FINAL

Clarks Creek Sediment Reduction Action Plan

Prepared for

Puyallup Tribe of Indians

Puyallup, Washington

March 21, 2013

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Puyallup Tribe of Indians, Puyallup, Washington

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List of Abbreviations

Action Plan	Clarks Creek Sediment Reduction Action Plan (this document)
BC	Brown and Caldwell
BOD	biochemical oxygen demand
cfs	cubic feet per second
CIP	capital improvement project
City	City of Puyallup
County	Pierce County
DEM	digital elevation model
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
GIS	Geographic Information system
GPS	Global Positioning System
GSD	grain size distribution
HDS	hydrodynamic separator
HPA	Hydraulic Project Approval
HRU	hydrologic response unit
HSPF	Hydrologic Simulation Program—Fortran
LiDAR	Light Detection and Ranging
LF	linear feet
LID	low impact development
MFA	magnitude-frequency analysis
MS4 Permit	Municipal Separate Storm Sewer System Permits (also known as Phase I and Phase II Municipal Stormwater Permit)
NPDES	National Pollutant Discharge Elimination System
PSLC	Puget Sound LiDAR Consortium
QAPP	Quality Assurance Project Plan
SEPA	State Environmental Policy Act
SOW	Scope of Work
TKN	total Kjeldahl nitrogen
TMDL	total maximum daily load
TOC	total organic carbon
TP	total phosphorus
Tribe	Puyallup Tribe of Indians
TS	total solids
TSS	total suspended solids
WDFW	Washington State Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WSU	Washington State University

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Executive Summary

Purpose and Objectives

The Puyallup Tribe of Indians (Tribe) regards Clarks Creek as a very important water resource. Clarks Creek provides habitat for five species of salmonids and is home to Tribal and state fish hatcheries. Recent studies suggest that excess sediment is a key water quality concern for Clarks Creek. To help address this concern, the U.S. Environmental Protection Agency (EPA) awarded the Tribe a grant to develop this Clarks Creek Sediment Reduction Action Plan (Action Plan). According to the Tribe's grant application, full implementation of the measures identified by this project should result in the following outcomes at full build-out:

- ~ 50% reduction in sediments and nutrients to Clarks Creek
- ~30% reduction in fecal coliform bacteria concentrations
- ~ 30% reduction in effective impervious surface area within the catchment
- Support for all designated salmon uses in Clarks Creek (in the long term)
- Significant decrease in elodea growth (and annual elodea control costs)
- ~30% reduction in channel erosion (in the long term)
- Attainment of water quality standards for dissolved oxygen (DO) in Clarks Creek

This Action Plan describes a range of projects aimed at reducing sediment loads to Clarks Creek. Reducing sediment loads (and the pollutants commonly associated with sediment) should help improve habitat for Endangered Species Act (ESA)-listed salmonids, protect Tribal and state hatchery operations, meet dissolved oxygen (DO) and bacteria total maximum daily load (TMDL) objectives, and control elodea growth in the creek.

The Tribe retained Brown and Caldwell (BC) (with subconsultants Inter-Fluve, AHBL, and WH Pacific) and Tetra Tech to help develop the Action Plan. The Action Plan was developed through a collaborative effort involving the Tribe, the City of Puyallup (City), Pierce County (County), Washington State Department of Transportation (WSDOT), Washington State Department of Ecology (Ecology), EPA, and Washington State University (WSU).

Sediment Source Evaluation

BC identified and ranked upland and in-channel sediment sources based on the following data:

- geomorphological assessment of the Clarks Creek basin
- sampling and analysis of channel bottom sediments
- Hydrologic Simulation Program—Fortran (HSPF) modeling by Tetra Tech (under a separate contract)
- Geographic Information System (GIS) analysis of the factors affecting sediment loads
- field reconnaissance to ground-truth HSPF
- sediment transport magnitude-frequency analysis (MFA)

Figure ES-1 shows the steps in the source evaluation process.

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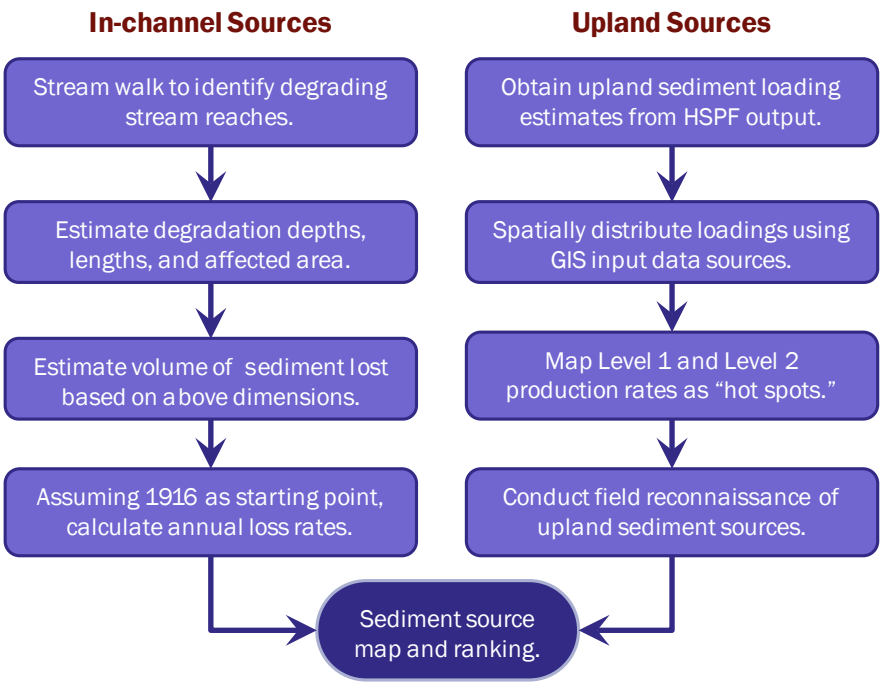

Figure ES-1. Sediment source evaluation process

Sediment Sources

The sediment source evaluation found that upland sources account for about 68 percent and in-channel sources account for about 32 percent of the average annual sediment load in the Clarks Creek basin (Figure ES-2). However, as shown in Figure ES-3, the in-channel sources generate considerably more sediment per unit area than do the upland sources. Moreover, the average annual channel erosion rate for recent years may be higher than the long-term average due to recent development in the upper watershed,

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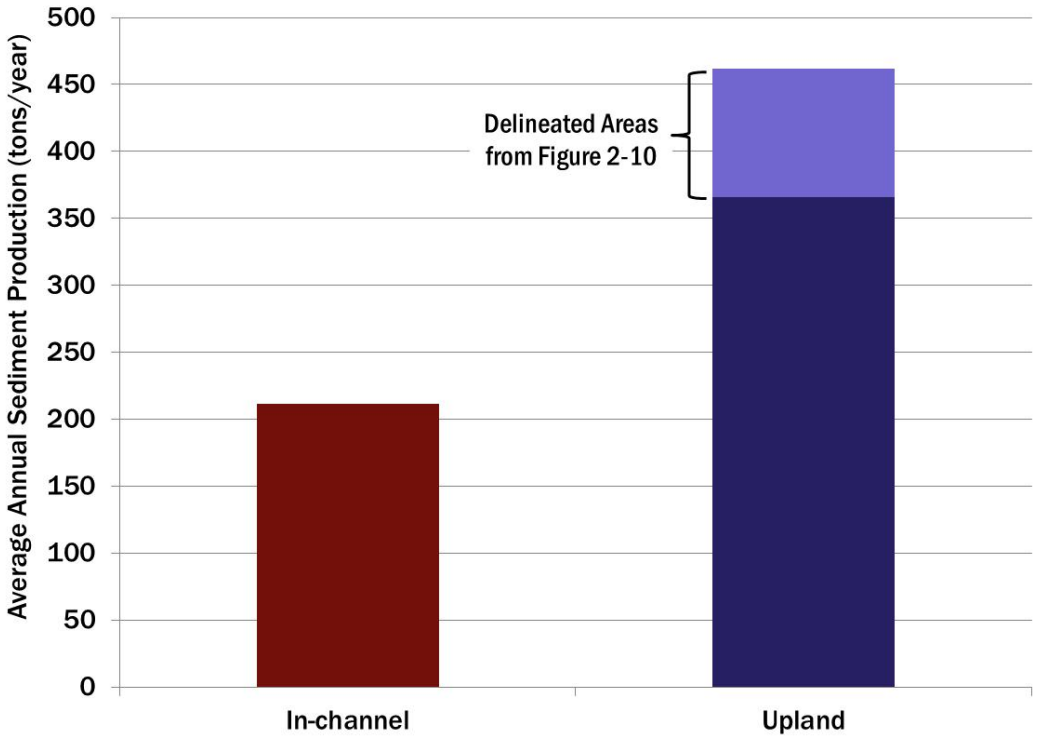

Figure ES-2. Average annual sediment production in Clarks Creek basin

Note: Upland source areas shown in Figure 2-10.

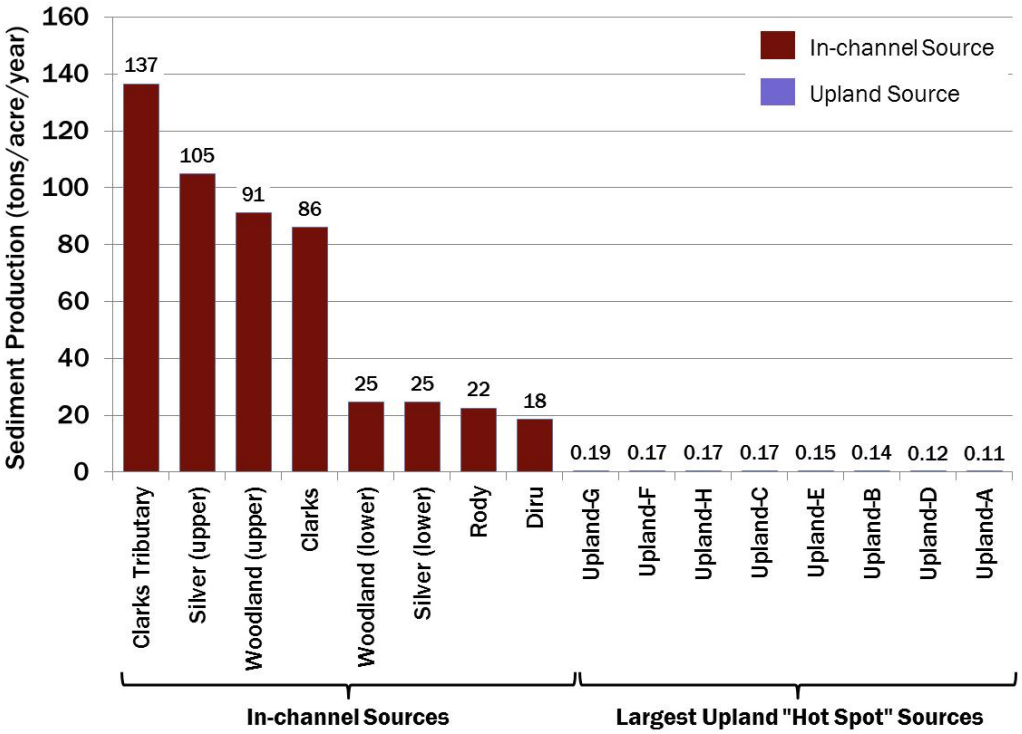

Figure ES-3. Average annual sediment production per unit area

Note: Upland source areas shown in Figure 2-10.

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Sediment Reduction Projects

BC worked with the Tribe, City, County, EPA, Ecology, WSU, and WSDOT to identify, evaluate, and select potential projects for reducing sediment loads from the key sources in the Clarks Creek watershed. BC used the HSPF model, developed by Tetra Tech, and MFA to estimate the sediment reduction benefits from each project. This analysis indicated that the selected projects should be able to achieve the Action Plan goal of 50 percent reduction in sediment loads (see Figure ES-4).

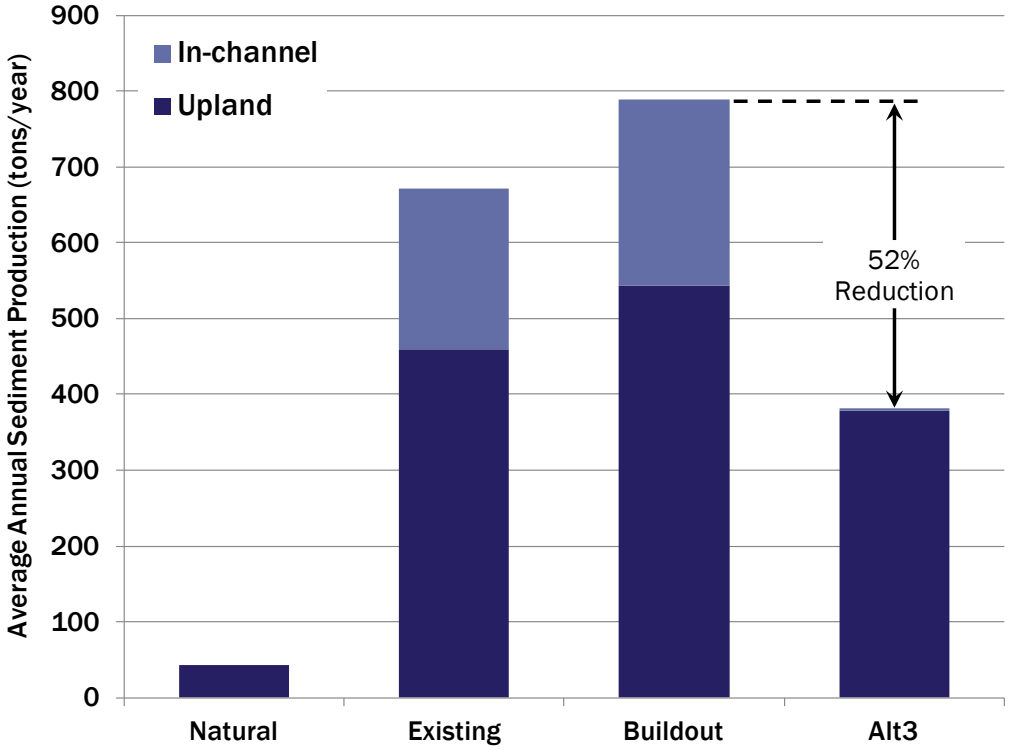

Figure ES-4. Estimated reduction in average annual sediment load from implementation of selected projects (Alt 3)

BC developed general planning-level concepts and cost estimates for the selected projects. Table ES-1 provides summary information for the selected projects.

Project costs were compared based on a normalized benefit-cost index. The index was calculated by dividing the annual sediment load reduction for each project by the estimated cost for that project, and then dividing that by the ratio for all projects. An index value greater than 1 indicates that a project has a benefit-to-cost ratio that is higher than the average for all of the projects included in Alt 3.

The benefit-cost index described in the previous paragraph is based on the identified sediment sources, which, in the case of in-channel sources, is limited to the erosional problem areas for each of the assessed streams. Projects that provide flow control can also help prevent future degradation of currently stable stream reaches. Table ES-1 also provides a qualitative rating of the flow control benefit for each project.

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Table ES-1. Project Results Summary

ID	Project description	Cost estimate	Annual sediment load reduction (ton/yr)	Normalized benefit-cost index (1.0 = average)	Flow control benefit
Pr01	Rody Creek channel stabilization	$1,109,000	6.7	0.8	Low
Pr02	Diru Creek bank stabilization	$194,000	7.7	5.5	Low
Pr03	Woodland Creek channel stabilization: lower	$571,000	13.5	3.3	Low
Pr04	Woodland Creek channel stabilization: upper	$1,033,000	38.9	5.2	Low
Pr05	Upper Clarks Creek channel stabilization	$1,962,000	77.0	5.4	Low
Pr06	Upper Clarks Tributary channel stabilization	$1,146,000	56.4	6.8	Low
Pr07	Silver Creek channel stabilization: lower	$366,000	8.2	3.1	Low
Pr08	Silver Creek channel stabilization: upper	$769,000	34.8	6.2	Low
Pr09	Rody Creek detention facility retrofit	$443,000	4.4	1.4	High
Pr10	Diru Creek detention facility	$2,051,000	5.9	0.4	High
Pr11	Woodland Creek detention facility	$5,748,000	11.2	0.3	High
Pr12	Clarks Creek detention facility	$8,848,000	5.1	0.1	High
Pr13	Silver Creek detention facility	$6,640,000	8.3	0.2	High
Pr14	Hatchery pond retrofit (sedimentation basin)	$472,000	9.5	2.8	Low
Pr15	15th Street stormwater diversion	$1,285,300	54.9	5.9	High
Pr16	7th Avenue stormwater diversion	$11,731,000	31.1	0.4	High
Pr17	72nd Street stormwater improvements	$551,000	0.8	0.2	Low
Pr18	North Pioneer stormwater treatment facility	$187,000	2.3	1.7	Low
Pr19	South Pioneer stormwater treatment facility	$173,000	1.4	1.1	Low
Pr20	16th Street SW stormwater treatment facility	$157,000	0.8	0.7	Low
Pr21	11th Street SW stormwater treatment facility	$164,000	1.1	0.9	Low
Pr22	Street edge/bioretention for secondary roadways	$1,607,000	3.9	0.3	Moderate
Pr23	Porous pavement for arterial roadways	$6,663,000	7.7	0.2	Moderate
	Total	**$53,870,300**	**391.6**	**1.0**	**–**

Implementation Strategy

Implementation of the Action Plan will depend on the availability of funding from grants, City and County stormwater utility fees, and other sources. Opportunities to coordinate with infrastructure improvement projects or take advantage of land availability could accelerate the implementation of specific projects. Therefore, the Action Plan is structured to support a flexible implementation strategy rather than a fixed sequence. Proponents can select the projects that align with anticipated revenues and take advantage of opportunities (e.g., grants, complementary projects, availability of land) as they arise.

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Full implementation of this Action Plan could take 20 years or more. Basin conditions are likely to change over time due to changes in land use/land cover, new regulations, and new infrastructure, as well as implementation of the Action Plan projects. Before implementing a given Action Plan project, the project proponent should assess the situation to confirm that the project is still necessary and revise it as necessary to align with current conditions.

The Action Plan projects are designed to alter the dynamic processes that are contributing excess sediment loads to Clarks Creek. Monitoring should be conducted during Action Plan implementation to evaluate changes in channel conditions and confirm that the implemented projects are functioning as intended. The monitoring results should help determine whether the concepts for the remaining unbuilt projects should be modified to enhance their effectiveness and/or reduce costs.

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Section 1
Introduction

This section presents a brief explanation of the background to this Action Plan, and describes the Action Plan purpose and objectives, project approach, and Action Plan document organization.

1.1 Background

Clarks Creek is a tributary to the Puyallup River in Water Resource Inventory Area (WRIA) 10. The 3.6–mile-long creek drains an area of approximately 6,600 acres of urban and rural land within the city of Puyallup (City) and Pierce County (County) (see Figure 1-1). Maplewood Springs provide 30 to 40 cubic feet per second (cfs) of baseflow to the Creek, which also receives flow from four smaller creeks and several storm drainage systems before discharging into the Puyallup River about 6 miles upstream of the Commencement Bay estuary.

The Puyallup Tribe (Tribe) regards Clarks Creek as an extremely important water resource. It is one of the few creeks in lower WRIA 10 that still supports Chinook, coho, and chum salmon as well as steelhead, bull, and cutthroat trout. The Chinook salmon and steelhead found in Clarks Creek have been listed as threatened under the Endangered Species Act (ESA). Moreover, the Puyallup Tribe operates a state-of-the-art salmon hatchery on the creek. The Washington State Department of Fish and Wildlife (WDFW) operates a trout hatchery upstream of the Tribe's hatchery.

The City and County also consider Clarks Creek to be a very important resource for aesthetic and recreational uses as well as aquatic habitat. Two City parks are located along the creek.

Past monitoring found that Clarks Creek often exceeded the state water quality criteria for fecal coliform bacteria. The Washington State Department of Ecology (Ecology) established a total maximum daily load (TMDL) to reduce fecal coliform levels in Clarks Creek and its tributary Meeker Creek.

Recent monitoring by the Tribe found dissolved oxygen (DO) concentrations that were below the state water quality standards for protection of salmonid habitat. The Tribe is working with the U.S. Environmental Protection Agency (EPA) and Ecology to develop a TMDL to improve DO in Clarks Creek.

Dense growth of *elodea nutalli* (western waterweed) has plagued Clarks Creek for many years. The elodea appears to contribute to the DO problems in the creek and physically reduces habitat for salmonids. In addition, the elodea can become so dense that it causes flooding of riparian areas during baseflow conditions. Elodea debris has clogged the intake screens at the Tribe's fish hatchery. The City and County have spent considerable time and effort on elodea control measures.

Recent studies suggest that excess sediment is a key concern for Clarks Creek. It appears to reduce DO, promote elodea growth, and adversely affect physical habitat, and it may serve as a transport mechanism and reservoir for fecal coliform bacteria. Nutrients (particularly phosphorus and organic nitrogen) are often associated with sediments. Reducing the sediment loads would help protect and improve Clarks Creek's uniquely valuable salmonid habitat and also reduce potential impacts on Puget Sound. Sediment load reductions could also help reduce fecal coliform levels in the creek.

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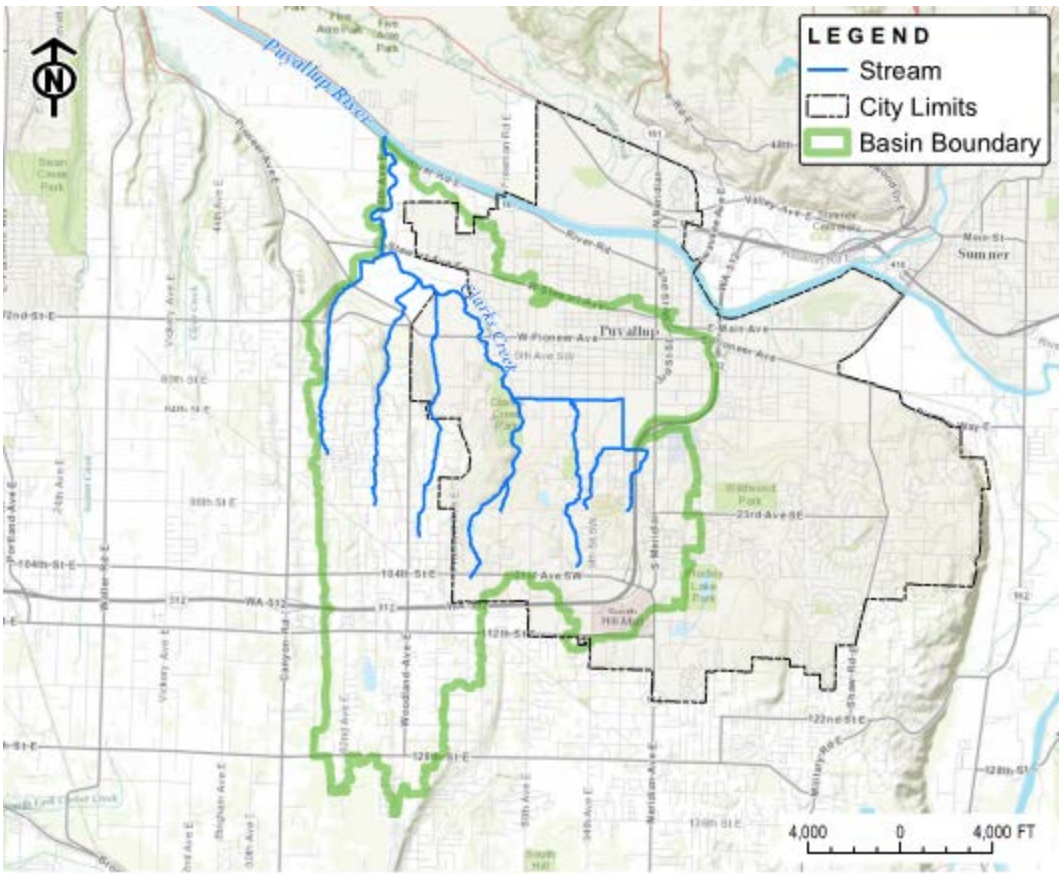

Figure 1-1. Clarks Creek basin

1.2 Action Plan Purpose and Objectives

The Tribe received an EPA grant for a project titled "Reducing Effective Impervious Surfaces in a Small Urban Catchment Using Low Impact Development (LID) Practices." As stated in the grant application, the project was intended to improve water quality in Clarks Creek by reducing sediment loads. The resultant water quality improvements should help improve habitat for ESA-listed salmonids, protect Tribal and state hatchery operations. Sediment reduction could also helpmeet the objectives of the existing bacteria TMDL as well as the DO TMDL that is currently being developed for Clarks Creek. Reduced sediment and nutrient loads could also help reduce elodea control costs for the City and County. The grant envisioned a collaborative effort involving the Tribe, the City, the County, and Washington State University (WSU) that would build on the County's recently adopted Clear/Clarks Creek Basin Plan and complement the City's ongoing LID, National Pollutant Discharge Elimination System (NPDES), and comprehensive planning programs.

After the grant award, the Tribe conducted a procurement process and selected Brown and Caldwell (BC) and Tetra Tech to help conduct the project outlined in the grant application. BC and Tetra Tech had separate but complementary contracts with the Tribe. Tetra Tech developed the Hydrologic Simulation Program—Fortran (HSPF) model that was used to help identify sediment sources and evaluate potential reduction measures. The BC team included WH Pacific (surveying), Inter-Fluve (geomorphology and channel stabilization), and AHBL (LID concepts).

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1.3 Project Approach

BC's Scope of Work (SOW) for this project consisted of the tasks outlined below.

Task 1: Project Initiation

- Hold kickoff meeting with key stakeholders (i.e., Tribe, EPA, Ecology, City, County, WSU)
- Set up Web-based project collaboration portal

Task 2: Compile Existing Data and Prepare QAPP for Field Investigations

- Compile existing data relevant to upland and channel sediment sources, water quality, and existing and planned water quality and runoff control measures
- Prepare Quality Assurance Project Plan (QAPP) to guide field data collection and hydraulic modeling

Task 3: Perform Field Investigations

- Conduct preliminary sediment source/geomorphology investigations data review and field reconnaissance)
- Prepare map showing the apparent sediment point sources, relatively unstable channel reaches, and depositional reaches
- Identify locations for sediment sampling and cross-section survey
- Survey 36 locations on Clarks Creek and tributaries
- Install monuments to facilitate future re-survey to assess trends and support adaptive management
- Collect composite sediment samples from 20 channel locations and analyze the samples for total organic carbon (TOC), total Kjeldahl nitrogen (TKN), total phosphorus (TP, bacteria, and grain size distribution (GSD)
- Prepare sediment data summary

Task 4: Evaluate Channel Erosion and Sediment Mobility

- Estimate historically eroded material based on comparison of current topography to the estimated former gradient and cross-sectional channel geometries
- Extend existing HEC-RAS model to include the upper reaches of Clarks Creek
- Perform uniform flow calculations to estimate flow depths and shear stresses for a range of flow rates for each of the tributary cross-section locations
- Estimate thresholds for channel erosion using incipient motion analyses to determine relative sediment mobility and in-stream flow rates required to erode channel boundaries

Task 5: Support HSPF Modeling and Prepare Sediment Source Summary

- Meet with Tetra Tech staff to discuss the assumptions for HSPF modeling
- Provide Tetra Tech with relevant Geographic Information System (GIS) files for HSPF modeling
- Review and comment on the HSPF model calibration report prepared by Tetra Tech
- Visit key sediment source areas identified based on the HSPF modeling, Task 3 geomorphology investigation, and Task 4 sediment mobility assessment
- Prepare a table summarizing the upland and channel sediment sources and a map showing the key source areas

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Task 6: Evaluate Alternative Control Measures

- Identify potential sediment reduction measures and work with stakeholders to develop up to three alternatives
- Use the HSPF model developed by Tetra Tech to estimate the potential sediment load reductions associated with each alternative, assuming future land use conditions
- Meet with the Tribe and key stakeholders to select the preferred alternative

Task 7: Prepare Action Plan

- Meet with the Tribe and key stakeholders to discuss implementation strategy
- Develop concept drawings for the recommended LID measures and a map showing which LID measures are most appropriate for each portion of the basin
- Develop a fact sheet (including a map, preliminary sizing, and planning-level cost estimate) for the capital improvement project (CIP) measures that appear implementable within the next 6 years given anticipated resources
- Prepare draft Action Plan and revise if needed based on stakeholder comments

Task 8: Project Management

The Tribe issued a separate contract to Tetra Tech to provide modeling support for this project. Tetra Tech's SOW included development of an HSPF model to simulate flow and water quality in the Clarks Creek basin.

1.4 Document Organization

The SOW for this project called for a concise Action Plan that focuses on the recommended sediment reduction measures and facilitates preparation of grant applications for these measures. Therefore, the remainder of this document is organized as follows:

- **Section 2** provides a brief summary of the sediment source investigations.
- **Section 3** describes how sediment reduction measures were identified and evaluated.
- **Section 4** contains the Action Plan, which includes the following:
  - a fact sheet for each of the measures that comprise the selected alternative
  - the recommended sequence for implementing the measures
  - recommendations for post-implementation monitoring and adaptive management
- **Section 5** summarizes the project limitations.
- **Section 6** contains references.

Appendices A through F contain detailed information on the activities and evaluations that were used to develop the Action Plan recommendations (e.g., field reconnaissance, sediment sampling, surveying, modeling, and sediment transport calculations).

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Section 2
Sediment Source Evaluation

This section summarizes the field investigations and analyses used to identify and prioritize sediment sources in the Clarks Creek basin.

2.1 Field Investigations

Field investigations were conducted to assess the geomorphic conditions of streams within the basin, survey the existing channel geometry, and characterize the bed sediments found within the stream system. Subsection 2.1.1 summarizes the results from a geomorphic assessment of Clarks Creek and its major tributaries, Subsection 2.1.2 summarizes the results from a cross-section survey, and Subsection 2.1.3 summarizes the results of the sediment sampling and analysis. Additional information is provided in Appendix A.

2.1.1 Geomorphologic Assessment

In June 2011, field reconnaissance was conducted along Clarks, Diru, Meeker, Rody, Silver, and Woodland creeks to assess the existing geomorphic conditions, identify potential sources of sediment, and make visual estimates regarding the volume of material lost along erosional stream reaches. Additional background research was performed to gain an understanding of the context of the current conditions with respect to historical anthropogenic influences. The following paragraphs summarize the key findings from this assessment; more detailed descriptions of the sediment source areas are included with the discussion of specific sediment sources (Section 2.2).

Geologic Setting. The drop in elevation from the headwaters of the Clarks, Rody, Diru, Woodland, and Silver creek watersheds to the Puyallup River valley bottom is approximately 450 feet. Creeks within the study area drain relatively flat upland surface topography before running down a steep glacial terrace that forms the southern boundary of the Puyallup River Valley within the study area. The terrace is composed of glacial advance outwash sand and gravels, glacial till, and recessional outwash sand and gravels. When eroded, these provide a substantial sediment supply for downstream segments of each tributary and Clarks Creek as it flows out to the Puyallup River.

Erosion and Degradation. Clarks, Diru, Rody, Silver, and Woodland creeks all exhibit some signs of head cut erosion, stream bed lowering, and/or lateral slope instability. Although sufficient data are not available to determine precise causes, the observed erosional conditions likely resulted from a combination of the following historical events:

- Propagation of a lowered bed elevation at the mouth of Clarks Creek, due to the channelization and straightening of the Puyallup River in 1916 (see Figure 2-1). This steepened the slope of the lower channel, thereby increasing the potential for channel erosion.
- Increased runoff caused by land clearing and development within the Clarks Creek watershed
- Recent large storms and floods, which may have triggered massive erosion in areas that had already become unstable.

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Figure 2-1. Clarks Creek entering new channel in 1916

Deposition and Aggradation. Sediment deposition has occurred in the low gradient reaches of Clarks, Rody, Woodland, and Silver creeks. Deposited materials in these reaches appear to be mostly sands with some silts; however, the lower reach of Clarks Creek near the Tribe's hatchery contains larger amounts of silts and finer materials. Depositional zones containing sand and gravel were found in some places along upper reaches of Rody, Clarks, and Silver creeks, typically occurring for a short distance downstream of major erosional areas. A masonry dam located near the Puyallup Trout Hatchery has also created a large depositional area. The reservoir behind the dam is nearly full of sediment and the upstream channel appears to be substantially aggraded.

2.1.2 Channel Gradient and Geometry

Channel cross-sections were surveyed at 36 locations in the Clarks Creek basin (see Figure 2-2, Appendix B). The survey was conducted to provide channel geometry data needed for hydraulic modeling, geomorphic evaluations, and support development of control measures. In addition, two monuments were installed at each cross-section so that it can be re-surveyed in the future to assess trends and support adaptive management. Additional cross-section data were obtained from an existing hydraulic model developed for flood hazard mapping along lower Clarks Creek and lower Meeker Creek (NHC, 2005).

Additional topographic data were obtained from the Puget Sound LiDAR Consortium (PSLC, 2011). PSLC data are developed from detailed Light Detection and Ranging (LiDAR) aerial surveys, and are provided in the form of digital elevation models (DEMs), which are data grids formatted for use with GIS. The DEM obtained for the Clarks Creek basin has a 6-foot grid resolution. LiDAR DEM data were used to create preliminary stream profiles by extracting elevations every 100 feet. The preliminary profiles were then adjusted to match the thalweg (i.e., lowest point) elevations from the cross-section surveys described above. The resulting adjusted stream profiles were used to calculate the slope along any particular stream reach. Figure 2-3 shows the profiles for Clarks Creek and its tributaries.

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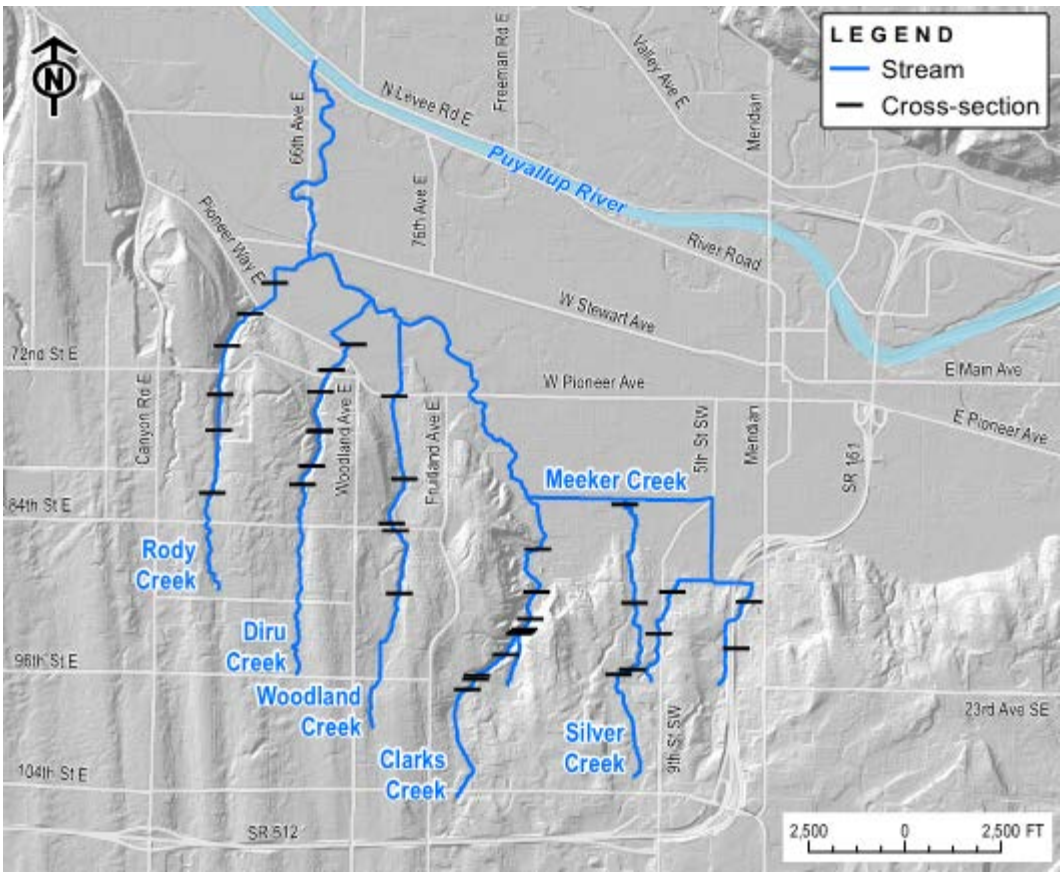

Figure 2-2. Channel cross-section survey locations

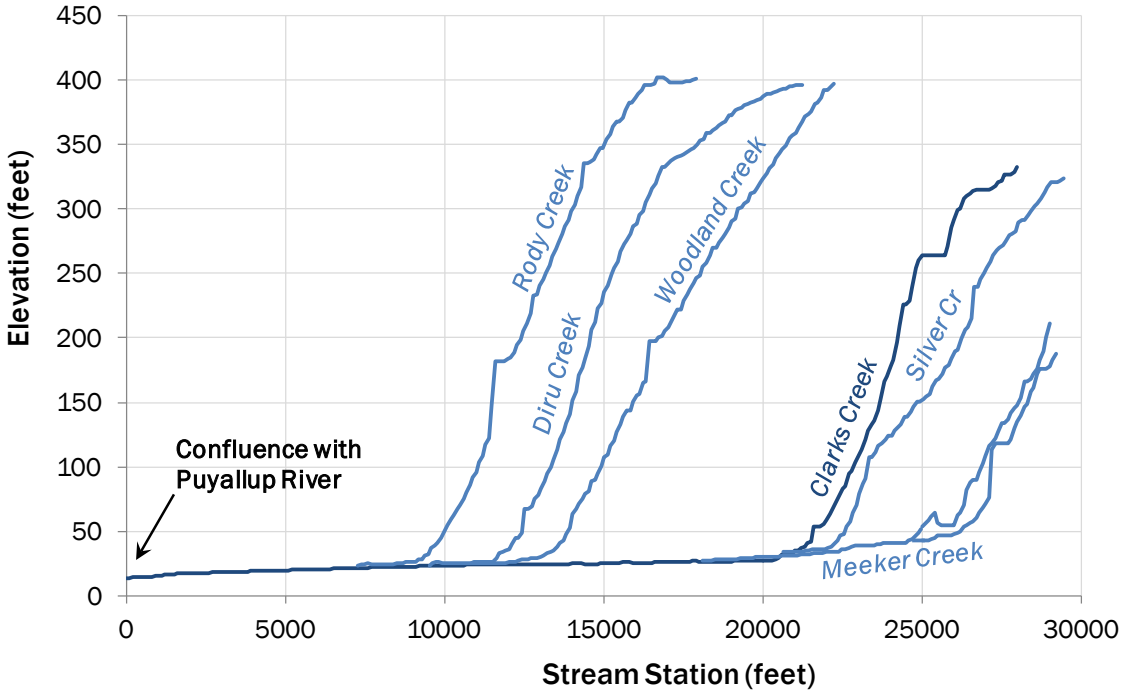

Figure 2-3. Stream profile plots based on LiDAR and cross-section surveys

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2.1.3 Bed Sediment Sampling

Sediment samples were collected at 20 locations (see Figure 2-4). The locations were selected based on the geomorphologic assessment and previous water quality monitoring efforts. The samples were collected shortly after the City and County had completed their annual cutting of elodea in Clarks Creek.

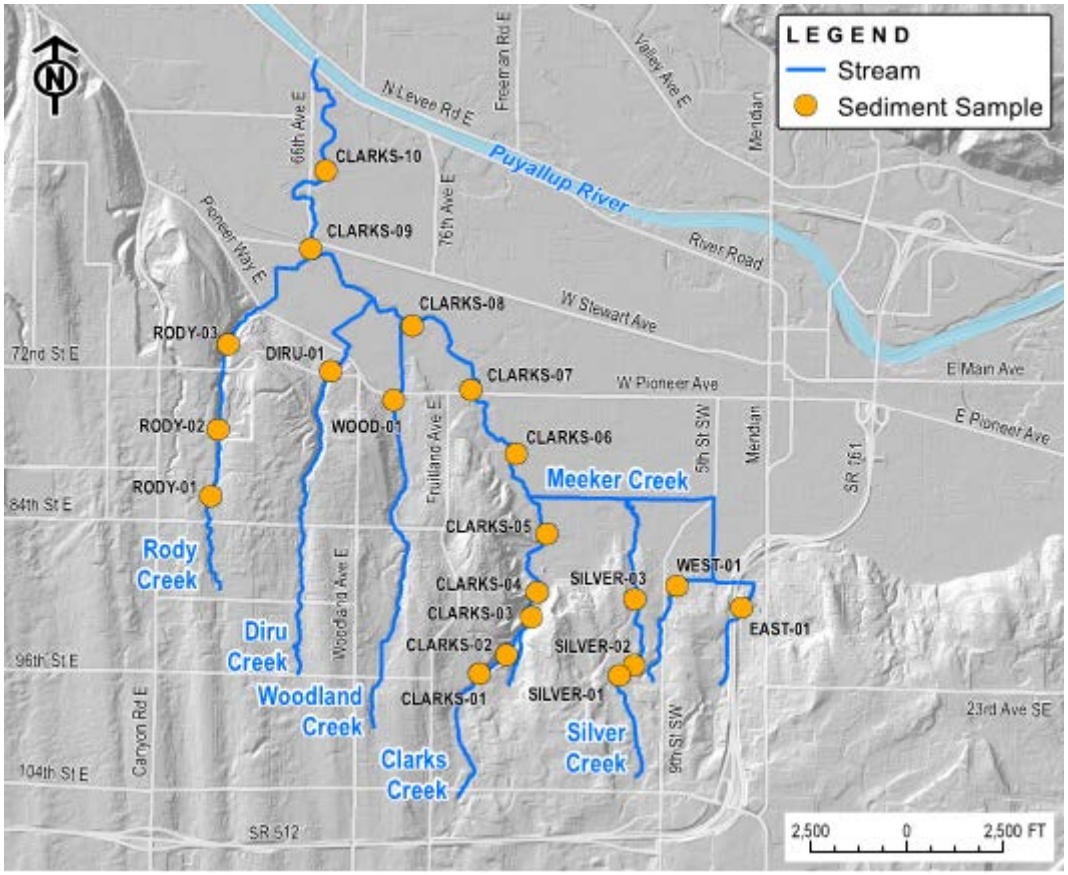

Figure 2-4. Sediment sampling locations

The sediment samples were analyzed for TOC, total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen, total phosphorus (TP), biochemical oxygen demand (BOD), fecal coliform bacteria, total solids (TS), and grain size distribution (GSD). Samples taken along lower Clarks Creek (Clarks-05 through Clarks-10) had relatively high quantities of silt and clay (Figure 2-5). Concentrations of TP, nitrogen, BOD, and TOC appeared to be higher in samples with higher percentages of fines. Fecal coliform bacteria concentrations were generally low and did not appear to increase with percent fines.

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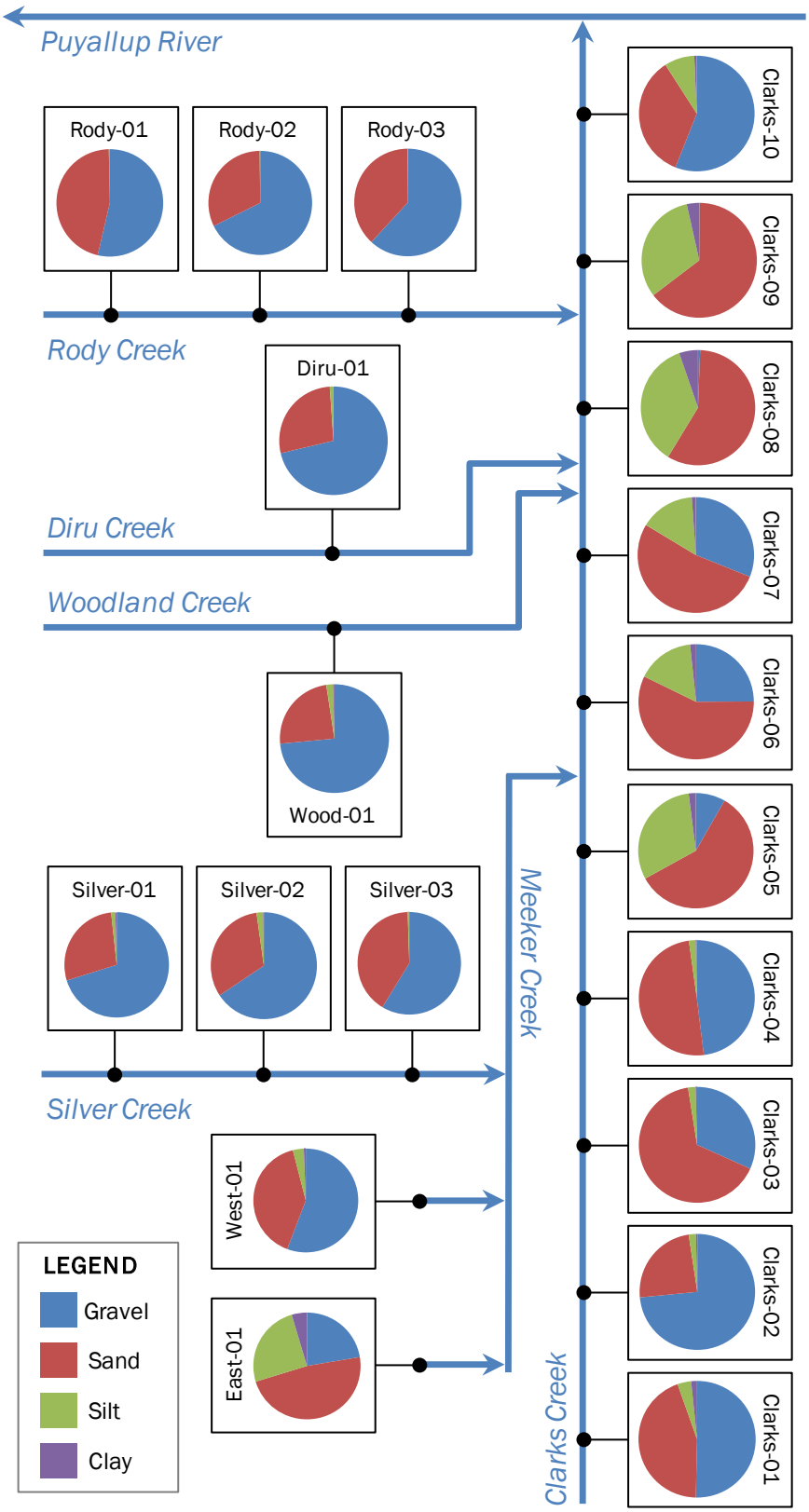

Figure 2-5. Grain size distribution of bottom sediment samples

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2.2 Quantifying Sediment Sources

After the field investigations were completed, it was determined that sediment sources in the Clarks Creek basin can be divided into two general categories:

- **In-channel sources:** Channel instability and degrading stream reaches are a substantial source of sediment to Clarks Creek and its tributaries. Incising and widening channels recruit new material from the bed and banks. The additional sediment is then mobilized and transported downstream. Although some of the coarser sediments may settle out a short distance downstream, finer sediments (fine sand, silt, and clay) are likely to be transported to the low gradient reaches along the valley floor, particularly along lower Clarks Creek, where flow velocities are low enough to allow much of the fine sediment to settle out. Appendix C contains annotated profiles for Clarks Creek and each of the major tributaries with degrading reaches.
- **Upland sources:** Sediment is generated from both pervious and impervious surfaces. Sediment is generated from pervious land surfaces through soil erosion (i.e., rainfall, runoff, and overland flow). Sediment from impervious surfaces is generated through the buildup and wash-off of accumulated sediments (from traffic, debris, wind-blown dust, etc.). Sediment production from pervious land surfaces is typically limited by the amount of runoff available to transport the material. Sediment production from impervious surfaces is typically limited by the sediment accumulation rate.

Analyses were performed to estimate the amount of sediment being generated by each of the identified sources. In-channel sources were quantified using field-approximated volumes of eroded material, converted to an average annual loss rate assuming a 1916 start date. It is highly likely that erosion rates have increased due to more recent development in the upper watershed; therefore, the estimated annual channel erosion rates are likely to be conservative.

A hydrologic model was used to estimate upland sediment production rates. Figure 2-6 illustrates the process used to quantify and rank specific sediment sources.

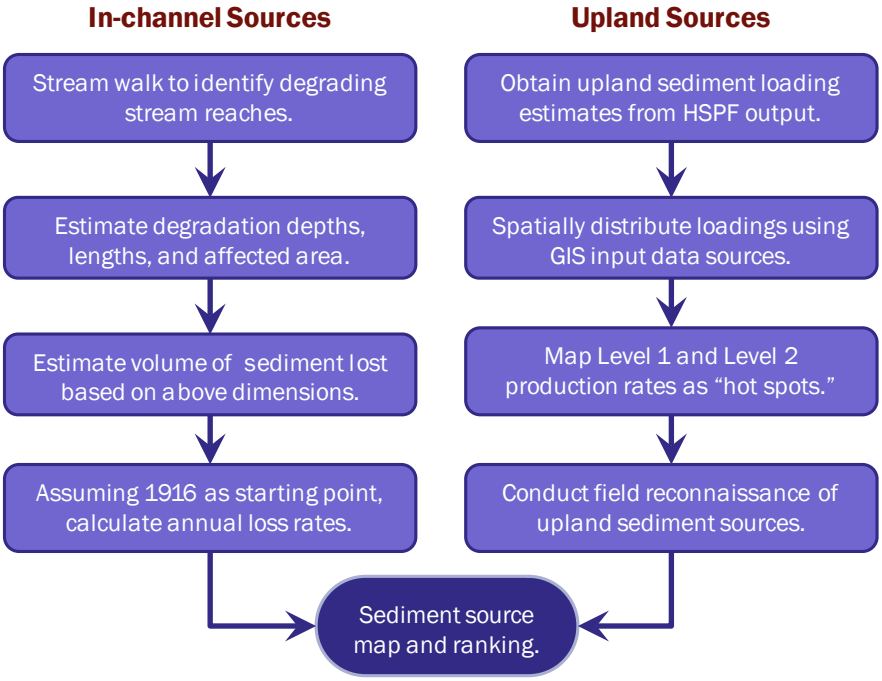

Figure 2-6. Sediment source evaluation process

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2.2.1 In-Channel Source Estimates

Specific problem areas were identified during the field investigations, particularly areas exhibiting severe erosion and degradation. Figure 2-7 highlights specific problem areas found on Diru, Clarks, Rody, Silver, and Woodland creeks.

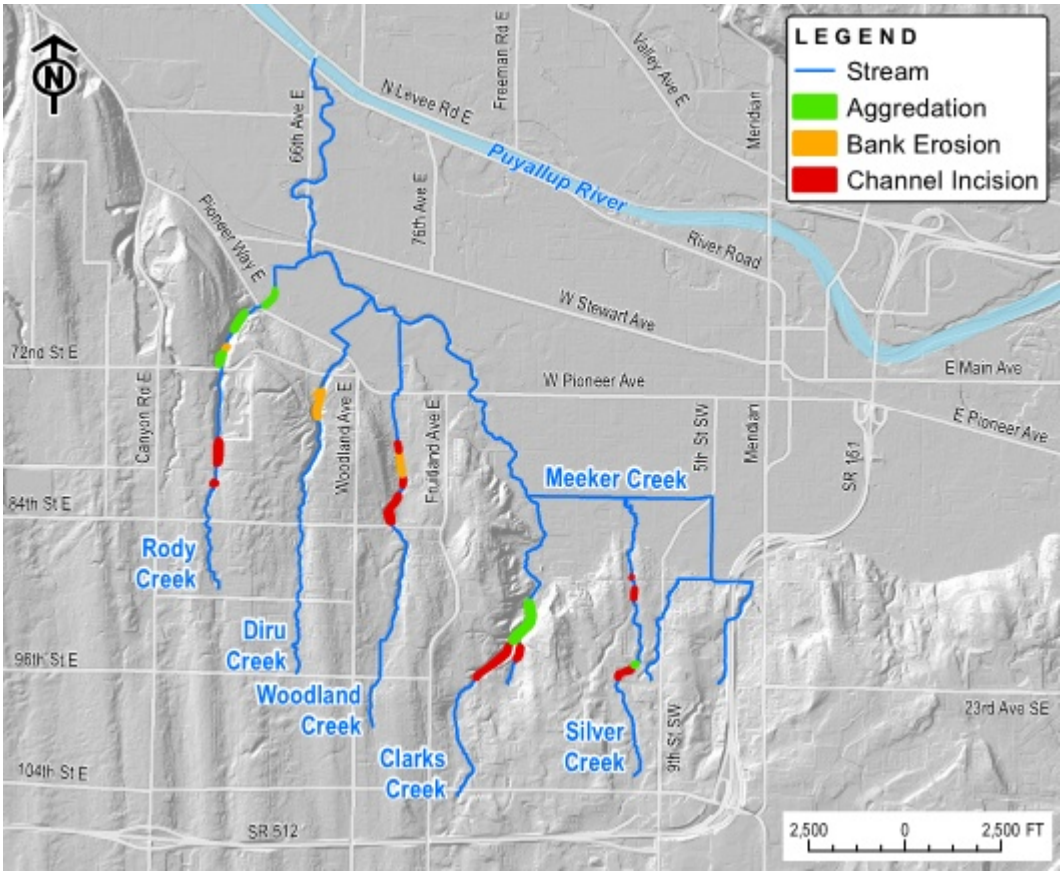

Figure 2-7. Eroded channel reaches in the Clarks Creek basin

Erosion and sediment transport rates are often highly variable and difficult to estimate, even with extensive field measurements and detailed modeling. For the Clarks Creek project, volumes of eroded material were estimated based on visual indicators of depth of incision, channel width, and bank height. Depth of incision was estimated from grade controls including trail and road crossings, roots, and logs spanning the channel. Nearby intact channel conditions were visually extrapolated to eroded sections to estimate depth of incision and channel width. Bank erosion was visually estimated by comparing exposed banks to nearby intact banks. An estimate of the eroded cross-section height and width (lateral migration), and whether the section was generally rectangular or triangular in shape were noted (see Figure 2-8).

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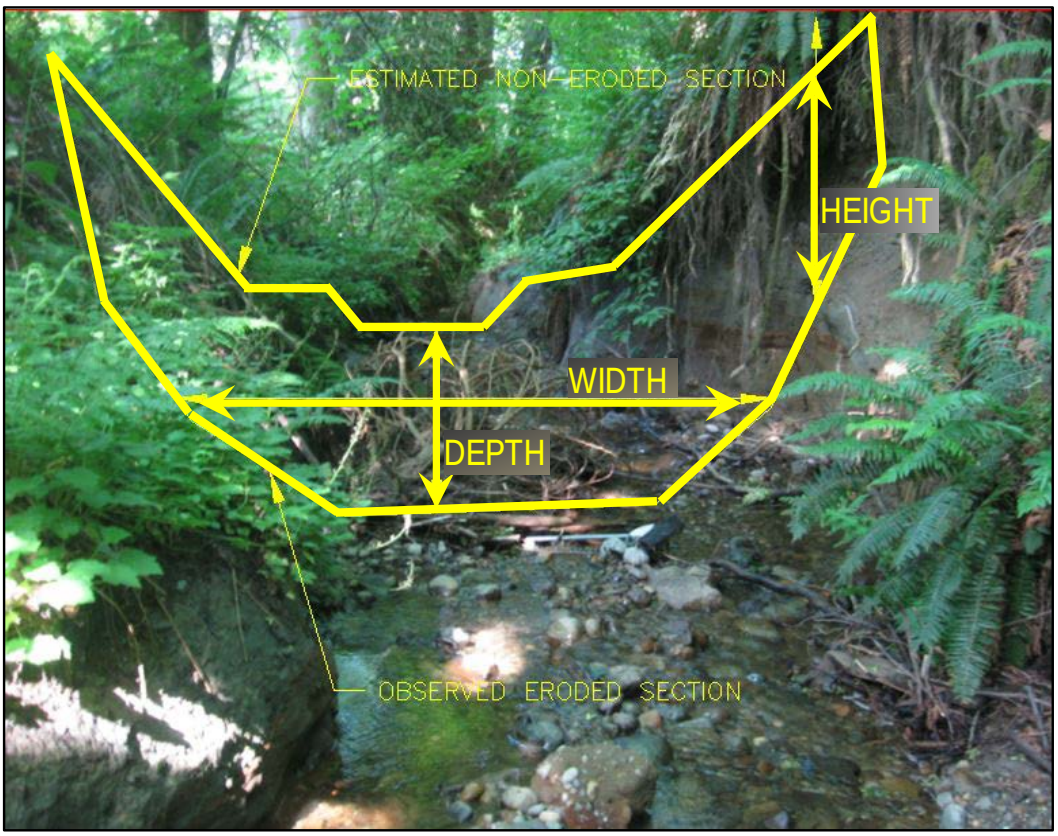

Figure 2-8. Estimation of the volume of eroded material

Lengths of eroded segments were estimated using a handheld Global Positioning System (GPS) device, hip chain, pacing, or visual estimates. Total volumes of eroded material were estimated by multiplying the cross-sectional area by the length. Table 2-1 provides the resulting estimates of eroded material from each of the problem areas.

Table 2-1. Estimated Volume of Past Channel Erosion

Stream name	Length of eroded reach (ft)	Average loss per linear foot (yd^3/ft)	Total eroded material		
			Total (yd^3)	Total[a] (tons)	Annual[b] (tons/year)
Clarks Creek downstream of 23rd Ave. SE	1,300	3.5	4,600	6,100	64.2
Diru Creek upstream of 72nd St. E	700	0.8	530	710	7.4
Rody Creek downstream of 80th St. E	500	0.9	460	610	6.4
Silver Creek upstream of 15th Ave. SE	500	1.0[c]	500	670	7.0
Silver Creek downstream of 23rd Ave. SE	500	4.3	2,100	2,900	30.1
Upper Clarks Creek Tributary near 23rd Ave. SE	600	5.6	3,300	4,500	47.0
Woodland Creek downstream of 80th St. E	900	1.0[c]	900	1,200	12.7
Woodland Creek downstream of 84th St. E	700	3.7	2,600	3,500	36.6
Total/average	**5,700**	**2.6**	**14,990**	**20,190**	**211**

a. Weight calculated from volume assuming a bulk density of 1.34 tons per cubic yard (approximately 100 pounds per cubic foot).

b. Annual rate calculated assuming a 95-year time period (1916 to 2011), see discussion below.

c. Assumed based on similar moderately incised reaches on Diru and Rody creeks.

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The period over which the erosion occurred is unknown and the rate of erosions is difficult to gauge due to the varied stability and material composition between layers of glacial till and outwash. The assumed period of 95 years was based on the span between 1916 (when the Puyallup River was channelized) and 2011 (when the observations were made); however, it is highly likely that the observed erosion has occurred over a much more recent time frame. Therefore, the annual erosion rates provided in Table 2-1 are likely to be conservative.

2.2.2 Hydrologic Modeling

Tetra Tech (April 2012) developed a watershed model of the Clarks Creek basin using the HSPF model, which is distributed by the EPA as part of the BASINS modeling platform. HSPF uses long-term meteorological data to simulate rainfall-runoff, interflow, and subsurface flow to streams. The model also simulates the production and transport of sediment and other pollutants as a function of land use and flow. A copy of Tetra Tech's hydrologic modeling report is provided in Appendix D.

HSPF Model Calibration and Validation. Tetra Tech performed calibration and validation of the hydrologic (stream flows) and sediment transport (sediment loadings) components of the model. Detailed discussions regarding performance targets, modeling results, and uncertainty are provided in Sections 5, 6, and 7 of the report in Appendix D.

In general, the calibration and validation runs of the model found the simulated stream flows to fit the observed streams within the performance targets characterized as "good" to "very good[1]." These simulations were based on several years of flow data, and thus, provide a reasonably high level of confidence in the long-term simulated stream flows.

Calibration and validation of sediment loadings were based on limited observations of total suspended solids, and no small-scale monitoring has been conducted to estimate loads from individual land use areas. Nonetheless, the model provides a reasonable description of the processes contributing to sediment load and transport within the creek, based on multiple lines of evidence.

Upland Sediment Loading. The HSPF model uses a variety of input parameters to represent pervious and impervious land surfaces, accounting for slope, soil properties, and land cover conditions. The model contains inputs for a wide variety of combinations, referred to as hydrologic response units (HRUs). For example, the model includes a specific HRU to represent a pervious land surface with well-drained soils (i.e., hydrologic soil group "B"), moderate slope, and agricultural/pasture land cover.

The model computes flow rates and sediment production[2] rates for all of the HRUs contained in the model and then multiplies those rates by the respective areas covered by each HRU type. The HSPF model estimated that upland sources contribute about 460 tons of sediment per year to streams in the Clarks Creek basin (Tetra Tech, 2012). The computations within the model are aggregated into subbasins (i.e., sub-drainage areas), allowing flows and sediment loading rates to be output at numerous discharges points. Figure 2-9 shows the subbasins delineated for the Clarks Creek basin along with the calculated annual upland sediment loading rates for each subbasin.

[1] Performance targets and the associated ratings of "very good," "good," "fair," or "poor" are described in detail in Section 5 of Appendix D.

[2] The phrases "sediment production" and "sediment loading" are roughly synonymous in the context of this report. However, "sediment production" generally refers to the amount of sediment generated by a sediment source, and "sediment loading" generally refers to the amount of sediment discharged into the stream network at a particular point.

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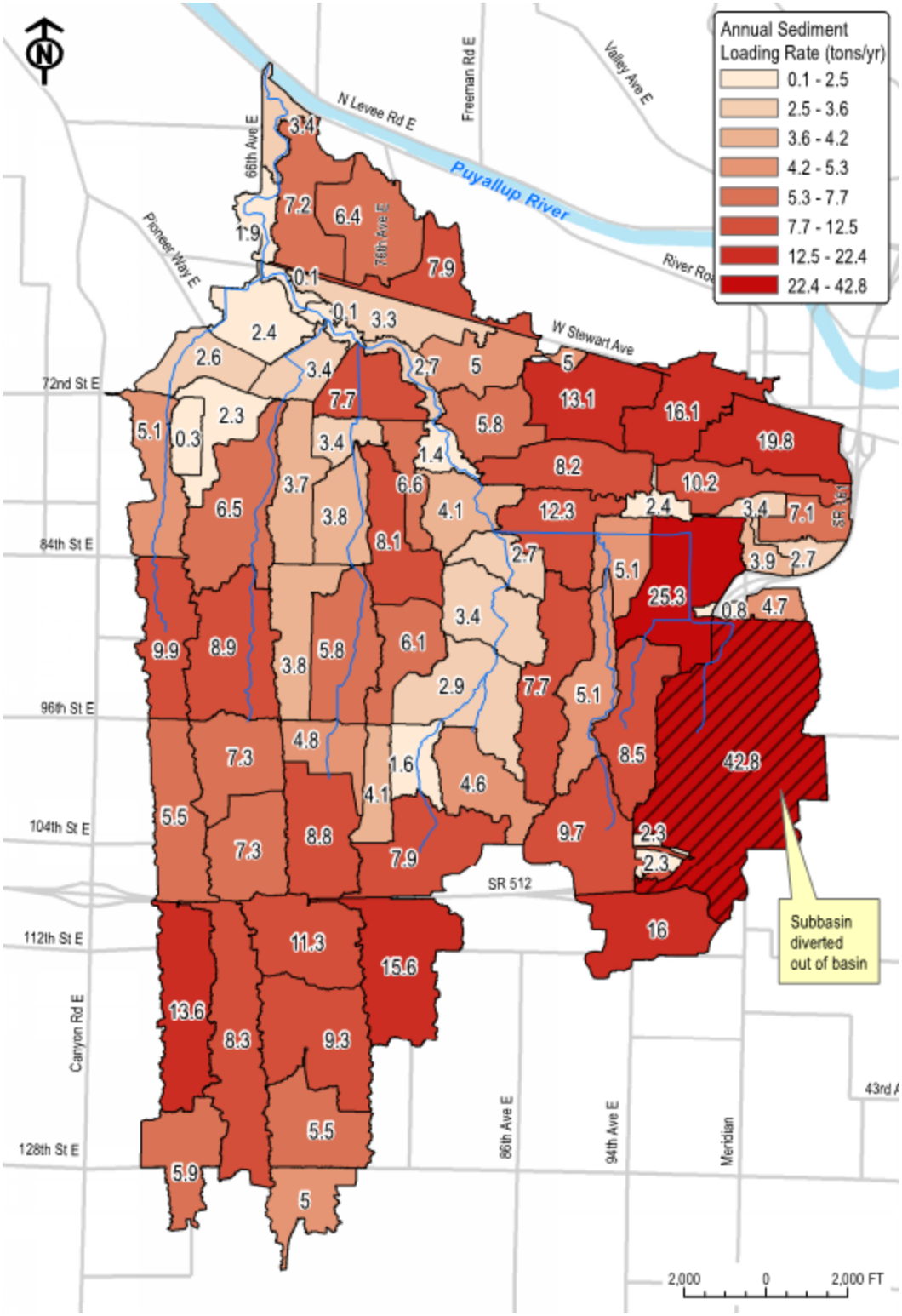

Figure 2-9. Annual upland sediment production by subbasin based on HSPF modeling

Values labeled for each subbasin represent sediment loading to streams in tons per year.

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Hot Spot Mapping. In addition to the subbasin results, sediment production rates for each HRU type (combination of soil, slope, and land cover) were obtained from the HSPF model. Upland sediment loading rates were found to be highest in highly developed areas with high levels of imperviousness. The HSPF modeling results suggest that impervious areas tend to produce higher sediment loads because more overland flow is available for transporting sediment to streams. However, much of the sediment probably originates from pervious areas directly adjacent to impervious areas (Tetra Tech 2012). Table 2-2 provides the HSPF-calculated sediment production rates by land use classification.

Table 2-2. Upland Sediment Production Rates from HSPF Modeling

Land use	Sediment production (tons/ac/yr)	Impervious percentage
Wetland	0.000	0%
Forest	0.011	0%
Grass and pasture	0.030	0%
Agricultural	0.033	0%
Low-density development	0.038	5%
Medium-density development	0.034	10%
High-density development	0.168	78%
Parks and institutional	0.071	15%
Roadway	0.173	71%
Average	**0.076**	**27%**

Geospatial soil, slope, and land cover data were used to calculate the HRU areas within each subbasin. These same input data sets were then used to disaggregate and spatially map the upland sediment loading rates within each subbasin. In other words, sediment production rates were calculated for each HRU type and spatially distributed using the original GIS mapping data. The production rates were then divided into ranges (i.e., Level 1 through Level 4, with Level 1 being the highest) and mapped (see Figure 2-10). Specific hot spot areas were delineated from the largest areas mapped as Level 1 or Level 2 sediment production zones.

GIS data and aerial photography were then used to verify the reasonableness of the hot spots, and additional field reconnaissance was performed to “ground-truth” the results. Based on these checks, some upland source areas were marked as non-contributing for conditions such as:

- Impervious surfaces that do not appear to be directly connected to the drainage network (i.e., not considered to be effective impervious)
- Areas draining to ponds or other stormwater infrastructure that could remove sediments
- Areas that were observed to be mostly pervious with good vegetative cover.

Note that within hot spot areas, focus should be placed on directly connected impervious areas and exposed soil immediately adjacent to those surfaces.

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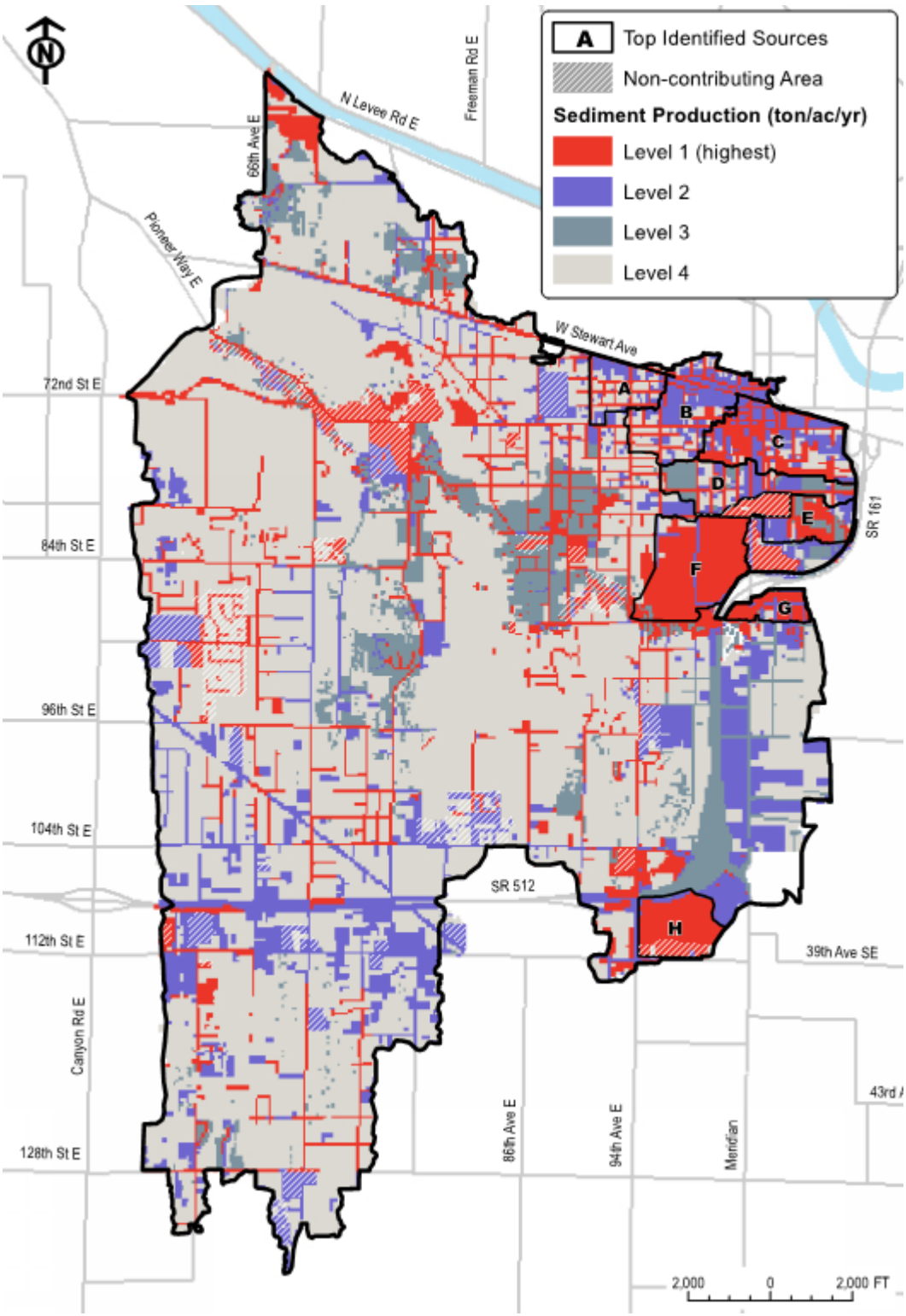

Figure 2-10. Upland sediment source "hot spots" identified by HSPF model and GIS analyses

Note: Non-contributing areas (white hatch) are not expected to contribute appreciable sediment (see page 2-11).

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2.3 Prioritizing Sediment Sources

Total annual sediment production rates for in-channel and upland sources are summarized in Figure 2-11. Upland sources account for about 68 percent and in-channel sources account for about 32 percent of the average annual sediment load in the Clarks Creek basin. As discussed previously, the average annual load estimates for in-channel sources assume that the observed sediment loss occurred at a constant rate between 1916 and 2012. It is likely that the current rate of channel erosion is higher than the long-term average due to recent urban development in the basin. Thus, in-channel sources may actually account for more than 32 percent of the current average annual sediment load.

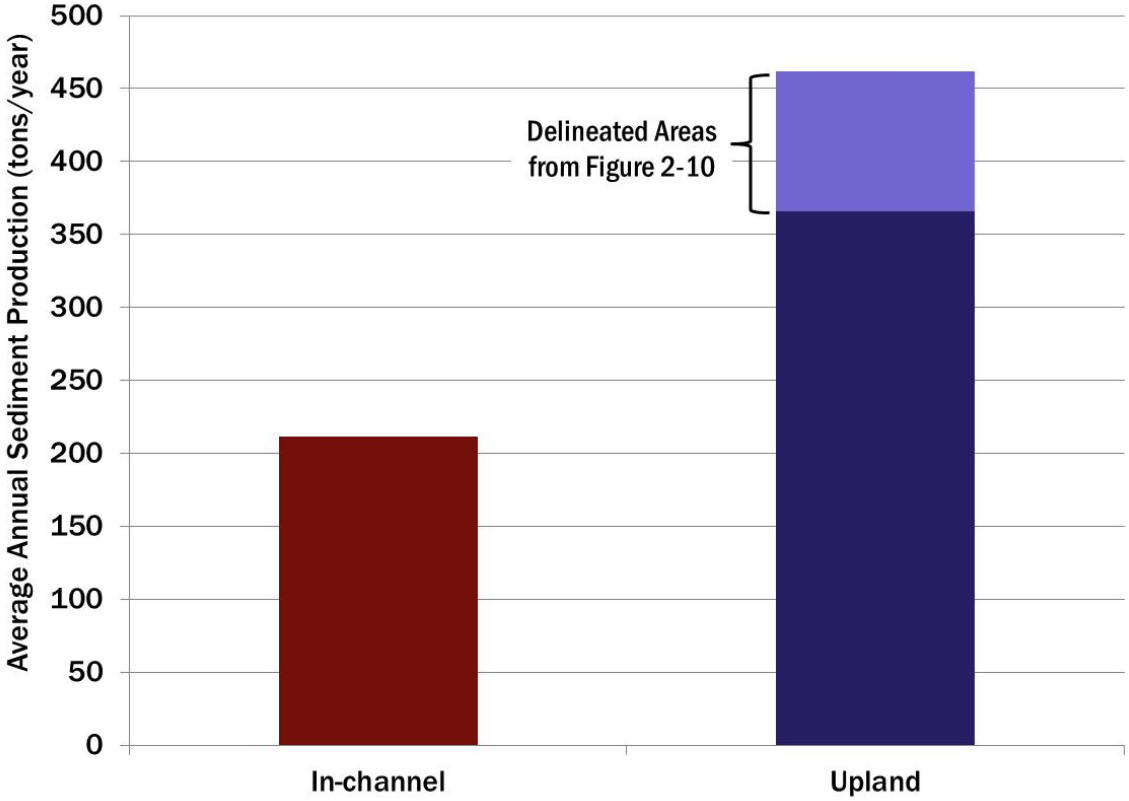

Figure 2-11. Average annual sediment production in Clarks Creek basin

Note: Upland source areas shown in Figure 2-10.

The annual sediment loading rates for the eight largest in-channel sources were graphed along with the annual sediment loading rates for the eight largest upland sediment "hot spots," as shown in Figure 2-12. The upland sources are much larger and more diffuse than the in-channel sources. For example, the upland source areas included in Figure 2-12 each cover between 28 and 123 acres. The in-channel sources generate much more sediment per unit area than do the upland sources (see Figure 2-13).

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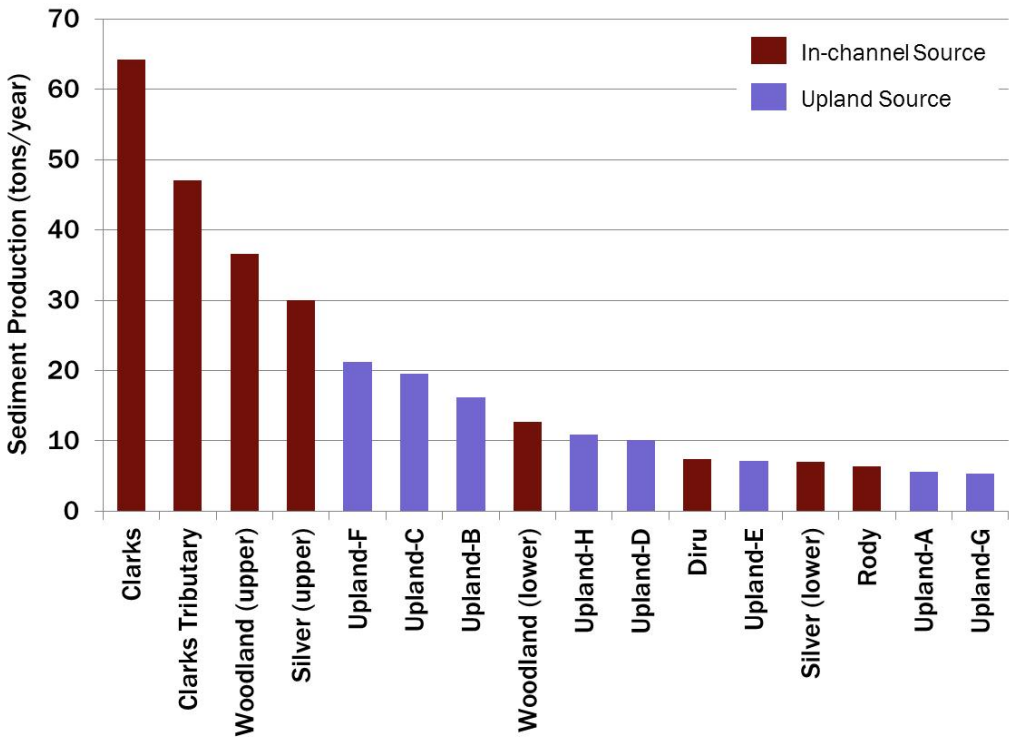

Figure 2-12. Annual sediment production for the 16 largest identified sources

Note: Upland source areas are shown in Figure 2-10.

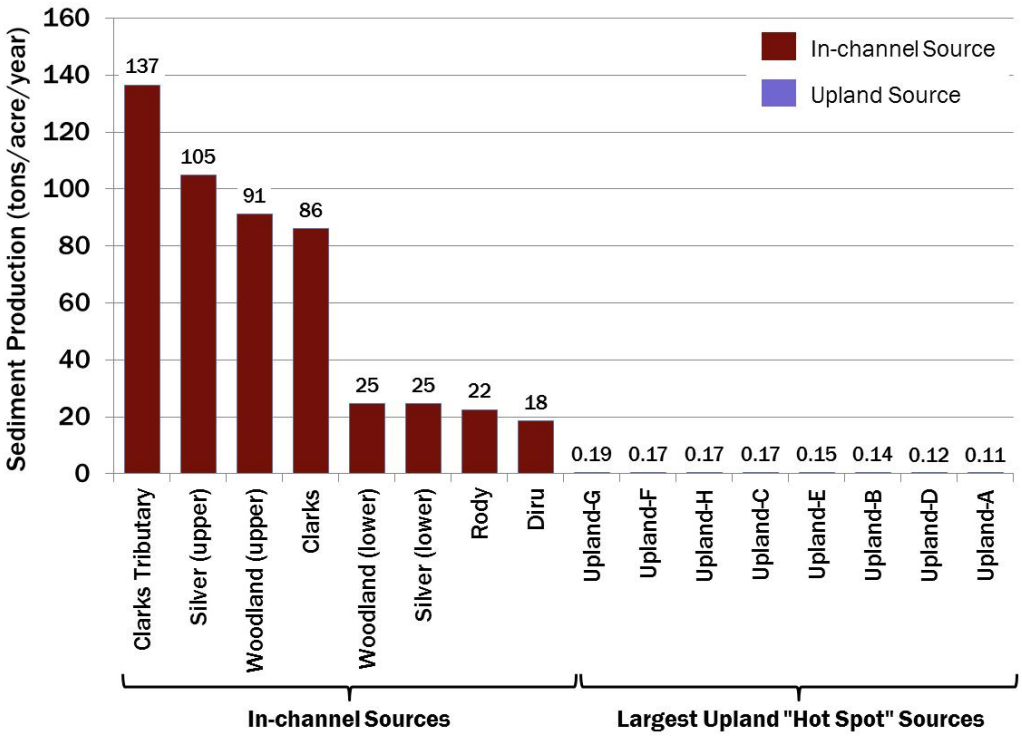

Figure 2-13. Annual sediment production per unit area for 16 largest sources

Note: Upland source areas are shown in Figure 2-10.

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Section 3

Evaluation of Potential Sediment Reduction Measures

This section describes how sediment control measures were identified and evaluated for inclusion in the Action Plan. Figure 3-1 provides an overview of the process.

3.1 Formulation of Alternatives

BC reviewed the results of the sediment source evaluation to identify potential approaches for reducing sediment loads from the key sources in the Clarks Creek watershed. As noted in Section 2.3, steep, unstable channel reaches were found to be the most concentrated sediment sources in the watershed. The geomorphic assessment (Section 2.1) identified altered watershed hydrology as a likely cause for the observed channel erosion and bank failures. Loss of forest cover, creation of impervious surfaces, and construction of stormwater drainage systems have increased the duration of the "geomorphically significant flows" that cause bedload movement and accelerate channel and bank erosion.

The Phase I and Phase II Municipal Stormwater Permits (also known as Municipal Separate Storm Sewer System [MS4] Permits) require onsite stormwater management (such as LID) and flow control measures for new development and redevelopment activities that replace or add hard surfaces. Minimum Requirements 5 and 7 are intended to reduce the duration of geomorphically significant flows that cause channel erosion and other adverse impacts. These requirements are summarized below.

- **Minimum Requirement 5, "On-site Stormwater Management,"** contains a LID performance standard that applies to projects that result in greater than 2,000 square feet of new plus replaced hard surfaces. The requirement reads as follows:

  > *Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 8% of the 2-year peak flow to 50% of the 2-year peak flow. Refer to the Standard Flow Control Requirement section in Minimum Requirement #7 for information about the assignment of the pre-developed condition. Project sites that must also meet minimum requirement #7 shall match flow durations between 8% of the 2-year flow through the full 50-year flow.*

- **Minimum Requirement 7: "Flow Control,"** contains a standard flow control requirement that applies to projects that result in greater than 5,000 square feet of new plus replaced hard surfaces. The requirement reads as follows:

  > *Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. The pre-developed condition to be matched shall be a forested land cover unless [specific conditions are met.]*

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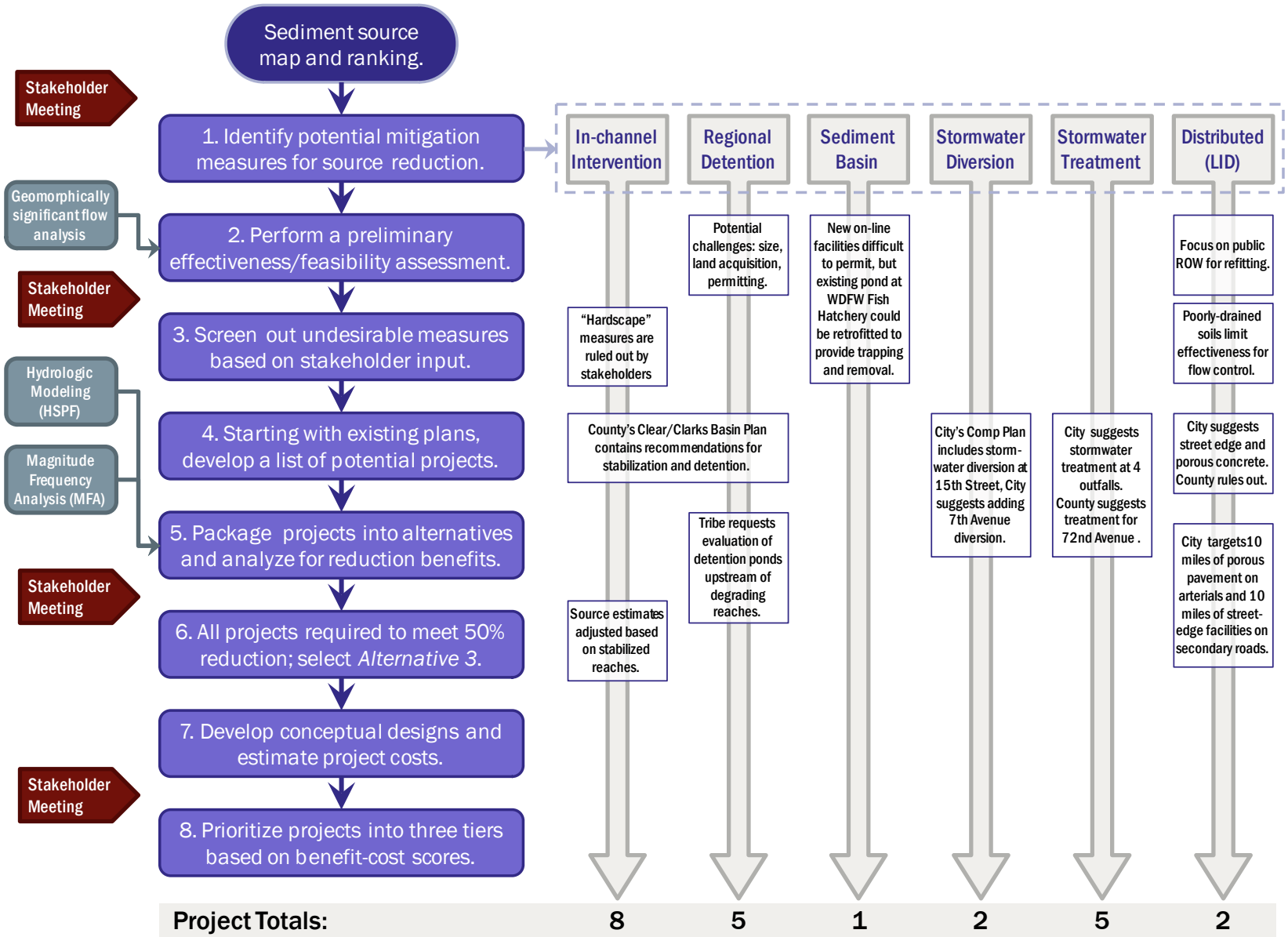

Figure 3-1. Process used to evaluate potential sediment reduction measures

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BC calculated geomorphically significant flows for key channel locations in the Clarks Creek watershed to estimate the level of flow control that would be needed to reduce channel erosion. BC used the HSPF model, channel geometry data, and particle size data to calculate the geomorphically significant flows for 83 channel locations on the mainstem and tributaries. The results were compared to the flow control criteria contained in Minimum Requirements 5 and 7. Appendix E describes the methods and results. The following bullets summarize the key findings:

- Calculated geomorphically significant flows vary widely within the Clarks Creek watershed (see Figure 3-2).
- Calculated geomorphically significant flows for lower Clarks Creek correspond roughly to the flow thresholds of Minimum Requirement 7 in the MS4 Permit (i.e., 50 percent of the 2-year forested discharge through the approximately the 50-year forested discharge).
- Calculated geomorphically significant flows for upper Clarks Creek vary; the lower bound ranges from 5 percent of the 2-year forested discharge up to about 38 percent of the 2-year forested discharge). The upper bound tends to be two to three times larger than the 50-year forested discharge, likely due to the flow increases caused by urbanization.
- Calculated geomorphically significant flows for the tributaries vary widely from reach to reach. The lower bound ranges from as little as 5 percent of the 2-year forested discharge to greater than 100 percent of the 2-year forested discharge. The upper bound can be as much as six times larger than the 50-year forested discharge, likely due to the flow increases caused by urbanization.
- The lower flow bound was very low for the steepest, most incised stream reaches. This indicates that even small flows can cause bedload movement in these reaches. Controlling flows down to this level would be very difficult. Low-permeability soils cover most of the upper watershed, so infiltration potential is limited. Detention facilities would need to be very large in order to achieve the level of flow control needed to protect the steepest channel reaches.

Given the wide range of geomorphically significant flows, it would be difficult to establish a “one size fits all” flow control standard tailored to the Clarks Creek watershed. The geomorphically significant flow analysis does suggest that the default standards described in Minimum Requirements 5 and 7 of the MS4 Permits would be a substantial improvement in the current flow regime and help to mitigate the potential for future channel instabilities

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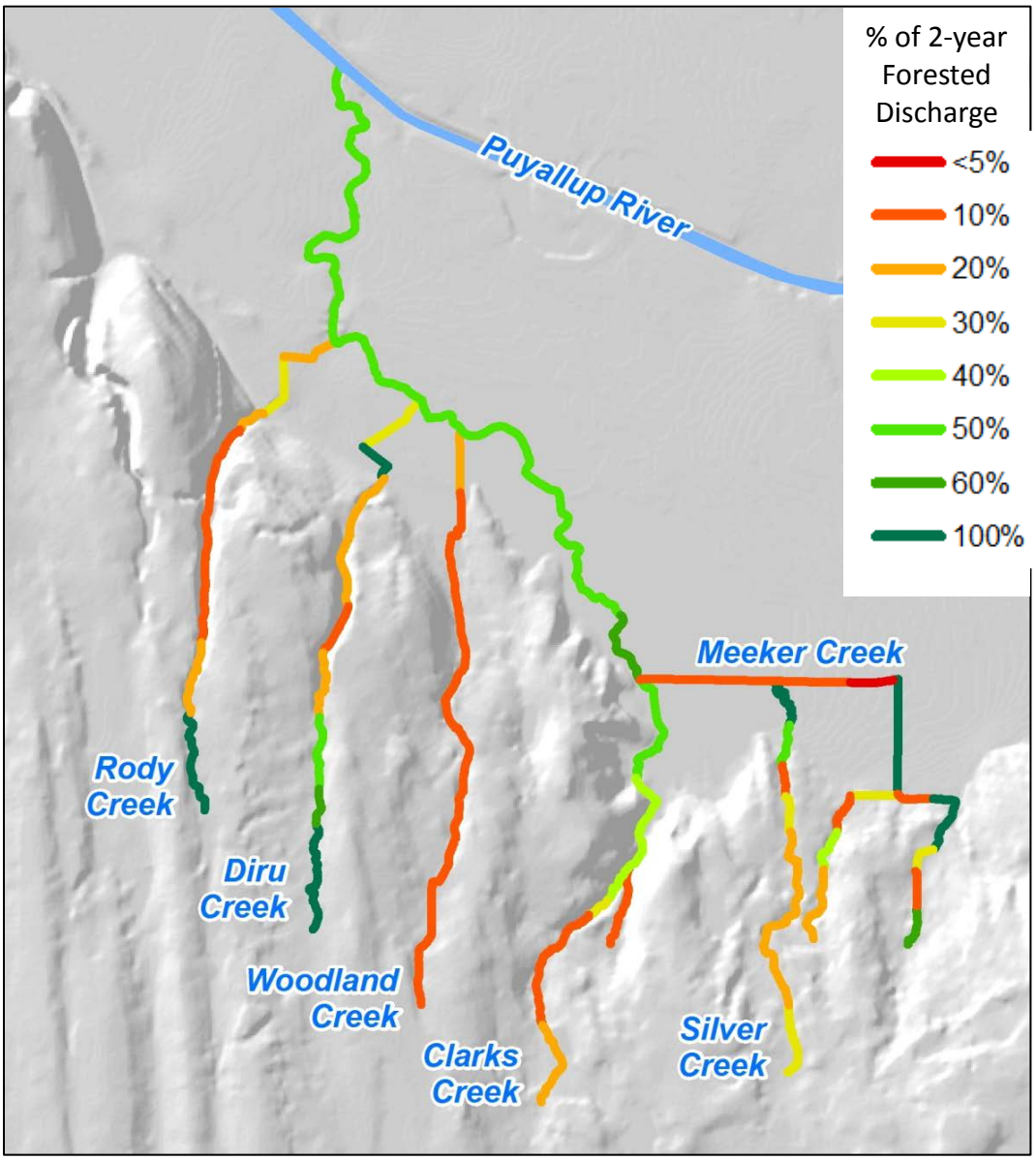

Figure 3-2. Lower bound for geomorphically significant flows in Clarks Creek

Achieving high levels of flow control will take many years and will not adequately address in-channel sources in the near term. Therefore, flow control regulations will likely need to be supplemented by capital projects. BC reviewed the City's 2012 *Comprehensive Drainage Plan* and the County's 2006 *Clear-Clarks Creek Basin Plan* to identify recommended projects that could help address the key sediment sources. The project team compiled an initial list of measures that could help address the key sediment sources in the watershed:

- **rain gardens and similar LID measures** to remove upland sediment and reduce erosive flows and channel erosion
- **pervious pavement** to reduce erosive flows and transport of sediment

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- **detention ponds** to reduce erosive flows and channel erosion, and trap sediment as well
- **sediment traps** to reduce the downstream sediment transport
- **stormwater treatment devices** to remove sediment from runoff
- **high-flow bypass pipes** to convey high stream flows past unstable channel reaches
- **stormwater diversion pipes** to divert runoff and sediment away from Clarks Creeks and its tributaries
- **in-channel measures** to reduce erosion of the bed and banks in steep, unstable reaches

The team met with the Tribe, City, County, WSU, Ecology, and EPA on July 31, 2012, to discuss the potential measures and formulate alternatives for evaluation. The team also had a number of follow-up discussions with City and County staff. The following bullets summarize the key points of these discussions:

- LID measures are likely to be effective for sediment removal but not very effective for flow control due to low-permeability soils in much of the watershed. Design concepts for onsite LID measures have been included in Appendix F.
- The City would like to retrofit its arterials with pervious pavement in order to reduce the need for costly stormwater detention and treatment facilities. The retrofitting would be done when the roads are due for repaving. For secondary roads that require only patching or replacement of the wear layer (rather than repaving), the City would like to install bioinfiltration facilities in the rights-of-way. The City plans to continue its incentive program to encourage voluntary LID retrofitting on private land, but cannot reliably predict how much retrofitting will occur as a result.
- The County does not plan to retrofit its roads in the watershed with pervious pavement or bioinfiltration facilities.
- The County basin plan recommends using the existing pond near the WDFW hatchery as a sediment trap. The City noted that this pond is owned by WDFW.
- The County's basin plan also includes recommendations for detention ponds and channel stabilization measures that could help address key sediment sources.
- Review of existing GIS data identified several additional areas where regional detention ponds might be feasible. Although additional data are needed to fully assess the feasibility of constructing regional detention ponds, stakeholders requested that detention projects be included on Diru, Woodland, Clarks, and Silver creeks. Regional ponds could reduce sediment loads by reducing the geomorphically significant flows that cause channel erosion and by trapping sediment from upstream areas. Potential ancillary benefits include removal of other pollutants and reduced downstream flooding. The County noted that regional facilities are generally easier to maintain than small distributed facilities. Possible challenges for regional ponds include land acquisition, site suitability, hydraulic constraints, and environmental permitting.
- The City and County were recently awarded grants for stormwater treatment projects in the Clarks Creek watershed.
- The City's *Comprehensive Drainage Plan* recommends a project to divert stormwater from the downtown area away from Clarks Creek and into the Puyallup River. Tribal staff expressed concern about discharging untreated runoff to the river. City staff noted that runoff from the diversion area would be treated in a Vortechs 9000 hydrodynamic device prior to discharge into the Puyallup River about 1.4 miles upstream of the confluence with Clarks Creek. The City installed the treatment device during the first phase of the diversion project. It is sized to treat runoff from the entire drainage basin after the diversion project is completed.

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- In-channel measures will be needed to reduce channel erosion because of the limited opportunities for flow control upstream of the eroding reaches, at least in the near term. Over the long term, the flow regime should improve due to flow control requirements for new development and redevelopment, LID retrofits, and regional detention facilities.
- Stakeholders would prefer to avoid "hard" channel stabilization measures, such as shotcrete and concrete drop structures.
- Stakeholders also expressed disinclination toward flow bypass projects due to potential permitting difficulties and concerns for long-term maintenance.
- The City and County are already sweeping streets throughout the basin on a regular basis.

BC formulated three alternatives based on the July 31, 2012, meeting and follow-up discussions with the City, County, and other stakeholders. Table 3-1 summarizes the measures in each alternative.

Table 3-1. Selected Projects for Alternatives Analysis

Project type	Brief description	Location	Jurisdiction	Target source	Alt 1	Alt 2	Alt 3
In-channel intervention	Rody Creek channel stabilization	Downstream of 80th Street E	County	In-channel	✓	✓	✓
	Diru Creek bank stabilization	Upstream of 72nd Street E	County	In-channel	✓	✓	✓
	Woodland Creek channel stabilization: lower	Downstream of 80th Street E	County	In-channel	✓	✓	✓
	Woodland Creek channel stabilization: upper	Downstream of 84th Street E	County	In-channel	✓	✓	✓
	Upper Clarks Creek channel stabilization	Downstream of 23rd Street SE	City	In-channel	✓	✓	✓
	Upper Clarks Tributary channel stabilization	Downstream of 23rd Street SE	City	In-channel	✓	✓	✓
	Silver Creek channel stabilization: lower	Downstream of 15th Street SE	City	In-channel	✓	✓	✓
	Silver Creek channel stabilization: upper	Downstream of 23rd Street SE	City	In-channel	✓	✓	✓
Regional detention	Rody Creek detention facility retrofit	Upstream of 90th Street E	County	Upland/in-channel		✓	✓
	Diru Creek detention facility	Downstream of 84th Street E	County	Upland/in-channel			✓
	Woodland Creek detention facility	Near 90th Street E	County	Upland/in-channel		✓	✓
	Clarks Creek detention facility	Upstream of 23rd Street SE	City	Upland/in-channel			✓
	Silver Creek detention facility	Upstream of 23rd Street SE	City	Upland/in-channel			✓
Sediment trap	Hatchery pond retrofit (sedimentation basin)	Clarks Cr. near WDFW hatchery	WDFW	Upland/in-channel		✓	✓
Stormwater diversion	15th Street stormwater diversion	Pioneer Avenue storm drain	City	Upland		✓	✓
	7th Avenue stormwater diversion	Diverted at 16th Street	City	Upland			✓

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Table 3-1. Selected Projects for Alternatives Analysis

Project type	Brief description	Location	Jurisdiction	Target source	Alt 1	Alt 2	Alt 3
Stormwater treatment	72nd Street stormwater improvements	72nd Street draining to Rody	County	Upland			✓
	North Pioneer stormwater treatment facility	Clarks Creek stormwater outfall	City	Upland		✓	✓
	South Pioneer stormwater treatment facility	Clarks Creek stormwater outfall	City	Upland		✓	✓
	16th Street SW stormwater treatment facility	Meeker Creek stormwater outfall	City	Upland		✓	✓
	11th Street SW stormwater treatment facility	Meeker Creek stormwater outfall	City	Upland		✓	✓
Distributed (LID)	Street edge/bioretention for secondary roadways	Secondary roadways in city	City	Upland/in-channel			✓
	Porous pavement for arterial roadways	Arterial roadways in city	City	Upland/in-channel			✓

3.2 Evaluation of Alternatives

Sediment reductions were evaluated using a combination of HSPF hydrologic simulations and magnitude-frequency analysis (MFA). The HSPF model developed by Tetra Tech (April 2012) was used to estimate upland source reductions and simulate changes in stream flow durations and frequency resulting from flow control measures. MFA computations were used to evaluate in-channel erosion potential under various combinations of flow regime, sediment composition, and hydraulic conditions.

The most comprehensive alternative (Alt 3) was evaluated first to determine whether it would meet the overall project goal (50 percent reduction in average annual sediment loads). The initial evaluation was performed assuming full implementation of all 23 of the individual measures that comprise Alt 3. To evaluate the effect of each individual measure, the modeling was repeated assuming implementation of all measures except the measure in question. The results were then compared to the full implementation scenario in order to show the sediment reductions associated with a given measure.

3.2.1 HSPF Modeling

Tetra Tech modified the existing conditions model to develop two additional scenarios: natural conditions (i.e., fully forested) and future/buildout conditions (see Appendix D). The buildout scenario assumes that all parcels have been converted to their zoned land use except where protected from development (Tetra Tech, 2012). This change results in a higher level of total imperviousness. However, the buildout scenario also mitigates for this increased imperviousness based on current stormwater requirements for new development/redevelopment. In other words, impervious surfaces from redeveloped areas were routed through a hypothetical stormwater facility to adjust for current flow control requirements. Additional details are provided in Appendix D.

The buildout scenario served as the baseline for evaluating future sediment reductions. The buildout conditions model was modified to represent the proposed Alt 3 scenario by adjusting for each of the 23 projects listed in Table 3-1. Details regarding the conceptual designs and sizing assumptions for each project are provided in the project fact sheets in Section 4.

Upland Source Reductions. Upland sediment loadings to the stream network were calculated for each scenario. The difference between the total upland sediment loadings for Alt 3 and buildout equates to

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the total reduction combined reduction resulting from implementation of all 23 projects. In total, Alt 3 resulted in about a 30 percent reduction in upland sediment sources.

Additional HSPF simulations were run to estimate the individual reduction benefits for each of the proposed projects. These additional scenarios were modified versions of Alt 3, where the project being evaluated was *removed* from the model. In other words, the modified condition represents a scenario with only 22 of the 23 projects. The increase in upland sediment loading caused by removal of any particular project corresponds with the sediment reduction benefit that was being contributed by that project. The analysis must be done in this way to account for the overlapping benefits some projects have when they target the same sediment source.

Flow Control. The HSPF model was also used to generate long-term stream flow hydrographs to evaluate changes in stream flow frequency and duration, and the resultant effects on erosion potential within the stream channels. Output hydrographs were processed into flow duration curves and flow frequency histograms (i.e., distributions of flow within specified bins). These data were used as input for subsequent MFA evaluations.

3.2.2 Magnitude-Frequency Analysis

MFA was performed to examine geomorphically significant flows (see Section 3.1 and Appendix E) and to evaluate measures for mitigating erosion potential in identified in-channel source reaches. Although the HSPF model developed by Tetra Tech contains sediment transport algorithms that can perform a similar function, MFA was used because it could be applied to specific problem locations and provides a more flexible framework for analyzing erosion potential.

Effective Work. MFA is based on the concept of "effective work." Wolman and Miller (1960) described how the geomorphic evolution of landscapes is strongly influenced by the amount of "work" done by the forces acting on the system. In streams, flowing water exerts shear stress on the bed and bank materials, and when sufficient force is applied, sediment is displaced and transported. The movement of sediment by water can be represented by a power function relating sediment transport to effective shear stress as follows:

$$q = k(\tau - \tau_c)^n$$

where: q = the rate of sediment transport,

k = a constant related to the characteristics of the transported material,

τ = the shear stress per unit area,

τ_c = the critical or threshold shear stress required to move the material, and

n = an exponent (Leopold et al. 1964)

The magnitude of the shear stress (τ) depends on the hydraulic characteristics of the stream channel (slope, geometry, roughness). The critical shear stress parameter (τ_c) represents the threshold below which no movement will occur, and is dependent upon the composition of the bed and bank sediments.

Wolman and Miller (1960) also explained that the relative amount of work done depends not only on the magnitude of the force applied, but also on the frequency of occurrence. Therefore, the amount of work done in a stream depends not only on hydraulic and sediment characteristics, but also on the frequency and duration of stream flows. The product of the frequency of the occurrences and the magnitude of the influencing force is referred to as the "effective work."

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Effective Work Index. In physics, work is defined as the integral of force over a distance of displacement. In the case of stream systems, work can be calculated based on stream power, or the product of flow velocity and shear stress. Total effective work was calculated using an effective work index defined as follows:

$$W = C \sum_{i=1}^{n} (\tau_i - \tau_c)^b \cdot V_i \cdot \Delta t$$

where: W = the index of total work done (units of foot-pounds per square foot),

C = a constant to dimensional or dimensionless units of work,

n = the number of increments in the flow histogram,

t = the applied hydraulic shear stress (pounds per square foot),

t_c = the critical shear stress that initiates bed movement (pounds per square foot),

e = an exponent that captures the exponential rise in stream power with flow,

V = the mid-channel flow velocity (feet per second),

Δt = the duration of flow for each time increment (seconds)

The exponent, b, captures the exponential rise in stream power with increasing flow rates. For this analysis, b was assumed to be equal to 1.5, which is consistent with standard bedload transport functions such as the equation developed by Meyer-Peter and Muller (1948).

MFA Tool. BC developed a spreadsheet tool to perform MFA calculations. This tool combines the flow frequency results from HSPF with hydraulic parameters and bed sediment sampling data to calculate effective work curves and estimate the effective work index under various scenarios (Figure 3-3).

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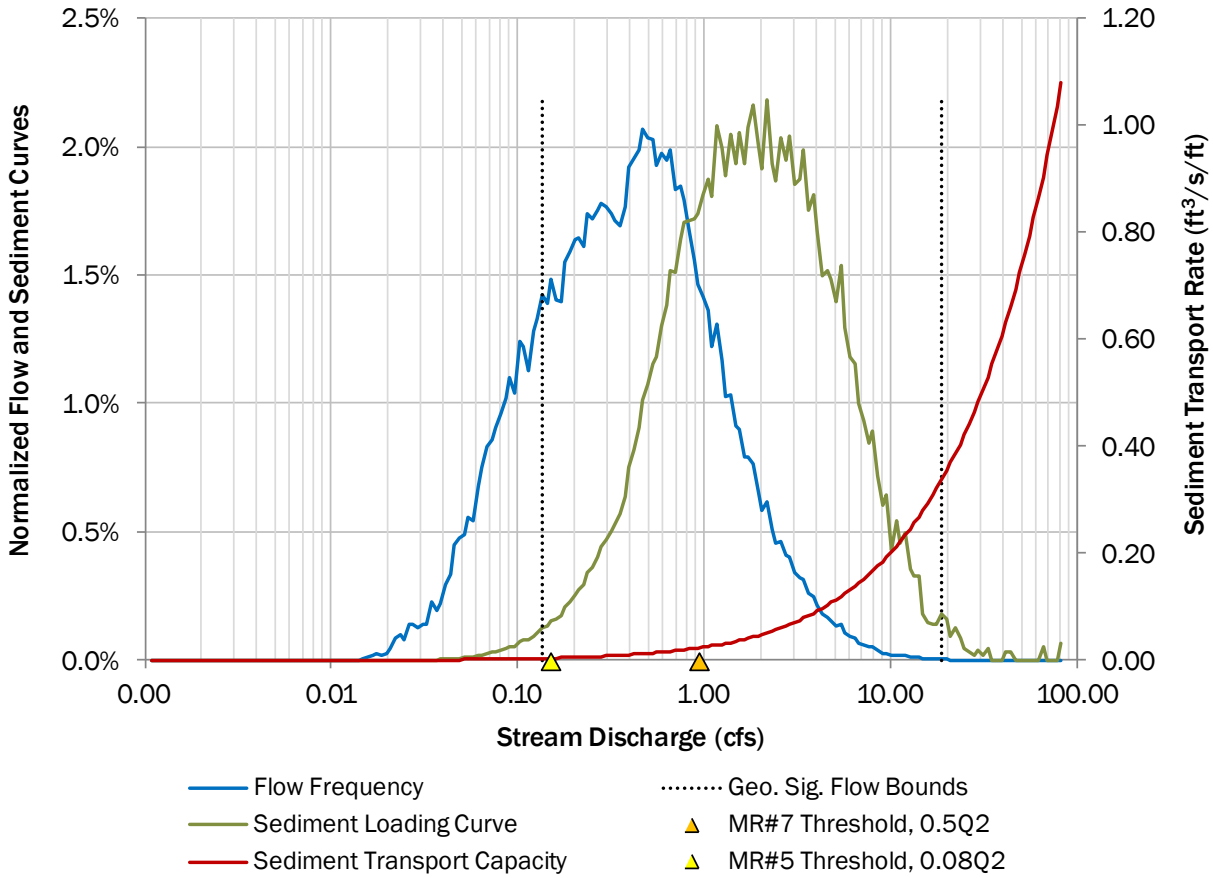

Figure 3-3. Example of an effective work graph from the MFA spreadsheet tool

The sediment transport capacity curve (red) represents the rate of sediment movement (i.e., magnitude of work) applied, while the flow frequency curve (blue) represents the frequency of the applied force. The product of those two curves results in the sediment loading (i.e., effective work) curve (green). The total area under that curve represents the effective work index.

