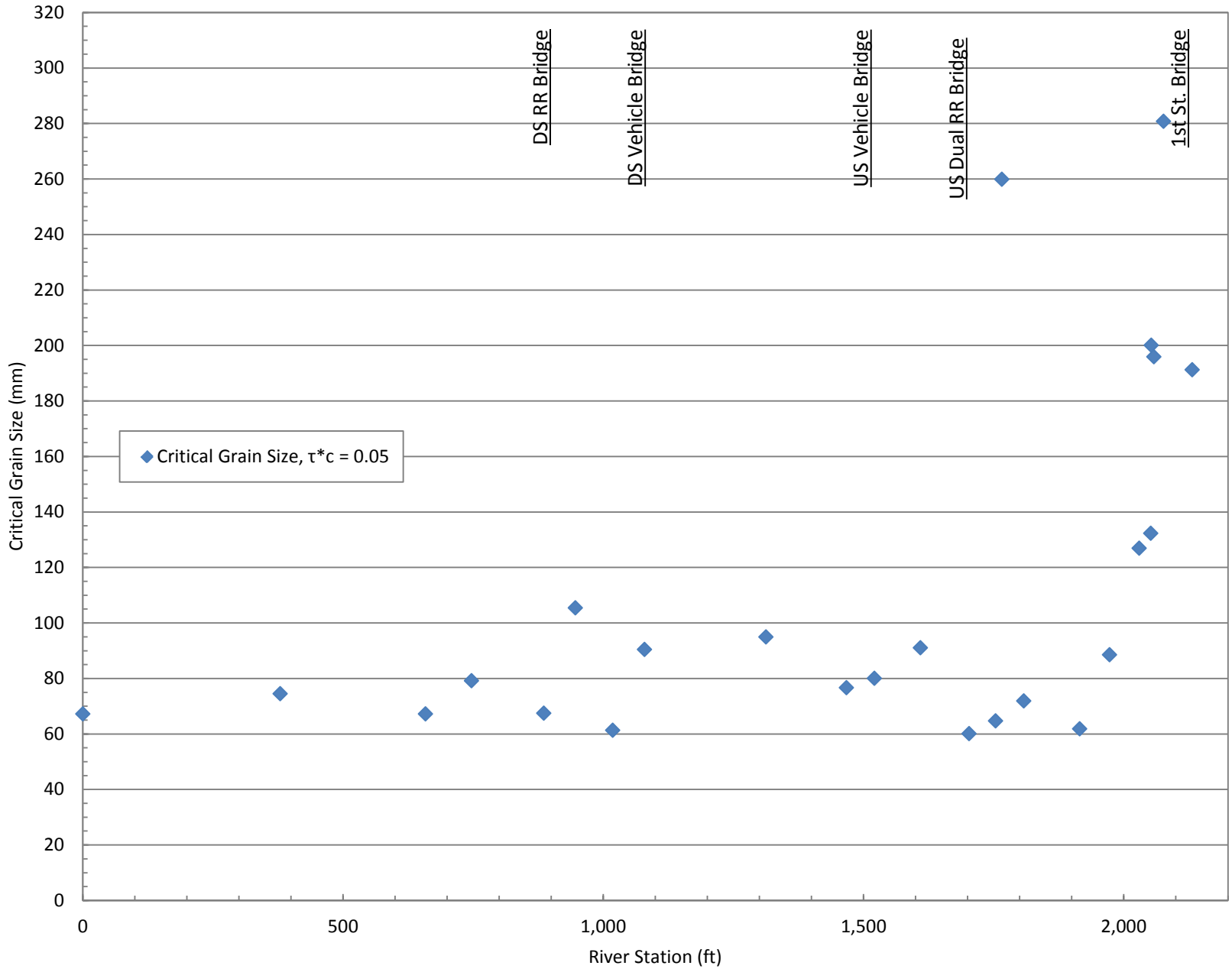

Figure E-8
Critical Grain Size for a 50-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