The HSPF and MFA results indicated that the most comprehensive alternative (Alt 3) would achieve just over the Action Plan goal of 50 percent reduction in future sediment loads (see Figure 3-4). Therefore, no additional analyses were conducted on the less comprehensive alternatives (Alt 1 and Alt 2), whose measures were included in Alt 3. Based on stakeholder input, Alt 3 was selected for conceptual design and cost estimates (see Section 4).

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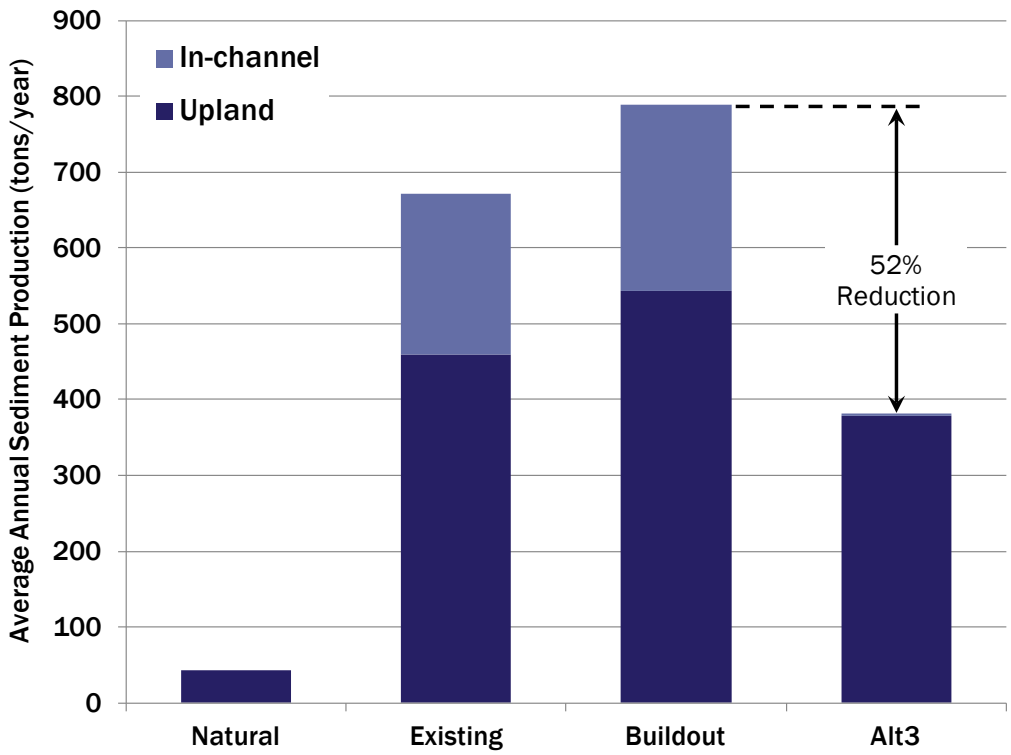

Figure 3-4. Estimated reduction in average annual sediment load from implementation of Alt 3

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Section 4
Action Plan

Section 4.1 describes the selected projects for the Clarks Creek Sediment Reduction Action Plan. Section 4.2 discusses the strategy for implementing these projects. Section 4.3 prescribes long-term monitoring of channel conditions to evaluate progress and adjust the Action Plan as needed.

4.1 Proposed Projects

Table 4-1 lists the projects comprising Alt 3, and provides summary information regarding project benefits and costs. A normalized benefit-cost index was calculated by dividing the annual sediment load reduction for each project by the estimated cost for that project, and then dividing that by the ratio for all projects. An index value greater than 1 indicates that a project has a benefit-to-cost ratio that is higher than the average for all of the projects included in Alt 3. Conversely, an index value less than 1 indicates that a project has a lower benefit-to-cost ratio that is lower than the average.

As discussed above, due to recent development in the upper watershed, current channel erosion rates are probably higher than the long-term (1916-2011) average. Therefore, the estimated annual sediment reductions for channel stabilization projects could be conservatively low.

Table 4-1 also provides a qualitative rating of the flow control benefit for each project. The benefit-cost index described in the previous paragraph is based on the identified sediment sources, which in the case of in-channel sources, is limited to the erosional problem areas for each of the assessed streams. However, projects that provide flow control can also help prevent future degradation of currently stable stream reaches.

Eight projects (Pr01, Pr02, Pr03, Pr04, Pr09, Pr10, Pr11, and Pr17) are located in unincorporated Pierce County. The total estimated sediment load reduction from these projects is about 89 tons/year. Pierce County is now designing Pr09 and Pr17. The fact sheets for these projects should be updated to align with the County's most recent design concepts and costs estimates.

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Table 4-1. Project Results Summary					
ID	Project description	Cost estimate	Annual sediment load reduction (tons/yr.)	Normalized benefit-cost index (1.0 = average)	Flow control benefit
Pr01	Rody Creek channel stabilization	$1,109,000	6.7	0.8	Low
Pr02	Diru Creek bank stabilization	$194,000	7.7	5.5	Low
Pr03	Woodland Creek channel stabilization: lower	$571,000	13.5	3.3	Low
Pr04	Woodland Creek channel stabilization: upper	$1,033,000	38.9	5.2	Low
Pr05	Upper Clarks Creek channel stabilization	$1,962,000	77.0	5.4	Low
Pr06	Upper Clarks Tributary channel stabilization	$1,146,000	56.4	6.8	Low
Pr07	Silver Creek channel stabilization: lower	$366,000	8.2	3.1	Low
Pr08	Silver Creek channel stabilization: upper	$769,000	34.8	6.2	Low
Pr09	Rody Creek detention facility retrofit	$443,000	4.4	1.4	High
Pr10	Diru Creek detention facility	$2,051,000	5.9	0.4	High
Pr11	Woodland Creek detention facility	$5,748,000	11.2	0.3	High
Pr12	Clarks Creek detention facility	$8,848,000	5.1	0.1	High
Pr13	Silver Creek detention facility	$6,640,000	8.3	0.2	High
Pr14	Hatchery pond retrofit (sedimentation basin)	$472,000	9.5	2.8	Low
Pr15	15th Street stormwater diversion	$1,285,300	54.9	5.9	High
Pr16	7th Avenue stormwater diversion	$11,731,000	31.1	0.4	High
Pr17	72nd Street stormwater improvements	$551,000	0.8	0.2	Low
Pr18	North Pioneer stormwater treatment facility	$187,000	2.3	1.7	Low
Pr19	South Pioneer stormwater treatment facility	$173,000	1.4	1.1	Low
Pr20	16th Street SW stormwater treatment facility	$157,000	0.8	0.7	Low
Pr21	11th Street SW stormwater treatment facility	$164,000	1.1	0.9	Low
Pr22	Street edge/bioretention for secondary roadways	$1,607,000	3.9	0.3	Moderate
Pr23	Porous pavement for arterial roadways	$6,663,000	7.7	0.2	Moderate
	Total	**$53,870,300**	**391.6**	**1.0**	--

4.2 Implementation Strategy

Implementation of the Action Plan is voluntary and will depend on the availability of funding from grants, City and County stormwater utility fees, and other sources. Opportunities to coordinate with infrastructure improvement projects or take advantage of land availability could accelerate the implementation of specific projects. Therefore, the Action Plan is structured to support a flexible implementation strategy rather than a fixed sequence. Proponents can select the projects that align with anticipated revenues and take advantage of opportunities (e.g., grants, complementary projects, availability of land) as they arise.

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Full implementation of this Action Plan could take 20 years or more. Basin conditions are likely to change over time due to changes in land use/land cover, new regulations, and new infrastructure, as well as implementation of the Action Plan projects. Before implementing a given Action Plan project, the project proponent should assess the situation to confirm that the project is still necessary and revise it as necessary to align with current conditions.

The Action Plan projects are designed to alter the dynamic processes that are contributing excess sediment loads to Clarks Creek. Monitoring should be conducted during Action Plan implementation to evaluate changes in channel conditions and confirm that the implemented projects are functioning as intended (see Section 4.3). The monitoring results should help determine whether the concepts for the remaining unbuilt projects should be modified to enhance their effectiveness and/or reduce costs.

4.3 Monitoring and Adaptive Management

This Action Plan describes a range of projects that are intended to reduce sediment loads to Clarks Creek. These projects are designed to alter the dynamic processes that are contributing to excess sediment loads. Creek channel conditions should be monitored during Action Plan implementation to evaluate the impacts of the projects on channel stability and sediment, and help determine whether the concepts for the remaining unbuilt projects should be modified to enhance effectiveness or reduce costs.

Channel monitoring should begin after the initial Action Plan projects have been constructed. The monitoring program should include the elements outlined below.

- **Geomorphic reconnaissance:** Geomorphic reconnaissance should be performed following project implementation to document channel conditions in the potentially affected reaches. The reconnaissance should be done using the same methods Inter-Fluve used to perform the 2011 geomorphic reconnaissance (see Appendix A). The affected reaches should be inspected once per year for 3 to 5 years and as soon as possible after large (greater than 5-year recurrence interval) storm events. Comparing the post-project channel conditions to 2011 channel conditions may help discern the effects of the Action Plan projects.
- **Cross-section survey:** The cross-sections established for this project should be re-surveyed every 5 to 10 years to assess changes in channel geometry. Appendix B contains the 2011 survey data for each cross-section. The data from the re-survey can be compared to the baseline (2011) survey in order to discern changes in the channel.
- **Channel photographs:** Permanent photo points should be established at each cross-section to document upstream and downstream channel conditions. Photographs should be taken during each cross-section survey. Comparison of photos from different points in time may help identify changes in the channel.

If the channel monitoring identifies potential problems, focused investigations and analyses may be needed to evaluate the cause(s) and support development of adaptive management measures. Additional investigations could include survey of new cross-sections, pebble counts, and MFAs.

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Project:	Rody Creek Channel Stabilization	ID:	Pr01
Location:	Rody Creek beginning near 80th Street East and ending approximately 500 feet downstream	Stream:	Rody Creek
		Project Cost:	$1,109,000
Jurisdiction:	Pierce County	Source Reduction:	6.7 tons/year
Proj. Type:	Channel stabilization (roughening)	Reduction-cost Score:	0.8
Target:	Degrading stream reach	Flow Control Benefit:	Low

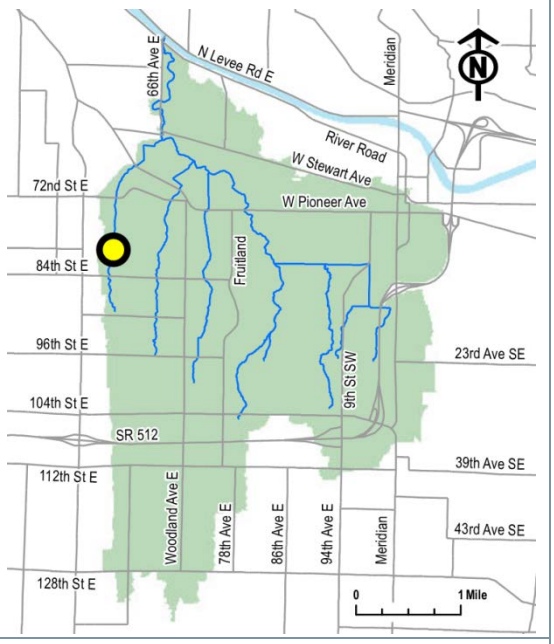
Narrative

During the 2011 field investigation, moderate channel incision was observed in this reach.

The recommended project is to stabilize this reach by roughening the channel within the degraded reach (approximately 500 linear feet) to reduce continued degradation and downstream transport of sediment into the lower reaches of Rody Creek.

A stabilization project was identified in Pierce County's 2009 Clear/Clarks Creek Basin Plan to address potential property damage from failing stream bank stabilization measures in this vicinity (Project CIP03-RY-SBS02).

Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.



Conceptual Design

- 500 LF of roughened channel using a mixture of large boulders, cobbles, gravel, sand, and large wood.
- Roughened area assumed to be approximately 25 feet wide to accommodate up to 100-year discharge.
- A mobile hydraulic crane could be used to place roughening material from outside the stream channel.
- Channel roughening cost assumed to be $200 per ton of material placed, based on recent project experience.
- Cost estimate assumes 600 LF of temporary access road would need to be constructed at $200 per linear foot.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the Washington State Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek, a Section 7 consultation will be required to ensure that the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- Easement may be required to provide construction and maintenance access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	6,000	1.1	7,000
Temporary access road	LF	200	600	120,000
Streambed roughening mixture (boulder, cobble, wood, gravel, sand)	TON	200	1,850	370,000
Riparian planting (restoration after access road removal)	LF	150	600	90,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**667,000**
Contractor overhead, profit, and mobilization			*10%*	67,000
Washington State sales tax				0
Construction contingency			*20%*	147,000
Subtotal construction costs				**881,000**
Administration, engineering design, permitting			*30%*	200,000
Land acquisition and easements			*LS*	27,500
Total cost				**1,109,000**

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Project:	Diru Creek Bank Stabilization		ID: Pr02
Location:	Diru Creek upstream of 72nd Street East	Stream:	Diru Creek
		Project Cost:	$194,000
Jurisdiction:	Pierce County	Source Reduction:	7.7 tons/year
Proj. Type:	Channel stabilization (banks)	Reduction-cost Score:	5.5
Target:	Eroding stream banks	Flow Control Benefit:	Low

Narrative

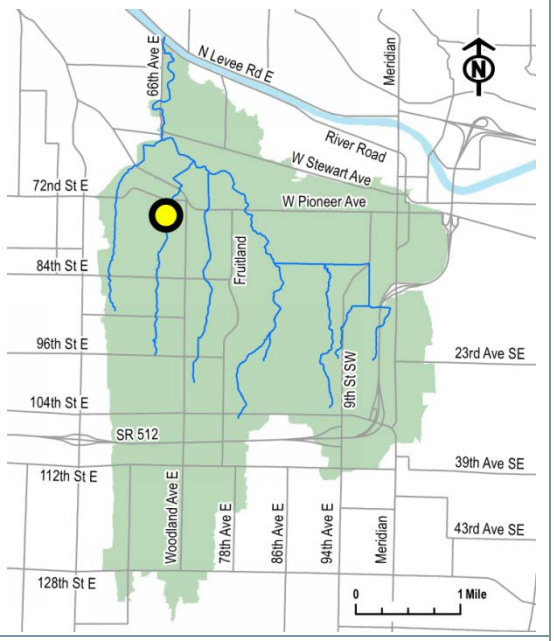
Current channel conditions were evaluated as part of this study in 2011, and the current channel appears to be relatively stable, with large wood complexes storing sediment within the channel already in place. Only moderate bank erosion was observed upstream of 72nd Street E.

The recommendation for Diru Creek is to use woody material and riparian plantings to provide additional bank stability in this reach (approximately 700 LF).

This is a low cost alternative designed to provide bank stability and reduced downstream sedimentation in a reach that appears to be relatively stable. This reach does not require more extensive stabilization techniques at this point in time.

Pierce County's 2009 Clear/Clarks Creek Basin Plan included a project to stabilize the stream channel downstream of 72nd Street where channel down cutting was observed at the time of their field reconnaissance (Project CIP03-DU-SBS01).

Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.



Conceptual Design

- Project consists of 700 LF of bank stabilization using woody material and riparian plantings; assumed $50 per linear foot.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- No land acquisition required for this project.

Considerations for Implementation

- A predesign study should be conducted to determine plant selection for achieving stable banks.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	6,000	0.8	5,000
Wood and riparian planting along banks	LF	50	700	35,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**120,000**
Contractor overhead, profit, and mobilization			*10%*	12,000
Washington State sales tax				0
Construction contingency			*20%*	26,000
Subtotal construction costs				**158,000**
Administration, engineering design, permitting			*30%*	36,000
Land acquisition and easements				0
Total cost				**194,000**

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Project:	Woodland Creek Channel Stabilization: Lower	ID:	Pr03
Location:	Woodland Creek downstream of 80th Street East	Stream:	Woodland Creek
		Project Cost:	$571,000
Jurisdiction:	Pierce County	Source Reduction:	13.5 tons/year
Proj. Type:	Channel stabilization (restoration)	Reduction-cost Score:	3.3
Target:	Degrading stream reach	Flow Control Benefit:	Low

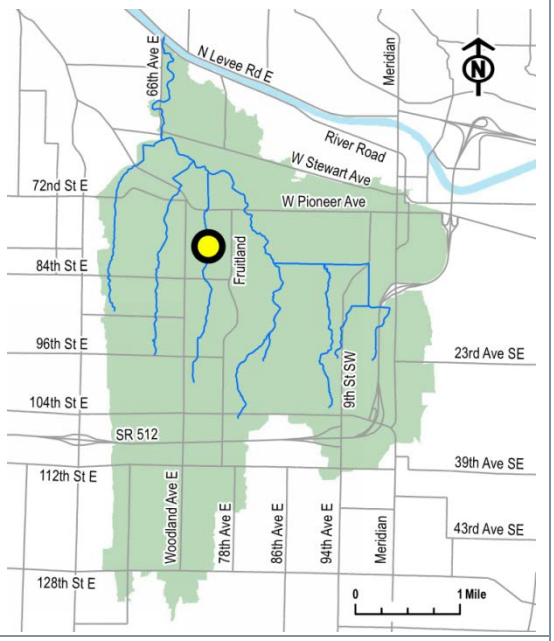
Narrative

During the 2011 field investigation, it was noted that there is incision about 3 feet deep, with no riparian buffer located on the east side of the channel, immediately downstream of 80th Street E.

The recommended project is to stabilize this reach by installing grade control and channel roughening features such as large wood. Additionally, woody vegetation would be planted on the banks and adjacent field on the east side of the channel for additional stabilization.

This project will provide reduced stream bank and bed sediment sources from contributing to downstream sedimentation, as well as an improved riparian habitat and floodplain connection.

Pierce County's 2009 Clear/Clarks Creek Basin Plan included a project to stabilize the stream channel downstream of 80th Street where channel down cutting was observed at the time of their field reconnaissance (Project CIP03-WO-SBS02). Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.



Conceptual Design

- 900 LF of stream restoration, including grade control, large woody debris, and habitat restoration.
- Restoration cost assumed to be $250 per linear foot, based on recent project experience.
- Large woody debris will be applied to provide hydraulic diversity and to enhance habitat for fish and other aquatic organisms.
- Assumed the site can be accessed without construction of a temporary access road.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A site-specific hydraulic analysis to evaluate sizes of in-stream structures will need to be conducted.
- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- Easement may be required to provide construction and maintenance access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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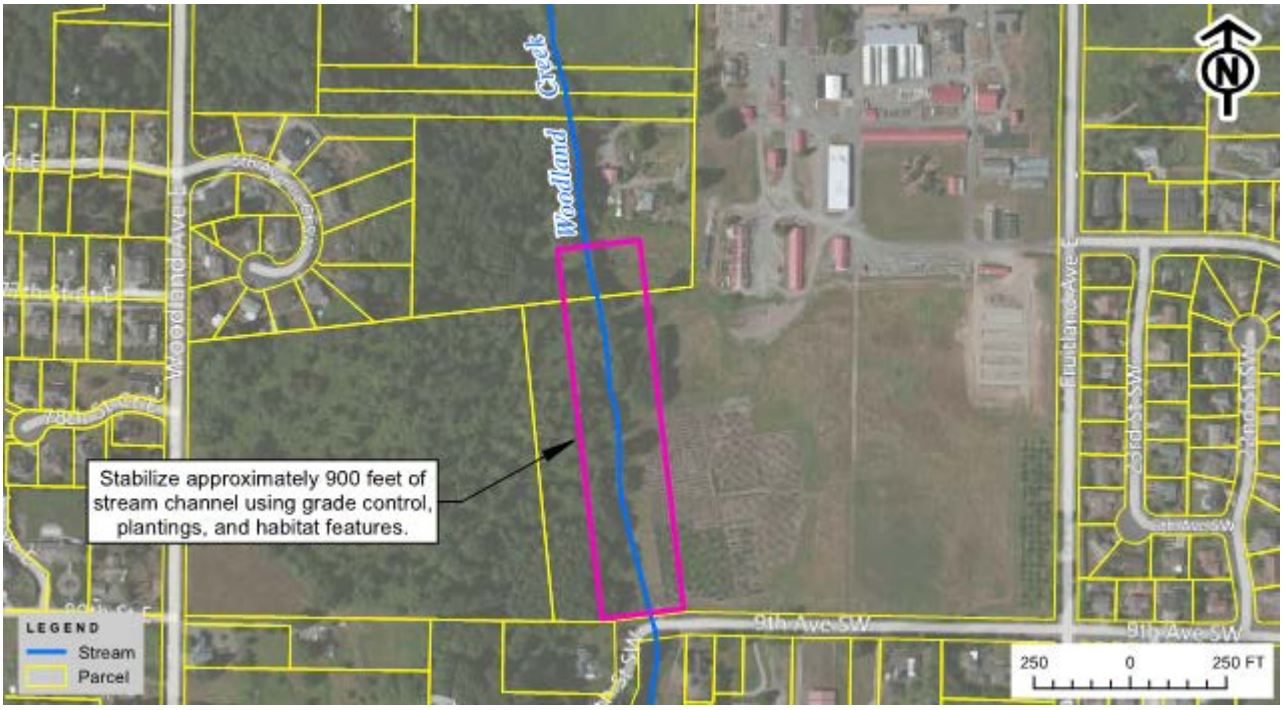

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	6,000	1.03	6,200
Stream restoration (grade control and habitat restoration)	LF	250	900	225,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**311,200**
Contractor overhead, profit, and mobilization			*10%*	31,000
Washington State sales tax				0
Construction contingency			*30%*	103,000
Subtotal construction costs				**445,200**
Administration, engineering design, permitting			*30%*	93,000
Land acquisition and easements			*LS*	32,000
Total cost				**571,000**

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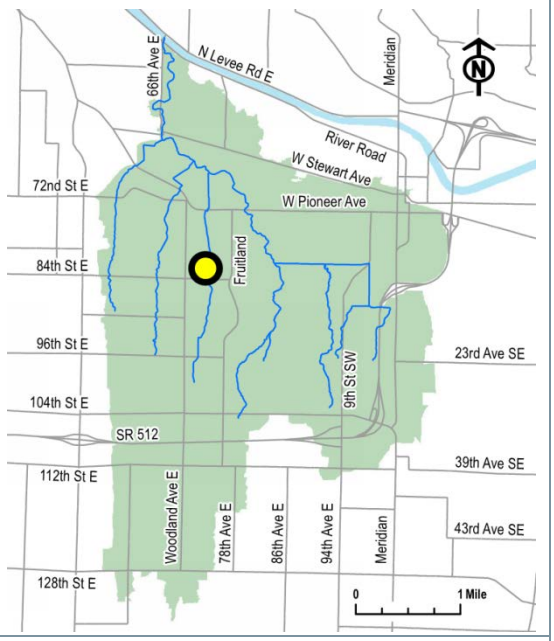
Project:	Woodland Creek Channel Stabilization: Upper	ID:	Pr04
Location:	Woodland Creek downstream of 84th Street	Stream:	Woodland Creek
		Project Cost:	$1,033,000
Jurisdiction:	Pierce County	Source Reduction:	38.9 tons/year
Proj. Type:	Channel stabilization (roughening)	Reduction-cost Score:	5.2
Target:	Degrading stream reach	Flow Control Benefit:	Low

Narrative

High stream flows have caused channel down cutting with 5-foot-deep channel incision in the reach downstream of 84th Street E. Local scour is observed at the outlet of the culvert under 84th Street E where a 12-foot-high cascade waterfall is located immediately downstream. Sedimentation within the channel and floodplain upstream of 80th Street E are caused by this upstream erosion activity.

The recommended project is to stabilize this reach by roughening the channel within the degraded reach (approximately 700 LF) to reduce continued degradation and downstream transport of sediment into the lower reaches of Woodland Creek.

Channel roughening would be accomplished with natural material, such as large boulders, cobbles and gravel, and large wood. A mobile hydraulic crane would be used where possible to place material into the stream channel from above.



Conceptual Design

- 700 LF of roughened channel using a mixture of large boulders, cobbles, gravel, sand, and large wood.
- Roughened area assumed to be approximately 25 feet wide to accommodate up to 100-year discharge.
- A mobile hydraulic crane could be used to place roughening material from outside the stream channel.
- Channel roughening cost assumed to be $200 per ton of material placed, based on recent project experience.
- Assumed the site can be accessed without construction of a temporary access road.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $4,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- Easement may be required to provide construction and maintenance access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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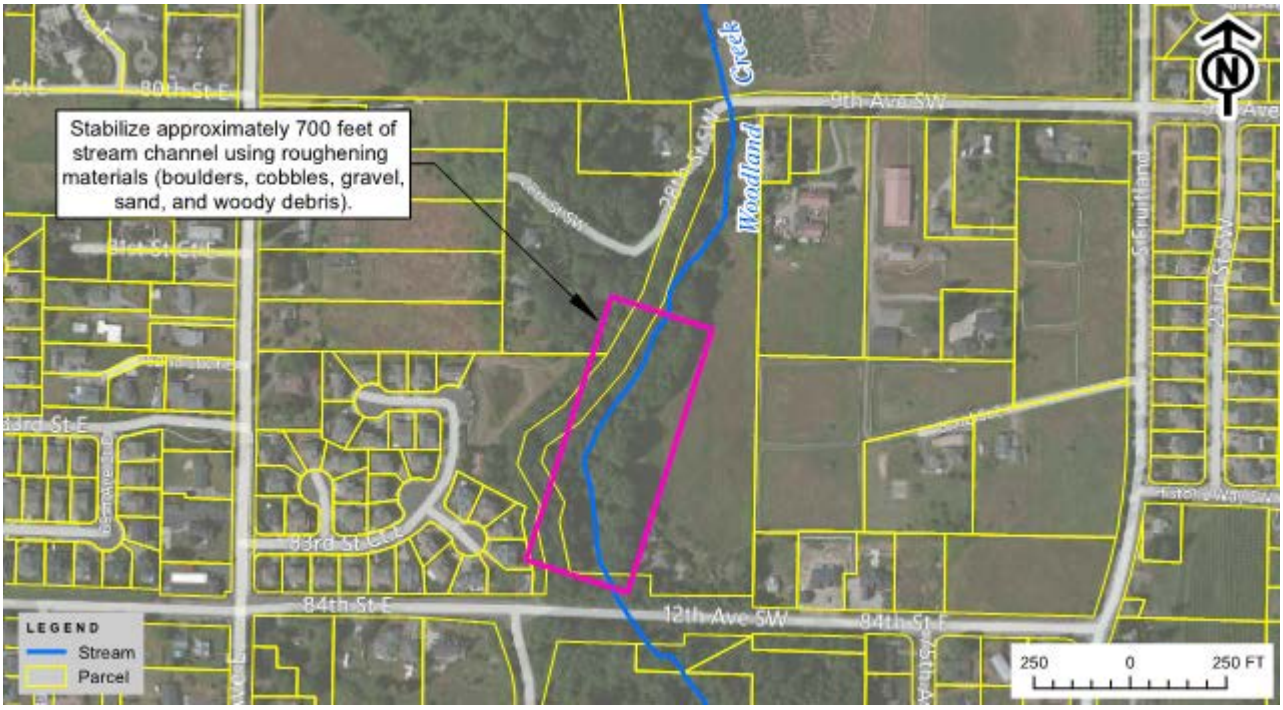

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	4,000	2.6	11,000
Streambed roughening mixture (boulder, cobble, wood, gravel, sand)	TON	200	2,590	518,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**609,000**
Contractor overhead, profit, and mobilization			*10%*	61,000
Washington State sales tax				0
Construction contingency			*20%*	134,000
Subtotal construction costs				**804,000**
Administration, engineering design, permitting			*30%*	183,000
Land acquisition and easements				46,000
Total cost				**1,033,000**

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Project:	Upper Clarks Creek Channel Stabilization		ID: Pr05
Location:	Upper Clarks Creek downstream of 23rd Avenue SW	Stream:	Upper Clarks Creek
		Project Cost:	$1,962,000
Jurisdiction:	City of Puyallup	Source Reduction:	77.0 tons/year
Proj. Type:	Channel stabilization (headcut repair and roughening)	Reduction-cost Score:	5.4
Target:	Degrading stream reach	Flow Control Benefit:	Low

Narrative

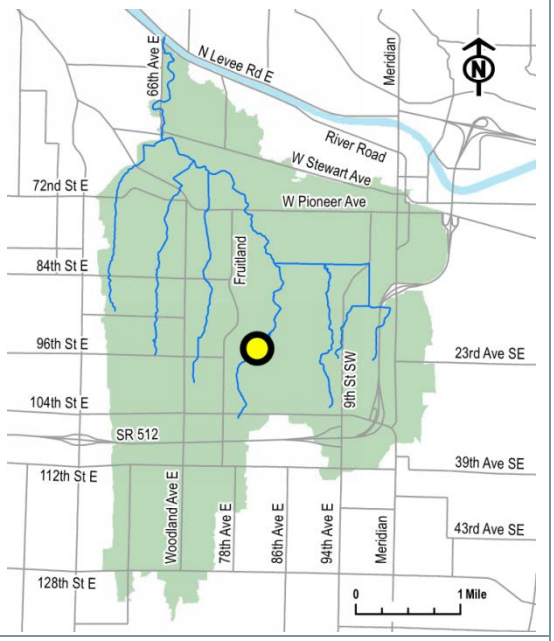
This project was identified during the field reconnaissance conducted in 2011. The upper reach of Clarks Creek is severely incised downstream of 23rd Avenue SW. A 12-foot-high headcut is located approximately 120 feet downstream of the road crossing and has the potential to migrate upstream toward the road.

The recommended project in this location is to stabilize the headcut and roughen the channel in the incised reach for approximately 1,000 LF of channel to reduce continued channel degradation and downstream transport of sediment into the lower reaches of Clarks Creek.

Channel roughening would be accomplished with natural material, such as large boulders, cobbles, gravel, sand, and large wood. A mobile hydraulic crane would be used where possible to place material into the stream channel from above (either from 23rd Avenue SW and/or access points to the east or west of the channel).

This project will reduce the risk to public infrastructure, including 23rd Avenue SW, which could eventually be threatened by erosion if the headcut continues to migrate upstream.

This project could be completed in conjunction with project Pr06. Cost reductions would result from shared resources, such as the temporary access road.



Conceptual Design

- 100 LF of fill and roughened channel material (large boulders, cobbles, gravel, sand) at headcut.
- 900 LF of roughened channel using a mixture of large boulders, cobbles, gravel, sand, and large wood.
- Roughened area assumed to be approximately 25 feet wide to accommodate up to 100-year discharge.
- A mobile hydraulic crane could be used to place roughening material from outside the stream channel.
- Channel roughening cost assumed to be $200 per ton of material placed, based on recent project experience.
- Cost estimate assumes 1,000 LF of temporary access road would need to be constructed ($200/LF).
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $4,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- No land acquisition required for this project.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- No easement required to provide construction access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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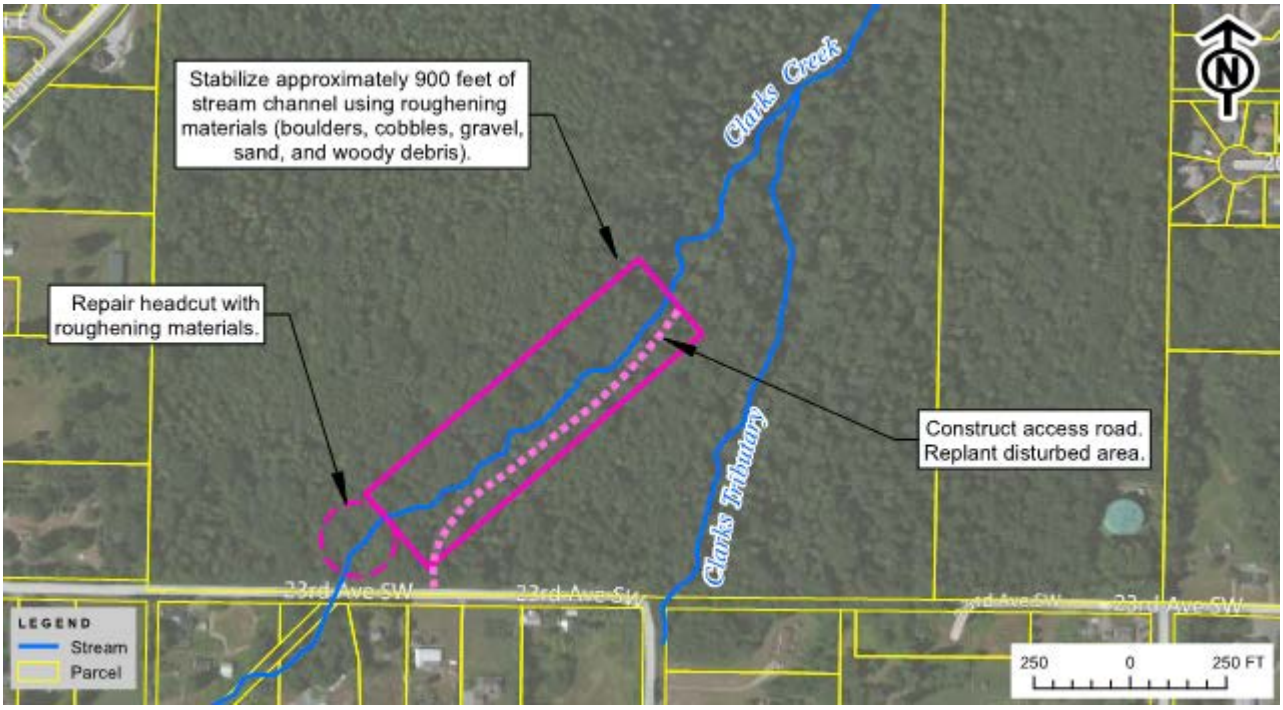

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	4,000	3.45	13,800
Temporary access road	LF	200	1,000	200,000
Streambed roughening mixture (boulder, cobble, wood, gravel, sand)	TON	200	4,070	814,000
Riparian planting (restoration after access road removal)	LF	150	1,000	150,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**1,257,800**
Contractor overhead, profit, and mobilization			*5%*	63,000
Washington State sales tax				0
Construction contingency			*20%*	264,000
Subtotal construction costs				**1,584,800**
Administration, engineering design, permitting			*30%*	377,000
Land acquisition and easements				0
Total cost				**1,962,000**

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Project:	Upper Clarks Tributary Channel Stabilization		ID: Pr06
Location:	Tributary to Upper Clarks Creek downstream of 23rd Avenue SW	Stream:	Upper Clarks Creek
		Project Cost:	$1,146,000
Jurisdiction:	City of Puyallup	Source Reduction:	56.4 tons/year
Proj. Type:	Channel stabilization (roughening)	Reduction-cost Score:	6.8
Target:	Degrading stream reach	Flow Control Benefit:	Low

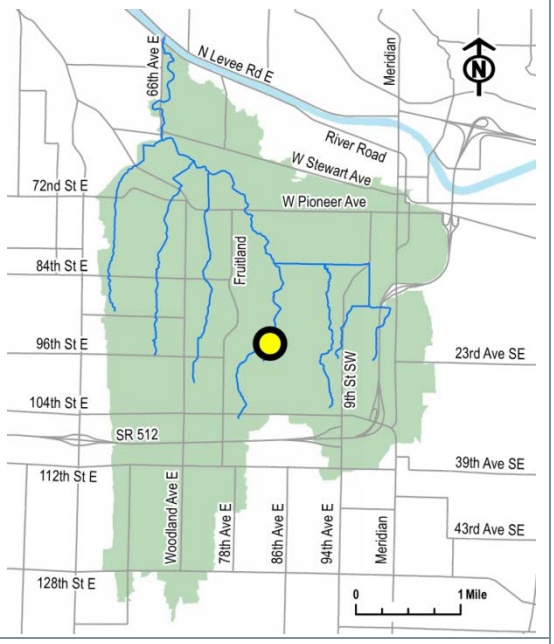
Narrative

This project was identified during field reconnaissance conducted in 2011. The tributary to Clarks Creek is currently incised up to 5 feet deep.

The recommended project is to stabilize this reach by roughening the channel within the degraded incised reach (approximately 400 LF) to reduce continued degradation and downstream transport of sediment into the lower reaches of Clarks Creek.

Channel roughening would be accomplished with natural material, such as large boulders, cobbles and gravel, and large wood. A mobile hydraulic crane would be used where possible to place material into the stream channel from above.

This project could be completed in conjunction with project Pr05. Cost reductions would result from shared resources, such as the temporary access road.



Conceptual Design

- 400 LF of roughened channel using a mixture of large boulders, cobbles, gravel, sand, and large wood.
- Roughened area assumed to be approximately 25 feet wide to accommodate up to 100-year discharge.
- A mobile hydraulic crane could be used to place roughening material from outside the stream channel.
- Channel roughening cost assumed to be $200 per ton of material placed, based on recent project experience.
- Cost estimate assumes 1,000 LF of temporary access road would need to be constructed at $200 per linear foot.
- Riparian habitat features are not included in this project due to intermittent flow conditions; however, plantings will be required to restore area disturbed by access road (assumed $150 per linear foot).
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $25,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- No easement required to provide construction access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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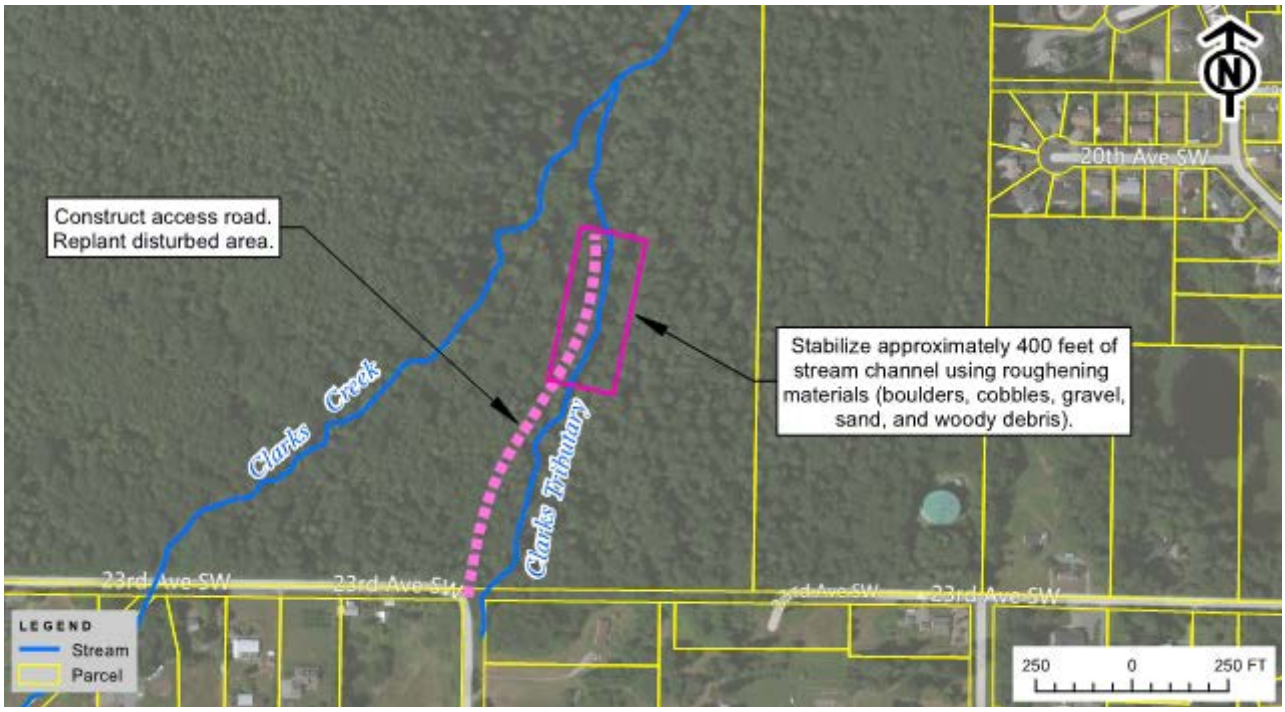

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	6,000	1	6,000
Temporary access road	LF	200	1,000	200,000
Streambed roughening mixture (boulder, cobble, wood, gravel, sand)	TON	200	1,480	296,000
Riparian planting (restoration after access road removal)	LF	150	1,000	150,000
Equipment rental and operation	LS	25,000	1	25,000
			Subtotal	**707,000**
Contractor overhead, profit, and mobilization			*10%*	71,000
Washington State sales tax				0
Construction contingency			*20%*	156,000
Subtotal construction costs				**934,000**
Administration, engineering design, permitting			*30%*	212,000
Land acquisition and easements				0
Total cost				**1,146,000**

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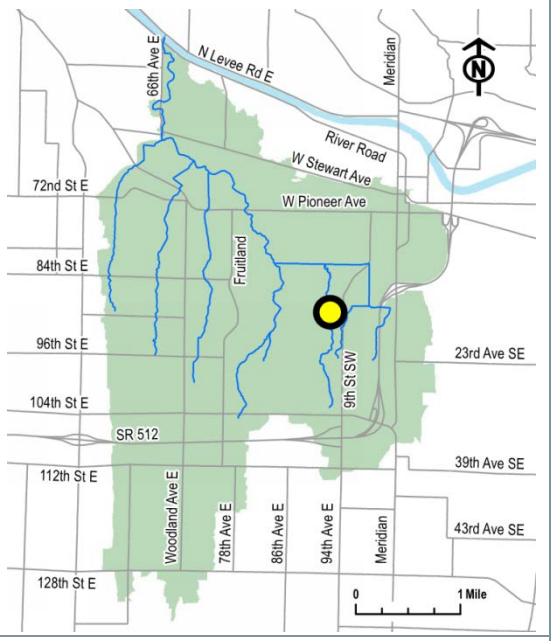
Project:	Silver Creek Channel Stabilization: Lower	ID:	Pr07
Location:	Silver Creek upstream of 15th Avenue SW	Stream:	Silver Creek
		Project Cost:	$366 ,000
Jurisdiction:	City of Puyallup	Source Reduction:	8.2 tons/year
Proj. Type:	Channel stabilization (restoration)	Reduction-cost Score:	3.1
Target:	Degrading stream reach	Flow Control Benefit:	Low

Narrative

This project was identified during the field reconnaissance conducted in 2011.

Degraded channel conditions were observed upstream of 15th Avenue SW. The level of incision is less than what was observed in the upper reach near 23rd Avenue SW.

The recommended project is to stabilize this reach by installing grade control and channel roughening features such as large wood. Additionally, woody vegetation would be planted on the banks and adjacent field on the east side of the channel for additional stabilization.



Conceptual Design

- 500 LF of stream restoration, including grade control, large woody debris, and habitat restoration.
- Restoration cost assumed to be $250 per linear foot, based on recent project experience.
- Large woody debris will be applied to provide hydraulic diversity and to enhance habitat for fish and other aquatic organisms.
- Assumed the site can be accessed without construction of a temporary access road.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $25,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A site-specific hydraulic analysis to evaluate sizes of in-stream structures will need to be conducted.
- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- Easement may be required to provide construction and maintenance access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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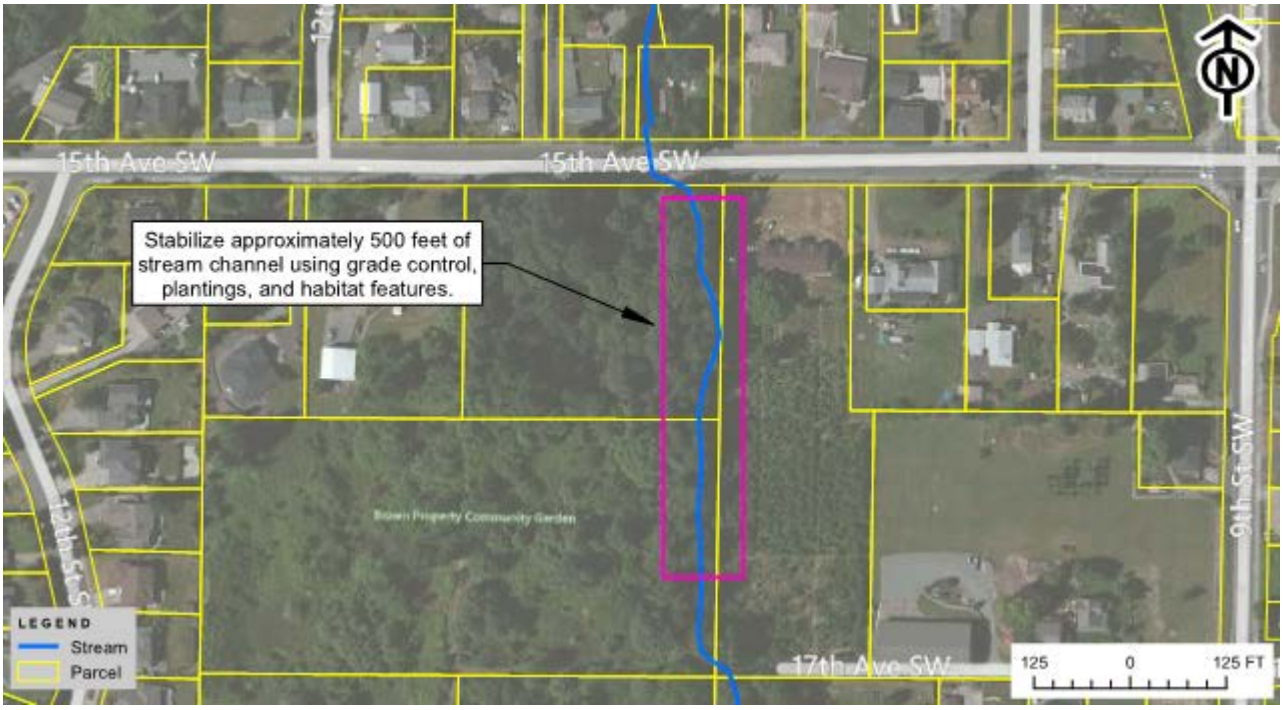

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	30,000	1	30,000
Site survey	AC	6,000	1.2	7,000
Stream restoration (grade control and habitat restoration)	LF	250	500	125,000
Equipment rental and operation	LS	25,000	1	25,000
			Subtotal	**187,000**
Contractor overhead, profit, and mobilization			*10%*	19,000
Washington State sales tax				0
Construction contingency			*20%*	62,000
Subtotal construction costs				**268,000**
Administration, engineering design, permitting			*30%*	75,000
Land acquisition and easements				23,000
Total cost				**366,000**

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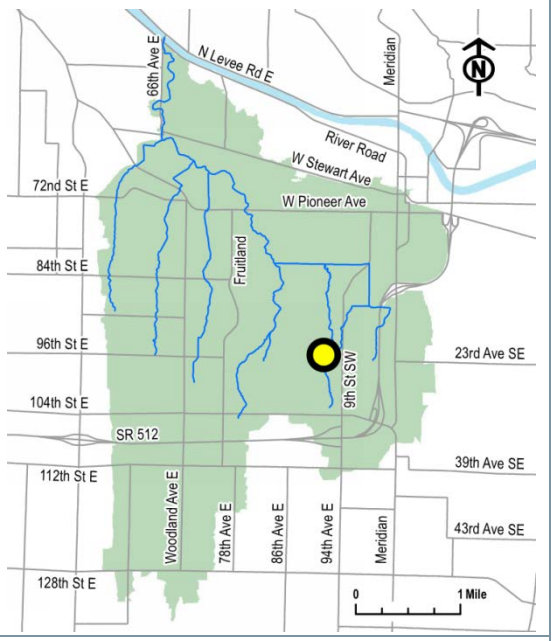
Project:	Silver Creek Channel Stabilization: Upper	ID:	Pr08
Location:	Silver Creek downstream of 23rd Avenue SW	Stream:	Silver Creek
		Project Cost:	$769,000
Jurisdiction:	City of Puyallup	Source Reduction:	34.8 tons/year
Proj. Type:	Channel stabilization (roughening)	Reduction-cost Score:	6.2
Target:	Degrading stream reach	Flow Control Benefit:	Moderate

Narrative

This project was identified during the field reconnaissance conducted in 2011. The stream channel was found to be severely incised with steep banks.

The recommended project is to stabilize this reach by roughening the channel within the degraded reach (approximately 500 LF) to reduce continued degradation and downstream transport of sediment into the lower reaches of Woodland Creek.

Channel roughening would be accomplished with natural material, such as large boulders, cobbles and gravel, and large wood. A mobile hydraulic crane would be used where possible to place material into the stream channel from above.



Conceptual Design

- 500 LF of roughened channel using a mixture of large boulders, cobbles, gravel, sand, and large wood.
- Roughened area assumed to be approximately 25 feet wide to accommodate up to 100-year discharge.
- A mobile hydraulic crane could be used to place roughening material from outside the stream channel.
- Channel roughening cost assumed to be $200 per ton of material placed, based on recent project experience.
- Assumed the site can be accessed without construction of a temporary access road.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $30,000.
- Cost estimate includes a site survey (assumed $6,000 per acre).
- Assumed lump sum of $50,000 for equipment rental and operation.
- Assumed all project activities can be completed within easements; no land acquisition.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Depending on the time of year, efforts for dewatering and/or fish removal may be needed.
- For the construction phase, access and staging areas will be critical. Locations will need to be identified for storing material and placing a crane such that material can be delivered to the channel from above without a disturbance to the surrounding riparian area and adjacent hill slopes.
- Easement may be required to provide construction and maintenance access, and a clearing and grading permit may be necessary for construction of the temporary access road. The temporary access road will be restored and revegetated upon completion of the project.

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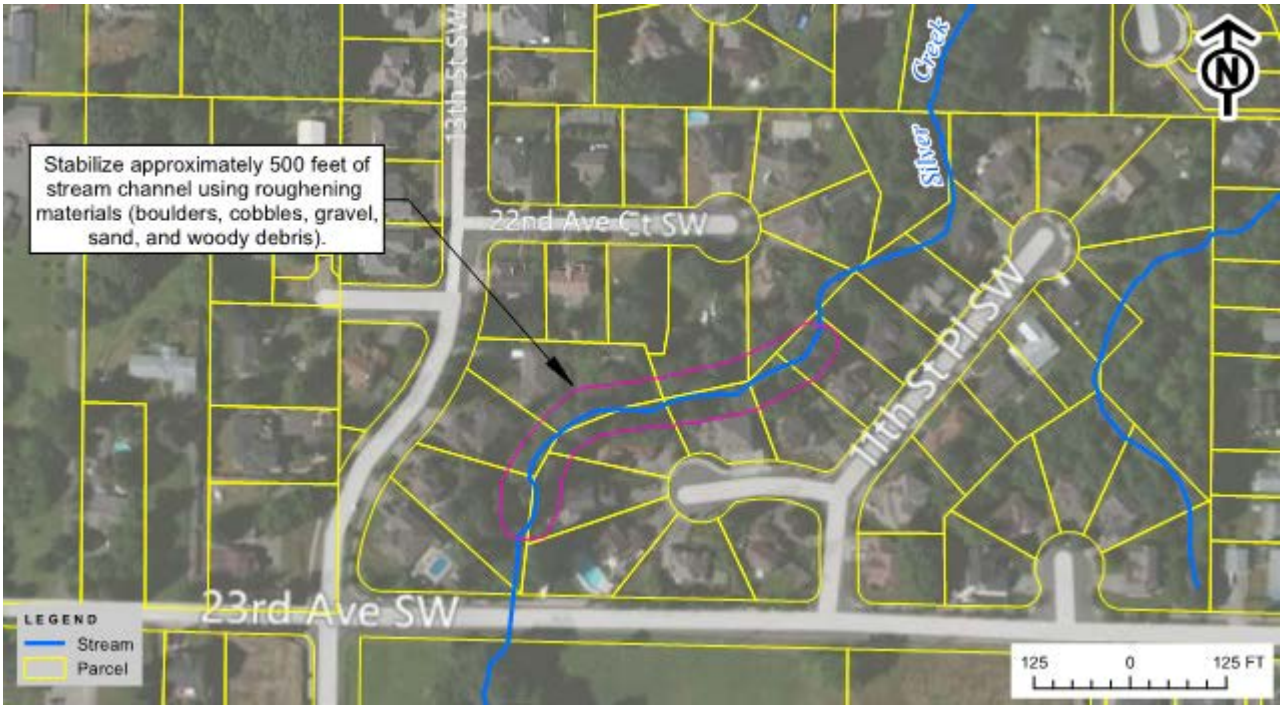

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control, mitigation for in-stream work	LS	10,000	1	10,000
Site survey	AC	6,000	1.2	7,000
Contractor staging area	EA	20,000	1	20,000
Streambed roughening mixture (boulder, cobble, wood, gravel, sand)	TON	200	1,850	370,000
Equipment rental and operation	LS	50,000	1	50,000
			Subtotal	**457,000**
Contractor overhead, profit, and mobilization			*10%*	46,000
Washington State sales tax				0
Construction contingency			*20%*	101,000
Subtotal construction costs				**604,000**
Administration, engineering design, permitting			*30%*	137,000
Land acquisition and easements				28,000
Total cost				**769,000**

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Project:	Rody Creek Detention Facility Retrofit		ID: Pr09
Location:	Rody Creek south of 90th Street East	Stream:	Rody Creek
		Project Cost:	$443,000
Jurisdiction:	Pierce County	Source Reduction:	4.4 tons/year
Proj. Type:	Regional detention facility (retrofit of existing facility)	Reduction-cost Score:	1.4
Target:	Flow control for Rody Creek	Flow Control Benefit:	High

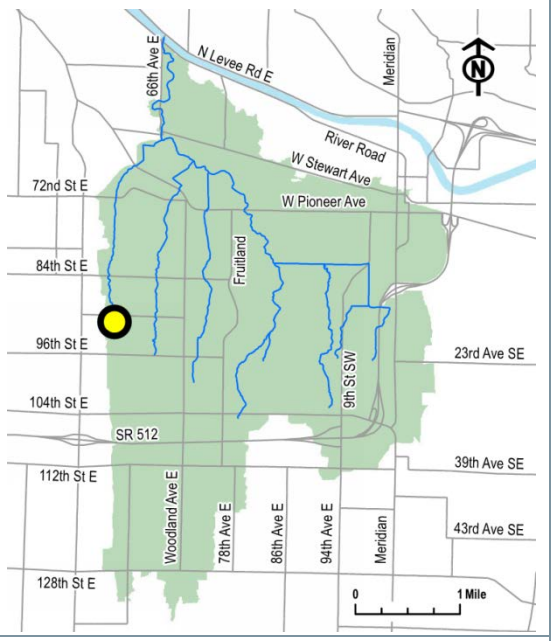
Narrative

The purpose of this project is to retrofit the existing detention facility to achieve additional flow duration control and water quality treatment.

Pierce County's 2009 Clear/Clarks Creek Basin Plan included a project to retrofit the existing facility on Rody Creek to increase capacity and provide additional flow control benefits for downstream stabilization projects (Project CIP03-RY-DP01).

Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.

Only capital expenditures necessary to retrofit the detention pond were included in the cost estimate. Annual inspection and periodic maintenance would be necessary for the detention pond to function as designed. Annual inspection and maintenance costs may be on the order of 3%–5% of the capital cost.



Conceptual Design

- Expand pond size to approximately 34 acre-feet.
- Add two wet cells for water quality treatment.
- Excavation assumed to be $20 per cubic yard including haul.
- A new pond outlet control structure will be required; assumed lump sum of $20,000.
- Project assumed to include seeding and mulching, shrub plantings and tree plantings.
- Cost estimate includes erosion/water pollution mitigation during in-stream work.

Considerations for Implementation

- Additional hydrologic analysis should be conducted to optimize flow and duration control benefits.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- This project will require a clearing and grading permit.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	14,000	1	14,000
Excavation including haul	CY	20	4,500	90,000
Embankment compaction	CY	5	3,000	15,000
Pond outlet control structure	EA	20,000	1	20,000
Seeding and mulching	AC	4,500	5	22,000
Shrub plantings	EA	150	266	40,000
Tree plantings	EA	250	132	33,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
			Subtotal	**237,000**
Contractor overhead, profit, and mobilization			*10%*	24,000
Washington State sales tax			*9.5%*	25,000
Construction contingency			*30%*	86,000
Subtotal construction costs				**372,000**
Administration, engineering design, permitting			*30%*	71,000
Land acquisition and easements				0
Total cost				**443,000**

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Project:	Diru Creek Detention Facility		ID: Pr10
Location:	North side of 84th Street East adjacent to Diru Creek	Stream:	Diru Creek
		Project Cost:	$2,051,000
Jurisdiction:	Pierce County	Source Reduction:	5.9 tons/year
Proj. Type:	Regional detention facility	Reduction-cost Score:	0.4
Target:	Flow control for Diru Creek	Flow Control Benefit:	High

Narrative

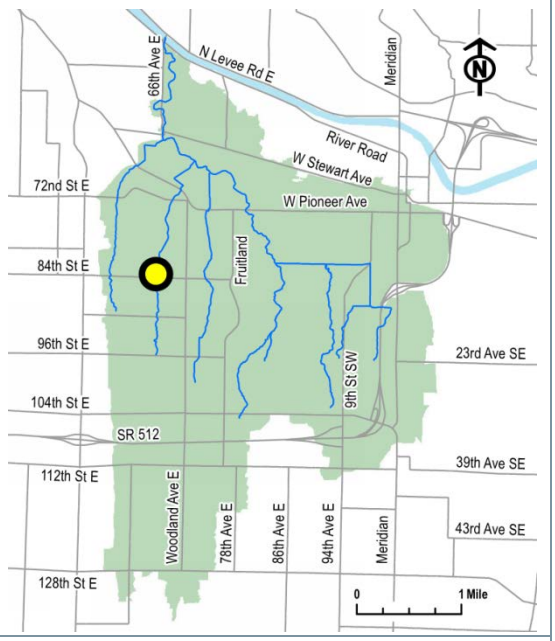
Urbanization in the Diru Creek basin has increased runoff rates and durations, which has led to stream channel instability. Future development within the basin could exacerbate these conditions unless flow control measures are implemented.

Construction of a detention facility would provide flow control benefits in lieu of onsite measures and reduce erosion potential in downstream reaches. In addition, a detention pond facility could be configured to capture and remove sediments.

A site for the detention facility was selected by visual inspection of aerial photography to identify one or more relatively undeveloped parcels upstream of the steepest stream reaches. Additional investigations should be conducted to assess site suitability, spatial and hydraulic constraints, and likelihood of acquisition.

Pierce County's 2009 Clear/Clarks Creek Basin Plan included a project to construct a regional detention facility on Diru Creek to provide flow control benefits for downstream stabilization projects (Project CIP03-DU-DP01). Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.

Only capital expenditures necessary to construct the detention pond were included in the cost estimate. Annual inspection and periodic maintenance would be necessary for the detention pond to function as designed. Annual inspection and maintenance costs may be on the order of 3%–5% of the capital cost.



Conceptual Design

- Construct a 17-acre-foot detention facility on available site upstream of unstable stream reaches. Sizing for the conceptual design was based on an assumed available area and maximum storage depth of 6 feet; actual facility size should be based on site investigations and predesign studies.
- Excavation assumed to be $20 per cubic yard including haul; excavated volume assumed to be 80% of storage plus 2 feet over-excavation.
- Assumed 20% of storage obtained by constructing banks.
- Access road will need to be constructed; $25,000 lump sum.
- A pond outlet control structure will be constructed; assumed $8,000 lump sum.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Cost estimate also includes riprap inlet/outlet, clearing and grubbing, seeding and mulching/ tree/shrubs.
- Land acquisition costs based on assessed parcel values plus 50%.

Considerations for Implementation

- An in-line pond is likely to be difficult to permit; an off-line facility may need to be considered. Assumed off-line facility for cost estimate.
- It was assumed that upstream flows can be routed through the pond by gravity.
- Additional hydrologic analysis should be conducted to optimize flow and duration control benefits.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- This project will need a clearing and grading permit.
- A critical areas study may be needed (wetland delineation).
- Access and staging areas will need to be developed for the construction phase.
- High groundwater levels may be limit the depth of the pond and reduce the available storage.
- Temporary erosion and sediment control may need to be applied.
- Land acquisition and easements will be required.
- Project could encompass multiple parcels and therefore require negotiations with multiple landowners.
- Conduct stakeholder involvement to identify potential concerns (e.g., vectors, safety) and incorporate mitigation into design.

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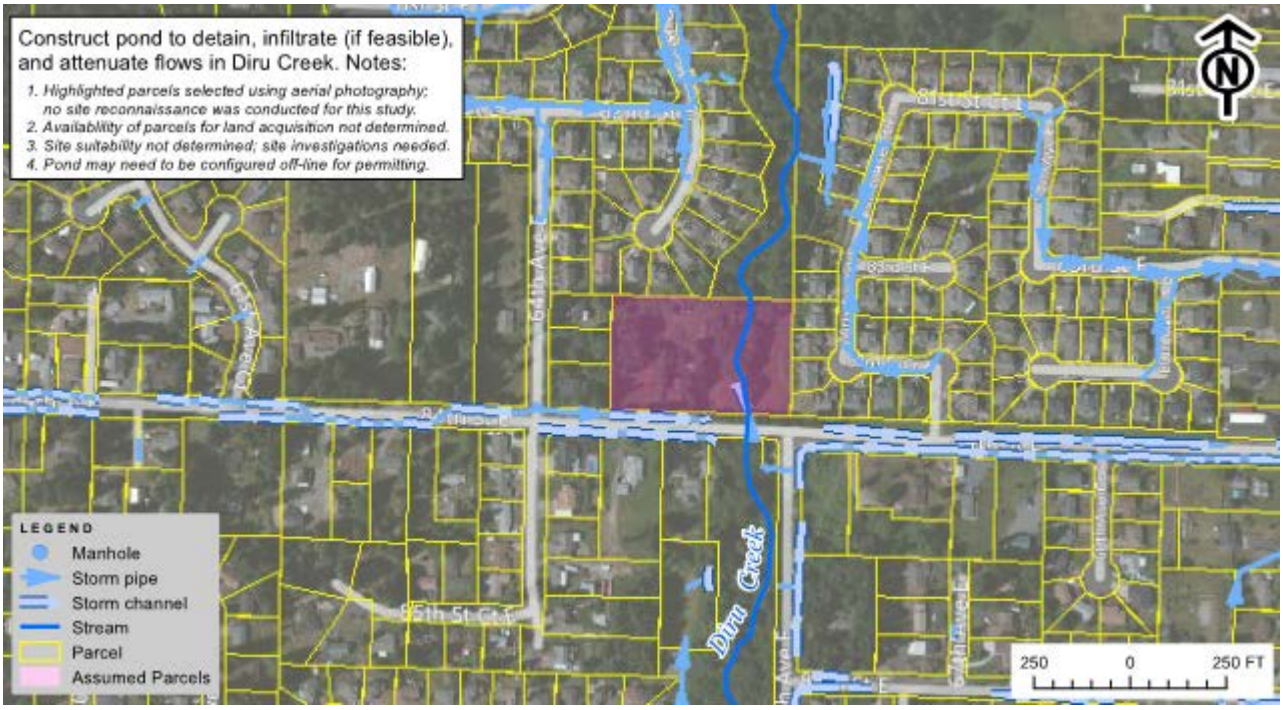

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Site survey	AC	3,000	4	12,000
Erosion and water pollution control	LS	10,000	1	10,000
Clearing and grubbing	AC	3,000	4	12,000
Excavation including haul	CY	20	31,834	637,000
Select borrow including haul	TON	20	1,100	22,000
Embankment compaction	CY	10	600	6,000
Quarry spalls (riprap)	TON	35	86	3,000
Access road	LS	25,000	1	25,000
Pond outlet control structure	EA	8,000	1	8,000
Modifications to existing stormwater collection system	LS	15,000	1	15,000
Seeding and mulching	AC	4,500	4	18,000
Shrub plantings	EA	150	332	50,000
Tree plantings	EA	250	166	42,000
Chain link fence (Type 3)	LF	30	430	43,000
Double 20-foot fence gate	EA	2,000	1	2,000
Temporary traffic control	DAY	300	30	9,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
			Subtotal	**917,000**
Contractor overhead, profit, and mobilization			*10%*	92,000
Washington State sales tax			*9.5%*	96,000
Construction contingency			*30%*	332,000
Subtotal construction costs				**1,437,000**
Administration, engineering design, permitting			*30%*	275,000
Land acquisition and easements				$338,400
Total cost				**2,051,000**

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Project:	Woodland Creek Detention Facility	ID:	Pr11
Location:	Near 72nd Avenue East and 90th Street East	Stream:	Woodland Creek
		Project Cost:	$5,748,000
Jurisdiction:	Pierce County	Source Reduction:	11.2 tons/year
Proj. Type:	Regional detention facility	Reduction-cost Score:	0.3
Target:	Flow control for Woodland Creek	Flow Control Benefit:	High

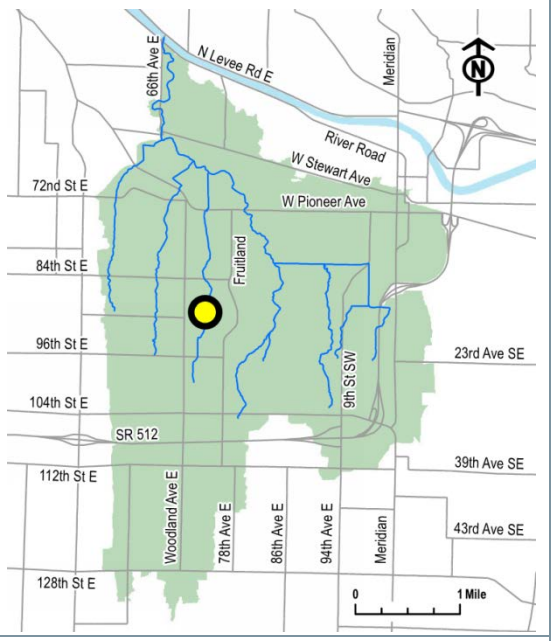
Narrative

Urbanization in the Woodland Creek basin has increased runoff rates and durations, which has led to stream channel instability. Future development within the basin could exacerbate these conditions unless flow control measures are implemented.

Construction of a detention facility would provide flow control benefits in lieu of onsite measures and reduce erosion potential in downstream reaches. In addition, a detention pond facility could be configured to capture and remove sediments.

A site for the detention facility was selected by visual inspection of aerial photography to identify one or more relatively undeveloped parcels upstream of the steepest stream reaches. Additional investigations should be conducted to assess site suitability, spatial and hydraulic constraints, and likelihood of acquisition.

Only capital expenditures necessary to construct the detention pond were included in the cost estimate. Annual inspection and periodic maintenance would be necessary for the detention pond to function as designed. Annual inspection and maintenance costs may be on the order of 3%–5% of the capital cost.



Conceptual Design

- Construct a 50-acre-foot detention facility on available site upstream of unstable stream reaches. Sizing for the conceptual design was based on an assumed available area and maximum storage depth of 6 feet; actual facility size should be based on site investigations and predesign studies.
- Excavation assumed to be $20 per cubic yard including haul; excavated volume assumed to be 80% of storage plus 2 feet over-excavation.
- Assumed 20% of storage obtained by constructing banks.
- Access road will need to be constructed; $25,000 lump sum.
- A pond outlet control structure will be constructed; assumed $8,000 lump sum.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Cost estimate includes a site survey (assumed $3,000 per acre).
- Cost estimate also includes riprap inlet/outlet, clearing and grubbing, seeding and mulching/ tree/shrubs.
- Land acquisition costs based on assessed parcel values plus 50%.

Considerations for Implementation

- An in-line pond is likely to be difficult to permit; an off-line facility may need to be considered. Assumed off-line facility for cost estimate.
- It was assumed that upstream flows can be routed through the pond by gravity.
- Additional hydrologic analysis should be conducted to optimize flow and duration control benefits.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- This project will need a clearing and grading permit.
- A state dam safety permit would be required because the pond capacity would exceed 10 acre feet. A critical areas study may be needed (wetland delineation).
- Access and staging areas will need to be developed for the construction phase.
- High groundwater levels may be limit the depth of the pond and reduce the available storage.
- Temporary erosion and sediment control may need to be applied.
- Land acquisition and easements will be required.
- Project could encompass multiple parcels and therefore require negotiations with multiple landowners.
- Conduct stakeholder involvement to identify potential concerns (e.g., vectors, safety) and incorporate mitigation into design.

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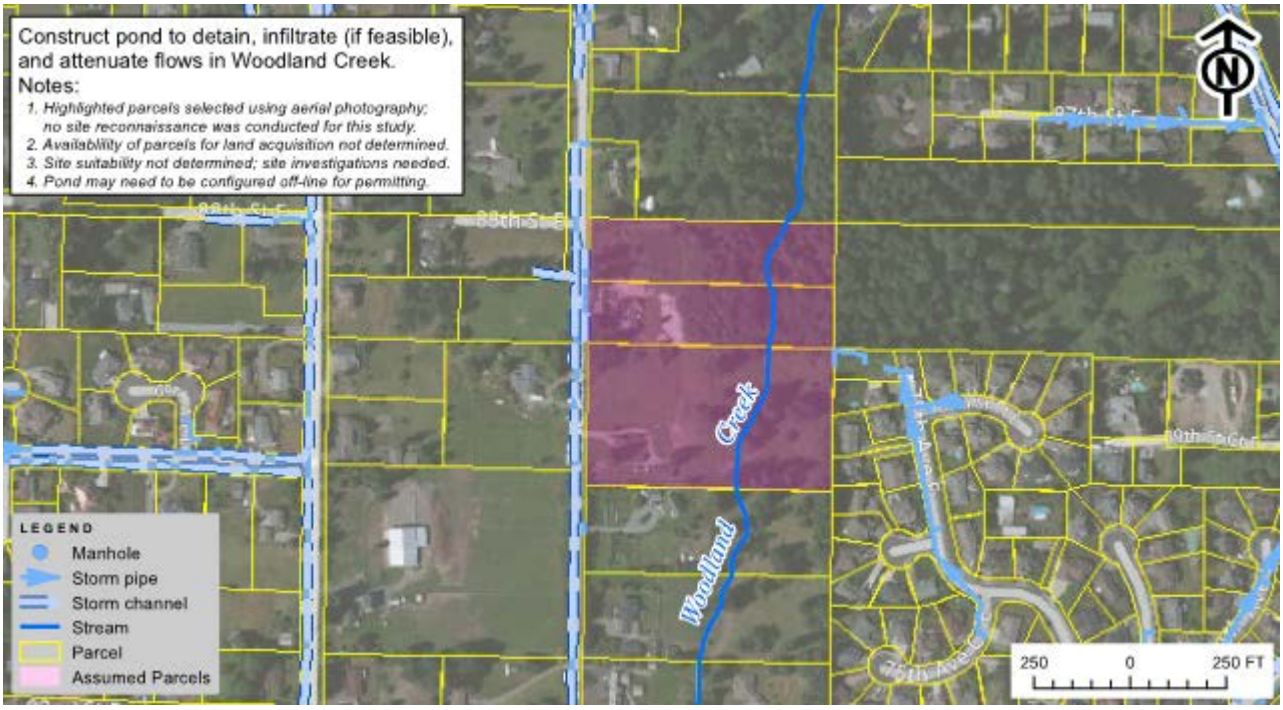

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Site survey	AC	3,000	11.7	35,000
Erosion and water pollution control	LS	48,000	1	48,000
Clearing and grubbing	AC	3,000	11.7	35,000
Excavation including haul	CY	20	105,543	2,111,000
Select borrow including haul	TON	20	1,950	39,000
Embankment compaction	CY	10	1,100	11,000
Quarry spalls (riprap)	TON	35	86	3,000
Access road	LS	25,000	1	25,000
Pond outlet control structure	EA	8,000	1	8,000
Modifications to existing stormwater collection system	LS	15,000	1	15,000
Seeding and mulching	AC	4,500	11.7	52,000
Shrub plantings	EA	150	567	85,000
Tree plantings	EA	250	284	71,000
Chain link fence (Type 3)	LF	30	2,430	73,000
Double 20-foot fence gate	EA	2,000	1	2,000
Temporary traffic control	DAY	300	30	9,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
			Subtotal	**2,625,000**
Contractor overhead, profit, and mobilization			*10%*	263,000
Washington State sales tax			*9.5%*	274,000
Construction contingency			*30%*	949,000
Subtotal construction costs				**4,111,000**
Administration, engineering design, permitting			*30%*	788,000
Land acquisition and easements				$848,250
Total cost				**5,748,000**

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Project:	Clarks Creek Detention Facility	ID:	Pr12
Location:	Upstream of 23rd Avenue SW (96th Street E) near Fruitland Avenue E	Stream:	Clarks Creek
		Project Cost:	$8,848,000
Jurisdiction:	City of Puyallup	Source Reduction:	5.1 tons/year
Proj. Type:	Regional detention facility	Reduction-cost Score:	0.1
Target:	Flow control for Clarks Creek	Flow Control Benefit:	High

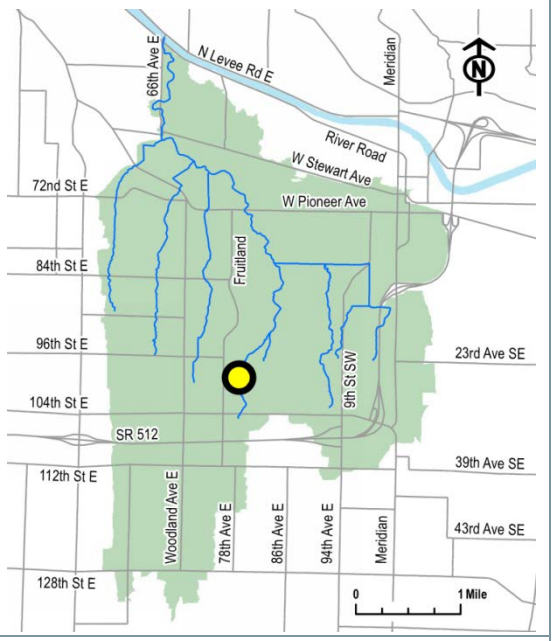
Narrative

Urbanization in the Clarks Creek basin has increased runoff rates and durations, which has led to stream channel instability. Future development within the basin could exacerbate these conditions unless flow control measures are implemented.

Construction of a detention facility would provide flow control benefits in lieu of onsite measures and reduce erosion potential in downstream reaches. In addition, a detention pond facility could be configured to capture and remove sediments.

A site for the detention facility was selected by visual inspection of aerial photography to identify one or more relatively undeveloped parcels upstream of the steepest stream reaches. Additional investigations should be conducted to assess site suitability, spatial and hydraulic constraints, and likelihood of acquisition.

Only capital expenditures necessary to construct the detention pond were included in the cost estimate. Annual inspection and periodic maintenance would be necessary for the detention pond to function as designed. Annual inspection and maintenance costs may be on the order of 3%–5% of the capital cost.



Conceptual Design

- Construct an 80-acre-foot detention facility on available site upstream of unstable stream reaches. Sizing for the conceptual design was based on an assumed available area and maximum storage depth of 6 feet; actual facility size should be based on site investigations and predesign studies.
- Excavation assumed to be $20 per cubic yard including haul; excavated volume assumed to be 80% of storage plus 2 feet over-excavation.
- Assumed 20% of storage obtained by constructing banks.
- Access road will need to be constructed; $25,000 lump sum.
- A pond outlet control structure will be constructed; assumed $8,000 lump sum.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Cost estimate includes a site survey (assumed $3,000 per acre).
- Cost estimate also includes riprap inlet/outlet, clearing and grubbing, seeding and mulching/ tree/shrubs.
- Land acquisition costs based on assessed parcel values plus 50%.

Considerations for Implementation

- An in-line pond is likely to be difficult to permit; an off-line facility may need to be considered. Assumed off-line facility for cost estimate.
- It was assumed that upstream flows can be routed through the pond by gravity.
- Additional hydrologic analysis should be conducted to optimize flow and duration control benefits.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- This project will need a clearing and grading permit.
- A critical areas study may be needed (wetland delineation).
- Access and staging areas will need to be developed for the construction phase.
- High groundwater levels may be limit the depth of the pond and reduce the available storage.
- Temporary erosion and sediment control may need to be applied.
- Land acquisition and easements will be required.
- Project could encompass multiple parcels and therefore require negotiations with multiple landowners.
- Conduct stakeholder involvement to identify potential concerns (e.g., vectors, safety) and incorporate mitigation into design.

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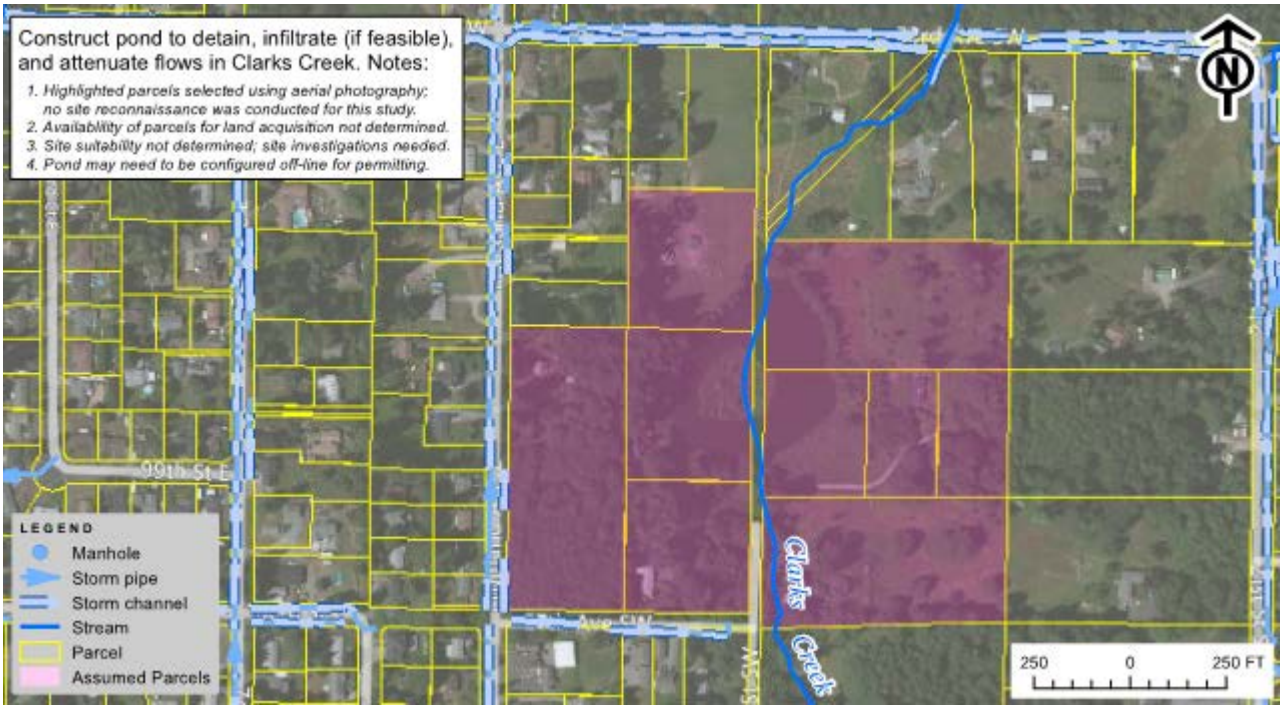

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Site survey	AC	3,000	17	50,000
Erosion and water pollution control	LS	73,000	1	73,000
Clearing and grubbing	AC	3,000	17	50,000
Excavation including haul	CY	20	156,506	3,131,000
Select borrow including haul	TON	20	2,337	47,000
Embankment compaction	CY	10	1,263	13,000
Quarry spalls (riprap)	TON	35	86	3,000
Access road	LS	25,000	1	25,000
Pond outlet control structure	EA	8,000	1	8,000
Modifications to existing stormwater collection system	LS	15,000	1	15,000
Seeding and mulching	AC	4,500	17	75,000
Shrub plantings	EA	150	680	102,000
Tree plantings	EA	250	340	85,000
Chain link fence (Type 3)	LF	30	2,900	87,000
Double 20-foot fence gate	EA	2,000	1	2,000
Temporary traffic control	Day	300	30	9,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
			Subtotal	**3,778,000**
		Contractor overhead, profit, and mobilization	*10%*	378,000
		Washington State sales tax	*9.5%*	395,000
		Construction contingency	*30%*	1,365,000
		Subtotal construction costs		**5,916,000**
		Administration, engineering design, permitting	*30%*	1,133,000
		Land acquisition and easements		$1,798,050
		Total cost		**8,848,000**

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Project:	Silver Creek Detention Facility		ID: Pr13
Location:	Near 13th Street SW and 23rd Avenue SE	Stream:	Silver Creek
		Project Cost:	$6,640 ,000
Jurisdiction:	City of Puyallup	Source Reduction:	8.3 tons/year
Proj. Type:	Regional detention facility	Reduction-cost Score:	0.2
Target:	Flow control for Silver Creek	Flow Control Benefit:	High

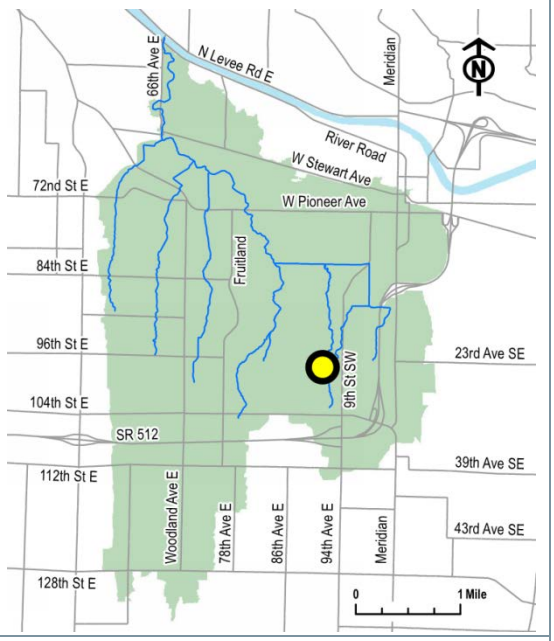
Narrative

Urbanization in the Silver Creek basin has increased runoff rates and durations, which has led to stream channel instability. Future development within the basin could exacerbate these conditions unless flow control measures are implemented.

Construction of a detention facility would provide flow control benefits in lieu of onsite measures and reduce erosion potential in downstream reaches. In addition, a detention pond facility could be configured to capture and remove sediments.

A site for the detention facility was selected by visual inspection of aerial photography to identify one or more relatively undeveloped parcels upstream of the steepest stream reaches. Additional investigations should be conducted to assess site suitability, spatial and hydraulic constraints, and likelihood of acquisition.

Only capital expenditures necessary to construct the detention pond were included in the cost estimate. Annual inspection and periodic maintenance would be necessary for the detention pond to function as designed. Annual inspection and maintenance costs may be on the order of 3%–5% of the capital cost.



Conceptual Design

- Construct a 65-acre-foot detention facility on available site upstream of unstable stream reaches. Sizing for the conceptual design was based on an assumed available area and maximum storage depth of 6 feet; actual facility size should be based on site investigations and predesign studies.
- Excavation assumed to be $20 per cubic yard including haul; excavated volume assumed to be 80% of storage plus 2 feet over-excavation.
- Assumed 20% of storage obtained by constructing banks.
- Access road will need to be constructed; $25,000 lump sum.
- A pond outlet control structure will be constructed; assumed $8,000 lump sum.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Cost estimate includes a site survey (assumed $3,000 per acre).
- Cost estimate also includes riprap inlet/outlet, clearing and grubbing, seeding and mulching/ tree/shrubs.
- Land acquisition costs based on assessed parcel values plus 50%.

Considerations for Implementation

- An in-line pond is likely to be difficult to permit; an off-line facility may need to be considered. Assumed off-line facility for cost estimate.
- It was assumed that upstream flows can be routed through the pond by gravity.
- Additional hydrologic analysis should be conducted to optimize flow and duration control benefits.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- This project will need a clearing and grading permit.
- A critical areas study may be needed (wetland delineation).
- Access and staging areas will need to be developed for the construction phase.
- High groundwater levels may be limit the depth of the pond and reduce the available storage.
- Temporary erosion and sediment control may need to be applied.
- Land acquisition and easements will be required.
- Project could encompass multiple parcels and therefore require negotiations with multiple landowners.
- Conduct stakeholder involvement to identify potential concerns (e.g., vectors, safety) and incorporate mitigation into design.

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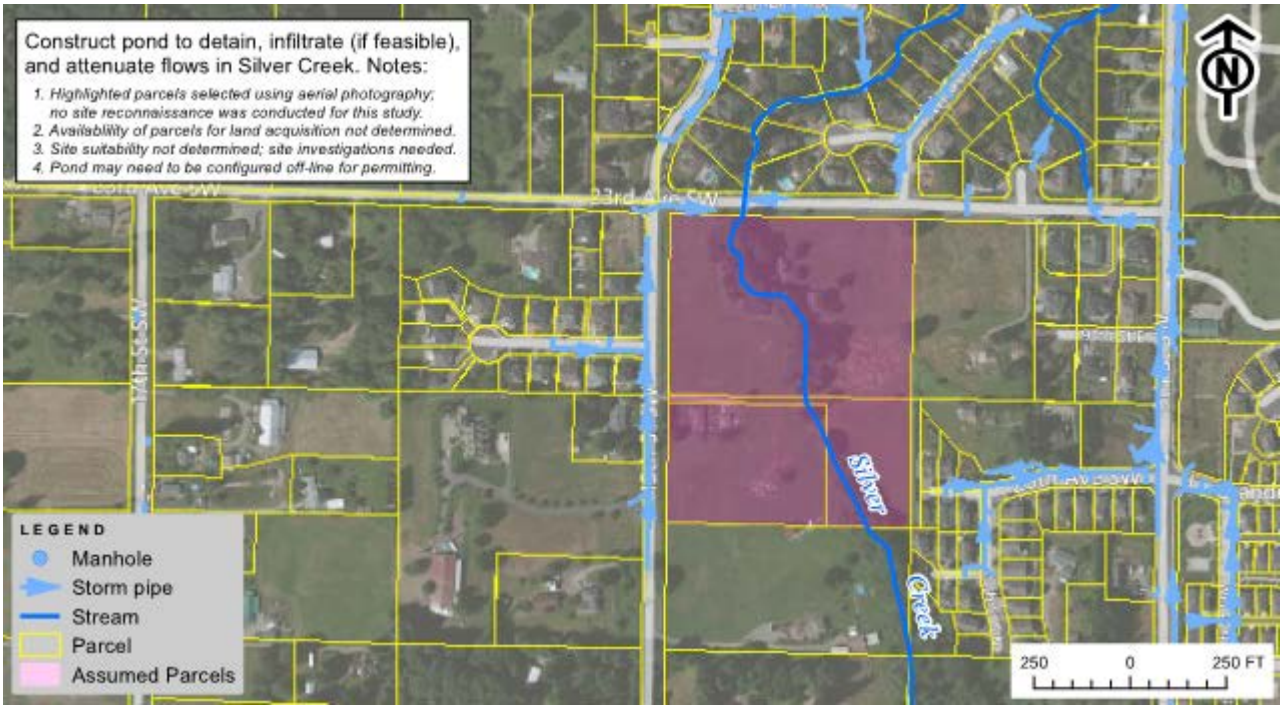

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Site survey	AC	3,000	13	39,000
Erosion and water pollution control	LS	55,000	1	55,000
Clearing and grubbing	AC	3,000	13	39,000
Excavation including haul	CY	20	120,603	2,413,000
Select borrow including haul	TON	20	2,058	42,000
Embankment compaction	CY	10	1,113	12,000
Quarry spalls (riprap)	TON	35	86	3,000
Access road	LS	25,000	1	25,000
Pond outlet control structure	EA	8,000	1	8,000
Modifications to existing stormwater collection system	LS	15,000	1	15,000
Seeding and mulching	AC	4,500	13	59,000
Shrub plantings	EA	150	607	91,000
Tree plantings	EA	250	301	76,000
Chain link fence (Type 3)	LF	30	2,600	78,000
Double 20-foot fence gate	EA	2,000	1	2,000
Temporary traffic control	Day	300	30	9,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
			Subtotal	**2,969,000**
		Contractor overhead, profit, and mobilization	*10%*	297,000
		Washington State sales tax	*9.5%*	310,000
		Construction contingency	*30%*	1,073,000
		Subtotal construction costs		**4,649,000**
		Administration, engineering design, permitting	*30%*	891,000
		Land acquisition and easements		$1,099,650
		Total cost		**6,640,000**

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Project:	Hatchery Pond Retrofit (Sedimentation Basin)	ID:	Pr14
Location:	WDFW State Fish Hatchery: Modify pond to capture and remove sediment	Stream:	Clarks Creek
		Project Cost:	$472,000
Jurisdiction:	WDFW	Source Reduction:	9.5 tons/year
Proj. Type:	Sedimentation facility	Reduction-cost Score:	2.8
Target:	Sediment transported from Upper Clarks Creek	Flow Control Benefit:	Low

Narrative

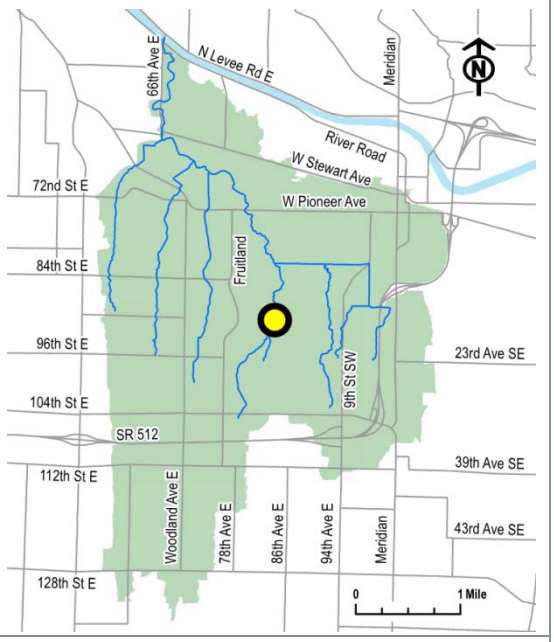
This project was identified in Pierce County's 2009 Clear/Clarks Creek Basin Plan (CKSP01).

The purpose of this project is to retrofit the existing pond above the WDFW state fish hatchery to serve as a sedimentation basin.

Sediment would be excavated from the existing facility and a control structure would be installed.

Subsequent removal of sediment would be expected to be necessary, at a frequency dependent on upstream sediment loading rates.

Only capital expenditures necessary to modify the hatchery pond were included in the cost estimate. Annual inspection and periodic dredging would be necessary when capacity is substantially reduced.



Conceptual Design

- Efforts to control and mitigate erosion and water pollution will be applied.
- A stream diversion structure will be constructed.
- A dewatering system will be developed for use during construction efforts.
- An estimated volume of 5,000 cubic yards of material will need to be mechanically dredged.
- The existing dam will need to be modified with a new control structure.
- The existing access road will be extended to provide better site access for maintenance activities.
- Riparian planting to restore the site will be conducted.
- Approximately 300 LF of Type 3 chain link fence will be installed, as well as a 20-foot fence gate.
- Land acquisition will not be required.
- Annual maintenance will need to be conducted.

Considerations for Implementation

- A Hydraulic Project Approval (HPA) permit will need to be obtained from the Washington State Department of Fish and Wildlife (WDFW).
- This project will require a Section 404 permit (for discharge of dredged or fill materials to waters of the U.S.) and a Section 401 water quality certification obtained from the state Department of Ecology. Additionally, due to the presence of Endangered Species Act (ESA) listed species in Clark's Creek a Section 7 consultation will be required to ensure the project does not jeopardize listed species.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- A critical areas study may be needed (wetland delineation).
- A temporary stream flow bypass and/or fish removal may need to be implemented during construction.

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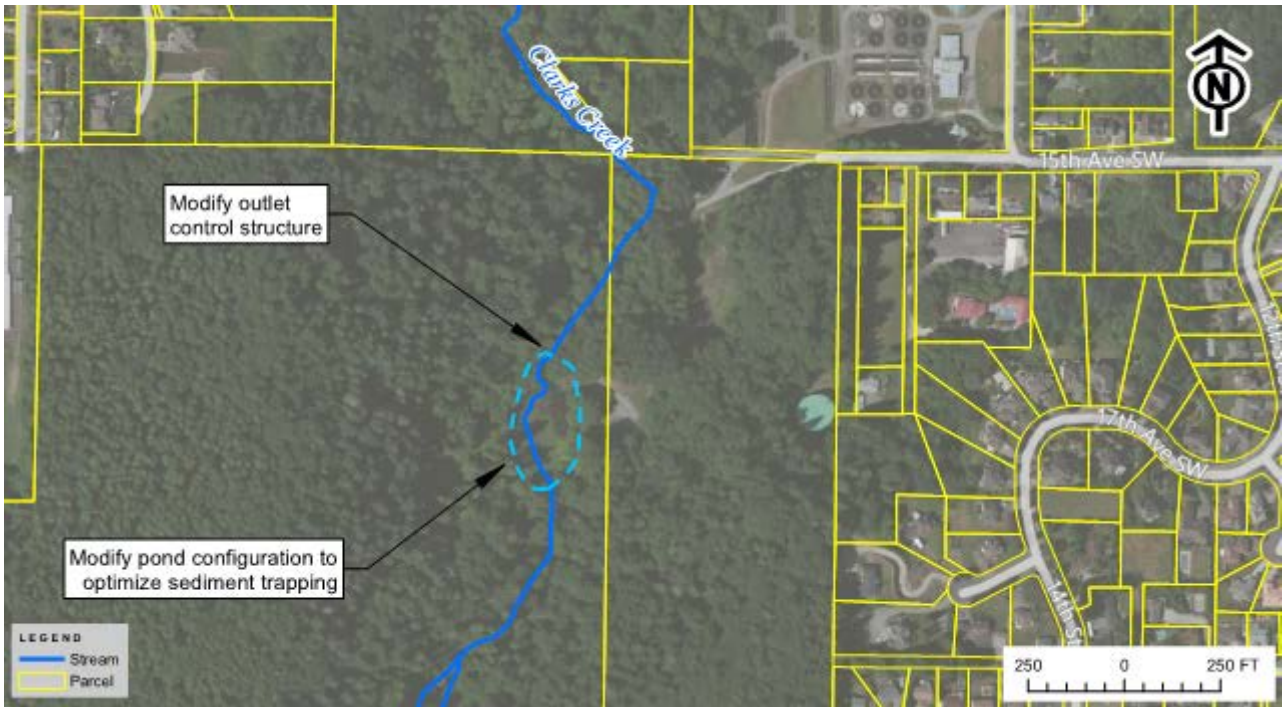

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Stream diversion	LS	30,000	1	30,000
Dewatering system	LS	25,000	1	25,000
Mechanical dredging	CY	20	5,170	104,000
Modification to outlet control structure	EA	20,000	1	20,000
Access road	LF	200	500	25,000
Riparian planting	LF	150	233	35,000
Chain link fence (Type 3)	LF	30	300	9,000
Double 20-foot fence gate	EA	2,000	1	2,000
Spill Prevention, Control, and Countermeasure (SPCC) plan	LS	3,000	1	3,000
Annual maintenance	%	3	-	8,000
			Subtotal	**271,000**
Contractor overhead, profit, and mobilization			*10%*	27,000
Washington State sales tax			*9.5%*	28,000
Construction contingency			*20%*	65,000
Subtotal construction costs				**391,000**
Administration, engineering design, permitting			*30%*	81,000
Land acquisition and easements				0
Total cost				**472,000**

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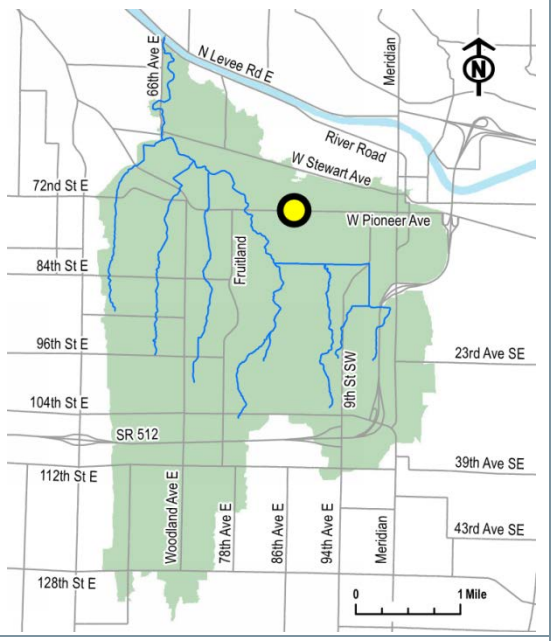
Project:	15th Street Stormwater Diversion		ID: Pr15
Location:	Pioneer Avenue stormwater pipe diverted north at 15th Street, running approximately 1,668 linear feet to 4th Avenue NW	Stream:	Storm drain to Clarks Creek
		Project Cost:	$1,285,300
Jurisdiction:	City of Puyallup	Source Reduction:	54.9 tons/year
Proj. Type:	Stormwater diversion	Reduction-cost Score:	5.9
Target:	Upland sediments from stormwater runoff	Flow Control Benefit:	High

Narrative

This project was identified in the City of Puyallup's 2012 Comprehensive Storm Drainage Plan (CIP-ST-1). This project would allow for diversion of downtown Puyallup stormwater flow directly to the Puyallup River. The diversion will occur at the intersection of 15th Street NW and W Pioneer Avenue. New stormwater conveyance, ranging in diameter from 48 to 60 inches, will be constructed along 15th Street NW to the Puyallup River outfall (City outfall 18). This project would be constructed in two phases. The first phase, conveyance construction north of 4th Avenue NW, has been constructed. The second phase includes construction of 48-inch-diameter conveyance from W Pioneer to 4th Avenue NW along 15th Street NW. A flow control vault will also be constructed at the point of diversion from existing storm conveyance on W Pioneer Avenue. The project also includes replacing existing storm, water, and sanitary infrastructure within the project limits. This project also includes street, potable water, and sanitary infrastructure components.

Earlier phases of this project installed a Vortechs Model 9000 water quality treatment device. Completing this project will eliminate the discharge of untreated stormwater from the diversion area into Clarks Creek, and discharge of treated stormwater into the Puyallup River.



Conceptual Design

- Costs were adjusted to match the cost estimate developed in the City of Puyallup's 2012 Comprehensive Storm Drainage Plan (CIP-ST-1).
- The project costs do NOT include costs for components other than stormwater. Shared costs (general items and mobilization) are pro-rated for the stormwater component of the project
- Traffic control, potholing, and dewatering activities will need to be conducted for this project.
- An estimated 1,668 LF of 48-inch pipe will need to be installed; this activity will include the applicable excavation, shoring, and backfilling to meet the project objectives.
- A diversion structure will need to be installed; assumed lump sum of $30,000.

Considerations for Implementation

- This project has already been designed; however, prior to construction the facility sizes and performance should be verified using calibrated hydrologic and hydraulic models (as proposed by CIP-ST-4).
- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Land acquisition is not required; work will be conducted in the right-of-way.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
48-inch pipe install, excavation, shoring and backfill	LF	479	1,668	799,200
Diversion structure	LS	30,000	1	30,000
General items (traffic control, potholing, dewatering)	LF	59	1,668	98,400
			Subtotal	**927,600**
Contractor overhead, profit, and mobilization			*7%*	64,900
Washington State sales tax			*9.5%*	94,300
Construction contingency			*10%*	99,250
Subtotal construction costs				**1,186,050**
Administration, engineering design, permitting			*10%*	99,250
Land acquisition and easements				0
Total cost				**1,285,300**

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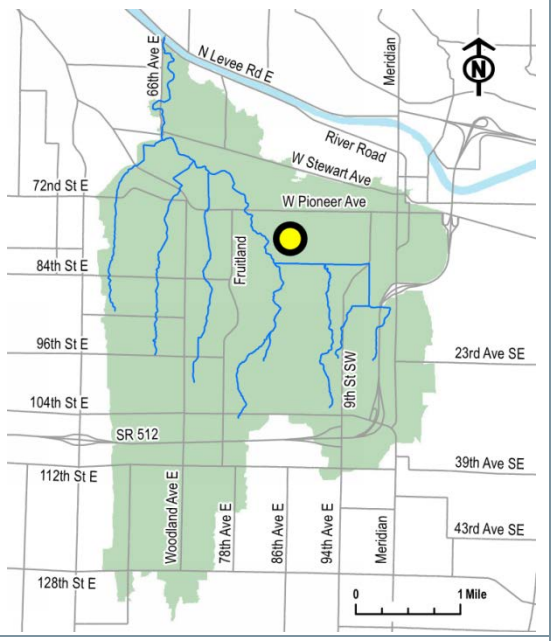
Project:	7th Avenue Stormwater Diversion		ID: Pr16
Location:	7th Avenue stormwater pipe diverted north at 16th Street, running approximately 7,200 linear feet to the Puyallup River	Stream:	Storm drain to Clarks Creek
		Project Cost:	$11,646,000
Jurisdiction:	City of Puyallup	Source Reduction:	31.1 tons/year
Proj. Type:	Stormwater diversion	Reduction-cost Score:	0.4
Target:	Upland sediments from stormwater runoff	Flow Control Benefit:	High

Narrative

The purpose of this project is to divert flows containing large amounts of total suspended solids from Clarks Creek to the Puyallup River, reducing erosion potential in Clarks Creek.

If desired, this project could be expanded to handle flows from two existing pump stations that currently discharge to Meeker Creek.



Conceptual Design

- Costs are based on the 15th Street Diversion project costs extrapolated using the same costs per linear foot.
- An estimated 3,300 LF of 48-inch pipe will need to be installed; this activity will include the applicable excavation, shoring, and backfilling to meet the project objectives.
- Traffic control, potholing, and dewatering activities will need to be conducted for this project.
- A diversion structure will need to be installed; assumed lump sum of $30,000.
- Additional modifications to the stormwater system included; assumed lump sum of $30,000.
- Include stormwater treatment costs for 35 acres of impervious surface (40% of total impervious area); the unit cost for this treatment was estimated based on the average per-acre costs for other stormwater treatment projects.
- This project would require a new outfall to the Puyallup River as well as a backflow prevention device.

Considerations for Implementation

- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Land acquisition is not required; work will be conducted in the right-of-way.
- Coordination with Burlington Northern Santa Fe (BNSF) railroad would be required to route a new outfall pipe under the railroad tracks.
- Contingencies for this project are higher than average because of potential permitting and construction challenges with construction of a new outfall,
- Hydrologic and hydraulic modeling are required for design development.

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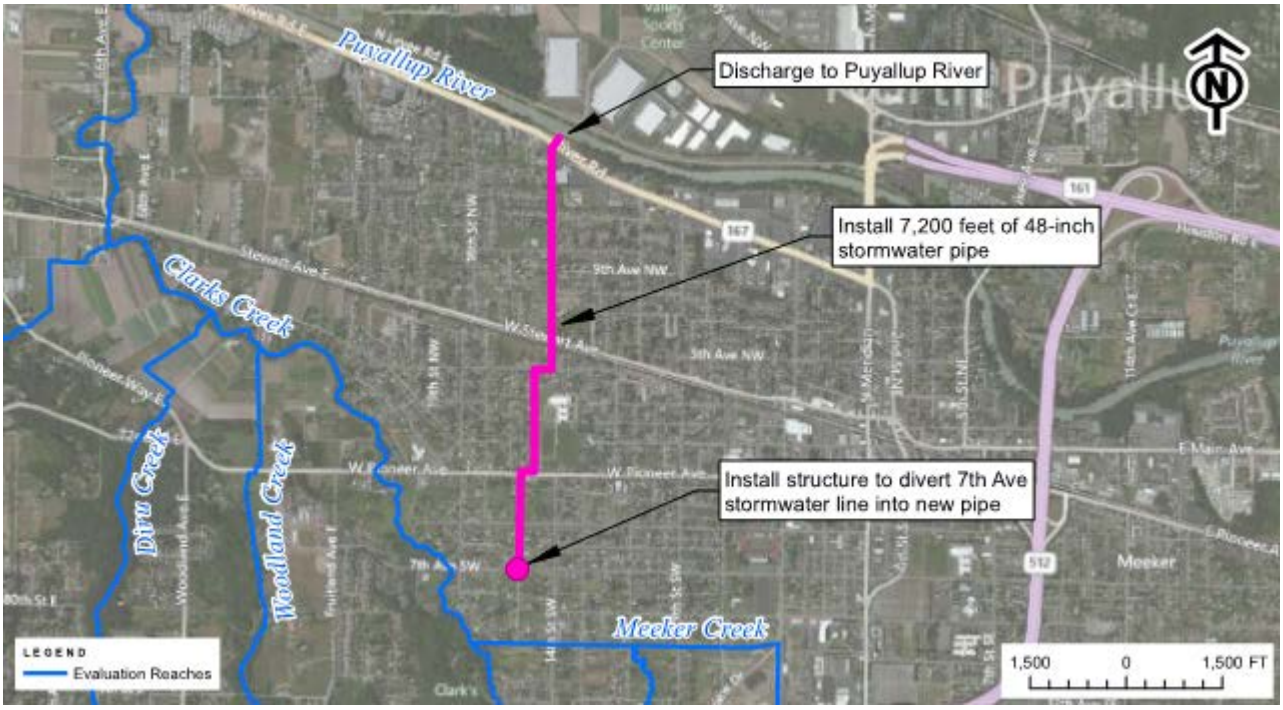

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
48-inch pipe install, excavation, shoring and backfill	LF	479	7,200	3,449,800
Diversion structure	LS	30,000	1	30,000
General items (traffic control, potholing, dewatering)	LF	59	7,200	424,800
Modifications to existing stormwater collection system	LS	30,000	1	30,000
Stormwater treatment	AC	50,500	35	1,783,300
Backflow prevention device	Ea	15,000	1	15,000
			Subtotal	**5,732,900**
Contractor overhead, profit, and mobilization			*7%*	402,000
Washington State sales tax			*9.5%*	584,000
Construction contingency			*40%*	2,458,000
Subtotal construction costs				**9,188,000**
Administration, engineering design, permitting			*40%*	2,458,000
Land acquisition and easements				0
Total cost				**11,646,000**

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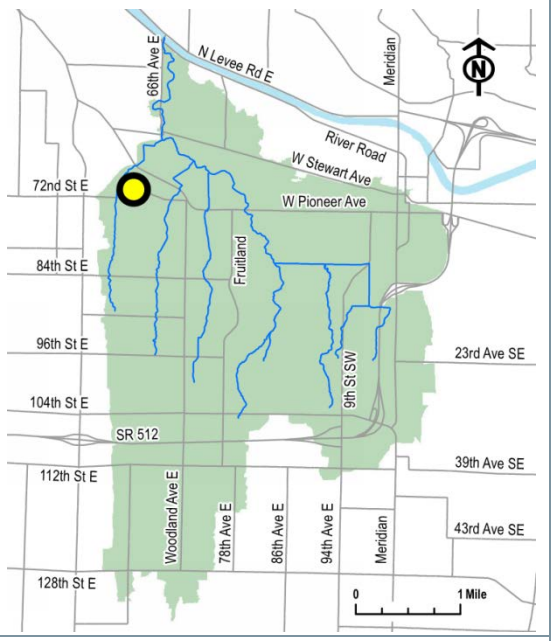
Project:	72nd Street Stormwater Improvements		ID: Pr17
Location:	72nd Street SW: Treat roadway runoff with storm filters	Stream:	Storm drain to Rody Creek
		Project Cost:	$551,000
Jurisdiction:	Pierce County	Source Reduction:	0.8 tons/year
Proj. Type:	Stormwater treatment	Reduction-cost Score:	0.2
Target:	Upland sources from 72nd Street SW	Flow Control Benefit:	Low

Narrative

The purpose of this project is to provide water quality treatment using vaults equipped with StormFilters™ that are designed to remove TSS (total suspended solids).

Pierce County is currently designing this project. This fact sheet should be revised after Pierce County has completed its 30% design.



Conceptual Design

- Install StormFilter™ prefabricated vault to meet water quality treatment requirements for 12 acres of roadway; sized to treat approximately 2 cfs using 51 medium head cartridges.
- Existing structure will be modified to split flow to the treatment facility.
- An estimated 550 LF of 12-inch-diameter buried storm sewer pipe, plus an additional 300 LF of aboveground pipe will need to be installed.
- Excavation assumed to be $20 per cubic yard including haul.
- Gravel backfill assumed to be $40 per ton including haul.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Modifications to the existing stormwater collection system will be required.
- Land acquisition is not required. Work will be conducted in the right-of-way.
- Additional costs include pavement repair, miscellaneous site restoration, and traffic control.

Considerations for Implementation

- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Long-term maintenance plans and schedules to be coordinated with the Pierce County Road Maintenance crews will need to be developed.
- The incorporation of StormFilters™ with other roadway improvement projects will need to be considered.
- The continual maintenance and costs of ensuring the adequate treatment capacity of these structures will need to be considered.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Excavation including haul	CY	20	550	11,000
Gravel backfill including haul	TON	40	1,950	78,000
Storm filters and vault	EA	150,000	1	150,000
Modify existing structure to split flow	EA	20,000	1	20,000
Schedule A storm sewer pipe 12-inch diameter	LF	45	867	39,000
Connecting to existing drainage	EA	1,000	2	2,000
HMA Cl 1/2-inch for pavement repair	TON	130	130	17,000
Site restoration	EA	10,000	1	10,000
Temporary traffic control	Day	300	10	3,000
			Subtotal	**340,000**
Contractor overhead, profit, and mobilization			*18%*	61,000
Washington State sales tax			*9.5%*	38,000
Construction contingency			*10%*	44,000
Subtotal construction costs				**483,000**
Administration, engineering design, permitting			*20%*	68,000
Land acquisition and easements				0
Total cost				**551,000**

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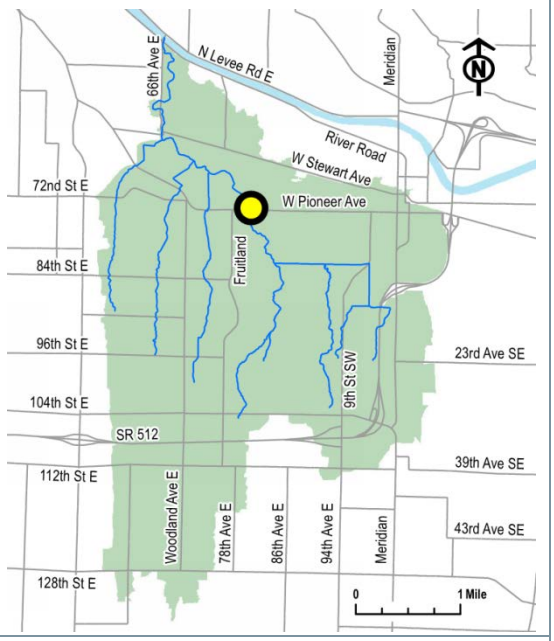
Project:	North Pioneer Stormwater Treatment Facility		ID: Pr18
Location:	Stormwater outfall to Clarks Creek near W Pioneer Avenue (north side of the street)	Stream:	Storm drain to Clarks Creek
		Project Cost:	$187,000
Jurisdiction:	City of Puyallup	Source Reduction:	2.3 tons/year
Proj. Type:	Stormwater treatment	Reduction-cost Score:	1.7
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Low

Narrative

The purpose of this project is to provide water quality treatment using vaults equipped with StormFilters™ and hydrodynamic separators (HDS) that are designed to remove TSS (total suspended solids).

This series of treatment facilities would be installed at an outfall that discharges to Clarks Creek near W Pioneer Avenue.



Conceptual Design

- Install StormFilter™ prefabricated vault and hydrodynamic separator to treat approximately 136 gallons per minute using 19 medium head cartridges.
- Cost estimate includes prefabricated flow splitter at $5,500 (installed).
- An estimated 200 LF of 12-inch-diameter Schedule A storm sewer pipe will need to be installed. This activity will include the applicable excavation, shoring, and backfilling.
- Excavation assumed to be $20 per cubic yard including haul.
- Gravel backfill assumed to be $40 per ton including haul.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Modifications to the existing stormwater collection system will be required.
- Land acquisition is not required. Work will be conducted in the right-of-way.
- Additional costs include pavement repair, miscellaneous site restoration, and traffic control.

Considerations for Implementation

- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Long-term maintenance plans and schedules to be coordinated with the City road crews will need to be developed.
- The incorporation of StormFilters™ with other roadway improvement projects will need to be considered.
- The continual maintenance and costs of ensuring the adequate treatment capacity of these structures will need to be considered.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Excavation including haul	CY	20	200	4,000
Gravel backfill including haul	TON	40	475	19,000
Hydrodynamic separator	EA	20,000	1	20,000
Storm filter	EA	35,000	1	35,000
Flow splitter	EA	6,000	1	6,000
Schedule A storm sewer pipe 12-inch diameter	LF	45	200	9,000
Connect to existing drainage	EA	1,000	2	2,000
HMA Cl 1/2-inch for pavement repair	TON	130	31	4,000
Site restoration	EA	3,000	1	3,000
Temporary traffic control	Day	300	10	3,000
			Subtotal	**115,000**
		Contractor overhead, profit, and mobilization	*18%*	21,000
		Washington State sales tax	*9.5%*	13,000
		Construction contingency	*10%*	15,000
		Subtotal construction costs		**164,000**
		Administration, engineering design, permitting	*20%*	23,000
		Land acquisition and easements		0
		Total cost		**187,000**

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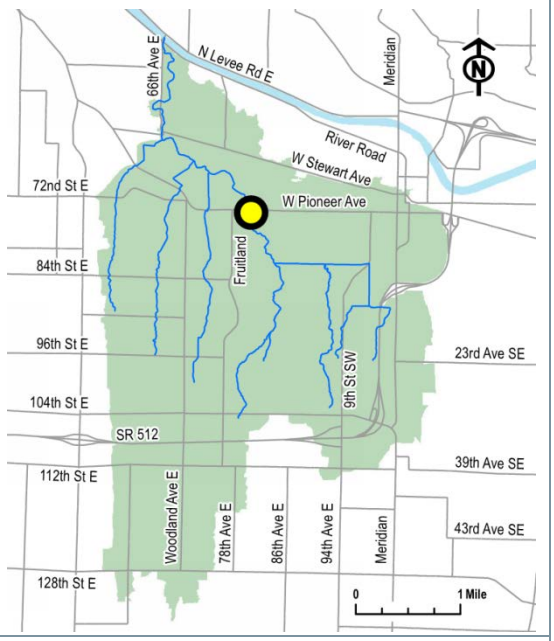
Project:	South Pioneer Stormwater Treatment Facility		ID: Pr19
Location:	Stormwater outfall to Clarks Creek near W Pioneer Avenue (south side of the street)	Stream:	Storm drain to Clarks Creek
		Project Cost:	$173,000
Jurisdiction:	City of Puyallup	Source Reduction:	1.4 tons/year
Proj. Type:	Stormwater treatment	Reduction-cost Score:	1.1
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Low

Narrative

The purpose of this project is to provide water quality treatment using vaults equipped with StormFilters™ and hydrodynamic separators (HDS) that are designed to remove TSS (total suspended solids).

This series of treatment facilities would be installed at an outfall that discharges to Clarks Creek near W Pioneer Avenue.



Conceptual Design

- Install StormFilter™ prefabricated vault and hydrodynamic separator to treat approximately 100 gallons per minute using 14 medium head cartridges.
- Cost estimate includes prefabricated flow splitter at $5,500 (installed).
- An estimated 200 LF of 12-inch-diameter Schedule A storm sewer pipe will need to be installed. This activity will include the applicable excavation, shoring, and backfilling.
- Excavation assumed to be $20 per cubic yard including haul.
- Gravel backfill assumed to be $40 per ton including haul.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Modifications to the existing stormwater collection system will be required.
- Land acquisition is not required. Work will be conducted in the right-of-way.
- Additional costs include pavement repair, miscellaneous site restoration, and traffic control.

Considerations for Implementation

- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Long-term maintenance plans and schedules to be coordinated with the City road crews will need to be developed.
- The incorporation of StormFilters™ with other roadway improvement projects will need to be considered.
- The continual maintenance and costs of ensuring the adequate treatment capacity of these structures will need to be considered.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Excavation including haul	CY	20	200	4,000
Gravel backfill including haul	TON	40	475	19,000
Hydrodynamic separator	EA	20,000	1	20,000
Storm filter	EA	27,000	1	27,000
Flow splitter	EA	6,000	1	6,000
Schedule A storm sewer pipe 12-inch diameter	LF	45	200	9,000
Connect to existing drainage	EA	1,000	2	2,000
HMA Cl 1/2-inch for pavement repair	TON	130	31	4,000
Site restoration	EA	3,000	1	3,000
Temporary traffic control	Day	300	10	3,000
			Subtotal	**107,000**
		Contractor overhead, profit, and mobilization	*18%*	19,000
		Washington State sales tax	*9.5%*	12,000
		Construction contingency	*10%*	14,000
		Subtotal construction costs		**152,000**
		Administration, engineering design, permitting	*20%*	21,000
		Land acquisition and easements		0
		Total cost		**173,000**

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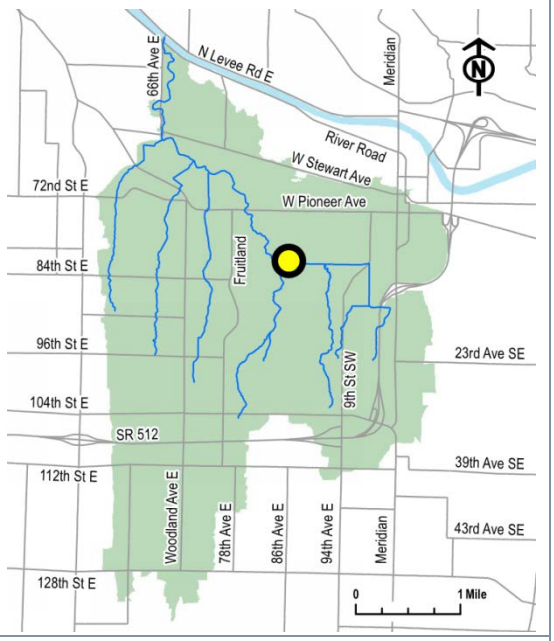
Project:	16th Street SW Stormwater Treatment Facility		ID: Pr20
Location:	Stormwater outfall to Meeker Creek near 16th Street SW	Stream:	Storm drain to Meeker Creek
		Project Cost:	$157,000
Jurisdiction:	City of Puyallup	Source Reduction:	0.8 tons/year
Proj. Type:	Stormwater treatment	Reduction-cost Score:	0.7
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Low

Narrative

The purpose of this project is to provide water quality treatment using vaults equipped with StormFilters™ and hydrodynamic separators (HDS) that are designed to remove TSS (total suspended solids).

This series of treatment facilities would be installed at an outfall that discharges to Meeker Creek near 16th Street SW.



Conceptual Design

- Install StormFilter™ prefabricated vault and hydrodynamic separator to treat approximately 55 gallons per minute using 8 medium head cartridges.
- Cost estimate includes prefabricated flow splitter at $5,500 (installed).
- An estimated 200 LF of 12-inch-diameter Schedule A storm sewer pipe will need to be installed. This activity will include the applicable excavation, shoring, and backfilling.
- Excavation assumed to be $20 per cubic yard including haul.
- Gravel backfill assumed to be $40 per ton including haul.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Modifications to the existing stormwater collection system will be required.
- Land acquisition is not required. Work will be conducted in the right-of-way.
- Additional costs include pavement repair, miscellaneous site restoration, and traffic control.

Considerations for Implementation

- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Long-term maintenance plans and schedules to be coordinated with the City road crews will need to be developed.
- The incorporation of StormFilters™ with other roadway improvement projects will need to be considered.
- The continual maintenance and costs of ensuring the adequate treatment capacity of these structures will need to be considered.

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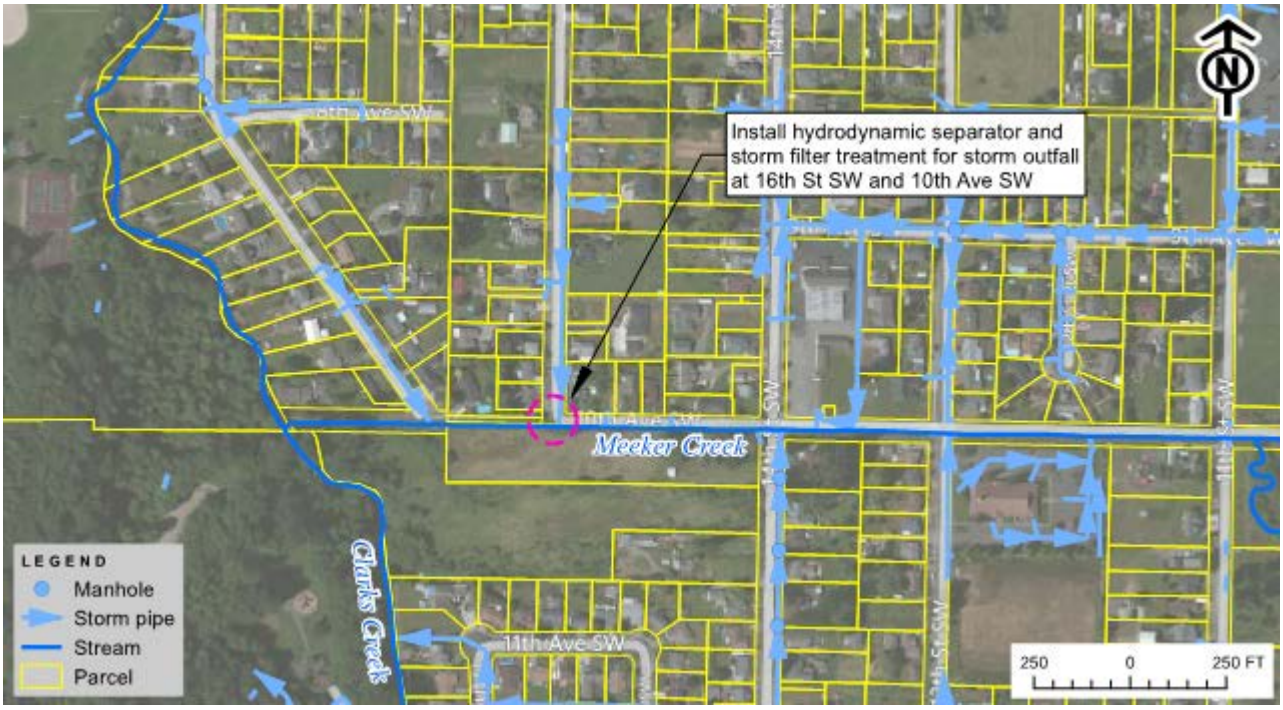

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Excavation including haul	CY	20	200	4,000
Gravel backfill including haul	TON	40	475	19,000
Hydrodynamic separator	EA	20,000	1	20,000
Storm filter	EA	17,000	1	17,000
Flow splitter	EA	6,000	1	6,000
Schedule A storm sewer pipe 12-inch diameter	LF	45	200	9,000
Connect to existing drainage	EA	1,000	2	2,000
HMA Cl 1/2-inch for pavement repair	TON	130	31	4,000
Site restoration	EA	3,000	1	3,000
Temporary traffic control	Day	300	10	3,000
			Subtotal	**97,000**
		Contractor overhead, profit, and mobilization	*18%*	17,000
		Washington State sales tax	*9.5%*	11,000
		Construction contingency	*10%*	13,000
		Subtotal construction costs		**138,000**
		Administration, engineering design, permitting	*20%*	19,000
		Land acquisition and easements		0
		Total cost		**157,000**

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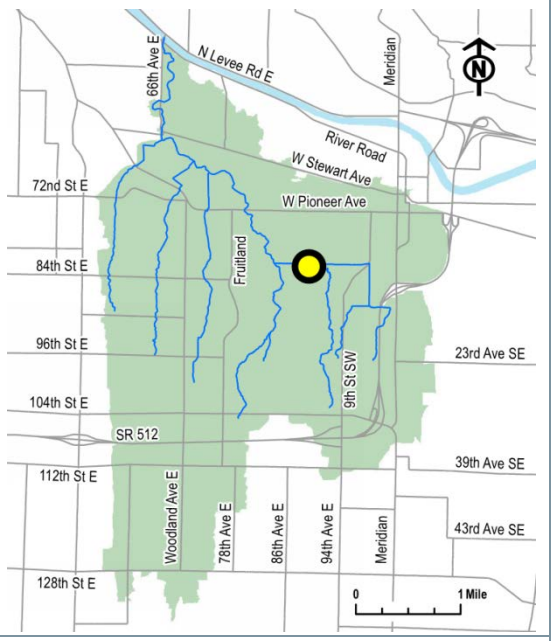
Project:	14th Street SW Stormwater Treatment Facility		ID: Pr21
Location:	Stormwater outfall to Meeker Creek near 11th Street SW	Stream:	Storm drain to Meeker Creek
		Project Cost:	$166,000
Jurisdiction:	City of Puyallup	Source Reduction:	1.1 tons/year
Proj. Type:	Stormwater treatment	Reduction-cost Score:	0.9
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Low

Narrative

The purpose of this project is to provide water quality treatment using vaults equipped with StormFilters™ and hydrodynamic separators (HDS) that are designed to remove TSS (total suspended solids).

This series of treatment facilities would be installed at an outfall that discharges to Meeker Creek near 14th Street SW.



Conceptual Design

- Install StormFilter™ prefabricated vault and hydrodynamic separator to treat approximately 75 gallons per minute using 11 medium head cartridges.
- Cost estimate includes prefabricated flow splitter at $5,500 (installed).
- An estimated 200 LF of 12-inch-diameter Schedule A storm sewer pipe will need to be installed. This activity will include the applicable excavation, shoring, and backfilling.
- Excavation assumed to be $20 per cubic yard including haul.
- Gravel backfill assumed to be $40 per ton including haul.
- Cost estimate includes erosion/water pollution mitigation during in-stream work; use lump sum of $10,000.
- Modifications to the existing stormwater collection system will be required.
- Land acquisition is not required. Work will be conducted in the right-of-way.
- Additional costs include pavement repair, miscellaneous site restoration, and traffic control.

Considerations for Implementation

- City permits for work conducted in the right-of-way will need to be obtained.
- City permits pertaining to new road construction will need to be obtained.
- This project will require compliance with the State Environmental Policy Act (SEPA) as well as local critical areas codes and ordinances.
- Long-term maintenance plans and schedules to be coordinated with the City road crews will need to be developed.
- The incorporation of StormFilters™ with other roadway improvement projects will need to be considered.
- The continual maintenance and costs of ensuring the adequate treatment capacity of these structures will need to be considered.

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Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Erosion and water pollution control	LS	10,000	1	10,000
Excavation including haul	CY	20	200	4,000
Gravel backfill including haul	TON	40	475	19,000
Hydrodynamic separator	EA	20,000	1	20,000
Storm filter	EA	22,000	1	22,000
Flow splitter	EA	6,000	1	6,000
Schedule A storm sewer pipe 12-inch diameter	LF	45	200	9,000
Connect to existing drainage	EA	1,000	2	2,000
HMA Cl 1/2-inch for pavement repair	TON	130	31	4,000
Site restoration	EA	3,000	1	3,000
Temporary traffic control	Day	300	10	3,000
			Subtotal	**102,000**
		Contractor overhead, profit, and mobilization	*18%*	18,000
		Washington State sales tax	*9.5%*	11,000
		Construction contingency	*10%*	14,000
		Subtotal construction costs		**144,000**
		Administration, engineering design, permitting	*20%*	20,000
		Land acquisition and easements		0
		Total cost		**164,000**

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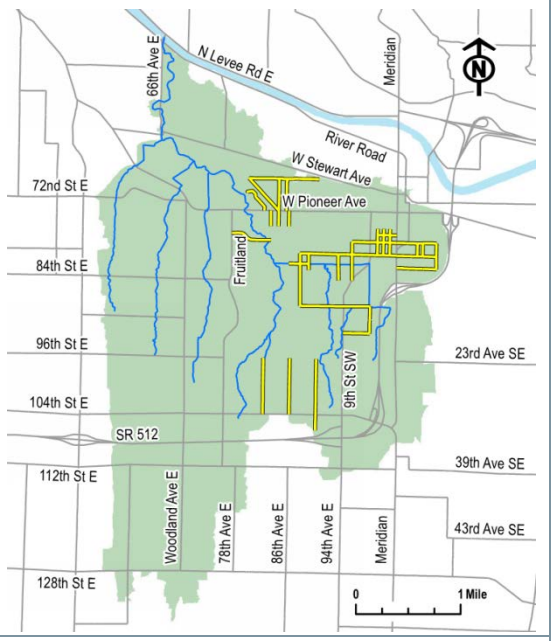
Project:	Street Edge/Bioretention Retrofits for Secondary Roadways	ID:	Pr22
Location:	Street-edge facilities along secondary streets within City of Puyallup	Stream:	Not Applicable/Distributed
		Project Cost:	$1,607,000
Jurisdiction:	City of Puyallup	Source Reduction:	3.9 tons/year
Proj. Type:	Distributed facilities (low impact development)	Reduction-cost Score:	0.3
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Moderate

Narrative

The purpose of this project is to retrofit existing secondary roadways with bioretention facilities for water quality treatment and flow control. Green infrastructure such as bioretention facilities function as filtration devices and can remove greater than 80% of suspended solids from stormwater runoff. Approximately 11 miles of roadway were assumed to be retrofitted.

In some cases, the use of porous concrete may be considered in lieu of street edge bioretention facilities (see Project 23).



Conceptual Design

- Assumed average roadway width of 32 feet, multiplied by 11 miles results in approximately 43 acres of impervious surface.
- Roadways areas were divided into well-drained and poorly drained soils, the latter requires facilities with under-drains.
- GSI-Calc software (available at the Washington Stormwater Center http://www.wastormwatercenter.org/GSI_calc) was used to determine facility sizing.
- Bioretention cells assumed to be 100 feet long by 8 feet wide, 1-foot ponding depth, 1.5-foot planting medium, and 1.5-foot gravel underdrain (where required).
- A total of 84 cells are required (29 in well-drained soils, 55 in poorly drained soils).
- Costs for each bioretention cell include an inlet grate, outlet structure with energy dissipation, and catch basin.
- Land acquisition is not required; work would be conducted in the right-of-way.

Considerations for Implementation

- Projects will require coordination with City Transportation Department; to the extent possible, roadway retrofits should be incorporated with other roadway improvement projects.
- Projects constructed within the right-of-way will require coordination with City road crews, City maintenance staff.
- Long-term maintenance costs are not included in the cost estimate, but should be considered during design and implementation.

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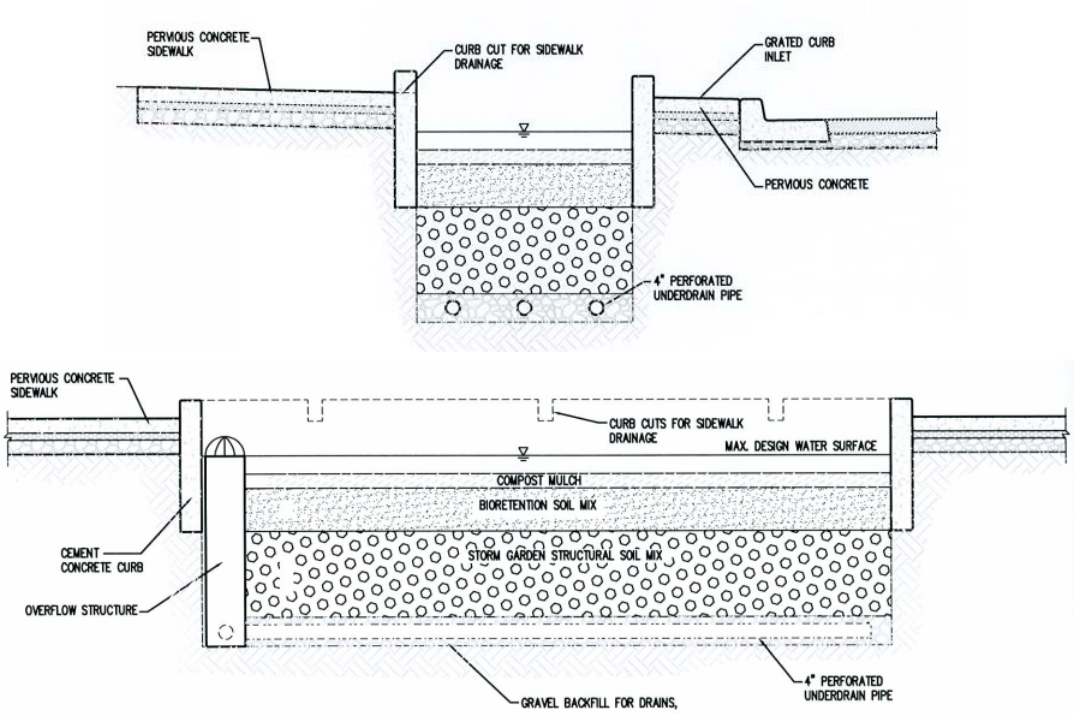

Project Cost Estimate

Item	Unit	Unit Cost	Quantity	Cost
Inlet/outlet energy dissipation using quarry spall riprap	EA	400.00	85	34,000
Underdrain pipe 8" dia.	LF	15.50	5,484	85,000
Type 1 catch basin	EA	1,200.00	84	101,000
Geotextile fabric over infiltration system	SY	3.10	968	3,000
Excavation and haul	CY	20.00	10,950	219,000
CB beehive grates	EA	500.00	84	42,000
Underdrain rock	TON	20.00	3,300	66,000
Rain garden plants	EA	7.50	33,600	252,000
Hydroseeding (pond bottom, slopes, and perimeter)	AC	2,250.00	1.78	4,000
Bioretention soil mix	CY	34.00	3,735	127,000
Mulch	CY	33.00	636	21,000
			Subtotal	**954,000**
		Contractor overhead, profit, and mobilization	*13%*	124,000
		Washington State sales tax	*9.5%*	102,000
		Construction contingency	*20%*	236,000
		Subtotal construction costs		**1,416,000**
		Administration, engineering design, permitting	*20%*	191,000
		Land acquisition and easements		0
		Total cost		**1,607,000**

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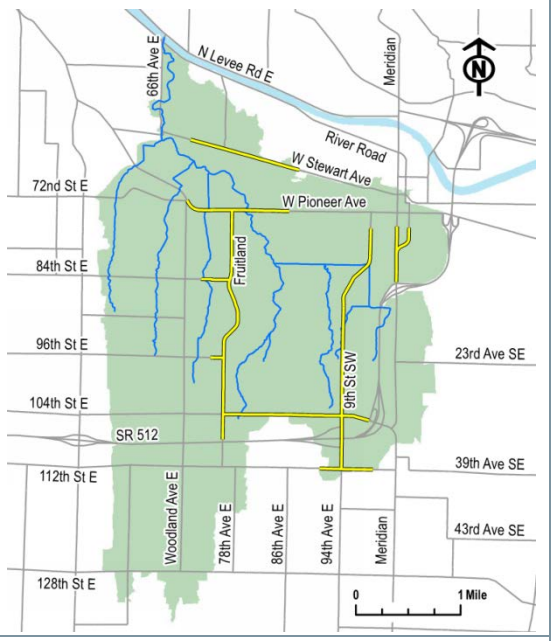
Project:	Porous Concrete for Arterial Roadways		ID: Pr23
Location:	Arterial roadways within City of Puyallup	Stream:	Not Applicable/Distributed
		Project Cost:	$6,663,000
Jurisdiction:	City of Puyallup	Source Reduction:	7.7 tons/year
Proj. Type:	Distributed facilities (low impact development)	Reduction-cost Score:	0.2
Target:	Upland sediment from stormwater runoff	Flow Control Benefit:	Moderate

Narrative

The purpose of this project is to resurface arterial roadways with porous concrete. Porous concrete allows rain to infiltrate into the roadway surface, thereby reducing the runoff rates and volumes. Reducing roadway runoff also reduces suspended sediments and other pollutants.

*The cost estimate provided for this project is based on the net difference between porous concrete and conventional street construction costs. In other words, the cost to build an equivalent amount of roadway using conventional methods was subtracted from the total estimated cost for constructing porous concrete roadways, with the difference being the net cost increase. Note that this does not include the potential cost savings from avoiding the need to acquire additional land to meet flow control requirements by constructing onsite facilities. For example, if we assumed that we need to acquire 4 acres of land (approximately 10% of total area to be redeveloped) at a cost of $100,000 per acre, then using porous concrete would potentially save as much as $400,000 in land acquisition costs.



Conceptual Design

- Assumed average roadway width of 32 feet, multiplied by 10 miles results in approximately 38 acres of replaced roadway surface.
- Project costs are based on the increase over conventional roadway resurfacing; i.e., the net cost for using pervious concrete was calculated by subtracting out the conventional costs. However, the conventional costs did not include the additional costs for mitigating the replaced impervious surface.
- Under-drains only included for roadways in poorly drained soils.
- The differential cost for pervious concrete was estimated to be approximately $4 per square foot higher than conventional concrete surfacing.
- Land acquisition is not required; work would be conducted in the right-of-way.

Considerations for Implementation

- Projects will require coordination with City Transportation Department; to the extent possible, roadway retrofits should be incorporated with other roadway improvement projects.
- Projects constructed within the right-of-way will require coordination with City road crews, City maintenance staff.
- Long-term maintenance costs are not included in the cost estimate, but should be considered during design and implementation.

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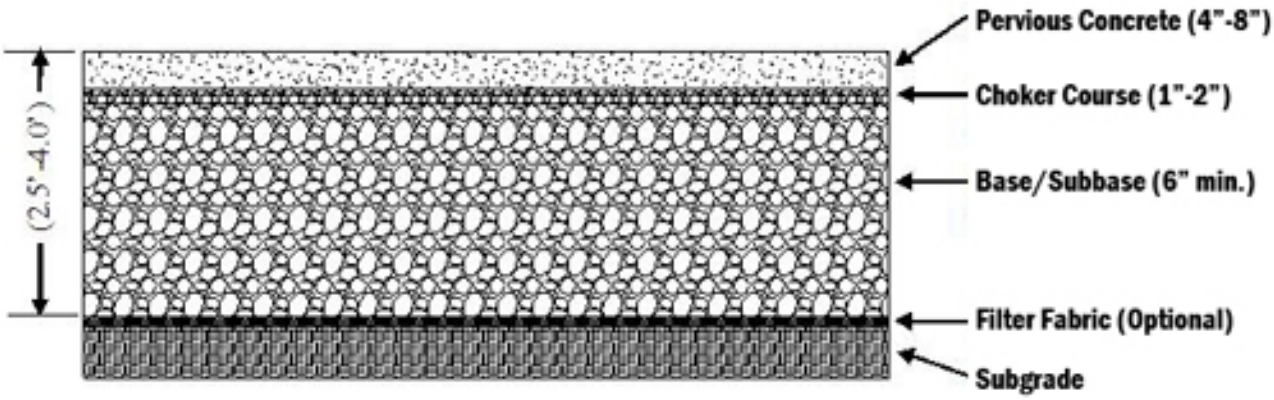

Source: U.S. Environmental Protection Agency

Project Cost Estimate				
Item	**Unit**	**Unit Cost**	**Quantity**	**Cost**
Crushed surfacing TC (choker) 2" depth	TON	30.00	13,800	414,000
Pervious concrete	SF	4.75	1,667,160	7,919,000
Permeable base course aggregate (12")	TON	25.00	82,720	2,068,000
Geotextile fabric (separation from native)	SY	2.00	185,500	371,000
Underdrain pipe 8" dia. (only for areas with poorly drained soils)	LF	16.00	34,100	546,000
Conventional street cost* (subtract to obtain net cost for pervious)	SF	3.86	1,666,992	-6,435,000
			Subtotal	**4,883,000**
			Contractor overhead, profit, and mobilization	*5%*	244,000
			Washington State sales tax	*9.5%*	487,000
			Construction contingency	*10%*	561,000
			Subtotal construction costs		**6,175,000**
			Administration, engineering design, permitting	*10%*	488,000
			Land acquisition and easements		0
			Total cost		**6,663,000**

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Section 5

Limitations

This document was prepared solely for Puyallup Tribe of Indians in accordance with professional standards at the time the services were performed and in accordance with the contract between Puyallup Tribe of Indians and Brown and Caldwell dated March 31, 2011. This document is governed by the specific scope of work authorized by Puyallup Tribe of Indians; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by Puyallup Tribe of Indians and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

Further, Brown and Caldwell makes no warranties, express or implied, with respect to this document, except for those, if any, contained in the agreement pursuant to which the document was prepared. All data, drawings, documents, or information contained this report have been prepared exclusively for the person or entity to whom it was addressed and may not be relied upon by any other person or entity without the prior written consent of Brown and Caldwell unless otherwise provided by the Agreement pursuant to which these services were provided.

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Section 6

References

Northwest Hydraulic Consultants Inc. (NHC). June 2005. *Draft Flood Insurance Mapping Study for Clarks Creek near Puyallup, Washington Pierce County, WA and Incorporated Areas, Community Number – 530138*. Prepared for the Federal Emergency Management Agency (FEMA) Prepared by Northwest Hydraulic Consultants Inc., 16300 Christensen Road, Suite 350, Seattle, Washington 98188-3418.

Puget Sound LiDAR Consortium (PSLC). 2011. Digital Elevation Models. URL: http://pugetsoundlidar.ess.washington.edu/.

Tetra Tech. April 4, 2012. *Clarks Creek Sediment Study Watershed Model Report – Revised Draft*. Prepared for the Puyallup Tribe of Indians by Tetra Tech, 3200 Chapel Hill-Nelson Hwy, Suite 105, PO Box 14409, Research Triangle Park, North Carolina 27709.

Tetra Tech. May 11, 2012 Memorandum from Jon Butcher to Clarks Creek Project Team titled *Clarks Creek Allocation Accounting*. Prepared by Tetra Tech, 3200 Chapel Hill-Nelson Hwy, Suite 105, PO Box 14409, Research Triangle Park, North Carolina 27709.

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Appendix A: Geomorphic Assessment and Sediment Analysis

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Brown AND Caldwell

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Technical Memorandum

Prepared for: The Puyallup Tribe of Indians
Project Title: Clarks Creek Sediment Reduction Study
Project No.: 140982.003

Subject: Field Investigations
Date: October 24, 2011
To: Char Naylor, PTI Project Manager
From: R. Victoria Zeledon, Brown and Caldwell
Mike Milne, Brown and Caldwell

Limitations:

This is a draft memorandum and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.

This document was prepared solely for the Puyallup Tribe of Indians (PTI) in accordance with professional standards at the time the services were performed and in accordance with the contract between the PTI and Caldwell dated October 2011. This document is governed by the specific scope of work authorized by the PTI; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the PTI and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

1. Introduction

The Puyallup Tribe of Indians (PTI) retained Brown and Caldwell (BC) to lead the development of an Action Plan aimed at reducing sediment loading to Clarks Creek. BC subcontracted with Inter-Fluve, Inc. to help evaluate geomorphic processes, sediment source areas, and sediment depositional areas.

BC used the field reconnaissance observations to adjust locations for sediment sampling and hydraulic modeling. The hydraulic model was provided to the PTI's contractor, Tetra Tech, to aid in development of the HSPF model for the study area.

BC and PTI staff collected the sediment samples, which were sent to the Analytical Resources Inc. (lab) for analysis. The sample collection and analysis were performed in accordance with the *Quality Assurance Project Plan for the Clarks Creek Sediment Reduction Study* (QAPP) (Brown and Caldwell June 2011).

This technical memorandum summarizes the results of the geomorphological assessment and sediment sampling.

2. Geomorphological Assessment

The following section describes the geomorphological assessment of the Clarks Creek watershed conducted by Inter-Fluve, Inc.

2.1 Background

Inter-Fluve staff Dan Miller P.E. and Mike Brunfelt L.G. conducted a field reconnaissance on June 20–22, 2011. The objective of the field reconnaissance was to identify erosional and depositional reaches and point sources of sediment, and to gain an understanding of existing geomorphic conditions. Major point sources of sediment, unstable reaches, and field-based adjustments to tentative survey cross-section locations were identified with a hand-held Garmin GPSMAP 76Cx global positioning system (GPS) navigator (accuracy no better than 10 feet). This technical memorandum is a summary of our field observations and understanding of existing geomorphic processes based on our review of existing studies, reports, maps, aerial photos, and field work completed to date.

2.2 Study Area

Clarks Creek, which is a tributary to the Puyallup River, has a watershed of approximately 6,600 acres of rural and urban land use. It has four main tributaries: Rody, Diru, Woodland, and Silver Creeks. Each tributary (and Clarks Creek itself) runs in a general south-to-north direction toward the Puyallup River. Meeker Ditch runs down the Puyallup River Valley and delivers Silver Creek surface and storm drainage water to Clarks Creek. All tributaries combine with Clarks Creek within the Puyallup River Valley bottom. Clarks Creek flows into the Puyallup River near the 48th Street E Bridge.

2.3 Existing Conditions

The drop in elevation from the headwaters of the Clarks, Rody, Diru, Woodland, and Silver Creek watersheds to the Puyallup River valley bottom is approximately 450 feet. Creeks within the study area drain relatively flat upland surface topography before running down a steep glacial terrace that forms the southern boundary of the Puyallup River Valley within the study area. The terrace is composed of glacial advance outwash sand and gravels, glacial till, and recessional outwash sand and gravels. When eroded, these provide a substantial sediment supply for downstream segments of each tributary and Clarks Creek as it flows out to the Puyallup River.

There is a substantial groundwater base flow component to the hydrology of the Clarks Creek watershed. Clarks Creek and its tributaries have substantial gains in groundwater flow starting near the toe of the glacial outwash terrace and extending up the glacial terrace. In the case of Clarks Creek, these gains occur for a distance of approximately one-half mile. Water infiltrated in the upper watershed runs through an aquifer of gravel, sand, silt, and clay. The aquifer is expressed at the surface near the toe of the glacial terrace with several springs (Maplewood Spring is one example). Below the aquifer is a silt-clay confining unit and above it is Vashon till composed of unstratified clay, silt, cobbles, sand, and gravel.

2.4 Clarks Creek

Clarks Creek was walked in the upstream direction from the Washington Department of Fish and Wildlife (WDFW) Puyallup Trout Hatchery to 96th Street E. An unnamed tributary east of Clarks Creek was then walked downstream to its confluence with Clarks Creek upstream of Maplewood Springs. Segments of Clarks Creek were observed from the Puyallup River upstream to Clarks Creek Park at all major road crossings.

The Clarks Creek channel bed is composed of gravel, cobble, sand, and silt substrate as it runs down the steeper glacial terrace. As it flows out onto the Puyallup River Valley floor, the bed transitions from larger gravel/cobble to smaller sand and silt near the toe of the glacial terrace. The reduction in particle size is primarily a function of the reduction in channel slope and channel confinement, resulting in the deposition of the larger sediment particle sizes. Based on visual observations at major road crossings, Clarks Creek appears capable of transporting sand and silt out to the Puyallup River. Quantitative analysis of sediment transport characteristics will be completed in later phases of this study.

2.4.1 Sediment Point Sources and Instability

Major sediment source areas and instability within Clarks Creek are located in the steepest channel segments that run through confined, steeply sloped valleys that have eroded into the glacial terrace. The most actively eroding segments have nearly vertical valley walls composed of sand, silt, and small gravel. Currently, rotational slope failures and lateral stream migration into segments of unconsolidated glacial outwash appear to be the most common erosional processes delivering sediment to the channel.

Areas of consolidated glacial till are slowing or metering the volume of sediment delivered over time. The speed of erosion and rate of sediment delivery are unknown, variable, and difficult to gauge due to the varied stability and material composition between layers of glacial till and outwash. A large head cut (12–15 feet) forms the upstream boundary of channel instability. The height of the head cut gives some indication of how much bed material has been previously removed over time.

Although vertical bed lowering appears to have produced substantial historical sediment supply, current supply appears more dominated by steep vertical and failing valley walls previously undermined by the channel head cut. Valley wall material is dominated by small gravel, sand, and silt that is mobilized and transported downstream after entering the active channel. Large wood and vegetation locally store and reduce the rate of downstream sediment transport. Major sediment source areas within Clarks Creek can be viewed in attached drawings.

We observed no large head cuts within the unnamed tributary channel east of Clarks Creek. The degree of valley wall slope failure was relatively small and the degree of channel incision was approximately 3 feet.

Historical streambank sediment yield was estimated based on field measurements of bed incision and bank erosion. The total eroded volume from Clarks Creek‘s streambanks was estimated at 8,730 cubic yards, with 5,340 cubic yards originating in the mainstem and 3,390 cubic yards in the east fork. Please refer to Appendix A for a description of the methodology adopted and the estimated sediment yield by reach.

2.4.2 Depositional Reaches

A large area of deposition was identified upstream of a dam located near the Puyallup Trout Hatchery. The dam reservoir is nearly full of sediment, the channel above the reservoir is braided, and old stumps several hundred feet upstream are partially buried. These field conditions indicate that larger sediment particle sizes are not being transported and are depositing due to the change in slope caused by the dam. We estimate that it is possible that sediments consisting of pea-size gravel, sand, and silt are capable of making it past the nearly filled dam reservoir during flood flows. Based on visual observation, we estimate that source area sediments from the upper reaches of Clarks Creek could be up to 80 percent sand and silt. Immediately downstream of the dam, the stream appears to be dynamically stable with no tendencies toward erosion or deposition.

Downstream of the dam, channel slope is reduced as Clarks Creek encounters the Puyallup River Valley. Within most segments of the channel below the toe of the glacial terrace, sand and silt are significant components of channel bed substrate. Areas of temporary storage and deposition occur within and behind aquatic or riparian woody vegetation from the toe of the glacial terrace downstream to the confluence with the Puyallup River. Field observations and knowledge of creek management indicates that the aquatic vegetation stores sediment and acts to occlude the channel enough to raise water surface elevations over time.

2.4.3 General Geomorphic Condition and Observations

Clarks Creek exhibits signs of previous head cutting or stream bed lowering followed by lateral slope instability caused by bed lowering and removal of the toe of adjacent valley walls. To date, we have not been able to determine the exact timing and sequence behind the channel lowering and head cut observed in the field as we have found no firsthand local knowledge or quantitative historical information. However, we have surmised three possibilities that may play overlapping or combined roles in developing existing conditions in Clarks Creek and its tributaries.

The first was identified in a historical map that shows the straightening of the Puyallup River in the early 1900s. Based on map measurements, more than 3 miles of Puyallup River channel length was lost immediately downstream of the Clarks Creek’s confluence with the Puyallup River. The channel straightening, referred to as the Reservation Cutoff, is below another straightened segment, referred to as the Murphy Cutoff. The loss of this much channel length would have certainly decreased the base level of both the Puyallup River locally and caused Clarks Creek to fall off its former channel

bed down into the new lower elevation of the Puyallup River. The much steeper slope in Clarks Creek at the new lower-elevation, straightened Puyallup River confluence would have caused the bed substrate to erode in Clarks Creek. The steeper stream channel and subsequent erosion (head cut) would have worked its way upstream through Clarks Creek and its tributaries until finding substrate that could not be eroded at the steeper slope initiated by the Puyallup River lowering and straightening project. Based on this premise, the head cut we observed at the upstream boundary could be related to the initial Puyallup River straightening project in the early 1900s (see Figure 1). Erosion and head cutting would have likely slowed as the watershed area and runoff energy decreased and larger existing particle sizes were encountered. However, during flood flows, the head cutting may have been more active and local instability more pronounced.

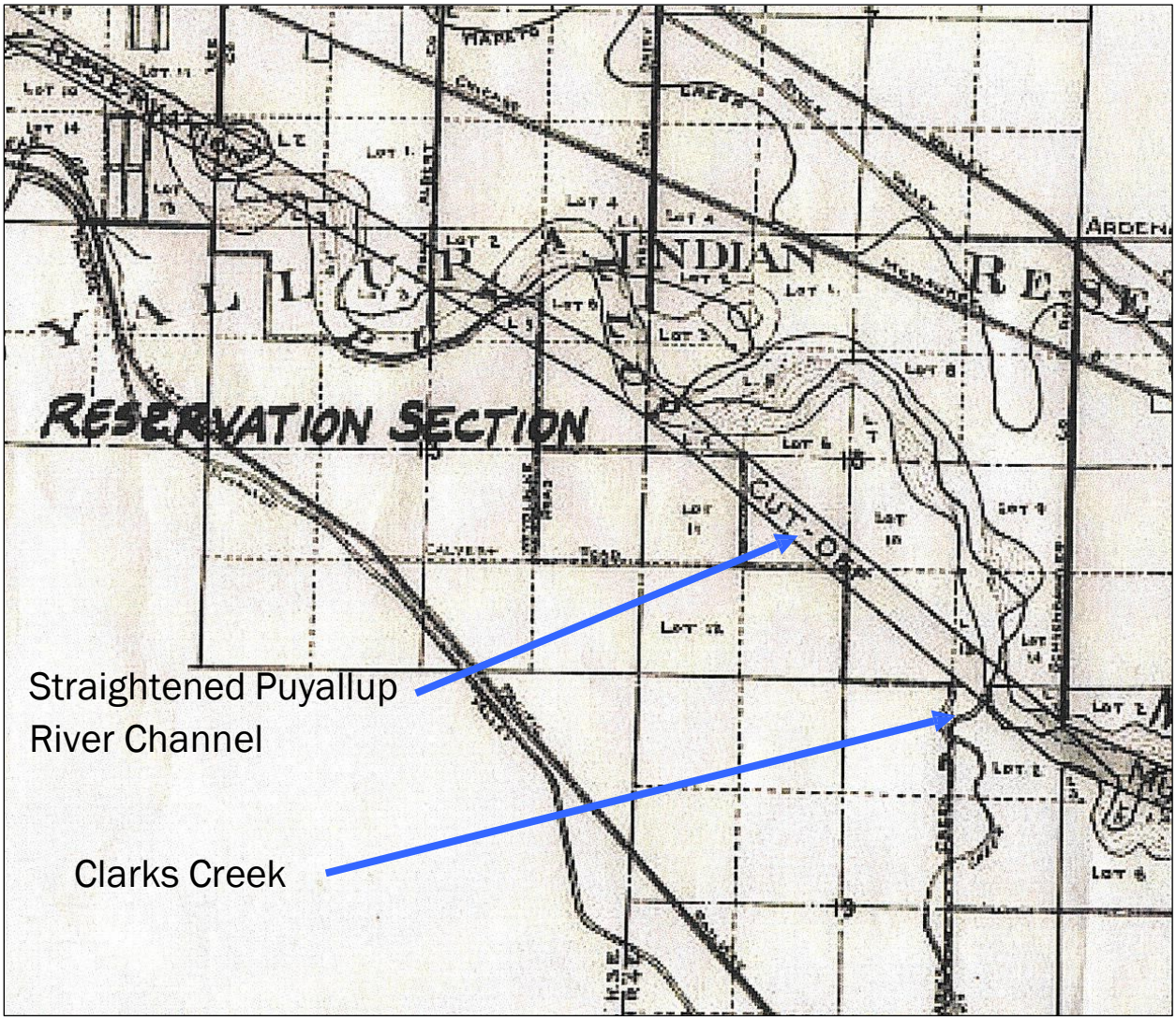

Figure 1. Historical map showing Puyallup River straightening downstream of Clarks Creek

The straightened channel is referred to as the "Reservation Cut-Off" on the map. From PTI map files.

The second possibility we considered is that bed erosion and channel expansion from increased runoff caused by land clearing and development within the Clarks Creek watershed could have caused the observed conditions. Removal of forest cover likely increased runoff volumes and rates by reducing evapotranspiration, canopy interception, and forest floor storage. Creation of impervious surfaces, such as houses, roads, and parking lots, further increased runoff volumes and rates. If runoff energy is increased beyond channel thresholds, bed erosion and channel expansion occur. Bed erosion and lateral bank failures observed in Clarks Creek are consistent with elevated runoff caused by development activity and the growth of impervious surfaces within the watershed.

Third, large regional winter storms and floods might have played a role in destabilizing adjacent hill slopes that were at or near instability thresholds. Relatively rare precipitation events could have created or rejuvenated instability in the channel and steep adjacent valley walls.

Field and historical map evidence suggests that channel straightening resulting in head cutting and channel degradation, increases in impervious surface runoff, and large regional floods have possibly combined to destabilize Clarks Creek.

2.5 Rody Creek

Rody Creek was walked from 84th Street E downstream to Pioneer Way E

2.5.1 Sediment Point Sources and Instability

Field observations indicate that Rody Creek has experienced approximately 3 feet of incision or down-cutting. Incision estimates were based on our estimates of head-cut height, degree of valley wall erosion, and comparisons with un-incised channel segments that existed upstream of head cuts and/or road crossings. With the exception of channel incision, the upstream half of Rody Creek is relatively stable. No substantial adjacent hill slope erosion and point sources were observed.

Approximately 700 feet upstream of 72nd Street E, several springs deliver groundwater to the channel. At the spring outfalls, large hill slope failures have delivered gravel, silt, and sand to the channel. These failures, combined with previous incision, appear to have delivered large volumes of sediment to the channel.

Downstream of 72nd Street E, one slope failure is located approximately 500 feet downstream of the Pioneer Avenue culvert. No other large and recent point sources of sediment were observed in Rody Creek.

The total eroded volume from Rody Creek's bed and banks was estimated at 2,490 cubic yards (Appendix A).

2.5.2 Depositional Reaches

Major zones of deposition in Rody Creek occur approximately 700 feet upstream of the 72nd Street E culvert inlet downstream to the Puyallup River Valley floor. The deposition occurring upstream of 72nd Street E is caused by the culvert inlet and engineered concrete tower inlet structure that allows water to run into the culvert even as debris and sediment block and aggrade the channel. To have developed this structure is evidence that a problem with sediment and debris plugging the culvert inlet has been reoccurring through time.

Downstream of 72nd Street E the channel deposition and aggradation from the sediment that has passed through the culvert is so great that the outlet of the pipe is partially buried. A braided channel condition exists downstream of 72nd Street E that continues to Pioneer Avenue, where the channel

must pass through another road culvert. A cross-valley riprap weir, approximately 3 feet high, exists approximately 100 yards upstream of Pioneer Avenue. Downstream of Pioneer Avenue, the channel is also depositional and has aggraded to the point where the landowner downstream of Pioneer Avenue has excavated out the channel and placed the spoils on the adjacent bank for a distance of approximately 500 feet. It appears that this activity may have occurred without a permit. A cease-and-desist letter was posted at this site.

The substrate particle sizes in the channel from 72nd Street E to that observed below Pioneer Avenue slowly decreases from large gravel and cobble down to small gravel and sand. This is primarily due to a reduction in slope moving downstream to the Puyallup River Valley and the large volume of sediment delivered to this reach of channel. The braided planform of the channel is indicative of the inability of the channel to transport the sediment load that is being delivered from upstream source areas.

2.5.3 General Geomorphic Condition and Observations

Rody Creek shows processes and conditions very similar to those previously addressed in Clarks Creek. Regional incision following the straightening of the Puyallup River, impervious-surface-induced runoff, erosion, and regional flooding appear to have destabilized the channel and adjacent hill slopes. In the case of Rody Creek the majority of the most recent hill slope failures occur within the zone of groundwater gain. In comparison, most of the hill slope failures in Clarks Creek occur upstream of the zone of groundwater gain.

Based on the large volume of sediment in the channel downstream of 72nd Street E, we would expect to see continued high sediment delivery to reaches of Rody Creek below Pioneer Avenue all the way to the Clarks Creek confluence. Based on visual observations, most of the material sizes transported downstream of Pioneer Avenue appear to be small gravels, sand, and silt.

2.6 Diru Creek

Diru Creek was walked in the upstream direction from approximately 300 feet downstream of Pioneer Avenue to 84th Street E.

2.6.1 Sediment Point Sources and Instability

Field observations indicate that Diru Creek has experienced 1 to 2 feet of incision or channel bed down-cutting. Existing large wood material has formed jams that have successfully stored sediment upstream of them. Currently, no major point sources of sediment occur within the channel and only minor hill slope failures were observed. Diru Creek is relatively intact and stable as there are no major source areas for sediment. The existing channel and vegetative conditions indicate that the channel has not experienced hydrologic runoff high enough to substantially destabilize the bed and adjacent hill slopes.

In Diru Creek, only 530 cubic yards of sediment were estimated to have been eroded from its banks over the years.

2.6.2 Depositional Reaches

No significant sediment depositional reaches are located in Diru Creek. Local areas of deposition have occurred upstream of large wood jams that are currently storing previously eroded sediment.

2.6.3 General Geomorphic Condition and Observations

Based on field observations, Diru Creek has experienced some regional incision; however, the channel has been able to withstand previous degradation and no major hill slope failures have occurred. Diru Creek is in the best condition of all the stream channels observed and would benefit most from any activities that would reduce future impervious surface peak flow impacts that might be caused from future development.

2.7 Woodland Creek

Segments of Woodland Creek were walked adjacent to the Puyallup Research and Extension Center upstream to 84th Street E. Segments of Woodland Creek were walked near Pioneer Avenue.

2.7.1 Sediment Point Sources and Instability

Woodland Creek has experienced approximately 5 feet of incision; however, upstream of 80th Street E, the channel has not incised and is stable. The most degraded channel segment is the 1,200 feet downstream of the 80th Street E culvert crossing. Within this segment, the channel has degraded and is expanding laterally. The steep vertical valley walls will continue to deliver small gravel, silt, and sand to Woodland Creek.

The total eroded volume from Woodland Creek‘s streambanks was estimated at 2,150 cubic yards.

2.7.2 Depositional Reaches

No major depositional areas are located within Woodland Creek until it runs onto the Puyallup River Valley floor, where the creek runs through a large reed canary grass wetland. The wetland, which runs on both sides of Pioneer Avenue, is very flat and poorly drained. The area provides a substantial sediment sink, and much of the sediment that is delivered from eroding upstream source areas is likely retained and stored in the wetland.

2.7.3 General Geomorphic Condition and Observations

Woodland Creek shows significant incision and ongoing lateral bank erosion. Historical incision has been stopped at the 80th Street E culvert crossing. The crossing controls the grade for the upstream un-incised channel. Below the crossing, the channel continues to laterally erode glacial outwash gravel, sand, and silt. This activity will slowly continue until more stable bank angles are reached and become vegetated.

The large reed canary grass wetland complex that Woodland Creek runs through is a natural sediment sink that appears to be storing and retaining large volumes of sediment. The wetland is large enough to continue to store substantial volumes of future sediment sources from steeper eroding segments of Woodland Creek. Therefore, the wetland provides a good buffer to reduce Woodland Creek-derived sediment to downstream channel segments and Clarks Creek.

2.8 Silver Creek

Silver Creek was walked from Meeker Ditch upstream to 19th Avenue SE and upstream and downstream of 23rd Avenue SE approximately 500 feet. Silver Creek was also viewed from 104th Street E and tributary watershed/channel segments viewed from 5th Street SE.

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2.8.1 Sediment Point Sources and Instability

Within the stream segments observed, Silver Creek has experienced approximately 3 to 4 feet of incision. No incision was observed at the 104th Street E road crossing. Upstream of 23rd Avenue SE, the creek reaches the top of the glacial terrace and the channel is no longer confined by steep valley walls. However, 3 to 4 feet of channel incision still exists.

Below 23rd Avenue SE, the channel is steeper and confined as it drops off the top edge of the glacial terrace and descends to the Puyallup River Valley floor. Recent lateral erosion has destabilized adjacent valley walls and delivered large volumes of gravel, sand, and silt to the channel. In some locations, vertically eroded valley walls are below existing homes. If the valley walls continue to erode, the foundations of these homes would be at risk of becoming undermined and failing.

A discussion with one homeowner indicated that discharge was thought to have increased in recent years and that the inlet to the 23rd Avenue SE culvert has been blocked by debris in the past. Efforts to remove these blockages have resulted in large short-term releases of water dammed upstream of the inlet. The rapid, high-pressure release of water following blockage removal has caused erosion downstream of the culvert outlet. Based on field observation, it could not be determined whether episodic increases from culvert plugging during large winter storm events and runoff, or systemic increases in watershed hydrology, have triggered the recent bed erosion and valley wall instability.

The total eroded volume from Silver Creek‘s streambanks was estimated at 1,190 cubic yards.

2.8.2 Depositional Reaches

A major area of deposition occurs in Silver Creek as it enters the Puyallup River Valley. A recent restoration project and culvert replacement project through 12th Avenue SE experienced significant sediment deposition in recent years. The project is located near the slope break between the steeper glacial terrace channel slope and that of the Puyallup River Valley. The zone of deposition is consistent with what was observed at Clarks, Rody, and Woodland Creeks, and appeared to be dominated by sand and silt. Deposition occurs in this reach of channel all the way to its confluence with Meeker Ditch.

A smaller area of deposition was observed immediately downstream of the 23rd Avenue SE culvert caused by the large area of valley wall erosion. This depositional area is downstream of a significant head cut running over a relatively resistant clay deposit.

2.8.3 General Geomorphic Condition and Observations

Silver Creek is very similar to most of its adjacent tributaries that run down the glacial terrace adjacent to the Puyallup River Valley. It also shows significant incision and lateral erosion along segments of channel that have delivered substantial volumes of sand- and silt-sized sediment to a downstream depositional reach between the Puyallup River Valley toe and its confluence with Meeker Ditch. Upstream sediment sources will likely continue to deliver sand, silt, and gravel to lower Silver Creek and Meeker Ditch.

2.9 Meeker Ditch

Meeker Ditch was viewed at 16th Street SE, 14th Street SE, and at its confluence with Silver Creek.

2.9.1 Sediment Point Sources and Instability

Meeker Ditch is a confined channel running within the Puyallup River Valley. No large point sources of sediment were observed.

2.9.2 Depositional Reaches

A small delta of deposited gravel and larger sediments was observed at the mouth of Silver Creek. Otherwise, no large depositional reaches were observed. The channel geometry and slope appear capable of transporting sediment that is delivered to the channel.

2.9.3 General Geomorphic Condition and Observations

Meeker Ditch is relatively stable and appears able to transport existing sediment loads. Silver Creek is the primary tributary to Meeker Ditch and is likely delivering upstream sand and silt from upstream source areas. A small segment of silt and sand deposition occurred at the confluence with Silver Creek.

3. Sediment Sampling and Analysis

Brown and Caldwell used existing data to tentatively identify cross-section locations for sediment sampling and hydraulic analyses. These tentative cross-section locations were then adjusted based on the field reconnaissance described above. Each cross-section was located using GPS and flagged in the field. Appendix B contains a map and coordinates for the each cross-section.

The project budget allowed for sediment sampling at 20 cross-sections, which are shown on Figure 2 and summarized below:

- 10 sampling locations in the Clarks Creek mainstem
- 3 sampling locations in Rody Creek
- 1 sampling location in Diru Creek
- 1 sampling location in Woodland Creek
- 3 sampling locations in Silver Creek
- 1 each on 2 unnamed tributaries east of Silver Creek

3.1 Methodology

Five surficial sediment subsamples were taken at equally spaced intervals along each cross-section. The subsamples were collected using a scoop where stream conditions allowed easy access. A Van Veen sampler was used where the benthic layer was not reachable or flow rates were too high. The five subsamples were combined in a stainless-steel mixing bowl to form one composite sample for laboratory analysis. The composite sediment samples were poured into two containers: one for analysis of conventional parameters and one for particle size distribution analysis. The containers were then packed in ice and delivered to the lab at the end of each sampling day.

The sediment samples were analyzed for total organic carbon (TOC), total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen, total phosphorus (TP), biochemical oxygen demand (BOD), fecal coliform bacteria, total solids (TS), and grain size distribution (GSD).

All samples were collected between July 27, 2011, and August 9, 2011. The samples were collected shortly after the City of Puyallup and Pierce County had completed their annual cutting of elodea in Clarks Creek downstream of sampling site Clarks-04.

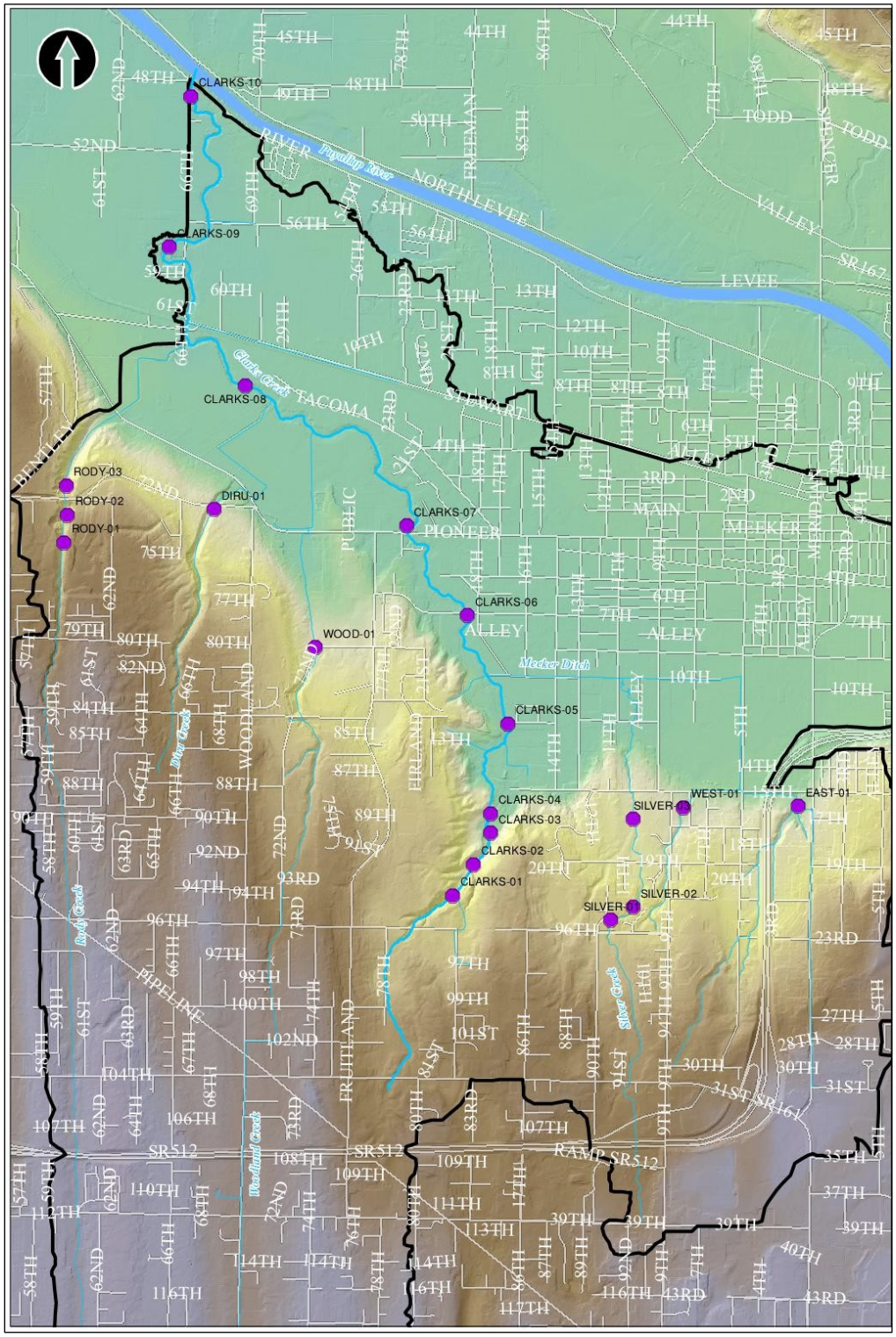

Figure 2. Sediment sampling sites

3.2 Data Quality Review

Data quality was assessed in terms of representativeness, comparability, precision, accuracy, and completeness, in accordance with the QAPP.

Representativeness. The sampling sites were selected based on previous data collection, field reconnaissance, and recommendations from the project geomorphologist. The objective of proper site selection was to capture the different conditions observed along Clarks Creek, including flow rates and benthic sediment composition, as well as capturing potential sediment point sources from the Clarks Creek main tributaries.

Care was taken to follow the laboratory recommendations when collecting and transporting the field samples for laboratory analyses. In addition, all of the proper documentation was filled out (e.g., sample labels, field notebooks, and chain of custody) before submitting them to the lab.

The case narratives from the sediment analyses report stated that some of the samples contained woody or other organic matter, which may have broken down during the sieving process. The presence of organic debris is representative of Clarks Creek and its tributaries.

Comparability. Sample comparability was ensured by following U.S. Environmental Protection Agency (EPA)-recommended sampling methods and analytical procedures, as described in the previous sections.

Precision. Duplicate samples were collected at four sites by filling two additional containers with the same homogenized bulk sample used for the field sample. The duplicate samples were assigned fictional sample locations and submitted to the lab for the same laboratory analyses: TOC, TKN, nitrate and nitrite, TP, BOD, fecal coliform, TS, and particle size distribution.

Precision was assessed by calculating the relative percent difference (RPD) between the duplicate samples. RPDs less than 40 percent are generally considered acceptable for field duplicates of sediment samples (EPA, 2001). The RPDs were consistently below the established criteria, with the exception of those presented in Table 1. The elevated RPDs are probably due to the heterogeneity of the sediment material rather than imprecision in the laboratory analyses.

Table 1. RPDs >40 Percent

Site ID	Total phosphorus	Total Kjeldahl nitrogen	Fecal coliform
Clarks-07	52.5%		52.5%
Rody-03	56.5%	84.0%	

Accuracy. The accuracy of the laboratory data was determined by analyzing matrix spike and blank samples. Matrix spikes and blanks were analyzed for each analytical batch.

The matrix spiked samples were all within the 75–125 percent recovery range prescribed in the QAPP, with the exception of BOD in two of the five analytical batches. Due to the incubation time required for BOD analysis, no corrective measures could be taken. The implications on the laboratory results were documented in the data analysis spreadsheet.

Blank samples are used as laboratory control samples (LCS) and to confirm standard reference material (SRM) reporting limits. For the LCS, a spike is introduced into blank material, as opposed to sediment matrix, and analyzed. The LCS should show recoveries within 75–125 percent. The SRM is

performed on blank samples with no spike. SRM's method detection limit (MDL) depends on the type of laboratory analysis. For a table of SRM and the control limits, please refer to the project QAPP. The SRM samples are required to be within an acceptance range from the MDL to confirm that no contamination is present in the sample. When the percent recovery of the sample (matrix) spikes is outside of the acceptance range, LCS and SRM are evaluated to determine if it is due to laboratory error or lack of sample homogeneity.

LCS associated with BOD analysis were lower than the acceptance range on two batches. However, because of the incubation period, the holding time had expired by the time results were read and no corrective action could be taken. The BOD concentration for the sampling sites in Silver and Rody Creeks could potentially be twice as high as the reported value, and for the sampling sites in Diru Creek and the unnamed tributaries approximately 30 percent higher than the reported value. No other anomalies were observed.

SRM recoveries for TP were higher than the reporting limit in 3 out of the 5 analytical batches. Because this concentration is significantly below the concentrations measured in all actual samples, it was considered acceptable.

No other anomalies were reported.

Completeness. In general, all of the sediment analysis results were deemed usable for the Clarks Creek sediment reduction management plan. The accuracy discrepancies described above will be annotated in the results spreadsheet for consideration when future samples are analyzed and compared.

3.3 Sediment Analysis

Section 3.3.1 summarizes the results of the grain size analyses. Section 3.3.2 summarizes the results for chemical analyses. Appendix C contains all of the sediment data.

3.3.1 Grain Size Distribution

Figure 3 shows the sediment grain size distribution at each cross-section. The following paragraphs describe the apparent patterns. Note that the item numbers go from upstream to downstream sampling sites in Clarks Creek, including where the tributaries enter it.

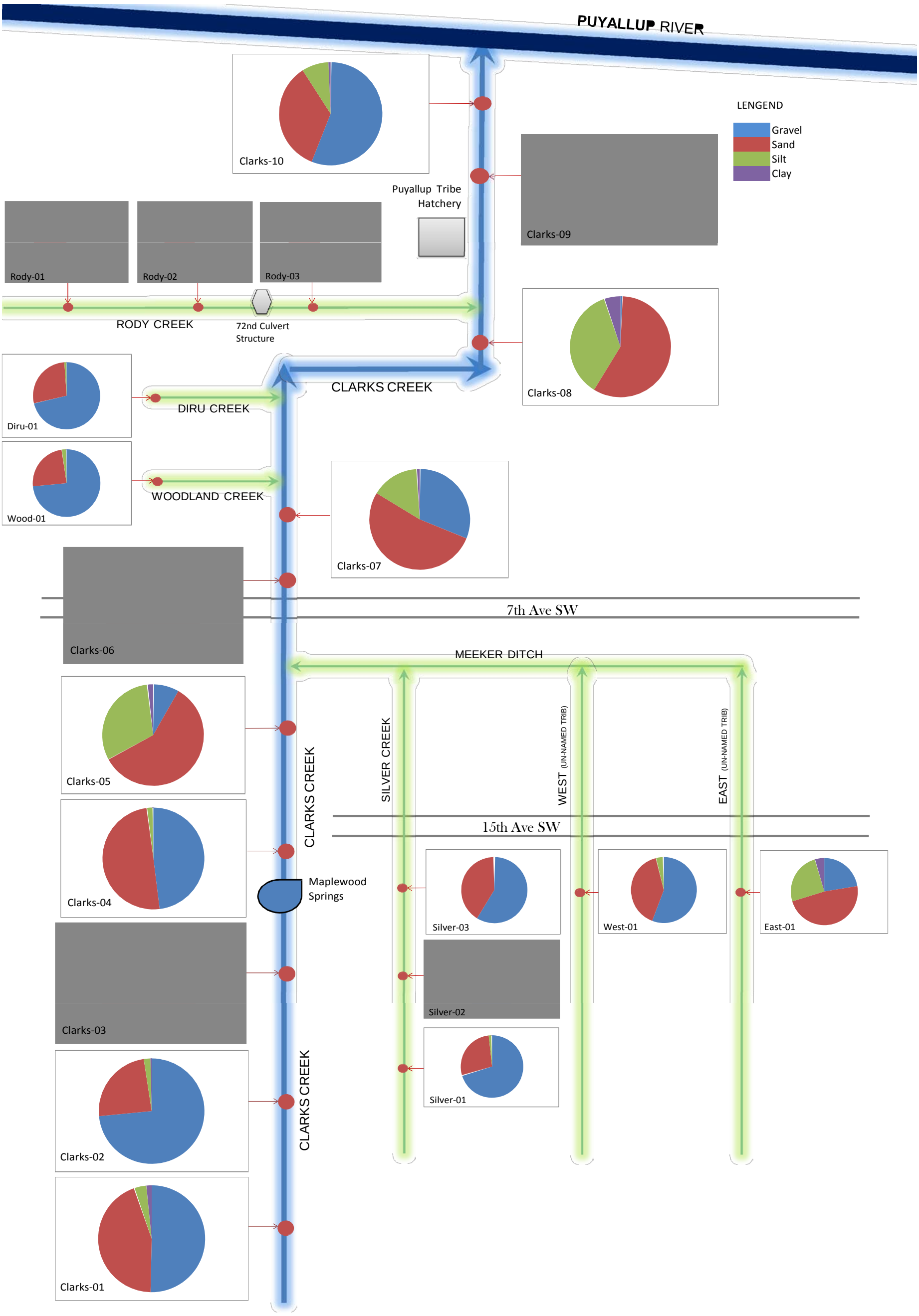

Figure 3. Sediment grain size distribution. Summer 2011.

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FieldInvestigationsMemo mm.docx

Clarks Creek Mainstem

Sediment samples collected at upstream sites generally had higher percentages of gravel and coarse sand than the downstream sites.

- Clarks-03, located upstream of the WDFW masonry dam, had a higher concentration of fine sand than the upstream sites. The geomorphologic report identified this site as a depositions area. On the other hand, Clarks-04, located downstream of the dam, shows an increase in gravel, which is consistent with the field observations of this reach having more stable conditions.
- Samples collected at Clarks-05 near the Clarks Creek Park south parking lot showed an increase in silt and clay content. This can be attributed to the changes in the channel hydraulic characteristics.

  Upstream of this site, Clarks Creek widens and the slope decreases as it enters the Puyallup River Valley. In addition, elodea growth starts approximately 200 feet upstream of this site. The elodea slows down the flow and raises the water depth, allowing fine sediment to settle.
- Downstream of Clarks-05 is the confluence of Meeker Ditch with Clarks Creek. Silver Creek and two unnamed tributaries discharge into Meeker Ditch, as described below:
  - **Silver Creek:** Three sites were sampled in Silver Creek. The composition of the channel bed was predominantly gravel and sand. In contrast to Rody Creek, Silver Creek contained a relatively high percentage of fine sand. It remained fairly constant along the sampled reaches. Silver Creek discharges to Meeker Ditch.
  - **West (unnamed tributary):** Only one site was sampled in this tributary. The sample showed a gravel and sand composition with a relatively low percentage of fine sand. This tributary stream discharges into Meeker Ditch.
  - **East (unnamed tributary):** Only one site was sampled in this tributary. The sample showed a very uniformly distributed composition of gravel, coarse sand, fine sand, and a small percentage of silt. This tributary stream discharges into Meeker Ditch.
- The sites downstream of the confluence with Meeker Ditch show little to no influence from Silver Creek and the two unmanned tributaries. According to the sediment source estimates, Silver Creek can potentially contribute an important volume of sediment to Clarks Creek, but recent restoration projects and culvert replacement have captured a large portion of the load, preventing it from reaching Meeker Ditch and Clarks Creek.
- Woodland and Diru Creeks appear to have little to no influence on Clarks Creek streambed composition. This is in accordance with the observation from the project geomorphologist that found that Diru Creek has a stable channel and while Woodland Creek showed channel instability, most of its sediment load is deposited in the canary grass wetland before entering Clarks Creek.
  - **Woodland Creek:** One site was sampled in Woodland Creek. The sample showed a composition of gravel and sand, which also included a relatively small percentage of fine sand.
  - **Diru Creek:** One site was sampled in Diru Creek. The sample was primarily gravel and sand.
- Rody Creek enters the Clarks Creel mainstem upstream of Clarks-09.

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- **Rody Creek:** Three sites were sampled in Rody Creek. The composition of the channel bed was predominantly gravel and sand. It remained fairly constant along the sampled reaches.

- Finally, the data showed a break in the pattern as we reach the most downstream site in Clarks Creek (Clarks-10). The bed load composition changes from primarily fine sand to gravel. This can be attributed to the load contributed from Rody Creek, which showed a primarily gravel streambed composition. The sampling results confirm the geomorphologist's observations that Rody Creek is a major source of sediment in Clarks Creek lower reaches and that the majority of the sediment contributed consists of small gravel, sands, and silt.

3.3.2 Conventional Parameters

The samples were analyzed for TOC, TKN, nitrate and nitrite, TP, BOD, fecal coliform bacteria, and TS. Table 2 summarizes the analytical results.

Table 2. Conventional Parameters Laboratory Results

Site ID	% TS	Total fines [a] (%)	TP (mg/kg)	TKN	NO_3+NO_2	BOD (mg/kg)	% TOC	Fecal coliform (CFU/g)
Clarks Creek								
Clarks-01	88.5	5.4	465	368	9	286	1.58	37
Clarks-02	83.4	2.4	203	80.8	0.11	0	0.454	52
Clarks-03	80.9	2.5	142	205	0.33	0	0.464	0
Clarks-04	84	2.2	209	146	0	169	0.684	2
Clarks-05	40.4	33	119	2,380	0	1,320	7.18	0
Clarks-06	46.3	17.8	1,090	1,860	0	1,710	3.19	129
Clarks-07	46.5	16.3	440	1,600	0	1,820	2.44	170
Clarks-08	39.7	41.2	1,740	2,540	0	3,070	3.49	49
Clarks-09	48.4	35.4	766	1,970	0	1,660	2.35	0
Clarks-10	71.1	9.1	660	591	0	550	1.06	28
Rody Creek								
Rody-01	84.2	0.3	168	96.6	0.98	0	0.481	527
Rody-02	79.2	0.2	197	260	0.57	0	0.607	0
Rody-03	83.5	0.1	120	193	0.47	0	0.287	0
Diru Creek								
Diru-01	83.6	1.1	161	157	0.48	0	0.259	0
Woodland Creek								
Wood-01	94.5	2.4	81.7	573	2.86	173	1.12	27
Silver Creek								

Table 2. Conventional Parameters Laboratory Results								
Site ID	% TS	Total fines [a] (%)	TP (mg/kg)	TKN	NO_3+NO_2	BOD (mg/kg)	% TOC	Fecal coliform (CFU/g)
Silver-01	78.3	1.7	321	370	0.24	229	2.35	27
Silver-02	86.7	2.2	205	355	0	337	0.999	192
Silver-03	81.5	0.5	142	93.7	0.19	163	0.667	28
Other tributaries								
West-01	82.3	4	3.93	211	0	145	0.583	92
East-01	64.5	29.7	277	1,970	0	340	3.97	36

a. *Total fines is the sum of the percentage of silt and clay particle size.*

In general, concentrations of TP, nitrogen, BOD, and TOC appeared to be higher in samples with higher percentages of fine-grained material. Fecal coliform bacteria concentrations did not appear to increase with percent fines.

4. Summary

The following bullets summarize the key findings from the summer 2011 geomorphology reconnaissance and sediment sampling:

- Field reconnaissance found evidence of substantial channel erosion on upper Clarks, Silver, Rody, and Woodland Creeks.
- Potential causes for the observed channel erosion include forest removal, creation of impervious surfaces, Puyallup River channel straightening, and large winter storms and floods.
- Channel erosion on upper Clarks and Rody Creeks appears to contribute substantial sediment to lower Clarks Creek.
- The masonry dam on Clarks Creek near the Puyallup Trout Hatchery appears to trap coarse sediment but not sand and smaller material.
- Much of the sediment from channel erosion on upper Silver and Woodland Creeks appears to be trapped before reaching Clarks Creek.
- Sediment samples with higher concentrations of fine sediment (silt and clay) generally had higher concentrations of TP, total nitrogen, BOD, and TOC. The data did not show an apparent relationship between fecal coliform and grain size distribution.

5. Limitations

This memorandum is a working document. The information contained in this memorandum will be used to help identify and evaluate sediment control measures. The information presented may be superseded by subsequent evaluations and reports.

The eroded sediment volumes were estimated based on field observations and measurements made during the summer of 2011. Little information was available regarding channel geometry and hydraulic characteristics under natural conditions. The sediment volume estimates were developed

to support identification and development of sediment control measures. The sediment estimates may or may not be appropriate for other uses.

The observations and measurements presented in this memorandum are based on one round of field reconnaissance and sediment sampling performed during the summer of 2011. They are only representative of the conditions at the time of sampling.

6. References

Clear/Clarks Creek Basin Plan Phase 2: Water Quality, Habitat and Flooding Problem Analysis. Appendix E. Pierce County.

Clarks Creek Watershed Pollution Reduction Project Submittal Report. 2005. URS Group Inc. and Brown and Caldwell. Prepared for the City of Puyallup Engineering Department.

Historical Platte Map. Puyallup Indian Reservation map files.

Savoca, M.E., Welch, W.B., Johnson, K.H., Lane, R.C., Clothier, B.G., and Fusser, E.T., 2010, Hydrogeologic framework, groundwater movement, and water budget in Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington: U.S. Geological Survey Scientific Investigations Report 2010-5055, 46 p.

Appendix A – Sediment Source Volumes

During the field investigations, visual estimates of eroded stream bed and bank materials were noted. Stream bed erosion was estimated based on visual indicators of depth of incision and channel width. Depth of incision was estimated from grade controls including trail and road crossings, roots and logs spanning the channel. Nearby intact channel conditions were visually extrapolated to eroded sections to estimate depth of incision and channel width. Bank erosion was visually estimated by comparing eroded banks to nearby intact banks. An estimate of the eroded cross section height, width (lateral migration) and whether the section was generally rectangular or triangular in shape were noted. Lengths of individual eroded segments were estimated using either GPS, hip chain, pacing or visual estimates. Erosion volumes of incremental eroded segments were estimated from cross sectional area multiplied by length. The following tables provide a summary of the estimated dimensions and order of magnitude volume of eroded material.

Clarks Creek

sediment source estimates - downstream to upstream

d/s GPS	u/s GPS	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
395	396	125	1	7	1	bed	32.4
		125	8	5	0.5	bank	92.6
396		30	8	10	0.5	bank	44.4
397		30	4	6	0.5	bank	13.3
398	399	35	1.5	10	1	bed	19.4
		30	4	6	0.5	bank	13.3
400		50	2	8	1	bed	29.6
		50	10	8	0.5	bank	74.1
401	402	105	6	10	0.5	bank	116.7
402	403	60	4	12	1	bed	106.7
		30	30	15	0.5	bank	250
403	404	40	20	12	0.5	bank	177.8
404	405	45	6	15	1	bed	150
		45	40	30	0.5	bank	1000
405	406				0.5 *	404-405	575
406	407				0.8 *	404-405	920
407	408	105		20	15	bank	0
408	409	75	4	10	1	bed	111.1
		75	12	10	0.5	bank	166.7
		75	12	10	0.5	bank	166.7
409	410	75	5	10	1	bed	138.9
		75	20	10	0.5	bank	277.8
		75	20	10	0.5	bank	277.8
410	411	70	12	10	1	bed	311.1
411	412 0.5*L	50	5	6	1	bed	55.6
	0.5*L	50	10	12	1	bed	222.2
						Total	5340

Clarks Creek Tributary

sediment source estimates - upstream to downstream

u/s hipchain	d/s hipchain	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
		50	20	10	1	bank x2	370.4
		50	5	10	1	bed	92.6
		27	30	15	1	bank x2	450
		27	5	10	1	bed	50
	90	40	40	15	1	bank x2	888.9
		40	5	15	1	bed	111.1
90	158	68	12	10	1	bank x2	302.2
		50	3	8	1	bed	44.4
158	202	44	20	15	1	bank x2	488.9
		44	4	10	1	bed	65.2
210	268	58	15	15	0.5	bank	241.7
		58	3	8	1	bed	51.6
302	326	24	15	10	0.5	bank	66.7
440	470	30	20	15	0.5	bank	166.7
688	= gps 413						
						Total	3390

Diru Creek

sediment source estimates - downstream to upstream

d/s GPS	u/s GPS	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
	424	35	12	10	0.5	bank	77.8
		35	3	10	1	bed	38.9
		20	8	10	0.5	bank	29.6
	425	15	8	6	0.5	bank	13.3
		25	12	12	0.5	bank	66.7
		20	6	6	0.5	bank	13.3
		50					
	431	40	10	10	0.5	bank	74.1
	433	50	15	10	0.5	bank	138.9
	435	50	8	10	0.5	bank	74.1
						Total	530

Rody Creek

sediment source estimates - upstream to downstream

u/s GPS	d/s GPS	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
448		100	2	5	1	bed	37
451		30	20	10	0.5	bank	111.1
		30	6	6	0.5	bank	20
		100	4.5	12	1	bed	200
452	gen'l		3	12	1	bed	0
453		40	5	5	0.5	bank	18.5
		100	2	5	1	bed	37
		50					
454		30	2	12	1	bed	26.7
		30	3	5	1	bed	16.7
		50	8	6	0.5	bank	44.4
457		30	15	10	0.5	bank	83.3
457		200	5	30	1	sed wedge	1111.1
466		40	5	10	1	landslide	74.1
467		40	8	8	0.5	bank	47.4
469		30	4.5	25	1	flood deposits	125
d/s of Pioneer Ave dredging		300	4	12	1	dredge	533.3
						Total	2490

Woodland Creek

sediment source estimates - upstream to downstream

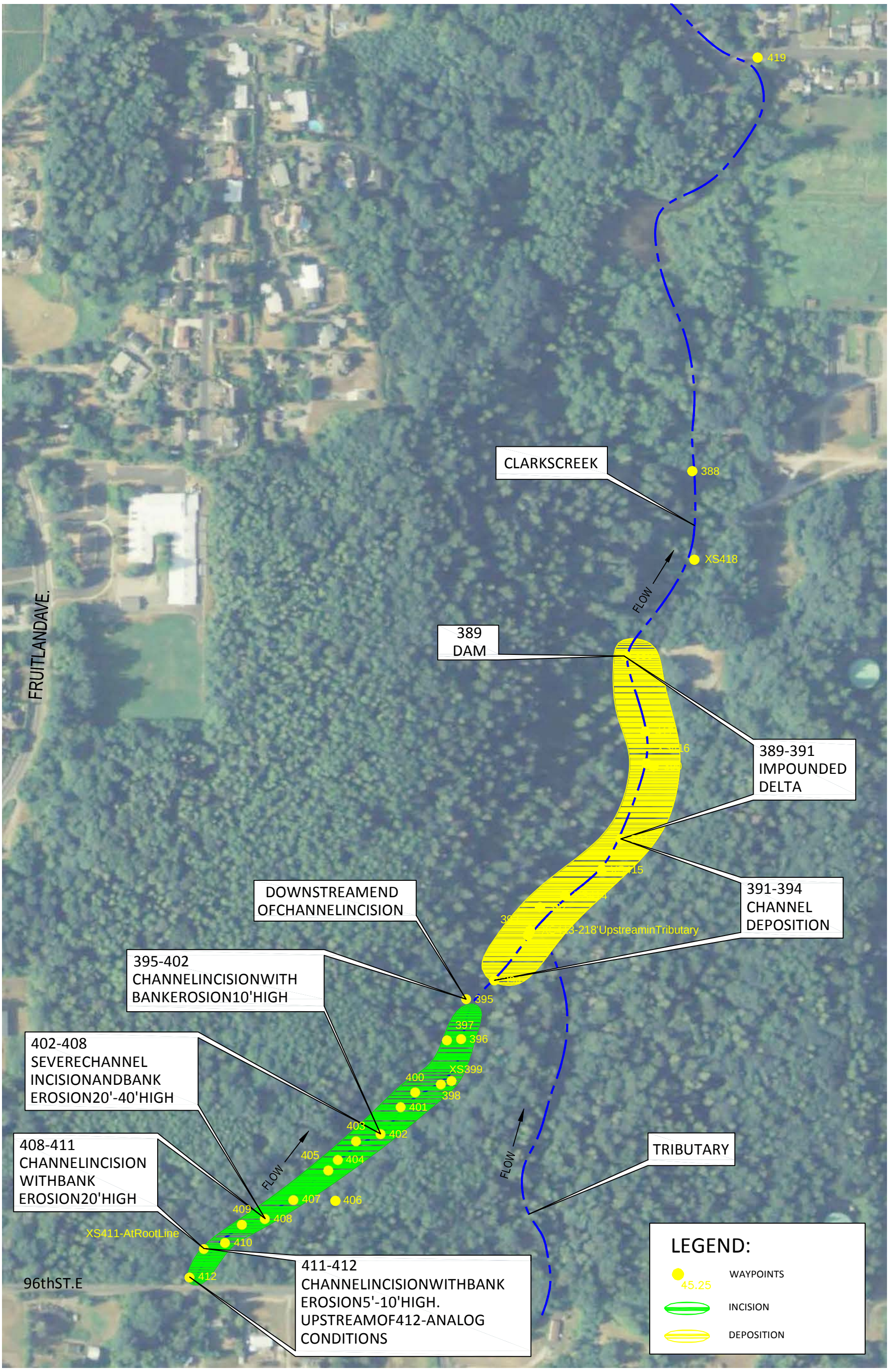
d/s hip chain	u/s hip chain	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
84th Ave							
0	100	100	4	8	1	bed	118.5
		30	6	20	1	bed	133.3
191	250	59	7	8	1	bed	122.4
250	290	40	10	12	1	bed	177.8
326	372	46	12	12	1	bed	245.3
		50					
372	444	72	8	12	1	bed	256
444	600	156	10	15	1	bed	866.7
496	524	28	30	15	0.5	bank	233.3
Other areas with 'relatively minor' erosion - midway along WSU reach							
						Total	2150

Silver Creek

sediment source estimates - upstream to downstream

d/s GPS	u/s GPS	L (ft)	Ht (ft)	Base (ft)	shape factor	shape feature	Volume c.y.
at u/s road Xing							
488	496	60	20	20	1	bed	890
		50	15	10	1	bank retreat	280
489	488	70	10	15	1	bed	390
	489	35	7.5	10.5	1	bed	100
490		40	5	6	1	bed	44
491	490	135	3	10	1	bed	150
		50	5	5	0.5	bank	23
u/s of 15th Ave SW							
485		30	6	5	1	bank retreat	33
d/s of 15th Ave		30	6	12	1	bed	80
						Total	1990

Appendix B – Site Maps



PLANVIEW

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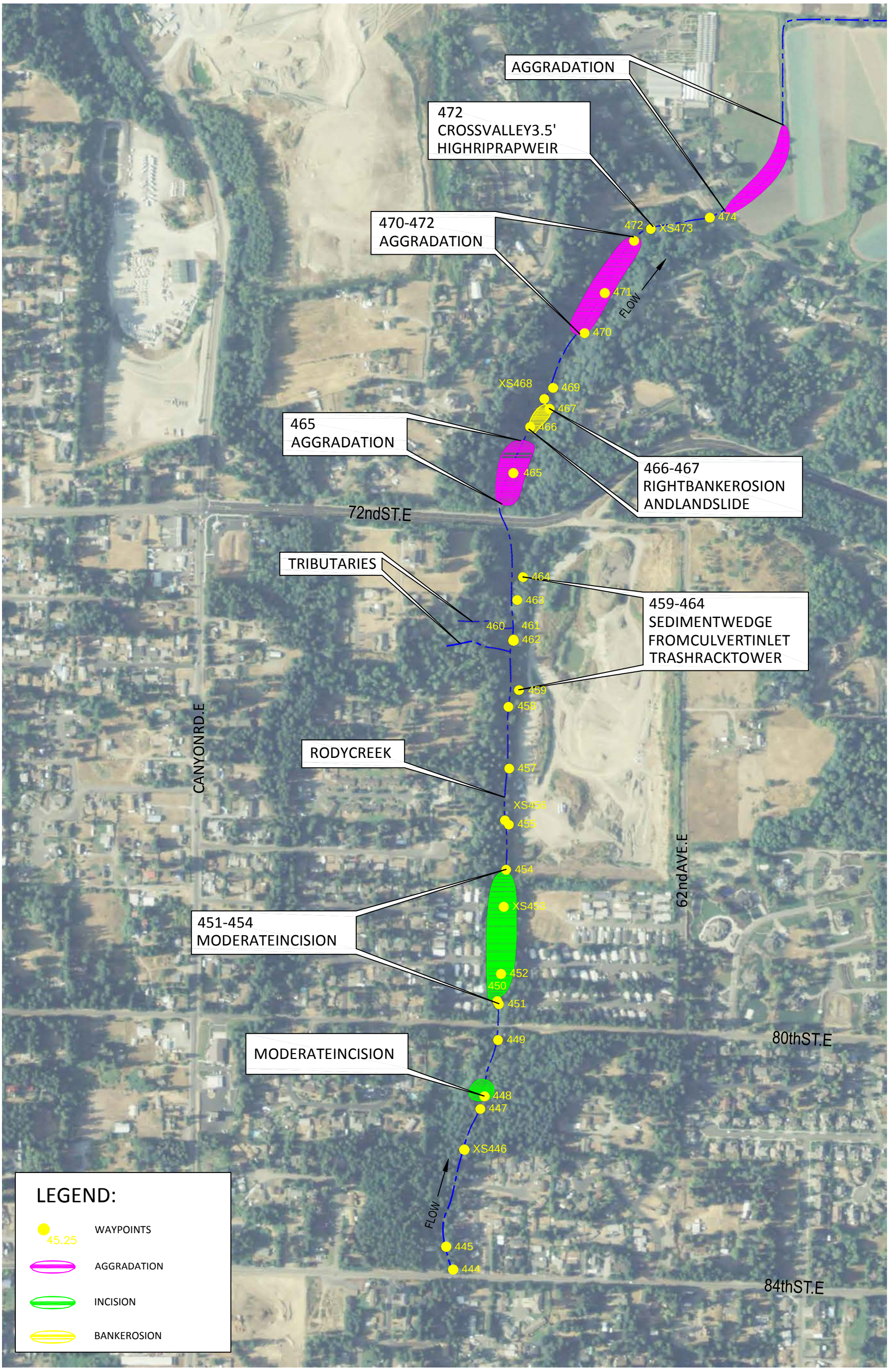
SCALE IN FEET

inter·fluve

PlanViewofClarks CreekWaypoints



PLANVIEW

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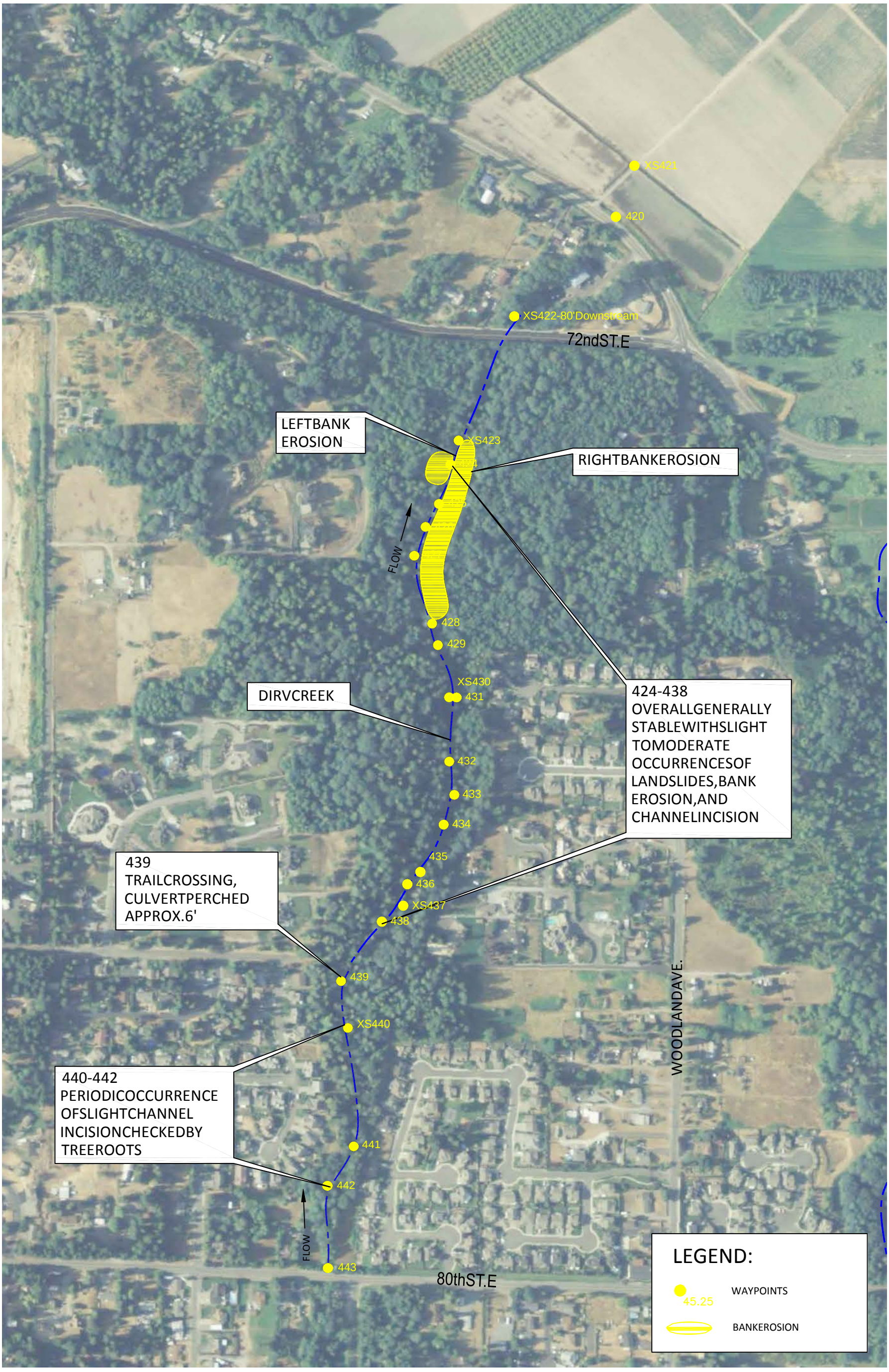
SCALE IN FEET

inter·fluve

PlanViewofRody CreekWaypoints



PLANVIEW

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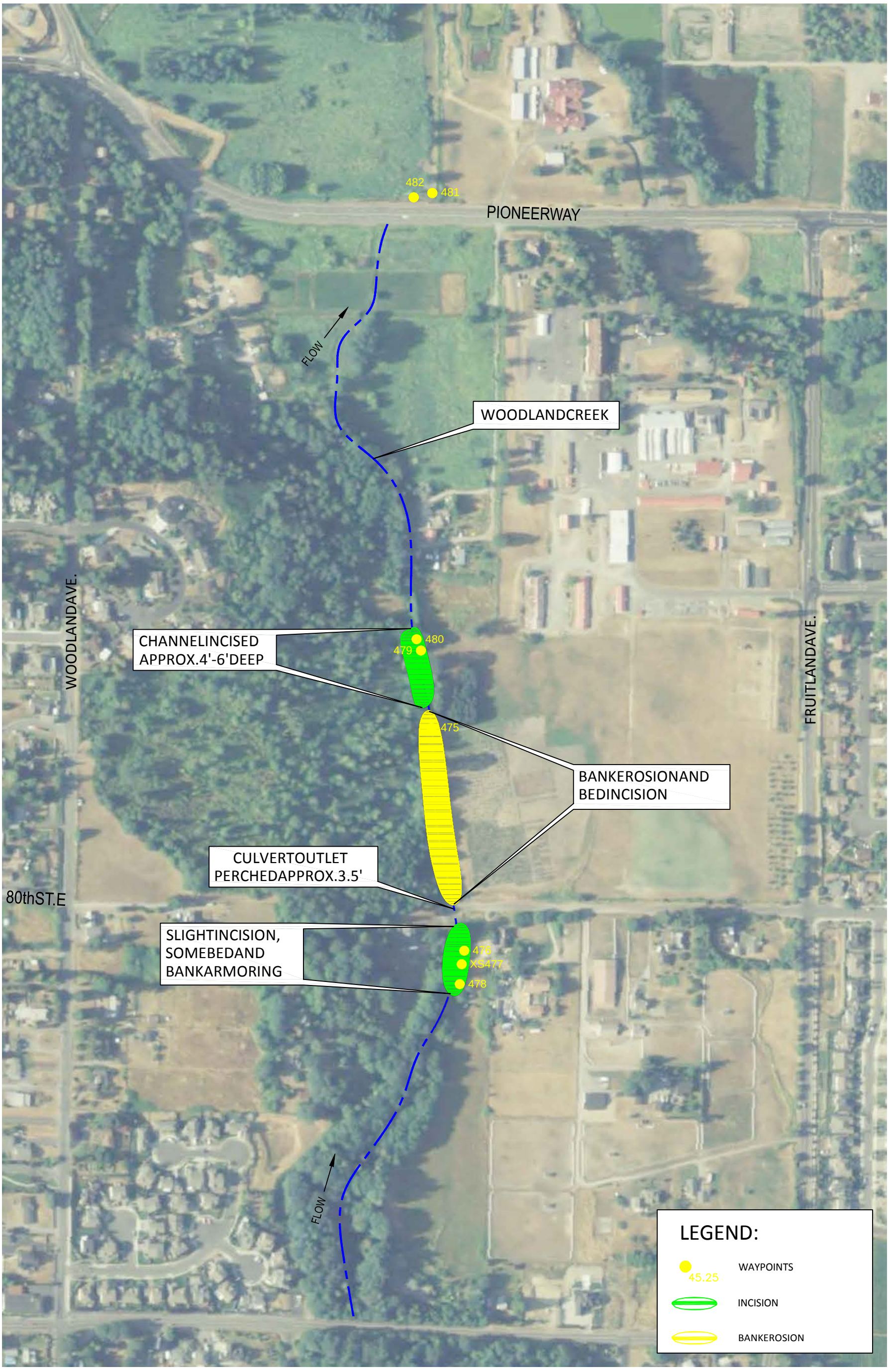
SCALE IN FEET

inter·fluve

PlanViewofDiru
CreekWaypoints



PLANVIEW

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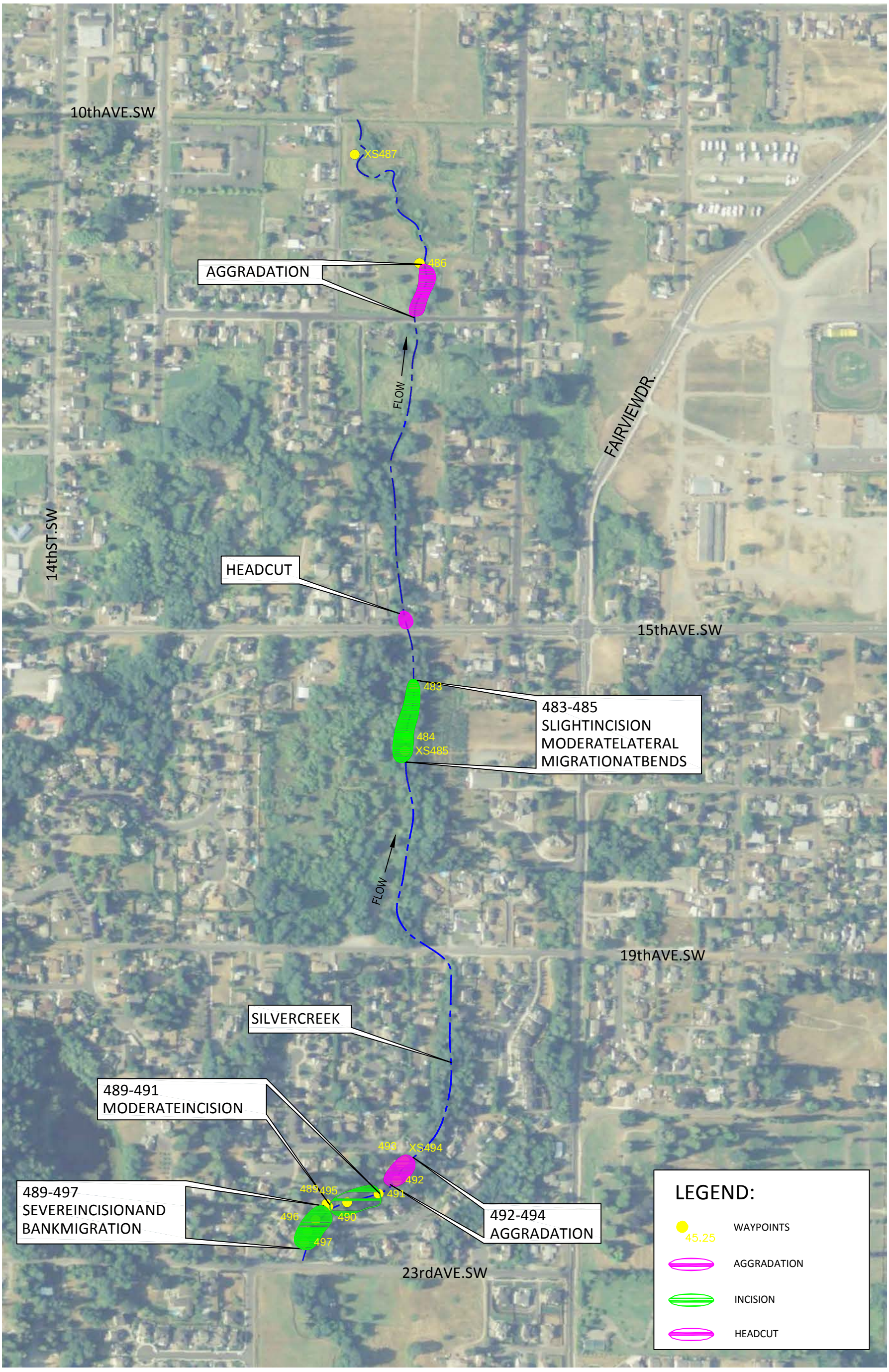
SCALE IN FEET

inter·fluve

PlanViewof
WoodlandCreek
Waypoints



PLANVIEW

0 400 800

SCALE IN FEET

inter·fluve

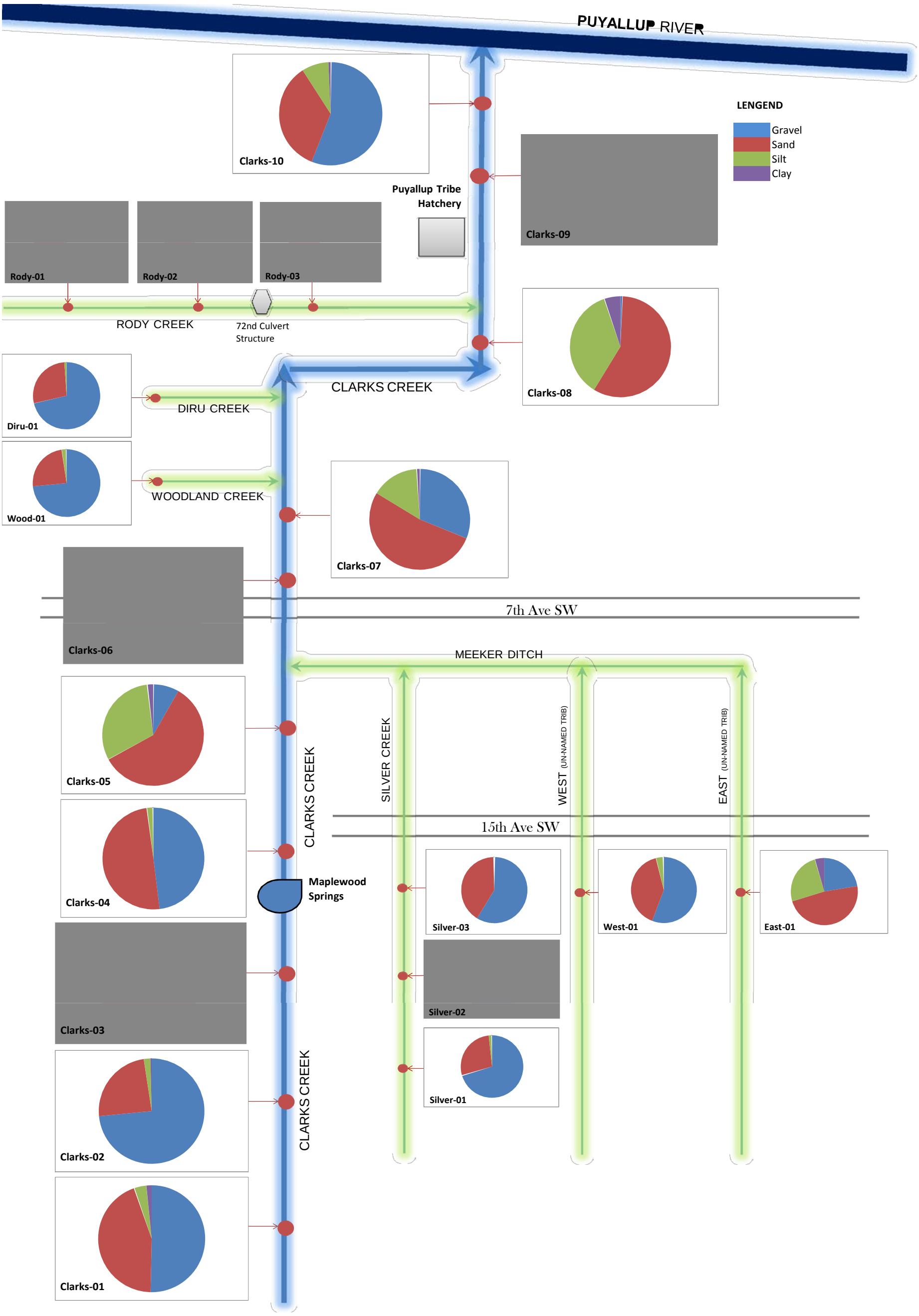
PlanViewofSilver CreekWaypoints

Appendix C – Sediment Data Analysis

General notes:

The Site ID was determined by the creek's name and its location as related to most upstream and most downstream.
The most upstream location is xxxx-01 and as the number increases, we move downstream.