ANCHOR QEA

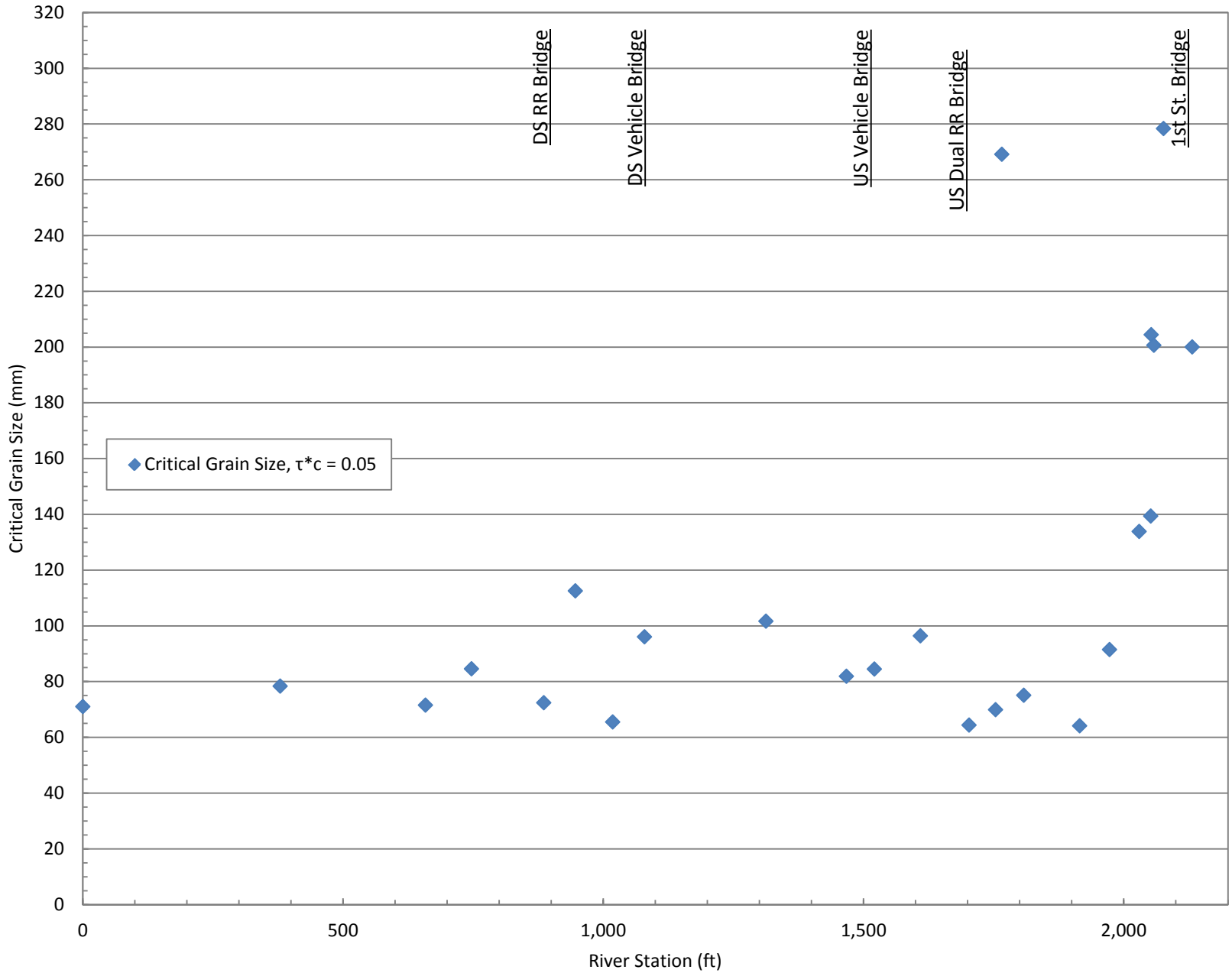

Figure E-9
Critical Grain Size for a 100-year Return Period
Appendix E, Lower Goldsborough Creek Site Assessment and Monitoring Plan
Squaxin Island Tribe

ANCHOR QEA