Site ID	Description/Comments
Clarks Creek	
Clarks-01	– This site is located within the Clarks Creek Park. – Accessed by foot through the park's trail system off of 23rd Ave. – The site is downstream of headcuts that are approximately 14 feet high. – No running water at the time of sampling. .
Clarks-02	– This site is located within the Clarks Creek Park. – Accessed by foot through the park's trail system off of 23rd Ave. – The site is downstream of headcuts that are approximately 14 feet high. – No running water at the time of sampling. .
Clarks-03	– This site is located upstream of the Maplewood Springs. – Accessed from the State's hatchery road system.
Clarks-04	– This site is located downstream of the City of Puyallup Maplewood Springs. – Accessed from the State's hatchery road system.
Clarks-05	– This site is located by the Clarks Creek Park south entrance parking lot. – Easily accessible. – This site was part of Brown and Caldwell's 2009 DO study.
Clarks-06	– This site is located by the Decoursey Park entrance parking lot. – Easily accessible. – This site was part of this year's Elodea Pulling pilot project.
Clarks-07	– This site is located at the intersection of 22nd and Pioneer. Under the bridge. – Easily accessible from the street.
Clarks-08	– This site is located in a residential area. Off of Tacoma road. – This site was part of Brown and Caldwell's 2009 DO study. – It was difficult to obtain the sediment samples from the bridge, so we waded across - with high water levels.
Clarks-09	– This site is located downstream of the Clarks Creek Puyallup Tribe hatchery intake and screens. – Accessed from the hatchery's property.
Clarks-10	– This site is located near the convergence of Clarks Creek into the Puyallup River. – Accessed through a residence.
Rody Creek	
Rody-01	– This site is located the most upstream from the 72nd culvert structure. – Accessed by foot from 72nd.
Rody-02	– This site is located the directly upstream from the 72nd culvert structure. – Accessed by foot from 72nd.
Rody-03	– This site is located directly upstream of the 72nd culvert structure. – Accessed by foot from 72nd.
Diru Creek	
Diru-01	– This site is located close to the confluence of Diru Creek into Clarks Creek. – Accessed by foot from Pioneer Rd.
Woodland Creek	
Wood-01	– This site is south of the wetland. – Easily accessible from Fruitland St.
Silver Creek	
Silver-01	– This site is located north of 23rd. – Accessed by foot from 23rd. – This site is within a residential area. – Samples were collected downstream of headcuts that were approximately 20 feet high
Silver-02	– This site is located north of 23rd. Downstream from Silver-01. – Accessed by foot from 23rd. – This site is within a residential area. – Samples were collected at a braid in the stream. The entire cross section was used for the composite sample.
Silver-03	– This site is located south of 15th. – Accessed by foot through a trail system. – This reach of Silver Creek was very urbanized and it resemble more a drainage ditch
Un-named Tributaries	
West-01	– This site is located east of Silver Creek and south of 15th. – Accessed through a residence.
East-01	– This site is located east of West-01 and south of 15th. – Accessed from a gas station parking lot.


PUYALLUP RIVER
LENGEND
Gravel
Sand
Silt
Clay
Clarks-10
Clarks-09
Puyallup Tribe Hatchery
Rody-01
Rody-02
Rody-03
RODY CREEK
72nd Culvert Structure
Clarks-08
CLARKS CREEK
Diru-01
DIRU CREEK
Wood-01
WOODLAND CREEK
Clarks-07
Clarks-06
7th Ave SW
MEEKER DITCH
Clarks-05
Clarks-04
CLARKS CREEK
SILVER CREEK
WEST (UN-NAMED TRIB)
EAST (UN-NAMED TRIB)
15th Ave SW
Maplewood Springs
Silver-03
West-01
East-01
Clarks-03
Silver-02
Silver-01
Clarks-02
CLARKS CREEK
Clarks-01

General Notes:

This sheet contains the laboratory results grouped as Grain Size Distribution (GSD) Analysis for composite samples; conventional parameters for composite samples; and the GSD Analysis for the Sub-armor samples. The Sub-armor layer GSD will not be analyzed as part of this task. It will used to in Task 4.

When a "U" appears next to a result, it means that the concentration was too low to be detected by the analytical method used. That just indicates that the concentration present was very small.

Results

GRAIN SIZE (COMPOSITE SAMPLE)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Coarse Silt	Medium Silt	Fine Silt		Very fine Silt	Clay
Site ID	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**75-32**	**32-22**	**22-13**	**13-9**	**9-7**	**7-3.2**	**<3.2**
Clarks-01	0	0	4.4	4.7	23.3	6.7	11.2	8.7	4.9	9.4	11.9	6	3.3	0	0.4	0.7	0.7	1.1	0.9	1.6
Clarks-02	0	0	9.5	23.2	20.7	8.5	11.5	7.1	5.5	4.8	3.6	2	1.1	1	0.3	0.1	0.1	0.2	0.3	0.4
Clarks-03	0	0	0	0	5.6	9.2	16.9	17.7	14.9	10.7	10.6	6.8	5	0.6	0	0.2	0.4	0.2	0.7	0.4
Clarks-04	0	0	0	3.8	12.7	10.6	20.9	16.5	10.4	11.3	7.2	2.6	1.7	0.1	0.5	0	0.3	0.5	0.5	0.3
Clarks-05	0	0	0	0	6.8	1.1	0.4	1.2	3.9	7.1	10.2	17.2	19.1	12	3.3	4.6	5.2	2.6	3.3	2
Clarks-06	0	0	0	0.5	9.7	3.2	11.5	5.6	3.3	3.6	8.1	16.3	20.4	5.7	2.6	2.6	3	0.9	1.3	1.7
Clarks-07	0	0	0	0	15.3	5	10.8	7.9	5.1	3.5	3.4	9.4	23.2	7.2	2.6	2.9	0.7	0.7	1.1	1.1
Clarks-08	0	0	0	0	0	0	0.6	0.4	1.5	3.4	7.1	17.3	28.4	17	5.3	5.3	3	2.3	3	5.3
Clarks-09	0	0	0	0	0	0	0.1	0.9	2.9	5.1	6.8	17.3	31.6	10.9	5.6	4.2	2.1	1.4	7.7	3.5
Clarks-10	0	0	0	4.6	18.1	15	18.3	6.3	3.5	4.6	4.7	5.6	10.2	4.9	0.5	0.7	1.6	0.5	0.2	0.7
Duplicates Samples																				
Clarks-A (Clarks-07)	0	0	0	5.9	12.2	3.3	7.4	5.8	5	3.3	3.5	9.9	26.4	6.3	3.2	1.4	3.2	0.5	1.4	1.4
Clarks-B (Clarks-04)	0	0	0	0	12.4	7.9	23.9	19.6	10.3	12.2	8	2.8	1.7	0.5	0	0	0.2	0	0	0.5

CONVENTIONALS (COMPOSITE SAMPLE)

	Total Solids	Nitrate + Nitrite (NO3+NO2)	Total Phosphorus	Total Kjeldahl Nitrogen	Biological Oxygen Demand	Total Organic Carbon	Fecal Coliforms
Site ID	**%**	**mg-N/kg**	**mg/kg**	**mg-N/kg**	**mg/kg**	**%**	**CFU/g**
Clarks-01	88.5	9	465	368	286	1.58	37
Clarks-02	83.4	0.11	203	80.8	11.1 U	0.454	52
Clarks-03	80.9	0.33	142	205	69.3 U	0.464	2 U
Clarks-04	84	0.12 U	209	146	169	0.684	2
Clarks-05	40.4	2.36 U	119	2380	1320	7.18	5 U
Clarks-06	46.3	1.06 U	1090	1860	1710	3.19	129
Clarks-07	46.5	1.05 U	440	1600	1820	2.44	170
Clarks-08	39.7	1.24 U	1740	2540	3070	3.49	49
Clarks-09	48.4	1 U	766	1970	1660	2.35	41 U
Clarks-10	71.1	0.67 U	660	591	550	1.06	28
Duplicates Samples							
Clarks-A (Clarks-07)	44	1.13 U	926	1780	1910	1.99	358
Clarks-B (Clarks-04)	83	0.12 U	283	176	100	0.667	2 U

GRAIN SIZE (SUB-ARMOR LAYER)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Silt and Clay
Site ID	**5-3"**	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**<75**
Clarks-01	0	0	7.7	29	18.5	16.2	6.1	7.1	4.3	2.7	2.8	2.2	1	0.6	2
Clarks-02	0	0	2.7	21.1	14.5	18.5	7.5	13.5	10.4	5.7	3.7	1.6	0.3	0.1	0.4
Clarks-03	0	0	0	5.3	9.6	21.9	10.1	21.4	15.5	8.8	5.3	1.6	0.3	0.1	0.1
Clarks-04	0	0	0	5.8	12.6	19.3	9.1	23.8	16.2	8	3.9	1.1	0.2	0.1	0

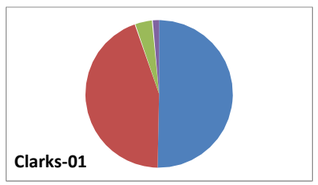
GRAPHICAL REPRESENTATION OF THE GRAIN SIZE DISTRIBUTION FOR CLARKS CREEK

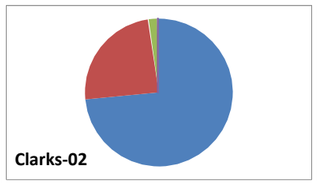
From the results presented in the Clarks Creek Sites tab:

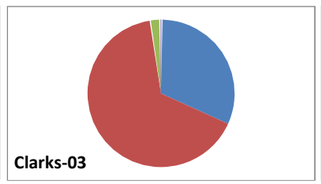
	Clarks-01	Clarks-02	Clarks-03	Clarks-04	Clarks-05	Clarks-06	Clarks-07	Clarks-08	Clarks-09	Clarks-10
Coarse Gravel (%)	9.1	32.7	0	3.8	0	0.5	0	0	0	4.6
Gravel (%)	41.2	40.7	31.7	44.2	8.3	24.4	31.1	0.6	0.1	51.4
Coarse Sand (%)	8.7	7.1	17.7	16.5	1.2	5.6	7.9	0.4	0.9	6.3
Medium Sand (%)	14.3	10.3	25.6	21.7	11	6.9	8.6	4.9	8	8.1
Fine Sand (%)	21.2	6.7	22.4	11.5	46.5	44.8	36	52.8	55.7	20.5
Very Coarse Silt (%)	0	1	0.6	0.1	12	5.7	7.2	17	10.9	4.9
Coarse Silt (%)	0.4	0.3	0	0.5	3.3	2.6	2.6	5.3	5.6	0.5
Medium Silt (%)	0.7	0.1	0.2	0	4.6	2.6	2.9	5.3	4.2	0.7
Fine Silt (%)	1.8	0.3	0.6	0.8	7.8	3.9	1.4	5.3	3.5	2.1
Very fine Silt (%)	0.9	0.3	0.7	0.5	3.3	1.3	1.1	3	7.7	0.2
Clay (%)	1.6	0.4	0.4	0.3	2	1.7	1.1	5.3	3.5	0.7

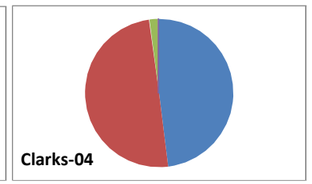
Further grouping of the grain sizes yields:

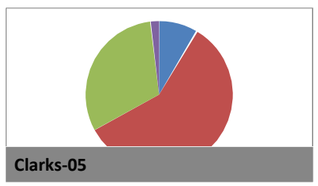
	Clarks-01	Clarks-02	Clarks-03	Clarks-04	Clarks-05	Clarks-06	Clarks-07	Clarks-08	Clarks-09	Clarks-10
Gravel	50.3	73.4	31.7	48	8.3	24.9	31.1	0.6	0.1	56
Sand	44.2	24.1	65.7	49.7	58.7	57.3	52.5	58.1	64.6	34.9
Silt	3.8	2.0	2.1	1.9	31.0	16.1	15.2	35.9	31.9	8.4
Clay	1.6	0.4	0.4	0.3	2	1.7	1.1	5.3	3.5	0.7

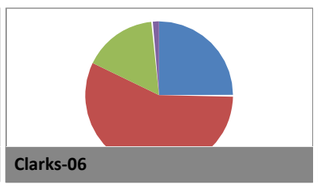


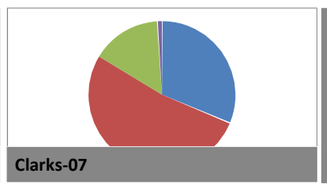


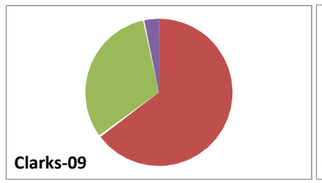


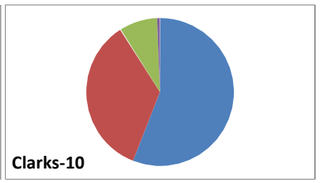








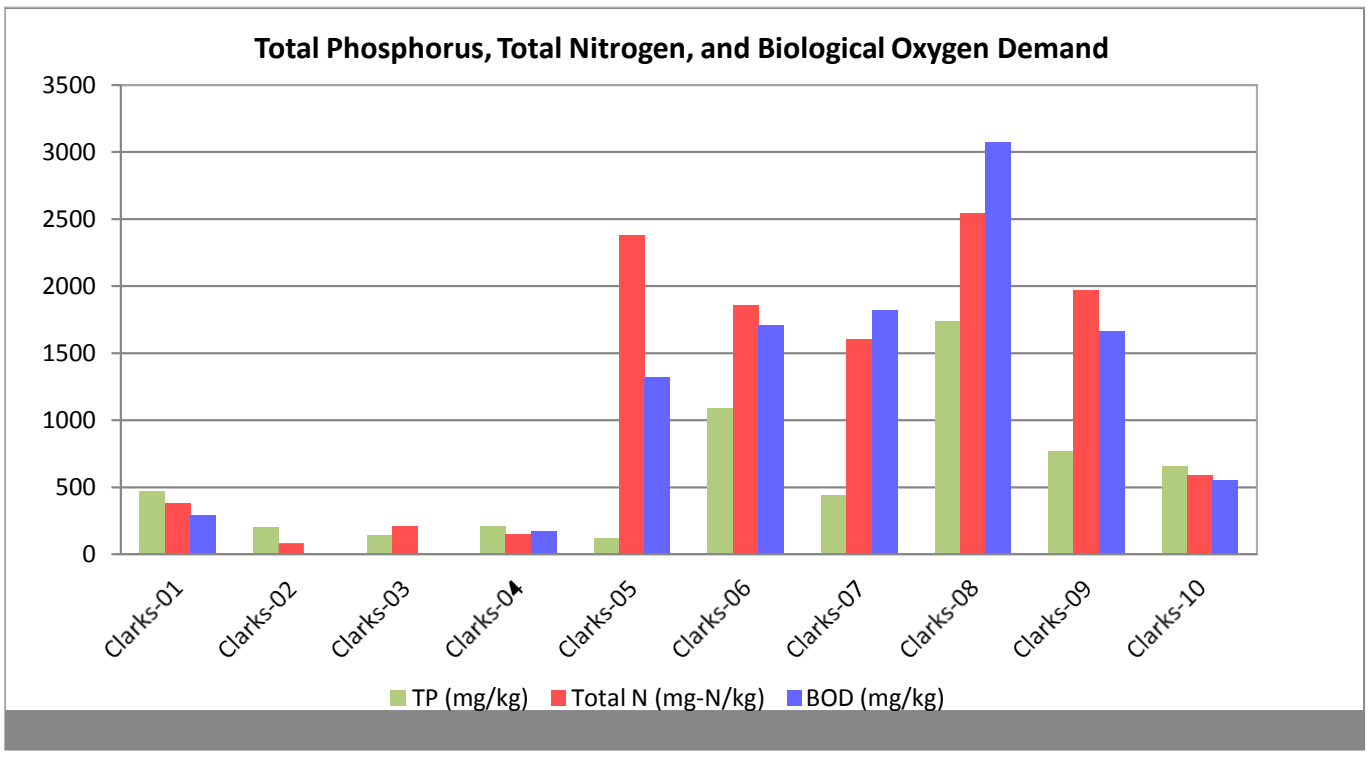


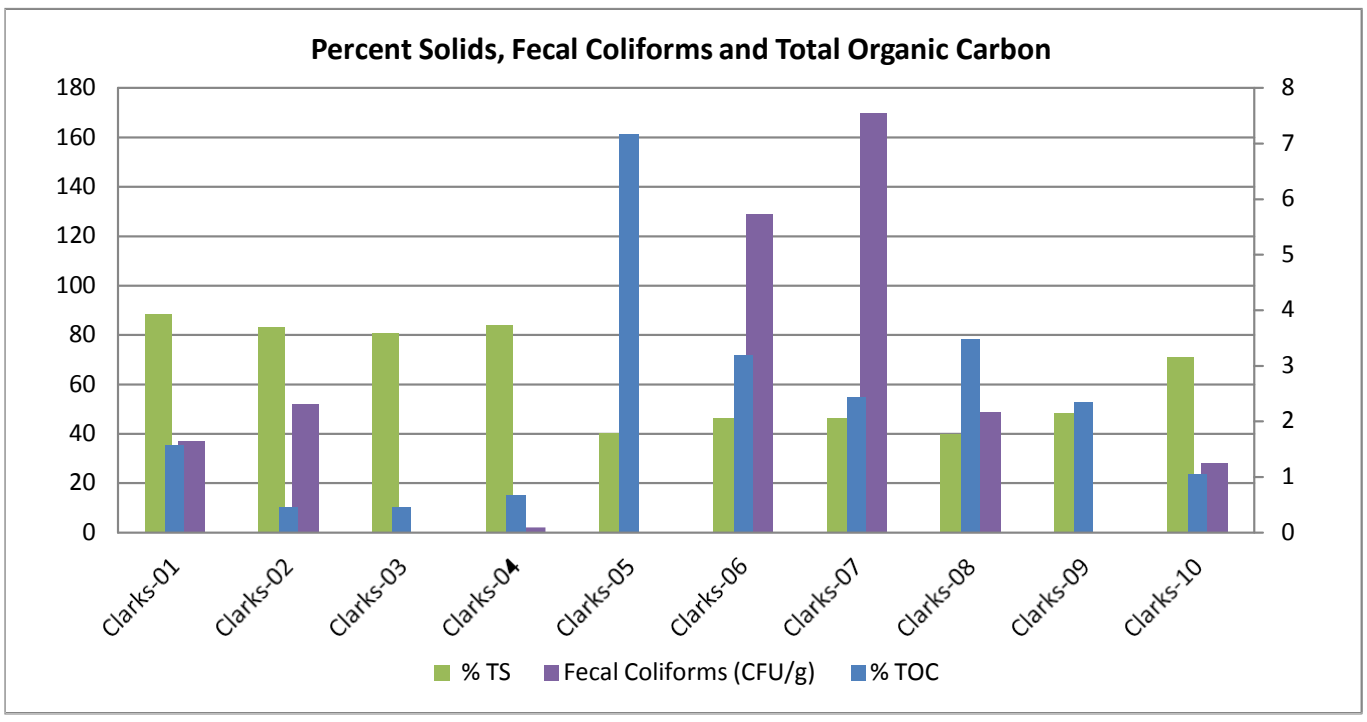


CONVETIONAL PARAMETERS RESULTS FOR CLARKS CREEK

From the results presented in the Clarks Creek Sites tab:

Site ID	% Fines	% TS	TP (mg/kg)	TKN	NO3+NO2	Total N (mg-N/kg)	BOD (mg/kg)	% TOC	Fecal Coliforms (CFU/g)
Clarks-01	5.4	88.5	465	368	9	377	286	1.58	37
Clarks-02	2.4	83.4	203	80.8	0.11	81	0	0.454	52
Clarks-03	2.5	80.9	142	205	0.33	205	0	0.464	0
Clarks-04	2.2	84	209	146	0	146	169	0.684	2
Clarks-05	33	40.4	119	2380	0	2380	1320	7.18	0
Clarks-06	17.8	46.3	1090	1860	0	1860	1710	3.19	129
Clarks-07	16.3	46.5	440	1600	0	1600	1820	2.44	170
Clarks-08	41.2	39.7	1740	2540	0	2540	3070	3.49	49
Clarks-09	35.4	48.4	766	1970	0	1970	1660	2.35	0
Clarks-10	9.1	71.1	660	591	0	591	550	1.06	28
	%	%	mg/kg	mg-N/kg	mg-N/kg	mg-N/kg	mg/kg	%	CFU/g





General Notes:

This sheet contains the laboratory results grouped as Grain Size Distribution (GSD) Analysis for composite samples; conventional parameters for composite samples; and the GSD Analysis for the Sub-armor samples. The Sub-armor layer GSD will not be analyzed as part of this task. It will used to in Task 4.

When a "U" appears next to a result, it means that the concentration was too low to be detected by the analytical method used. That just indicates that the concentration present was very small.

Results

GRAIN SIZE (COMPOSITE SAMPLE)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Coarse Silt	Medium Silt	Fine Silt		Very fine Silt	Clay
Site ID	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**75-32**	**32-22**	**22-13**	**13-9**	**9-7**	**7-3.2**	**<3.2**
Rody-01	0	0	0	0	12.3	15.7	25.6	19.6	12.2	9.9	3.4	0.7	0.2	0	0	0.1	0	0	0.2	0
Rody-02	0	0	5.1	10.4	21.1	10.8	20.3	13.2	7.8	6.6	3.4	0.8	0.3	0.1	0	0	0	0	0	0.1
Rody-03	0	0	0	8.2	16.7	10.2	26.8	17	8.8	7.3	3.8	0.9	0.2	0.1	0	0	0	0	0	0
Duplicates																				
Rody-B (Rody-02)	0	0	0	14.8	13.7	12.1	21.8	15	9.3	8	4.1	0.8	0.2	0	0	0	0	0	0	0

CONVENTIONALS (COMPOSITE SAMPLE)

	Total Solids	Nitrate + Nitrite (NO3+NO2)	Total Phosphorus	Total Kjeldahl Nitrogen	Biological Oxygen Demand	Total Organic Carbon	Fecal Coliforms	
Site ID	**%**	**mg-N/kg**	**mg/kg**	**mg-N/kg**	**mg/kg**	**%**	**CFU/g**	
Rody-01	84.2	0.98	168	96.6	146 U	0.481	527	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.
Rody-02	79.2	0.57	197	260	158 U	0.607	2 U	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.
Rody-03	83.5	0.47	120	193	148 U	0.287	2 U	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.
Duplicates								
Rody-B (Rody-03)	84.1	0.56	276	30.8	144 U	0.294	2 U	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.

GRAIN SIZE (SUB-ARMOR LAYER)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Silt and Clay
Site ID	**5-3"**	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**<75**
Rody-01	0	0	0	13.1	9.1	18.5	9.9	20.9	14	5.7	3.4	2.7	1.5	0.7	0.5
Rody-03	0	0	0	0	4.2	6.4	8.4	22	24.1	16.6	12.6	4.4	0.7	0.2	0.3

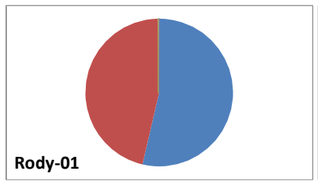
GRAPHICAL REPRESENTATION OF THE GRAIN SIZE DISTRIBUTION FOR RODY CREEK

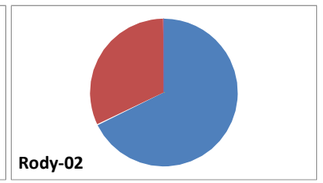
From the results presented in the Rody Creek Sites tab:

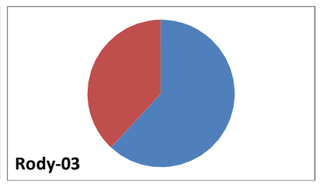
	Rody-01	Rody-02	Rody-03
Coarse Gravel (%)	0	15.5	8.2
Gravel (%)	53.6	52.2	53.7
Coarse Sand (%)	19.6	13.2	17
Medium Sand (%)	22.1	14.4	16.1
Fine Sand (%)	4.3	4.5	4.9
Very Coarse Silt (%)	0	0.1	0.1
Coarse Silt (%)	0	0	0
Medium Silt (%)	0.1	0	0
Fine Silt (%)	0	0	0
Very fine Silt (%)	0.2	0	0
Clay (%)	0	0.1	0

Further grouping of the grain sizes yields:

	Rody-01	Rody-02	Rody-03
Gravel	53.6	67.7	61.9
Sand	46	32.1	38
Silt	0.3	0.1	0.1
Clay	0	0.1	0



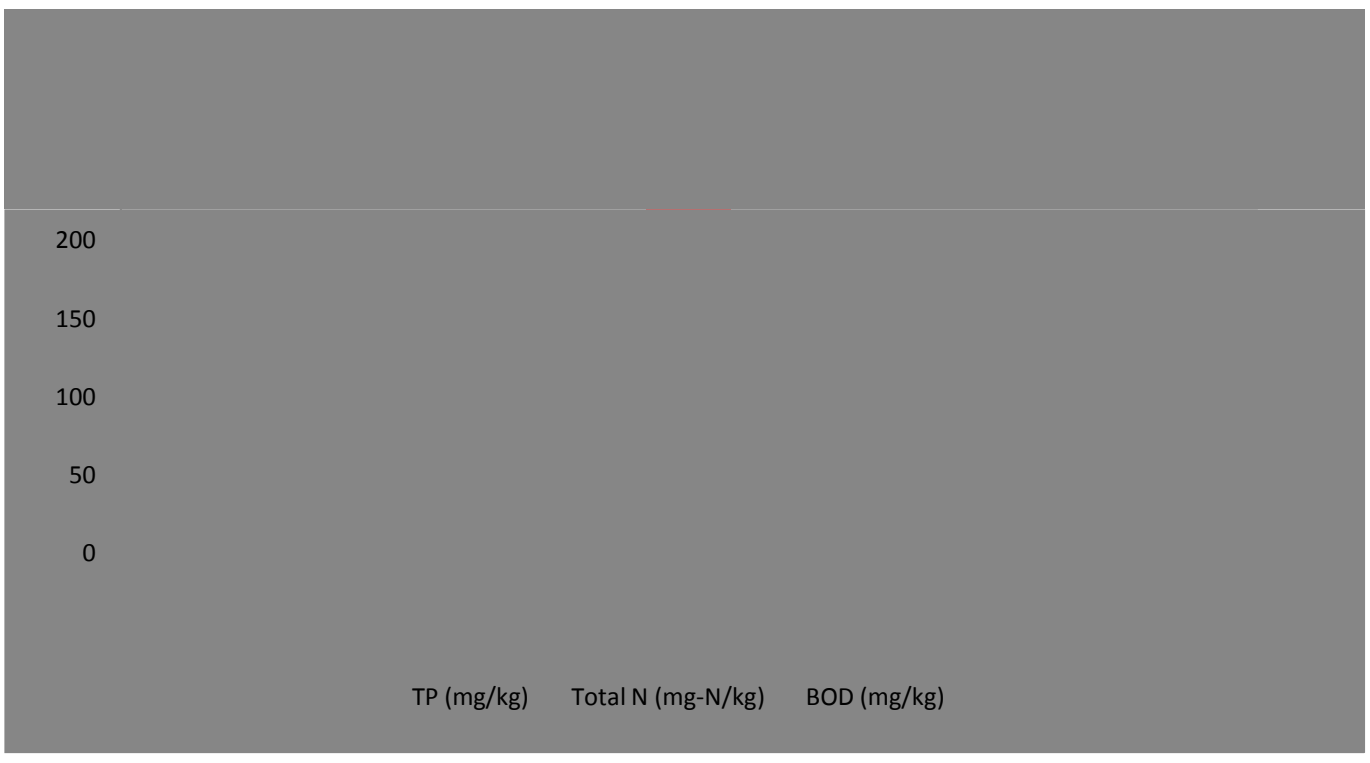


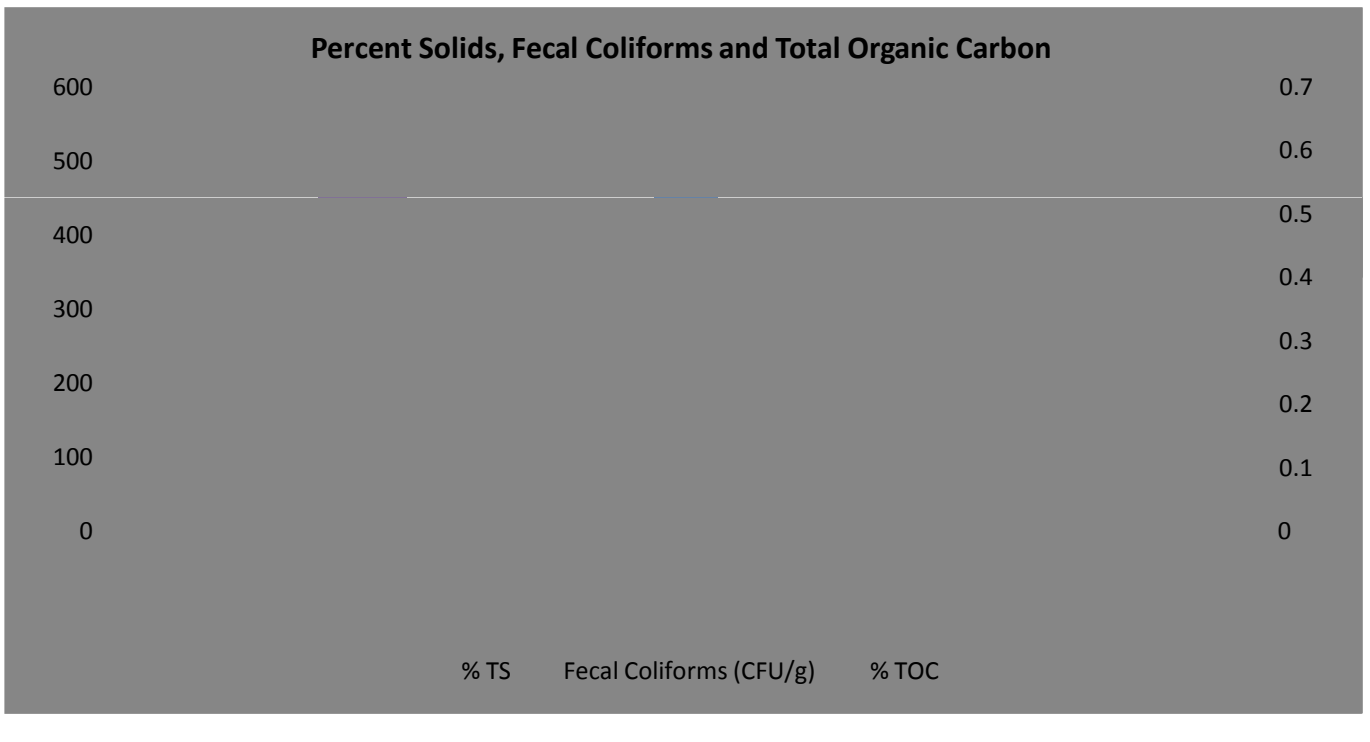


CONVETIONAL PARAMETERS RESULTS FOR RODY CREEK

From the results presented in the Rody Creek Sites tab:

Site ID	% Fines	% TS	TP (mg/kg)	TKN	NO3+NO2	Total N (mg-N/kg)	BOD (mg/kg)	% TOC	Fecal Coliforms (CFU/g)
Rody-01	0.3	84.2	168	96.6	0.98	98	0	0.481	527
Rody-02	0.2	79.2	197	260	0.57	261	0	0.607	0
Rody-03	0.1	83.5	120	193	0.47	193	0	0.287	0
	%	%	mg/kg	mg-N/kg	mg-N/kg	mg-N/kg	mg/kg	%	CFU/g





General Notes:

composite samples; conventional parameters for composite samples; and the GSD Analysis for the Sub-armor samples. The Sub-armor layer GSD will not be analyzed as part of this task. It will used to in Task 4.

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Results

GRAIN SIZE (COMPOSITE SAMPLE)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Coarse Silt	Medium Silt	Fine Silt		Very fine Silt	Clay
Site ID	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**75-32**	**32-22**	**22-13**	**13-9**	**9-7**	**7-3.2**	**<3.2**
Silver-01	0	0	22.2	20.5	9.7	6.6	11.3	9.8	5	3.8	4.5	3.2	1.9	0.3	0.1	0.3	0.2	0.2	0.2	0.4
Silver-02	0	0	3.1	10.1	23.8	10.6	17.8	8.3	4	4.8	6.7	5.1	3.2	0.8	0.4	0.2	0.2	0	0.4	0.2
Silver-03	0	0	8.5	5.7	18.3	8.2	18	11.7	7.5	7.3	7.5	4.7	2	0	0.1	0.1	0	0.1	0.1	0.1

GRAIN SIZE (SUB-ARMOR LAYER)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Silt and Clay
Site ID	**5-3"**	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**<75**
Silver-01	0	0	0	32.8	17.4	13.9	7.7	9.4	6.8	4.2	3	2.3	1.2	0.5	0.6
Silver-02	0	0	0	13.1	9.1	18.5	9.9	20.9	14	5.7	3.4	2.7	1.5	0.7	0.5

CONVENTIONALS (COMPOSITE SAMPLE)

	Total Solids	Nitrate + Nitrite (NO3+NO2)	Total Phosphorus	Total Kjeldahl Nitrogen	Biological Oxygen Demand	Total Organic Carbon	Fecal Coliforms	
Site ID	**%**	**mg-N/kg**	**mg/kg**	**mg-N/kg**	**mg/kg**	**%**	**CFU/g**	
Silver-01	78.3	0.24	321	370	229	2.35	27	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.
Silver-02	86.7	0.11 U	205	355	337	0.999	192	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.
Silver-03	81.5	0.19	142	93.7	163	0.667	28	Actual BOD concentrations at this site, could be twice as high as the value reported ,based on % recovery results from the lab.

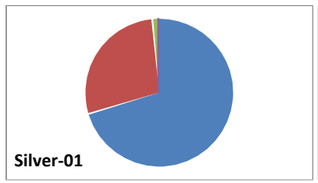
GRAPHICAL REPRESENTATION OF THE GRAIN SIZE DISTRIBUTION FOR SILVER CREEK

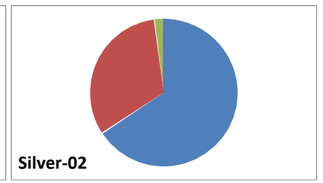
From the results presented in the Silver Creek Sites tab:

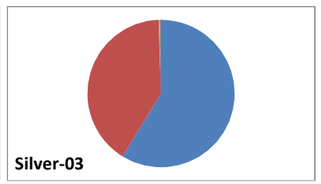
	Silver-01	Silver-02	Silver-03
Coarse Gravel (%)	42.7	13.2	14.2
Gravel (%)	27.6	52.2	44.5
Coarse Sand (%)	9.8	8.3	11.7
Medium Sand (%)	8.8	8.8	14.8
Fine Sand (%)	9.6	15	14.2
Very Coarse Silt (%)	0.3	0.8	0
Coarse Silt (%)	0.1	0.4	0.1
Medium Silt (%)	0.3	0.2	0.1
Fine Silt (%)	0.4	0.2	0.1
Very fine Silt (%)	0.2	0.4	0.1
Clay (%)	0.4	0.2	0.1

Further grouping of the grain sizes yields:

	Silver-01	Silver-02	Silver-03
Gravel	70.3	65.4	58.7
Sand	28.2	32.1	40.7
Silt	1.3	2.0	0.4
Clay	0.4	0.2	0.1



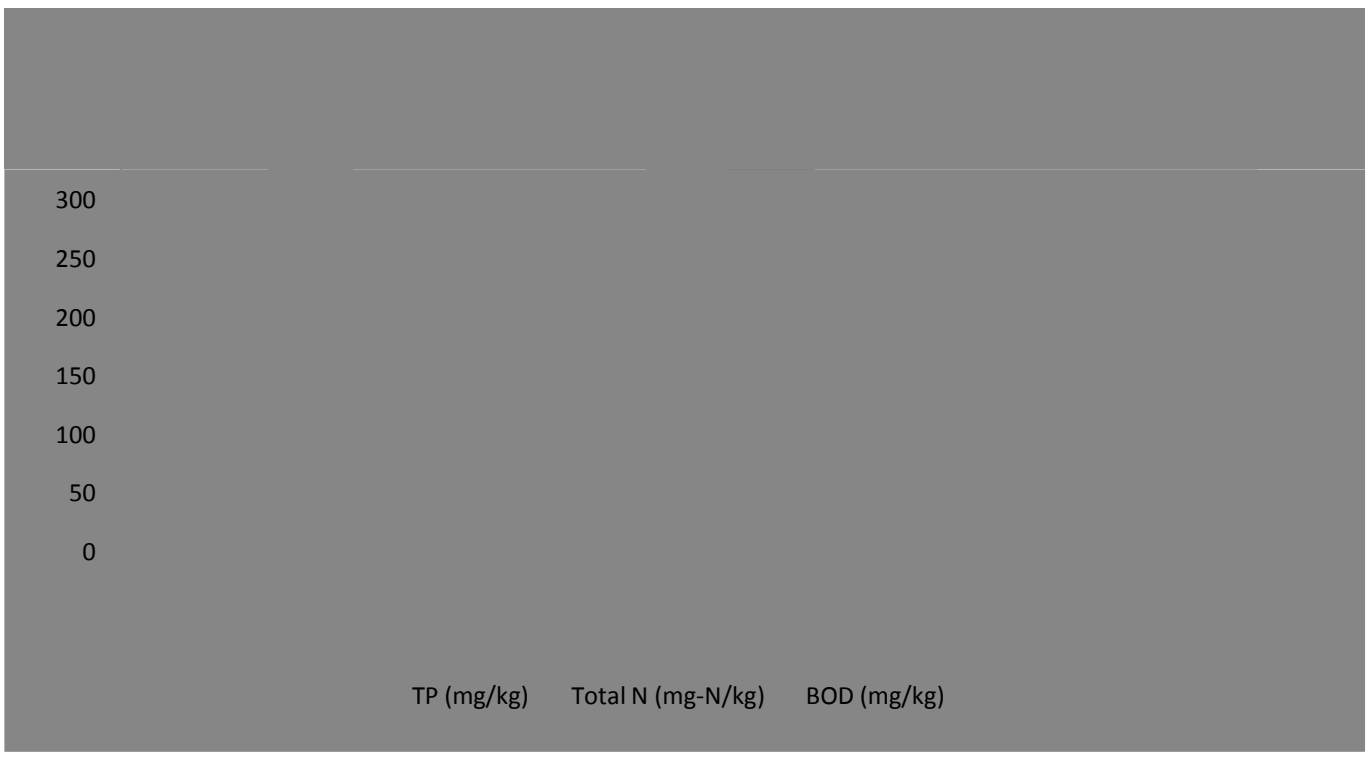


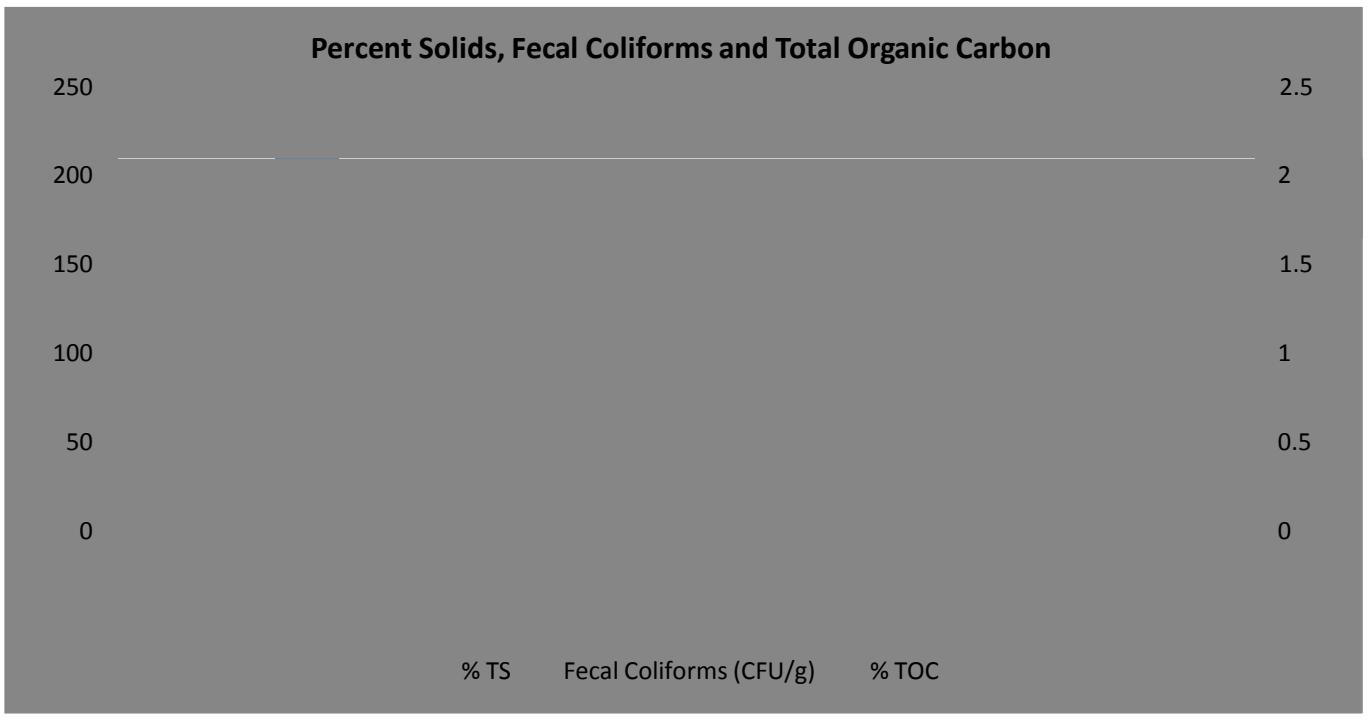


CONVETIONAL PARAMETERS RESULTS FOR SILVER CREEK

From the results presented in the Silver Creek Sites tab:

Site ID	% Fines	% TS	TP (mg/kg)	TKN	NO3+NO2	Total N (mg-N/kg)	BOD (mg/kg)	% TOC	Fecal Coliforms (CFU/g)
Silver-01	1.7	78.3	321	370	0.24	370	229	2.35	27
Silver-02	2.2	86.7	205	355	0	355	337	0.999	192
Silver-03	0.5	81.5	142	93.7	0.19	94	163	0.667	28
	%	%	mg/kg	mg-N/kg	mg-N/kg	mg-N/kg	mg/kg	%	CFU/g





General Notes:

This sheet contains the laboratory results grouped as Grain Size Distribution (GSD) Analysis for composite samples; conventional parameters for composite samples; and the GSD Analysis for the Sub-armor samples. The Sub-armor layer GSD will not be analyzed as part of this task. It will used to in Task 4.

When a "U" appears next to a result, it means that the concentration was too low to be detected by the analytical method used. That just indicates that the concentration present was very small.

Results

GRAIN SIZE (COMPOSITE SAMPLE)

	Coarse Gravel				Gravel			Coarse Sand	Medium Sand		Fine Sand			Very Coarse Silt	Coarse Silt	Medium Silt	Fine Silt		Very fine Silt	Clay
Site ID	**3-2"**	**2-1.5"**	**1.5-1"**	**1"-3/4**	**3/4-1/2"**	**1/2-3/8"**	**3/8"-4750**	**4750-2000**	**2000-850**	**850-425**	**425-250**	**250-150**	**150-75**	**75-32**	**32-22**	**22-13**	**13-9**	**9-7**	**7-3.2**	**<3.2**
Diru-01	0	0	7.7	14.1	16.1	12.5	20.8	14.7	6	4	2.1	0.6	0.2	0.6	0	0.1	0.1	0.1	0.1	0.1
Wood-01	0	0	9.5	23.2	20.7	8.6	11.5	7.1	5.5	4.8	3.6	2	1.1	1	0.3	0.1	0.1	0.2	0.3	0.4
West-01	0	0	7	5	13.1	12.2	18.4	15.6	10.1	7.3	4.8	1.3	1	0.7	0.6	0.6	0.3	0.6	0.6	0.6
East-01	0	0	0	5.2	7.3	3.1	6.7	7.9	7.9	10.6	9	6.1	6.3	7.5	4.6	4.9	2.1	1.8	4.2	4.6
Duplicates																				
Diru-D (Diru-01)	0	0	0	10.3	18.5	10.6	22.4	19	8.6	5.7	2.8	0.7	0.2	0.4	0	0	0.4	0.2	0.2	0.2
		21.8	49.4	14.7	10	2.9	0.6	0	0.1	0.2	0.1	0.1								

CONVENTIONALS (COMPOSITE SAMPLE)

	Total Solids	Nitrate + Nitrite (NO3+NO2)	Total Phosphorus	Total Kjeldahl Nitrogen	Biological Oxygen Demand	Total Organic Carbon	Fecal Coliforms	
Site ID	**%**	**mg-N/kg**	**mg/kg**	**mg-N/kg**	**mg/kg**	**%**	**CFU/g**	
Diru-01	83.6	0.48	161	157	120 U	0.259	2 U	Actual BOD concentrations at this site, could potentially be 30% higher than reported, based on % recovery results from the lab.
Wood-01	94.5	2.86	81.7	573	173	1.12	27	
West-01	82.3	0.12 U	3.93	211	145	0.583	92	Actual BOD concentrations at this site, could potentially be 30% higher than reported, based on % recovery results from the lab.
East-01	64.5	0.15 U	277	1970	340	3.97	36	Actual BOD concentrations at this site, could potentially be 30% higher than reported, based on % recovery results from the lab.
Duplicates								
Diru-D (Diru-01)	81.6	0.4	216	99	164	0.24	2 U	

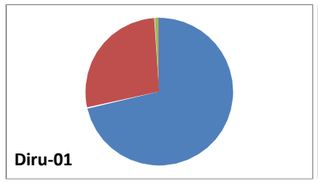
GRAPHICAL REPRESENTATION OF THE GRAIN SIZE DISTRIBUTION

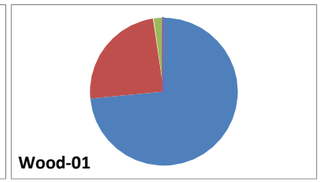
From the results presented in the rest of Clarks Creek's Tributaries Sites tab:

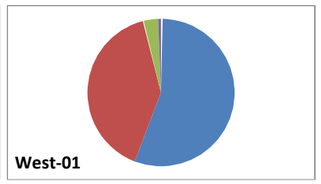
	Diru-01	Wood-01	West-01	East-01
Coarse Gravel (%)	21.8	32.7	12	5.2
Gravel (%)	49.4	40.8	43.7	17.1
Coarse Sand (%)	14.7	7.1	15.6	7.9
Medium Sand (%)	10	10.3	17.4	18.5
Fine Sand (%)	2.9	6.7	7.1	21.4
Very Coarse Silt (%)	0.6	1	0.7	7.5
Coarse Silt (%)	0	0.3	0.6	4.6
Medium Silt (%)	0.1	0.1	0.6	4.9
Fine Silt (%)	0.2	0.3	0.9	3.9
Very fine Silt (%)	0.1	0.3	0.6	4.2
Clay (%)	0.1	0.4	0.6	4.6

Further grouping of the grain sizes yields:

	Diru-01	Wood-01	West-01	East-01
Gravel	71.2	73.5	55.7	22.3
Sand	27.6	24.1	40.1	47.8
Silt	1.0	2.0	3.4	25.1
Clay	0.1	0.4	0.6	4.6



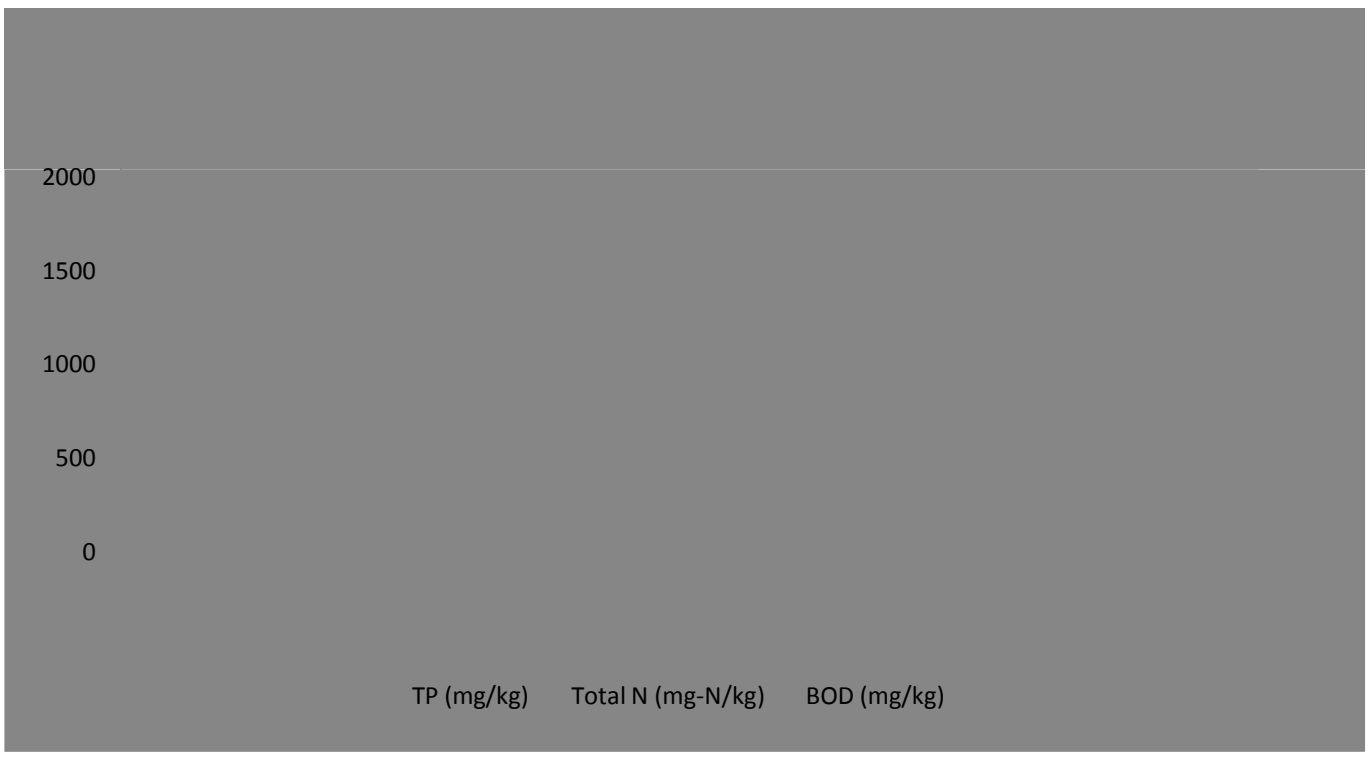


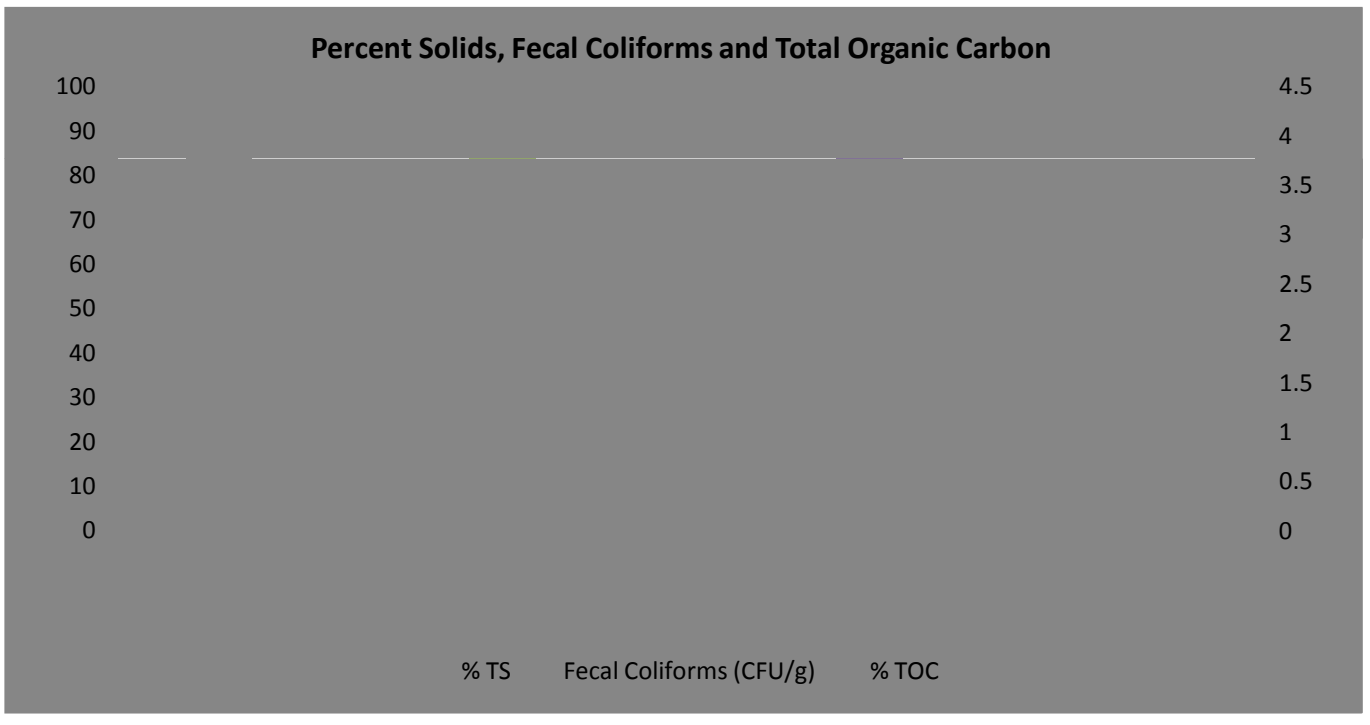


CONVETIONAL PARAMETERS RESULTS

From the results presented in the Other Tributaries Sites tab:

Site ID	% Fines	% TS	TP (mg/kg)	TKN	NO3+NO2	Total N (mg-N/kg)	BOD (mg/kg)	% TOC	Fecal Coliforms (CFU/g)
Diru-01	1.1	83.6	161	157	0.48	157	0	0.259	0
Wood-01	2.4	94.5	81.7	573	2.86	576	173	1.12	27
West-01	4	82.3	3.93	211	0	211	145	0.583	92
East-01	29.7	64.5	277	1970	0	1970	340	3.97	36
	%	%	mg/kg	mg-N/kg	mg-N/kg	mg-N/kg	mg/kg	%	CFU/g





Appendix B: Channel Cross-Section Survey

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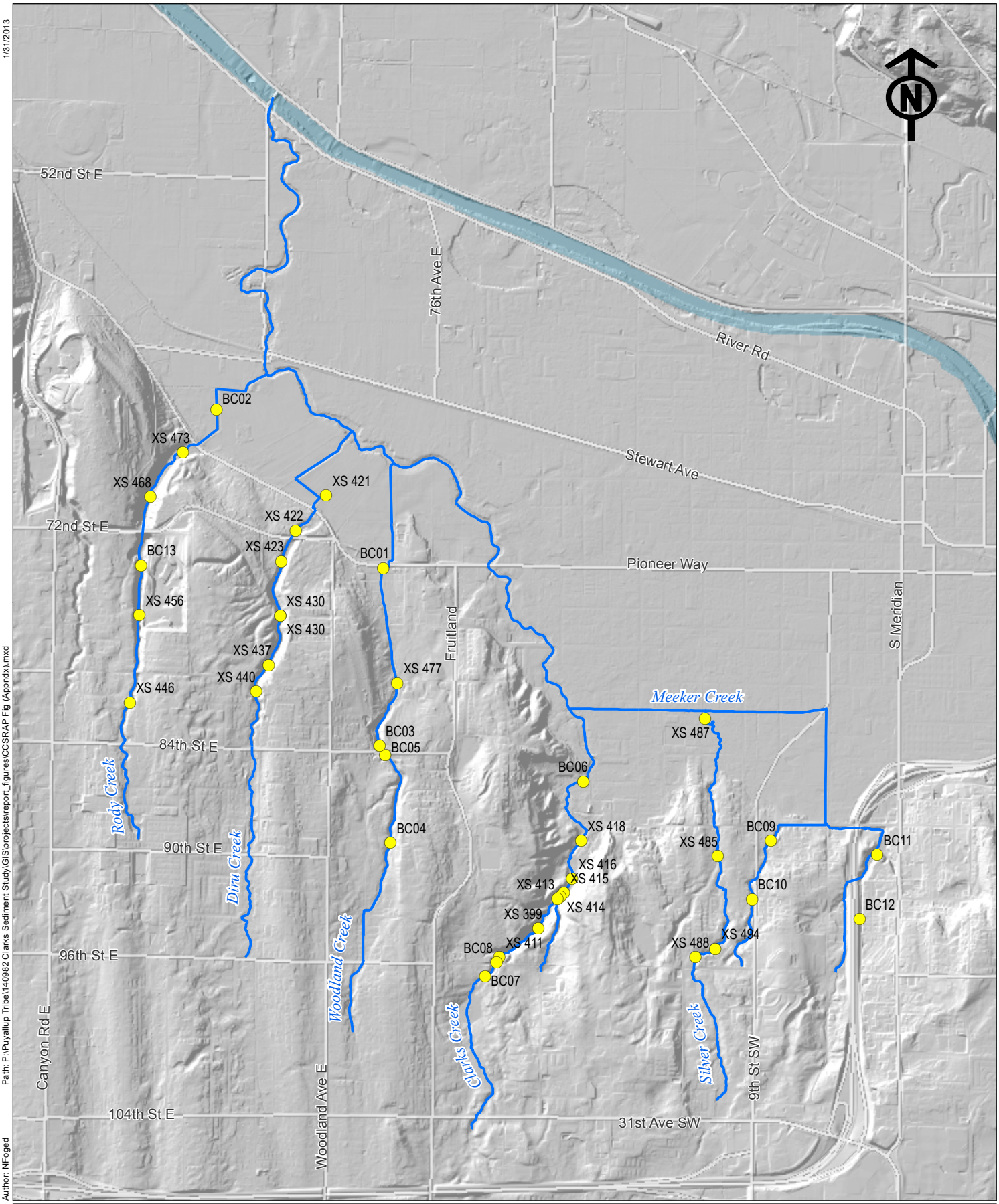

Author: NFoged

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1/31/2013

Brown AND Caldwell

1,200 0 1,200 FT

1 inch = 2,400 feet

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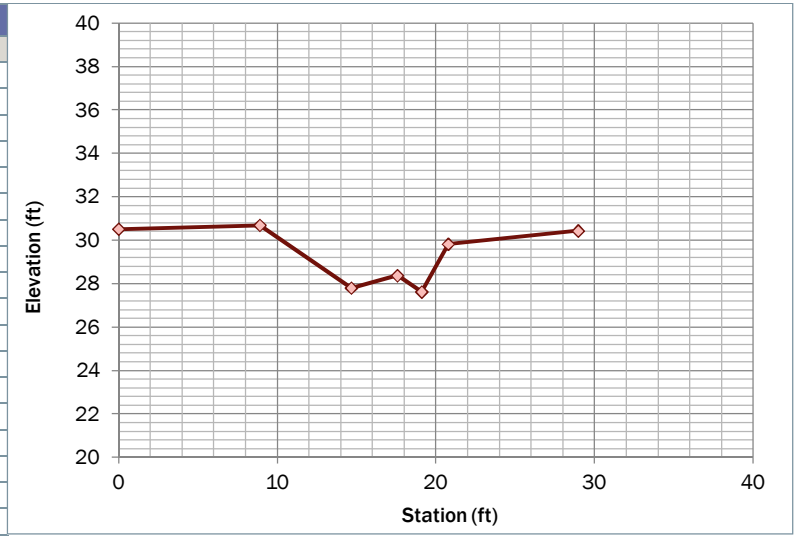
LEGEND

- New Surveyed Cross-section
- Evaluation Reaches
- Arterial Roadway

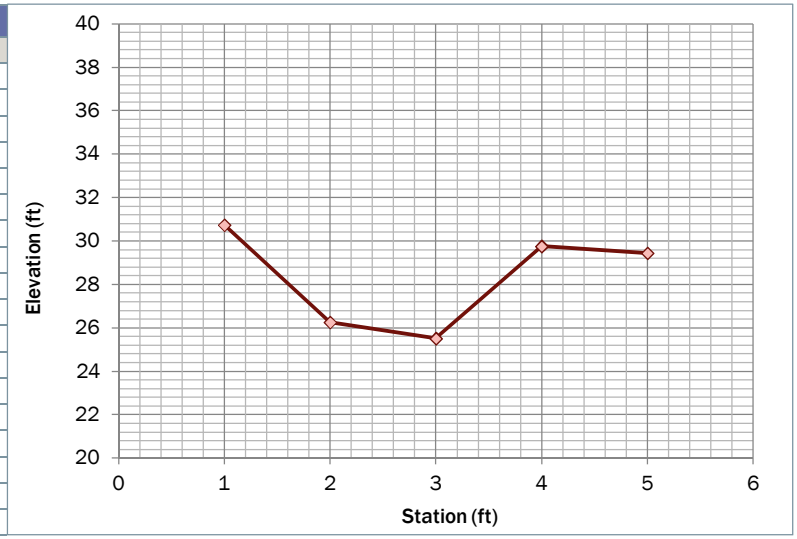
Appendix B
CROSS SECTION LOCATIONS

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN

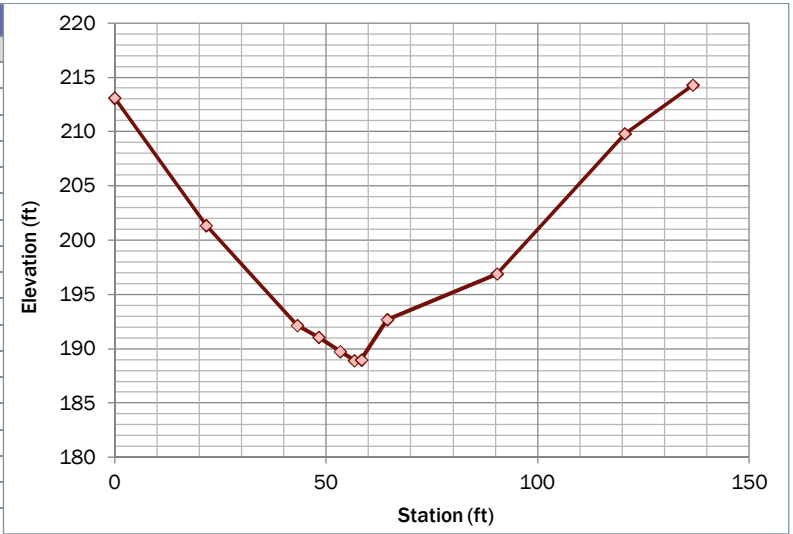
BC01 (Woodland Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	682400.611	1184806.547	30.51	(304)GRND SHOT
8.90	682400.708	1184815.443	30.69	(787)SET REBAR - CNTRL -
14.66	682401.304	1184821.198	27.80	(268)CREEK TOE
17.56	682401.284	1184824.105	28.37	(276)EDGE WATER
19.10	682401.092	1184825.647	27.62	(268)CREEK TOE
20.77	682401.059	1184827.312	29.82	(787)SET REBAR - CNTRL -
28.96	682400.920	1184835.505	30.43	(304)GRND SHOT



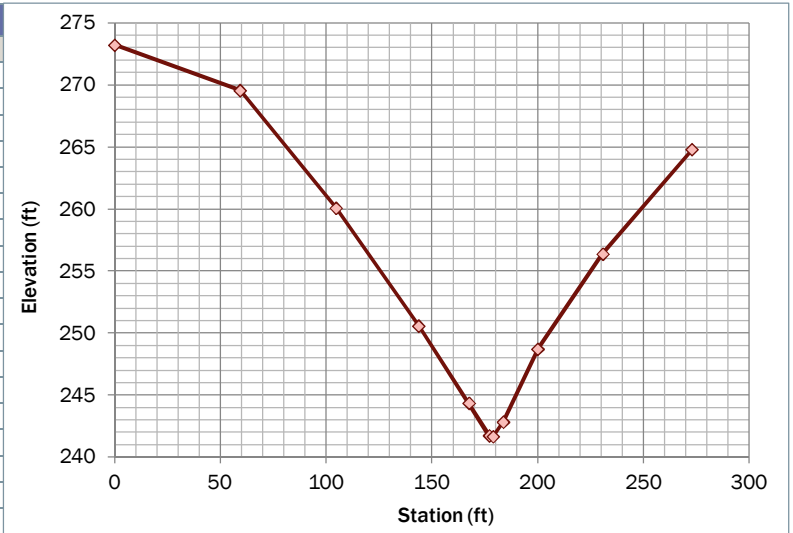
BC02 (Rody Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0+00.00	685373.039	1181720.160	30.73	(270)CREEK TOP
0+07.58	685372.417	1181728.180	26.25	(268)CREEK TOE
0+14.56	685377.354	1181734.071	25.51	(268)CREEK TOE
0+27.34	685380.743	1181746.397	29.75	(270)CREEK TOP
0+36.26	685382.537	1181755.153	29.44	(300)GRADE BRK



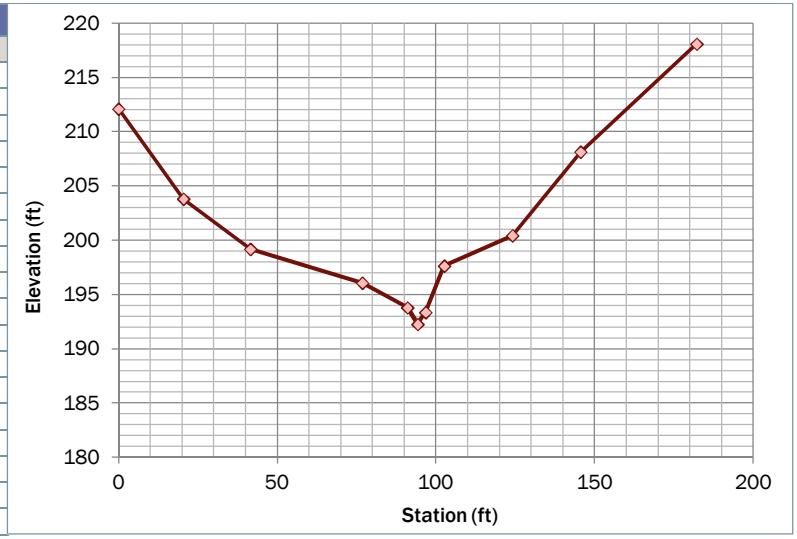
BC03 (Woodland Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675224.401	1187030.413	213.10	(787)SET REBAR - CNTRL -
21.63	675218.777	1187051.305	201.35	(304)GRND SHOT
43.14	675213.503	1187072.156	192.15	(300)GRADE BRK
48.26	675212.223	1187077.115	191.06	(270)CREEK TOP
53.29	675210.967	1187081.978	189.75	(268)CREEK TOE
56.63	675209.919	1187085.165	188.90	(256)CREEK CL
58.35	675209.560	1187086.843	188.97	(268)CREEK TOE
64.46	675208.442	1187092.870	192.69	(270)CREEK TOP
90.37	675201.698	1187117.886	196.90	(300)GRADE BRK
120.57	675194.149	1187147.125	209.81	(304)GRND SHOT
136.64	675190.132	1187162.685	214.29	(300)GRADE BRK



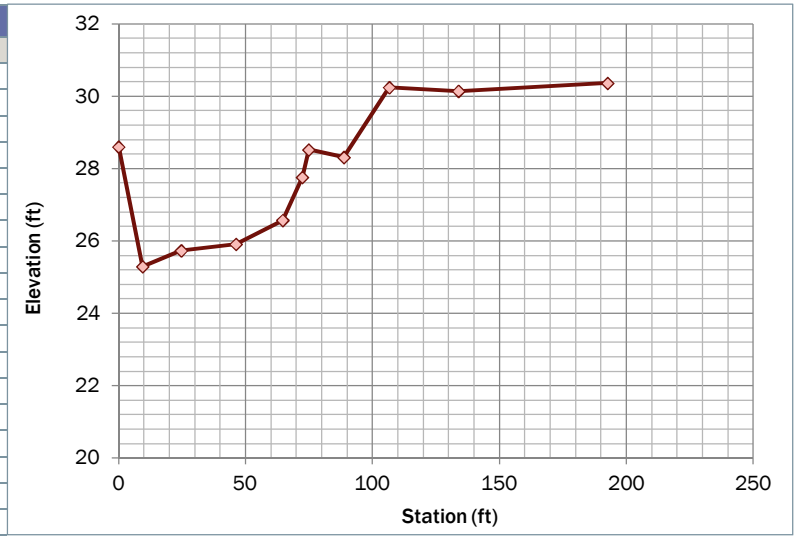
BC04 (Woodland Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	674353.571	1187854.577	273.21	(787)SET REBAR - CNTRL -
59.31	674380.820	1187907.253	269.55	(300)GRADE BRK
104.69	674401.670	1187947.560	260.07	(304)GRND SHOT
143.69	674419.592	1187982.205	250.57	(304)GRND SHOT
167.50	674430.532	1188003.355	244.35	(270)CREEK TOP
177.13	674434.905	1188011.934	241.73	(268)CREEK TOE
178.92	674435.726	1188013.523	241.65	(268)CREEK TOE
183.70	674437.919	1188017.764	242.83	(270)CREEK TOP
199.99	674445.402	1188032.241	248.70	(300)GRADE BRK
230.75	674459.526	1188059.563	256.37	(304)GRND SHOT
272.83	674478.848	1188096.946	264.79	(304)GRND SHOT



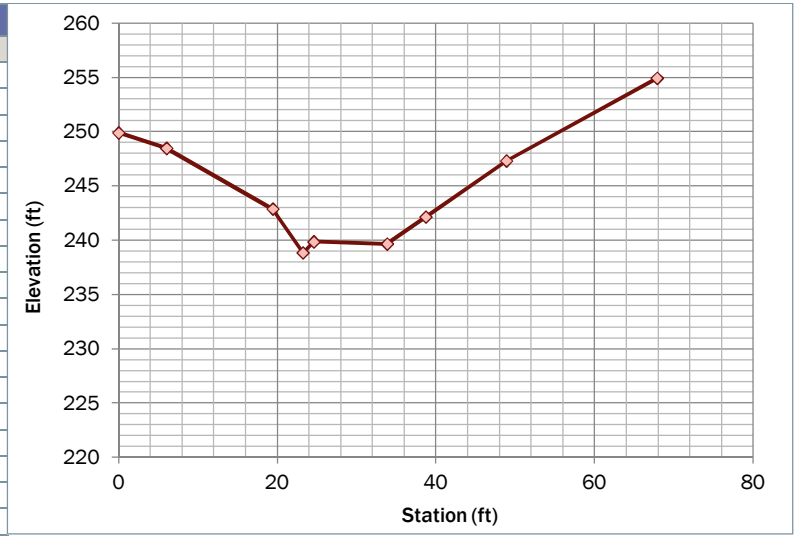
BC05 (Woodland Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	678905.726	1184808.370	212.08	(300)GRADE BRK
20.46	678908.913	1184828.583	203.79	(300)GRADE BRK
41.57	678912.193	1184849.431	199.16	(300)GRADE BRK
76.82	678917.686	1184884.251	196.06	(270)CREEK TOP
91.03	678919.899	1184898.288	193.78	(268)CREEK TOE
94.25	678920.404	1184901.475	192.25	(714)""" "
96.75	678920.791	1184903.941	193.35	(268)CREEK TOE
102.62	678921.705	1184909.736	197.62	(270)CREEK TOP
124.13	678925.055	1184930.986	200.42	(300)GRADE BRK
145.61	678928.461	1184952.194	208.12	(300)GRADE BRK
182.16	678934.094	1184988.306	218.07	(334)TOP OF BANK



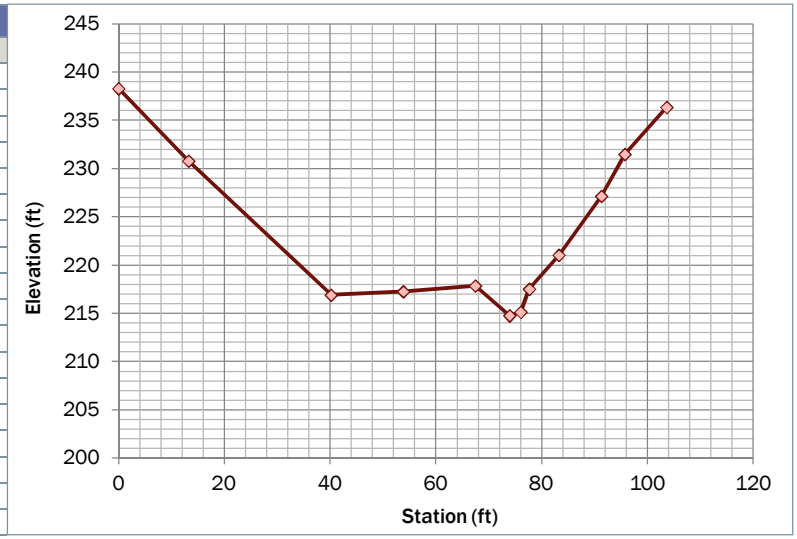
BC06 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	678417.529	1188474.226	28.60	(270)CREEK TOP
9.44	678415.899	1188483.524	25.29	(268)CREEK TOE
24.66	678413.274	1188498.514	25.73	(304)GRND SHOT
46.20	678409.558	1188519.733	25.91	(304)GRND SHOT
64.59	678406.384	1188537.849	26.57	(268)CREEK TOE
72.36	678405.046	1188545.501	27.76	(276)EDGE WATER
74.89	678404.607	1188547.994	28.52	(787)SET REBAR - CNTRL -
88.74	678402.221	1188561.633	28.31	(304)GRND SHOT
106.63	678399.133	1188579.262	30.24	(304)GRND SHOT
133.90	678394.430	1188606.118	30.14	(304)GRND SHOT
192.61	678384.300	1188663.953	30.36	(782)SET HUB/TACK -



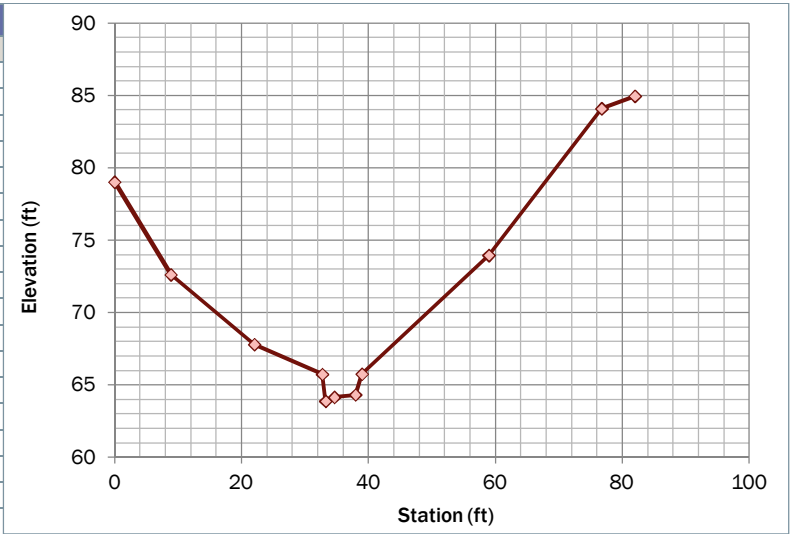
BC07 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	674800.001	1186698.467	249.89	(787)SET REBAR - CNTRL -
6.03	674794.006	1186697.790	248.47	(300)GRADE BRK
19.43	674780.693	1186696.289	242.89	(270)CREEK TOP
23.24	674776.910	1186695.862	238.84	(268)CREEK TOE
24.60	674775.558	1186695.709	239.86	(276)EDGE WATER
33.85	674766.359	1186694.672	239.66	(268)CREEK TOE
38.72	674761.524	1186694.127	242.15	(300)GRADE BRK
48.89	674751.419	1186692.987	247.32	(300)GRADE BRK
67.86	674732.577	1186690.801	254.93	(787)SET REBAR - CNTRL -



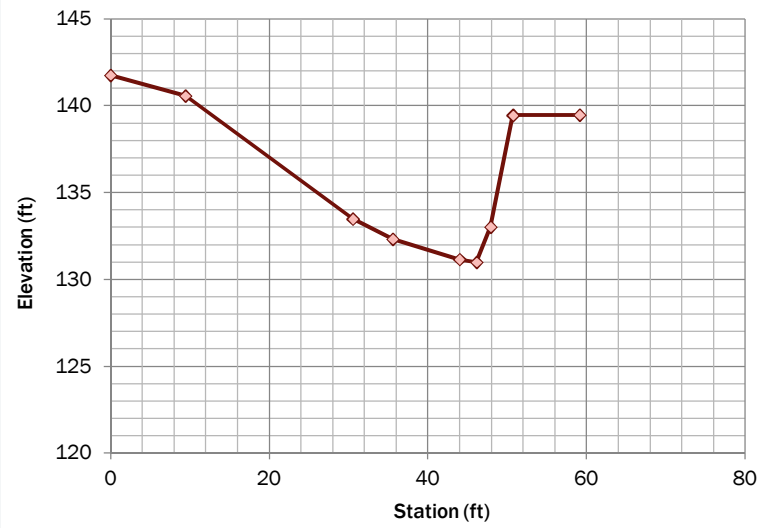
BC08 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675072.529	1186838.524	238.29	(787)SET REBAR - CNTRL -
13.22	675066.743	1186850.423	230.78	(300)GRADE BRK
40.18	675056.254	1186875.256	216.90	(300)GRADE BRK
53.82	675050.466	1186887.614	217.26	(300)GRADE BRK
67.43	675045.007	1186900.080	217.85	(270)CREEK TOP
73.93	675043.202	1186906.388	214.76	(268)CREEK TOE
76.01	675042.367	1186908.292	215.12	(268)CREEK TOE
77.65	675040.909	1186909.443	217.51	(270)CREEK TOP
83.25	675038.666	1186914.573	221.03	(300)GRADE BRK
91.28	675035.472	1186921.949	227.14	(304)GRND SHOT
95.71	675033.669	1186925.989	231.49	(304)GRND SHOT
103.61	675030.502	1186933.225	236.34	(787)SET REBAR - CNTRL -



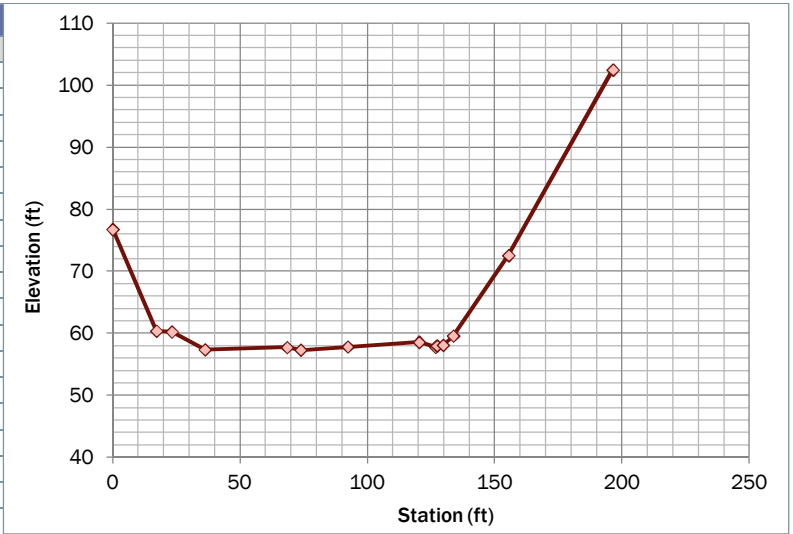
BC09 (Upper Meeker Creek West)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	677292.445	1192017.371	79.01	(320)RET WALL TOE
8.88	677289.803	1192025.847	72.62	(787)SET REBAR - CNTRL -
22.03	677285.777	1192038.370	67.80	(304)GRND SHOT
32.73	677282.376	1192049.061	65.74	(276)EDGE WATER
33.25	677281.983	1192050.384	63.88	(270)CREEK TOP
34.63	677281.519	1192051.394	64.15	(268)CREEK TOE
37.95	677280.983	1192053.546	64.32	(268)CREEK TOE
38.98	677280.672	1192054.534	65.75	(270)CREEK TOP
58.96	677274.649	1192073.586	73.95	(304)GRND SHOT
76.75	677269.287	1192090.545	84.09	(270)CREEK TOP
81.99	677267.707	1192095.544	84.95	(787)SET REBAR - CNTRL -



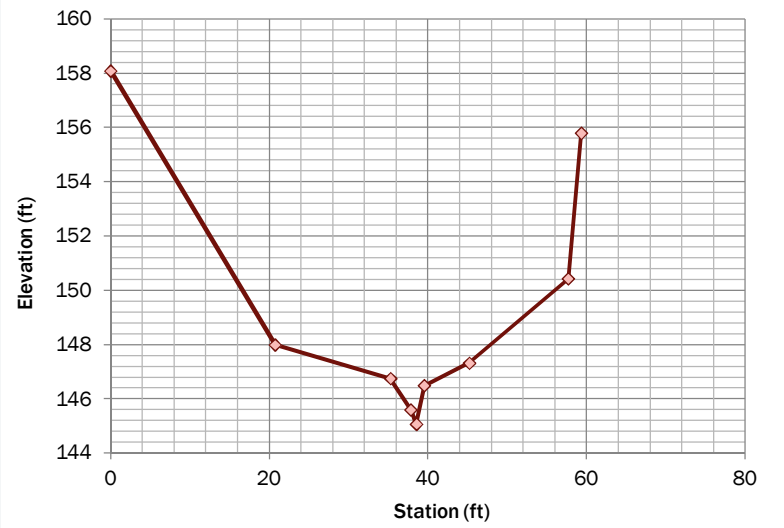
BC10 (Upper Meeker Creek West)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676196.277	1191647.674	141.75	(304)GRND SHOT
9.44	676195.356	1191657.071	140.57	(334)TOP OF BANK
30.54	676193.301	1191678.064	133.48	(270)CREEK TOP
35.57	676192.810	1191683.074	132.32	(268)CREEK TOE
43.99	676191.990	1191691.451	131.15	(256)CREEK CL
46.13	676191.781	1191693.587	130.99	(268)CREEK TOE
47.90	676191.608	1191695.343	133.02	(300)GRADE BRK
50.72	676191.479	1191698.169	139.45	(322)RET WALL TOP
59.12	676190.514	1191706.514	139.47	(784)SET PK/SPIKE - CNTRL -



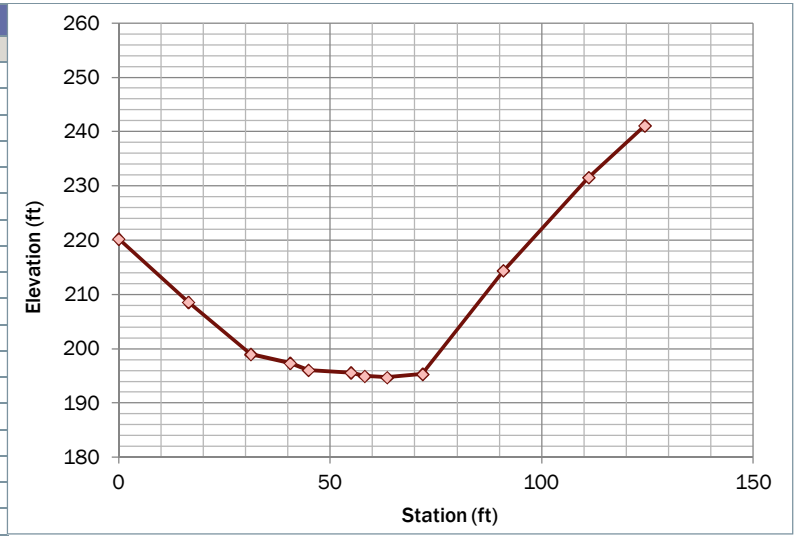
BC11 (Upper Meeker Creek East)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	677128.094	1193982.104	76.73	(304)GRND SHOT
17.21	677112.761	1193989.913	60.36	(300)GRADE BRK
23.27	677107.356	1193992.664	60.23	(300)GRADE BRK
36.22	677095.818	1193998.538	57.36	(332)TOE OF BANK
68.50	677067.053	1194013.186	57.72	(304)GRND SHOT
73.85	677062.288	1194015.612	57.29	(256)CREEK CL
92.35	677045.794	1194024.010	57.81	(304)GRND SHOT
120.37	677020.826	1194036.724	58.56	(270)CREEK TOP
126.75	677015.148	1194039.615	57.75	(268)CREEK TOE
127.35	677014.606	1194039.891	57.97	(276)EDGE WATER
129.80	677012.425	1194041.008	58.07	(268)CREEK TOE
133.76	677008.874	1194042.760	59.57	(332)TOE OF BANK
155.49	676989.535	1194052.658	72.54	(304)GRND SHOT
196.47	676953.016	1194071.254	102.45	(787)SET REBAR - CNTRL -



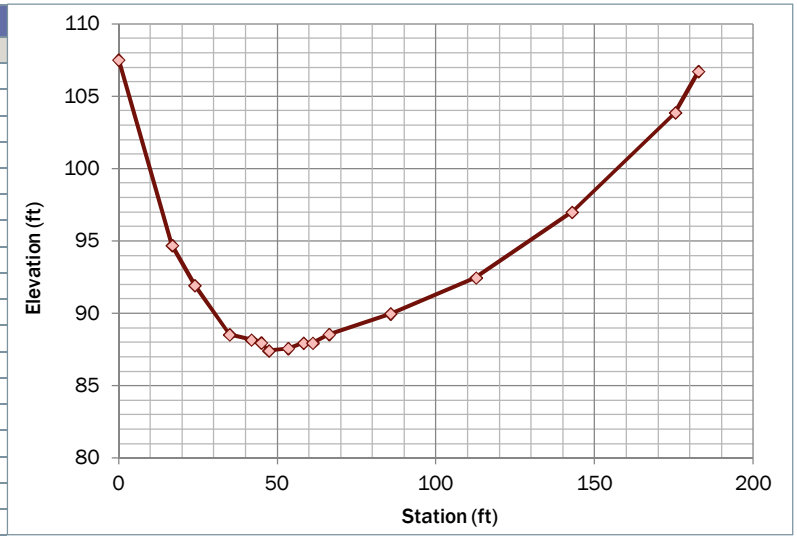
BC12 (Upper Meeker Creek East)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675810.830	1193659.831	158.08	(300)GRADE BRK
20.73	675812.656	1193680.485	147.99	(322)RET WALL TOP
35.28	675813.939	1193694.974	146.75	(270)CREEK TOP
37.83	675814.163	1193697.512	145.60	(268)CREEK TOE
38.54	675814.226	1193698.225	145.07	(268)CREEK TOE
39.53	675814.313	1193699.207	146.49	(270)CREEK TOP
45.22	675814.814	1193704.878	147.32	(300)GRADE BRK
57.67	675815.912	1193717.278	150.43	(300)GRADE BRK
59.32	675816.047	1193718.923	155.79	(334)TOP OF BANK



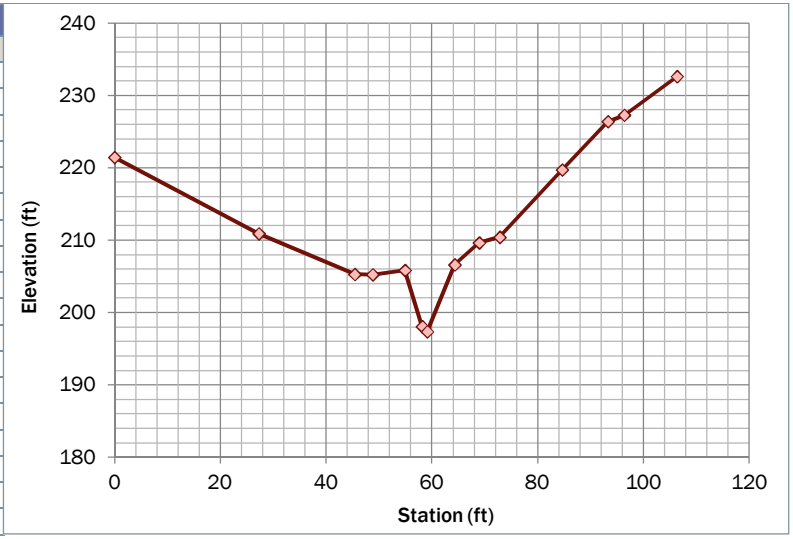
BC13 (Rody Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	682477.006	1180247.201	220.21	(304)GRND SHOT
16.48	682474.289	1180263.458	208.57	(304)GRND SHOT
31.22	682471.861	1180277.998	198.97	(300)GRADE BRK
40.55	682470.322	1180287.200	197.33	(300)GRADE BRK
44.88	682469.608	1180291.471	196.06	(300)GRADE BRK
54.89	682467.957	1180301.340	195.59	(300)GRADE BRK
58.11	682467.425	1180304.516	194.95	(268)CREEK TOE
63.42	682466.550	1180309.757	194.72	(266) CREEK
71.83	682465.165	1180318.049	195.32	(268)CREEK TOE
90.90	682462.021	1180336.857	214.38	(300)GRADE BRK
111.09	682458.695	1180356.770	231.54	(304)GRND SHOT
124.35	682456.495	1180369.844	241.08	(304)GRND SHOT



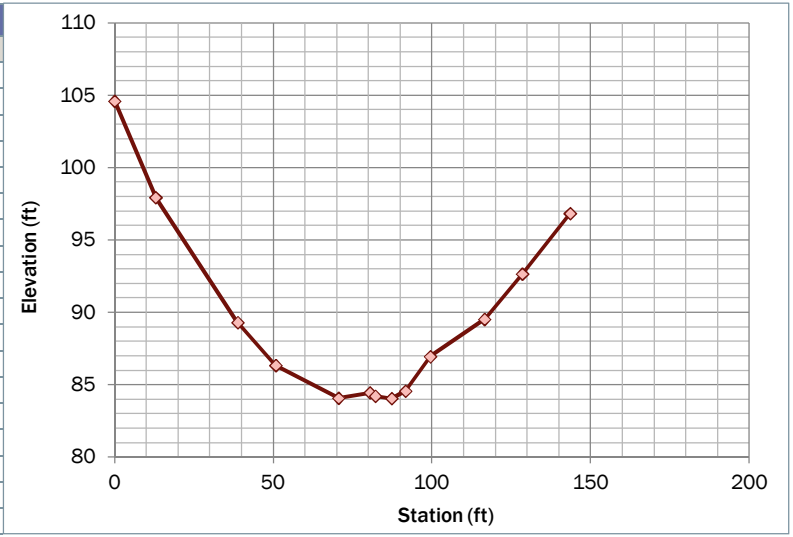
XS-399 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676192.320	1187945.421	107.50	(787)SET REBAR - CNTRL -
16.89	676181.348	1187958.264	94.69	(300)GRADE BRK
24.02	676176.909	1187963.853	91.92	(304)GRND SHOT
34.94	676170.122	1187972.401	88.53	(300)GRADE BRK
41.83	676165.835	1187977.801	88.17	(304)GRND SHOT
44.92	676163.441	1187979.829	87.96	(270)CREEK TOP
47.34	676162.375	1187982.090	87.42	(269)DITCH TOE
53.43	676158.321	1187986.634	87.58	(256)CREEK CL
58.26	676155.621	1187990.666	87.95	(782)SET HUB/TACK -
61.15	676153.806	1187992.922	87.95	(269)DITCH TOE
66.33	676150.495	1187996.908	88.55	(270)CREEK TOP
85.69	676138.207	1188011.870	89.97	(304)GRND SHOT
112.66	676121.091	1188032.712	92.46	(304)GRND SHOT
142.87	676101.921	1188056.056	96.99	(304)GRND SHOT
175.41	676081.268	1188081.207	103.86	(300)GRADE BRK
182.72	676076.429	1188086.692	106.71	(787)SET REBAR - CNTRL -



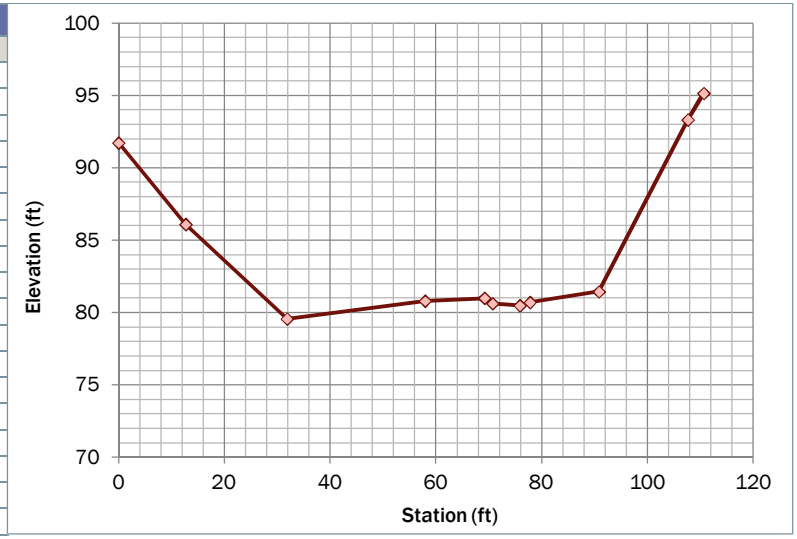
XS-411 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675167.541	1186932.521	221.44	(787)SET REBAR - CNTRL -
27.27	675146.468	1186949.839	210.91	(304)GRND SHOT
45.40	675132.757	1186961.698	205.28	(304)GRND SHOT
48.80	675130.184	1186963.923	205.25	(304)GRND SHOT
54.91	675125.561	1186967.921	205.84	(270)CREEK TOP
58.17	675123.096	1186970.058	198.07	(268)CREEK TOE
59.13	675122.370	1186970.684	197.36	(268)CREEK TOE
64.33	675118.437	1186974.083	206.61	(270)CREEK TOP
68.94	675114.950	1186977.099	209.65	(304)GRND SHOT
72.83	675112.012	1186979.640	210.41	(304)GRND SHOT
84.63	675103.088	1186987.359	219.72	(304)GRND SHOT
93.27	675096.552	1186993.012	226.39	(300)GRADE BRK
96.36	675094.214	1186995.034	227.27	(300)GRADE BRK
106.36	675086.647	1187001.579	232.61	(787)SET REBAR - CNTRL -



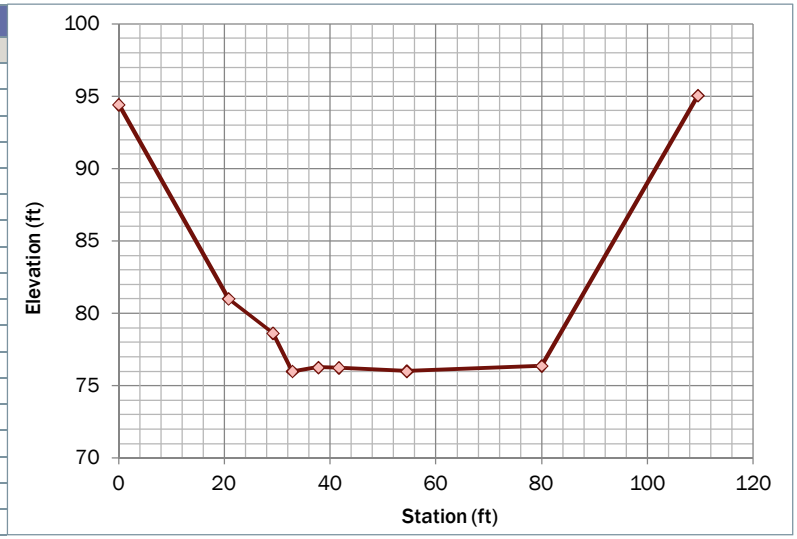
XS-413 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676282.894	1188009.791	104.59	(787)SET REBAR - CNTRL -
12.94	676272.349	1188017.287	97.94	(304)GRND SHOT
38.81	676251.326	1188032.364	89.30	(304)GRND SHOT
50.77	676241.624	1188039.369	86.34	(300)GRADE BRK
70.59	676225.458	1188050.832	84.08	(268)CREEK TOE
80.47	676217.316	1188056.421	84.45	(270)CREEK TOP
82.18	676215.614	1188056.990	84.22	(268)CREEK TOE
87.31	676211.535	1188060.100	84.05	(268)CREEK TOE
91.69	676207.867	1188062.502	84.56	(300)GRADE BRK
99.47	676201.491	1188066.960	86.94	(300)GRADE BRK
116.58	676187.677	1188077.049	89.52	(304)GRND SHOT
128.48	676178.134	1188084.169	92.65	(300)GRADE BRK
143.54	676165.879	1188092.925	96.83	(787)SET REBAR - CNTRL -



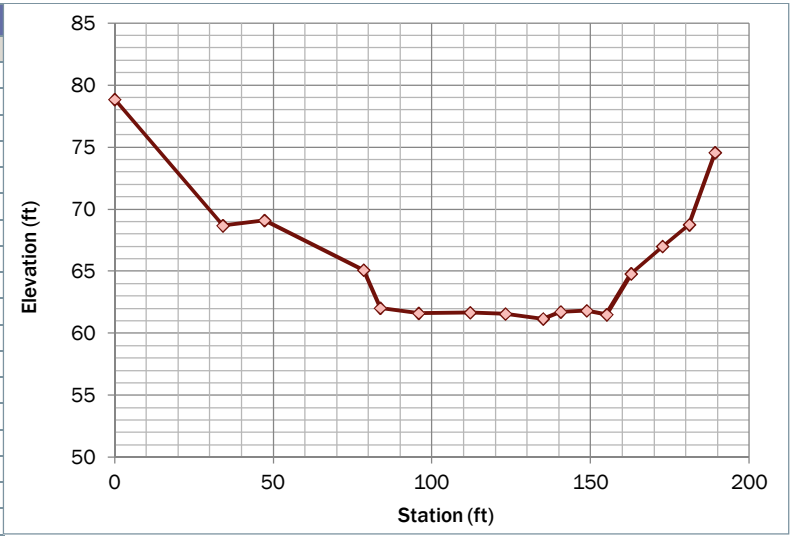
XS-414 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676318.281	1188078.215	91.72	(787)SET REBAR - CNTRL -
12.69	676307.412	1188084.777	86.09	(300)GRADE BRK
31.86	676291.803	1188095.943	79.57	(300)GRADE BRK
57.95	676268.992	1188108.710	80.80	(304)GRND SHOT
69.18	676260.449	1188116.191	80.99	(270)CREEK TOP
70.72	676258.854	1188116.547	80.62	(268)CREEK TOE
75.88	676254.794	1188119.792	80.48	(268)CREEK TOE
77.78	676252.969	1188120.462	80.70	(270)CREEK TOP
90.82	676241.225	1188126.287	81.44	(300)GRADE BRK
107.65	676227.961	1188136.801	93.32	(300)GRADE BRK
110.63	676224.997	1188137.683	95.15	(787)SET REBAR - CNTRL -



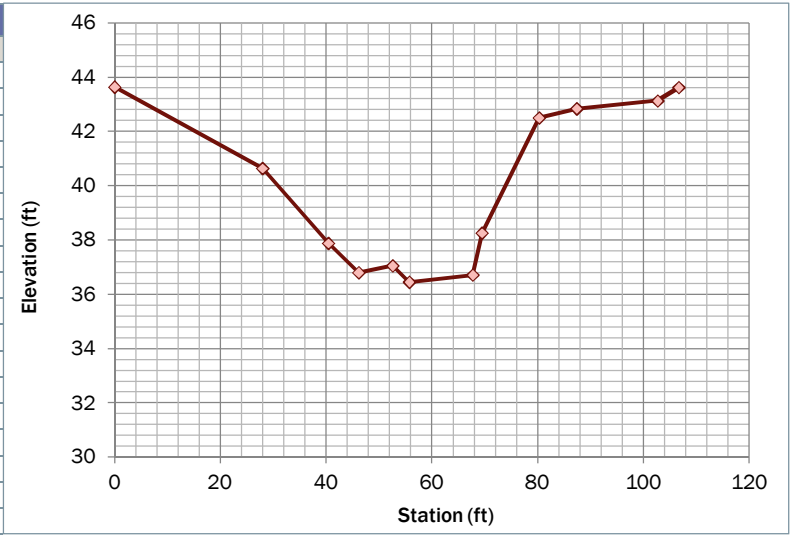
XS-415 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676370.070	1188162.088	94.42	(787)SET REBAR - CNTRL -
20.78	676351.242	1188170.891	81.01	(300)GRADE BRK
29.16	676343.461	1188174.025	78.64	(270)CREEK TOP
32.84	676340.073	1188175.467	76.00	(268)CREEK TOE
37.74	676335.527	1188177.288	76.27	(276)EDGE WATER
41.61	676332.073	1188179.046	76.25	(304)GRND SHOT
54.47	676320.556	1188184.788	76.01	(276)EDGE WATER
79.98	676297.932	1188196.691	76.38	(300)GRADE BRK
109.50	676270.218	1188207.042	95.05	(787)SET REBAR - CNTRL -



XS-416 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	676603.373	1188226.880	78.84	(787)SET REBAR - CNTRL -
34.12	676599.761	1188260.812	68.67	(304)GRND SHOT
47.22	676598.316	1188273.831	69.10	(300)GRADE BRK
78.44	676594.868	1188304.857	65.10	(270)CREEK TOP
83.70	676594.285	1188310.087	62.03	(268)CREEK TOE
95.79	676592.952	1188322.099	61.62	(304)GRND SHOT
112.03	676591.160	1188338.243	61.67	(276)EDGE WATER
123.15	676589.933	1188349.290	61.57	(787)SET REBAR - CNTRL -
134.99	676588.625	1188361.062	61.17	(304)GRND SHOT
140.54	676588.012	1188366.583	61.73	(304)GRND SHOT
148.74	676587.107	1188374.728	61.82	(276)EDGE WATER
155.03	676586.413	1188380.975	61.50	(268)CREEK TOE
162.75	676585.562	1188388.653	64.80	(270)CREEK TOP
172.64	676583.958	1188398.423	67.00	(300)GRADE BRK
181.07	676583.393	1188406.844	68.75	(300)GRADE BRK
189.19	676582.695	1188414.939	74.56	(787)SET REBAR - CNTRL -

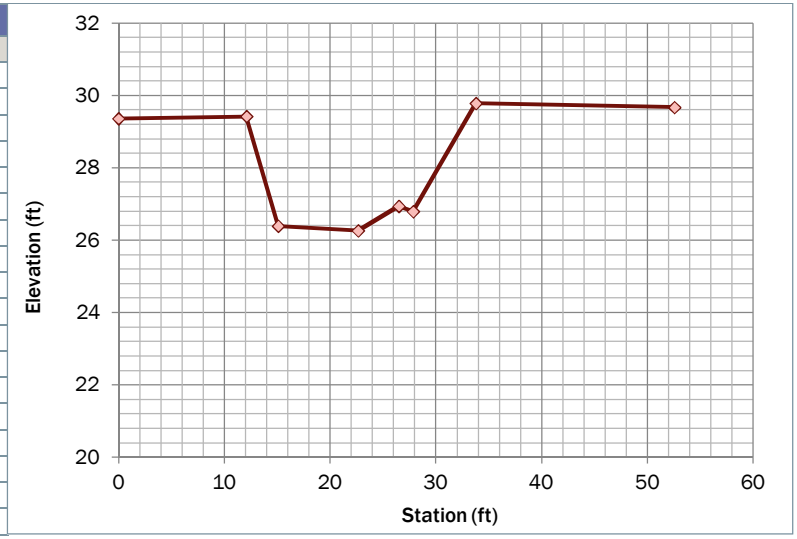


XS-418 (Clarks Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	677331.927	1188450.881	43.64	(787)SET REBAR - CNTRL -
27.97	677317.610	1188474.905	40.64	(270)CREEK TOP
40.41	677311.376	1188485.676	37.88	(300)GRADE BRK
46.13	677308.511	1188490.625	36.80	(268)CREEK TOE
52.57	677305.286	1188496.197	37.05	(276)EDGE WATER
55.72	677303.705	1188498.928	36.45	(304)GRND SHOT
67.71	677297.699	1188509.304	36.71	(268)CREEK TOE
69.46	677296.824	1188510.816	38.26	(300)GRADE BRK
80.26	677291.412	1188520.165	42.50	(270)CREEK TOP
87.38	677287.846	1188526.325	42.84	(633)GVL EDGE
102.66	677280.192	1188539.548	43.13	(633)GVL EDGE
106.66	677278.184	1188543.017	43.62	(787)SET REBAR - CNTRL -



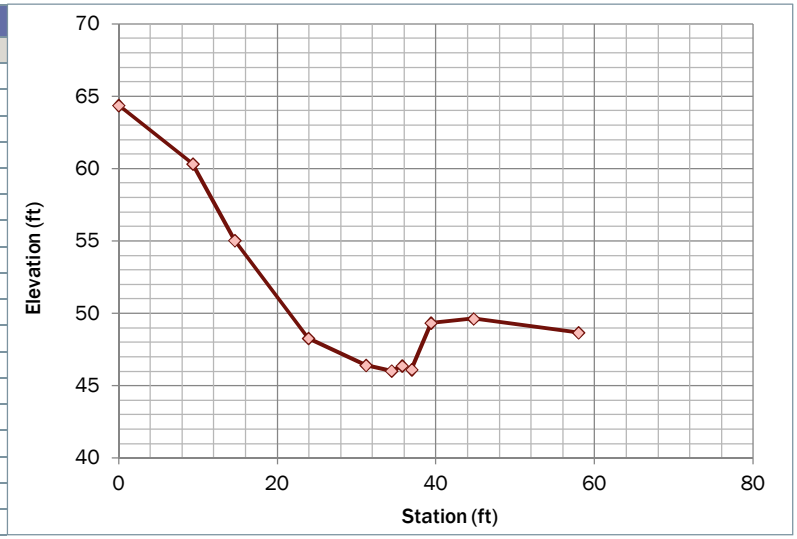
XS-421 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	683744.663	1183746.978	29.36	(304)GRND SHOT
12.09	683753.400	1183755.328	29.42	(270)CREEK TOP
15.09	683755.574	1183757.405	26.39	(268)CREEK TOE
22.64	683761.029	1183762.621	26.26	(272)DITCH CL
26.49	683763.815	1183765.285	26.94	(276)EDGE WATER
27.85	683764.792	1183766.218	26.79	(268)CREEK TOE
33.78	683769.080	1183770.316	29.78	(270)CREEK TOP
52.55	683782.654	1183783.290	29.67	(304)GRND SHOT



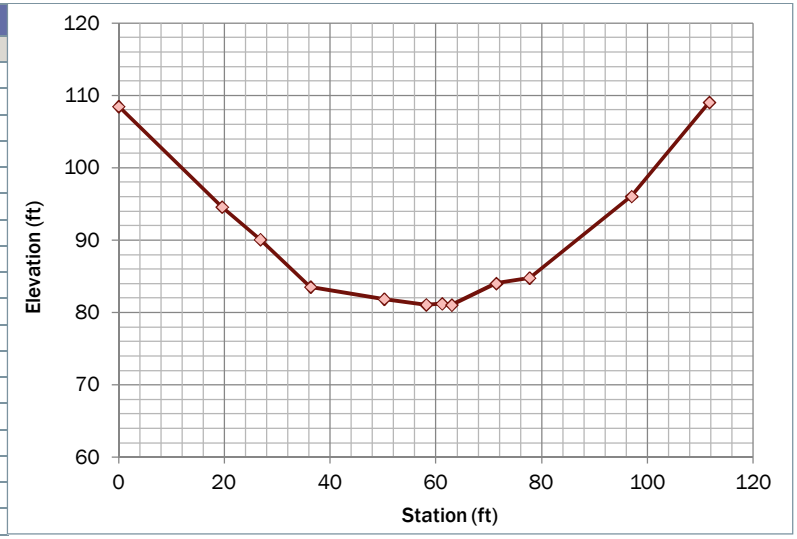
XS-422 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	683116.222	1183176.800	64.36	(787)SET REBAR - CNTRL -
9.35	683111.272	1183184.736	60.33	(300)GRADE BRK
14.63	683108.485	1183189.217	55.03	(300)GRADE BRK
23.92	683103.608	1183197.127	48.28	(300)GRADE BRK
31.18	683099.747	1183203.271	46.41	(268)CREEK TOE
34.38	683098.056	1183205.989	46.03	(272)DITCH CL
35.74	683097.340	1183207.140	46.38	(276)EDGE WATER
36.93	683096.708	1183208.155	46.12	(268)CREEK TOE
39.37	683095.419	1183210.228	49.34	(276)EDGE WATER
44.74	683092.585	1183214.783	49.63	(787)SET REBAR - CNTRL -
57.95	683085.602	1183226.004	48.67	(304)GRND SHOT



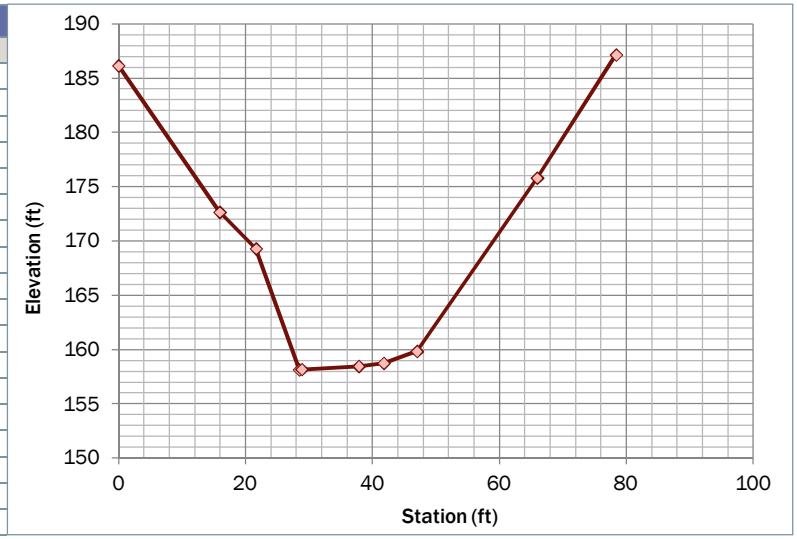
XS-423 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	682535.349	1182894.167	108.47	(787)SET REBAR - CNTRL -
19.57	682530.559	1182913.146	94.60	(304)GRND SHOT
26.77	682528.797	1182920.125	90.10	(300)GRADE BRK
36.29	682526.467	1182929.356	83.54	(332)TOE OF BANK
50.20	682523.064	1182942.837	81.87	(304)GRND SHOT
58.16	682521.115	1182950.561	81.09	(269)DITCH TOE
61.13	682520.389	1182953.437	81.23	(276)EDGE WATER
62.98	682519.935	1182955.234	81.04	(269)DITCH TOE
71.41	682517.873	1182963.409	84.03	(300)GRADE BRK
77.68	682516.339	1182969.488	84.79	(300)GRADE BRK
97.00	682511.609	1182988.215	96.06	(304)GRND SHOT
111.67	682508.007	1183002.438	109.06	(787)SET REBAR - CNTRL -



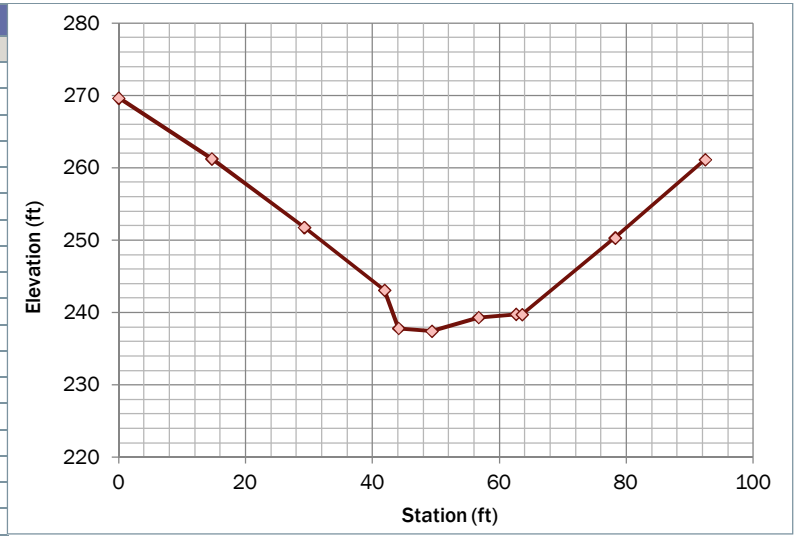
XS-430 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	681515.325	1182870.425	186.14	(787)SET REBAR - CNTRL -
15.95	681513.507	1182886.276	172.65	(304)GRND SHOT
21.67	681512.855	1182891.954	169.29	(270)CREEK TOP
28.46	681512.081	1182898.699	158.14	(269)DITCH TOE
28.86	681512.036	1182899.094	158.17	(276)EDGE WATER
37.85	681511.010	1182908.029	158.46	(782)SET HUB/TACK -
41.77	681510.563	1182911.926	158.75	(276)EDGE WATER
47.02	681509.964	1182917.143	159.84	(270)CREEK TOP
65.96	681507.750	1182935.950	175.81	(304)GRND SHOT
78.41	681506.543	1182948.337	187.14	(787)SET REBAR - CNTRL -



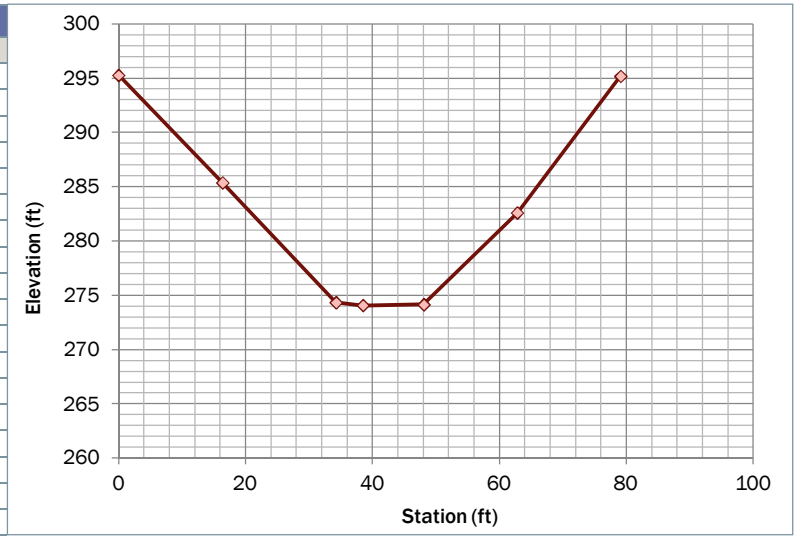
XS-437 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	680611.559	1182616.388	269.64	(787)SET REBAR - CNTRL -
14.67	680610.235	1182631.014	261.25	(304)GRND SHOT
29.26	680607.880	1182645.422	251.78	(304)GRND SHOT
41.89	680605.800	1182657.878	243.10	(300)GRADE BRK
44.10	680605.436	1182660.064	237.83	(268)CREEK TOE
49.34	680604.574	1182665.236	237.44	(268)CREEK TOE
56.71	680603.362	1182672.502	239.33	(300)GRADE BRK
62.61	680602.392	1182678.321	239.78	(782)SET HUB/TACK -
63.57	680602.268	1182679.273	239.73	(300)GRADE BRK
78.22	680600.714	1182693.854	250.32	(304)GRND SHOT
92.42	680598.520	1182707.884	261.14	(787)SET REBAR - CNTRL -



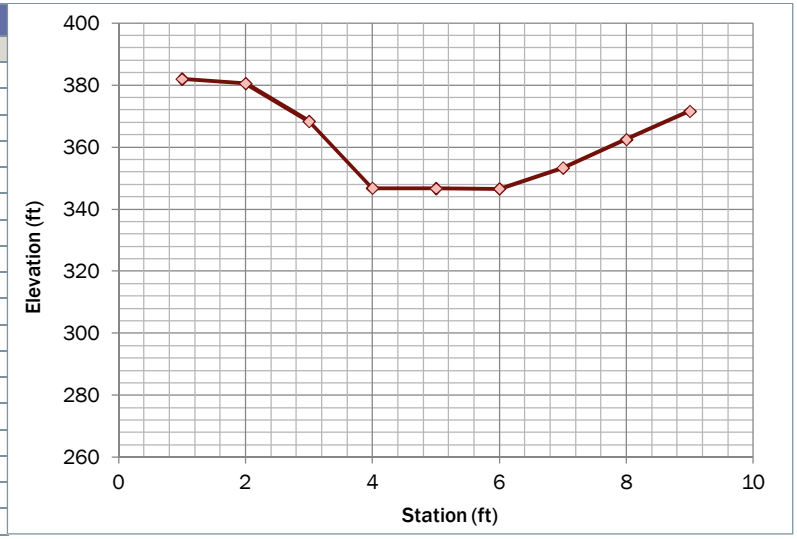
XS-440 (Diru Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	680094.482	1182416.093	295.26	(787)SET REBAR - CNTRL -
16.40	680101.395	1182430.967	285.37	(304)GRND SHOT
34.26	680108.918	1182447.158	274.33	(268)CREEK TOE
38.50	680110.707	1182451.008	274.07	(782)SET HUB/TACK -
48.08	680114.743	1182459.695	274.14	(268)CREEK TOE
62.82	680120.953	1182473.058	282.60	(304)GRND SHOT
79.12	680127.857	1182487.834	295.18	(787)SET REBAR - CNTRL -



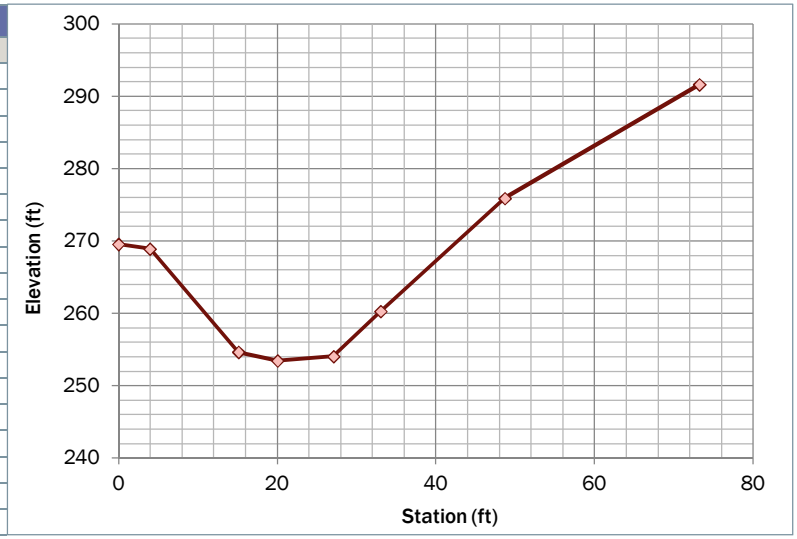
XS-446 (Rody Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0+00.00	679964.210	1180024.306	381.98	(787)SET REBAR - CNTRL -
0+04.42	679961.463	1180027.772	380.55	(304)GRND SHOT
0+22.68	679950.124	1180042.081	368.34	(304)GRND SHOT
0+50.94	679932.573	1180064.226	346.78	(268)CREEK TOE
0+58.17	679928.083	1180069.891	346.70	(256)CREEK CL
0+63.49	679924.774	1180074.068	346.59	(268)CREEK TOE
0+80.99	679913.906	1180087.782	353.33	(304)GRND SHOT
1+02.65	679900.454	1180104.756	362.51	(304)GRND SHOT
1+22.22	679888.335	1180120.125	371.59	(787)SET REBAR - CNTRL -

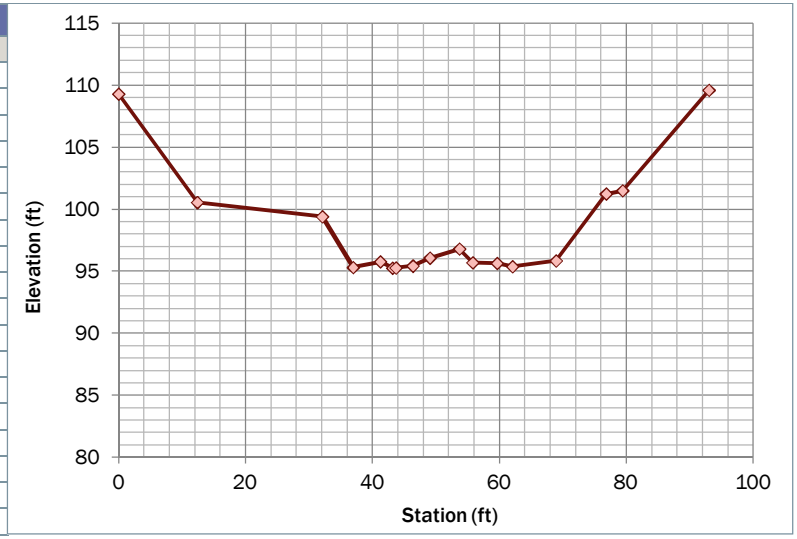


XS-456 (Rody Creek)

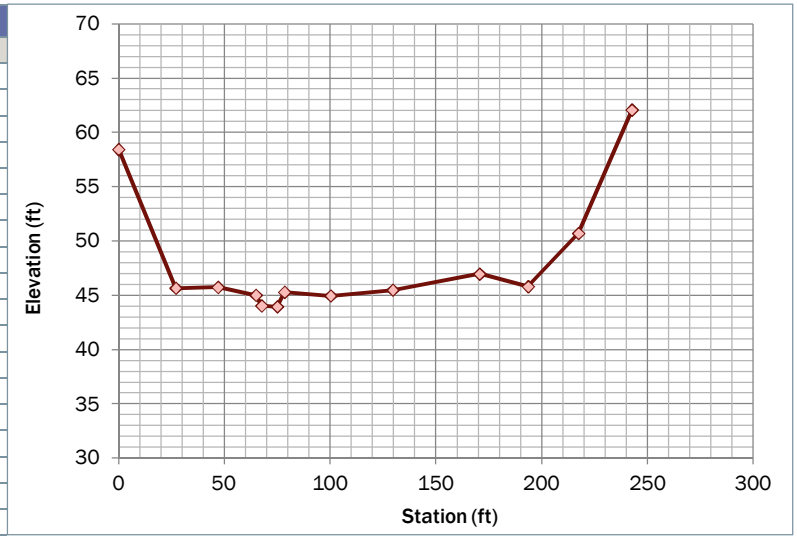
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	681536.235	1180252.959	269.53	(782)SET HUB/TACK -
3.96	681536.198	1180256.914	268.90	(270)CREEK TOP
15.13	681536.096	1180268.088	254.64	(268)CREEK TOE
20.04	681536.051	1180273.000	253.44	(256)CREEK CL
27.09	681535.990	1180280.051	254.04	(268)CREEK TOE
33.04	681535.936	1180285.998	260.27	(300)GRADE BRK
48.69	681535.794	1180301.648	275.88	(304)GRND SHOT
73.22	681535.571	1180326.179	291.60	(782)SET HUB/TACK -



XS-468 (Rody Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	683763.377	1180432.616	109.28	(304)GRND SHOT
12.40	683759.540	1180444.404	100.55	(332)TOE OF BANK
32.09	683753.442	1180463.129	99.40	(270)CREEK TOP
36.96	683751.936	1180467.756	95.31	(268)CREEK TOE
41.25	683750.605	1180471.842	95.77	(300)GRADE BRK
43.16	683750.015	1180473.652	95.26	(276)EDGE WATER
43.68	683749.852	1180474.154	95.27	(256)CREEK CL
46.36	683749.022	1180476.701	95.42	(300)GRADE BRK
49.05	683748.191	1180479.253	96.07	(300)GRADE BRK
53.70	683746.749	1180483.680	96.80	(300)GRADE BRK
55.78	683746.106	1180485.654	95.69	(300)GRADE BRK
59.64	683744.783	1180489.288	95.64	(276)EDGE WATER
62.06	683744.165	1180491.622	95.37	(256)CREEK CL
68.93	683742.037	1180498.155	95.84	(268)CREEK TOE
76.81	683739.597	1180505.647	101.23	(270)CREEK TOP
79.40	683738.794	1180508.114	101.49	(300)GRADE BRK
92.99	683734.585	1180521.036	109.59	(787)SET REBAR - CNTRL -

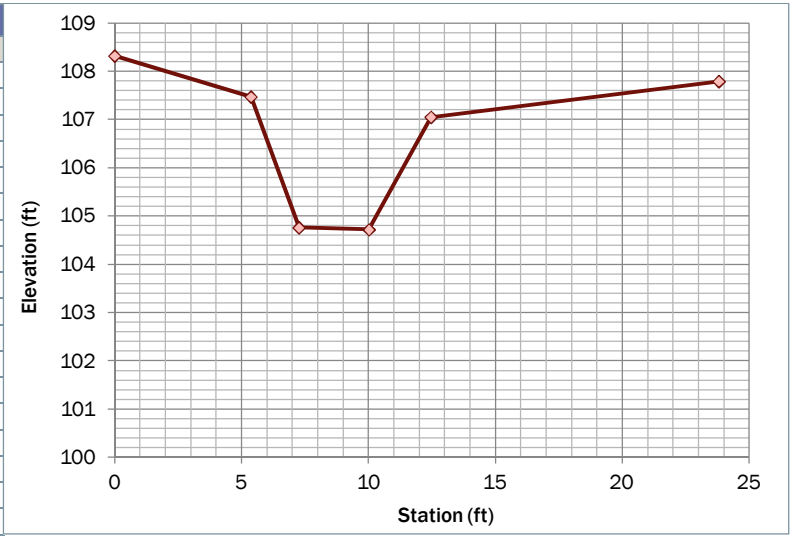


XS-473 (Rody Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	684689.959	1181046.877	58.44	(304)GRND SHOT
27.09	684664.611	1181056.428	45.66	(300)GRADE BRK
46.96	684646.018	1181063.434	45.74	(300)GRADE BRK
64.92	684629.212	1181069.766	45.01	(270)CREEK TOP
67.68	684626.625	1181070.741	44.04	(268)CREEK TOE
74.98	684619.794	1181073.315	43.95	(268)CREEK TOE
78.42	684616.580	1181074.526	45.30	(270)CREEK TOP
100.29	684596.109	1181082.239	44.95	(304)GRND SHOT
129.60	684568.684	1181092.573	45.48	(304)GRND SHOT
170.64	684530.282	1181107.042	46.96	(304)GRND SHOT
193.55	684508.838	1181115.122	45.80	(300)GRADE BRK
217.39	684486.526	1181123.529	50.71	(304)GRND SHOT
242.64	684462.902	1181132.430	62.07	(304)GRND SHOT



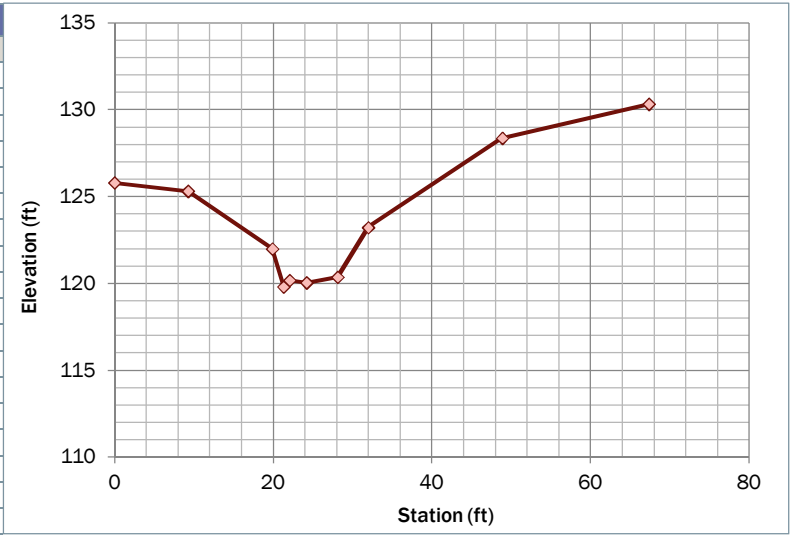
XS-477 (Woodland Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	680252.918	1185072.930	108.32	(787)SET REBAR - CNTRL -
5.37	680254.548	1185078.098	107.47	(270)CREEK TOP
7.26	680254.799	1185079.971	104.76	(268)CREEK TOE
10.02	680255.342	1185082.677	104.72	(268)CREEK TOE
12.46	680255.618	1185085.101	107.05	(270)CREEK TOP
23.80	680257.126	1185096.360	107.79	(787)SET REBAR - CNTRL -



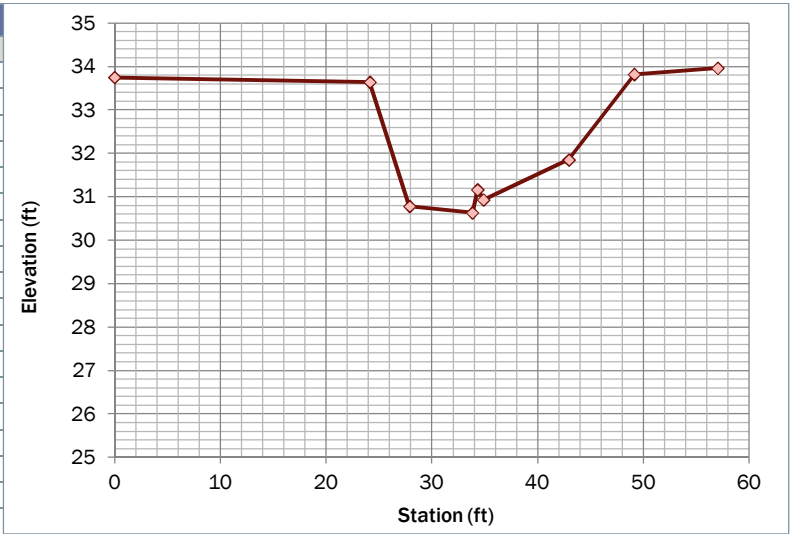
XS-485 (Silver Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	677001.089	1191033.834	125.79	(304)GRND SHOT
9.26	677002.597	1191042.968	125.31	(334)TOP OF BANK
19.90	677004.330	1191053.465	121.99	(270)CREEK TOP
21.31	677004.561	1191054.864	119.80	(268)CREEK TOE
22.08	677004.685	1191055.616	120.18	(276)EDGE WATER
24.21	677005.032	1191057.720	120.04	(256)CREEK CL
28.13	677005.670	1191061.585	120.36	(268)CREEK TOE
31.98	677006.298	1191065.387	123.22	(270)CREEK TOP
48.87	677009.050	1191082.050	128.36	(334)TOP OF BANK
67.34	677012.061	1191100.279	130.32	(787)SET REBAR - CNTRL -



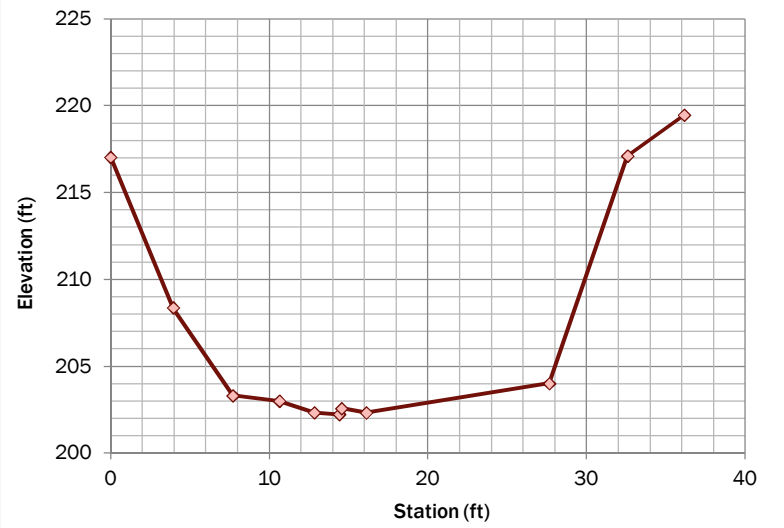
XS-487 (Silver Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	679575.914	1190799.098	33.75	(787)SET REBAR - CNTRL -
24.13	679568.363	1190822.014	33.64	(270)CREEK TOP
27.88	679567.187	1190825.582	30.78	(268)CREEK TOE
33.82	679565.329	1190831.220	30.63	(256)CREEK CL
34.31	679565.177	1190831.681	31.16	(276)EDGE WATER
34.86	679565.005	1190832.204	30.93	(268)CREEK TOE
42.94	679562.475	1190839.882	31.85	(300)GRADE BRK
49.12	679560.541	1190845.747	33.82	(270)CREEK TOP
57.01	679558.071	1190853.245	33.96	(304)GRND SHOT

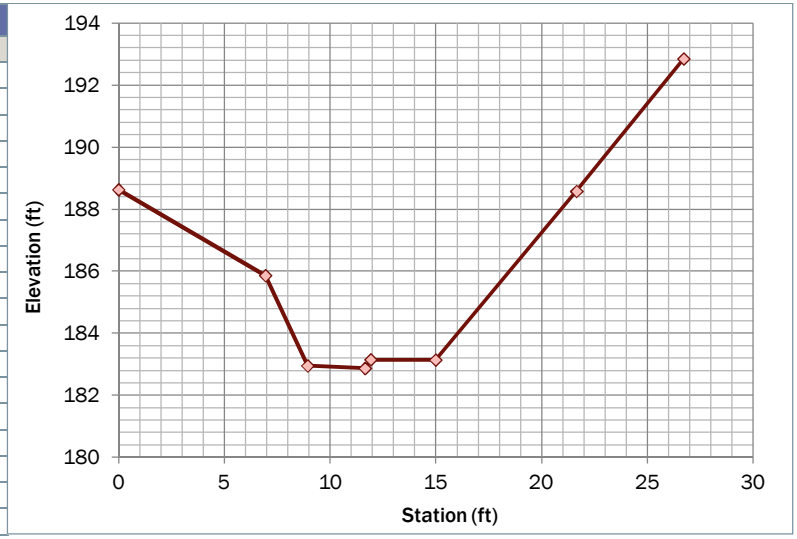


XS-488 (Silver Creek)

STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675136.384	1190626.389	217.03	(784)SET PK/SPIKE - CNTRL -
3.95	675133.633	1190629.222	208.37	(300)GRADE BRK
7.71	675131.036	1190631.937	203.31	(322)RET WALL TOP
10.64	675129.007	1190634.058	203.00	(782)SET HUB/TACK -
12.84	675127.485	1190635.649	202.33	(276)EDGE WATER
14.41	675126.403	1190636.780	202.23	(256)CREEK CL
14.56	675126.294	1190636.893	202.57	(276)EDGE WATER
16.12	675125.219	1190638.017	202.32	(276)EDGE WATER
27.65	675117.251	1190646.345	204.01	(332)TOE OF BANK
32.58	675113.842	1190649.909	217.11	(300)GRADE BRK
36.15	675111.421	1190652.540	219.46	(787)SET REBAR - CNTRL -



XS-494 (Silver Creek)				
STATION (FT)	NORTHING (FT)	EASTING (FT)	ELEV (FT)	DESCRIPTION (FT)
0.00	675276.158	1190993.315	188.63	(787)SET REBAR - CNTRL -
6.94	675273.449	1190999.765	185.86	(270)CREEK TOP
8.93	675272.765	1191001.637	182.95	(268)CREEK TOE
11.65	675271.705	1191004.168	182.87	(256)CREEK CL
11.92	675271.448	1191004.374	183.15	(276)EDGE WATER
14.98	675271.477	1191007.565	183.14	(268)CREEK TOE
21.65	675269.328	1191013.888	188.58	(270)CREEK TOP
26.71	675269.021	1191019.051	192.85	(774)FND REBAR/CAP - BNDY -



Appendix C: Annotated Stream Profiles

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CONDITION SUMMARY

Large sediment production upstream of 72nd from hillslopes and channel

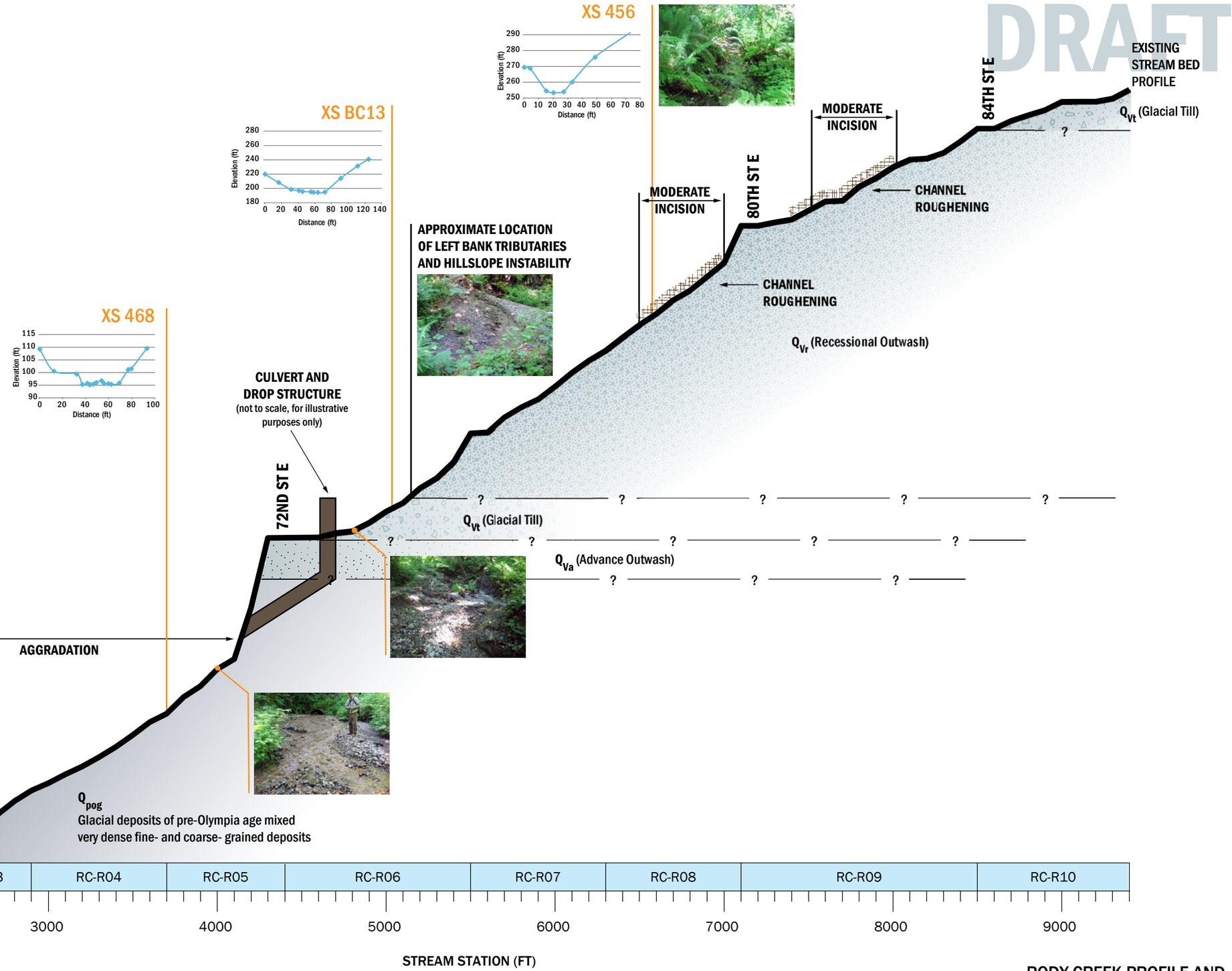
Subsequent aggradation downstream of 72nd

Moderate incision downstream of 80th St E and upstream of 80th St E

RECOMMENDATIONS

Channel roughening immediately downstream and upstream of 80th St E using large boulders, wood and streambed gravel mix

Sediment source analysis study

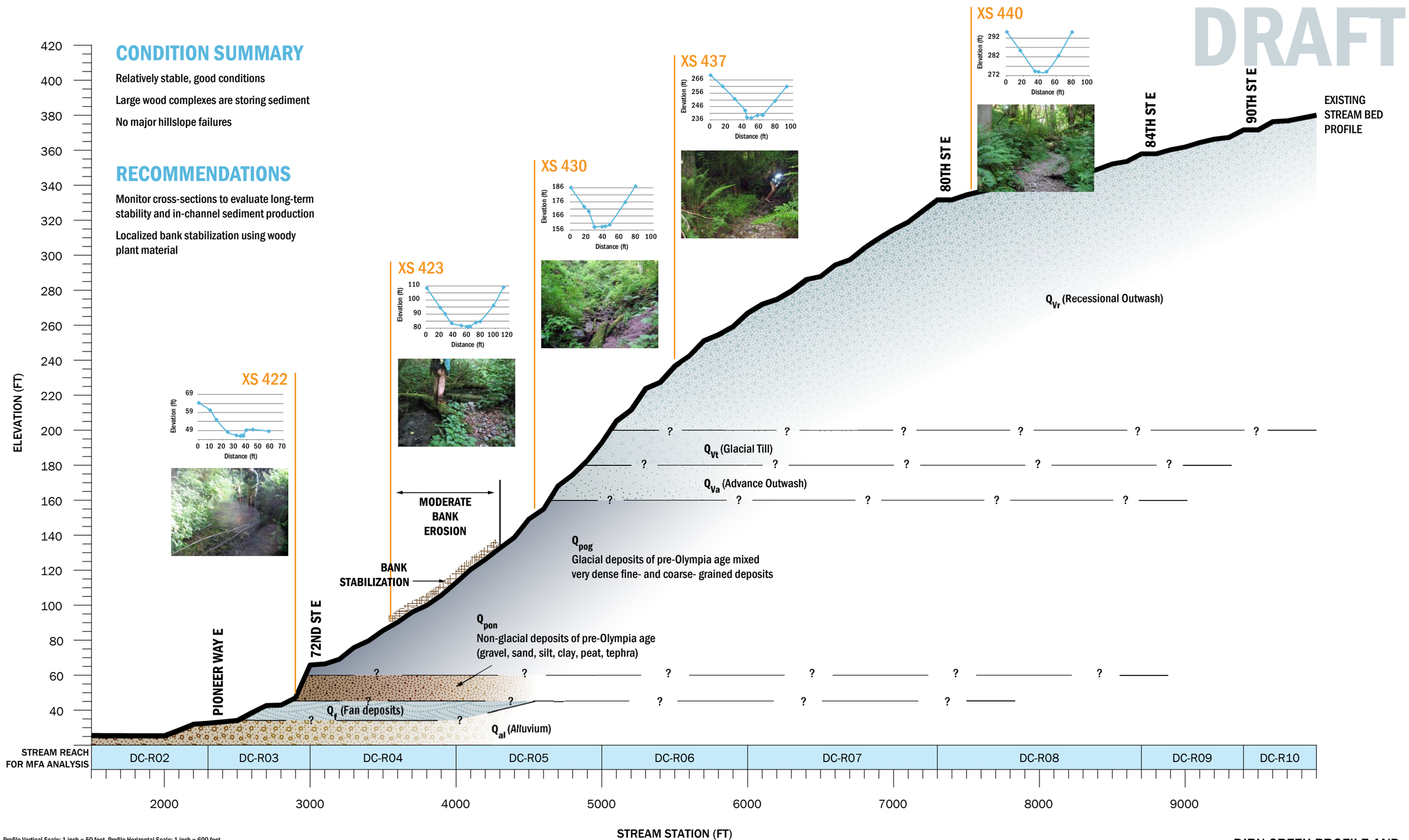


Profile Vertical Scale: 1 inch = 50 feet, Profile Horizontal Scale: 1 inch = 600 feet
Surface Geology from Troost, K.G. in Review, Geologic Map of the Puyallup 7.5 Munite Quadrangle, Washington: U.S. Geologic Survey Mischellaneous Field Investication, Scale 1:24,000

Brown AND Caldwell

RODY CREEK PROFILE AND GENERAL GEOMORPHIC CONDITIONS

Clarks Creek Sediment Reduction Action Plan



Profile Vertical Scale: 1 inch = 50 feet, Profile Horizontal Scale: 1 inch = 600 feet
Surface Geology from Troost, K.G. in Review, Geologic Map of the Puyallup 7.5 Munite Quadrangle, Washington: U.S. Geologic Survey Mischellaneous Field Investication, Scale 1:24,000

Brown AND Caldwell

DIRU CREEK PROFILE AND GENERAL GEOMORPHIC CONDITIONS
Clarks Creek Sediment Reduction Action Plan

DRAFT

CONDITION SUMMARY

Slightly degrading channel downstream of 80th St E

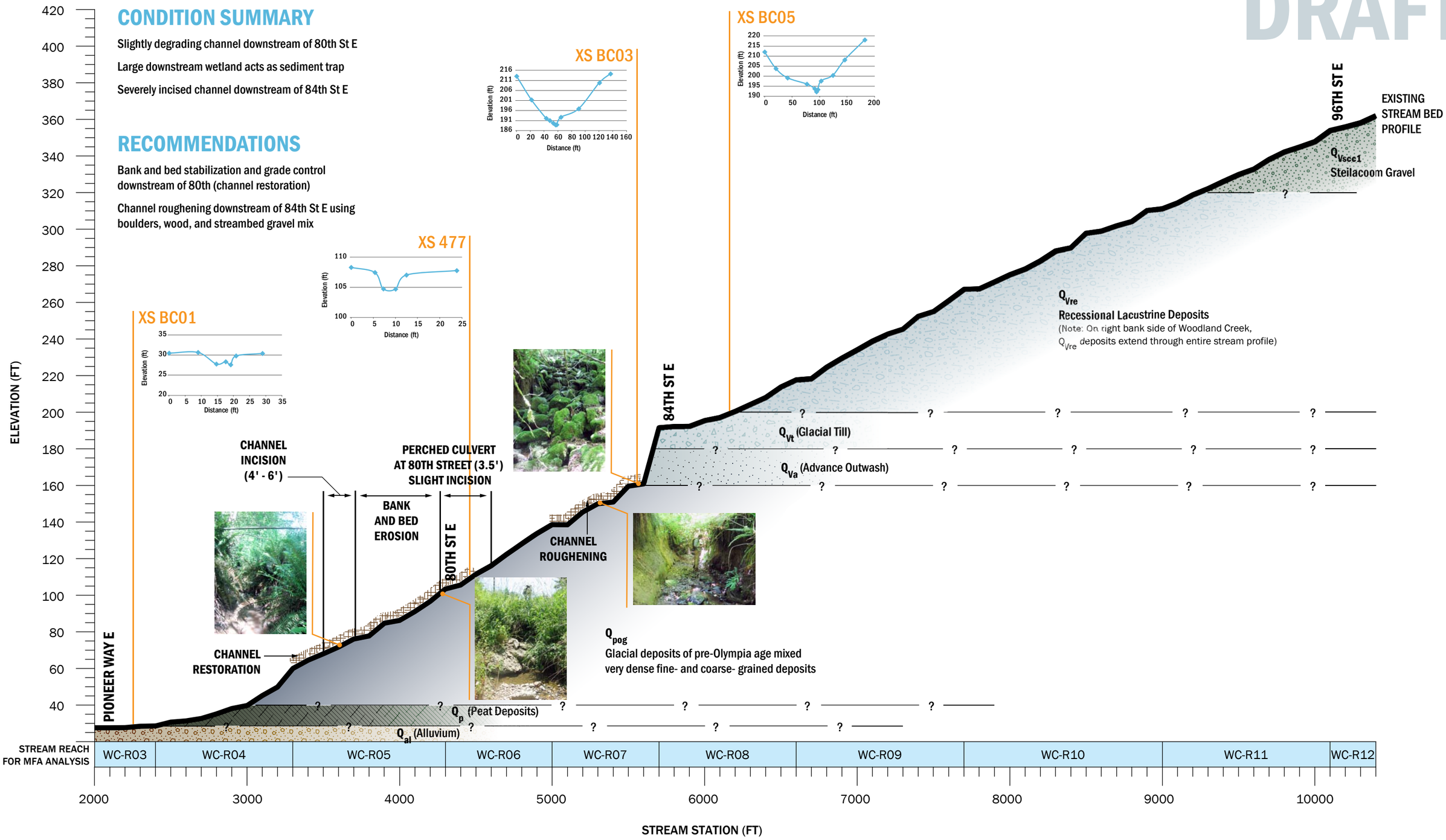
Large downstream wetland acts as sediment trap

Severely incised channel downstream of 84th St E

RECOMMENDATIONS

Bank and bed stabilization and grade control downstream of 80th (channel restoration)

Channel roughening downstream of 84th St E using boulders, wood, and streambed gravel mix



Profile Vertical Scale: 1 inch = 50 feet, Profile Horizontal Scale: 1 inch = 600 feet

Surface Geology from Troost, K.G. in Review, Geologic Map of the Puyallup 7.5 Munite Quadrangle, Washington: U.S. Geologic Survey Mischellaneous Field Investication, Scale 1:24,000

Brown AND Caldwell

WOODLAND CREEK PROFILE AND GENERAL GEOMORPHIC CONDITIONS

Clarks Creek Sediment Reduction Action Plan

DRAFT

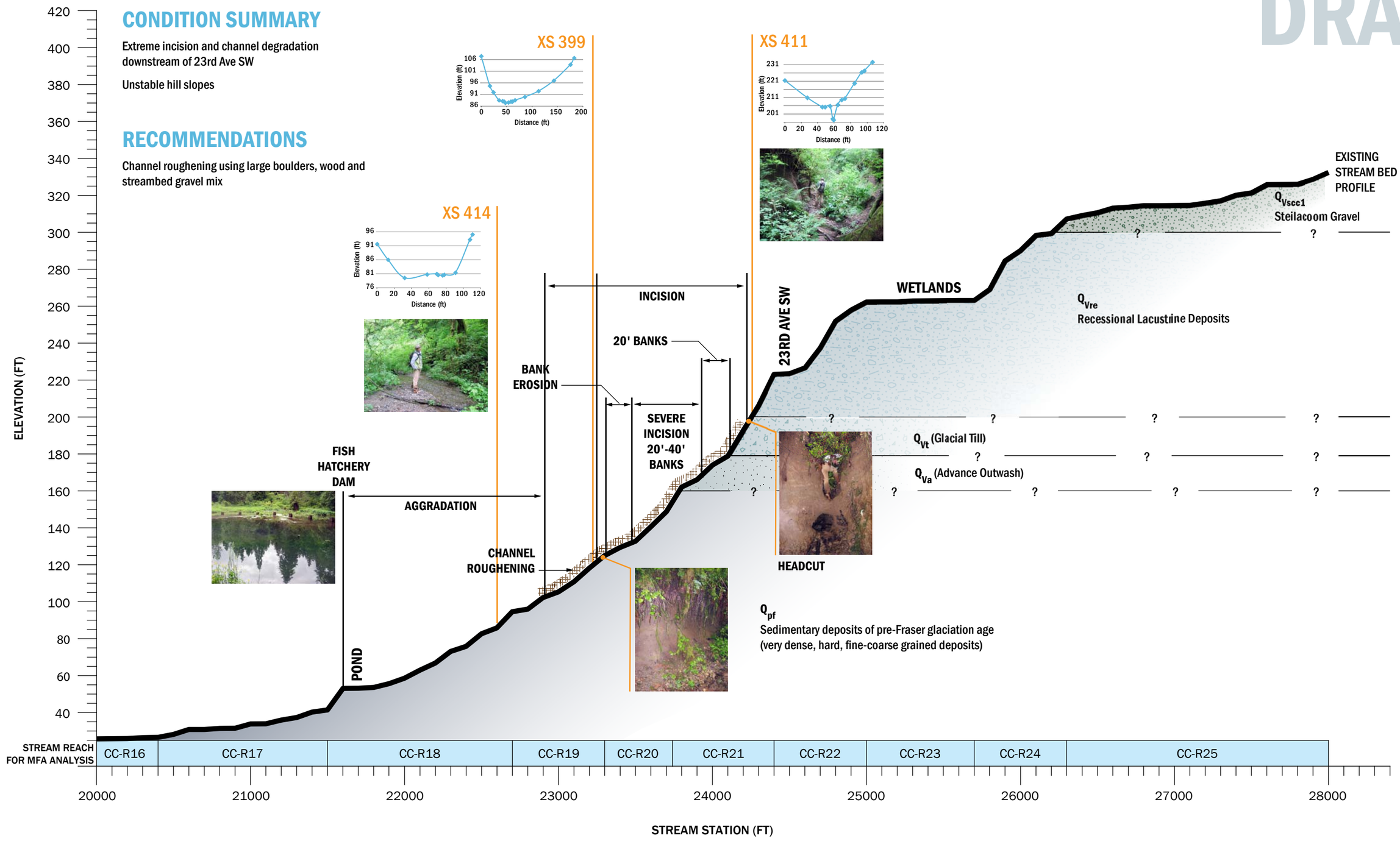
CONDITION SUMMARY

Extreme incision and channel degradation downstream of 23rd Ave SW

Unstable hill slopes

RECOMMENDATIONS

Channel roughening using large boulders, wood and streambed gravel mix



Profile Vertical Scale: 1 inch = 50 feet, Profile Horizontal Scale: 1 inch = 600 feet
Surface Geology from Troost, K.G. in Review, Geologic Map of the Puyallup 7.5 Munite Quadrangle, Washington: U.S. Geologic Survey Mischellaneous Field Investication, Scale 1:24,000

Brown AND Caldwell

UPPER CLARKS CREEK PROFILE AND GENERAL GEOMORPHIC CONDITIONS

Clarks Creek Sediment Reduction Action Plan

DRAFT

CONDITION SUMMARY

Vertically eroding valley walls near infrastructure

Severe channel incision downstream of 23rd Ave SW

Slight incision upstream of 15th Ave SW

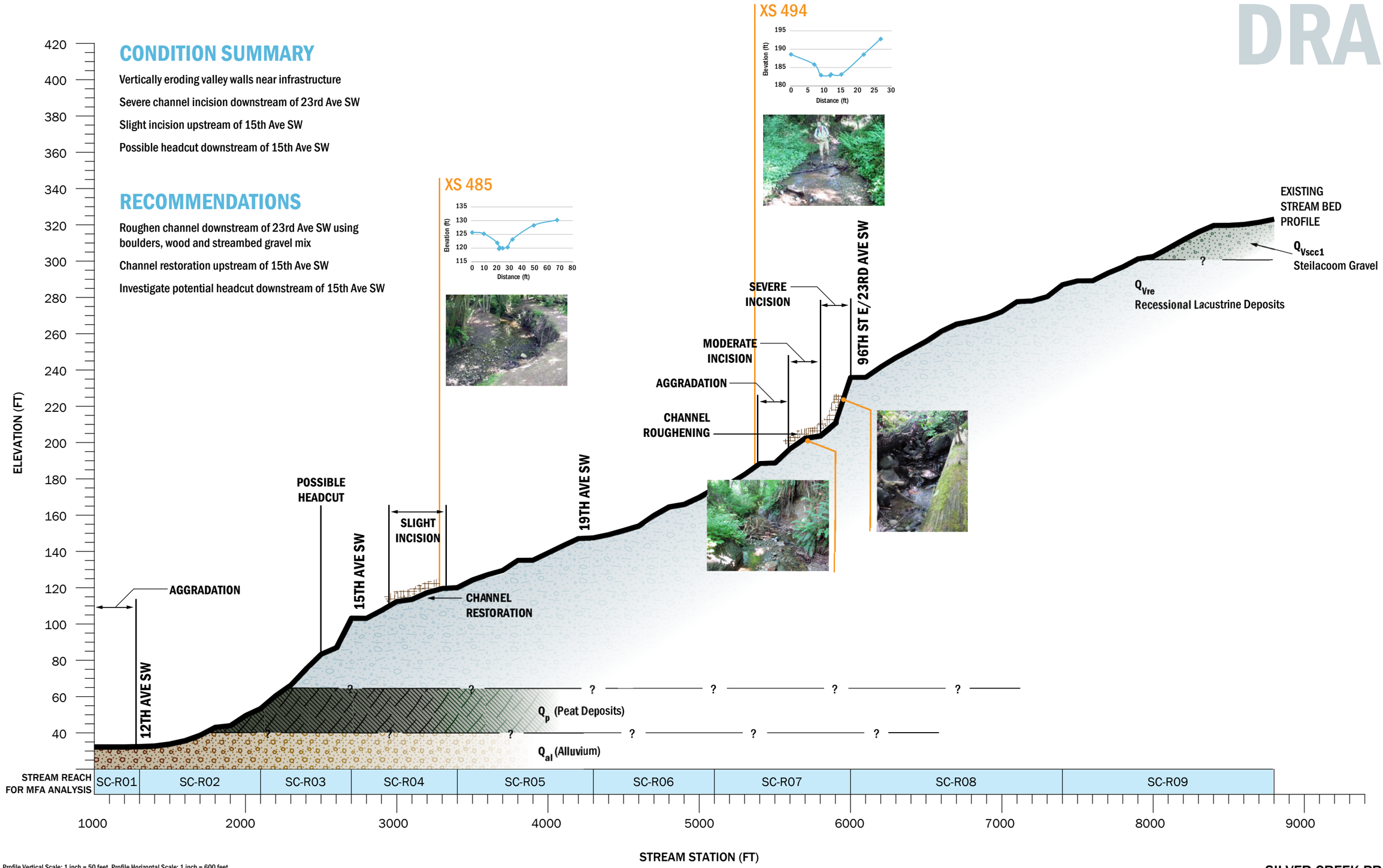
Possible headcut downstream of 15th Ave SW

RECOMMENDATIONS

Roughen channel downstream of 23rd Ave SW using boulders, wood and streambed gravel mix

Channel restoration upstream of 15th Ave SW

Investigate potential headcut downstream of 15th Ave SW



Profile Vertical Scale: 1 inch = 50 feet, Profile Horizontal Scale: 1 inch = 600 feet
Surface Geology from Troost, K.G. in Review, Geologic Map of the Puyallup 7.5 Munite Quadrangle, Washington: U.S. Geologic Survey Mischellaneous Field Investication, Scale 1:24,000

Brown AND Caldwell

SILVER CREEK PROFILE AND GENERAL GEOMORPHIC CONDITIONS

Clarks Creek Sediment Reduction Action Plan

Appendix D: Tetra Tech's Watershed Modeling Report

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Clarks Creek Sediment Study
Watershed Model Report

Prepared for

Puyallup Tribe of Indians

Prepared by

TETRA TECH

3200 Chapel Hill-Nelson Hwy, Suite 105 • PO Box 14409
Research Triangle Park, NC 27709

REVISED DRAFT

April 4, 2012

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1 Introduction

1.1 CLARKS CREEK

The Clarks Creek watershed is located in the lower Puyallup River Basin, not far from Commencement Bay (southern end of Puget Sound) and the northwest corner of Pierce County, WA (Figure 1-1). It is within Washington Department of Ecology's Water Resources Inventory Area (WRIA) 10. The Clarks Creek watershed area is divided between the City of Puyallup and unincorporated areas of Pierce County. The most northern portion of the watershed is within the Puyallup Tribal Reservation.

The surface drainage occupies an area of 10.4 square miles of glacial deposits, foothill ridges, and flat valley land along the Puyallup River. Additional groundwater flow in Clarks Creek is derived from portions of an internally drained area to the south and east of the surface drainage network, known as the Potholes region. The headwaters of the Clarks Creek surface drainage network start approximately one-third of a mile south of Maplewood Springs and flow 3.6 miles through Pierce County, the City of Puyallup, and Puyallup Tribal lands before discharging into the Puyallup River.

The surficial geology of the Clarks Creek area is a product of glaciations and subsequent alluvial processes (Jones et al., 1999). The headwaters of the Clarks Creek drainage are primarily in the Vashon recessional till. From there, the creek descends for a few miles through the upper aquifer unit before transitioning to alluvial soils in the Puyallup River valley.

The highly permeable surface aquifers of upper Clarks Creek result in substantial exchanges between the surface and ground water systems (Savoca et al., 2010). Groundwater movement in the surface aquifer (Vashon recessional till or A1 aquifer) generally follows the land surface gradient, with seeps and springs where this layer thins out, as at Maplewood Springs, which forms the headwaters of Clarks Creek. The USGS is in the process of creating a regional groundwater model, and the initial framework report (Savoca et al., 2010) suggests that water in the A1 aquifer may flow to Maplewood Springs from a distance of up to five miles or more from the south and east.

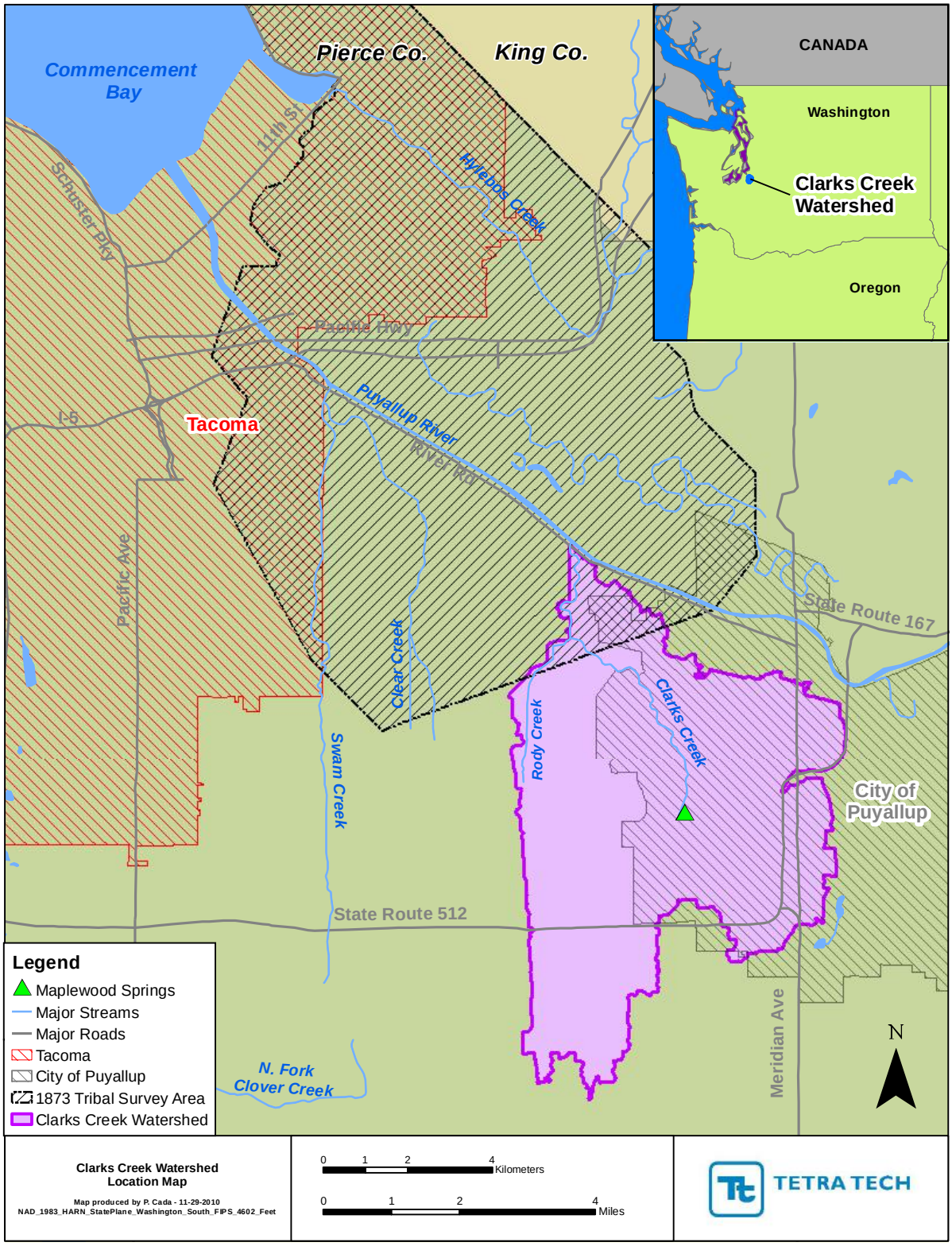

Figure 1-1. Clarks Creek Watershed Location Map

1.2 SCOPE OF THIS REPORT

The Puyallup Tribe of Indians (PTI) has been working for many years to improve water quality in Clarks Creek. As part of this effort, PTI received an EPA-funded grant entitled "Reducing Effective Impervious Surfaces in a Small Urban Catchment Using LID Practices." The overall contract to support work under this grant was issued to Brown and Caldwell, while Tetra Tech was issued a companion work assignment to support watershed modeling.

The watershed model focuses on flow and sediment loading in the watershed. Excess sediment loading contributes to a variety of water quality problems in Clarks Creek. Notably, fine sediment accumulation is an important factor in promoting dense growths of the nuisance waterweed elodea that adversely impact DO concentrations, in turn threatening salmonid success, and clog the Tribe's hatchery intakes. Sediment loads may also contain elevated nutrient concentrations that promote macrophyte growth, as well as elevated fecal coliform bacteria concentrations that can contribute to impairment of uses.

The overall goal of the project is to improve water quality in Clarks Creek by reducing sediment load. To accomplish this, the following objectives must be met:

1. Sediment sources must be identified and characterized.
2. Sediment pathways to Clarks Creek must be understood.
3. Anthropogenic elements of sediment load must be understood.
4. Methods to reduce the anthropogenic sediment load must be developed and implemented.

The Clarks Creek watershed model is a tool to assist in evaluating the relationship between sediment sources, urban stormwater, and conditions within Clarks Creek. This report documents the development, calibration, and validation of the watershed model. Following review and approval of the model, the tool can be used to aid in the selection of management efforts to protect and restore Clarks Creek.

1.3 PROJECT QUALITY OBJECTIVES

Environmental simulation models are simplified mathematical representations of complex real world systems. Models cannot accurately depict every one of the multitude of processes occurring at all physical and temporal scales in a watershed. Models can, however, make use of known interrelationships among variables to predict how a given quantity or variable would change in response to a change in an interdependent variable or forcing function. In this way, models can be useful frameworks for investigations of how a system would likely respond to a perturbation from its current state. To provide a credible basis for prediction and the evaluation of mitigation options, the ability of the model to represent real world conditions should be demonstrated through a process of model calibration and corroboration or validation.

USEPA (2002) recommends following a systematic planning process to define quality objectives and performance criteria. For modeling projects, systematic planning identifies the expected outcome of the modeling, its technical goals, cost and schedule, and the criteria for determining whether the inputs and outputs of the various intermediate stages of the project, as well as the project's final product, are acceptable. The systematic planning approach begins with identifying Principal Study Questions, and designs the modeling effort to answer these questions. This process is described in the modeling Quality Assurance Project Plan (QAPP; Tetra Tech, 2011).

Principal Study Questions

A detailed description of water quality and use assessment in Clarks Creek by Washington Department of Ecology, along with information on land use, geology, vegetation, and other watershed characteristics is provided in the Clarks Creek Data Review (Tetra Tech, 2010) conducted for USEPA Region 10 in

support of the Clarks Creek Dissolved Oxygen (DO) TMDL. Depressed DO in Clarks Creek occurs as the net result of a series of complex processes. Excess sediment loading contributes in a variety of ways to the DO problems in Clarks Creek. Notably, fine sediment accumulation is an important factor in promoting dense growths of elodea that adversely impact DO concentrations both directly, through diurnal respiration, and indirectly through contributions to SOD. Elodea growth in turn slows flows in the creek, which reinforces sediment deposition and accumulation and leads to flooding problems. Sediment loads may also contain elevated nutrient concentrations that promote macrophyte growth, as well as elevated bacterial concentrations.

In addition to use assessments conducted by Ecology, fisheries stakeholders (including the Puyallup Tribe) have an interest in reducing geomorphically significant flows that could result in salmon redd scour or burial and reduced juvenile salmon survival. The Puyallup Tribe is also interested in reducing downstream channel erosion.

In sum, the Principal Study Questions to be addressed by modeling in this project are:

1. What are the principal sources of sediment load in the Clarks Creek watershed?
2. How are sediment loads in the watershed transported to Clarks Creek?
3. What is the significance of sources of instream generation of sediment load due to scour and bank failure and what factors control these loads?
4. What is the optimal selection of management measures to reduce both the anthropogenic sediment load and excess flows that promote instream generation of sediment load via channel degradation?

Identify the Decision

The intended end product of this work is the development of a sediment management plan for Clarks Creek. The watershed simulation model should provide the ability to evaluate the relative benefit of different management alternatives that may control upland sediment loads and the occurrence of flows that cause channel scour with subsequent deposition in the lower reaches of Clarks Creek.

Identify the Inputs to the Decision

The watershed model developed as a result of this TO will be used to evaluate a variety of potential management scenarios (to be developed by Brown and Caldwell). The model provides decision-related inputs on the impacts of these scenarios on total sediment load to Clarks Creek from both upland and instream sources and anticipated rates of sediment deposition within Clarks Creek.

Develop a Decision Rule for Information Synthesis

The purpose of a decision rule is to integrate the outputs from the study into a single statement that describes the logical basis for choosing among alternative actions. Output from the previous steps will be used to guide decision makers in efforts to choose from alternative actions. The model is applied in the context of a larger stakeholder process and management scenario development being conducted by Brown and Caldwell for PTI. The overall decision rule relative to the watershed model is:

> To support uses in Clarks Creek it is necessary to control a variety of factors that contribute – directly or indirectly – to elevated sedimentation in the creek. A watershed model that is capable of evaluating flow, upland sediment sources, and instream sediment processes will be used to evaluate the contributions of different sources to current sedimentation conditions and to determine load reductions necessary to achieve standards. The evaluation of the sensitivity and importance of different stressor sources will be used to identify, evaluate, and test potential implementation strategies to reduce sedimentation in Clarks Creek. The modeling will be used to provide evaluations of the potential benefits of candidate management strategies that will be developed by Brown and Caldwell in consultation with PTI and other stakeholders.

Specify Tolerance Limits on Decision Errors

To help guide the interpretation of the technical information provided by the water quality model, general performance targets for the modeling are described in Section 5. The performance targets are based on generally accepted values from the literature and experience with previous projects. Specific numeric acceptance criteria cutoffs are not specified for the model.

1.4 MODEL SELECTION

Addressing the principal study questions requires a modeling framework that can provide a dynamic simulation of flow, upland sediment loading, and instream sediment transport processes. The Hydrologic Simulation Program – FORTRAN (HSPF) model (Bicknell et al., 2005) was selected for this purpose for several reasons:

1. HSPF provides dynamic simulation of water and sediment, including both upland and instream sediment processes at a user-specified level of detail and complexity, and is thus suitable for addressing the principle study questions.
2. HSPF models have previously been developed to address storm flows in Clarks Creek (Mastin, 1995, CH2MHill, 2003, Pierce Co., 2009). While these models are not fully calibrated for hydrology and have not yet been developed for water quality simulation, they provide a basis for additional development of the current HSPF model.
3. HSPF is supported by EPA with open source code and has a long history of well-documented applications for addressing hydrology and sediment management applications. It also provides a platform for full simulation of nutrients, bacteria, and other endpoints of potential interest.

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2 Meteorology

HSPF requires input time series of precipitation and potential evapotranspiration (PET) at a minimum. For the simulation of water and sediment only other meteorological series such as solar radiation and humidity are not required. Air temperature is needed for hydrologic simulations only if snowmelt is simulated. As snowfall is rare in Clarks Creek watershed temperature was not needed.

Meteorological time series for Clarks Creek have been assembled over time for a variety of projects. A long period of record is desirable for evaluation of a wide range of potential conditions, and data series assembled for October 1948 through March 2010 were provided by Brown and Caldwell in an HSPF water data management (WDM) file.

As described by Doten (2011) these data came from a variety of sources. Data through September 1999 were previously assembled for the City of Puyallup State Highway Basin Plan simulation modeling conducted by Brown and Caldwell and originally assembled by NHC for the Clear and Canyon Creeks Flood Insurance Mapping Study in 2003. Brown and Caldwell extended these data through March of 2010 primarily through use of data collected at the AgNet weather station at Washington State University, Puyallup Campus. This station, located in the center of the Clarks Creek watershed, commenced operation in 1995 but has many data gaps prior to September 1999. Tetra Tech subsequently extended the time series through December of 2010, using data obtained directly from the AgNet site.

Prior to the WSU AgNet site coming online, much of the precipitation data was obtained from McMillin Reservoir (Cooperate ID 455224), which reports both hourly and 15-minute precipitation. The precipitation data sources are shown in Table 2-1.

Table 2-1. Cited Precipitation Data Sources

Time Period	Source
Oct. 1949 – Sept. 1961	Seattle-Tacoma International Airport
Oct. 1961 – Nov. 1980	McMillin Reservoir
Dec. 1980 – Nov. 1985	Seattle-Tacoma International Airport
Dec. 1985 – Sept. 1989	McMillin Reservoir
Oct. 1989 – Sept. 1992	Canyon Road
Oct. 1992 – Sept. 1999	McMillin Reservoir
Oct. 1999 – Dec. 2010	WSU Puyallup AgNet

Doten (2011) notes certain problems with the earlier data assembled by NHC (2003). Most of the data are reported at intervals of hundredths of an inch, but the data from 3/31/1977 – 11/30/1980 and 11/30/1985 – 9/30/1989 are at a much coarser resolution of tenths of an inch. It is also believed that NHC replaced some of the McMillin Reservoir data for 1990-1994 due to poor quality. Further, only summary of the day results are available from McMillin for October 1996 to April 1998, and data from this period were likely disaggregated, although this is not explained in the modeling documentation.

Data commencing in October 1999 are believed to be much more accurate, and also are from within the watershed. Doten (2011) documents filling 11 brief periods of missing data using King County rain gauges.

For evapotranspiration, the WSU Puyallup station reports daily actual evapotranspiration (ETr) from alfalfa grown under controlled conditions. The NHC weather data set through 1999 purports to include PET derived from pan evaporation data from Puyallup multiplied by a factor of 0.75 (a standard factor to relate pan evaporation, which is influenced by heating of the exposed sides and bottom of the pan, to potential evaporation from crops) – although it appears that the full set of data may be derived from multiple sources and estimation methods. For the period beginning in October 1999, Brown and Caldwell created daily PET series from the Puyallup reported ETr, divided by 0.85 to get pan evaporation, and then multiplied by 0.75 to get PET. Doten (2011) demonstrates that the resulting PET estimates are generally consistent with the historical data, although it appears that monthly average PET for August – December is slightly lower for the estimates based on ETr from WSU.

It is important to note that meteorological data through Sept. 1999 have been accepted from earlier work without revision or detailed quality checks. The data from 1999 on clearly have a higher degree of internal consistency and reliability.

3 Hydrologic Response Unit Representation

This section describes the representation of upland land areas in the HSPF model for the Clarks Creek sediment reduction project.

HSPF is a lumped model. That is, the land surface is not simulated as an explicit grid. Rather, similar components of the land surface are simulated on a unit-area basis, and the unit-area results are then multiplied by the relevant area to estimate the outflow from a subbasin to a stream reach. These land surface components should be defined in a way that facilitates both parameter identification and the evaluation of management alternatives. In general, this is best accomplished by using a Hydrologic Response Unit (HRU) approach, in which upland model areas are defined on the basis of an overlay and unique combination of soil characteristics, slope, and land use/land cover.

The previous HSPF models that cover part or all of Clarks Creek use an HRU approach that was developed for the original USGS model of the Clover Creek and Clear-Clarks Creek basins (Mastin, 1996). This employed a fairly simple classification in which an HRU represented a soil group (till, outwash, or saturated area), a land cover group (forest or grass only for pervious areas), and a slope class (flat, medium, or steep). The steepness classification was applied only to the till areas, while the saturated areas are not subdivided by either land cover or slope.

Significant amounts of additional spatial data have become available since the USGS model was developed, allowing refinement of the USGS approach. In addition, the simplified representation of land cover used by Mastin for evaluating sediment sources to Clarks Creek did not consider land use (as opposed to cover), which can be an important factor in determining sediment load. For instance, agricultural land uses typically have higher sediment loading rates than lawns on similar soils and slopes. For these reasons, it is appropriate to develop a revised HRU approach. The following sections describe the key inputs (geology and soils, land use/land cover, slopes), followed by the final HRU definition (Section 3.4).

3.1 Soils and Geology

The soil series in the watershed largely reflect the surficial geology. Both are important to the model: the soils largely control infiltration rates and erodibility, while the underlying hydrogeology controls groundwater interactions. A dominant feature of the watershed is the presence of headwater springs on the Clarks Creek mainstem which occur where the overlying Vashon recessional till and outwash tails out onto lower lying alluvial soils.

Two recent USGS reports build a picture of the hydrogeology of the watershed that can be used to complement the soil surveys. Jones et al. (1999) provide an initial account. This has been superseded by Savoca et al. (2010). Savoca et al. use a rather different nomenclature, but maintain the basic distinction between the glacial uplands and lower outwash/alluvial plain. The hydrogeological conceptual framework of Savoca et al. is shown in Figure 3-1.

The surface hydrogeology of the higher elevation areas of the Clarks Creek watershed is referred to by Savoca et al. as the A1 aquifer (Jones' Qvr; the Vashon recessional outwash) and the lower permeability A2 unit (Jones' Qvt; the Vashon recessional till), both of which are underlain by the C or sea-level sand and gravel aquifer (Jones' Qc1), while the downstream, lower elevations of the stream are atop the AL alluvial aquifer (corresponds to Jones' Qc1 aquifer and Qf1 semi-confining unit).

The soil series boundaries conform to the major division of till versus alluvial hydrogeologic units. Soil data were obtained from the NRCS's SSURGO database via the USDA Data Gateway. As shown in Figure 3-2 and Figure 3-3, soils in the watershed are dominated by Alderwood gravelly sandy loam, Kitsap silt loam, Kapowsin gravelly loam, and Puyallup fine sandy loam. Most of these soils were

formed in consolidated glacial till (hardpan) and typically yield lower infiltration rates, although they may include an overlay of well-drained outwash sands and gravel.

NRCS (2001) has defined four Hydrologic Soil Groups (HSGs; Table 3-1). The hydrologic soil group classification provides a means for grouping soils by similar infiltration and runoff characteristics for model parameterization. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. The dominant HSG in the watershed is group C, soils with slow infiltration rates, which covers half of the watershed area.

Table 3-1 NRCS Hydrologic Soil Groups in Clarks Creek Watershed

Hydrologic Soil Group	Description	Percentage of Clarks Creek Watershed
A	Soils with high infiltrations rates. Usually deep, well-drained sands or gravels. Little runoff.	7%
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well-drained soils.	22%
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.	50%
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.	21%

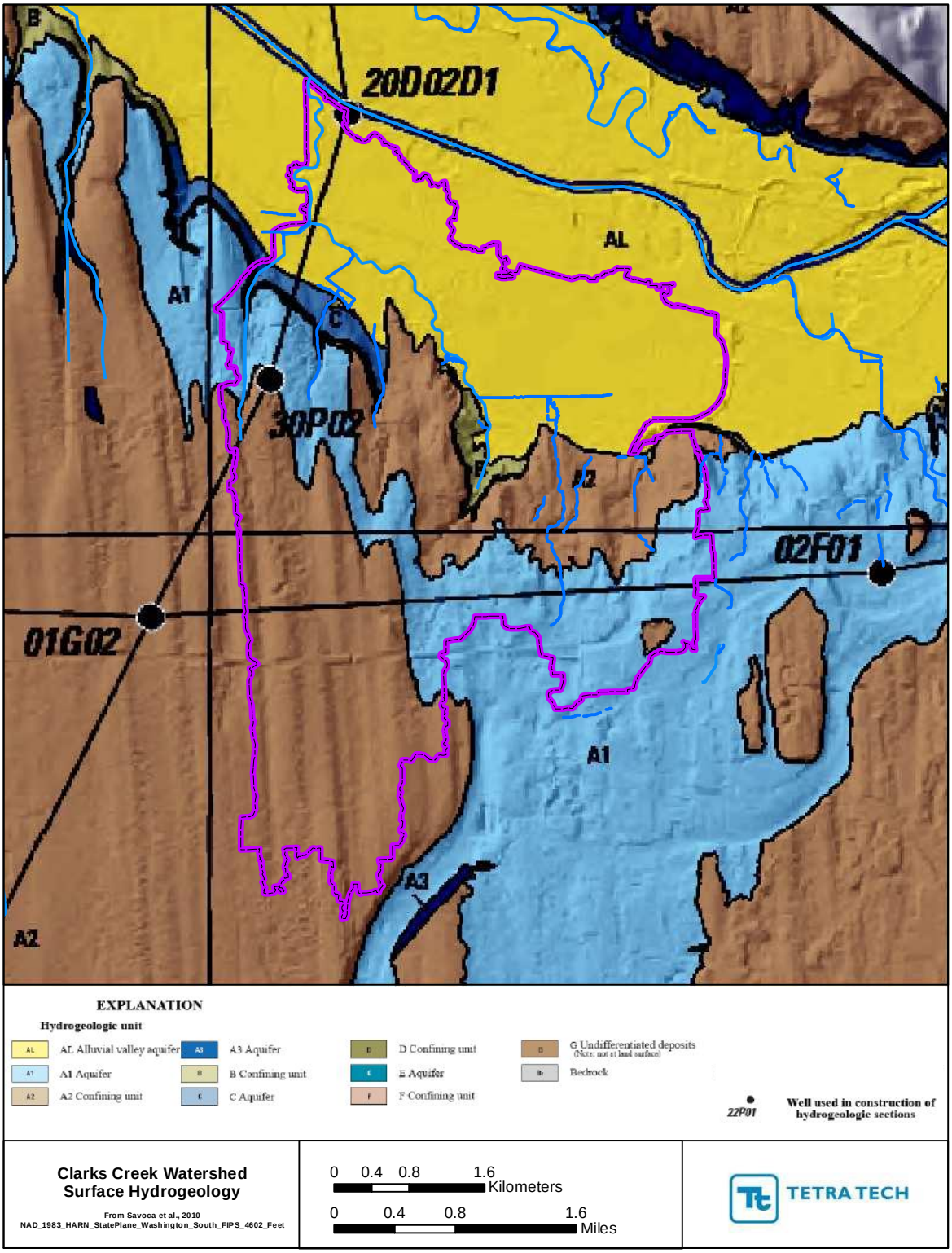

Figure 3-1. Surface Hydrogeology of the Clarks Creek Watershed (Savoca et al., 2010)

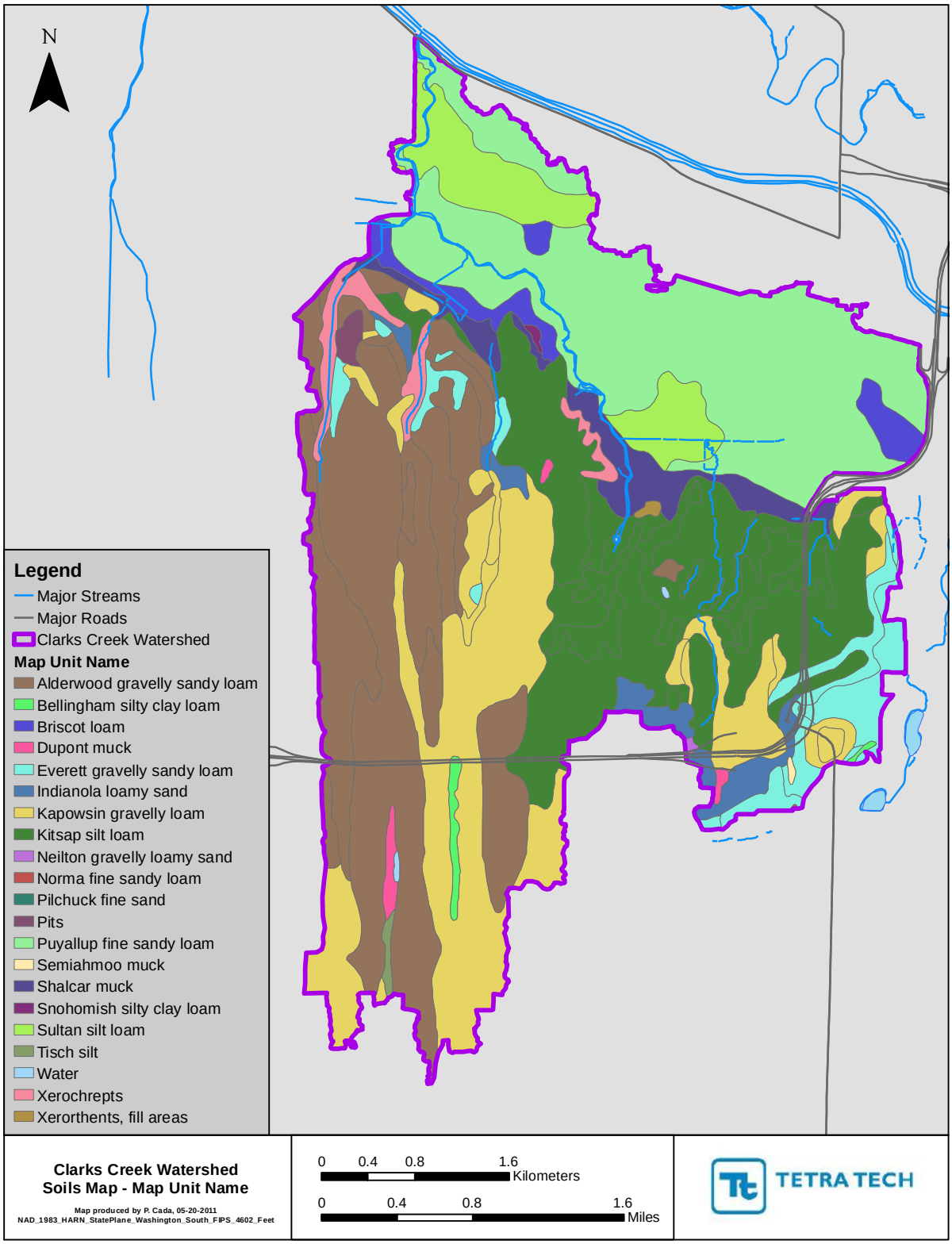

Figure 3-2 Soil Series in the Clarks Creek Watershed

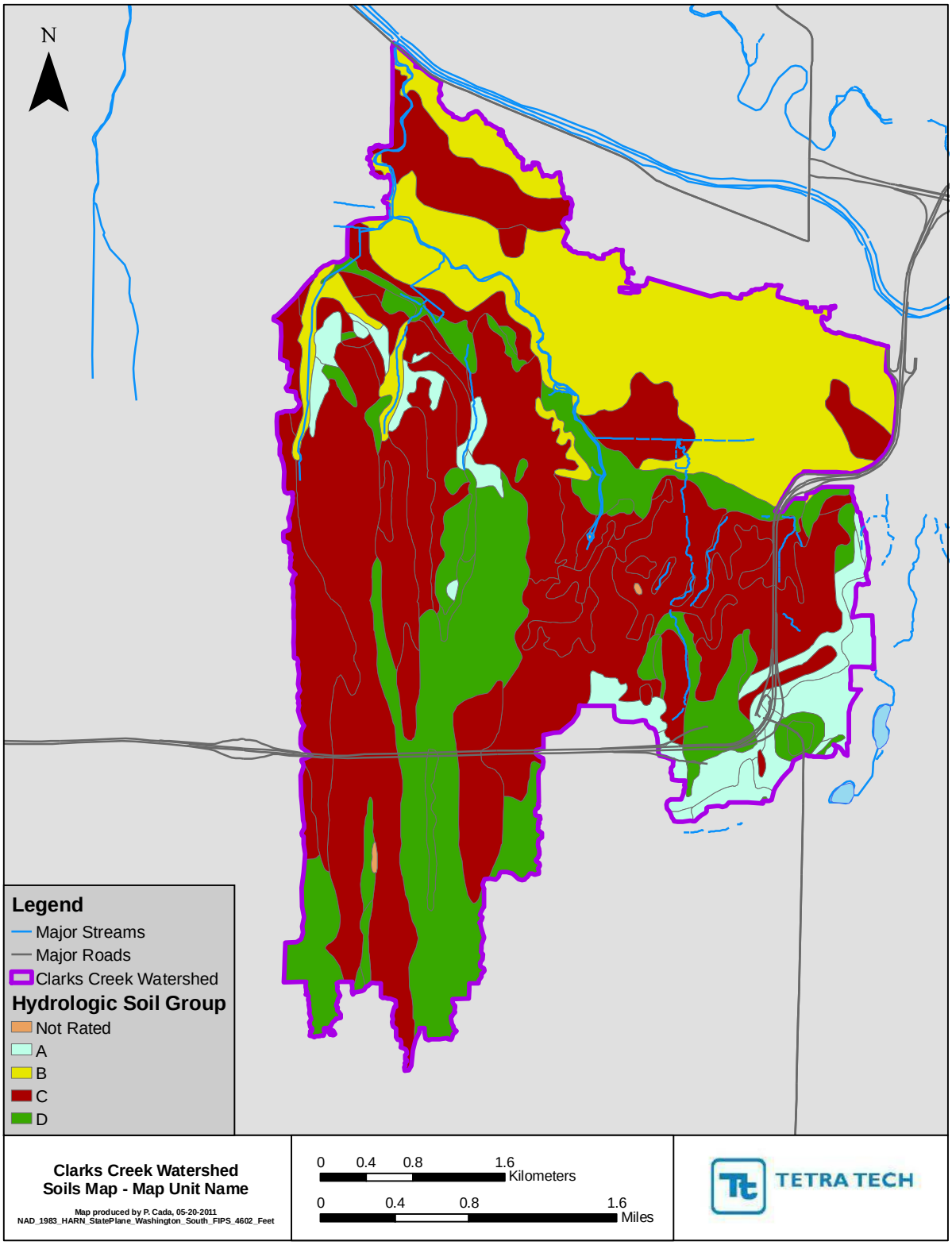

Figure 3-3 Hydrologic Soil Groups in the Clarks Creek Watershed

The Kapowsin-type soils have the lowest infiltration rates in the watershed (HSG D), while the Alderwood and Kitsap soils are more moderately drained (HSG C; see Table 3-2). The Puyallup loam, which was formed in alluvium and located along the Puyallup River Basin valley portion of the watershed, is classified as well-drained (HSG B). Several wetland areas exist in the southern headwaters of the watershed due to perched water tables and poor soil infiltration rates common in that area.

Table 3-2. Soil Series in the Clarks Creek Watershed

HSG	Soil Series	Area (acres)	Percentage
Water		4.6	0.07%
A	Everett gravelly sandy loam	287.4	4.32%
	Indianola loamy sand	135.4	2.03%
	Neilton gravelly loamy sand	3.1	0.05%
	Pits	19.5	0.29%
B	Puyallup fine sandy loam	1,346.60	20.22%
	Xerochrepts	107.7	1.62%
C	Alderwood gravelly sandy loam	1,552.30	23.31%
	Briscot loam	132.7	1.99%
	Kitsap silt loam	1,332.50	20.01%
	Pilchuck fine sand	0.3	0.00%
	Semiahmoo muck	2.7	0.04%
	Sultan silt loam	317.6	4.77%
D	Bellingham silty clay loam	25.8	0.39%
	Dupont muck	26.9	0.40%
	Kapowsin gravelly loam	1,141.10	17.14%
	Norma fine sandy loam	0.5	0.01%
	Shalcar muck	202	3.03%
	Snohomish silty clay loam	3.7	0.06%
	Tisch silt	11	0.17%
	Xerorthents, fill areas	5.4	0.08%
Grand Total		**6,658.7**	

The Mastin (1996) model separately identified saturated areas based on soil characteristics – although the category was not restricted to specifically hydric soils. These delineations do not seem to be strongly correlated with the extent of wetland areas and may be of limited use due to extensive alteration of the watershed by development and drainage. Therefore, it is more useful to identify as a separate class extant wetlands based on the Pierce County wetlands coverage.

In sum, the soils/geology component of the revised HRU classification of pervious area is as follows:

1. Till, high permeability (HSG A with some B)
2. Till, moderate permeability (HSG C)
3. Till, low permeability (HSG D)
4. Alluvial outwash soils (HSG A,B – predominantly B)
5. Alluvial outwash soils (HSG C,D – predominantly C)
0. Wetlands

3.2 LAND USE / LAND COVER

The Clarks Creek watershed (as defined by the surface drainage) occupies an area of 6,631 acres, much of which is developed land in and adjacent to the City of Puyallup, WA. Hydrologic and pollutant generating characteristics of pervious lands are determined by both the land use and the vegetative land cover. While the two categories are highly correlated (e.g., a land cover of pumpkins is likely to be an agricultural land use) they convey different information (e.g., grass on the edge of a highway is more likely to be subject to disturbance by vehicles and less likely to be fertilized than grass on a residential lawn).

In general, satellite coverages yield land cover, while parcel and tax data yield additional information on land use. Many new sources are available for both land cover and land use in the Clarks Creek watershed. Satellite-based land cover is available from the National Land Cover Dataset (NLCD; available for 1991, 2001, and 2006); the Crop Data Layer (CDL) from U.S. Department of Agriculture - National Agricultural Statistics Service, Research and Development Division (available from 2006-2007, and 2009-2010 for Washington); and the LANDFIRE coverage from USFS (2001 and 2008) (Figure 3-4 through Figure 3-6). Parcel-based land use is available in a spatial coverage from Pierce County (Figure 3-7).

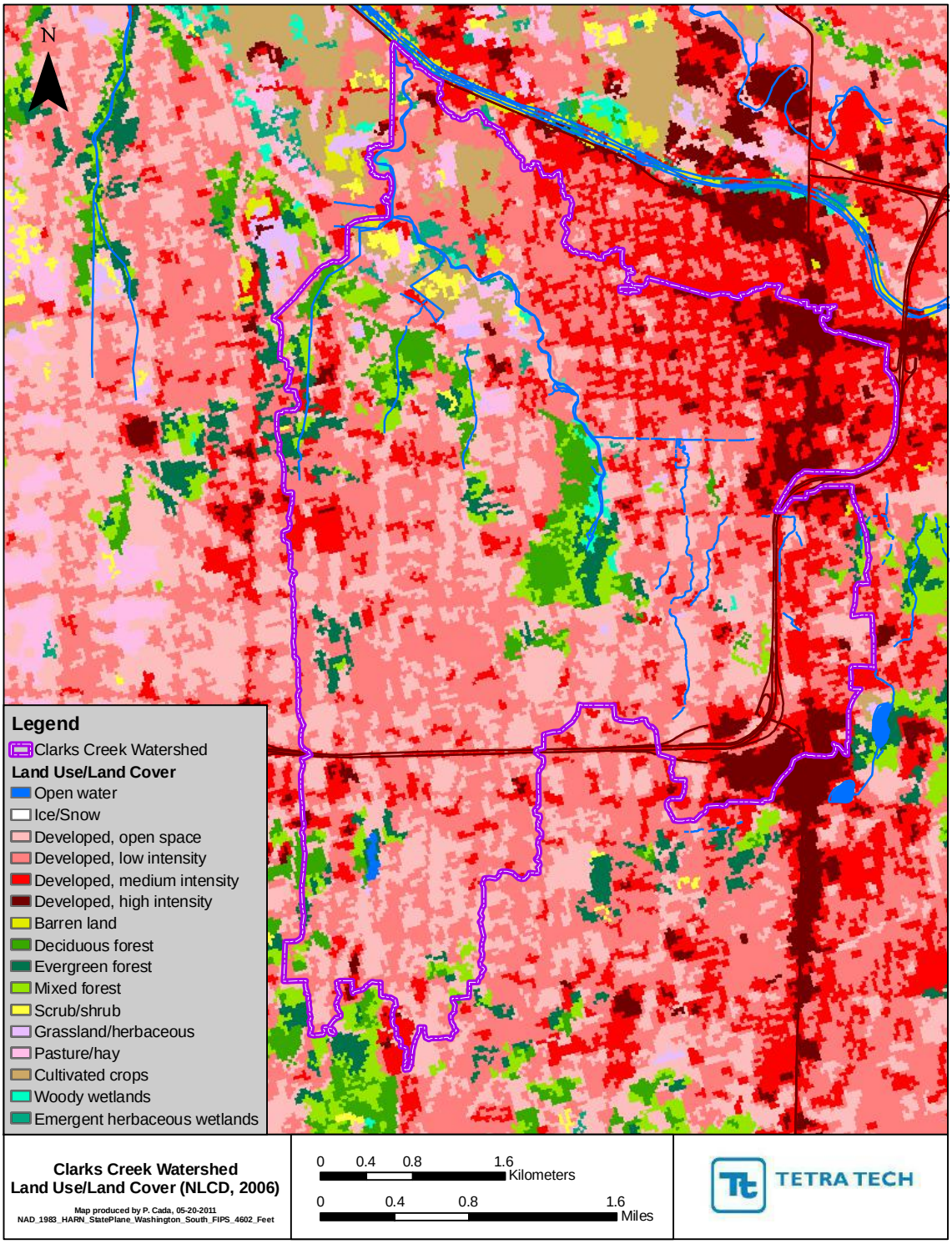

Figure 3-4. NLCD Land Use/Land Cover for the Clarks Creek Watershed

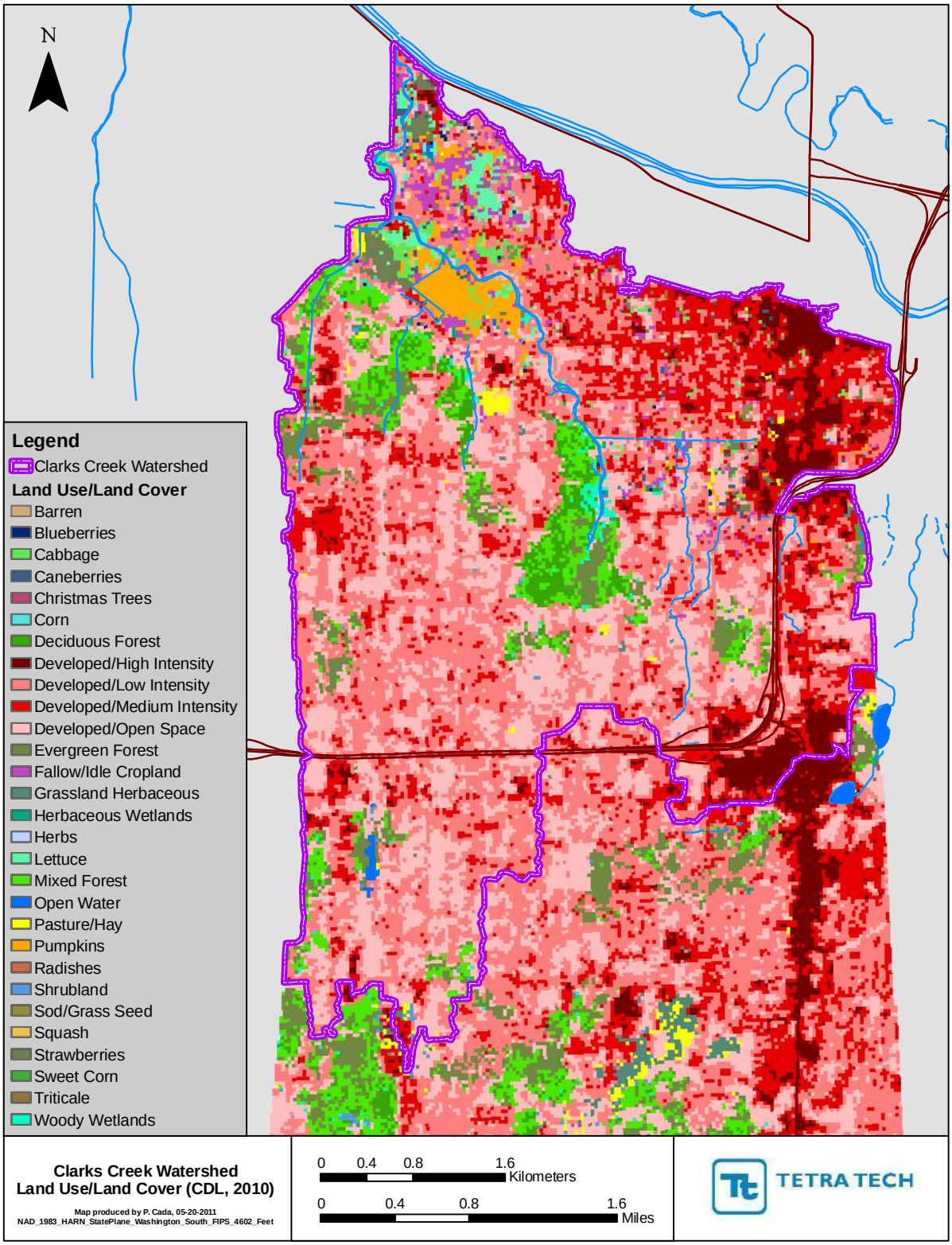

Figure 3-5. Crop Data Layer for the Clarks Creek Watershed

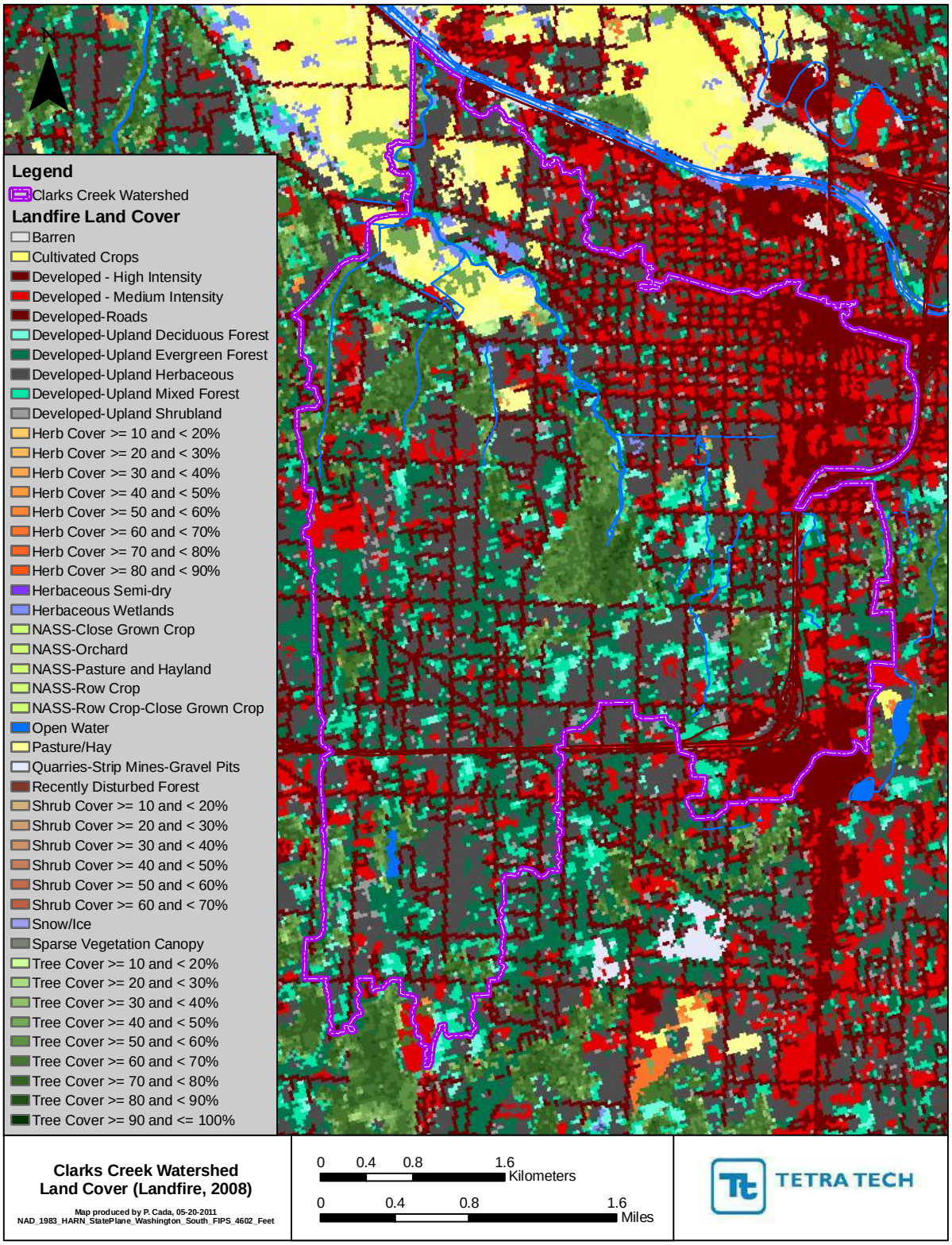

Figure 3-6. LANDFIRE Land Cover for the Clarks Creek Watershed

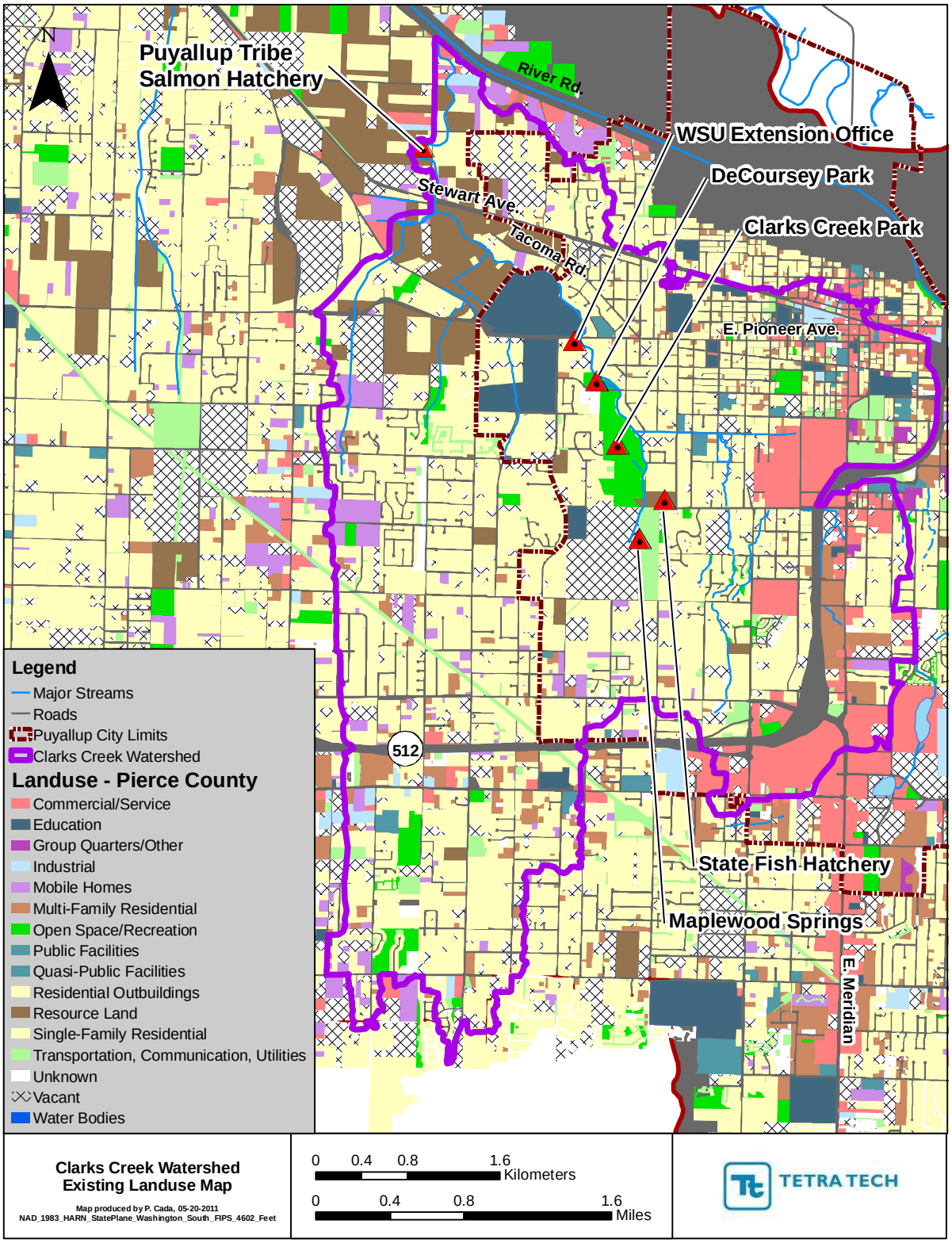

Figure 3-7 Existing Land Use from Pierce County Tax Parcel Data (3/08)

Each of these coverages was created for different purposes, and each has its advantages and disadvantages. For instance, the CDL is available yearly and gives high resolution on crop type, but does not separately distinguish roads. LANDFIRE identifies roads and gives details on tree canopy coverage (important to erosion estimation; see Figure 3-8), but does not identify specific agricultural or developed land uses, which are revealed more clearly by the Pierce County parcel-based coverage (Figure 3-7).

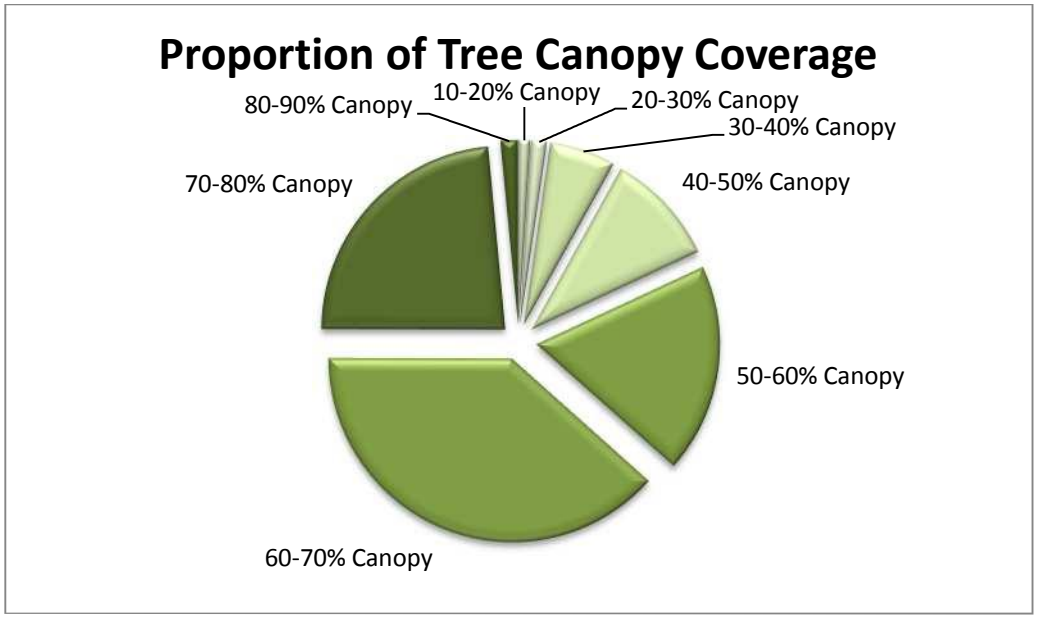

Figure 3-8. Distribution of LANDFIRE Canopy Coverage in Forest Areas of Clarks Creek

Combining the various sources of land use and land cover data provides the most useful basis for HRU determination. These data sources have been selected to account for potentially significant differences in hydrologic behavior and/or sediment load generation. The land categories developed from combining the land use and land cover data are as follows (with the numbering reflecting the scheme for pervious surfaces):

1. Forest (Tree canopy coverage > 70 percent and not within developed parcels < 1 ac)
2. Forest (Tree canopy coverage 40 – 70 percent, and not within developed parcels < 1 ac)
3. Agriculture – row crop
4. Pasture, hay, close grown crops
5. High density development (commercial, industrial, multi-family)
6. Medium density residential (1/8 - 1 ac/DU)
7. Low density single family residential (> 1 ac/DU)
8. Roads (right of way not contained within tax parcels)
9. Park and institutional land (exclusive of forest cover in categories 1 and 2, but including any miscellaneous land that does not fit into categories 1 through 8).

As noted above, wetlands are separately defined as a unique HRU category as well (with LULC code 0).

Extent of canopy coverage is included in the HRU definitions because canopy protection from rainfall impact is an important factor in determining soil erosion, as well as affecting hydrology. The 70 percent breakpoint approximates the cover factor breakpoint of 75 percent for high cover in woodlands used in the Universal Soil Loss Equation (USLE). Below 40 percent canopy cover, the USLE cover factor for forest becomes similar to that for pasture and idle land.

Forest cover is separated out of larger residential lots (> 1 ac/DU) to account for the protection of forest cover against erosion. Separating forest is not feasible for smaller lots, as the 30-m resolution of the LANDFIRE coverage cannot effectively distinguish land cover fractions within a lot size of 1 acre or less. Pervious land use within residential land use categories having lot sizes of 1 acre or less and within the non-forest portion of larger residential lots are represented as having a typical land cover of grass with shrubs and scattered trees.

The methods developed by Tetra Tech for combining the LANDFIRE, NLCD, CDL, and Pierce Co. parcel datasets into the 9 land use categories in the model are illustrated in Figure 9. LANDFIRE serves as the base coverage for areas that are classified as forest, agriculture, or pasture/hay, including fragments within residential lots greater than 1 acre in size. Residential, commercial, industrial, institutional, and park lands are classified primarily by the county land use data, after subtracting areas identified as forest, agricultural, or pasture/hay in larger parcels.

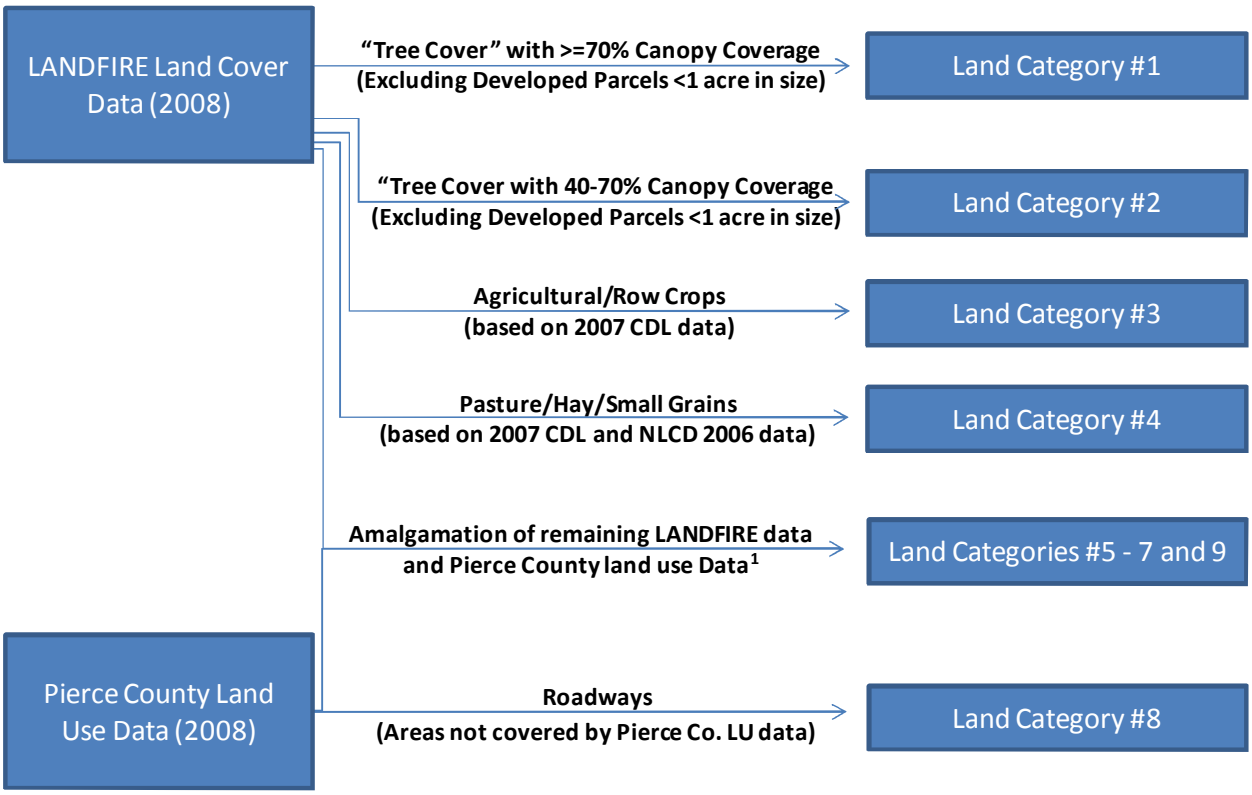

Figure 9. Methods for Combining LANDFIRE, NLCD and CDL Data Sets for Land Use/Land Cover Definition of HRUs

The remaining step of land use/land cover development for the model is the separation of impervious and pervious surfaces. HSPF models pervious areas (PERLNDs) and impervious areas (IMPLNDs) separately because of their different hydrologic behavior. Properly, the area assigned to IMPLNDs should be the directly connected (or *effective*) impervious area; impervious areas that drain onto pervious lands are typically incorporated within the PERLND representation.

Impervious surface planimetrics are not available for Pierce County (and would not show the directly connected impervious area in any case). Therefore, impervious area contained within land categories 5 through 9 are assigned on a percentage basis. The proportioning of roads (Category 8) into pervious and impervious surfaces was also adjusted by inspection of recent aerial imagery throughout the watershed. Details of the determination of directly connected impervious area are addressed in a separate

memorandum included as Appendix A. Overall, about 25 percent of the watershed is occupied by directly connected impervious area.

IMPLNDs are numbered separately from PERLNDs in HSPF. Nonetheless, the same numbering scheme is retained for IMPLNDs as is used for PERLNDs for ease in reassembling total flow and loads from specific land uses. Thus, PERLND 611 and IMPLND 611 refer to the pervious and impervious portions, respectively, of medium density development on A or B till soils on low slopes.

3.3 SLOPE

Subdivision of HRUs by slope is useful for sediment simulation as slope is a factor that determines the velocity of flow, its kinetic energy, and the associated transport of detached sediment and/or initiation of gully formation. Mastin's (1996) approach of identifying three slope classes that correspond to the soil-slope associations is adequate, but can be refined through a DEM-based analysis of slope. The higher slope classes are found primarily on the till portion of the watershed. The three classes are:

1. Low slope (0-6%)
2. Medium slope (6-12%)
3. High slope (>12%)

3.4 HRU NUMBERING

The soil, land/use cover, and slope components of the pervious land HRUs each have less than nine classes. For Clarks Creek a single weather station is used and the PERLND HRUs can be numbered in a straightforward fashion as *abc*, a three-digit number, where

a is the land use category,

b is the soil category, and

c is the slope category.

The land use category is given first so that all members of a given land use are grouped together, which is advantageous for the development of management scenarios. HRUs can be sorted on the second digit (*b*) for specification of hydrologic parameters that are primarily dependent on soil characteristics.

There are a total of 9 land use x 4 soil groups x 3 slope potential HRU categories (plus the unique wetland category). However, wetlands are not distinguished by soil or slope and only low slopes coincide with the alluvial soils, leaving a total of 122 PERLND HRUs that are actually simulated in the model.

As noted above, the numbering scheme for IMPLND HRUs is matched to that of the corresponding PERLND HRU, allowing ready reconstruction of total pervious and impervious surface flows and loads from a single parent land use. This applies to categories 511 and higher.

4 Routing Network and Segmentation

The HSPF model consists of upland subbasins and waterbody reaches. In most cases there is a one-to-one match between reach segments and subbasins. Model segmentation first should accurately reflect the surface drainage network. Additional considerations for model segmentation include the following:

- Reach segment breaks should coincide with gage and monitoring locations
- Significant inflows should coincide with breaks in the reach segments
- Different upland subbasins are used to define areas associated with different weather records
- Upland subbasin should be sufficiently small to allow for appropriate spatial targeting of management opportunities
- Segment and subbasin boundaries should reflect major changes in topography and soils to the extent practicable

For many HSPF applications, segments are designed to provide a consistent relationship to individual weather stations. For Clarks Creek a single weather station is used, and the major decision is thus the appropriate subbasin size for building management scenarios. There is a tradeoff between model resolution, model run times, and level of effort in model setup. An appropriate scale for the development, calibration, and application of a computationally efficient sediment model is one that isolates the major urban storm drainages, but does not require more than 100 or so total subbasins to simulate the entire basin. For Clarks Creek this results in subbasins on the scale of approximately 100 acres.

4.1 Surface Drainage Segmentation

The available data for completing the segmentation are a fine-scale digital elevation model (DEM) obtained from 6-foot resolution LiDAR, hydrographic coverage from the National Hydrography Dataset (NHD), detailed stormwater system mapping from both the City of Puyallup and Pierce County, and jurisdictional boundaries.

Subbasins were delineated consistent with the DEM, NHD, and stormwater system information. Subbasins are generally arranged so that tributaries and major storm sewer inputs enter at the upstream end, and subbasin boundaries are set to correspond to critical water quality and flow monitoring points (Figure 4-1). The final subbasin segmentation is shown in Figure 4-2.

Two areas of special interest are highlighted on Figure 4-2. The area in light red (subbasins 201 – 203) represents storm drainage along Pioneer Way that is being considered for diversion to the Puyallup River at 15th Street. The area in blue (subbasin 301) represents a subwatershed that is controlled by a flow splitter owned by WSDOT. The flow splitter directs most of the flow to the Puyallup River, but does allow some overflow into the Clarks Creek watershed (see Section 4.2.4).

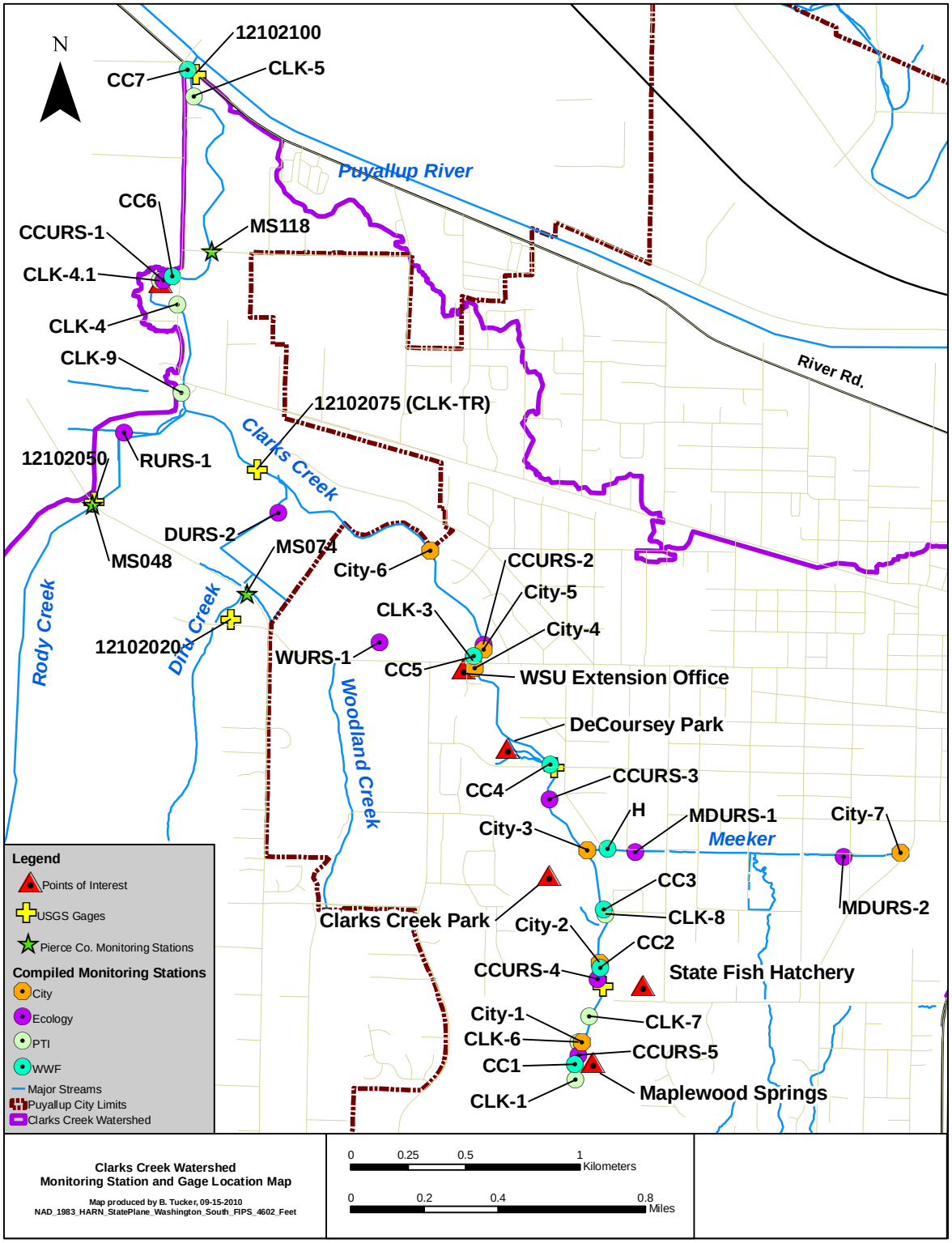

Figure 4-1. Monitoring and Gage Locations in Clarks Creek

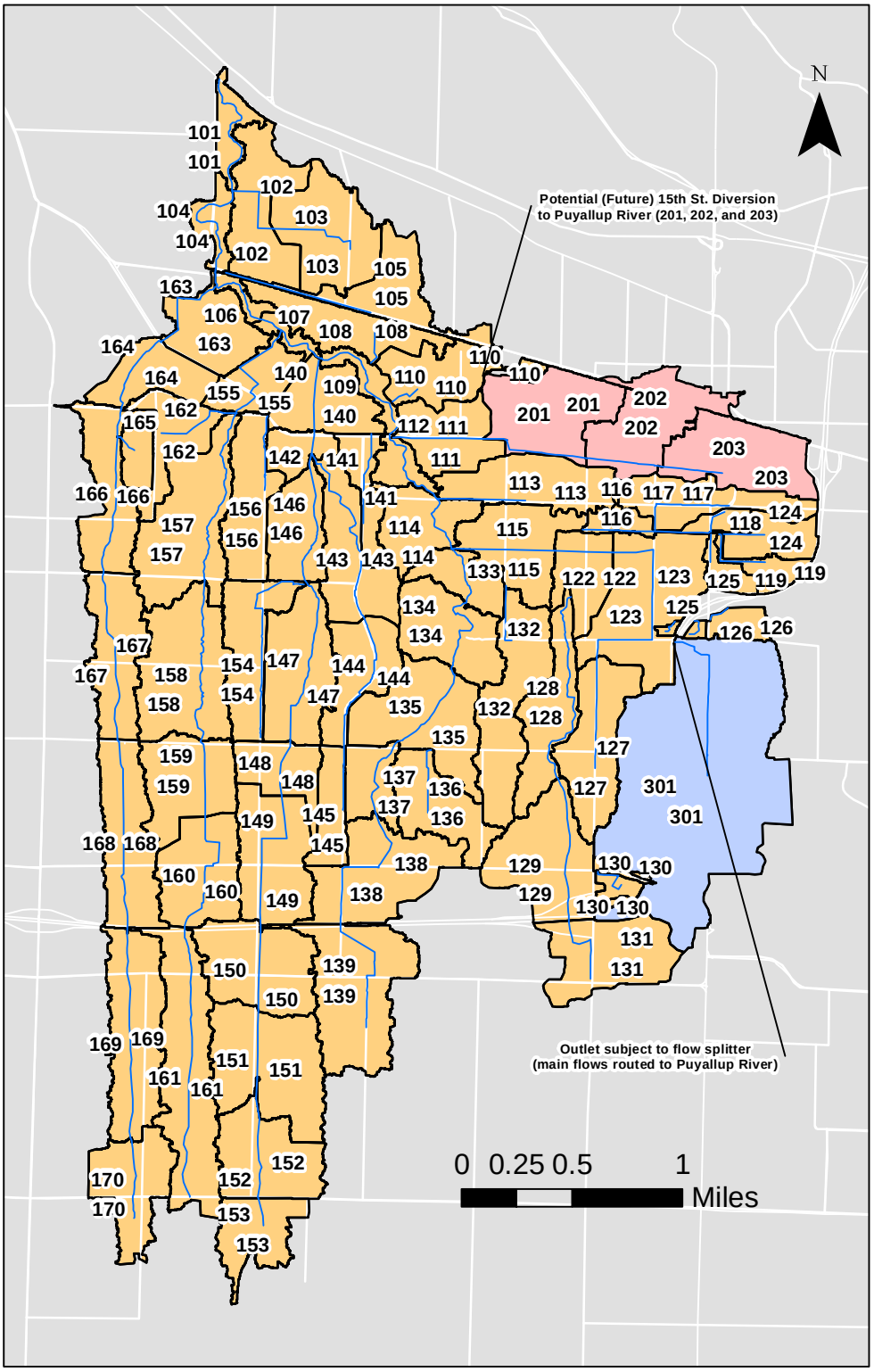

Figure 4-2. Subbasin Delineation for Clarks Creek HSPF Model

4.2 REACH HYDRAULICS

HSPF models hydrology, but does not directly simulate hydraulics. That is, the model is based on the principal of conservation of mass, but not the conservation of momentum. Hydraulic details, such as the speed of propagation of flood waves, have little impact on the water balance at time steps of a day or longer; however, hydraulics have important impacts on the energy exerted by flow, which is crucial to the examination of sediment scour and deposition. Therefore, it is important to incorporate a strong hydraulic representation in HSPF models that are designed for simulation of sediment transport.

In HSPF, the hydraulic behavior of stream reaches is specified externally through use of Functional Tables (FTables) that define stage-storage-discharge relationships. This is essentially a lookup table that enables the program to determine via interpolation, given an instantaneous value of storage in the reach, what is the corresponding depth, surface area, wetted perimeter, outflow, and flow velocity. Where available, this information can be developed directly from a hydraulic model, such as HEC-RAS or SWMM. Both models are available for portions of the Clarks Creek drainage network. Simpler methods are used for other areas where hydraulic models have not been developed.

4.2.1 HEC-RAS Modeling

HEC-RAS (Brunner, 2010) is a one-dimensional hydraulic model of water flowing through open channels. Capable of modeling complex stream networks, hydraulic structures, dendritic systems or a single river reach, HEC-RAS is typically used for channel flow analysis and floodplain determination. HEC-RAS applications provide an excellent basis for creating the FTables at selected points within a stream network. The accuracy of the generated FTable is dependent upon the spacing and number of HEC-RAS cross sections throughout a stream network, as well as the accuracy of the measured flows used to correlate river stage to discharge. Starting with the design flow profiles provided with a HEC-RAS model (e.g., flows from the 10-, 50-, 100-, 500-year return periods), the HSPF modeler can interpolate additional flow profiles to complete a model FTable.

For Clarks Creek, a HEC-RAS model of the mainstem and a part of Meeker Creek was developed as part of the Flood Insurance Study (NHC, 2005). Additional cross sections were collected and the model expanded by Brown and Caldwell as part of this sediment study (Figure 4-3). The resulting model extends from mile zero (the confluence with the Puyallup River) to mile 4.502 (in subbasin 135 in Clarks Creek Park). It also covers the lower 0.9 miles of Meeker Creek.

Tetra Tech added additional flow profiles to the HEC-RAS model. For each flow profile, HEC-RAS provides the following outputs that can be used for FTable generation:

- Q Total – total flow in cross section (cfs)
- Length Wt – weighted cross section reach length based on flow distribution (ft)
- Max Chl Dpth – maximum main channel depth (ft)
- SA Total – cumulative surface area for entire cross section from the bottom of the reach (acres)
- Volume – cumulative volume of water in the direction of computation (acre-ft)

Each point (or flow profile) representing the discharge-storage-surface area relationship by computed FTable is thus a weighted average of channel stage and discharge that is based on the weighted cross section reach length within the entire modeled reach. Also included for each flow profile in the FTable are the cumulative surface area and water volume between the reaches' upstream and downstream cross section. The HEC-RAS model provides FTables for HSPF reaches 101, 104, 106, 107, 109, 112, 114, 115, 122, 123, 133, 134, and 135.

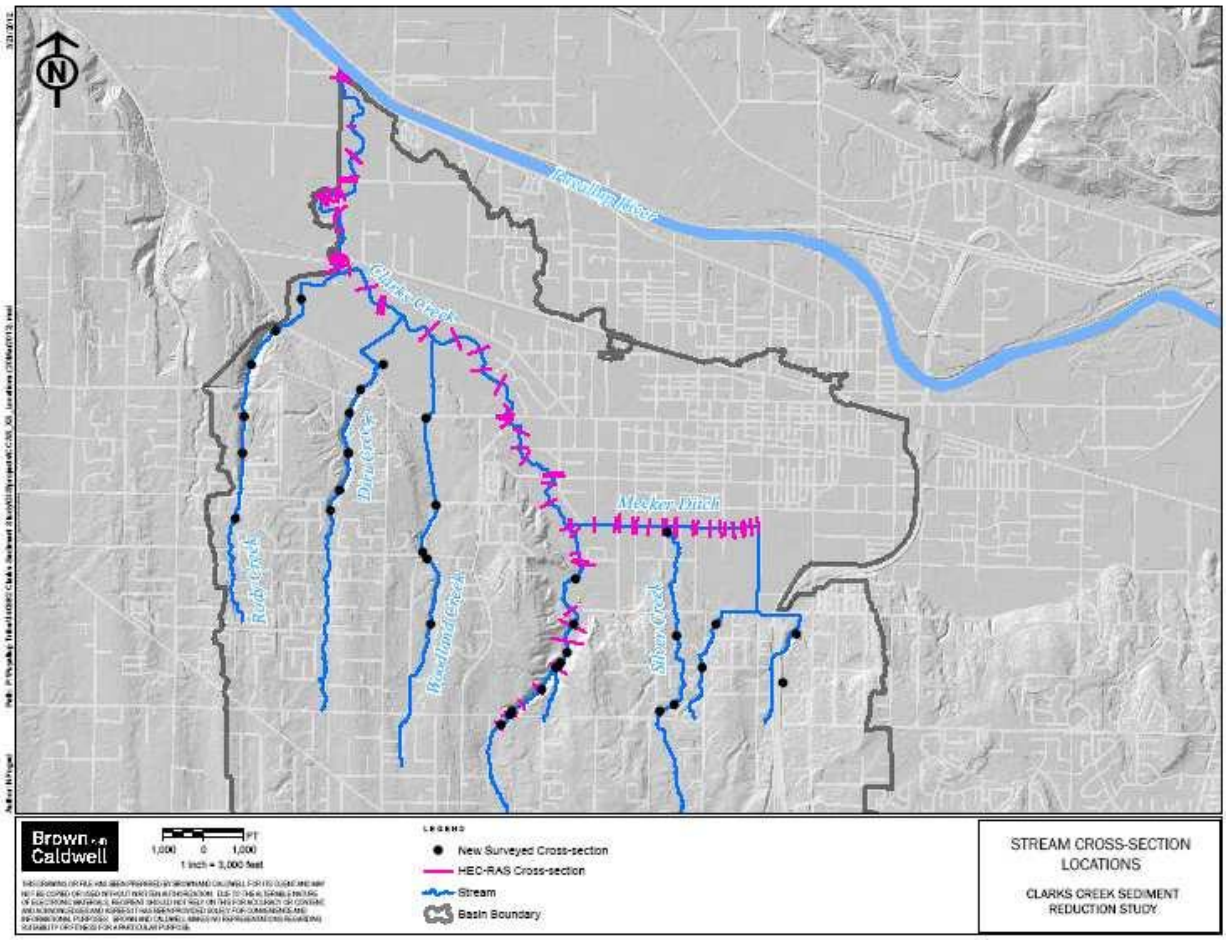

Figure 4-3. HEC-RAS Model and Additional Stream Cross-Section Locations for Clarks Creek

Figure courtesy of Brown and Caldwell.

4.2.2 SWMM Modeling

The Storm Water Management Model (SWMM; Rossman, 2010) is a hydraulic model that can simulate both open channel and piped flow, including pressurized flow. Brown and Caldwell developed a SWMM application for the Pioneer Avenue drainages in downtown Puyallup (Figure 4-4). Stormwater in this area is primarily conveyed in closed pipes, so the existence of a SWMM model is particularly useful. Output from SWMM can be used in a manner similar to output from HEC-RAS to develop FTables. This was done using custom VBA scripts to retrieve output from the SWMM binary output file. This yields FTables for subbasins 111, 201, 202, and 203 in the HSPF model.

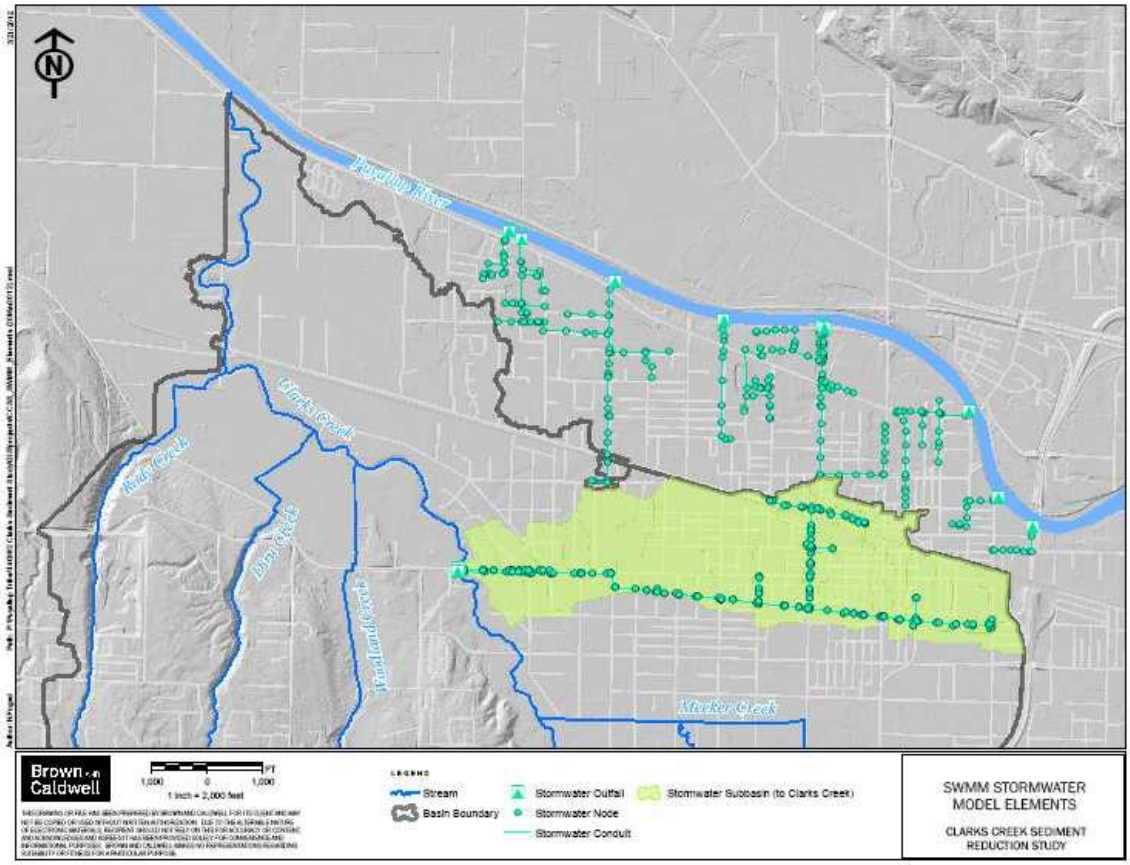

Figure 4-4. SWMM Model Incorporating Pioneer Avenue Drainage to Clarks Creek

Figure courtesy of Brown and Caldwell

4.2.3 Other Cross Sections

Brown and Caldwell also collected cross-section data for a number of locations outside the HEC-RAS model (shown by black dots in Figure 4-3). Flow at these cross sections was analyzed using a normal depth approximation in the WinXSPro™ software by Brown and Caldwell. These results were aggregated in a manner similar to the output from the HEC-RAS models to produce FTables for reaches 127, 128, 142, 146, 147, 155, 157, 163, 164, and 166.

In the remaining (mostly smaller, headwater) reaches in the model for which hydraulic models are not available, FTables were generated by the same method used in the BASINS system for HSPF model development (Moore, 2007). This approach is based on trapezoidal channel assumptions and simplified regression relationships for channel form and will have reduced accuracy relative to the FTables developed from site-specific hydraulic models. Of particular note, no hydraulic models were available for the piped stormwater conveyance systems at 7th Avenue.

4.2.4 WSDOT Flow Splitter

Reach 301 is a special case due to the presence of a flow splitter at Highway 512. As build plans from WSDOT show a concrete weir was constructed at this location in 1993 to divert flows into a 30” diameter PCCP stormwater pipe that proceeds along Highway 512 and drains to the Puyallup River. Excess flows

that exceed the weir crest overflow into a 6' x 4' box culvert that proceeds under Highway 512 toward Clarks Creek. Flow starts topping the weir at about 26.2 cfs total outflow, but the pipe flow increases with increased head to a maximum of about 48 cfs. The weir was designed to also have a low flow orifice leading to the culvert, but that is reported to be plugged with sediment based on personal inspection by the Brown and Caldwell team. An FTable was therefore created for this reach that conforms to the as-built plans and has two exits, with only the weir overflow routed into the next segment of the Clarks Creek model.

4.3 GROUNDWATER INTERACTIONS

As noted above, an important feature of the watershed is the presence of headwater springs on the Clarks Creek mainstem. A detailed north-south conceptual representation of the hydrogeology just west of the Clarks Creek mainstem (according to Savoca et al., 2010) is shown in Figure 4-5, while the plan view extent of the various aquifers is summarized in Figure 4-6. Under Savoca's conceptualization, the springs at the headwaters of Clarks Creek (which also occur to a lesser extent on its major tributaries) are due to a combination of discharges from the A1, A3, and C aquifers, the first two of which tail out at the point where Clarks Creek and its tributaries enter the lower alluvial valley, and all of which have hydraulic heads higher than ground surface in the alluvial valley (Figure 4-6).

The preliminary evaluation of flow directions in each aquifer provided by Savoca et al. (Figure 4-6) suggests that flow to the Clarks Creek springs may derive from a considerable distance to the south and southeast. This finding appears to be confirmed by recent groundwater modeling of the aquifers (Johnson et al., 2011). However, the exact contributing area to the springs (and the groundwater divide with the Clover Creek drainage) does not appear to be firmly established – although it is likely that that the Clarks Creek groundwatershed includes some of the internally drained pothole regions to the south and east of the surface drainage network.

Because the surface area contributing flow to the Clarks Creek springs is not fully known, an empirical approach was developed to simulate the till groundwater balance on a unit area basis with the applicable area determined during calibration. The development of this representation is described in Section 6.2.

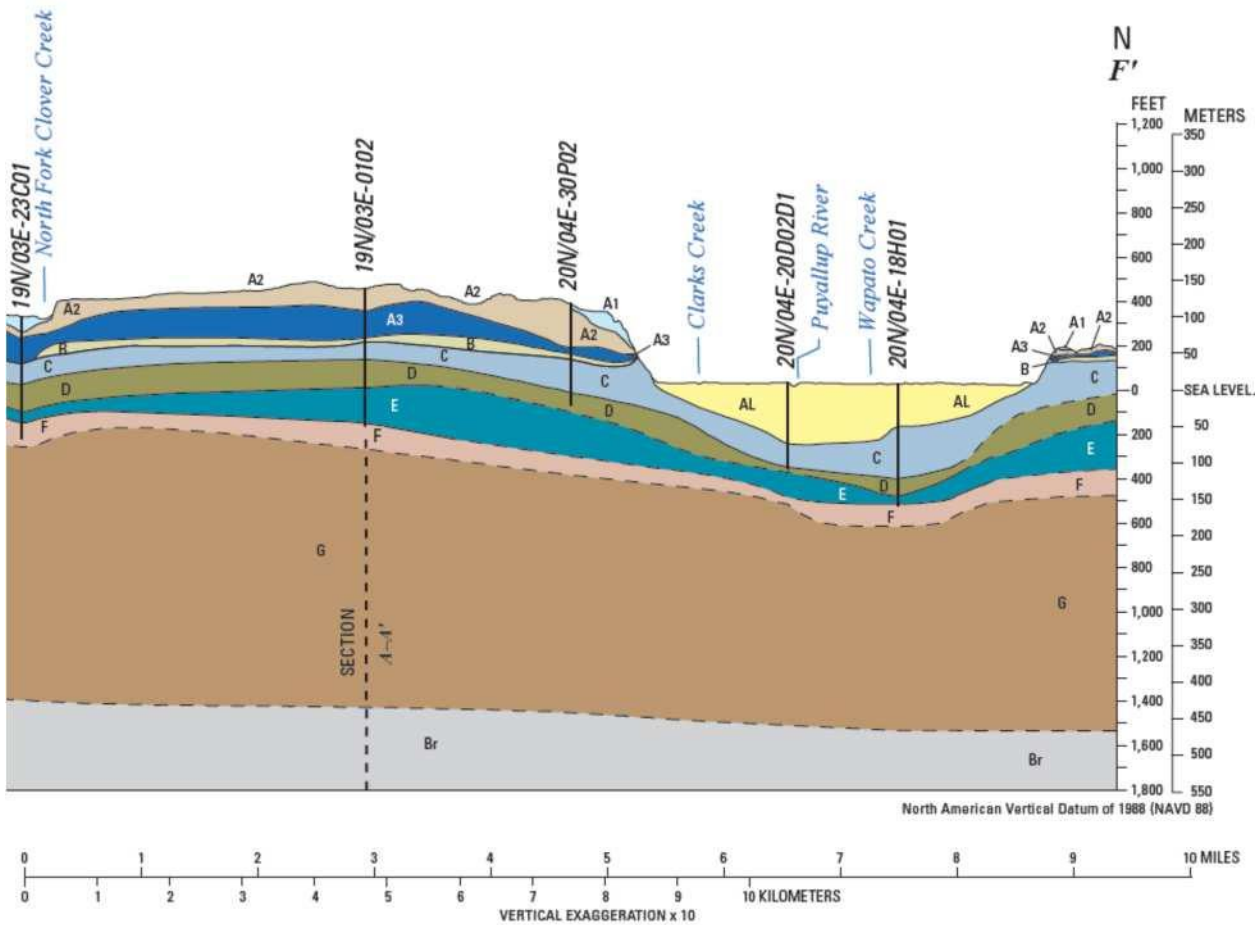

Figure 4-5. Detail of North-South Section West of Clarks Creek Headwaters (from Savoca et al., 2010, Plate 2)

4.4 STORMWATER PONDS

Many developments in the Clarks Creek watershed were built with stormwater detention ponds to control peak flows. These were mostly built under older rules that were focused on flooding issues and not on water quality or protection of channel morphology and are thus designed to achieve only short-term retention of storm flows. Nonetheless, these ponds do provide some flow-control and water quality benefits.

Unfortunately, the exact details on existing private stormwater infrastructure in the watershed are not well established. Pierce County has an inventory and GIS coverage of private stormwater ponds within its jurisdictional area, but this does not include complete information on pond size or drainage area. There are also anecdotally many private stormwater ponds within the City of Puyallup, but no comprehensive database on these ponds has been assembled. Therefore, an approximation approach is needed to address the role of private stormwater ponds in the watershed.

It is assumed that most of the stormwater ponds in the watershed receive primarily runoff from impervious surfaces that is temporarily detained but not infiltrated. This behavior is approximated as surface detention storage in the impervious land simulation. In HSPF, precipitation onto impervious areas is first subject to retention (on overhanging trees, flat roofs, etc.) that is subject to evaporation. Once this store is filled, supply is routed to surface storage. The surface storage (which is not subject to evaporation) runs off in accordance with a simple Chezy-Manning representation that considers surface

roughness (Manning's n) and path length. The surface storage routine can be used to represent temporary detention by decreasing the value of the routing variable, SRC, which is calculated internally as

$$SRC = 1020 \cdot \frac{\sqrt{SLSUR}}{NSUR \cdot LSUR},$$

where *SLSUR* is the slope, *NSUR* is the Manning's roughness coefficient, and *LSUR* is the slope length (ft). Increasing the value of the product *NSUR·LSUR* will effectively decrease the routing variable, approximating stormwater detention. The program does not allow *NSUR* to exceed 1; however, *LSUR* has no prescribed upper limit. Therefore, artificially high values of *LSUR* are used to approximate detention.

The appropriate value of *LSUR* in this representation is a calibration parameter because the fraction of stormwater that is subject to such detention is not known. The product *NSUR·LSUR* was set to 4,950 for high density residential impervious surfaces and 2,475 for medium density residential impervious surfaces in the final model. Other impervious surfaces were assumed, on average, to not be subject to significant amounts of stormwater detention.

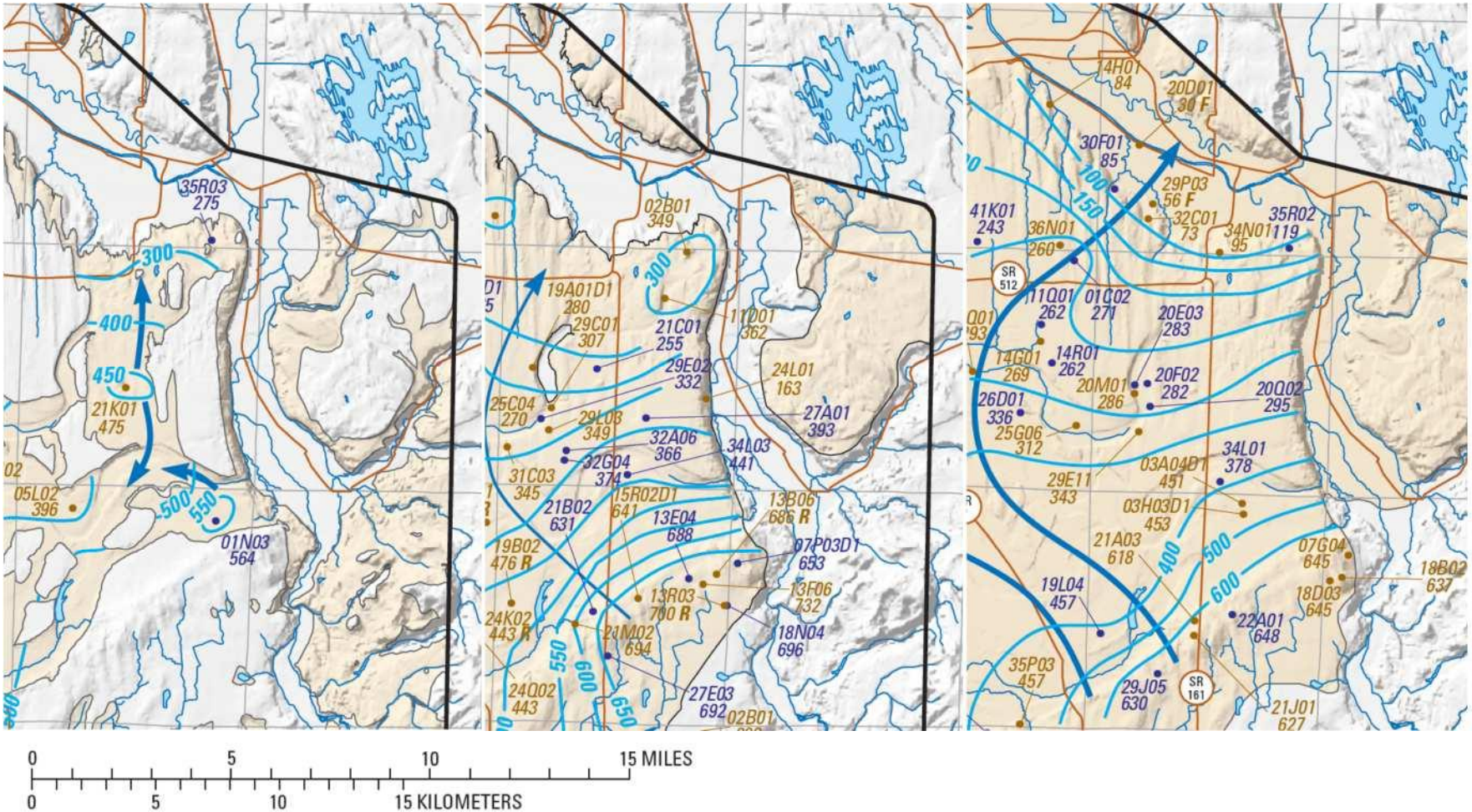

Figure 4-6. Interpreted Groundwater Flow in the A1, A3, and C Aquifers in the Vicinity of Clarks Creek (details from Savoca et al., 2010, figures 17-19)

Note: Clarks Creek shown in upper left of each figure.

The original USGS model (Mastin, 1996) covered Clear, Swan, and Canyon Creeks, but only Rody (West Fork Clarks Creek) and Diru Creek in the Clarks Creek watershed. This model was later expanded to include all of Clarks Creek as part of the 2003 basin plan. When the model was expanded, the original approach taken by Mastin to represent groundwater interactions was retained. Specifically, each creek is represented as having a losing reach that contributes to a common groundwater reservoir (represented in the model as a stream reach segment). The groundwater reservoir in turn yields flow back to downstream segments of various reaches, including Rody, Diru, and Clarks Creek, but not Woodland Creek. In the case of the Clarks Creek mainstem, losses to groundwater are represented as occurring between the State Hatchery and Meeker Ditch, while discharges from groundwater to the stream are represented as occurring at the confluence with Diru Creek. Similarly, Rody and Diru Creek have losses to groundwater in the upper reaches and gains from groundwater in the reach immediately above the confluence with Clarks Creek.

The representation of groundwater interactions in the existing model is now known to be inconsistent with the hydrogeology of the area. Specifically, significant discharges from groundwater to stream occur along the slope face where the outwash merges into the alluvial valley. Estimates of stream gain or loss presented by Savoca et al. (2010) suggest there may be minor losses from the stream in the general vicinity of Meeker Ditch, and perhaps small inflows between Tacoma Road and the mouth (both interactions with the AL aquifer), as is also shown by flow estimates during the 2002-2003 field sampling effort analyzed by Tetra Tech as part of the dissolved oxygen TMDL effort. The interactions with the AL aquifer correspond to the general longitudinal profile of Clarks Creek (Figure 4-7), as the groundwater elevation along lower Clarks Creek is about 25 m (Savoca et al., 2010). However, inflow from groundwater below Tacoma Road is likely derived from upstream portions of the Puyallup River, rather than from a local groundwater reservoir derived from losing reaches of Clarks Creek and its tributaries.

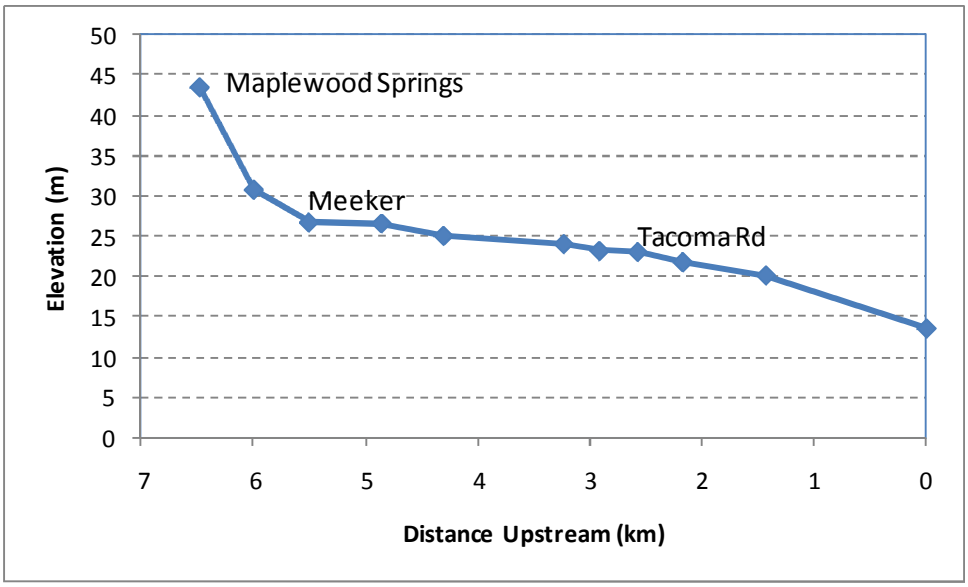

Figure 4-7. Longitudinal Profile of Clarks Creek

The additional insights on hydrogeology of the system suggested it was appropriate to refine the approach in the original USGS model. Simulation of a groundwater reservoir is still useful to represent the springs at the edge of the glacial outwash, such as Maplewood Springs. However, this reservoir is filled not by losses from the streams but rather by infiltration to the aquifers in an upstream area that includes pothole regions not connected by surface drainage to Clarks Creek. The groundwater reservoir, representing the A1 and A3 aquifers, should thus be simulated as receiving water from pervious upland segments with an areal extent greater than the local drainage area. The revised method is described in Section 6.2.

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5 Model Calibration and Validation Approach

Calibration consists of the process of adjusting model parameters to provide a match to observed conditions. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest.

Calibration tunes the models to represent conditions appropriate to the waterbody and watershed under study. However, calibration alone is not sufficient to assess the predictive capability of the model, or to determine whether the model developed via calibration contains a valid representation of cause and effect relationships, especially those associated with the principal study questions. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a corroboration or validation step. In the corroboration step, the model is typically applied to a set of data independent from that used in calibration. This helps to ensure that the calibration is robust, and that the quality of the calibration is not an artifact of over-fitting to a specific set of observations. Corroboration or validation tests can also provide a direct estimate of the magnitude of uncertainty that may be expected when the model is applied to conditions outside of the calibration series.

5.1 Acceptance Criteria for Model Calibration

The quality of model calibration and validation is evaluated relative to acceptance criteria and performance targets specified in the QAPP (Tetra Tech, 2011).

The intended uses of the model focus on the effectiveness and cost-effectiveness of different implementation strategies relative to management of sediment in Clarks Creek. As such, the ability of the models to represent the relative contributions of different source areas and the relative performance of different management measures is of greatest importance, while obtaining a precise estimate of loading time series is of less direct interest. Ideally, the models should attain tight calibration to observed data; however, a less precise calibration can still provide useful information.

In light of these uses of the models, it is most informative to specify performance target ranges of precision that characterize the model results as “very good,” “good,” “fair,” or “poor.” These characterizations inform appropriate uses of the model: Where a model achieves an excellent fit it can assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit it should assume a much less prominent role in the overall weight-of-evidence evaluation of management options.

The general acceptance criterion for models to be applied in this project is to achieve a quality of fit of “good” or better. In the event that this level of quality is not achieved on some or all measures the model may still be useful; however, a detailed description of its potential range of applicability should be provided.

5.2 Performance Targets for HSPF

For HSPF, a variety of performance targets have been specified, including Donigian et al. (1984), Lumb et al. (1994), and Donigian (2000). Based on these references and previous experience with the model, the HSPF performance targets for simulation of the water balance components are summarized in Table 5-1.

Table 5-1. Performance Targets for HSPF Hydrologic Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE*); Daily and Monthly R^2)

Model Component	Very Good	Good	Fair	Poor
1. Error in total volume	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
9. R^2 daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
10. R^2 monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

In addition, the Nash-Sutcliffe coefficient of model fit efficiency (*E*) is reported for all calibration and validation runs – although no specific acceptance criteria were proposed in the QAPP. This is calculated as

$$E = 1 - \frac{\sum \left[O_i - P_i \right]^2}{\sum \left[O_i - \overline{O} \right]^2},$$

where O_i indicates an observed value, P_i a predicted value, and the overbar indicates an average. An *E* value of 1 indicates a perfect fit between measured and predicted values for all events. The resulting index can range from negative infinity to 1, with higher values indicating better fit. A value of zero indicates that the calibrated model is no better than using the average value of all the measured data to predict individual measurements.

General performance targets for water quality simulation with HSPF are also provided by Donigian (2000) and are shown in Table 5-2. These are calculated from observed and simulated daily values, and should only be applied in cases where there are a minimum of 20 observations

Table 5-2. Performance Targets for HSPF Water Quality Simulation (Magnitude of Relative Error (*RE*) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
1. Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%
2. Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

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6 Hydrologic Calibration and Validation

The hydrology model is calibrated to observed flow gaging data. The primary source of flow data for calibration is the USGS gage on Clarks Creek at Tacoma Road (Station 12102075; see Figure 4-1). Gage records at this station are available for 3/1/1995 through 11/25/2008. Figure 6-1 compares recorded flows on Clarks Creek to those on nearby Clover Creek. Clarks Creek immediately stands out as having a near constant baseflow, and also being somewhat less responsive to winter storm events

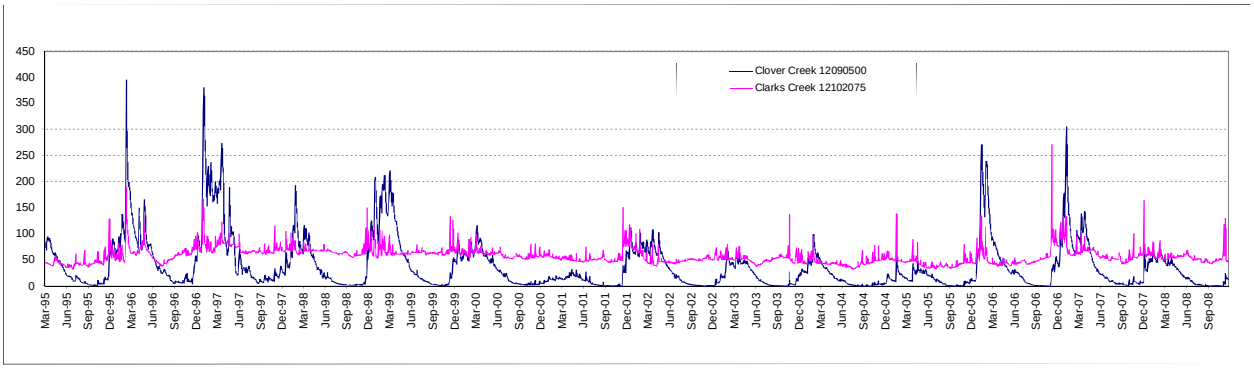


Figure 6-1. Comparison of Flow Gaging on Clarks Creek and Clover Creek, 1995-2008

To provide for model validation, flow calibration was undertaken on the gage data for 2000 – 2008, while the data for 1995 – 1999 were used for a validation test.

Scattered flow measurements exist for other locations, but are not sufficient for formal calibration. The comparison of the model to these records is discussed in Section 6.5.

6.1 Parameter Selection

The existing HSPF model of the area (Mastin, 1996) was used as a starting point for parameter values used in calibration; however, a need for significant modification was expected due to the more refined analysis of HRUs in the current model. From this starting point, parameters were varied in accordance with recommended ranges and other guidance for the HSPF model (USEPA, 2000).

Model parameters are assigned in a spreadsheet to individual HRUs based on the intersection of soil group, land use, and slope. Table 6-1 shows key hydrologic parameters that are assigned by soil group. One of the most important is INFILT, which is HSPF's index to mean soil infiltration rate (in/hr; the actual infiltration rate depends on soil moisture storage). Mastin used values for INFILT that were not divided by HSG. The revised model fits well with values that are within or near the recommended ranges for each HSG.

Table 6-1. Hydrologic Parameter Assignment by Soil Group

<table>
<tr><th rowspan="2">Soil</th><th colspan="3">INFILT (in/hr)</th><th colspan="3">LZSN (in)</th></tr>
<tr><th>This Model</th><th>Mastin (1996)</th><th>Recommended (USEPA, 2000)</th><th>This Model</th><th>Mastin (1996)</th><th>Recommended (USEPA, 2000)</th></tr>
<tr><td>Till AB</td><td>0.4</td><td rowspan="3">0.08 (forest)
0.3 (other)</td><td>0.1 – 1.0</td><td>13</td><td>6</td><td rowspan="5">3.0 – 8.0 (typical)
2.0 – 15.0 (possible)</td></tr>
<tr><td>Till C</td><td>0.12
(0.09 ag.)</td><td>0.05 – 0.1</td><td>12</td><td>6</td></tr>
<tr><td>Till D</td><td>0.05</td><td>0.01 – 0.05</td><td>12</td><td>6</td></tr>
<tr><td>Alluvial A</td><td>0.6</td><td rowspan="2">2.0 (forest)
0.8 (other)</td><td>0.4 – 1.0</td><td>12</td><td>5</td></tr>
<tr><td>Alluvial CD</td><td>0.10
(0.15 forest)</td><td>0.01 – 0.10</td><td>11</td><td>5</td></tr>
<tr><th></th><th colspan="3">AGWRC</th><th colspan="3">DEEPFR</th></tr>
<tr><td>Till AB</td><td rowspan="3">0.980
0.993 (forest)</td><td rowspan="3">0.800</td><td rowspan="6">0.92 – 0.99 (typical)
0.85 – 0.999 (possible)</td><td>0.20</td><td rowspan="3">0.25</td><td rowspan="6">0 – 0.20 (typical)
0 – 0.50 (possible)</td></tr>
<tr><td>Till C</td><td>0.20</td></tr>
<tr><td>Till D</td><td>0.15</td></tr>
<tr><td>Alluvial A</td><td rowspan="2">0.996</td><td rowspan="2">0.996</td><td rowspan="2">0</td><td rowspan="2">0</td></tr>
<tr><td>Alluvial CD</td></tr>
</table>

A parameter of particular interest is LZSN, the lower zone nominal soil storage (in). LZSN is an index of the amount of water that soil can hold within the root zone and subject to evapotranspiration by plants and is independent of infiltration rates. We found that model calibration statistics improved markedly with higher values of LZSN, and this was increased greatly from the values proposed by Mastin (1996) to a value of 11 - 13 inches, near the top of the typical range cited in USEPA (2000). Attempts to find alternate model fits with lower values of LZSN by modifying other parameters such as INFILT and INTFW uniformly yielded poorer fits to the observed gage records. The choice of a high value of LZSN means that, even where infiltration rates are low, the ultimate infiltration capacity of the soil is large, resulting in greater fractions of the total flow proceeding by interflow and groundwater pathways. This results in much of the direct stormflow in the Clarks Creek basin being simulated as derived from impervious surfaces.

The other parameters in Table 6-1 are the active groundwater recession coefficient (AGWRC) and the fraction of active groundwater storage that is lost to deep pathways (DEEPFR). A relatively large value is appropriate for DEEPFR on the till due to the recharge that feeds springs throughout the area.

Parameters that control interflow are varied by soil and slope (Table 6-2). Mastin fit very high values of the interflow inflow parameter, INTFW, for the till and these were retained after demonstrating that reduced values provided a poorer fit. Interflow was also activated for the alluvial soils. On the other hand, Mastin's values for the interflow recession coefficient (IRC) appear far too low and were revised to more typical values (USEPA, 2000).

Monthly parameter values were assigned to the lower zone ET factor (LZETP) and forest interception (CEPSC) consistent with past experience with HSPF models in the Northwest. These parameters are primarily determined by plant growth stage and are summarized in Table 6-3. Retention on impervious surfaces is also varied by month and shown in Table 6-3.

Table 6-2. Hydrologic Parameter Assignments by Slope and Soil

Slope	INTFW			IRC		
	This Model	**Mastin (1996)**	**Recommended (USEPA, 2000)**	**This Model**	**Mastin (1996)**	**Recommended (USEPA, 2000)**
0 – 6%	6 (till) 2 (alluvial)	6 (till) 0 (alluvial)	1 – 3 (typical) 1 – 10 (possible)	0.7 (A-B) 0.8 (C-D)	0.15 (till)	0.5 – 0.7 (typical) 0.3 – 0.85 (possible)
6 – 12%	9 (till) 2 (alluvial)	9 (till) 0 (alluvial)		0.65 (A-B) 0.76 (C-D)	0.12 (till)	
> 12%	11 (till) 2 (alluvial)	11 (till) 0 (alluvial)		0.6 (A-B) 0.7 (C-D)	0.10 (till)	

Table 6-3. Hydrologic Parameter Assignments by Month

	LU	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LZETP	Forest	0.4	0.5	0.55	0.65	0.65	0.65	0.6	0.55	0.35	0.35	0.3	0.3
	Agriculture	0.16	0.19	0.2	0.25	0.35	0.65	0.8	0.8	0.56	0.18	0.14	0.14
	Pasture	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	Residential Pervious	0.45	0.45	0.45	0.45	0.45	0.5	0.45	0.4	0.35	0.35	0.35	0.4
	Road Pervious	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	Park	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.55	0.4	0.4	0.4	0.4
CEPSC	Forest > 70%	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.2	0.15	0.15	0.15
	Forest < 70%	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	Agriculture	0.04	0.04	0.04	0.04	0.05	0.06	0.12	0.143	0.15	0.105	0.07	0.05
	Pasture	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Residential Pervious	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Road Pervious	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Park	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
RETN (in)	MD – HD Residential Impervious	0.1	0.15	0.15	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05
	LD Residential Impervious	0.25	0.25	0.25	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0.1
	Road Impervious	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Park Impervious	0.25	0.25	0.25	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05	0.1

6.2 GROUNDWATER MODEL SETUP FOR SPRING DISCHARGE

One of the biggest challenges for simulating the hydrology of Clarks Creek is representing the incremental groundwater inflow from the Vashon Till. As described in Section 4.3, this flow originates from an area that is significantly larger than the surface drainage network of Clarks Creek – but, at this time, the extent of the contributing area is not exactly known. Flow recorded at the USGS gage on Clarks Creek at Tacoma Road shows a persistent baseflow component ranging between 40 and 60 cfs that is associated with these springs. This baseflow is always present, but does respond to climate, declining after dry periods and increasing after wet periods.

Given that no groundwater model is currently available and the size of the contributing area for baseflow is unknown an iterative approach was taken to simulating the spring flow entering the system. In essence, this approach involved simulating a representative pervious land segment (on a per-acre basis) and optimizing a fit to estimated spring flow based on the pervious land segment contributions to active groundwater. The target for the optimization is a smoothed lower bound estimate of spring flow obtained by applying a sliding window baseflow separation routine to observed flows at Tacoma Road, then identifying the objective function as the smoothed 3-month average of the 25th percentile of the monthly baseflow sums.

Aquifer outflows to the surface water model were calculated separately in a spreadsheet. The aquifer mass balance is represented at a monthly scale by a storage (S_t) and an outflow (O_t) term (both in/mo). In addition, there is assumed to be leakage to lower aquifers that do not reemerge in Clarks Creek. The monthly aquifer storage is:

$$S_t = S_{t-1} + I_t - k\,S_{t-1}{}^2 - O_t\,,$$

where k is a leakage coefficient. The outflow term (in/mo) is then given as a central difference on previous and partially updated storage terms:

$$O_t = \frac{\left[a\,S_{t-1}{}^b + a\,MAX(S_{t-1} - O_{t-1}, 0)^b\right]}{2} \cdot m_t\,,$$

where a and b are parameters and m is a monthly adjustment factor. Finally, the outflow in in/mo can be converted to an outflow in cfs (Q) by multiplying by an area factor, r, which has units of cfs/(in-mo) but is essentially a calibration factor to relate the unit area outflow term to the unknown contributing area:

$$Q = r \cdot O_t\,.$$

This model has four constants (a, b, k, and r), plus a set of monthly factors (m).

For fitting purposes, inflow to the aquifer was assumed to occur from a forested land segment on low slopes with A soils, characterized by the parameters assumed for the Mastin (1996) model. The A soils assumption is appropriate given the assumption that the majority of the recharge occurs over more pervious sand deposits. Fit was based on minimizing squared differences on the smoothed objective function over the period of gaging at Tacoma Road (1995-2008), using a model run that started in 1960 with an assumed storage of 34 in (a value selected to maintain an approximately stable groundwater storage over the 50-year simulation period). Optimized parameter values are shown in Table 6-4. Note that the value obtained for r suggests that there is an additional drainage area of approximately 1 ½ square miles contributing to the groundwater flow that discharges to Clarks Creek through springs at the base of the Vashon Till.

Table 6-4. Groundwater Model Parameter Estimates for Clarks Creek

Parameter	Estimate
a	$2.09 \cdot 10^{-11}$ in
b	5.611
k	$2.26 \cdot 10^{-4}$ (in-mo)$^{-1}$
r	6,980 cfs/(in-mo)

These parameters provide a reasonable match to the lower bound estimates of spring-fed baseflow for 1995-2008 over long term simulations started in 1960 (Figure 6-2). The match is not, however, exact, and appears to introduce discrepancies in some years.

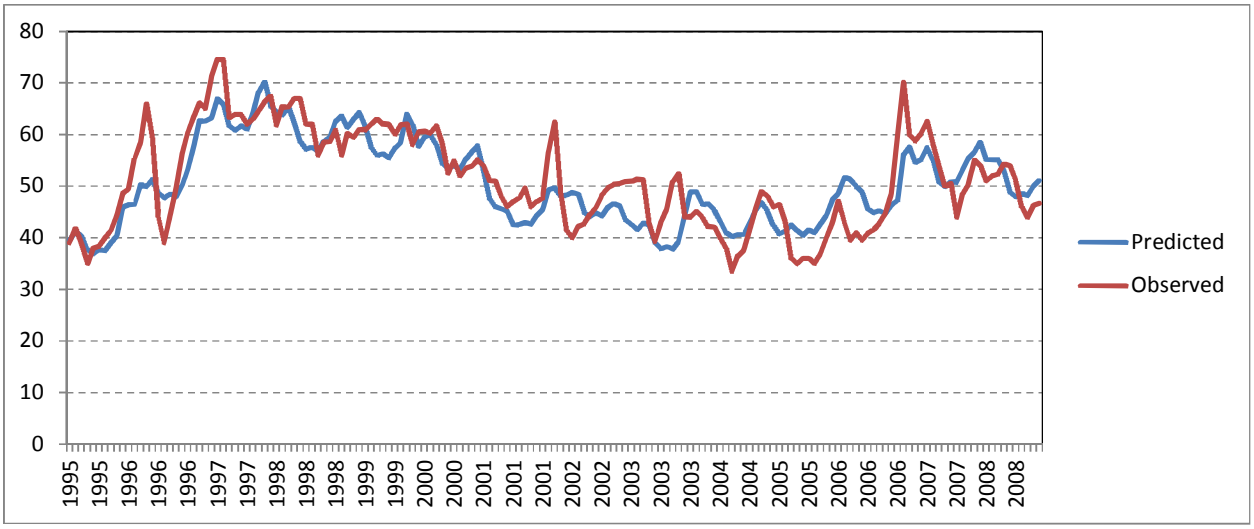


Figure 6-2. Calibrated Fit to Inferred Spring Contribution to Clarks Creek Flow

The outflow from the groundwater springs upstream of the Tacoma Road gage was assigned 77% to Reach 133, 17 % to reach 134, and 6% to reach 135 based on limited flow monitoring at various points in the system conducted in 2002-2003. In addition, small amounts of spring outflow were assigned to Rody Creek (1.85% of the flow to the mainstem) and Diru Creek (1.06% of the flow to the mainstem).

6.3 Hydrology Model Calibration

The hydrology model calibration (2000 – 2008) is summarized below in Figure 6-3 through Figure 6-10, Table 6-5, and Table 6-6. At certain points during this period the uncertainties introduced by the spring discharge model are evident (e.g., the second half of 2003, during which baseflow steadily increased despite the absence of significant rain). Nonetheless, the overall model fit is rated as good.

As shown in Table 6-6, all of the annual and seasonal relative mean error statistics are in the "very good" range (refer to the performance targets in Table 5-1). The uncertainties introduced by the spring simulation, which has some difficulties in representing the short-term variations in baseflow discharge, are, however, evident in the relatively low daily *E* value of 0.54. The coefficient of determination (R^2) for daily discharges is 0.70 (Figure 6-5), which is in the good range. The coefficient of determination for monthly discharges is, however, poor (Figure 6-6). This is largely due to two periods in which the model under-predicts observed flow (Nov.-Dec. 2002 and Nov.-Dec. 2006). Despite this, the monthly *E* (0.95) is very high. Therefore, the model calibration is deemed acceptable.

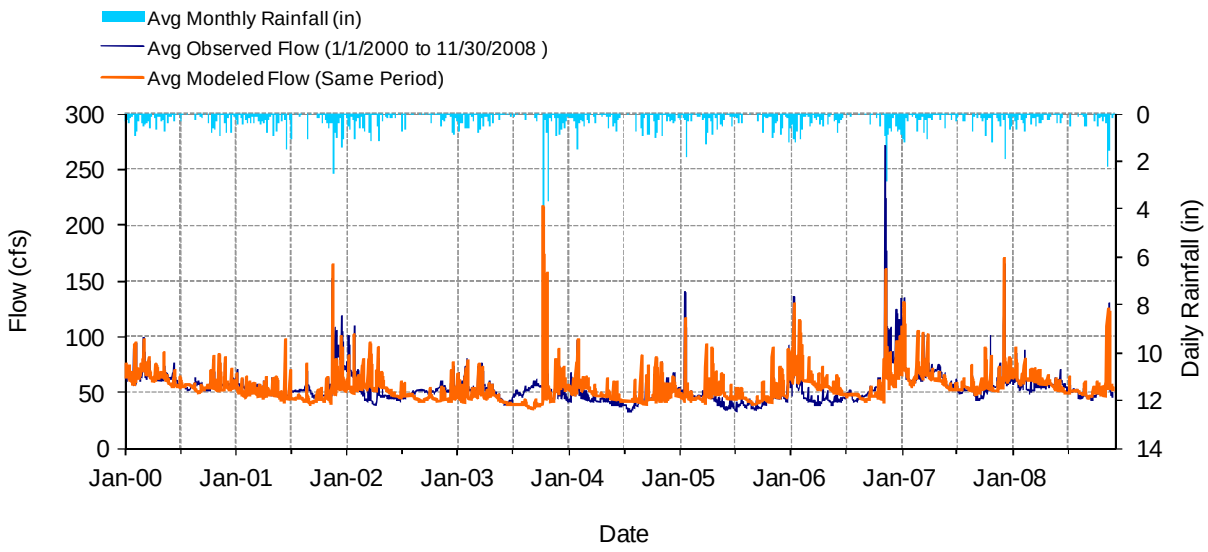


Figure 6-3. Mean Daily Flow: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

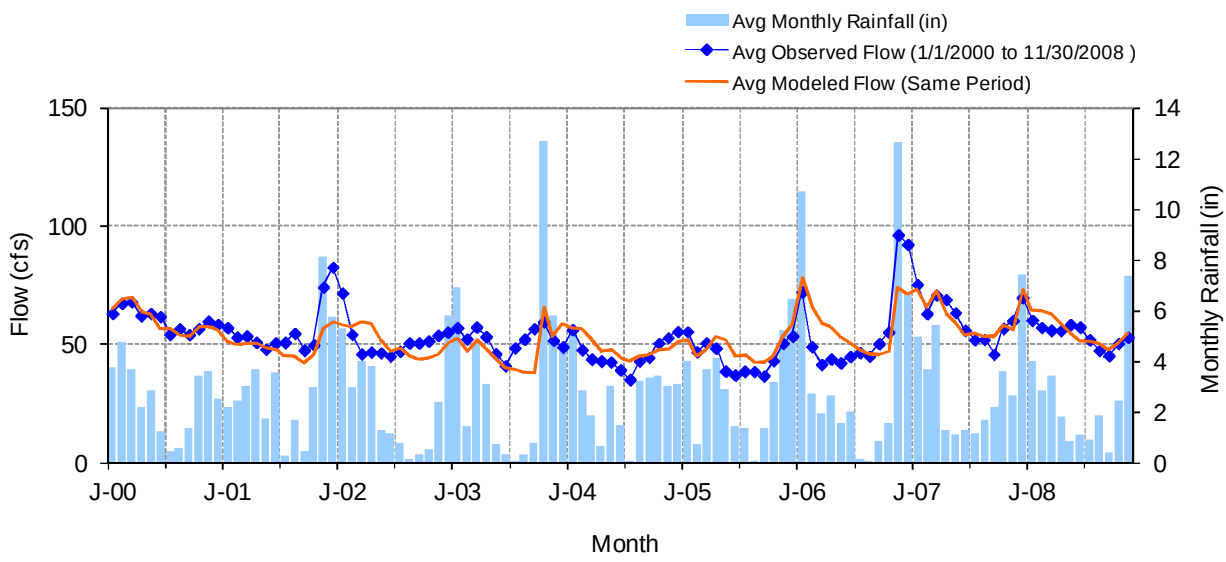


Figure 6-4. Mean Monthly Flow: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

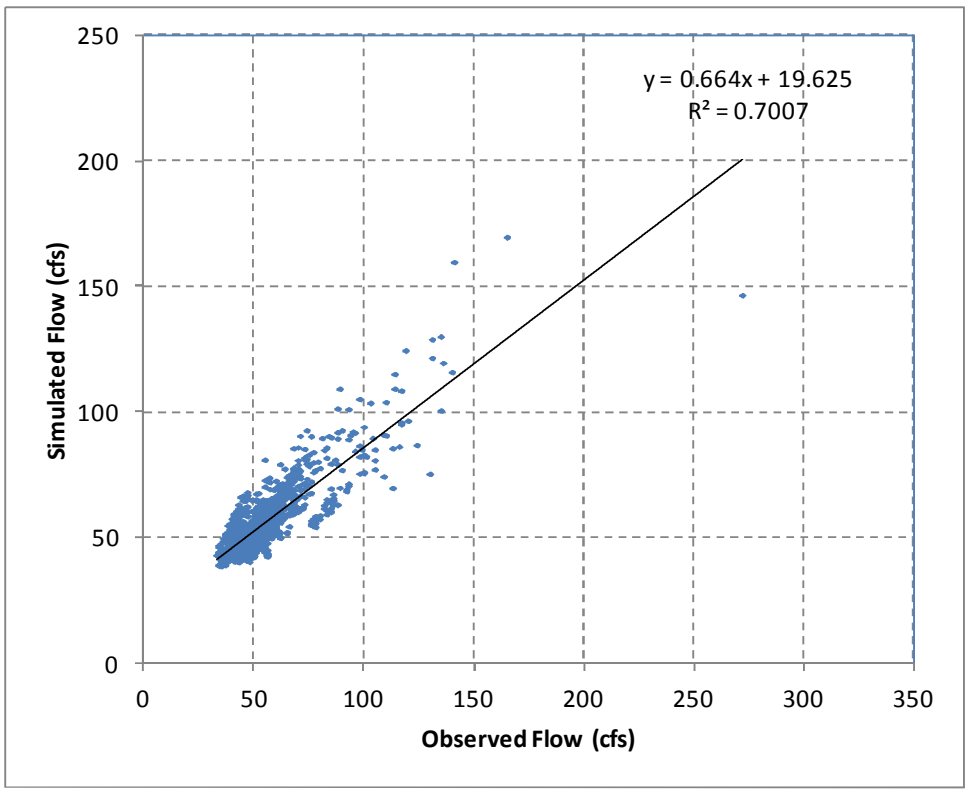


Figure 6-5. Daily Flow Regression: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

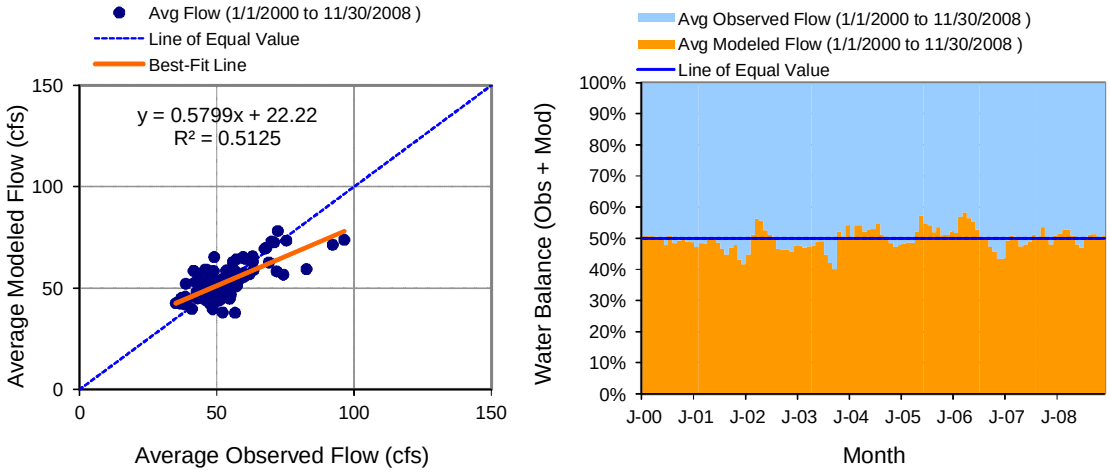


Figure 6-6. Monthly Flow Regression and Temporal Variation: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

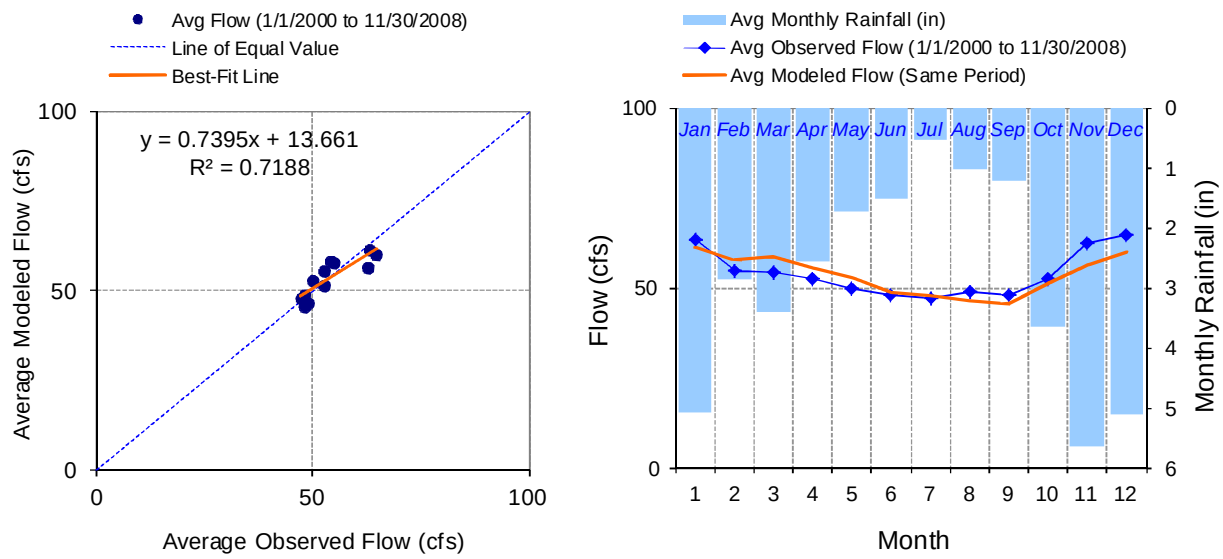


Figure 6-7. Seasonal Regression and Temporal Aggregate: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

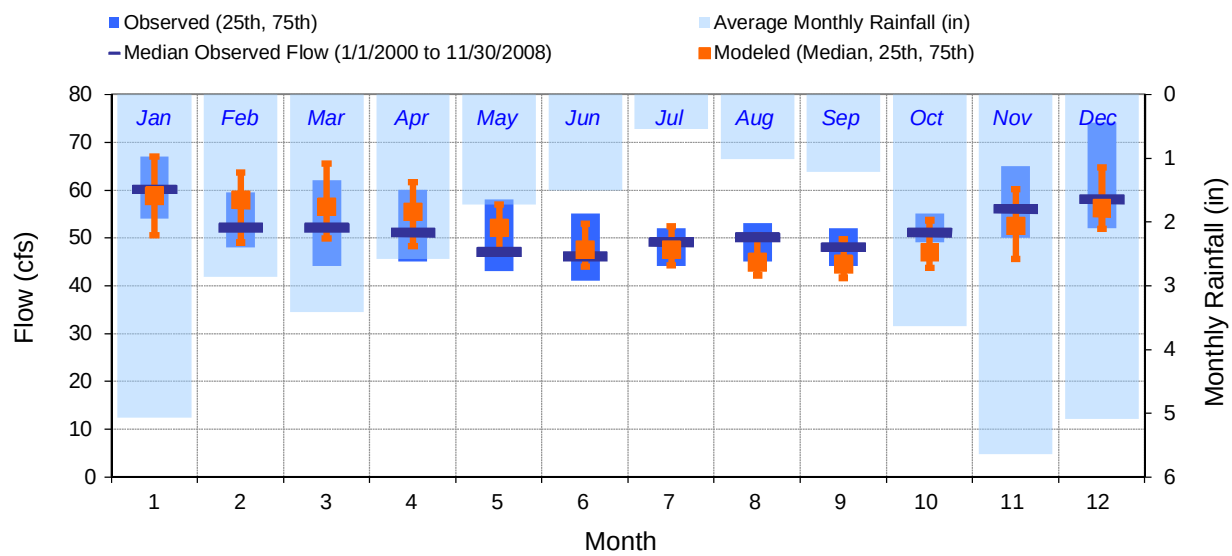


Figure 6-8. Seasonal Medians and Ranges: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

Table 6-5 Seasonal Summary: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	63.17	60.00	54.00	67.00	61.33	58.73	50.54	66.92
Feb	54.58	52.00	48.00	59.50	57.88	57.88	48.94	63.65
Mar	54.19	52.00	44.00	62.00	58.37	56.49	49.86	65.51
Apr	52.56	51.00	45.00	60.00	55.60	55.41	48.26	61.58
May	49.89	47.00	43.00	58.00	52.69	52.04	47.32	56.92
Jun	48.09	46.00	41.00	55.00	48.54	47.48	43.91	52.90
Jul	47.21	49.00	44.00	52.00	47.91	47.47	44.23	52.34
Aug	48.91	50.00	45.00	53.00	46.39	44.88	42.13	50.50
Sep	47.96	48.00	44.00	52.00	45.69	44.43	41.61	49.69
Oct	52.59	51.00	49.00	55.00	51.31	46.95	43.73	53.62
Nov	62.54	56.00	50.00	65.00	56.34	52.46	45.54	60.11
Dec	64.54	58.00	52.00	74.00	59.80	56.16	51.87	64.65

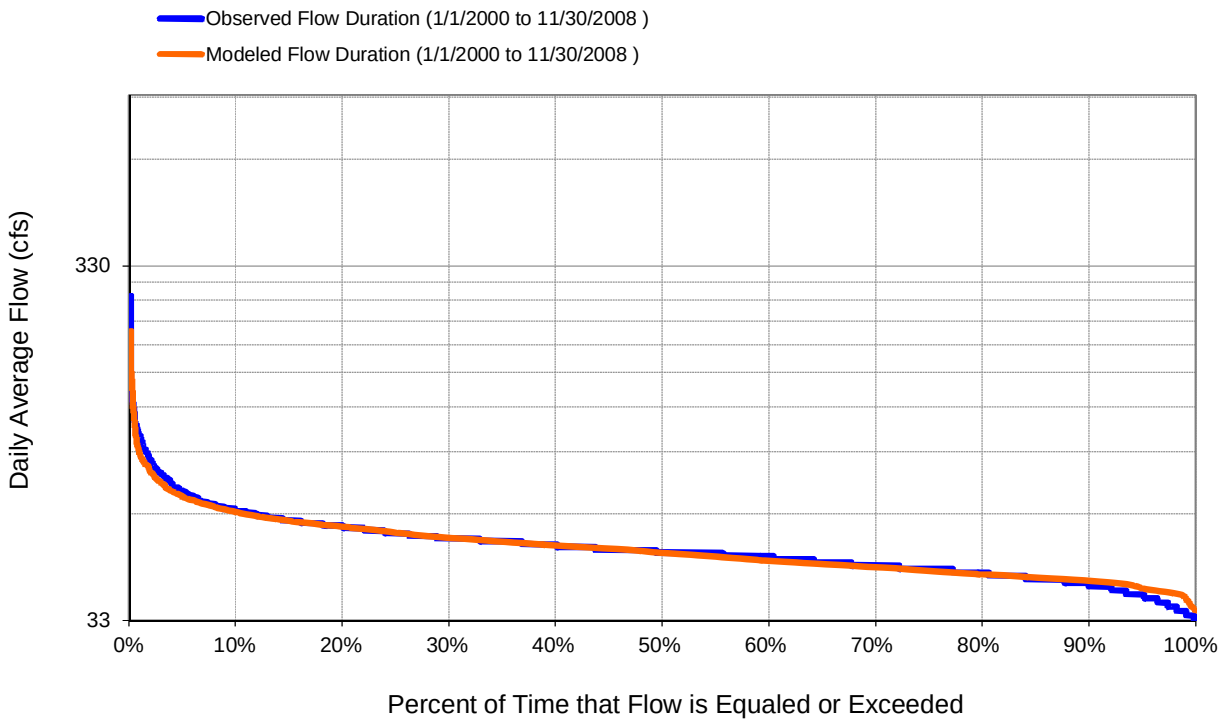


Figure 6-9. Flow Exceedence: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

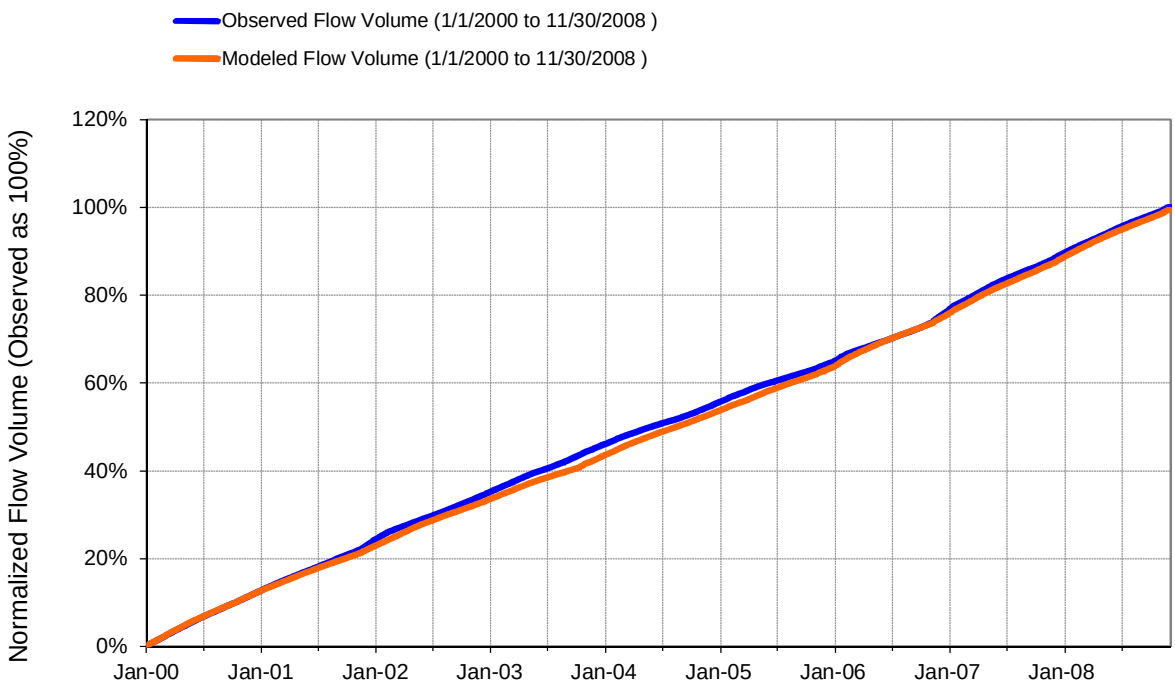


Figure 6-10 . Flow Accumulation: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

Table 6-6. Summary Statistics: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Calibration Period

HSPF Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM DSN 103 8.92-Year Analysis Period: 1/1/2000 - 11/30/2008 Flow volumes are (inches/year) for upstream drainage area This version has fix to hydrograph separation		USGS 12102075 CLARKS CREEK AT TACOMA ROAD NEAR PUYALLUP, WA Hydrologic Unit Code: 17110014 Latitude: 47.19760016 Longitude: -122.337343 Drainage Area (sq-mi): 13		
Total Simulated In-stream Flow:	**55.72**	Total Observed In-stream Flow:		**56.07**
Total of simulated highest 10% flows:	**8.30**	Total of Observed highest 10% flows:		**8.64**
Total of Simulated lowest 50% flows:	**23.64**	Total of Observed Lowest 50% flows:		**23.61**
Simulated Summer Flow Volume (months 7-9):	**12.40**	Observed Summer Flow Volume (7-9):		**12.76**
Simulated Fall Flow Volume (months 10-12):	**14.14**	Observed Fall Flow Volume (10-12):		**15.16**
Simulated Winter Flow Volume (months 1-3):	**15.45**	Observed Winter Flow Volume (1-3):		**14.97**
Simulated Spring Flow Volume (months 4-6):	**13.74**	Observed Spring Flow Volume (4-6):		**13.18**
Total Simulated Storm Volume:	**2.60**	Total Observed Storm Volume:		**2.38**
Simulated Summer Storm Volume (7-9):	**0.21**	Observed Summer Storm Volume (7-9):		**0.23**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Prev Cal*
Error in total volume:	-0.62	10	-0.75	-0.41
Error in 50% lowest flows:	0.14	10	0.11	0.41
Error in 10% highest flows:	-3.94	15	-4.39	-3.93
Seasonal volume error - Summer:	-2.82	30	-2.78	-2.58
Seasonal volume error - Fall:	-6.72	30	-6.75	-6.67
Seasonal volume error - Winter:	3.20	30	2.79	3.43
Seasonal volume error - Spring:	4.19	30	4.10	4.54
Error in storm volumes:	9.10	20	8.47	8.80
Error in summer storm volumes:	-8.83	50	-8.79	-8.83
Nash-Sutcliffe Coefficient of Efficiency, E:	0.539	Model accuracy increases	0.540	0.538
Monthly NSE	0.950	as E approaches 1.0	0.950	0.950

6.4 HYDROLOGY MODEL VALIDATION

The hydrology validation was conducted for 1995-1999 and confirms the performance of the calibrated model (Figure 6-11 through Figure 6-18, Table 6-6, and Table 6-7). The relative mean error statistics (Table 6-7) are all "very good", with the exception of the storm volume error, which is only "good". Reassuringly, the validation period statistics show an increase in the daily Nash-Sutcliffe *E* to 0.699 and the coefficients of determination (R^2) are 0.744 for daily flows and 0.817 for monthly flows, both in the "good" range.

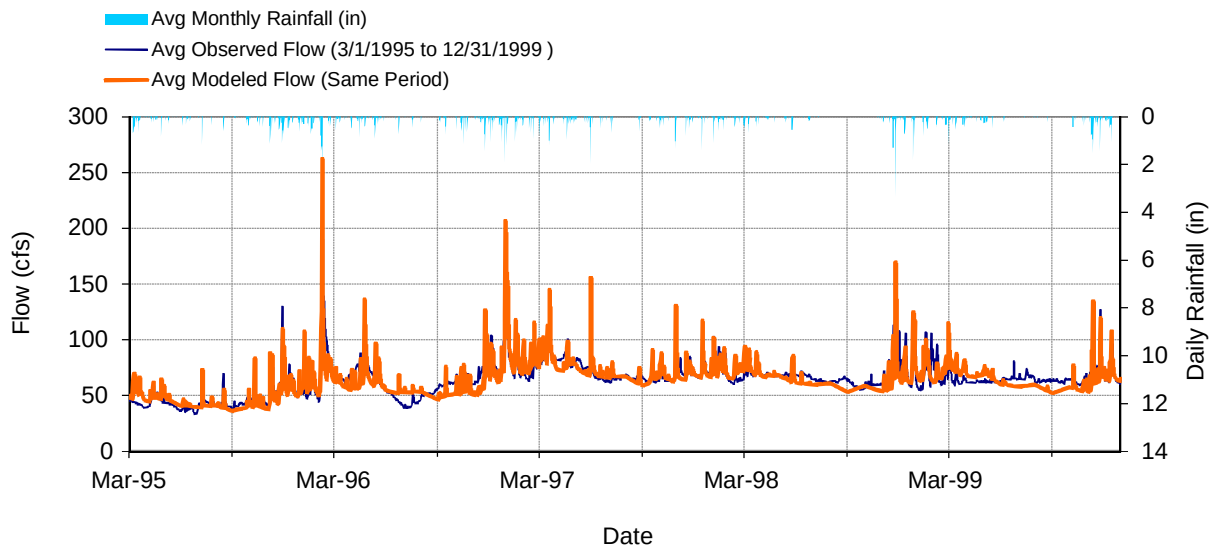


Figure 6-11. Mean Daily Flow: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

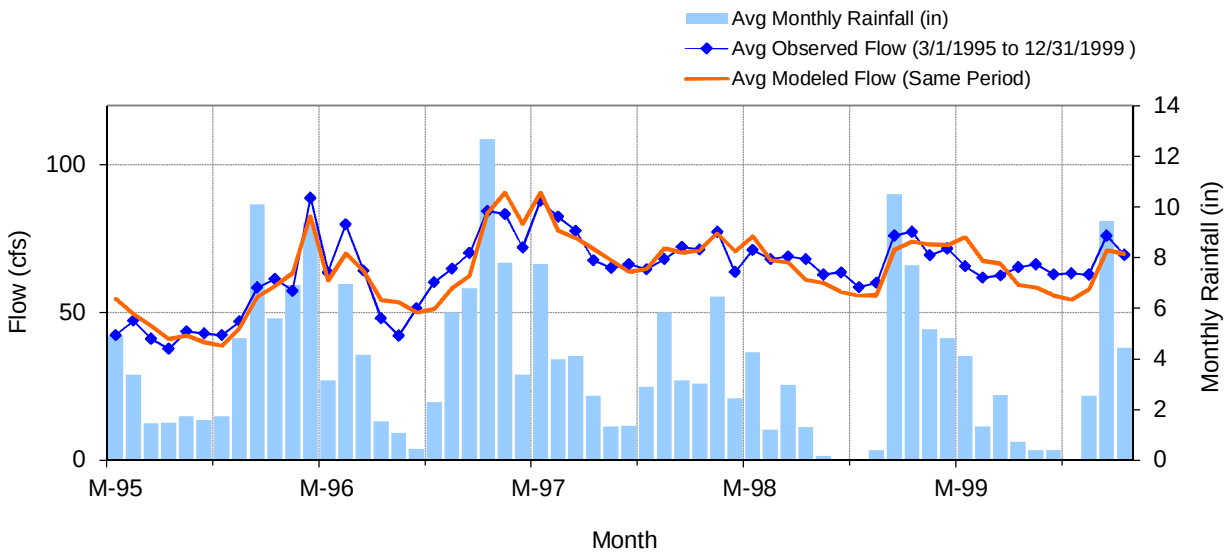


Figure 6-12. Mean Monthly Flow: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

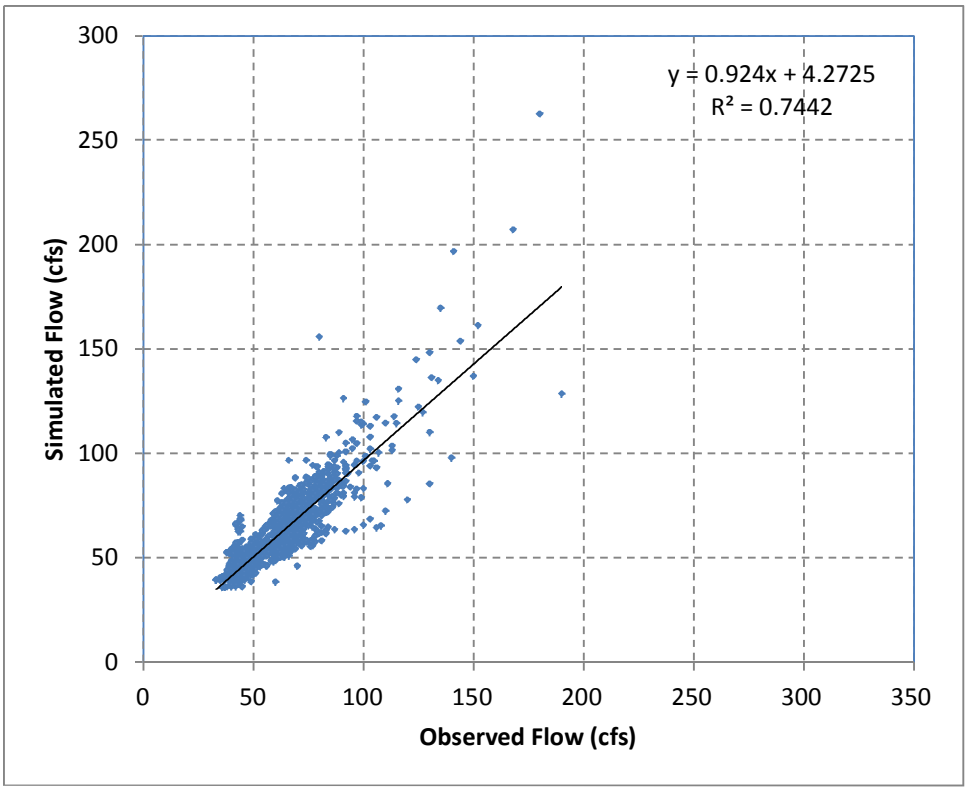


Figure 6-13. Daily Flow Regression: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

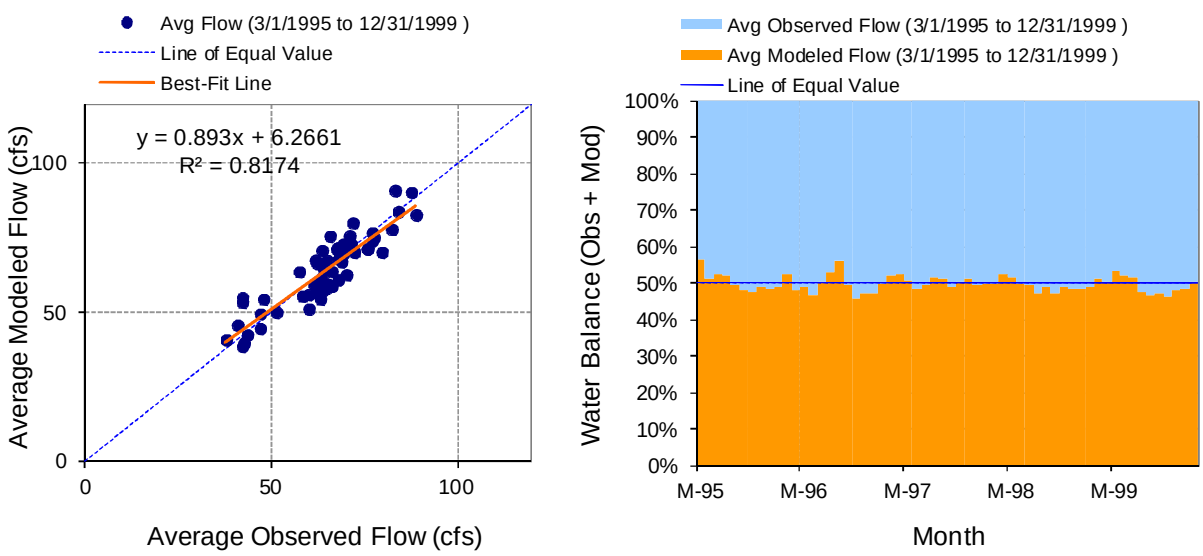
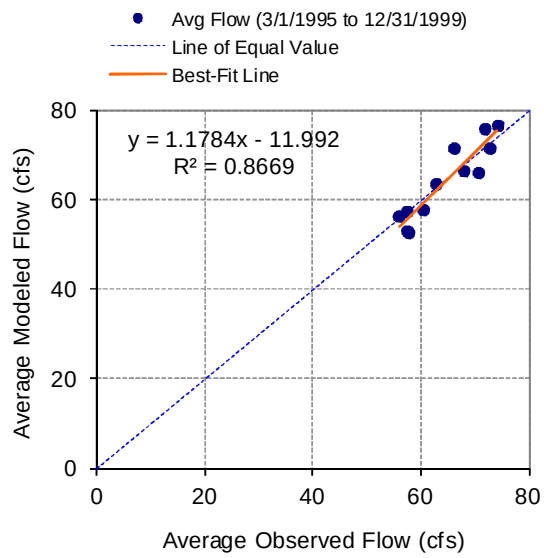


Figure 6-14. Monthly Flow Regression and Temporal Variation: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

Figure 6-15. Seasonal Regression and Temporal Aggregate: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period



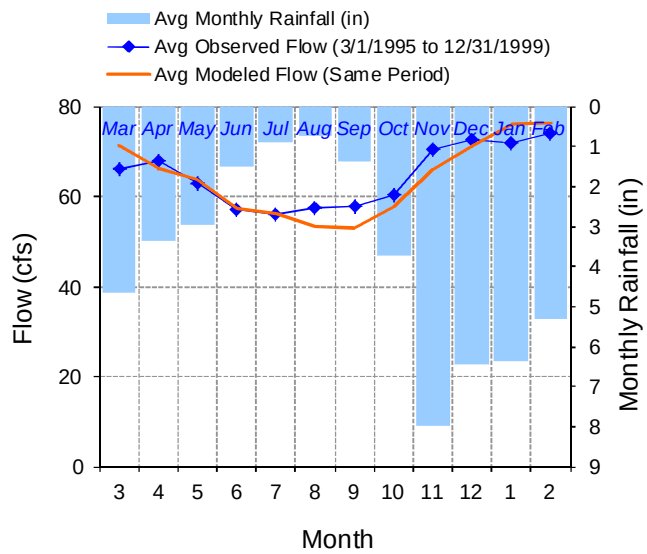


Figure 6-16. Seasonal Medians and Ranges: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

Table 6-7. Seasonal Summary: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Mar	66.01	65.00	60.00	77.50	71.42	70.92	61.21	80.40
Apr	67.78	67.50	61.00	78.00	66.40	67.33	59.35	71.77
May	62.79	65.00	60.00	71.00	63.61	65.01	59.10	70.11
Jun	57.25	64.00	44.25	66.75	57.31	59.11	52.39	61.82
Jul	55.89	62.00	43.50	65.00	56.27	58.47	52.40	60.32
Aug	57.35	62.00	51.00	64.00	53.16	54.47	48.14	59.06
Sep	57.72	61.00	56.00	63.00	52.84	53.80	49.37	57.09
Oct	60.45	62.00	59.00	64.00	57.61	56.30	52.54	63.29
Nov	70.48	69.00	62.00	73.00	66.01	63.79	54.20	70.89
Dec	72.68	68.00	63.00	77.50	71.43	66.82	63.28	72.89
Jan	71.77	69.00	58.75	81.00	75.91	71.26	65.37	83.17
Feb	74.07	67.00	63.00	76.00	76.52	72.60	65.66	78.77

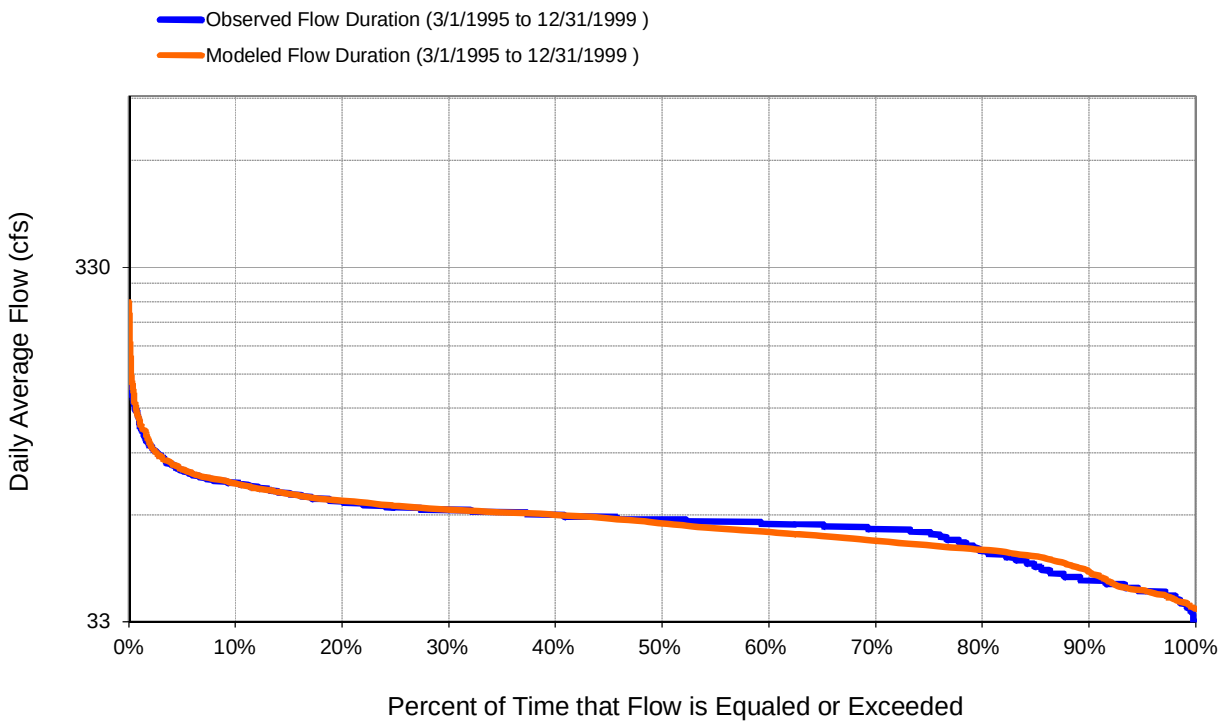


Figure 6-17. Flow Exceedence: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

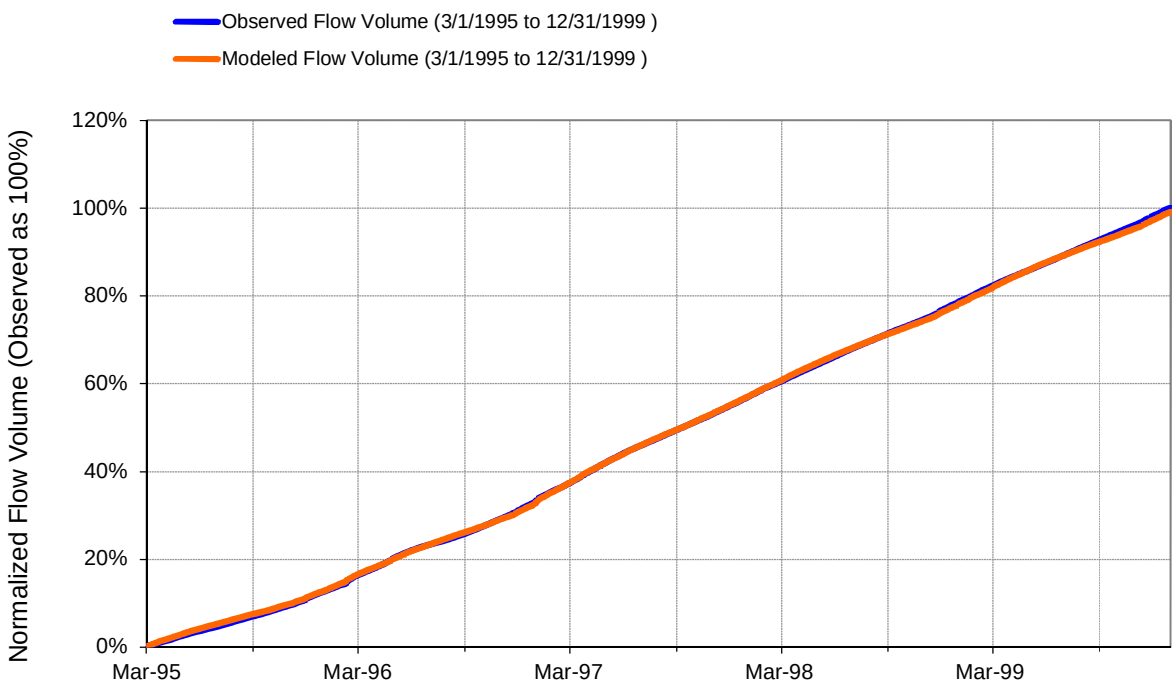


Figure 6-18. Flow Accumulation: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

Table 6-8. Summary Statistics: Model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, Validation Period

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 103 4.84-Year Analysis Period: 3/1/1995 - 12/31/1999 Flow volumes are (inches/year) for upstream drainage area This version has fix to hydrograph separation		USGS 12102075 CLARKS CREEK AT TACOMA ROAD NEAR PUYALLUP, WA Hydrologic Unit Code: 17110014 Latitude: 47.19760016 Longitude: -122.337343 Drainage Area (sq-mi): 13	
Total Simulated In-stream Flow:	**66.43**	Total Observed In-stream Flow:	**67.06**
Total of simulated highest 10% flows:	**10.21**	Total of Observed highest 10% flows:	**10.01**
Total of Simulated lowest 50% flows:	**27.42**	Total of Observed Lowest 50% flows:	**28.25**
Simulated Summer Flow Volume (months 7-9):	**14.72**	Observed Summer Flow Volume (7-9):	**15.50**
Simulated Fall Flow Volume (months 10-12):	**17.68**	Observed Fall Flow Volume (10-12):	**18.45**
Simulated Winter Flow Volume (months 1-3):	**17.22**	Observed Winter Flow Volume (1-3):	**16.26**
Simulated Spring Flow Volume (months 4-6):	**16.80**	Observed Spring Flow Volume (4-6):	**16.85**
Total Simulated Storm Volume:	**3.30**	Total Observed Storm Volume:	**2.79**
Simulated Summer Storm Volume (7-9):	**0.20**	Observed Summer Storm Volume (7-9):	**0.26**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-0.94	10	
Error in 50% lowest flows:	-2.94	10	
Error in 10% highest flows:	1.95	15	
Seasonal volume error - Summer:	-5.05	30	
Seasonal volume error - Fall:	-4.18	30	
Seasonal volume error - Winter:	5.92	30	
Seasonal volume error - Spring:	-0.25	30	
Error in storm volumes:	18.52	20	
Error in summer storm volumes:	-21.90	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.699	Model accuracy increases as E approaches 1.0	
Monthly NSE	0.950		

6.5 Simulation of Hourly Flows

The USGS NWIS system provides access to 15-minute raw flow estimates from the Tacoma Road gage for the period 3/28/1995 – 9/30/2008 (with gaps). These can be used to evaluate model performance at its native hourly time step. Typical results for fall 2007 are shown in Figure 6-19. In general, the model simulation appears accurate, with good representation of storm hydrograph timing and shape for most events. There is one period on November 4, 2007 when gaged flow increased above 100 cfs with no recorded rainfall. Subdaily gage data are missing for December 16 to December 17, 2007.

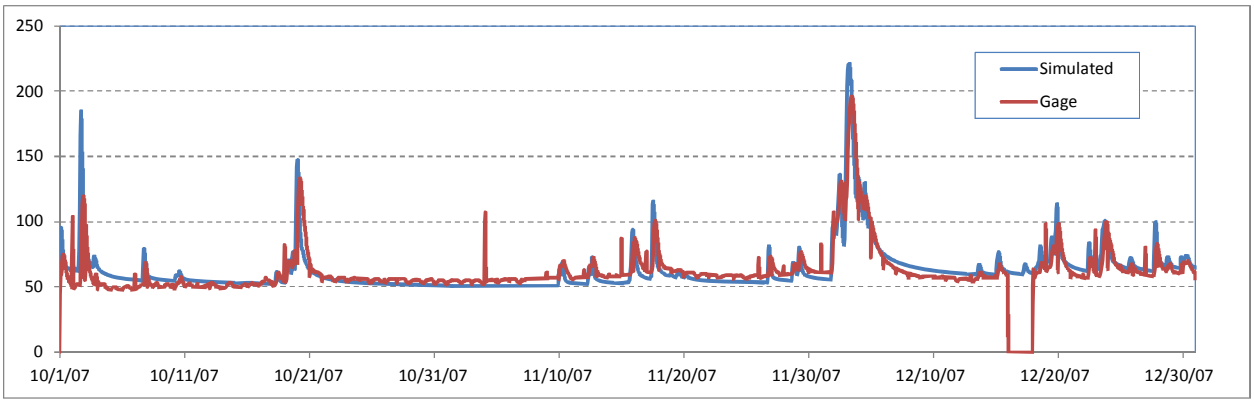


Figure 6-19. Hourly Flow Prediction for Clarks Creek at Tacoma Rd., Fall 2007

In contrast, results for fall 2003 are shown in Figure 6-20 and reveal several anomalies. Most notably, an extremely large flow is predicted for October 8, 2003, whereas the gage shows almost no response on that date. The large predicted flow is due to the precipitation record, as the WSU Puyallup station reported 4.85 inches total rainfall for this date. If correct, this would be an extraordinarily large rainfall event for the area. However, the reported data are suspect: On this date, the Seatac airport station reported only 0.27 inches, while the McMillin Reservoir gage reported about 0.3 inches. Thus, the WSU record for this day may be incorrect.

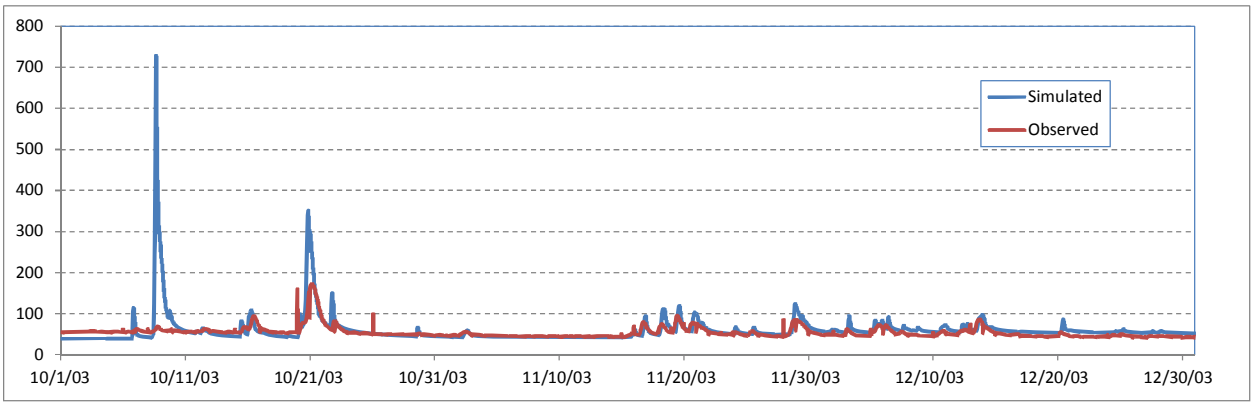


Figure 6-20. Hourly Flow Prediction for Clarks Creek at Tacoma Rd., Fall 2003

Note: Precipitation data appear to be incorrect for 10/8/2003.

Figure 6-20 also shows an actual major event on October 20 – October 21, 2003. This storm caused approximately $800,000 damage and set record daily rainfall totals at Seatac Airport, Olympia, and other locations according to NOAA event record details (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~ShowEvent~521417). In Pierce County, 5.7 inches of precipitation was recorded at McMillin Reservoir on this date and 3.7 inches at WSU, with approximately another 0.5 inches on the following day. The model appears to overpredict the results from the gage, which had a daily average flow of only 138 cfs and a peak of 165 cfs on 10/21. However, instantaneous flow measurements made downstream at 56th Street during water quality sampling reported 279 cfs on this day, in line with the model predictions. If both gage records are accurate this storm may have been spatially heterogeneous, with more intense rainfall on the downstream portions of Clarks Creek.

6.6 Comparison to Additional Flow Information

Limited instantaneous flow measurements are available at locations other than Tacoma Road. Between 1981 and 1997, 41 field measurements of flow are reported by USGS for Clarks Creek at the mouth (gage 12102100). For the period 2006-2008, USGS has also taken 9 field measurements on Clarks Creek at Puyallup (gage 12102000, located at the upstream end of Clarks Creek Park; this was also monitored continuously from March 1946 to May 1948) and two field measurements from Clarks Creek at 7th Ave. SW (gage 12102010). USGS also reports 12 measurements at the mouth of Rody Creek (12102050). Additional instantaneous flow measurements at multiple locations on Clarks Creek and tributaries were taken during the 2002-2003 water quality sampling used to develop the fecal coliform TMDL (WA ECY, 2008), including measurements on several of the tributaries.

The USGS flow measurements were obtained using standard, quality assured methods, and are mostly rated by USGS as of only fair accuracy. The additional 2002-2003 flow data are based on rating curves developed from a limited number of measurements and no detailed quality assessments are available. These data should be considered as of unknown accuracy.

The most extensive and likely most reliable of these additional series are those associated with the USGS stations at the mouth of Clarks Creek and Rody Creek (Figure 6-21), although these are instantaneous

rather than daily average measurements. Note that the non-USGS measurements on Rody were not obtained at exactly the same location as the USGS measurements.

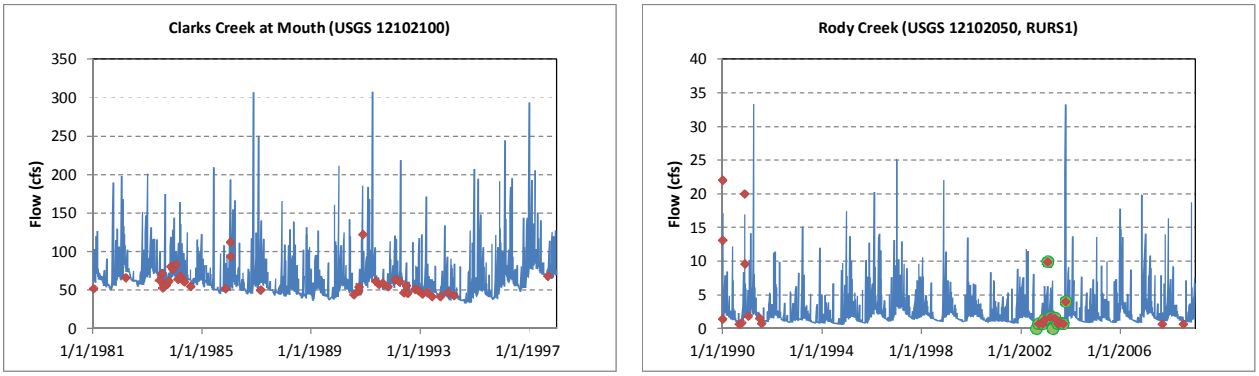


Figure 6-21. Comparison of Observed and Simulated Flows for Clarks Creek at Mouth and Rody Creek (cfs)

Note: Non-USGS measurements are shown with a green halo; simulated flows are daily averages, observed flows are instantaneous measurements.

The agreement between observations and predictions appears reasonable, particularly given that the observations are instantaneous. The average error at the mouth is 8.03 percent, while that on Rody Creek is 15.35 percent.

Comparisons at eight additional stations are shown in Figure 6-22. The model appears reasonable. Some individual events appear to be under-predicted, but this is likely due to the 2002-2003 instantaneous measurements targeting peak storm flows.

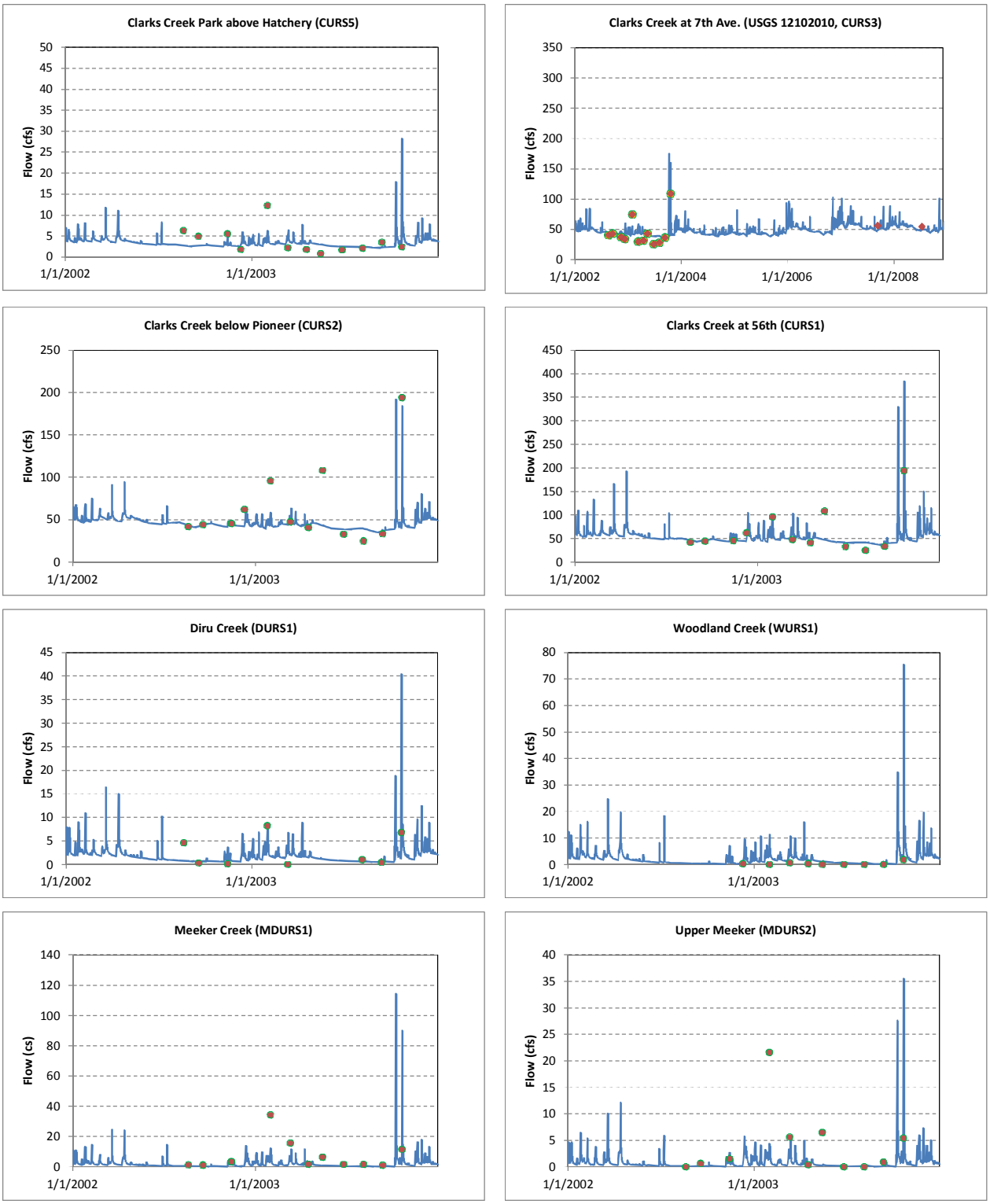


Figure 6-22. Comparison of Observed and Simulated Flows for Miscellaneous Clarks Creek Measurements (cfs)

Note: Non-USGS measurements are shown with a green halo; simulated flows are daily averages, observed flows are instantaneous measurements.

Additional flow observations are available in the area of the State Hatchery (USGS 12102000 and CURS4). The stations appear to be not exactly coincident, although the location given for the 2002-2003 station (CURS4) is uncertain as the coordinates do not fall on the streamline. Both are in the general neighborhood of the overflow releases from Maplewood Springs and the return flow from the hatchery, but the exact spatial relationship is unclear. This is also an area where significant amounts of spring flow enter the stream from the foot of the Vashon Till. The two gages are in the middle of HSPF reach 135, so also are not exactly matched to the model. USGS measurements at this location fall slightly below model predictions, while the 2002-2003 measurements at CURS4 tend to be higher (Figure 6-23). These discrepancies are likely related to the location of the gage sites relative to the complex inflows in this reach.

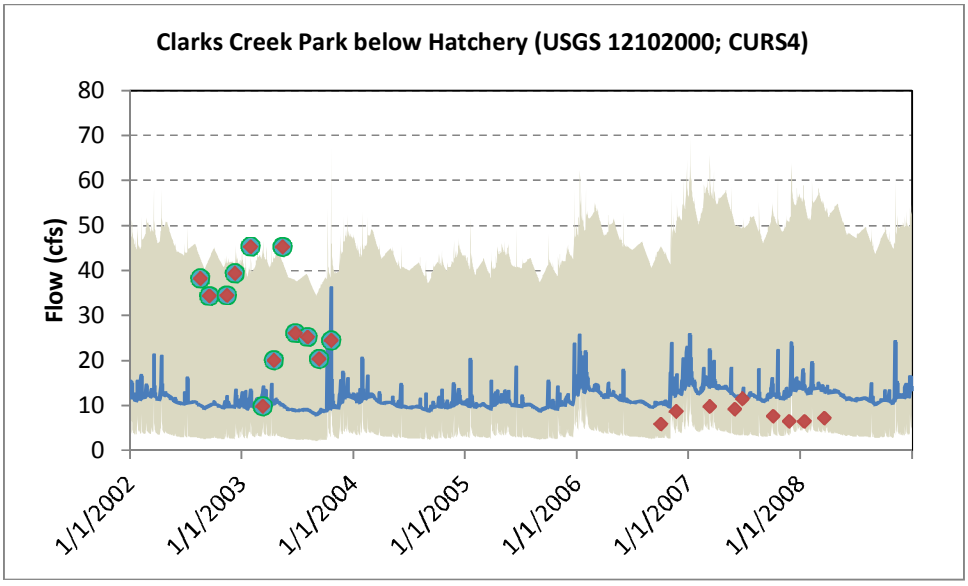


Figure 6-23. Flow Measurements in Vicinity of State Hatchery

Note: Blue line shows model predictions for Reach 134. Grey area shows range from upstream Reach 135 to downstream reach 133. Non-USGS measurements are shown with a green halo; simulated flows are daily averages, observed flows are instantaneous measurements.

7 Sediment Calibration and Validation

The HSPF model has the capability to simulate a variety of processes related to sediment and solids transport. On pervious and impervious upland areas the model simulates a single bulk solids class, subject to some or all of the following processes:

- Detachment of sediment from pervious surfaces by rainfall splash or human influences (as a function of rainfall intensity, cover, soil characteristics, and management practices).
- Accumulation of solids on impervious surfaces.
- Wind deposition of solids on pervious and impervious surfaces.
- Reattachment of solids into the soil matrix or removal of solids from impervious surfaces by wind, street cleaning, or other mechanisms.
- Washoff of detached solids to receiving streams as a function of surface flow depth.
- Scour of the soil matrix by concentrated flow (gully formation).

The bulk solids simulated on the uplands are converted to three size fractions (sand, silt, clay) when load enters the receiving water. This is a user specification: the model does not compute size fractions on the upland or calculate enrichment of fines during transport.

Within the stream network, the model simulates the three size classes separately, performing mass balances in both the water column and stream bed. Solids in the stream are subject to the following processes:

- Advective transport.
- Settling and deposition to the stream bed at lower flows as a function of flow velocity (for non-cohesive sand) or shear stress (for cohesive silt and clay).
- Scour from the stream bed and bank at higher flows as a function of flow velocity (for non-cohesive sand) or shear stress (for cohesive silt and clay).
- Point source load additions.

A stream reach is represented as a fully mixed segment and the model does not contain detailed geometry of the channel at the within-reach scale, so the resolution of processes is limited to the scale of reach. The model thus simulates aggradation and degradation of stream reaches in an approximate, summary manner that is appropriate to a watershed scale mass balance, but does not identify the exact location of aggradation and degradation processes in specific stream reaches.

7.1 Sediment Calibration Approach

Calibration of watershed sediment models is complex because instream observations of TSS are the net result of a variety of complex processes, including sediment detachment on the uplands, transport of detached sediment from the land surface to streams, and bank erosion, scour, and deposition within the streams. In addition, data for calibration are often limited – certainly the case for Clarks Creek. As a result, there is often not a unique solution to model calibration, as, for example, high concentrations observed in stream could result from elevated upland loads and/or sediment scour within the channel. These two sources are not readily distinguished through observations unless auxiliary information (such as radionuclide data) is collected to identify the fraction of stream sediment that has been in recent contact with the atmosphere.

An additional challenge for sediment calibration is that sediment concentrations often vary rapidly over short time intervals. For instance, the first flush phenomenon can result in TSS concentrations that spike up in the rising limb of the storm hydrograph, then decline. Instantaneous grab samples may provide little

information on the daily average sediment concentration, while sub-daily model predictions and observations for the same time interval may show large discrepancies if there are small differences in the timing of predicted and observed flows. Flow-weighted composites over the storm hydrograph are most informative. For Clarks Creek, most available TSS samples are grab samples – and the time of collection is not available for most of the samples. The recourse is to compare these point-in-time samples to daily average concentrations produced by the model and attempt to obtain a representation that is unbiased over the long term, recognizing that there will be significant discrepancies between some individual observations and model predictions.

The approach undertaken for sediment calibration follows the guidance of USEPA (2006) and Donigian and Love (2003).

The general strategy for sediment calibration of the Clarks Creek model, following Donigian and Love (2003), consists of the following steps:

- Specify initial upland parameter values for soil erodibility (detachment rates) on pervious land and soil accumulation rates on impervious surfaces based on external information (e.g., soils data, literature).
- Adjust upland sediment transport rates from individual land uses to achieve general consistency with annual sediment loading rates reported in the literature (preferably from local studies).
- Analyze the instream sediment mass balance on a reach by reach basis to ensure reasonable representation of areas of scour and deposition.
- Adjust instream/channel parameters to match observed total suspended solids (TSS) concentrations and loads.

Each of these steps is described below.

7.2 UPLAND PARAMETER SPECIFICATION

Parameters controlling the erodibility of the soil are specified based on soil properties. The HSPF model does not use the Universal Soil Loss Equation (USLE) for sediment simulation; however, some of the parameters used in HSPF are similar to those in the USLE. The USDA State Soils (SSURGO) database provides a number of USLE parameter estimates by soil type, and these can be used to set initial parameter values – ensuring relative consistency between the HSPF and USLE approaches.

HSPF erosion parameters for pervious land uses were estimated based on a theoretical relationship between HSPF algorithms and documented soil parameters, ensuring consistency in relative estimates of erosion based on soil type and cover. Sediment is available for transport once it is detached from the soil matrix. HSPF calculates the detachment rate of sediment by rainfall energy (in tons/acre) as

$$DET = (1 - COVER) \cdot SMPF \cdot KRER \cdot P^{JRER}$$

where DET is the detachment rate (tons/acre), COVER is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, SMPF is the dimensionless management practice factor, KRER is the coefficient in the soil detachment equation, JRER is the exponent in the soil detachment equation, which is recommended to be set to 1.81, and P is precipitation in inches. Actual sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation (Wischmeier and Smith, 1978) where RE is the rainfall erosivity, K is the soil erodibility factor, LS is the length-slope factor, C is the cover factor, and P is the practice factor,

$$RE \cdot K \cdot LS \cdot C \cdot P.$$

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that *DET*≈*DETS* if *AFFIX* is greater than zero. Further, during a large runoff event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE yield from an event should approximate *DET* in HSPF.

With these assumptions, the HSPF variable *SMPF* may be taken as fully analogous to the USLE P factor. The complement of *COVER* is equivalent to the USLE C factor (i.e., (1 - *COVER*) = C). This leaves the following equivalence (given JRER = 1.81):

$$KRER \cdot P^{JRER} \quad = \quad RE \cdot K \cdot LS \text{, or}$$

$$KRER = {RE \cdot K \cdot LS}\Big/{P^{1.81}}$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in units of MJ-mm/ha-h) in terms of precipitation:

$$RE \quad = \quad 64.6 \cdot a_t \cdot R^{1.81}$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. As shown in Haith et al. (1992), the expression for RE can be re-expressed in units of metric tons/ha as:

$$RE \quad = \quad 0.132 \cdot 64.6 \cdot a_t \cdot R^{1.81}$$

This relationship suggests that the HSPF exponent on precipitation, *JRER*, should be set to 1.81.

The remainder of the terms in the calculation of *RE* must be subsumed into the *KRER* term of HSPF, with a units conversion. Writing *RE* in terms of tons/acre and using precipitation in inches:

$$RE\,(tons/ac) \quad = \quad \left[0.132 \cdot 64.6 \cdot a_t\right] \cdot P\,(in)^{1.81} \cdot (2.54\,cm/in)^{1.81} \cdot (1\,ton/ac)/(2.24\,tonnes/ha)$$

The average value for a_t for this part of Washington is about 0.18 (Selker et al., 1990), yielding

$$RE = 3.7032 \cdot P^{1.81}$$

The power term for precipitation can then be eliminated from the equation for *KRER*, leaving the following expression (English units) in terms of the USLE K factor:

$$KRER \quad = \quad 3.7032 \cdot K \cdot LS$$

The K factor is available directly from soil surveys, while the LS factor can be estimated from slope, using the expression of Wischmeier and Smith (1978):

$$LS = \left(0.045\,L\right)^b \cdot \left(65.41 \sin^2 \theta_k + 4.56 \sin \theta_k + 0.065\right) \text{, where}$$

$\theta = \tan^{-1}(S/100)$, *S* is the slope in percent, *L* is the slope length, and *b* takes the following values: 0.5 for S ≥ 5, 0.4 for 3.5 ≤ S < 5, 0.3 for 1 ≤ S < 3, and 0.2 for S < 1.

This approach establishes initial values for *KRER* that are consistent with USLE information. It should be noted that Donigian and Love (2003) recommend setting *KRER* directly equal to the USLE *K* factor. As can be seen from the discussion above, this is theoretically incorrect, although *KRER* will be proportional to *K*, depending on slope.

Other soil erosion parameters were assigned based on land use. The *SMPF* factor is typically used to describe row crop agricultural management practices, and was left at 1 for all land uses in the watershed except agriculture, where a value of 0.75 was assigned, representing approximately 50 percent adoption

of erosion reduction BMPs. *COVER* was assigned to PERLND as the complement of the USLE *C* factor, estimated on a monthly basis. Basic *C* factors were assigned according to Novotny and Chesters (1981).

Evidence was not available to support a detailed analysis of gully formation outside the stream network, although this can be a significant source of sediment load. The gully routines were turned on for the highest-sloped forest land segments.

For impervious surfaces (including roads), availability of solids is simulated with a buildup-washoff formulation, which requires an accumulation rate (ACCSD) and a removal rate (REMSDP). The asymptotic steady-state limit of storage mass (under conditions of no washoff) is equal to the accumulation rate divided by the removal rate. Initial values were set based on literature and experience (Table 7-1). Accumulation rates are set to vary within a relatively narrow range from 0.01 tons/ac/day to 0.02 tons/ac/day, with higher rates for high density urban land uses, consistent with studies summarized in USEPA (2006) and Novotny and Olem (1994). Removal rates for most land uses are set at 0.04 per day, in the typical range recommended by USEPA (2006). Higher removal rates are set for roads. On transportation arteries significant removal is caused by wind turbulence caused by passing cars, while many urban streets are subject to mechanical street cleaning. While empirical relationships have been developed to describe the effect of traffic density, curb height, and street cleaning frequency on removal rates for solids (Novotny and Olem, 1994), such data were not readily available for the Clarks Creek watershed.

Table 7-1. Sediment Buildup Parameters for Impervious Lands

Impervious Land Use	Accumulation (ACCSDP, t/ac/day)	Removal (REMSDP; day^{-1})
High density developed	0.020	0.040
Medium density developed	0.015	0.040
Low density developed	0.015	0.040
Road (till area)	0.012	0.100
Road (alluvial areas)	0.012	0.100
Park	0.010	0.040

Washoff of sediment from high and medium density impervious areas was simulated with sediment option SDOP=0, which calculates transport capacity as a function of depth of flow, not depth of flow plus surface storage. Use of this option is essential for impervious surfaces in Clarks Creek because surface storage is being used to approximate partial stormwater detention, as described in Section 4.4, and this storage should not be included in transport capacity.

7.3 SEDIMENT TRANSPORT TO STREAM

HSPF simulates transport of detached sediment as a function of overland flow depth, controlled by a coefficient (KSER) and an exponent (JSER) on flow depth. The exponent, JSER, was set to the recommended value of 1.67, while the coefficient, KSER, was adjusted to obtain a reasonable representation of average annual solids loading by land use (as a function of hydrology) while also providing an amount of suspended solids load consistent with instream observations. One useful reference from western Washington is the Green-Duwamish study in King Co. (Herrera, 2007). This reports average annual loading rates from low-to-medium-density development of 0.07 tons/ac/yr and from high density development of 0.077 tons/ac/yr. Herrera also reports suspended solids load from agriculture that seem low (0.0215 t/ac/yr) and from forest that seem high (0.0489 t/ac/yr), but may reflect the specific circumstances of their monitoring watersheds. Intact forest can often have much lower loading rates, whereas agriculture with poorer management practices can have significantly higher loads.

Notably, Herrera's forest tributaries were about 90 percent forest, with the remainder including roads, grass, and some development, which could account for a majority of the load. The Clarks Creek model separates intact forest from these other land uses and is expected to have low unit area loading rates.

National data on solids loads from roads provide averages mostly in the range of 0.14 to 2 t/ac/yr (Driscoll et al., 1990), with the higher loads tending to occur in areas that combine high traffic with high amounts of wind-blown dust deposition. The average simulated loading rates for the Clarks Creek watershed are thus expected to fall at the lower end of this range.

A reasonable representation of sediment yield by land use was obtained by setting a uniform value of the pervious land sediment transport coefficient KSER at 10.0 while varying the impervious land transport coefficient KEIM from 0.054 to 0.065, with the higher values specified for roads, which are generally designed for efficient water removal. The resulting upland sediment yield rates are summarized in Figure 7-1.

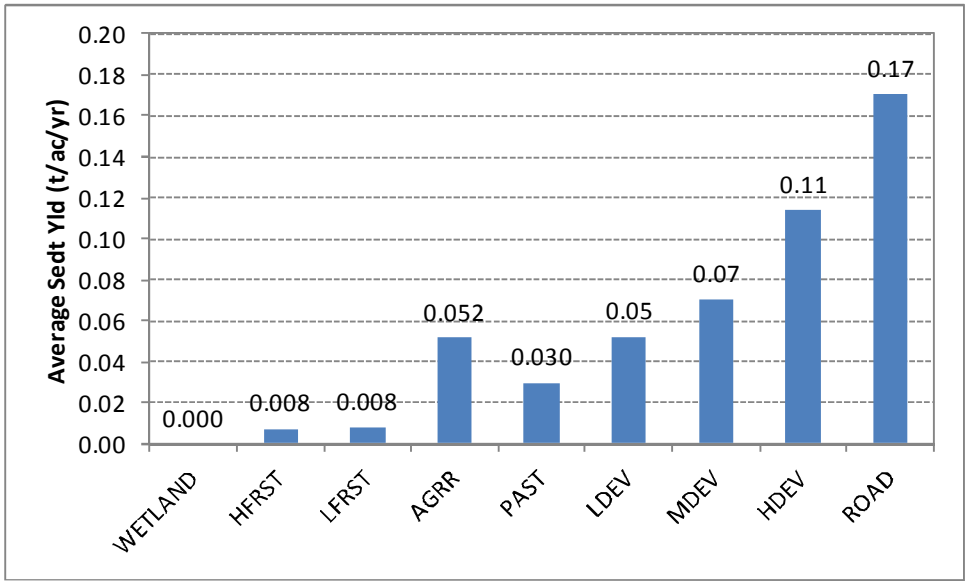


Figure 7-1. Average Annual Sediment Yield by Land Use

Note: Unweighted averages across all soils and slopes are shown for comparison to literature values. Impervious area percentages are assumed to be 5% for low density development (LDEV), 20% for medium density development (MDEV), 45% for high density development (HDEV), and 67% for roads for purposes of comparison.

HSPF simulates total sediment on the uplands, but represents sand, silt, and clay separately in the stream reaches. Assignment to these classes is made in the MASS-LINK block, which routes the upland load to the stream. Across the whole watershed, the area-weighted composition of surficial sediment is 48 percent sand, 40 percent silt, and 11 percent clay based on the SSURGO soil survey coverage. Sediment detachment and transport processes, however, result in a progressive enrichment of the finer fractions and proportionately less transport of the heavier sand fraction. Because the probability of redeposition of clays during overland transport is very small, Walling (1983) showed that the enrichment ratio for clay is approximately equal to the inverse of the delivery ratio (and thus should vary by subbasin size). For the small subbasins in the Clarks Creek model, an initial estimate of a delivery ratio as a function of area of around 30 percent is reasonable based on Roehl (1962); thus the clay fraction was increased from 11 to 37 percent and the silt fraction from 40 to 45 percent, leaving 18 percent sand. Note that even though loading may be enriched in fines much of the sediment bed is made up of sand. This occurs because the clay and much of the silt wash through the stream without settling out.

7.4 REACH SEDIMENT SETUP

Complex cycles of deposition and scour occur in stream reaches, determined by the shear stress exerted on the bed material and the external sediment supply. The model simulates deposition and scour (aggradation and deposition) of silt and clay in stream reaches based on exerted shear stress relative to critical shear stresses for deposition and scour (τ_{CD} and τ_{CS}) for each sediment size class, particle deposition velocities, and a limiting maximum potential rate of scour (W, lb/ft^2/d). The parameters τ_{CD}, τ_{CS}, and W are site-specific and vary by reach. (HSPF is a spatially lumped model, with stream reaches represented as fully mixed, and the simulated boundary shear stress represents reach-averaged conditions, while actual shear varies continuously based on local characteristics of the channel. As the processes are non-linear, a single set of parameters will not adequately represent the behavior of bed sediment in all reaches; instead, these should be set on a reach-by-reach basis.)

For the non-cohesive, sand fraction of sediment, HSPF provides several options, including the Toffaletti method, the Colby method, and a simplified exponential relationship to flow. The Toffaletti and Colby methods are most appropriate for wide sand-bed rivers and additionally can cause stability problems in the model, so the third (exponential equation) approach is used for Clarks Creek. In this approach sand transport capacity is a function of KSAND · AVVELE ^{EXPSND}, where AVVELE is the average velocity and KSAND and EXPSND are user-specified parameters.

Following the advice of Donigian and Love (2003) and USEPA (2006), critical shear stresses for cohesive sediments were initially set to percentiles of the overall shear (Tau) distribution, which is closely tied to flow (Figure 7-2). Specifically, τ_{CD} was set at the 25th and 20th percentiles of the distribution, for silt and clay, respectively, while τ_{CS} was set at the 95th and 90th percentiles for silt and clay. This allows scour to occur only at higher flows, with clay scouring prior to silt. Model predictions of scour at high flows are sensitive to these values; however, sufficient monitoring data of extreme events is not available to refine these values further.

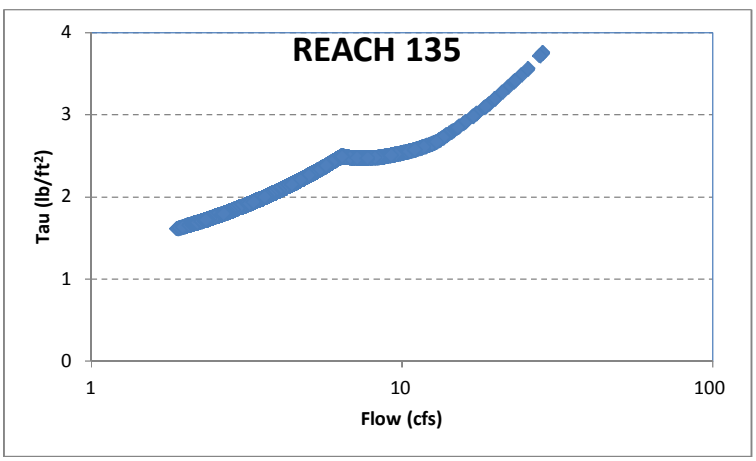


Figure 7-2. Example Relationship between Tau and Flow, Reach 135

Simulation of channel scour and deposition must provide a reasonable mass balance in the stream reaches in addition to matching observed TSS concentrations. The total change in simulated nominal bed depth over the 51-year simulation period is summarized by reach in Figure 7-3. (This is a "nominal" rather than actual change because HSPF represents the reaches in a simplified, one-dimensional manner). As seen in this figure, most stream reaches remain approximately stable over time. Degradation (decrease in bed depth) is simulated primarily in reaches that intersect the face of the Vashon Till (134 on the mainstem, 128 on Silver Creek, 147 on Woodland Creek, 157 on Diru Creek, and 166 on Rody Creek), while aggradation is simulated in the most downstream reaches of Woodland, Diru, and Rody, and in the mainstem after in enters the alluvial plain of the Puyallup River.

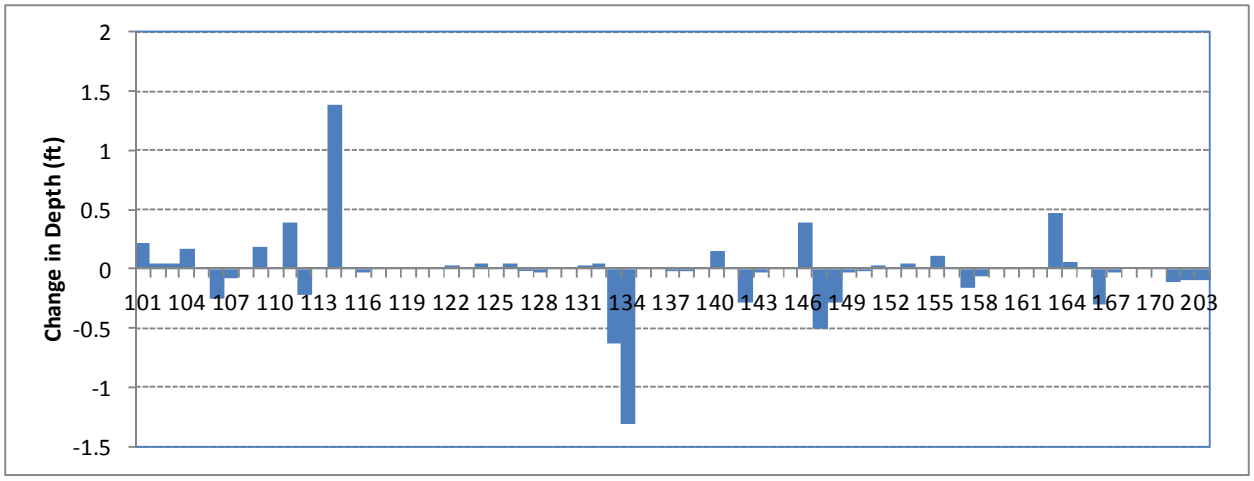


Figure 7-3. Simulated Change in Bed Depth by Model Reach, 1960-2010

Note: Depth changes are relative measures of scour/deposition in a one-dimensional reach model,

7.5 INSTREAM SEDIMENT CALIBRATION

The full sediment model is calibrated through comparison to observed total suspended solids concentrations by adjusting the parameters that control the scour and deposition of sand, silt, and clay (as well as by adjusting the upland transport simulation.) Suspended solids observations are available at multiple stations, but the number of samples at individual stations is limited. The calibration period was selected as the more data rich period of 2002 – 2010, while earlier data were used for validation. Unfortunately, the desired minimum sample size of 20 observations is attained at only a few of the stations. Accordingly, a weight of evidence approach was used, for which model fit statistics are supplemented with a variety of graphical comparisons.

It should be noted that a technical limitation of the HSPF model creates potential problems for fitting to observed concentrations in very small streams. Specifically, HSPF subroutine BDEXCH turns off the simulation of cohesive sediment scour and deposition when reach average depth falls below 0.17 ft (2 inches), where average depth is defined as the reach volume divided by the surface area. This is designed to prevent model instability. With the exception of the mainstem of Clarks Creek downstream of Maplewood Springs, most reaches in the model experience average depths that are less than 0.17 ft at least some of the time. During these periods settling of silt and clay is not simulated; instead, both are transported through the reach unchanged, whereas in fact significant settling is likely to occur during such low flow conditions. This limits the model's ability to reproduce low flow observations, including observations in the mainstem that are affected by simulated concentrations in smaller tributaries. This is not a significant problem, however, as the load transported at low flows will be small and will not contribute significantly to solids concentrations and loads in the Clarks Creek mainstem.

Figure 7-4 through Figure 7-7 show sediment calibration results at four stations on Clarks Creek mainstem, arranged in downstream order. For each of these observation points the model predicts the range of TSS observations reasonably well, although not all individual observations are matched. The lowest observations (less than 2 mg/L) are over-estimated at 7th Street and 12th Street primarily due to an assumption that low levels of fines are associated with the baseflow from springs in the upper reaches of the creek (1 mg/L above the State Hatchery and 2 mg/L below). These constant concentration assumptions (which represent a typical background condition due to factors such as animal activity as well as any fine sediment actually discharged or eroded at the spring outfalls) fit the majority of the data, but over-predict some individual low-flow measurements.

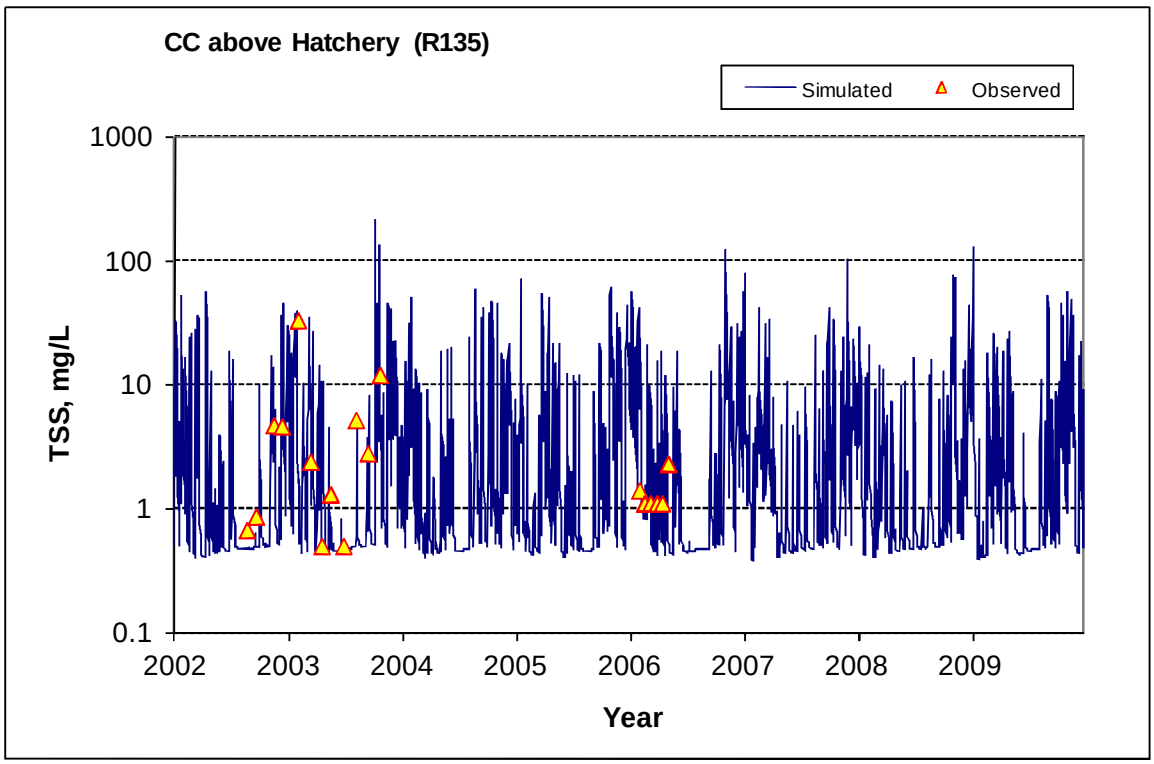


Figure 7-4. Time Series Comparison for TSS, Clarks Creek above State Hatchery, 2002-2010

Note: Data shown are for stations CCURS-5 and Clk-4

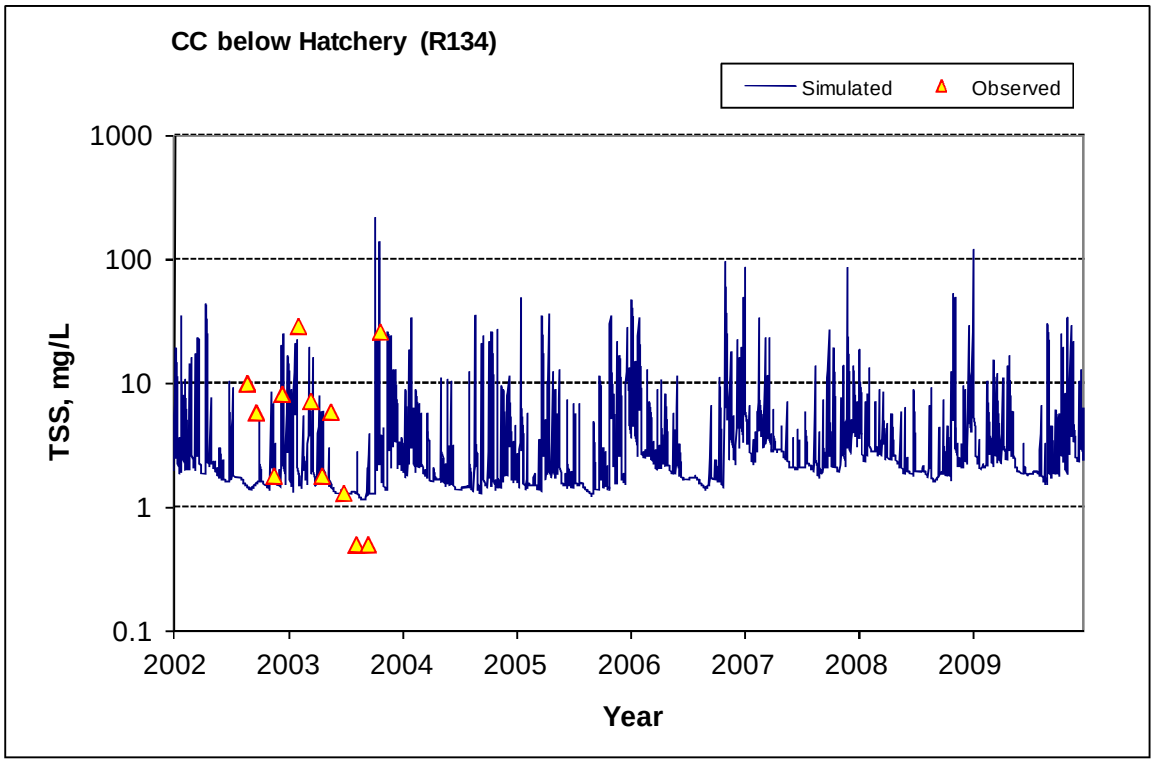


Figure 7-5. Time Series Comparison for TSS, Clarks Creek below State Hatchery, 2002-2010

Note: Data shown are for station CCURS-2

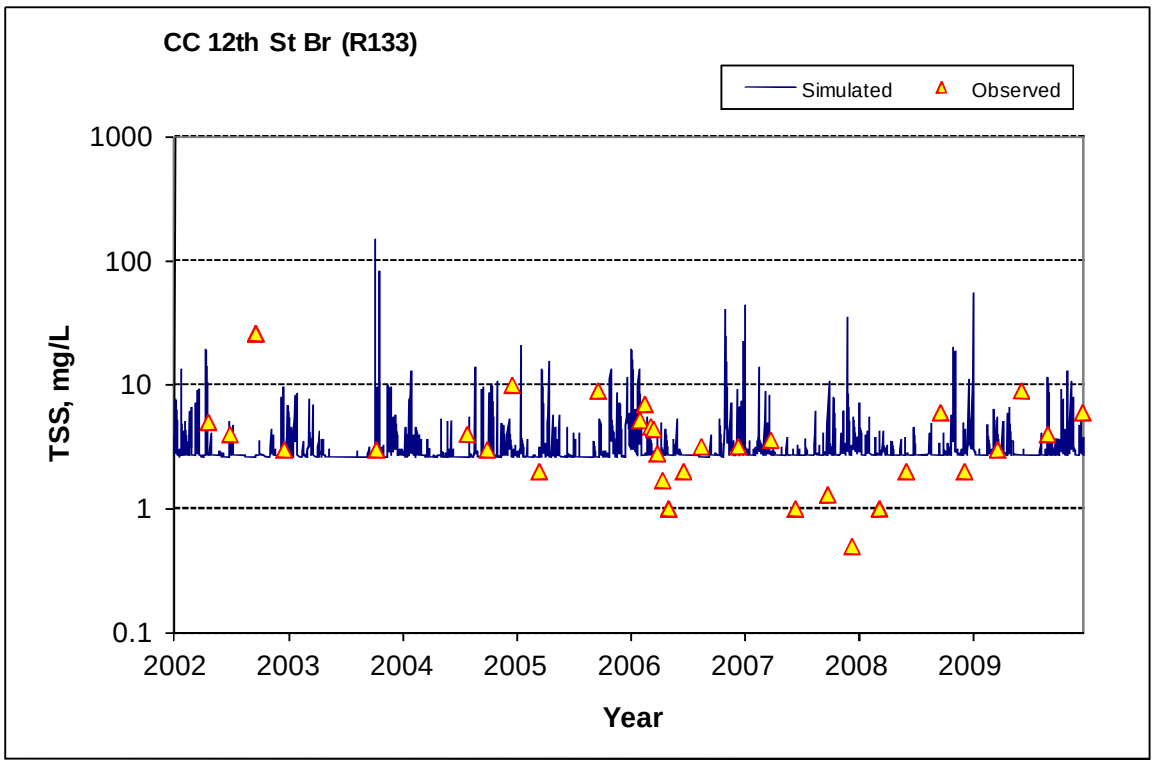


Figure 7-6. Time Series Comparison for TSS, Clarks Creek at 12th St. Bridge, 2002-2010

Note: Data shown are for station Clk-8

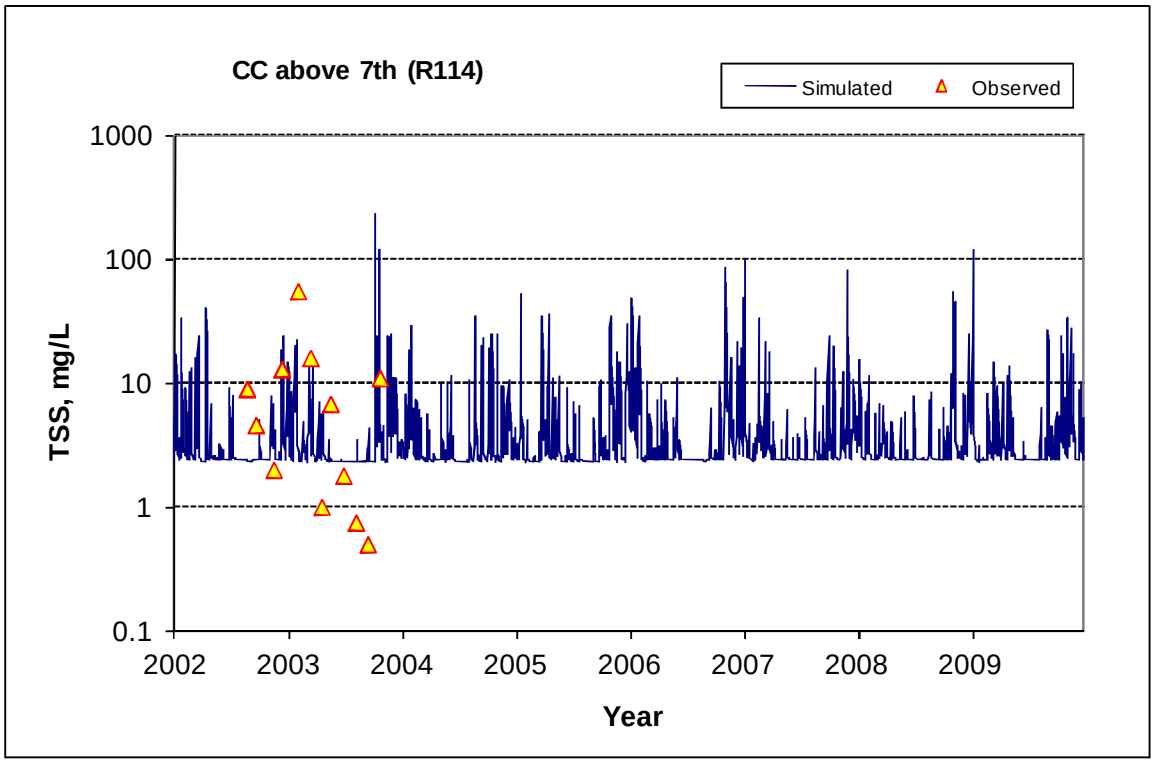


Figure 7-7. Time Series Comparison for TSS, Clarks Creek above 7th Street, 2002-2010

Note: Data shown are for station CCURS-3

The calibration procedure is illustrated in more detail for the downstream station on Clarks Creek at 66th Street. In addition to standard time series plots (Figure 7-8), power plots of load and concentration versus flow were used to ensure that the model and data show similar relationships (Figure 7-9). Plots of prediction error versus month and flow are used to check whether there are significant trends with season or flow magnitude, recognizing that considerable variability is expected from the comparison of grab samples to daily averages. For this station (Figure 7-10 and Figure 7-11), the errors are relatively evenly distributed against month (it could be contended that December TSS is over-estimated, but the sample size is small). Distribution of errors versus flow also does not show any strong bias. Observations appear to be somewhat over-predicted at high flows, but this may be a result of small differences in timing and the comparison of model daily averages to grab samples. In addition, the HSPF representation of reaches cannot distinguish between bedload and suspended load and will thus overpredict observations of TSS if a significant fraction of solids is moving as bedload and is not represented in water column grab samples.

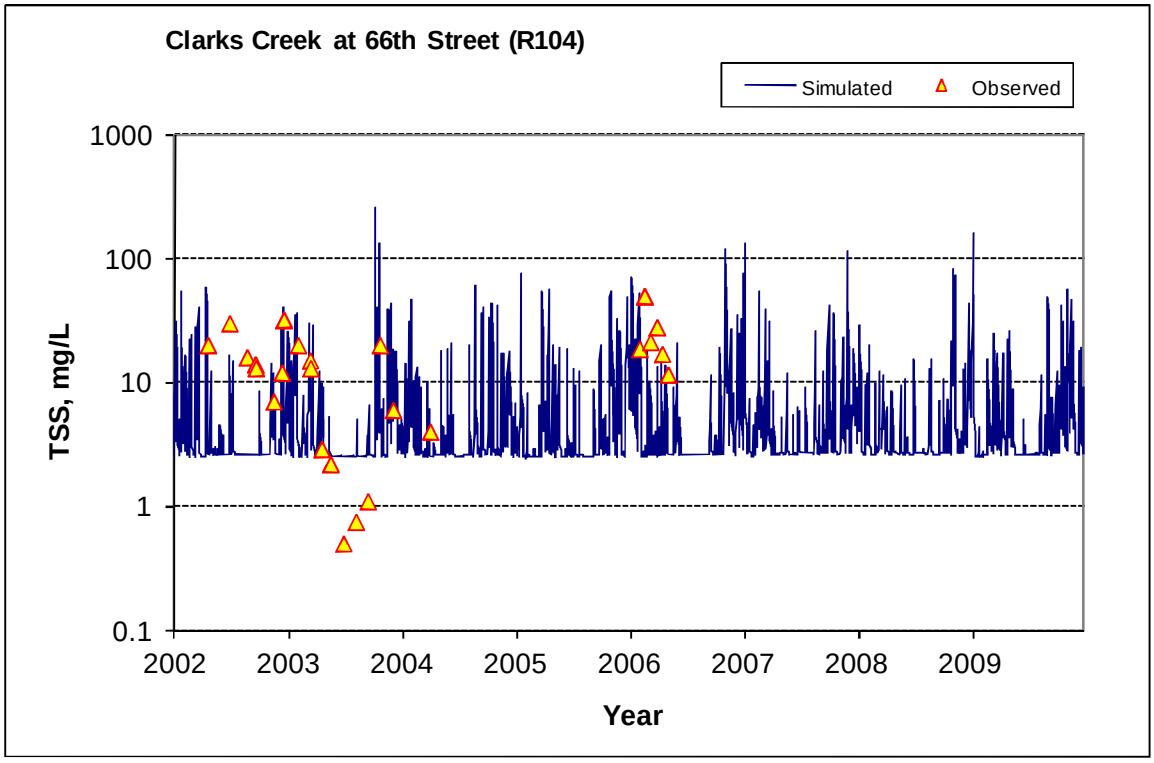


Figure 7-8. Time Series Comparison for TSS Calibration, Clarks Creek at 66th Street, 2002-2010

Note: Data shown are for stations CLK-4.1, Clk-4, and CCURS-1.

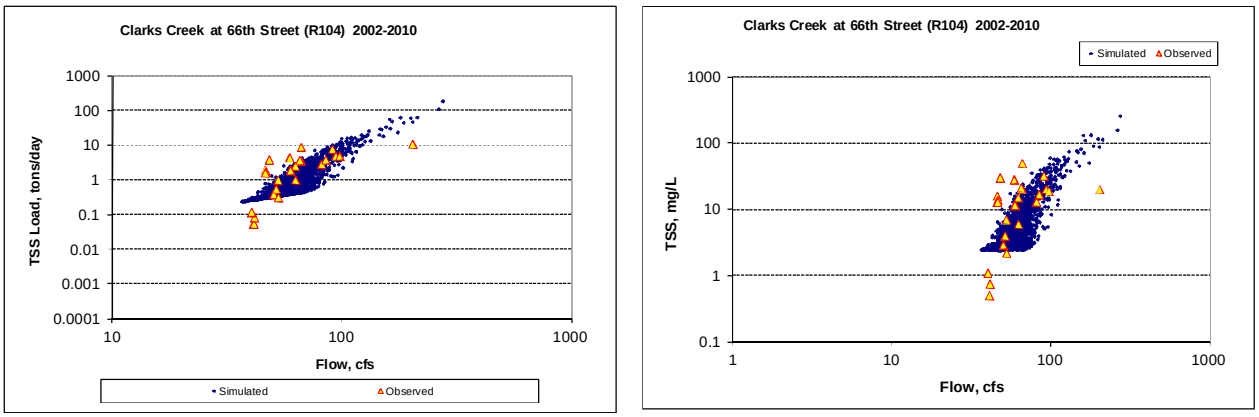


Figure 7-9. Power Plots of TSS Load and Concentration versus Flow, Clarks Creek at 66th Street, 2002-2010

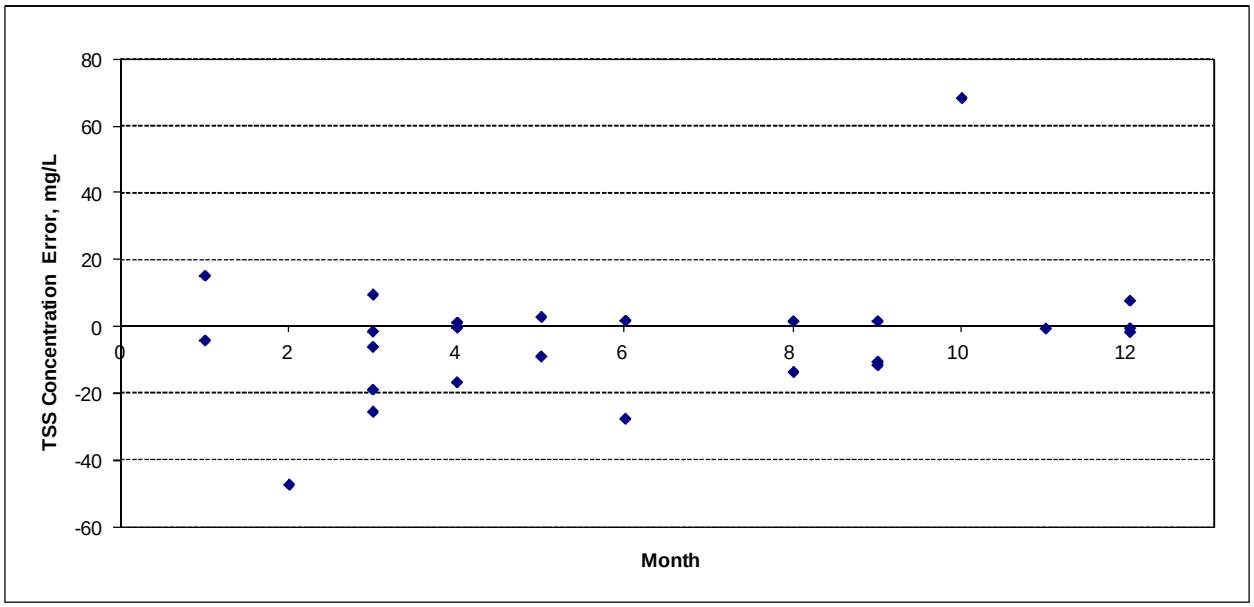


Figure 7-10. TSS Prediction Error versus Month, Clarks Creek at 66th Street, 2002-2010

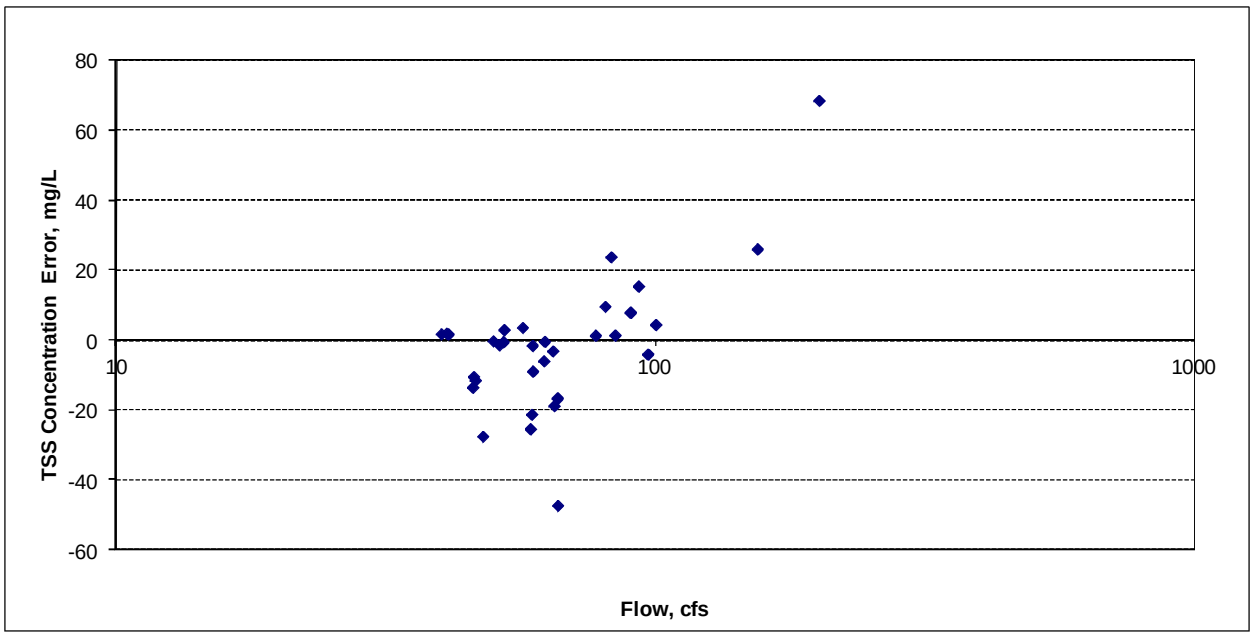


Figure 7-11. TSS Prediction Error versus Flow, Clarks Creek at 66th Street, 2002-2010

Further examination of TSS prediction errors at 66th Street suggest that much of the uncertainty in storm flow concentration predictions could be due to small errors in timing. The observations are point-in-time grab samples that are likely to vary rapidly in time due to pulses from the nearby storm drains. Comparison is shown above to daily average model output as the majority of data do not show time of sample collection. Even if time of collection is available, small shifts in phase between the model and data due to reliance on a single weather station are likely to lead to relatively large discrepancies between the model and individual observations. The strong intra-day variability in predicted sediment concentrations at this station is shown in a detailed examination of December 2002 results (Figure 7-12).

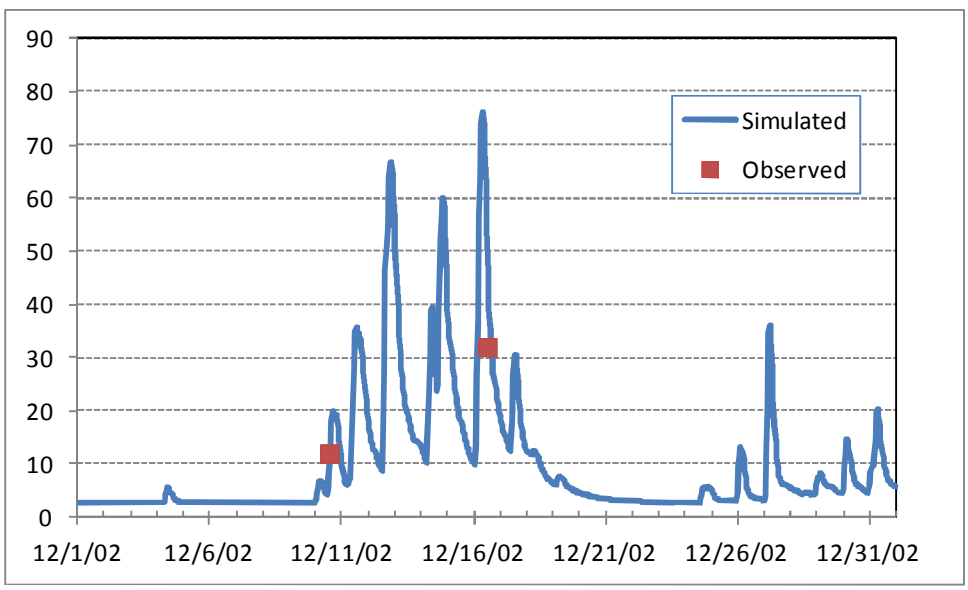


Figure 7-12. Hourly Variability in Predicted Sediment Concentration, Clarks Creek at 66th Street, December 2002

Additional data, mostly from 2002-2003, are available at the mouths of Meeker, Rody, and Diru Creeks. Calibration statistics for TSS are presented in Table 7-2. Most of the stations either do not meet the

minimum data requirement for quantitative analysis of 20 samples (see Section 5.2), or exceed it by a small amount. This leaves the results open to undue influence by outliers. This can be mitigated by examining median rather than average relative errors. Good or very good results are obtained for most stations and high average relative errors are mostly attributable to outliers. For example, at the 12th Street monitoring site, the large average relative error is mostly due to a large error associated with the event of 10/8/2003 when the model predicted a daily average of 145 mg/L, but the observation showed only 3 mg/L. As was noted in Section 6.5, the extreme precipitation recorded for this day may be in error.

Results for Clarks Creek above the State Hatchery should be viewed in light of the observation that flow is often under-predicted at this site due to uncertainty as to exactly where the spring-fed baseflow enters the stream (see Figure 6-23). Therefore, the over-estimation, on average, of TSS at this location is not unexpected.

The limited sampling at the mouths of Meeker, Rody, and Diru Creeks and upstream on Meeker Creek is also affected by occasional outliers and mistiming of event peaks, although the overall results appear consistent with the observations. Further, the simulated concentrations in Meeker, Rody, and Diru are consistent with the observed concentrations just downstream in Clarks Creek at 66th Street.

Table 7-2. Calibration Statistics for Total Suspended Sediment, 2002 – 2010

Station	Observation Count	Mean Observed (mg/L)	Average Relative Error	Median Relative Error
Clarks Creek at 66th Street	25	15.03	-21.7%	-8.6%
Clarks Creek above 7th Street	12	9.00	6.9%	-7.6%
Clarks Creek at 12th Street	32	4.48	70.4%	-7.2%
Clarks Creek below State Hatchery	12	8.17	17.4%	-0.8%
Clarks Creek above State Hatchery	18	4.26	152.3%	3.7%
Meeker Creek mouth	12	28.61	1.7%	-6.8%
Meeker at Reach 123	11	43.98	-27.0%	5.6%
Rody Creek mouth	11	30.67	-6.1%	-2.1%
Diru Creek mouth	11	14.02	51.3%	4.0%

Note: Relative errors are calculated as simulated minus observed normalized to the observed mean.

In sum, data for model calibration to TSS are limited; however, the model appears to perform adequately in predicting the available data. Sample sizes are small and easily influenced by a few outliers. The model does represent both the temporal and spatial trends in observed TSS.

7.6 Sediment Model Testing

The greatest amount of data is for 2002-2003, so observations from 2002 on were used for model calibration. Data from the period prior to 2002 was not used for calibration but reserved for additional testing of the sediment model. Ordinarily, this would be termed a validation test. Unfortunately, sample

sizes for this period are small, with the maximum number of available samples at a single station being nine. Therefore, examination of model predictions for this period is treated as a more qualitative corroboration test. Nonetheless, the general performance of the model for this period appears reasonable. Note that some of the samples collected at 66th Street prior to 2002 were apparently downstream of the Tribal hatchery rearing pond discharge, whereas later samples were upstream, which may help explain the results at that station.

Table 7-3. Validation Statistics for Total Suspended Sediment, 1996 – 2001

Station	Observation Count	Mean Observed (mg/L)	Average Relative Error	Median Relative Error
Clarks Creek at 66th Street	7	8.36	60.0%	43.4%
Clarks Creek above 7th Street	0	ND	ND	ND
Clarks Creek at 12th Street	3	4.63	47.7%	32.1%
Clarks Creek below State Hatchery	8	11.21	-28.2%	-8.5%
Clarks Creek above State Hatchery	9	34.6	-72.2%	1.8%
Meeker Creek mouth	5	123.78	-84.4%	-6.4%
Meeker at Reach 123	3	2.30	267.0%	348.7%
Rody Creek mouth	0	ND	ND	ND
Diru Creek mouth	0	ND	ND	ND

7.7 SEDIMENT LOAD SOURCES

The Clarks Creek model simulation indicates that most flow from pervious surfaces proceeds by interflow and groundwater pathways, rather than direct surface runoff. As a result, the majority of sediment load is simulated as coming from impervious surfaces (although much of this load will actually arise at the interface between impervious and pervious surfaces). The presence of some sediment load coming from interflow through macropores or soil “tubes” is in part accounted for by assigning a small sediment concentration to the spring discharges.

The overall sediment balance for the 51-year simulation period is summarized in Table 7-4. Over the entire stream network there is a net flux to the water column from the stream bank and bed (scour minus deposition) of 17.1 tons/yr. This obscures the fact that reaches at the face of the Vashon till are simulated as having substantial degradation. Degrading reaches are estimated to export a total of 103 tons/yr of sediment to the system, on average.

Table 7-4. Clarks Creek Sediment Balance for 1960-2010 Simulation

Source	Sediment Load (tons/yr)
Upland Sources (load to stream network)	459.8
Baseflow Sources (assigned to spring inflows)	104.0
Net Channel Processes	17.1
Outflow to Puyallup River	581.0

Over the whole watershed (excluding reach 301, where most flow and load is diverted to the Puyallup River by the WSDOT flow splitter), the largest source of sediment is runoff from the uplands. Details of the source of this load are shown in Table 7-5. These reflect generally low loading rates for pervious surfaces (and small areas associated with the agriculture and pasture land uses). High density development (which accounts for 13.3 percent of the land area in the watershed) is estimated to provide 30.5 percent of the total upland sediment load – largely because it contains 40 percent of the impervious area in the watershed. This suggests that strategies to reduce sediment load could focus on areas of more dense development. However, the mainstem of Clarks Creek is also strongly influenced by channel degradation in the area near and above the State Hatchery, estimated by the model to contribute about 42 tons/yr on average. Analysis of tributary contributions to the Clarks Creek mainstem (Table 7-6) suggests that Meeker Creek is the largest tributary contributor of sediment load. The high rates of load suggested by Table 7-6 for Woodland Creek may be an over-estimate as filtering in the wetland reported to be present at the confluence of Woodland Creek and Clarks Creek is not explicitly accounted for in the model.

Table 7-5. Upland Sediment Load Sources for 1960-2010 Simulation

Land Use	Average Total Load to Streams (tons/yr)
Forest	6.6
Agriculture and Pasture	6.7
High Density Development	140.4
Medium Density Development	53.8
Low Density Development	40.3
Roads	146.3
Parks	65.6

Table 7-6. Major Tributary Contributions to Sediment Load to Clarks Creek Mainstem

Tributary	Average Annual Load to Mainstem (tons/yr)
Clarks Creek Mainstem above Meeker Creek	180.8
Meeker Creek	107.8
7th Street Storm Drains	28.8
Pioneer Way Storm Drains	54.2
Woodland Creek	101.8
Diru Creek	52.2
Rody Creek	46.4

7.8 EFFECTIVE WORK ANALYSIS

An effective work analysis based on HSPF model simulated shear stress and geomorphic field work was conducted to estimate potential scour and depositional zones in the Clarks Creek mainstem channel. This is accomplished by combining flow and bed shear stress estimates from Tetra Tech's HSPF hydrology model with estimates of critical shear stress for incipient motion based on bed particle characteristics of individual stream reaches provided by Brown and Caldwell[1].

In physics, "work" is the product of a force times the distance through which it acts and is equivalent to a measure of energy – for example, the energy required to lift a bucket of water 10 feet, or to move a ton of sand 100 yards. The rate of movement of sediment is a function of stream power, which is the product of velocity and boundary shear stress ($ft/s \cdot lb/ft^2$ in English units). If velocity is high but boundary shear is low, few particles will be eroded from the bed. Conversely, if shear is high but velocity is low, particles will be eroded, but little transport will occur. The sum or integral of power over time has units of work, and measures the total amount of sediment transport potential affecting a stream reach. Leopold et al. (1964) recognized that much of the total work done in erosion and transport of sediment occurs through the accumulation of events that have moderate to low power, but occur frequently. It is partly for this reason that bankfull flows (typically with a recurrence interval from 1.3 to 1.7 years) determine the cross-sectional shape of natural channels, rather than larger, more extreme events that may exhibit more power, but occur infrequently. Therefore, an analysis of the effective work done on a channel is an important indicator of channel stability – particularly for the evaluation of impacts of potential changes in hydrology.

It should be noted that the available data are not sufficient to produce quantitative estimates of total erosion. Critical shear stress is based on characteristic particle size (d_{50}) and does not reflect the full range of particles present in the bed, while shear stress time series are calculated from a one-dimensional model in which channel dimensions represent averages over model reaches. Instead, the analysis is most useful for relative evaluation.

[1] Critical Shear Stress Values for Use in Effective Work Analysis, Clarks Creek Sediment Study. Memorandum from Nathan Foged, Brown and Caldwell, December 15, 2011.

The effective work index, *W*, is an integrated measure of the magnitude of work done by flows that exceed a specified critical value for the streambed. The effective work index (in work units of ft-lb/ft^2) is calculated as

$$W = C \sum_{i=1}^{n} (\tau_i - \tau_c)^e V_i \, \Delta t \text{, for } \tau_i > \tau_c,$$

where *C* is a units conversion constant dependent on the exponent *e*, *n* is the number of flow records, τ_i is the exerted boundary shear stress (lb/ft^2) determined using the central channel conditions, τ_c is the critical shear stress that initiates bed mobility (lb/ft^2), *e* is an exponent that captures the rise in stream power with flow (range 1.0 to 2.5), *V* is the mid-channel velocity (ft/s), and Δt is the duration of each flow record (s). Note that the resulting index depends on both the frequency at which τ_c is exceeded and the degree of skew in the flow histogram.

For the Clarks Creek analysis, *e* is assumed to be 1.5 (consistent with theoretical analyses of bedload transport such as Meyer-Peter-Muller), and *C* is ignored, as a relative comparison is the main object. Sixty years of hourly model output are available (529,960 records). To simplify the analysis, this record was sub-sampled to extract one (hourly) record per day. Results for the mainstem model segments (outlined in blue in Figure 7-13) are shown in Table 7-7.

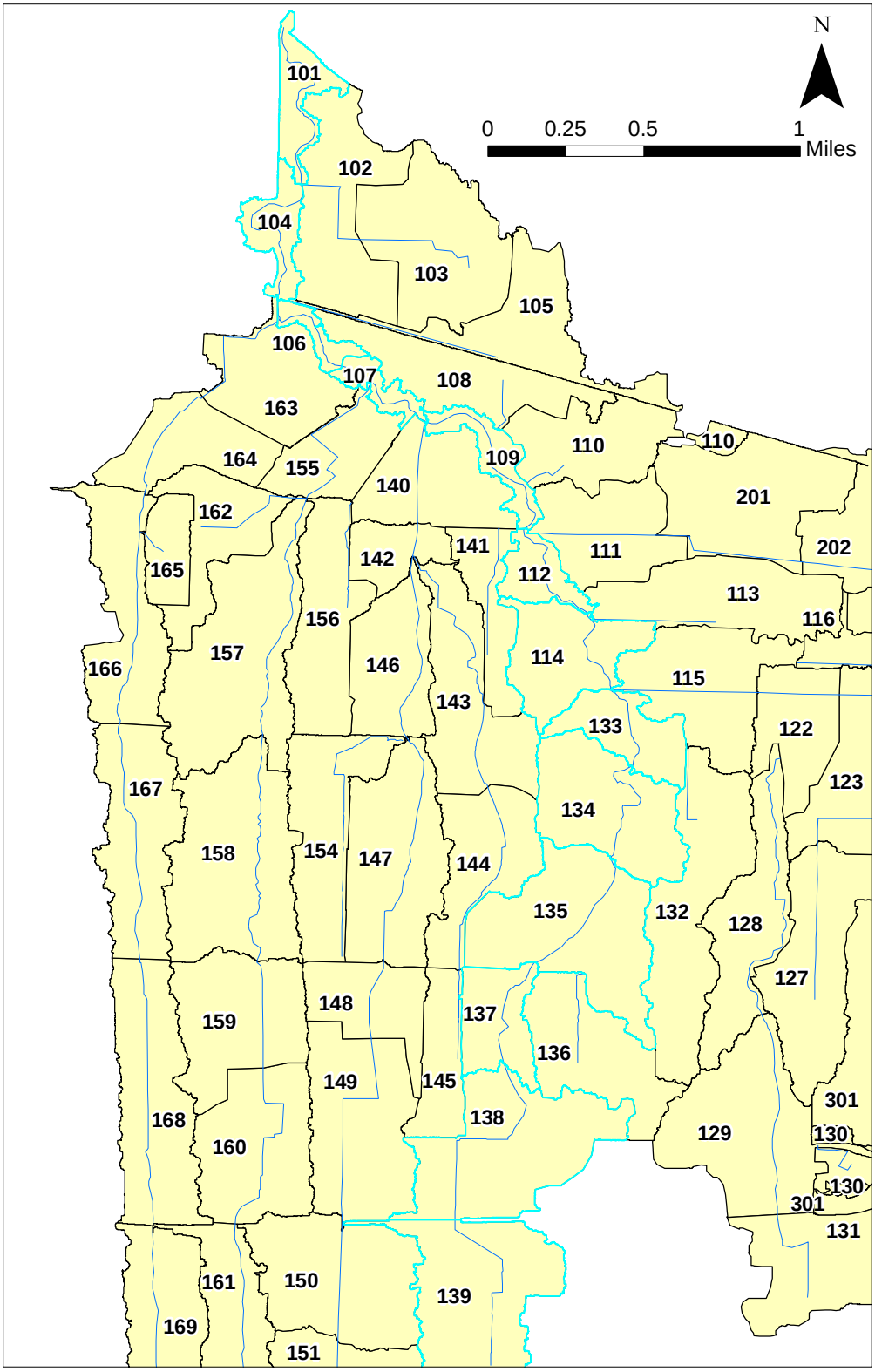


Figure 7-13. Mainstem Reaches, Clarks Creek

Reaches 104, 106, 107, 109, 112, 114, 133, 134,135,137, 138, and 139 constitute the Clarks Creek mainstem.

Table 7-7. Effective Work Analysis for Clarks Creek Mainstem

HSPF Reach	Particle Diameter (d_{50}, mm)	Classification for d_{50}	Critical Shear Stress, τ_c (lb/ft^2)	Average Velocity (ft/s)	Effective Work Index, W (60-year sum)
101	5.97	Fine gravel	0.0818	1.65	$5.12 \cdot 10^8$
104	5.97	Fine gravel	0.0818	1.10	$1.36 \cdot 10^8$
106	0.10	Very fine sand	0.0024	1.20	$2.46 \cdot 10^8$
107	0.09	Very find sand	0.0023	1.81	$1.47 \cdot 10^8$
109	0.09	Very fine sand	0.0023	1.67	$1.10 \cdot 10^8$
112	0.29	Medium sand	0.0043	0.96	$4.77 \cdot 10^7$
114	0.22	Fine sand	0.0036	0.70	$6.49 \cdot 10^7$
133	0.14	Fine sand	0.0028	0.73	$2.52 \cdot 10^7$
134	4.28	Fine gravel	0.0555	1.12	$3.76 \cdot 10^9$
135	13.57	Medium gravel	0.2034	2.08	$8.77 \cdot 10^9$
137	4.84	Fine gravel	0.0642	14.98	$3.80 \cdot 10^9$
138	4.84	Fine gravel	0.0642	10.80	$6.53 \cdot 10^8$
139	4.84	Fine gravel	0.0642	8.48	$1.92 \cdot 10^8$

The longitudinal profile of the effective work index is shown in Figure 7-14. The effective work index reaches a maximum in reach 135, the steep reach upstream of the State Hatchery in Clarks Creek Park. This is consistent with the coarse nature of the sediment in this reach which reflects the impact of cumulative work removing fines. Active scouring is likely occurring in this reach. As the stream emerges from the face of the Vashon Till onto the alluvial plain the gradient, effective work, and the diameter all decrease dramatically, suggesting areas that are primarily depositional. Effective work increases again in the most downstream reaches, consistent with a coarsening of the sediment.

Effective work curves (plotting the summed work index versus flow range bins) are most useful for examining potential channel response to changes in conditions (e.g., pre- and post-development). Portions of the curve in which work increases dramatically provide an indication of the flow range that may need to be controlled to promote channel stability. Figure 7-15 shows effective work curves for existing conditions in the till area. When natural condition and full buildout runs are completed these can be used to examine potential changes in channel stability. Pre and post-development conditions can also be summarized by the Erosion Potential (MacRae, 1992), E_p, calculated as W_{post}/W_{pre}. An E_p value greater than about 1.5 is typically a strong indicator of potential channel instability.

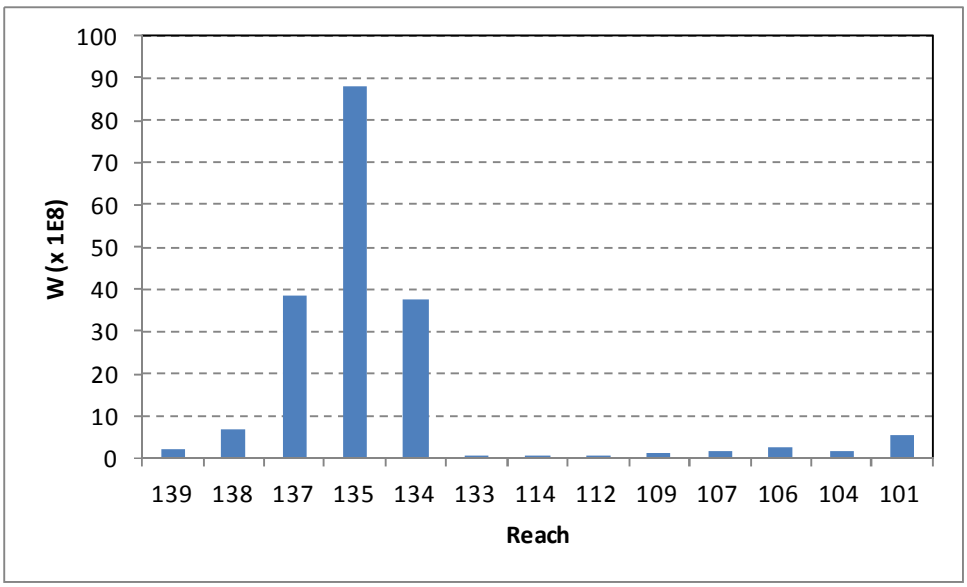


Figure 7-14. Longitudinal Profile of Effective Work Index (W)

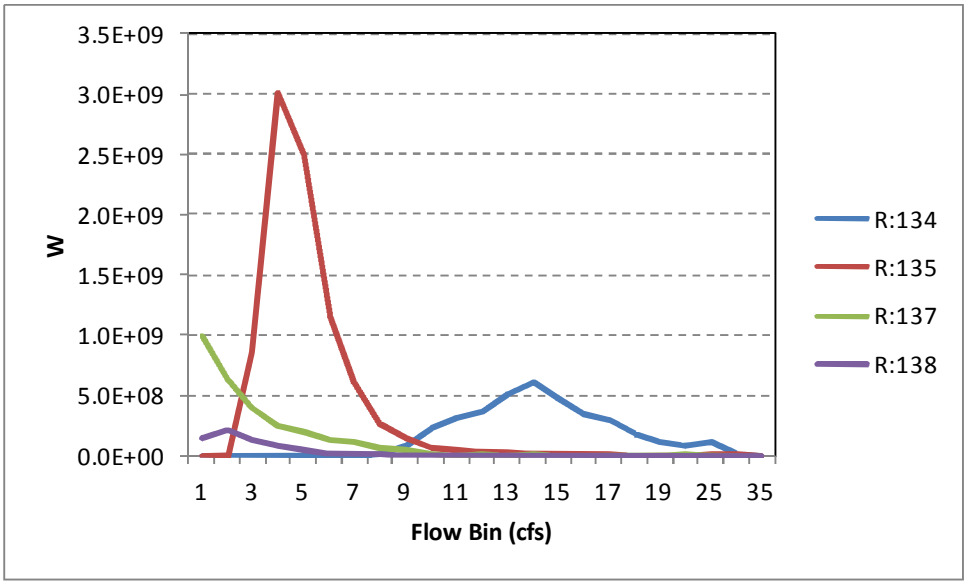


Figure 7-15. Effective Work (W) Curves for Reaches in the Till Area, Existing Conditions

Note: Flow bins show the high value of the flow interval summarized in the graph, using 1 cfs increments up to 20 cfs.

The effective work analysis shows the potential for work to be done (movement of sediment over distance) relative to the current median sediment diameter. The peak value in Reach 135 suggests that ongoing degradation of the channel is likely occurring in this reach.

7.9 SENSITIVITY OF SEDIMENT MODEL RESULTS

Sufficient data are not available to strongly constrain a unique solution to the simulation of sediment in Clarks Creek. Nonetheless, the model provides a reasonable description of the processes contributing to sediment load and transport within the creek, based on multiple lines of evidence. The model is useful, but not necessarily always correct. In particular, attribution of loads to specific sources is uncertain given the relatively small amount of local monitoring data. Model predictions are especially sensitive to the following assumptions:

- The relative importance of loads from pervious surfaces is in large part determined by the amount of overland flow simulated from such surfaces. Flow at the only continuous stream gage in Clarks Creek (Tacoma Road) is strongly influenced by spring discharges, so the fit of model partitioning between surface and subsurface flows is subject to some uncertainty.
- Loads from pervious surfaces appear to be more strongly controlled by transport capacity than by detached sediment availability. The current model is consistent with studies from the Green-Duwamish watershed in King Co.; however, detailed local monitoring could refine and improve the fit.
- The majority of land area in the Clarks Creek watershed is occupied by medium density residential land uses and roads. Total sediment load predictions are thus sensitive to the loads predicted for residential and road impervious surfaces. Unlike pervious surfaces, load from impervious surfaces is more strongly controlled by solids availability than transport capacity. Thus, the model predictions are particularly sensitive to the ratio of solids accumulation to solids removal on impervious surfaces (ACCSDP/REMSDP), which determines the limiting concentration of solids available for transport to the stream.

The current model is based on limited observations of flow and TSS. No small-scale monitoring has been conducted to estimate loads from individual land use areas. As additional data are collected it is likely that the Clarks Creek model can be improved. However, the existing model, despite uncertainties, is believed to provide a strong basis for the initial evaluation of potential sediment control options.

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8 Other Water Quality Parameters

Clarks Creek is impaired due to excessive concentrations of fecal coliform bacteria and due to low dissolved oxygen concentrations that appear to be related to nutrient enrichment and overgrowth of the invasive macroalgae *Elodea nuttalli*. Therefore, estimates of both bacterial and nutrient/organic matter loads to the creek are of considerable importance.

8.1 Water Quality Model Setup

Unfortunately, resources were not available to undertake full calibration of the watershed model to bacteria and nutrients at this time. As an alternative, information on land use and model simulated surface and subsurface flows by land use were combined with event mean concentrations (EMCs) obtained from a nearby watershed to estimate likely bacterial and nutrient loading. The concentrations were obtained from the Green-Duwamish watershed in King County, where detailed monitoring and analysis of concentrations and loads by land use has been conducted (Herrera, 2007).

This report (Table 5-12) gives pollutant loads for different land cover types (high density developed, low-to-medium density developed, agriculture, and forest – see Table 8-1) and reports flow and loading rates separately for baseflow and event runoff conditions.

Table 8-1. Green-Duwamish Loading Rates by Land Use (Herrera, 2007)

Constituent	Flow Component	High Density Developed	Low-Medium Density	Agriculture	Forest
Inorganic N (lb/ac/yr)	Baseflow	2.85	2.41	6.69	4.73
	Runoff	4.82	3.03	5.00	2.23
Inorganic P (lb/ac/yr)	Baseflow	0.04	0.04	0.06	0.10
	Runoff	0.11	0.05	0.49	0.02
Organic P (lb/ac/yr)	Baseflow	0.12	0.04	0.11	0.04
	Runoff	0.32	0.15	0.21	0.11
Fecal Coliform (#/ac/yr)	Baseflow	2.76E+10	6.60E+09	1.20E+09	1.40E+09
	Runoff	1.12E+11	6.25E+10	4.71E+10	4.60E+09

The information in Table 8-1 was converted to event mean concentrations (EMCs) to allow portability to a slightly different precipitation-runoff regime. For calculating EMCs for developed lands, the flow attributable to impervious surfaces was estimated as

$$Q_I = \frac{Q_{tot} - Q_P \cdot (1 - I)}{I},$$

where Q_{tot} is the total unit area runoff (volume per area per year), I is the impervious fraction, Q_I is the unit area runoff from impervious surfaces, and Q_P is the unit area runoff from developed pervious surfaces, assumed to be equivalent to the runoff rate cited for agriculture (0.12 ML/ha/yr). Low-to-medium density developed land was assumed to have an effective imperviousness of 25 percent, and high density developed land was assumed to have an effective imperviousness of 75 percent. Baseflow EMCs

are assumed to apply to groundwater discharge, while storm event EMCs are assumed to apply to surface runoff and interflow (as most of the storm event volume simulated for Clarks Creek occurs as rapid interflow.) Finally, EMCs for pervious runoff from developed land use categories are assumed to be similar to forest, although the load is scaled up to agricultural runoff rates. The resulting EMCs are shown in Table 8-2. Note that Herrera (2007) does not provide results for total N or organic N, so only the inorganic N components (nitrate, nitrite, and ammonia nitrogen) are shown.

Table 8-2. Green-Duwamish EMCs for Nutrients and Bacteria

Constituent	Flow Component	High Density Developed	Low-Medium Density	Agriculture	Forest
Inorganic N (mg/L)	Pervious Runoff	22.727	22.727	46.667	22.727
	Baseflow	16.842	13.500	41.667	9.464
	Impervious Runoff	10.485	15.051	NA	NA
Inorganic P (mg/L)	Pervious Runoff	0.182	0.182	4.583	0.182
	Baseflow	0.263	0.250	0.389	0.196
	Impervious Runoff	0.255	0.485	NA	NA
Organic P (mg/L)	Pervious Runoff	1.091	1.091	1.917	1.091
	Baseflow	0.684	0.250	0.667	0.089
	Impervious Runoff	0.727	0.798	NA	NA
Fecal Coliform Bacteria (#/L)	Pervious Runoff	4.182E+04	4.182E+04	3.925E+05	4.182E+04
	Baseflow	1.453E+05	3.300E+04	6.667E+03	2.500E+03
	Impervious Runoff	2.461E+05	6.526E+05	NA	NA

Note: "Pervious Runoff" includes both surface flow and interflow. EMCs are calculated from Table 5-12 in Herrera (2007).

In addition to runoff from the land surface, a nitrate concentration of 2 mg/L is assigned to the spring outflows that feed Clarks Creek, based on data summarized by Jones et al. (1999). No pollutant loads are assigned to the two hatchery discharges: these loads are believed to be small and very little data are available.

8.2 WATER QUALITY MODEL RESULTS

The EMC approach provides reasonable estimates of loading to the Clarks Creek system. It does not provide reliable concentration estimates because (1) actual concentrations in runoff will vary with event, (2) processes within the stream channel, such as uptake of nutrients by macrophytes or losses to the sediment are not simulated, and (3) the water quality simulation is not calibrated.

Table 8-4 shows the average annual distribution of upland load sources by land use. Of note here is the large inorganic N load attributed to "springs". This represents the 2 mg/L nitrate-N concentration assigned to the spring-fed baseflow in Clarks Creek, as documented by Jones et al. (1999). As the flow from the springs is on the order of 40-50 cfs this represents 37 percent of the total inorganic N load.

Table 8-3. Upland Nutrient and Bacteria Load Sources for 1960-2010 Simulation

Land Use	Inorganic N (lb/yr)	Inorganic P (lb/yr)	Organic P (lb/yr)	Fecal Coliform (#/yr)
Forest	22,244	391	424	1.5E+07
Agriculture and Pasture	29,450	523	541	4.7E+12
High Density Development	58,657	1,322	3,785	5.5E+14
Medium Density Development	83,706	1,609	2,566	3.9E+14
Low Density Development	52,808	896	1,605	1.6E+14
Roads	62,859	1,388	3,985	5.7E+14
Parks	47,523	1,001	1,599	3.2E+14
Springs	209,058	0	0	0

The distribution of loads by tributary is provided in Table 8-4 and Figure 8-1. Note that these are summations of upland loads to a tributary, not actual loads within the tributary, which will be subject to various uptake and transformation processes.

Table 8-4. Major Tributary Contributions of Nutrient and Bacteria Load to Clarks Creek

Tributary	Inorganic N (lb/yr)	Inorganic P (lb/yr)	Organic P (lb/yr)	Fecal Coliform (#/yr)
Clarks Creek Mainstem above Meeker	243,300	653	1,290	1.59E+14
Meeker Creek	61,418	1,308	2,937	4.44E+14
7th Street Storm Drains	16,048	360	760	1.27E+14
Pioneer Way Storm Drains	28,377	666	1,404	2.56E+14
Woodland Creek	77,196	1,457	3,042	3.94E+14
Diru Creek	47,070	870	1,704	2.14E+14
Rody Creek	43,242	753	1,523	1.90E+14

Note: Loads do not reflect any instream losses or retention.

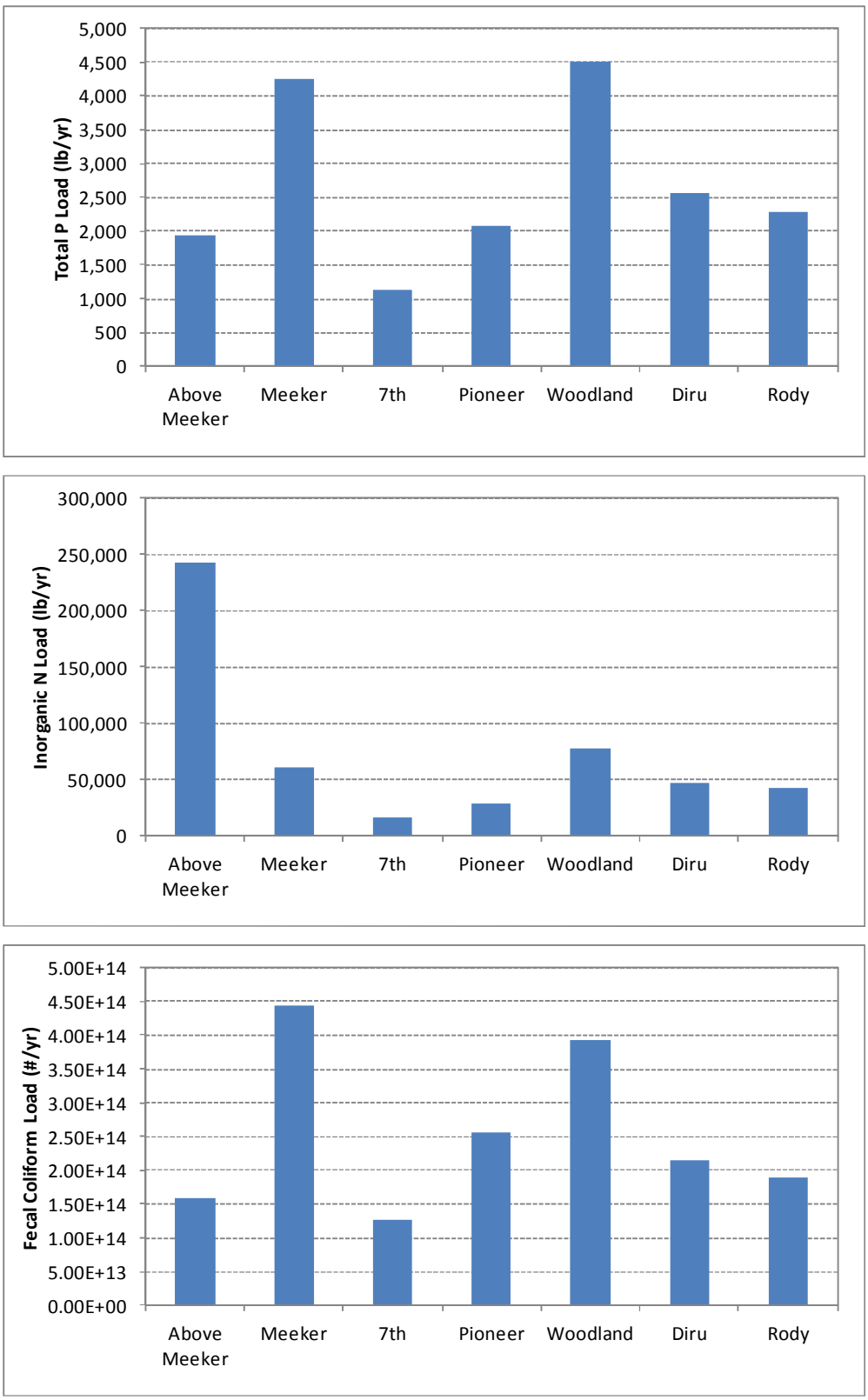

Figure 8-1. Nutrient and Bacterial Loads by Tributary to Clarks Creek Mainstem

9 Natural Condition and Buildout Scenarios

9.1 Natural Conditions Scenario

The natural conditions scenario is intended to evaluate flows and sediment loads in Clarks Creek in the absence of anthropogenic development. To do this, land use in the model was reverted to a representation of presumed natural conditions, eliminating all developed land use classes (including roads) and converting non-wetland areas back to mature forest. Note that the drainage network and channel characteristics were generally *not* modified for this scenario as their pre-development conditions are not well documented. The major exception is that the flow splitter that currently routes most of the flow from subbasin 301 to the Puyallup River was removed from the model.

9.2 Buildout Scenario

The buildout scenario examines the potential impacts of full buildout in the watershed. The land use for this case is obtained by converting existing undeveloped land uses to zoned land uses except where protected from development (e.g., parks). This reveals the maximum amount of development and impervious surfaces that could occur in the watershed under current land use plans. The buildout land use changes the amount of directly connected impervious area in the watershed from 25 percent to 31 percent. Comparison of existing to future buildout land uses in the watersheds (Figure 9-1) shows that this scenario involves a significant amount of redevelopment from low density to medium density developed land uses.

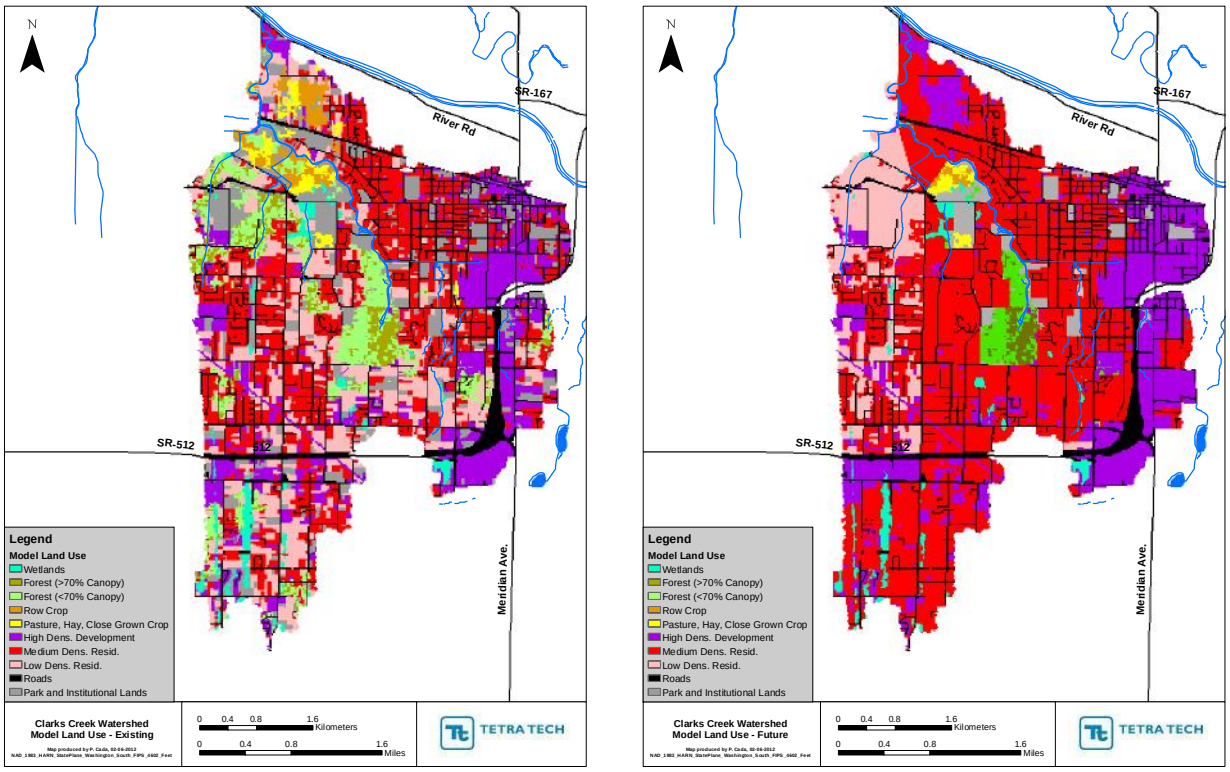

Figure 9-1. Current and Future Buildout Land Uses in Clarks Creek Watershed

Ecology's draft Phase II Municipal Stormwater Permit, Minimum Requirement #5, "On-site Stormwater Management," specifies Low Impact Design (LID) requirements that would apply to development

projects that result in greater than 2,000 square feet of new plus replaced hard surfaces. Specifically, this says "Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 8% of the 2-year peak flow to 50% of the 2-year peak flow." If more than 5,000 square feet of hard surface is created, then Minimum Requirement #7 also applies, which requires stormwater BMPs to control flow duration from one half of the 2-year peak flow up to the 50-year peak flow.

The type of stormwater controls that can be expected for future development thus depends in part on the size of projects: smaller projects would need to meet Minimum Requirement #5, while larger requirements would need to meet both Minimum Requirement #5 and Minimum Requirement #7. The intent of the buildout simulation is to provide a future baseline that represents a realistic worse case that is still consistent with the regulations. Some unknown portion of the new development would occur in smaller projects so that Minimum Requirement #7 would not apply. Therefore, the buildout scenario is constructed under the assumption that all new development will meet Minimum Requirement #5 (but not #7) to provide a reasonable worst-case baseline against which to evaluate additional BMP requirements.

The majority of peak runoff comes from impervious surfaces, and the difference in peak flows between developed pervious and undeveloped pervious will be much less than the difference between impervious and undeveloped pervious lands. Therefore, Minimum Requirement #5 is approximated by designing a BMP representation that controls runoff from impervious surfaces to not exceed pre-development pervious surface runoff from 8 percent of the 2-year peak flow to 50 percent of the 2-year peak flow. The BMP is represented in HSPF as a "stream reach" on a unit area basis, the hydraulic behavior of which is described in an FTable relating storage to outflow. This unit area simulation is multiplied by the area in new impervious surfaces draining to each stream reach to represent the impacts of new development constructed in accordance with Minimum Requirement #5.

To construct the analysis, the pre-development condition was assumed to be dense forest on C soils - essentially the median soil type for the watershed. Analysis of 51 years of simulated runoff events using the BASINS Synoptic Analysis tool gives a 2-year peak flow of 0.00623 in/hr, so the control requirements apply from 0.000498 to 0.00311 in/hr.

The generic BMP (which could, for instance, be bioretention) is represented as having a treated outflow, Q_{Treat} and a bypass outflow, Q_{Bypass}, so the total outflow is $Q_{Out} = Q_{Treat} + Q_{Bypass}$, all in units of in/hr. The treated outflow is simulated as following a first-order recession curve, similar to groundwater discharge. A continuous mass balance of the BMP behavior relative to an input series (Q_{In}) from simulation of one acre of impervious cover (without any extra surface storage) can then be constructed as follows:

$$Q_{Treat} = \text{Min}\ \{K_{GW} \cdot V_{t-1}, Q_{Max}\},$$

where V_{t-1} is the storage volume at the end of the previous time step, Q_{Max} is the maximum allowed outflow rate, and $K_{GW} = 1 - A_{GWRC}^{1/24}$, where A_{GWRC} is a daily recession parameter, with the same functional interpretation as the recession parameter in HSPF. Bypass flow occurs when the storage volume exceeds the maximum storage capacity of the BMP:

$$Q_{Bypass} = \text{Max}\ \{0, V_{t-1} + Q_{In} - V_{Max}\},$$

where Q_{In} is the inflow for the time step and V_{Max} is the maximum storage capacity. Finally, the new volume at time t is updated as

$$V_t = \text{Min}\ \{V_{t-1} - Q_{Treat} + Q_{In} - Q_{Bypass} - Q_{Seep}, V_{Max}\},$$

where Q_{Seep} represents net losses that may include seepage to groundwater or evapotranspiration.

Iterative application of this model reveals a set of parameters that satisfies the control requirements of Minimum Requirement #5, with $A_{GWRC} = 0.985$, $Q_{Max} = 0.0023$ in/hr, $V_{Max} = 3.6$ in, and $Q_{Seep} = 0.003$ in/hr. (V_{Max} would be applied on the basis of acres of impervious area; if the BMP had a depth of 3 ft this would work out to a requirement of 4,356 ft^2 of BMP per each acre of imperviousness.) Application

results to the 1960-2010 simulation are shown in Figure 9-2. The green line shows unmitigated conditions for runoff from impervious surfaces, while the red line represents natural conditions flow, obtained from model simulation of undisturbed forest. The blue line shows mitigated flow, with the BMP representing Minimum Requirement #5 in place, and remains below the natural condition curve across the control range of 0.000498 to 0.00311 in/hr.

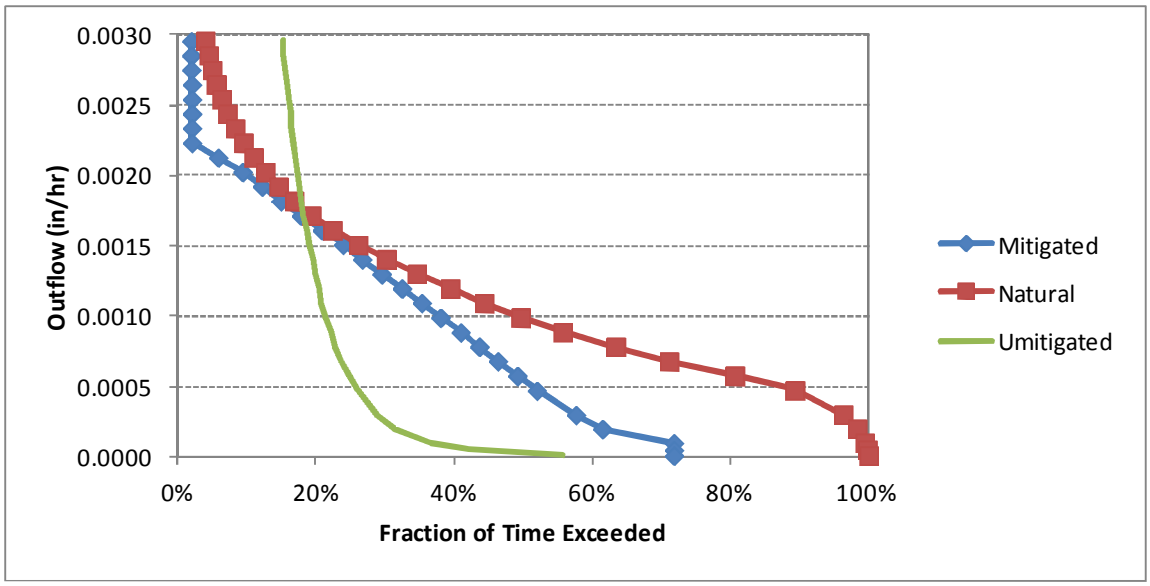

Figure 9-2. BMP Representation of LID Performance Standard for New Development

To implement this generic BMP in the HSPF model via a reach FTable, the output must be represented in units of cfs (per acre, as this is on a unit basis). A factor of 1.008333 converts outflow in ac-in/hr to cfs. The resulting FTable is shown in Table 9-1. Output from this FTable is multiplied by the appropriate area of new impervious surfaces (and the conversion from inches to feet) to link this "reach" to each receiving stream segment.

Table 9-1. HSPF FTable for Representing LID BMP on a Unit Area Basis

```
  FTABLE    100
Future Imperv LID Standard, in/ac        ***
 rows cols                               ***
   11    6
     DEPTH      AREA    VOLUME  treated   bypass    loss    ***
       in        ac     ac-in   ----- cfs/ac-in-hr -------- ***
     00.000  00.0000  00.00000  00.00000  00.00000  0.000000
     00.003  00.0972  00.00300  00.00000  00.00000  0.003025
     00.010  00.0972  00.01000  00.00000  00.00000  0.003025
     00.167  00.0972  00.16650  00.00010  00.00000  0.003025
     00.500  00.0972  00.50000  00.00032  00.00000  0.003025
     01.000  00.0972  01.00000  00.00063  00.00000  0.003025
     02.000  00.0972  02.00000  00.00127  00.00000  0.003025
     03.000  00.0972  03.00000  00.00190  00.00000  0.003025
     03.600  00.0972  03.50000  00.00222  00.00000  0.003025
     04.000  00.0972  04.00000  00.00222  04.02809  0.003025
     10.000  00.0972  10.00000  00.00222  10.07809  0.003025
  END FTABLE100
```

Flow into the BMP that is not bypassed is assumed to achieve a significant degree of sediment retention as the treated water will likely be filtered through the LID planting medium. Specifically, trapping of 100 percent of sand, 90 percent of silt, and 80 percent of clay is assumed.

9.3 SCENARIO RESULTS

Buildout conditions result in an increase in impervious area; however, the extent of directly connected impervious area is already high under current conditions. Therefore, the difference between current conditions and natural conditions is more dramatic than the difference between current and buildout conditions.

Scenario statistics for flow at a variety of key locations in the watershed are provided in Table 9-2. There are only small differences between scenarios for median and average flows. For the mainstem, the majority of the flow is provided by spring discharges which are assumed to remain unchanged under the three scenarios. In contrast, large differences are seen for the 2-year and 10-year recurrence daily flows. For the 2-year event, flows under current conditions are much greater than estimated for natural conditions both in the tributaries and at the downstream station on Clarks Creek at 66th Street. In contrast, 2-year and 10-year flows in Clarks Creek at 12th Street are predicted to have increased only slightly relative to natural conditions, mostly because a large portion of the upstream drainage area is protected by Clarks Creek Park.

Table 9-2. Scenario Results for Flow

Parameter	Scenario	Clarks Creek at 66th St.	Meeker Creek Mouth	Clarks Creek at 12th St.	Diru Creek Mouth	Rody Creek Mouth
Median Flow (cfs)	Current	63.8	1.4	54.5	1.7	1.8
	Natural	62.2	1.7	54.2	1.5	1.6
	Buildout	63.9	1.3	54.5	1.7	1.8
Average Flow (cfs)	Current	66.8	2.4	54.4	2.3	2.3
	Natural	63.1	2.1	54.0	1.7	1.8
	Buildout	67.3	2.5	54.4	2.3	2.3
2-year Daily Flow (cfs)	Current	182.5	27.0	86.5	16.6	14.3
	Natural	116.0	11.8	85.7	8.2	6.6
	Buildout	195.0	30.3	86.6	18.2	15.2
10-year Daily Flow (cfs)	Current	256.0	46.6	88.9	25.5	21.6
	Natural	147.8	19.6	87.1	13.4	10.5
	Buildout	279.9	54.6	88.9	28.0	23.3

Figure 9-3 displays flow-duration curves for Clarks Creek at 66th Street in two different ways. The top panel plots daily flow for each scenario versus the percent of time that flow is exceeded, which emphasizes the middle range of flows. The bottom panel plots flows versus empirical recurrence

frequency in the 51-year model simulation, which emphasizes the extreme flows. The top panel emphasizes that there is little difference between scenarios for median and small flows, which are largely determined by spring discharges, although the current and buildout scenarios diverge from natural conditions for flows that are exceeded less than 20 percent of the time – i.e., during wet weather runoff events. The bottom panel shows, in contrast, that there are large differences for larger storm flows that occur with a return frequency of two years or more.

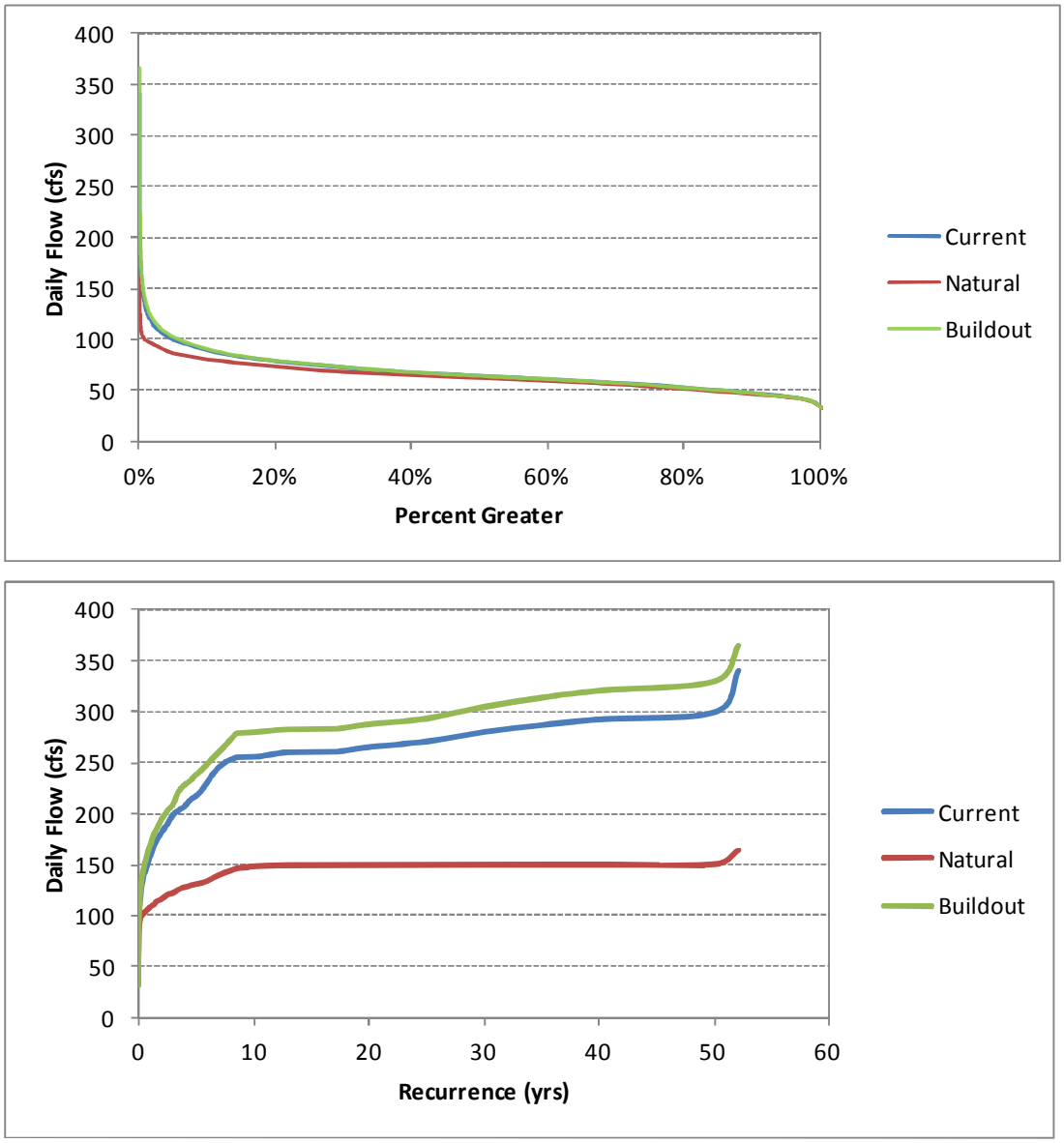

Figure 9-3. Flow Durations for Clarks Creek at 66th St. under Current, Natural, and Buildout Conditions

Scenario results for sediment (Table 9-3) generally follow the results for flow: There is only a small difference between current conditions and predicted conditions at buildout, but both the current and buildout scenarios have much higher TSS concentrations and sediment loads than are predicted for forested natural conditions. Interestingly, the predicted loads are somewhat lower under buildout conditions than under current conditions. This is due to the sediment removal simulated in the BMPs required under the proposed general permit, which includes lands that are predicted to be re-developed to higher density developed land uses. The simulation of sediment deposition at 12th Street on Upper Clarks

Creek suggests that there may have been significant deposition at this location even under natural conditions, due primarily to erosion in the steep reaches immediately upstream. If correct, this result suggests that this portion of Clarks Creek had not reached a dynamic equilibrium under natural conditions, but was instead still actively adjusting to conditions following the conclusion of the last glaciation.

Table 9-3. Scenario Results for Sediment

Parameter	Scenario	Clarks Creek at 66th St.	Meeker Creek Mouth	Clarks Creek at 12th St.	Diru Creek Mouth	Rody Creek Mouth
Median TSS (mg/L)	Current	2.9	5.9	2.8	2.8	2.8
	Natural	1.7	0.5	1.8	1.9	0.7
	Buildout	2.9	5.9	2.8	2.8	2.8
Average TSS (mg/L)	Current	6.1	14.8	3.3	9.0	11.0
	Natural	2.1	2.4	1.9	3.2	1.9
	Buildout	5.6	13.4	3.2	8.3	10.4
Average Annual Sediment Load (tons/yr)	Current	578.7	107.2	180.8	51.1	56.8
	Natural	138.5	9.9	99.5	7.6	5.7
	Buildout	545.0	98.7	174.1	50.1	56.4
Sediment Deposition (tons/yr)	Current	10.1	0.1	-11.7	2.6	3.1
	Natural	0.8	-0.2	-16.2	-2.3	-1.1
	Buildout	8.5	0.1	-10.9	3.7	3.9

The model simulates most active channel degradation as occurring in reach 134 (one reach above 13th Street), with an average of 30.0 tons/yr of scour under current conditions. The natural condition simulation shows less scour, but still simulates 26.0 tons/yr. The buildout condition scenario predicts a slight increase, to 31.0 tons/yr.

Relative to natural conditions, the model suggests a large increase in average TSS concentrations and annual sediment load. This is accompanied by a large increase in sediment deposition in lower Clarks Creek at the 66th Street monitoring point.

As seen above (Figure 9-3), buildout conditions result in a noticeable increase in the magnitude of large, low-frequency storm event flows, but only small changes in the more frequent flows that do the majority of the work on the channel. An effective work analysis was also conducted for buildout conditions and compared to the results for existing conditions for the Clarks Creek mainstem reaches through the ratio of the sum of the effective work indices, E_p, calculated as $W_{buildout}/W_{existing}$ (see Section 7.8). Results are summarized in Table 9-4. While E_p is greater than one, the largest value is about 1.06, far less than the criterion of 1.5 recommended as a strong indicator of potential channel instability by MacRae (1992). Thus, the anticipated conditions at buildout (with stormwater controls equivalent to Minimum Requirement #5) do not appear likely to induce significant additional channel instability.

Table 9-4. Change in Effective Work Index from Existing to Buildout Conditions

Reach	*W* at Buildout (x 10^{-8})	*W*, Existing (x 10^{-8})	E_p
139	1.97	1.95	1.00882
138	6.89	6.64	1.03713
137	40.72	38.58	1.05560
135	88.34	87.88	1.00523
134	37.71	37.61	1.00275
133	0.25	0.25	1.00099
114	0.65	0.65	1.00208
112	0.48	0.48	1.00241
109	1.10	1.10	1.00217
107	1.48	1.47	1.00435
106	2.46	2.46	1.00132
104	1.37	1.36	1.00613
101	5.21	5.13	1.01503

In sum, the watershed model scenarios suggest that existing development has substantially altered the natural hydrology and sediment dynamics of Clarks Creek, leading to increased peak flows, increased sediment load, degradation of upland stream reaches, and aggradation of reaches in the alluvial plain. However, risks from future development appear relatively small – mostly because most of the available land has already been developed. Mitigation of sediment problems in Clarks Creek would thus require addressing flow and sediment loads from existing development.

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Appendix A. Impervious Area Determination

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TETRA TECH

Memorandum

Date:	December 1, 2011
To:	Char Naylor/PTI
c:	*Jon Butcher/Tetra Tech* *Mike Milne/B&C*
From:	Jerry Scheller/Tetra Tech, Tracy Winjum/Tetra Tech
Project No./Name:	135-64934-11001-01/Clark Creek Sediment Study
Subject:	Impervious Surfaces Analysis

This memorandum presents the approach used for estimating impervious area in the Clark Creek Basin for input into the HSPF model developed for the Clarks Creek Sediment Reduction Project.

Roadways, parking lots sidewalks, roof tops and any other hard or paved surface that prevent rainfall from infiltrating into the ground are considered to be impervious surfaces. Impervious surfaces are classified two ways, directly-connected and indirectly-connected. Directly-connected impervious areas (DCIA) are impervious surfaces that are directly connected to the receiving water through a constructed drainage system. Usually these drainage conveyance systems are comprised of curb and gutter, pipes, and ditches and speed the flow of stormwater runoff to the receiving water. For this reason, DCIA has the greatest impact on peak flow and runoff volumes in the Clarks Creek basin. Indirectly-connected impervious surfaces are those surfaces located adjacent to vegetated areas such as lawn, forest or pasture, and usually exhibit runoff characteristics similar to the adjacent land cover. Total impervious area (TIA) is the combination of the directly- and indirectly-connected impervious area. For this memo, impervious surfaces will be presented as DCIA and TIA.

Impervious surface is represented in the HSPF model with a series of Hydrologic Response Units (HRUs), referred to as IMPLNDS, that define runoff characteristics during rainfall events. Four HSPF IMPLND classifications were identified in the memorandum *HRU's for Clarks Creek Model* (Tetra Tech, 2011). The four IMPLND classifications are described below:

IMPLND 1: Impervious area of major highways.

IMPLND 2: Impervious areas of roads and driveways in residential, park and institutional areas.

IMPLND 3: Impervious area of high-density development parking lots.

IMPLND 4: Building footprints.

Pervious HRU and HSPF model development is described in a separate memorandum.

IMPLND 1 impervious area for major highways was measured directly for the aerial photography. SR512 is the only major highway in the Clarks Creek Basin. Directly measured impervious highway area is documented in Table A-1 in Attachment A.

The impervious area for IMPLND 2, 3, and 4 classifications were computed by applying a representative fraction of TIA and DCIA for roads and driveways for a variety of land covers in the Clarks Creek basin. Impervious fractions were estimated by direct measurement from aerial photos by sampling of nine locations assumed to represent a range of land covers found in the basin. Sampled represented areas are documented in Attachment B.

The impervious fractions were applied to the landuse on a parcel basis taken from the Land Use shapefile provided by Piece County. Rights-of-way were classified as commercial, residential or rural based on adjoining parcel land use. Impervious fractions were applied to each right-of-way area. Figure 1 shows the land and right-of-way use in the Clarks Creek basin. Table 1 shows the corresponding impervious area fraction for each land use.

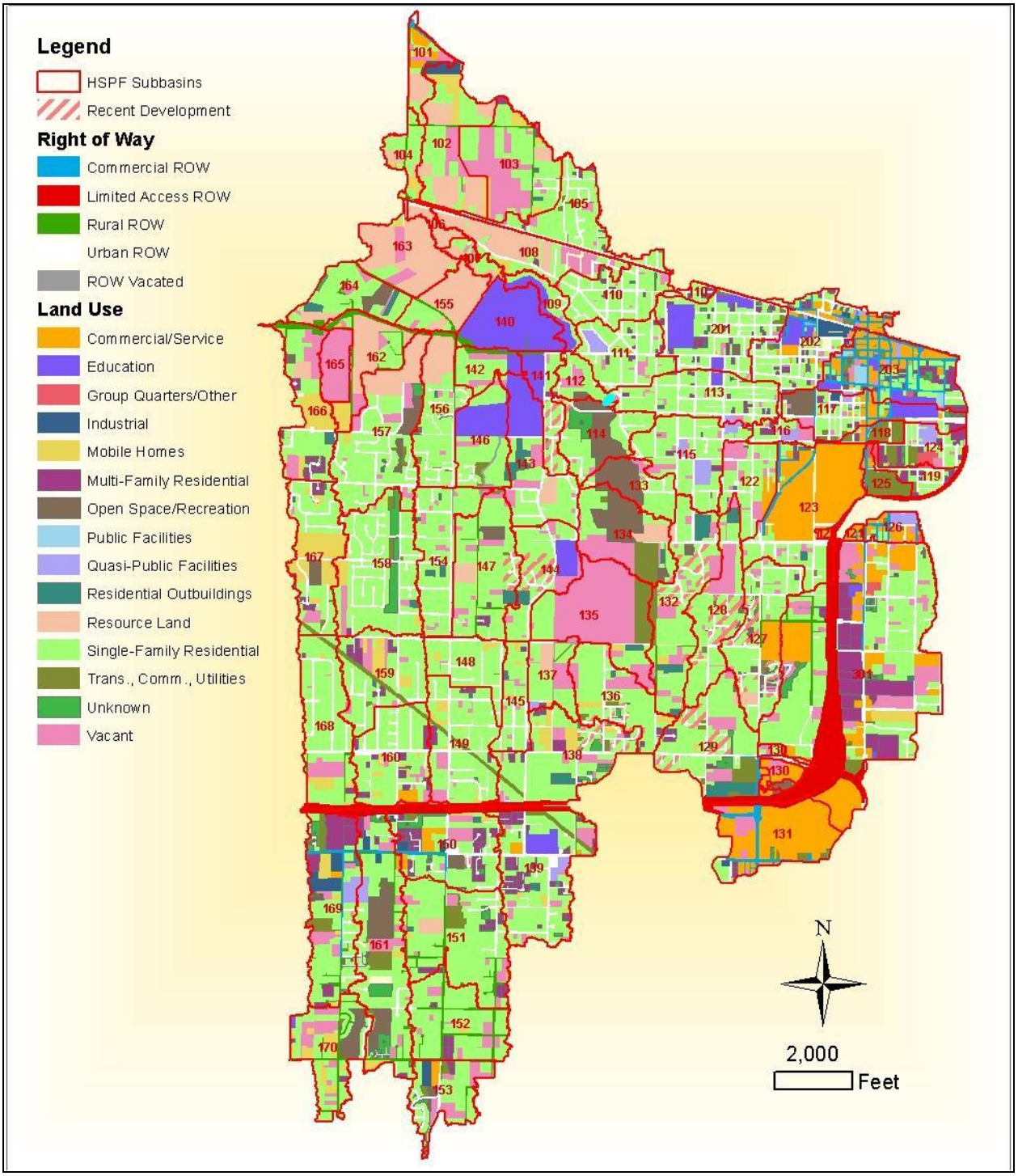


Figure 2 Land Use in the Clarks Creek Basin (Pierce County, 2011)

TABLE 1
PARCEL LAND USE ESTIMATED IMPERVIOUS AREA FRACTION

Land Use Category	TIA (%)	DCIA Fraction (%) Road-Parking	HD[a] Parking	Roof	Source
Unknown	0	0		0	
SFR (0-1/8 acre)	56	11		40	Sampled[b]
SFR (1/8-1/4 acre)	41	9		0	Sampled[b]
SFR (1/8-1/4 acre) - Recent[c]	41	9		20	Sampled[b]
SFR (1/4-1/2 acre)	39	10		0	Sampled[b]
SFR (1/4-1/2 acre) - Recent[c]	39	10		21	Sampled[b]
SFR (1/2-1 acre)	17	5		0	Sampled[b]
SFR (>1 acre)	17	5		0	Sampled[b]
MFR	75	0	48	25	Sampled[b]
MFR - Low-Density	40	10		5	By Inspection[d]
Group Quarters/Other	75	0	48	25	Assumed to be MFR
Mobile Homes	85	0	60	25	By inspection[d]
Residential Outbuildings	17	5		0	Assumed to be SFR (1/2 - 1 ac)
Commercial/Service	85	0	70	14	Sampled[b]
Industrial	90	0	45	45	By Inspection
Transportation, Communication, Utilities	90	90		0	
Education	53	0	24	26	Sampled[b]
Public Facilities	90	0	45	45	
Quasi-Public Facilities	90	0	45	45	By Inspection
Open Space/Recreation	5	5		0	
Open Space/Recreation - High-Density	86	0	70	14	By Inspection[d]
Resource Land	0	0		0	
Vacant	0	0		0	

DCIA = Directly Connected Impervious Area, TIA = Total Impervious Area, HD = High Density, SFR = Single Family Residential, MFR=Multi-Family Residential

a. High density parking associated with multi-car parking areas in commercial, MFR, etc.
b. Sampled areas documented in Attachment B.
c. Recent developments are assumed to have rooftops directly connected to storm drain system. See Figure 1 for Recent developments.
d. From aerial photography. See Table A-2 for list of parcels in this category.

The following assumptions were used to develop DCIA and TIA estimates:

- Single-family residential less than 1/8 acre assumed to have roof downspouts connected to storm drain.
- "Recent" single-family development between 1/8 and 1/2 acre assumed to have roof downspouts connected to storm drain. "Recent" developments identified by inspection of the aerial photos based on street and house patterns and are documented in Figure 1.
- Low density multi-family residential parcels identified by inspection of the aerial photo, DCIA values assumed. Parcels are listed Table A-2 in Attachment A.
- Mobile home parks identified by inspection of the aerial photos. DCIA assigned based on sampled multi-family residential values. Parcels are listed in Table A-3 in Attachment A.
- Non-park mobile homes assigned single-family residential DCIA values for older developments.
- High-density open space identified by inspection of the aerial photo. DCIA assigned based on sampled commercial values. Parcels are listed in Table A-2 in Attachment A.
- By inspection of the aerial photo, "Unknown" land use appears to cover open tracts of green space or native growth protection area. Three high-density properties identified and assigned commercial DCIA values
- Group Quarters/Other assigned multi-family residential DCIA values.
- Industrial, Transportation, Communication, Utilities, Public Facilities and Quasi-Public Facilities assigned DCIA values estimated by inspection of the aerial photo.

Estiamted DCIA and TIA for each HSPF Subbasin are shown in Figure 3 and Table 3.

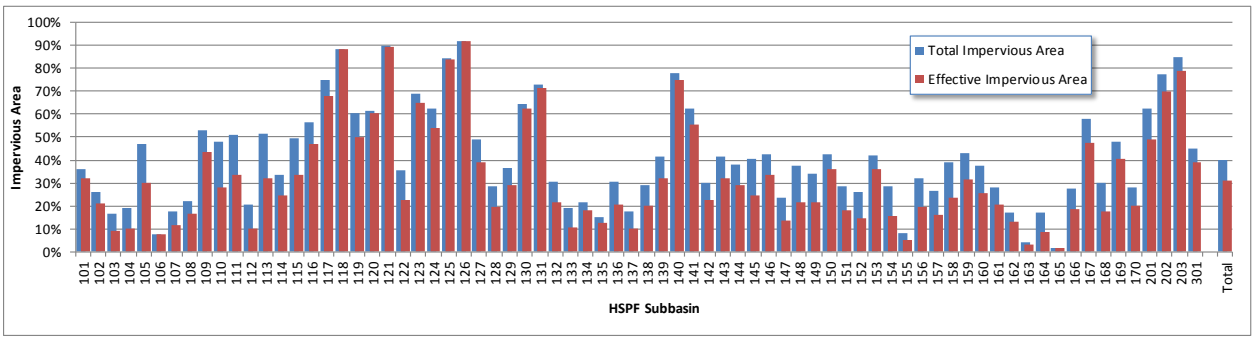


Figure 3. DCIA and TIA for Clarks Creek HSPF Subbasins

TABLE 3
HSPF IMPLND AREA

HSPF Subbasin	Area (acres)	TIA (acres)	TIA (%)	DCIA (acres) Road/Parking	Roof	HD Parking	Major Highway	Total DCIA	%DCIA
101	33.2	11.9	36%	3.7	1.7	5.1	0.0	10.6	32%
102	109.9	28.7	26%	3.5	5.6	8.4	5.6	23.0	21%
103	123.2	20.4	17%	8.1	0.8	1.4	0.8	11.1	9%
104	31.2	5.9	19%	3.1	0.0	0.0	0.0	3.1	10%
105	85.8	40.3	47%	24.0	0.4	0.8	0.4	25.7	30%
106	13.9	1.0	8%	1.0	0.0	0.0	0.0	1.0	8%
107	17.4	3.1	18%	0.6	0.3	0.7	0.3	2.0	11%
108	81.7	17.9	22%	11.0	0.7	1.3	0.7	13.5	17%
109	28.3	15.0	53%	1.6	3.7	3.4	3.7	12.4	44%
110	82.9	39.7	48%	20.7	0.6	1.1	0.6	23.1	28%
111	80.1	40.8	51%	17.0	3.0	3.8	3.0	26.9	34%
112	28.5	5.8	20%	2.5	0.1	0.2	0.1	2.9	10%
113	100.8	51.9	52%	24.5	2.3	3.1	2.3	32.2	32%
114	73.9	24.7	33%	9.3	2.5	3.6	2.5	18.0	24%
115	101.5	50.2	49%	19.1	5.0	5.1	5.0	34.3	34%
116	21.8	12.3	57%	4.5	1.8	2.1	1.8	10.2	47%
117	81.7	61.1	75%	21.7	8.1	17.5	8.1	55.4	68%
118	17.8	15.1	88%	13.6	0.4	1.3	0.4	15.7	88%
119	24.7	15.0	61%	5.8	1.6	3.1	1.9	12.3	50%
120	3.0	1.9	61%	0.0	0.3	1.4	0.1	1.8	61%
121	4.5	4.0	90%	0.5	0.5	2.5	0.5	4.0	89%
122	62.7	22.2	35%	9.1	0.7	3.6	0.7	14.1	23%
123	170.1	117.4	69%	18.7	14.9	75.2	1.9	110.6	65%
124	47.3	29.5	62%	12.3	5.1	7.5	0.6	25.5	54%
125	21.5	18.2	84%	15.0	0.6	2.0	0.6	18.1	84%
126	24.1	21.3	92%	5.1	3.6	9.9	3.6	22.2	92%
127	115.3	56.2	49%	24.5	6.1	8.2	6.1	44.9	39%
128	93.8	26.9	29%	10.4	4.0	0.0	4.0	18.4	20%
129	145.2	53.1	37%	29.4	5.6	4.6	2.2	41.8	29%
130	18.6	12.0	65%	1.6	1.4	7.2	1.4	11.6	62%
131	114.2	83.3	73%	13.8	11.5	55.2	1.2	81.7	72%
132	131.9	40.6	31%	20.9	3.7	0.0	3.7	28.3	21%
133	48.3	9.1	19%	5.0	0.0	0.0	0.0	5.0	10%

TABLE 3 (CONTINUED)
HSPF IMPLND AREA

HSPF Subbasin	Area (acres)	TIA (acres)	TIA (%)	DCIA (acres) Road/Parking	Roof	HD Parking	Major Highway	Total DCIA	%DCIA
134	100.2	21.6	22%	17.2	0.3	0.0	0.3	17.9	18%
135	139.7	20.8	15%	17.2	0.0	0.0	0.0	17.2	12%
136	91.3	27.9	31%	13.0	2.5	0.7	2.5	18.8	21%
137	49.0	8.7	18%	3.3	0.5	0.5	0.5	4.9	10%
138	138.4	39.9	29%	21.5	2.9	1.0	2.0	27.4	20%
139	167.3	69.4	41%	25.7	10.2	15.7	2.2	53.9	32%
140	80.0	62.3	78%	1.5	20.0	18.4	20.0	59.9	75%
141	46.1	28.8	62%	10.3	6.0	3.3	6.0	25.5	55%
142	34.3	10.3	30%	3.6	1.4	1.3	1.4	7.7	23%
143	103.2	42.9	42%	11.9	7.3	6.7	7.3	33.2	32%
144	80.4	30.8	38%	10.2	5.2	2.7	5.2	23.3	29%
145	46.6	18.9	41%	10.3	0.3	0.6	0.3	11.5	25%
146	78.3	33.3	42%	7.6	6.4	5.9	6.4	26.4	34%
147	123.0	28.9	24%	11.5	1.9	1.0	1.9	16.4	13%
148	61.5	23.2	38%	13.0	0.1	0.1	0.1	13.3	22%
149	125.3	42.7	34%	23.2	1.0	1.9	0.8	26.9	21%
150	128.4	54.8	43%	19.3	7.2	15.7	3.9	46.0	36%
151	161.5	46.4	29%	23.5	1.4	2.5	1.4	28.9	18%
152	106.5	27.6	26%	14.3	0.4	0.4	0.4	15.5	15%
153	68.3	28.6	42%	11.4	4.7	3.7	4.7	24.6	36%
154	93.3	26.8	29%	14.3	0.1	0.2	0.1	14.7	16%
155	56.1	4.5	8%	2.7	0.0	0.0	0.0	2.7	5%
156	94.8	30.3	32%	18.3	0.1	0.1	0.1	18.6	20%
157	163.4	43.1	26%	26.6	0.0	0.0	0.0	26.6	16%
158	155.8	60.9	39%	29.9	1.8	3.4	1.8	36.9	24%
159	104.4	44.8	43%	18.6	3.6	7.0	3.6	32.8	31%
160	106.5	40.1	38%	18.2	2.4	6.2	0.5	27.3	26%
161	184.7	51.9	28%	25.2	5.7	5.4	1.4	37.7	20%
162	68.8	11.7	17%	9.0	0.0	0.0	0.0	9.0	13%
163	80.5	3.2	4%	2.3	0.0	0.0	0.0	2.3	3%
164	69.1	11.8	17%	6.0	0.0	0.0	0.0	6.0	9%
165	31.4	0.5	1%	0.4	0.0	0.0	0.0	0.4	1%
166	97.7	27.0	28%	11.6	1.6	3.1	1.6	18.0	18%

TABLE 3 (CONTINUED)
HSPF IMPLND AREA

HSPF Subbasin	Area (acres)	TIA (acres)	TIA (%)	DCIA (acres) Road/Parking	Roof	HD Parking	Major Highway	Total DCIA	%DCIA
167	107.5	62.4	58%	16.5	8.8	17.0	8.8	51.1	48%
168	120.8	36.4	30%	18.5	0.3	0.6	1.5	21.0	17%
169	142.2	68.4	48%	22.7	14.5	19.5	0.9	57.7	41%
170	92.6	25.9	28%	11.7	3.3	0.4	3.3	18.7	20%
201	121.1	75.4	62%	29.1	10.2	10.0	10.2	59.4	49%
202	115.1	89.3	78%	35.4	11.6	21.7	11.6	80.3	70%
203	117.6	99.8	85%	36.5	13.9	28.8	13.9	93.1	79%
301	525.6	236.9	45%	55.8	29.9	93.2	25.5	204.3	39%
Total	6,717	2,675	40%	1,041	284	538	216	2,080	31%

ATTACHMENT A

TABLE A-1
DIRECTLY MEASURED SUBBASIN IMPERVIOUS AREA

Subbasin	Impervious Area (ac)
119	1.9
120	0.1
123	1.9
124	0.6
125	0.6
129	2.2
131	1.2
138	2.0
139	2.2
149	0.8
150	3.9
160	0.5
161	1.4
168	1.5
169	0.9
301	25.5

ATTACHMENT A (CONTINUED)

TABLE A-2
PARCELS WITH EXCEPTIONS TO LAND USE CLASSIFICATIONS

Mobile Home Parcels Assumed to be High Density Properties	Multi-Family Parcels assumed to be Low-Density Properties	Open-Space Parcels Assumed to be High Density Properties
0419061008	0420202009	6020120011
0420313004	7560011080	0420284126
0420317034	7560011080	
0420313071	7065000801	
0420313071	0419078034	
0420313075	0419077031	
0420313076	4315000643	
0420313076	4315000642	
3745000270	4315000641	
3745000270	0419077029	
0419065001	0419077029	
0420202088	0420331066	
0420195021	5505450082	
0420195021	0419056014	
0420191099	0419056015	
0420191100	7065000801	
0420202088	4005000023	
0420195021	4315001025	
0420195021	4315001024	
0420191099	4315001026	
0420191100	4315001027	
0420191101	0419176033	
0420292019	0419176032	
0420292019	0419181034	
0420292019	0419185010	
0420292024		
0420292024		
0420292024		
0420292024		
0420203006		
0420203006		
0420203006		

ATTACHMENT B

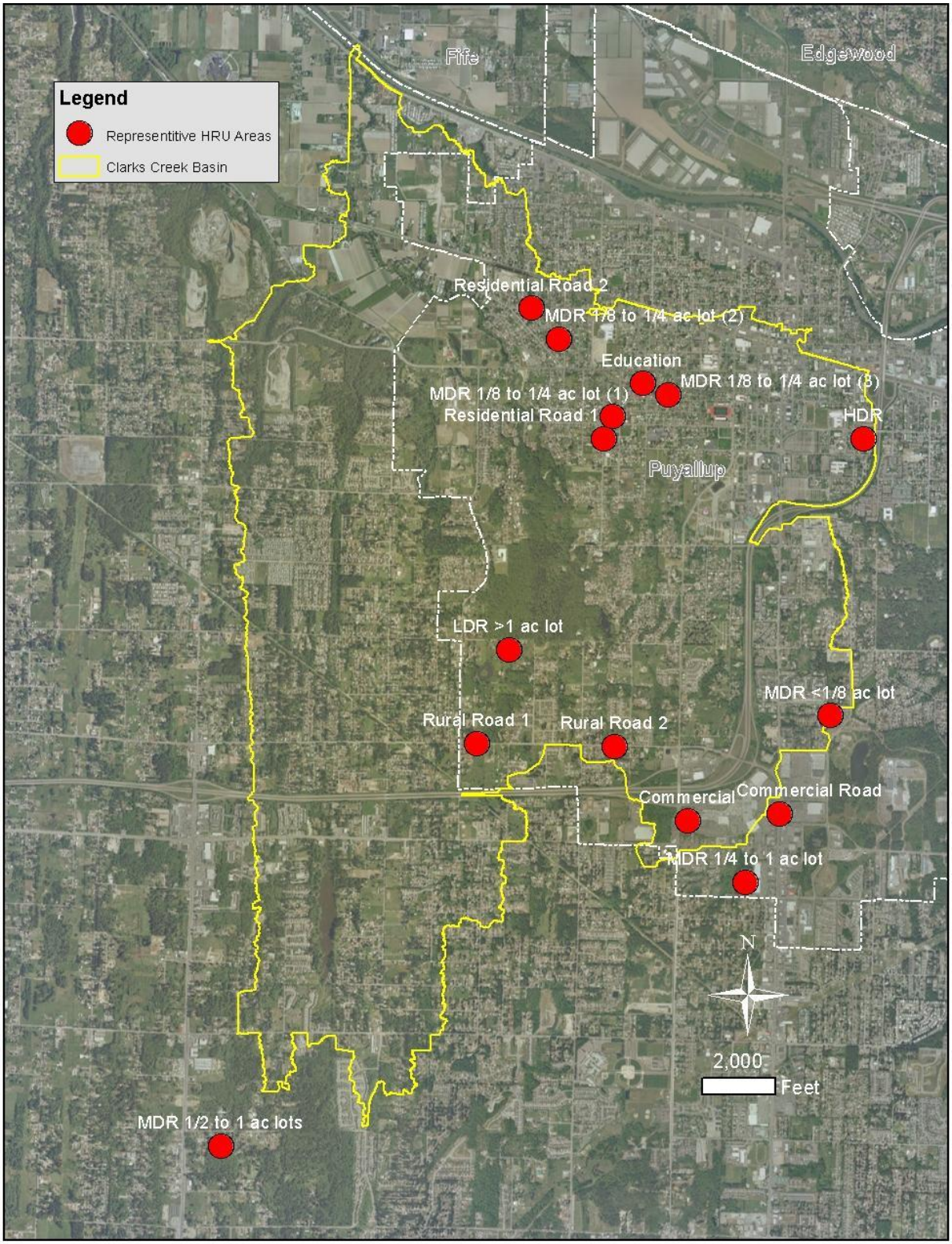


Figure B-1 Sampled Representative Impervious Areas

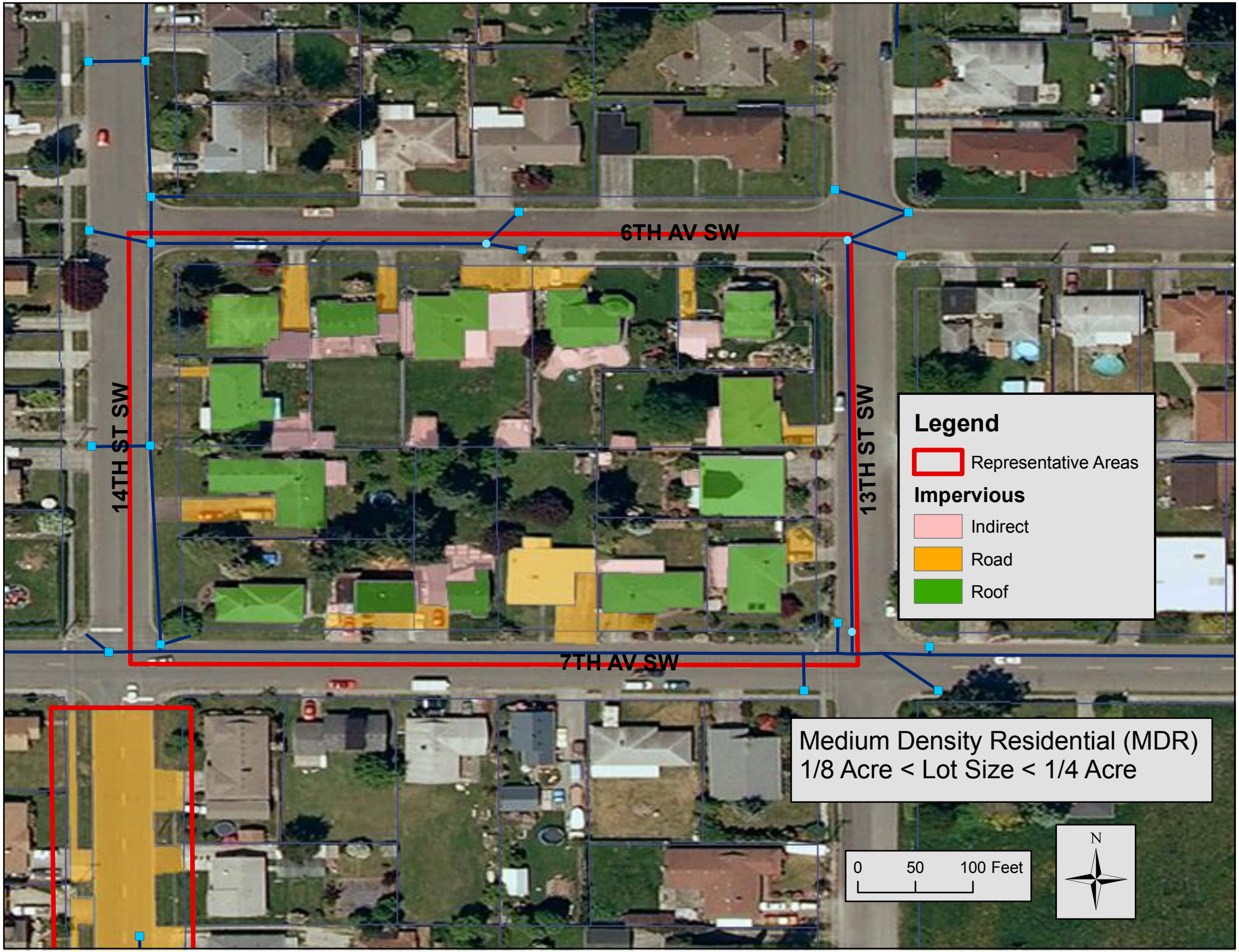
ATTACHMENT B (CONTINUED)

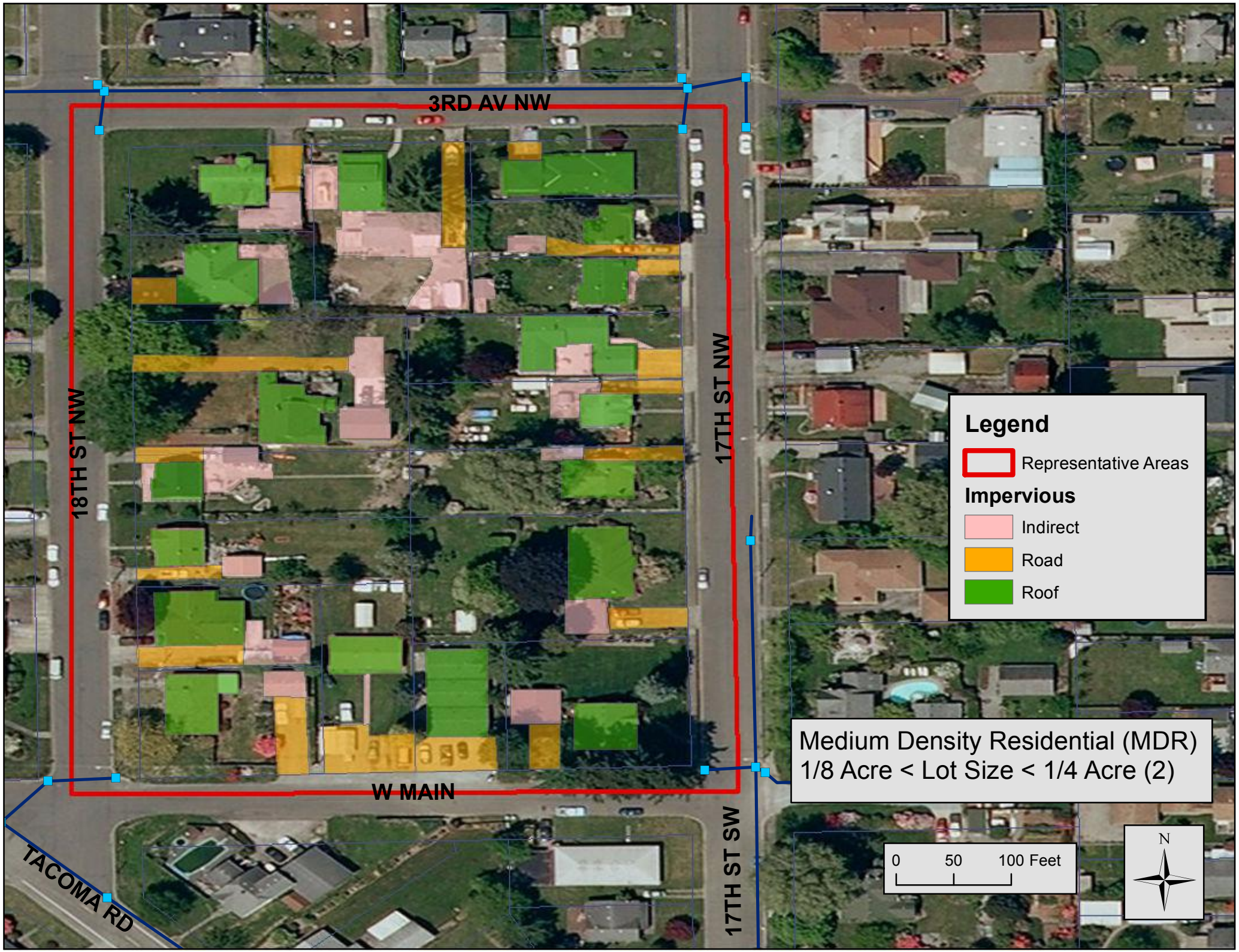
TABLE B-1
IMPERVIOUS AREA FROM REPRESENTATIVE LAND USE SAMPLING

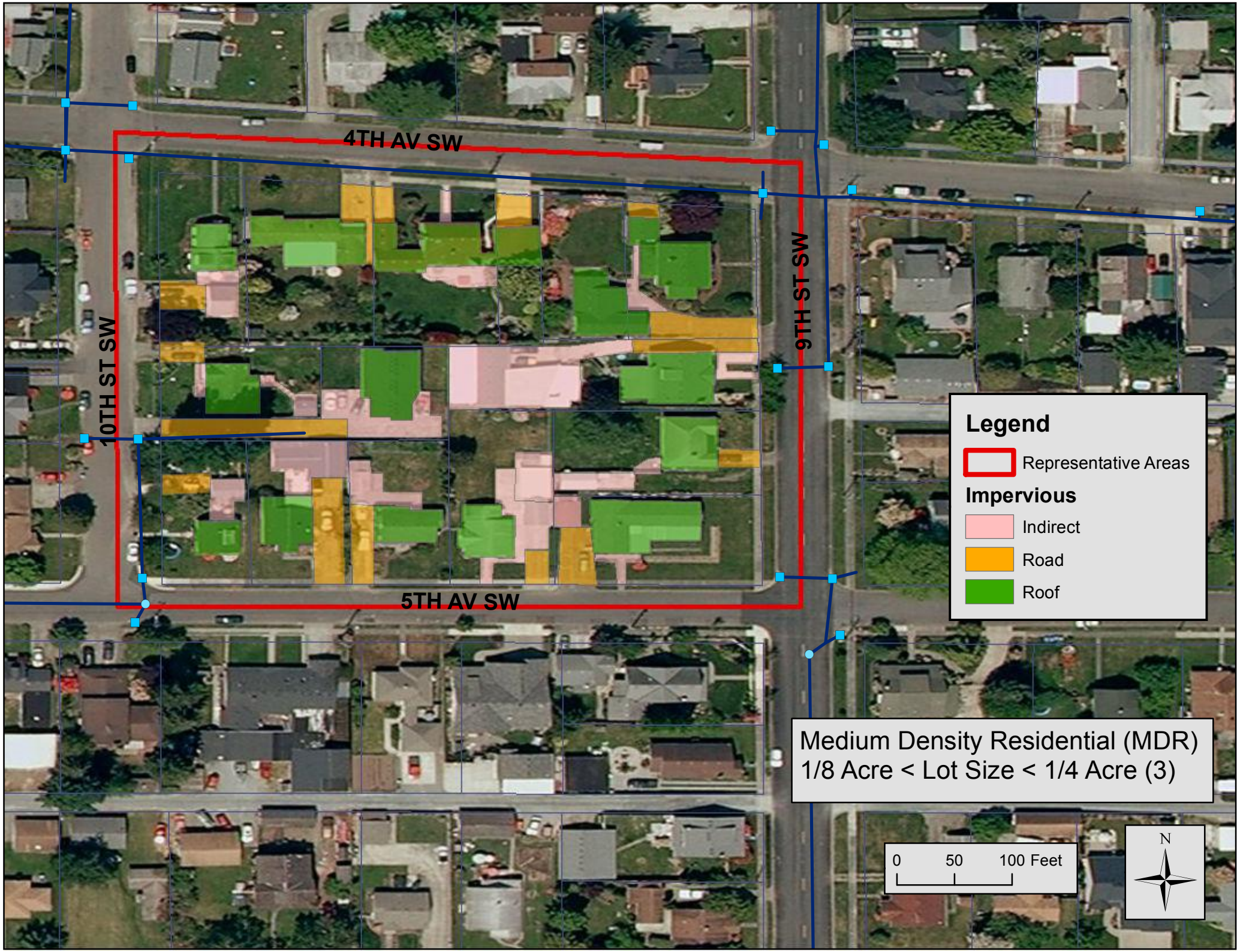
Land Use	TIA (%)	DCIA (%)	Roof Imp. (%)	Driveway/ Parking Imp. (%)
High Density/Multi-family Residential	75%	73%	25%	48%
Medium Density Residential/Single Family				
< 1/8 acre	56%	52%	40%	11%
1/8 acre to 1/4 acre (Roof Disconnected)	41%	9%		9%
Sample 1	39%	7%		7%
Sample 2	37%	10%		10%
Sample 3	45%	10%		10%
1/8 acre to 1/4 acre (Roof connected)	41%	30%	20%	9%
Sample 1	39%	30%	23%	7%
Sample 2	37%	28%	17%	10%
Sample 3	45%	31%	21%	10%
1/4 acre to 1/2 acre (Roof Disconnected)	39%	31%	21%	10%
1/4 acre to 1/2 acre (Connected)	39%	10%	0%	10%
1/2 acre to 1 acre	17%	5%	0%	5%
Low Density Residential > 1 acre	17%	5%	0%	5%
Commercial	85%	85%	14%	70%
Education	53%	50%	26%	24%
Rural Road	70%	70%		70%
Sample 1	66%	66%		66%
Sample 2	74%	74%		74%
Residential Road	78%	78%		78%
Sample 1	73%	73%		73%
Sample 2	83%	83%		83%
Commercial Road	100%	100%		100%

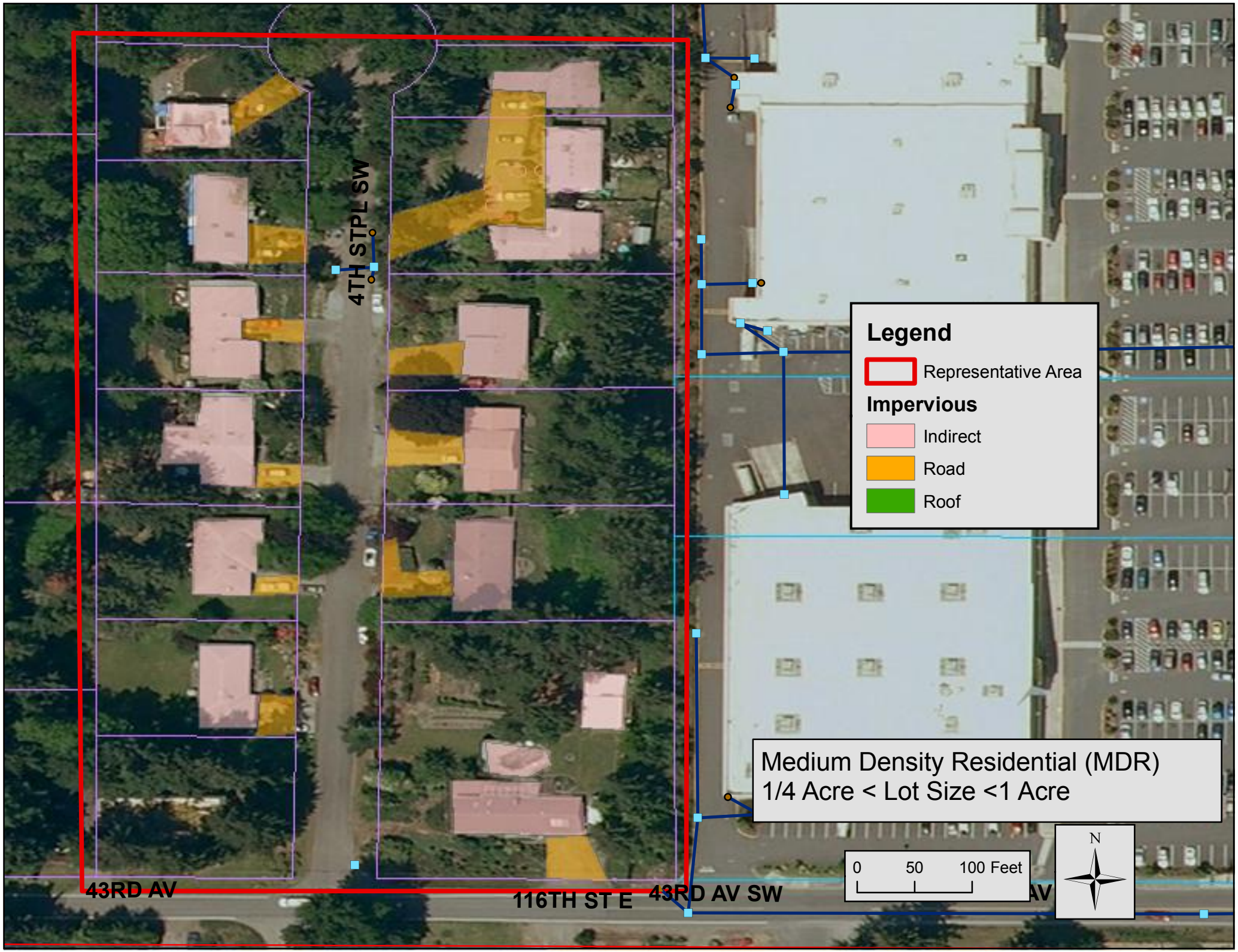
High Density Residential (HDR)
Legend
Representative Area
Impervious
Indirect
Road
Roof
7TH ST SE
9TH AV SE
8TH ST SE
RAMP SR512 RPN1 W
SR512 HWY W
SR512 HWY E
0
50
100 Feet
N

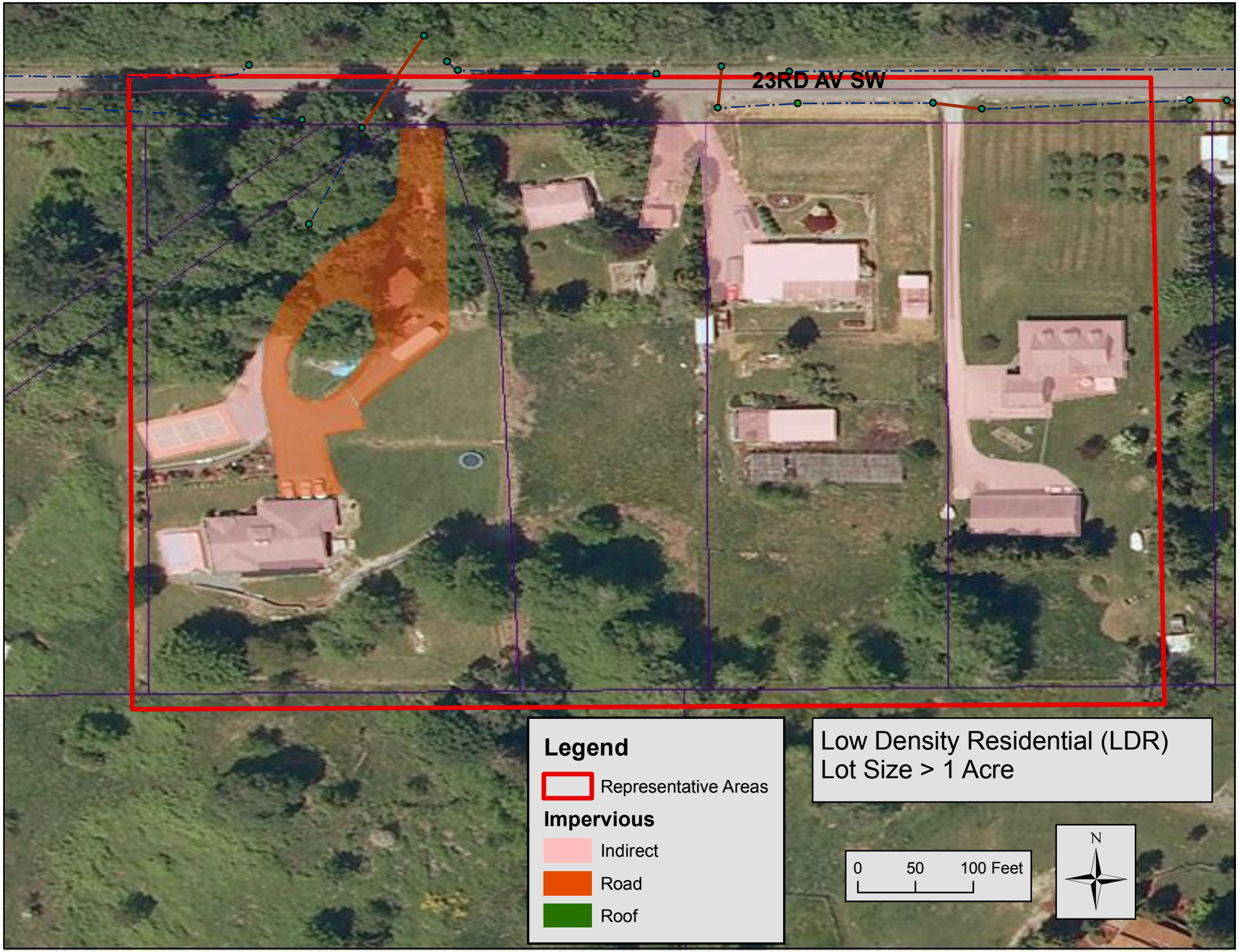
27TH AV SE
28TH AV SE
5TH ST SE
28TH AV SE
29TH AV SE
6TH ST SE
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Medium Density Residential (MDR)
Lot Size < 1/8 Acre
0
50
100 Feet
N


6TH AV SW
7TH AV SW
14TH ST SW
13TH ST SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Medium Density Residential (MDR)
1/8 Acre < Lot Size < 1/4 Acre
0
50
100 Feet
N

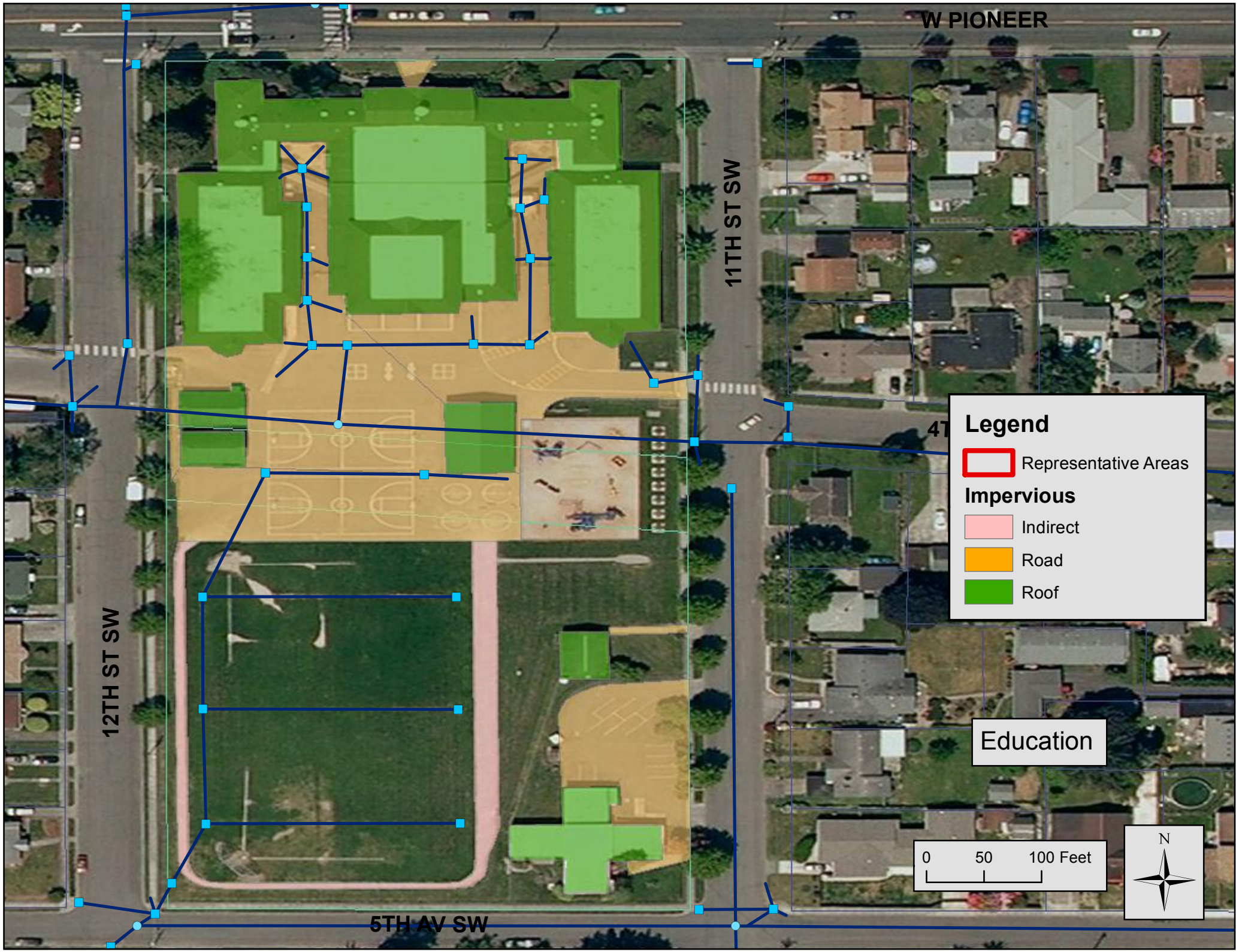

3RD AV NW
18TH ST NW
17TH ST NW
W MAIN
TACOMA RD
17TH ST SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Medium Density Residential (MDR)
1/8 Acre < Lot Size < 1/4 Acre (2)
0
50
100 Feet
N


4TH AV SW
5TH AV SW
10TH ST SW
9TH ST SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Medium Density Residential (MDR)
1/8 Acre < Lot Size < 1/4 Acre (3)
0
50
100 Feet
N


4TH STPL SW
43RD AV
116TH ST E
43RD AV SW
Legend
Representative Area
Impervious
Indirect
Road
Roof
Medium Density Residential (MDR)
1/4 Acre < Lot Size <1 Acre
0
50
100 Feet
N

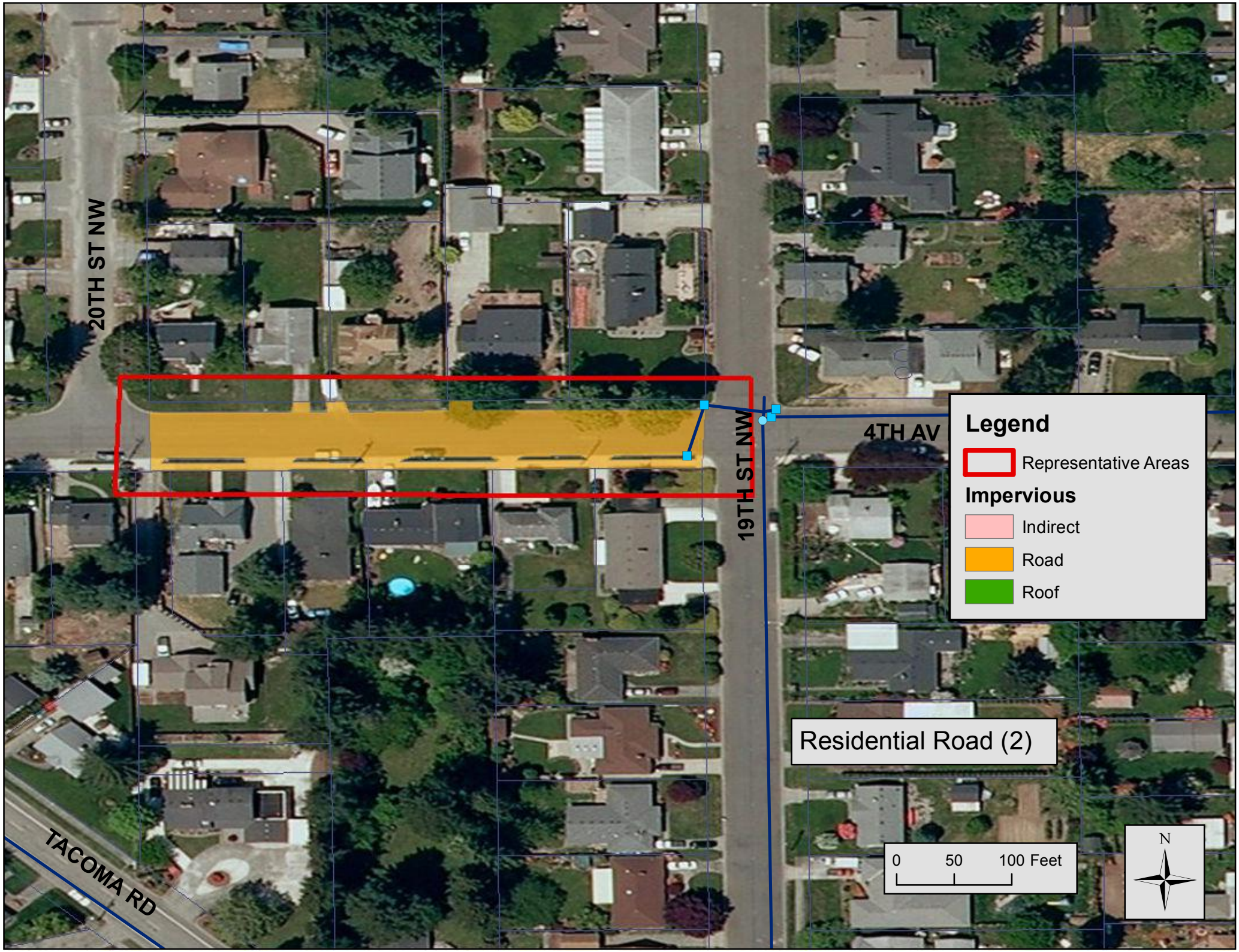

23RD AV SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Low Density Residential (LDR)
Lot Size > 1 Acre
0
50
100 Feet
N

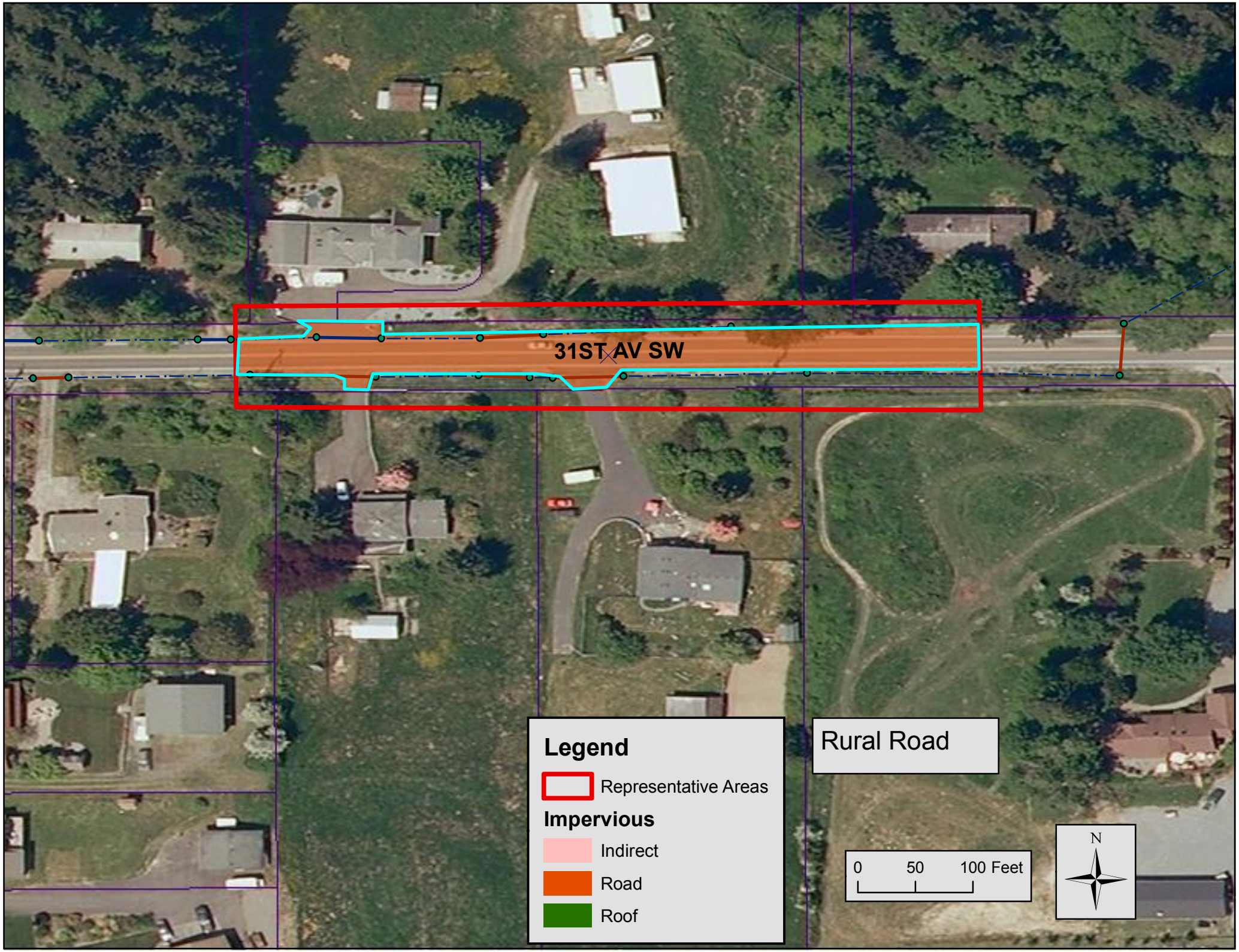
9TH ST SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
High Density Commercial
0
50
100 Feet
N


W PIONEER
11TH ST SW
12TH ST SW
5TH AV SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Education
0
50
100 Feet
N

Legend
Representative Area
Impervious
Indirect
Road
Roof
S MERIDIAN
37TH AV SE
Commercial Road
0
50
100 Feet
N

14TH ST SW
13TH ST SW
9TH AV SW
Legend
Representative Area
Impervious
Indirect
Road
Roof
Residential Road
0
50
100 Feet
N


20TH ST NW
19TH ST NW
4TH AV
TACOMA RD
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Residential Road (2)
0
50
100 Feet
N


31ST AV SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Rural Road
0
50
100 Feet
N

31ST AV SW
Legend
Representative Areas
Impervious
Indirect
Road
Roof
Rural Road (2)
0
50
100 Feet
N

Appendix E: Geomorphically Significant Flow Analysis

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Technical Memorandum

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Prepared for: Puyallup Tribe of Indians

Project Title: Clarks Creek Sediment Reduction Action Plan

Project No.: 140982-006

Technical Memorandum

Subject: Geomorphic Magnitude-Frequency Analysis for Clarks Creek and Tributaries

Date: November 21, 2012

To: Char Naylor, Water Quality Manager, Puyallup Tribe of Indians

From: Mike Milne, Managing Scientist, Brown and Caldwell

Copy to:

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Limitations:

This is a draft memorandum and is not intended to be a final representation of the work done or recommendations made by Brown and Caldwell. It should not be relied upon; consult the final report.

This document was prepared solely for Puyallup Tribe of Indians in accordance with professional standards at the time the services were performed and in accordance with the contract between Puyallup Tribe of Indians and Brown and Caldwell dated March 31, 2011. This document is governed by the specific scope of work authorized by Puyallup Tribe of Indians; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by Puyallup Tribe of Indians and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

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1. Introduction

Brown and Caldwell (BC) is currently working with the Puyallup Tribe of Indians (Tribe) on the Clarks Creek Sediment Reduction Action Plan (Action Plan). The purpose of the Action Plan is to identify sediment sources within the Clarks Creek watershed (see Map 1, Attachment A) and develop recommendations for reducing sediment loads to lower Clarks Creek.

As part of this project, BC has performed detailed analyses to evaluate stream stability and mitigation measures for reducing sediment loadings that originate from degrading stream reaches. BC's approach is based on the concept of "effective work" as described by Wolman and Miller (1960), where geomorphic processes are driven by the magnitude and frequency of the influencing forces. More specifically, fluvial morphology is strongly influenced by both the magnitude and frequency of stream flows. Thus, applying a magnitude-frequency-based methodology allows BC to examine the long-term channel-forming effects of a full range of stream flows. This type of analysis is commonly used to identify the "geomorphically significant flows" for a stream.

Objective: *The purpose of this technical memorandum is to describe the results of the geomorphic magnitude-frequency analysis performed by BC and provide the calculated ranges of geomorphically significant flows for Clarks, Rody, Diru, Woodland, Silver, and Meeker creeks.*

2. Background

The following subsections provide some background and context related to the effects of urbanization on stream geomorphology. Subsections 2.1 through 2.3 discuss fundamental concepts relating to stream channel formation and perturbations caused by watershed urbanization. Subsection 2.4 provides a brief discussion of the regulatory context with respect to stormwater management in Washington State.

2.1 Dynamic Equilibrium

Alluvial channels form and continually shift in response to temporal sequences of flow rate and sediment supply. Over periods of many years, channels adjust to flow and sediment regimes through changes in geometry (e.g., planform, cross-sectional dimensions, and longitudinal slope).

Given a period with a relatively constant flow regime and sediment supply, a channel approaches a stable geometry and is considered to be in "dynamic equilibrium." This is not to say the channel would be static, but rather that morphological responses to extreme events would only be temporary and that a more stable morphology would continually be restored over time by the long-term formative conditions of the system. This geomorphic concept of disturbance, channel adjustment, and dynamic equilibrium is qualitatively represented by Lane's Principle (1955):

$$Q_s D_{50} \propto Q_w S$$

where Q_s is sediment load, D_{50} is the 50th percentile of the sediment grain size distribution, Q_w is the stream discharge, and S is the channel slope

The relationship represented by Lane's Principle suggests that a long-term shift in any of these factors would destabilize the system and initiate a compensatory response in one or more of the other factors as the system attempts to restore equilibrium. For example, Lane's Principle suggests that if stream discharges were to increase while sediment supply and grain size distribution remain constant, then the channel slope would need to decrease to restore equilibrium.

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2.2 Hydromodification and Channel Instability

Urbanization within a watershed typically replaces natural vegetated landscapes with impervious surfaces such as roads, parking lots, and buildings. These changes reduce the capacity of the land surface to intercept and infiltrate precipitation. Furthermore, traditional stormwater infrastructure tends to route runoff from impervious surfaces through gutters and pipes, which increases the rate of conveyance to streams. Consequently, the magnitude, frequency, and duration of runoff reaching stream channels increases, thereby increasing the total discharges to streams and shifting the hydrologic flow regime. This phenomenon is referred to as "hydromodification."

Booth (1990) described how increased runoff associated with impervious surfaces in urbanized watersheds has contributed to channel instability and incision in Pacific Northwest streams. Bledsoe and Watson (2001) further described the effects of urbanization on streams by investigating explicit links between increased imperviousness and increased risk of channel instability.

The basic mechanism through which urban discharges destabilize streams can be conceptualized by applying Lane's Principle to a hypothetical stream reach. As flow rates within the stream reach increases, the sediment transport capacity also increases; however, the sediment supply coming into the stream reach stays the same, as does the size of the bed material (in the near term). Additional sediment is recruited from the stream bed and banks and conveyed downstream, thereby causing the channel to degrade vertically (incision) and laterally (channel widening). The process continues to reduce the slope of the stream channel until a new equilibrium slope is reached. Channel incision often results in the formation of headcuts, or abrupt steps in channel gradient that propagate upstream (see Figure 1).

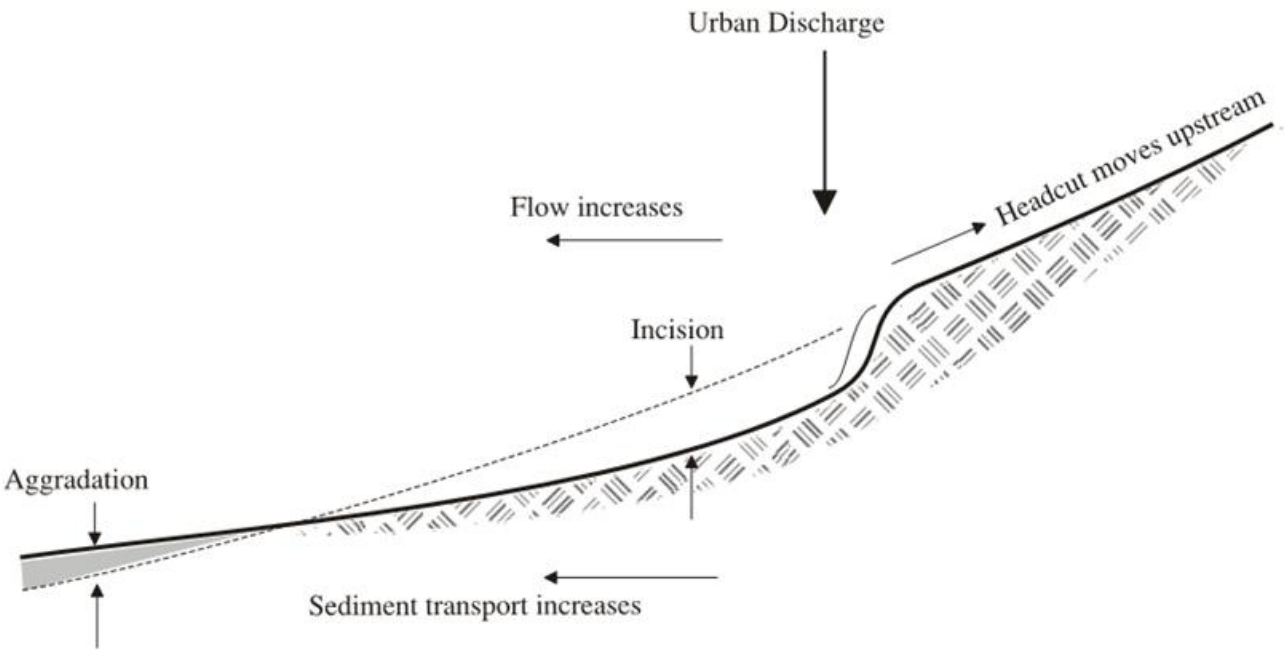

Figure 1. Conceptual illustration of channel incision caused by urban discharges

Image obtained from Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2005).

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2.3 Geomorphically Significant Flows

Although observations from catastrophic events often suggest that infrequent events of immense magnitude tend to drive geomorphic processes such as stream channel formation, this is typically not the case. Wolman and Miller (1960) described how the geomorphic evolution of landscapes is strongly influenced by the amount "work" done by the forces acting on the system (e.g., shear forces caused by flowing water), and that the relative amount of work done depends not only on the magnitude of the force, but also the frequency of occurrence.

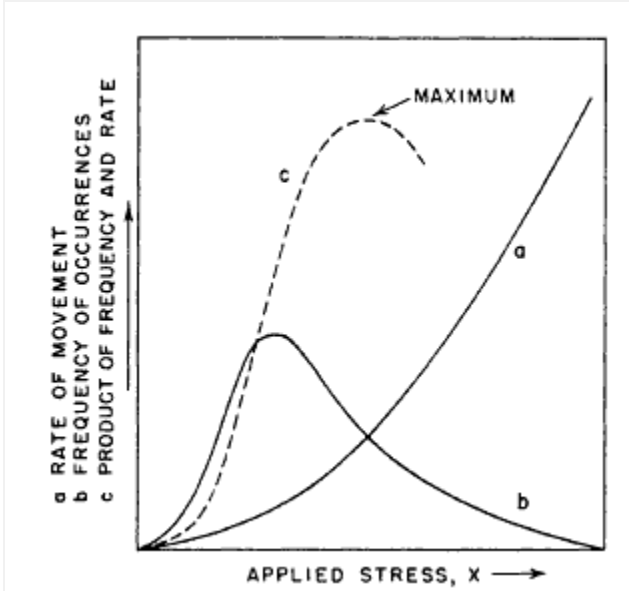

Figure 2. Relation between applied stress and frequency of occurrence in geomorphic processes

Image obtained from Wolman and Miller (1960).

Effective Work. Figure 2 is a graphical representation of the "work done" concept, where the frequency of occurrence is log-normally distributed and the magnitude of the influencing force (i.e., applied stress) increases in accordance with a power function. The product of the frequency of the occurrences and the magnitude of the influencing force is referred to as the "effective work" curve (noted "c" in Figure 2). The relationship shown in Figure 2 illustrates how frequent mid-range events do more effective work than extremely large relatively rare events.

The effective work relationship can be applied to fluvial processes because (a) hydrologic events tend to be log-normally distributed, and (b) the movement of sediment by water can be represented by a power function relating sediment transport to effective shear stress as follows:

$$q = k(\tau - \tau_c)^n$$

where q is the rate of sediment transport, k is a constant related to the characteristics of the transported material, τ is the shear stress per unit area, τ_c is the critical or threshold shear stress required to move the material, and n is an exponent (Leopold et al. 1964)

The critical shear stress parameter is particularly important in the above equation; the effective work curve applies only to flow rates in excess of a minimum threshold for sediment movement. In other words, if shear stresses exerted by flows are not sufficient to initiate movement of bed sediments (i.e., do not achieve incipient motion), then effective work is essentially zero.

Magnitude Frequency Analysis. Application of the effective work concept is often referred to as *magnitude-frequency analysis (MFA)*. Bledsoe et al. (2007) describes MFA as a fundamental tool for fluvial stream assessment. MFA can be used to define the "effective discharge" for a stream, which is the flow rate corresponding to the maximum work on the effectiveness curve (Bledsoe et al., 2007). The effective discharge is roughly equivalent to the channel-forming (or bankfull) discharge as defined by Leopold et al. (1964).

MFA can also be used to define geomorphically significant flows, or the range of flow rates over which a substantial portion of the channel-forming work is done. Leopold et al. (1964) describes geomorphically significant flows as the range of flow rates occurring between a lower limit of competence (critical stress necessary for grain movement) and an upper limit at which flow is no longer confined to the channel (i.e., greater than bankfull discharge).

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Figure 3 shows a modified version of the effective work concept where MFA is used to define the effective discharge and range of geomorphically significant flows for a stream.

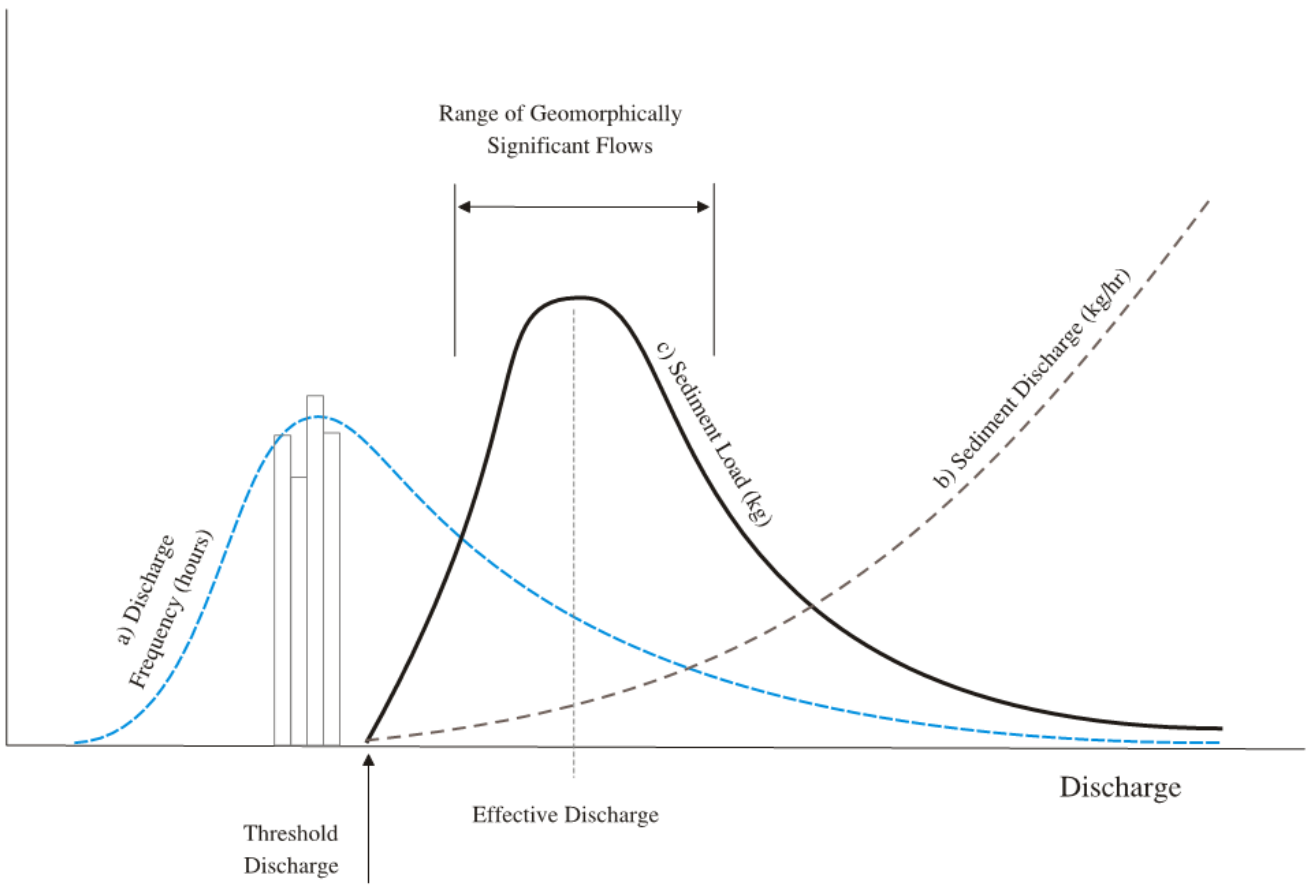

Figure 3. MFA used to define the effective discharge and geomorphically significant flows for a stream section

Image obtained from Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2005).

Discharge frequency distribution for the stream (curve "a" in Figure 3) is created using a series of discrete discharge[1] bins. The value at each point in the discharge frequency curve would represent the amount of time stream discharges fall within the specified bin range, typically expressed in terms of hours per year. The size of the bins can be variable as long as the distribution of discharges is adequately represented.

The sediment discharge curve (curve "b" in Figure 3) can be calculated by either a sediment transport function or an equivalent work rate function. In either case, the curve represents the rate at which sediment is mobilized for any given stream discharge (higher discharge rates result in greater mobilization for the particle sizes evaluated). Multiplying stream discharge rates by sediment transport rates (or effective work rates) provides results in terms of total sediment load or total effective work (units of mass mobilized or units of work per year). This is represented by curve "c" on Figure 3 (in this case, shown as sediment load).

[1] The terms "flow," "flow rate," and "discharge" are used interchangeably throughout this document. In general, the term "discharge" is used for an estimated or calculated quantity representing the volumetric rate of flow within a stream channel.

3. MFA Methodology

BC developed an MFA Spreadsheet Tool to evaluate effective work on stream channels within the Clarks Creek basin. The MFA Spreadsheet Tool brings together inputs from several data sources to calculate effective work curves. Subsection 3.1 describes the development of specific data inputs.

The calculated effective work curves were used to calculate geomorphically significant flow bounds assuming a specified level of control (see Subsection 3.2.1). The upper and lower flow bounds were then compared with permitted regulatory thresholds (see Subsection 3.2.2).

Results from the MFA are summarized in Section 4.

3.1 Effective Work Curves

The MFA Spreadsheet Tool requires three primary sources of input data: flow duration density curves (hydrology), stream channel rating curves (hydraulics), and sediment gradation curves (sediment). The following subsections describe each of these in more detail.

3.1.1 Flow Duration Density

MFA requires detailed flow frequency data in the form of a discretized flow frequency distribution, which can be developed from long-term stream flow hydrographs. Tetra Tech (April 2012) developed a continuous simulation hydrologic model of the Clarks Creek basin using the U.S. Environmental Protection Agency (EPA)'s Hydrological Simulation Program—Fortran (HSPF). The HSPF model computes hourly stream flow rates based on 51 years of historical rainfall and evapotranspiration data. Figure 4 shows an example of an output hydrograph developed from HSPF results; note that the graph displays only a small portion (4 years) of the full 51-year hydrograph. Flow hydrographs were output at 25 locations throughout the Clarks Creek basin (see Map 2, Attachment A).

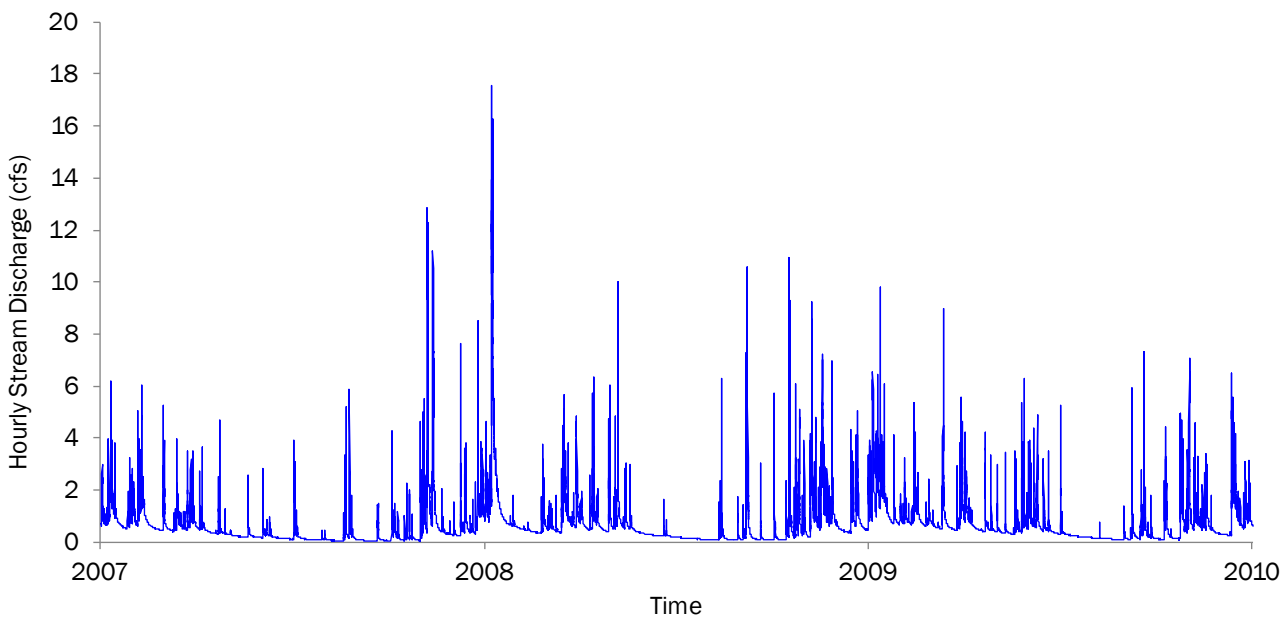

Figure 4. Example HSPF output hydrograph for Upper Clarks Creek

Note: graph displays only 4 years of data; full simulations produce 51 years of data spanning from 1960 through 2010.

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Flow hydrographs were processed into flow duration curves to visually examine the overall distribution of the flow data (see Figure 5). Two hundred discrete flow bins were created for each flow location to cover the range of flows exhibited by the flow duration curves. Flow bin divisions were based on logarithmic intervals rather than arithmetic (i.e., evenly spaced) intervals. Logarithmic intervals allow for more detail in the lower flow range where a majority of the flows occur. Raff et al. (2007) describe the equations used to obtain the upper and lower bounds of the logarithmic intervals as follows:

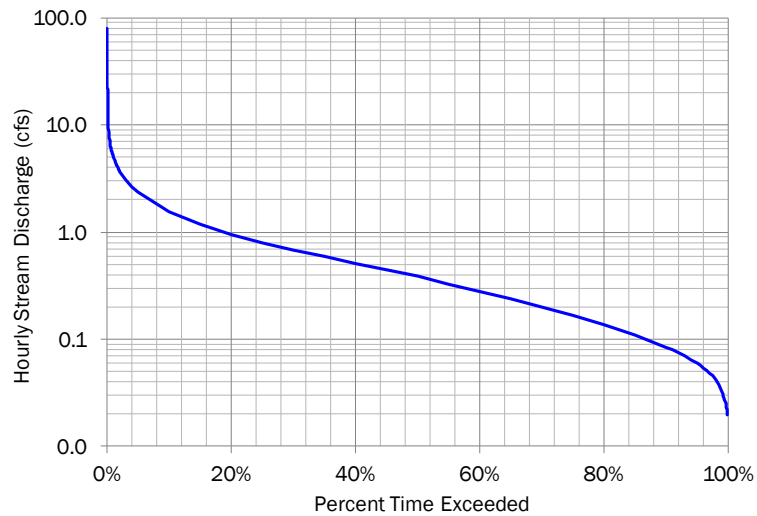

Figure 5. Example flow duration curve for Upper Clarks Creek

$$Upper_i = e^{(Log(Q_{min})+(B-1)LI)}$$

$$Lower_i = e^{(Log(Q_{min})+(B-2)LI)}$$

where Q_{min} is the minimum discharge, B is the bin number (i.e., $B \in 1, N_B$, where N_B is the total number of bins; in this case $N_B = 200$), and LI is the logarithmic interval between the minimum and maximum flows defined as:

$$LI = \frac{\ln(Q_{max}) - \ln(Q_{min})}{N_B - 1}$$

Hourly values from the stream flow hydrographs were totaled based on the upper and lower bounds for each flow bin. The total hourly values falling within each bin were then divided by 51 years to obtain the average number of hours per year for each flow bin. Figure 6 shows an example of the flow duration data developed for use in the MFA.

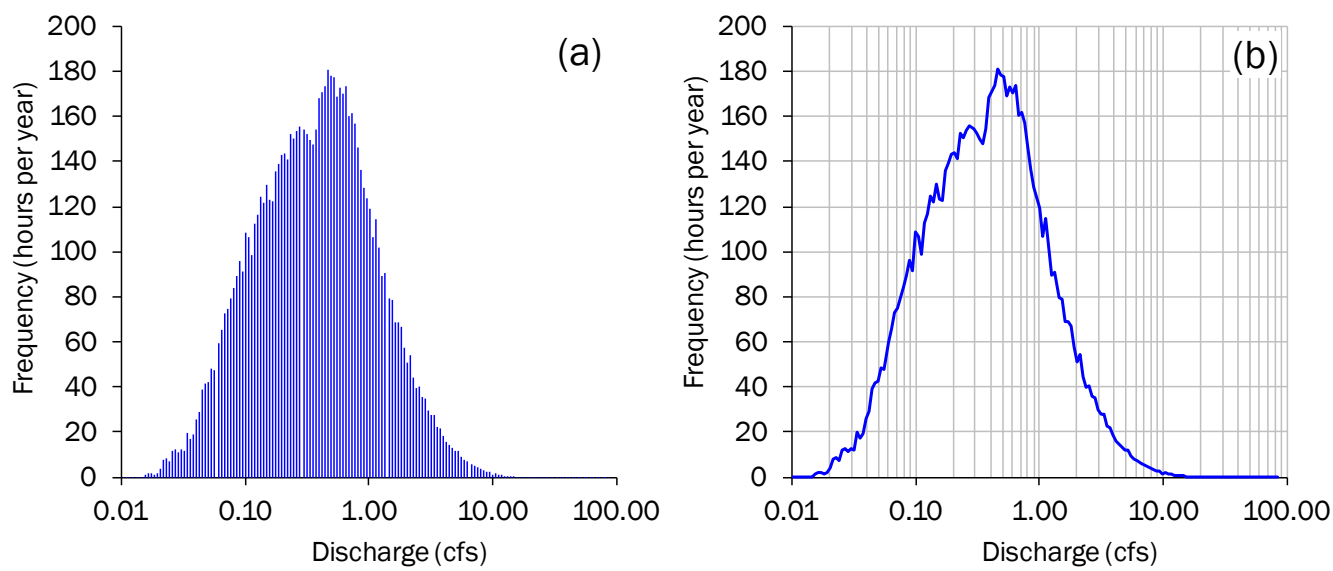

Figure 6. Example flow duration density/distribution data for Upper Clarks Creek

Data displayed as (a) frequency totals for discrete intervals and (b) as a continuous distribution curve.

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3.1.2 Stream Channel Hydraulics

MFA requires hydraulic parameters to estimate flow velocities and shear stresses exerted by various stream discharges. Uniform flow calculations were performed based on Manning's equation and the continuity equation as described in Chow et al. (1988):

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

$$Q = VA$$

$$R = \frac{A}{P}$$

where V is the flow velocity in (feet per second), n is the Manning's roughness coefficient, R is the hydraulic radius, S = energy slope (assumed equal to the bed slope of the channel), Q is the design discharge (cubic feet per second), A is the cross-sectional area of flow (feet squared), and P is the wetted perimeter of the cross-section (feet)

Effective work calculations in the MFA Spreadsheet Tool use stream discharge (Q) as the dependent variable and computations are based on the incremental flow bins described in the previous section. The above-described equations were used to calculate flow velocity, depth, and shear stress for each incremental discharge. To avoid the need for an iterative solution, extensive hydraulic lookup tables were created to relate discharge to hydraulic radius and cross-sectional flow area for each of the available stream cross-sections. Additional input values were obtained as follows:

- **Stream channel cross-sections:** Cross-section surveys were conducted at 36 locations along the stream network, primarily in the upper reaches. Additional cross-section data were obtained from an existing hydraulic model developed for flood hazard mapping along lower Clarks Creek and lower Meeker Creek (NHC, 2005). In total, 54 cross-sections were available for use in calculating stream channel hydraulics (see Map 3, Attachment A).
- **Manning's roughness:** Manning's roughness coefficients were estimated based on field observations using the general method presented in Chow (1959), which accounts for several factors, including channel material, degree of irregularity, variation in channel cross-section, obstructions, vegetation, and meandering. Values ranged from 0.030 to 0.055.
- **Stream channel slopes:** Topographic data for the entire Clarks Creek basin were obtained from the Puget Sound LiDAR Consortium (PSLC, 2011). PSLC data are developed from detailed Light Detection and Ranging (LiDAR) aerial surveys, and are provided in the form digital elevation models (DEMs), which are data grids formatted for use with geospatial information systems (GIS). The DEM obtained for the Clarks Creek basin has a 6-foot grid resolution. The LiDAR DEM data were used to create preliminary stream profiles by extracting elevations every 100 feet. The preliminary profiles were then adjusted to match the thalweg (i.e., lowest point) elevations from the cross-section surveys described above. The adjusted stream profiles were used to calculate the average slope along any particular stream reach.

The uniform flow calculations described above were used to estimate the hydraulic radius, which was then used to estimate mean channel shear stress as follows:

$$\tau = \gamma R S$$

where γ is the specific weight of the water, assumed to equal approximately 62.4 pounds per cubic foot

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3.1.3 Sediment Gradation

Calculation of sediment transport or effective work on the stream channel requires characterization of the bed sediments in terms of the size and gradation of the material. Sediment gradation data were obtained through laboratory analyses of surficial bed sediment samples taken at 20 locations along Clarks Creek and its major tributaries (see Map 4, Attachment A).

To apply the sediment gradation data more broadly throughout the stream network, the gradation curves were analyzed with respect to stream channel gradient (i.e., slope) to discern general trends. Based on observations and our knowledge of typical fluvial conditions, it is expected that the bed sediments in the stream channels with low gradients will be finer than the bed sediments in the stream channels with steeper gradients. This general trend is observed in the gradation data from the sediment samples; however, six samples were visually deemed as outliers (see Figure 7).

The remaining sediment samples were divided into three classes:

- **Class 1** sediment samples were located in the steepest reaches (greater than 6 percent slope).
- **Class 2** sediment samples were located in moderately steep reaches (between 1 and 6 percent slope).
- **Class 3** sediment samples were located in the low-gradient reaches (less than 1 percent slope).

Gradation data from the selected sediment samples were combined with equal weighting to create three composite gradation curves (see Figure 8). Calculated mean particle diameters (D_{50}) for each of the classes are provided in Table 1.

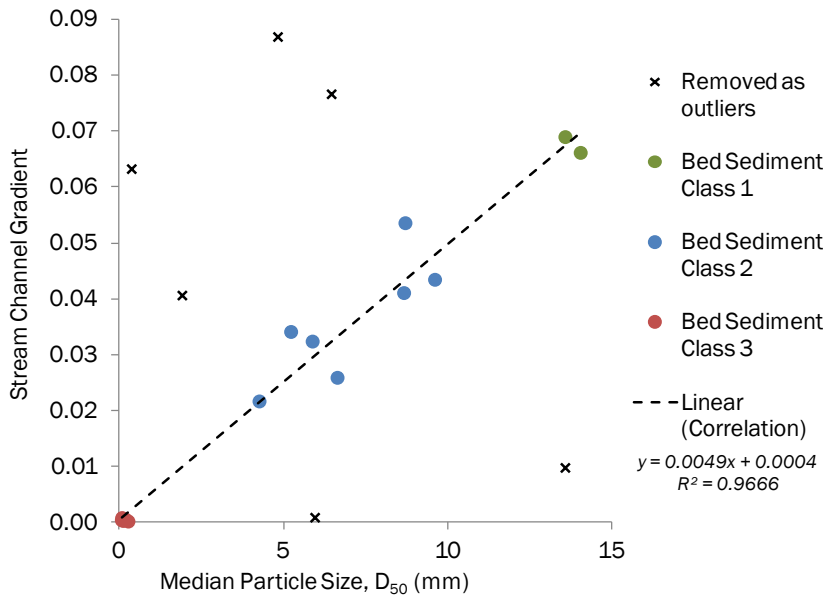

Figure 7. Selection of bed sediment classes

Of the 20 sediment samples, 14 showed a close correlation between stream channel gradient and mean particle size (R^2 = 0.97); 6 samples were removed as outliers.

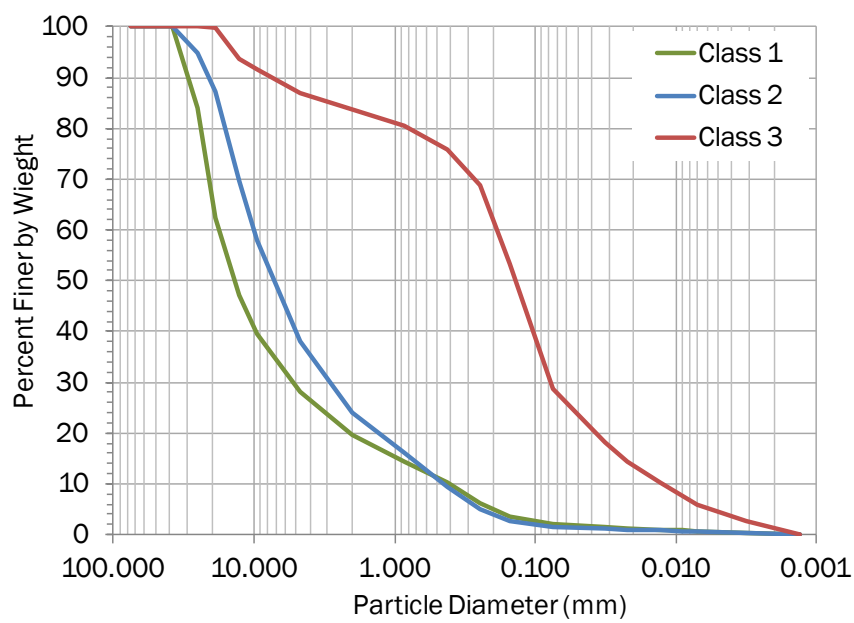

Figure 8. Composite gradation curves for bed sediment classes

Gradation curves calculated from selected sediment samples as shown in Figure 7.

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Table 1. Sediment Characteristics for Composite Sediment Classes			
Composite sediment class	Mean particle diameter D_{50} (mm)	Sediment size description*	Applicable slope range
Class 1	13.7	Medium gravel	Greater than 6%
Class 2	7.2	Fine gravel	Between 1% and 6%
Class 3	0.14	Fine sand	Less than 1%

**As defined by the American Geophysical Union Sediment Classification System.*

Mean particle diameters for the bed sediments were used in combination with stream channel hydraulics to calculate sediment transport rates/effective work potential.

3.1.4 Effective Work Index

In physics, work is defined as the integral of force over a distance of displacement. In the case of stream systems, work can be calculated based on stream power, or the product of flow velocity and shear stress. Total effective work was calculated using an effective work index defined as follows:

$$W = C \sum_{i=1}^{n} (\tau_i - \tau_c)^b \cdot V_i \cdot \Delta t$$

where W is the index of total work done (units of foot-pounds per square foot), C is a constant to dimensional or dimensionless units of work, n is the number of increments in the flow histogram, t is the applied hydraulic shear stress (pounds per square foot), t_c is the critical shear stress that initiates bed movement (pounds per square foot), e is an exponent that captures the exponential rise in stream power with flow, V is the mid-channel flow velocity (feet per second), Δt is the duration of flow for each time increment (seconds)

The exponent, b, captures the exponential rise in stream power with increasing flow rates. For this analysis, b was assumed to be equal to 1.5, which is consistent with standard bedload transport functions such as the equation developed by Meyer-Peter and Muller (1948).

Critical shear stress (τ_c) was calculated using the following equation:

$$\tau_c = \tau^*(\gamma_s - \gamma)D_{50}$$

where τ_c = critical shear stress (pounds per square foot), τ^* = dimensionless shear (i.e., Shield's parameter), γ_s = specific weight of the stone = 165 pounds per cubic foot, γ = specific weight of the water = 62.4 pounds per cubic foot, D_{50} = mean particle size from the sediment gradations curves (feet)

Dimensionless shear (τ^*) was calculated using an approximation developed by Wilcock (2004):

$$\tau^* = 0.105S^{*-0.3} + e^{-35S^{*-0.59}}$$

$$S^* = \sqrt{(\gamma_s/\gamma - 1) * g * D^3}/\upsilon$$

where S^* is the dimensionless kinematic viscosity, g is the gravitational constant (assumed to be 32.2 feet per second squared), and υ is the kinematic viscosity of water (assumed to be 1.12×10^{-5} feet squared per second)

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3.2 Geomorphically Significant Flows Evaluation

Geomorphically significant flows were calculated from the effective work curves using an assumed level of control (percentage of total work done). The calculation of the upper and lower bounds is described in Section 3.2.1. Regulatory thresholds related to Washington State flow control standards were also calculated to provide context to the results (see Subsection 3.2.2).

3.2.1 Calculation of the Lower and Upper Bounds

The qualitative description of the geomorphically significant flows presented by Leopold et al. (1964) suggests a lower limit at the flow rate necessary to produce incipient motion of bed sediments. However, incipient motion calculations based on critical shear stress (see Subsection 3.1.4) indicated that for many of the steep and incised stream reaches, the flow rate associated with incipient motion of the mean particle size was extremely small (less than 0.01 cubic feet per second [cfs]), and flows of that magnitude also tend to be intermittent and infrequent.

A similar problem is presented by the upper limit; Leopold et al. (1964) describes the upper limit as the flow rate at which the bankfull capacity of the channel is exceeded. However, many of the incised stream reaches do not have a clear bankfull channel as they are effectively disconnected from adjacent floodplains or are located in steep ravines that do not have a well-developed floodplain or bankfull condition.

Alternatively, a desired "level of control" was assumed based on the integral percentage of the effective work curve captured by the upper and lower bounds. For this study, that percentage was assumed to be 98 percent. The remaining 2 percent was divided evenly between the upper and lower "tails" of the effective work curve.

3.2.2 Regulatory Thresholds

The National Pollutant Discharge Elimination System (NPDES) Permit program is a requirement of the federal Clean Water Act, which is intended to protect and restore waters for "fishable, swimmable" uses. The EPA has delegated Permit authority to state environmental agencies, and these agencies can set Permit conditions in accordance with, and in addition to, the minimum federal requirements. In Washington, the State Department of Ecology (Ecology) is the NPDES-delegated Permit authority.

Ecology issues municipal stormwater permits to cover discharges from municipal separate storm sewer systems (MS4s). Pierce County and the City of Puyallup are the two MS4 jurisdictions located within the Clarks Creek basin. Pierce County is covered under the Phase I Municipal Stormwater Permit (Phase I Permit), and the City of Puyallup is covered by the Phase II Western Washington Stormwater Permit (Phase II Permit). On August 1, 2012, Ecology issued the Phase I and Phase II Permits for 2013 to 2018, due to become effective on August 1, 2013.

3.2.2.1 Flow Control Standards

The 2013–18 Municipal Stormwater Permits contain special requirements for new development and re-development projects. Minimum Requirement 5 (On-site Stormwater Management) and Minimum Requirement 7 (Flow Control) specify flow duration control standards for mitigating flow increases cause by increased impervious surfaces. More specifically,

- **Minimum Requirement 5, "On-site Stormwater Management,"** contains a low-impact development (LID) performance standard as follows:

  > *Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 8% of the 2-year peak flow to 50% of the 2-year peak flow. Refer to the Standard Flow Control Requirement section in Minimum Requirement #7 for information about the assignment of the pre-developed condition.*

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Project sites that must also meet minimum requirement #7 shall match flow durations between 8% of the 2-year flow through the full 50-year flow.

- **Minimum Requirement 7: "Flow Control,"** contains a standard flow control requirement as follows:

  Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. The pre-developed condition to be matched shall be a forested land cover unless [specific conditions are met.]

The intent behind Minimum Requirements 5 and 7 is to mitigate the impacts of increased stormwater flows through a range of flows that are considered geomorphically significant (as described in the previous subsection) such that erosive and unstable geomorphic conditions are minimized. The lower bound of the flow control standard corresponds roughly to the flow rate below which the effective work done on the channel is essentially negligible.

3.2.2.2 Discharges for the Pre-developed/Forested Condition

The HSPF model developed by Tetra Tech (April 2012) was used to simulate a pre-developed, fully forested condition. Flow hydrographs were then processed into partial duration series to obtain a series of discrete runoff events. The peak flow rates from each of these events were ranked and assigned an exceedance probability using the following plotting position formula:

$$P(X \geq x_n) = \frac{m - b}{n + 1 - 2b}$$

where $P(X \geq x_m)$ = exceedance probability, m = rank of event, n = number of years of record, and b = plotting parameter

The plotting parameter (b) used for this analysis was based on Cunnane (1978) as presented in (Maidment, 1993), where b is equal to 0.4. The calculated exceedance probability was converted to a return period, or recurrence interval (T_r) using the following equation:

$$T_r = \frac{1}{P(X \geq x_m)}$$

Two-year discharges for forested conditions were calculated and multiplied by 0.08 and 0.5 to calculate the lower flow thresholds for Minimum Requirements 5 and 7, respectively.

4. Results and Discussion

Stream profile plots were used to divide Clarks, Rody, Diru, Woodland, Silver, and Meeker creeks into computational stream reaches. The MFA Spreadsheet Tool was then used to calculate geomorphically significant flow ranges for each reach. Input data for each reach were selected based on the nearest relevant data point (see Maps 2 through 4, Attachment A). One-page results summaries for each reach are provided in Attachment B. Additional tabulated results comparing the calculated geomorphically significant flow bounds with forested-conditions regulatory thresholds are provided in Attachment C.

The following general trends were observed in the results:

- Calculated geomorphically significant flows vary widely within the Clarks Creek watershed.
- Calculated geomorphically significant flows for lower Clarks Creek (reaches CC-R01 through CC-R16) roughly correspond to the flow thresholds of Minimum Requirement 7; i.e., 50 percent of the 2-year forested discharge through the approximately the 50-year forested discharge (see Figure 9).
- Calculated geomorphically significant flows for upper Clarks Creek (reaches CC-R17 through CC-R23) vary; the lower bound ranges from 5 percent of the 2-year forested discharge up to about 38 percent of the 2-year forested discharge (see Figure 10). The upper bound tends to be two to three times larger than the 50-year forested discharge, likely due to the flow increases caused by urbanization.
- Calculated geomorphically significant flows for the tributaries vary widely from reach to reach. The lower bound ranges from as little as 5 percent of the 2-year forested discharge to greater than 100 percent of the 2-year forested discharge (see Map 5, Attachment B). The upper bound can be as much as six times larger than the 50-year forested discharge, likely due to the flow increases caused by urbanization.

Given the wide range of geomorphically significant flows, it would be difficult to establish a “one size fits all” flow control standard tailored to the Clarks Creek watershed. Flow control standards designed to arrest erosion in the most unstable stream reaches would require flows to be controlled down to an extremely low threshold, which given the poor soils and limited opportunities for detention in the upper watershed, is likely to be infeasible. The geomorphically significant flow analysis does suggest that the default standards described in Minimum Requirements 5 and 7 of the MS4 Permits would be a substantial improvement in the current flow regime and help to mitigate the potential for future channel instabilities.

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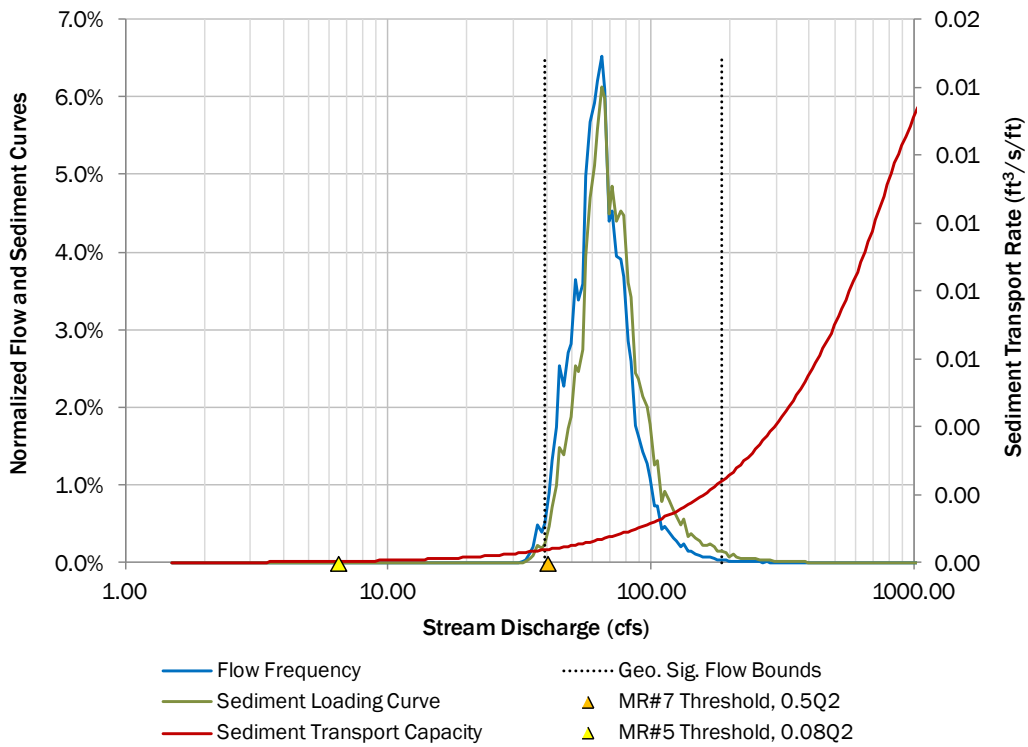

Figure 9. Example MFA results plot for lower Clarks Creek (Reach CC-R01)

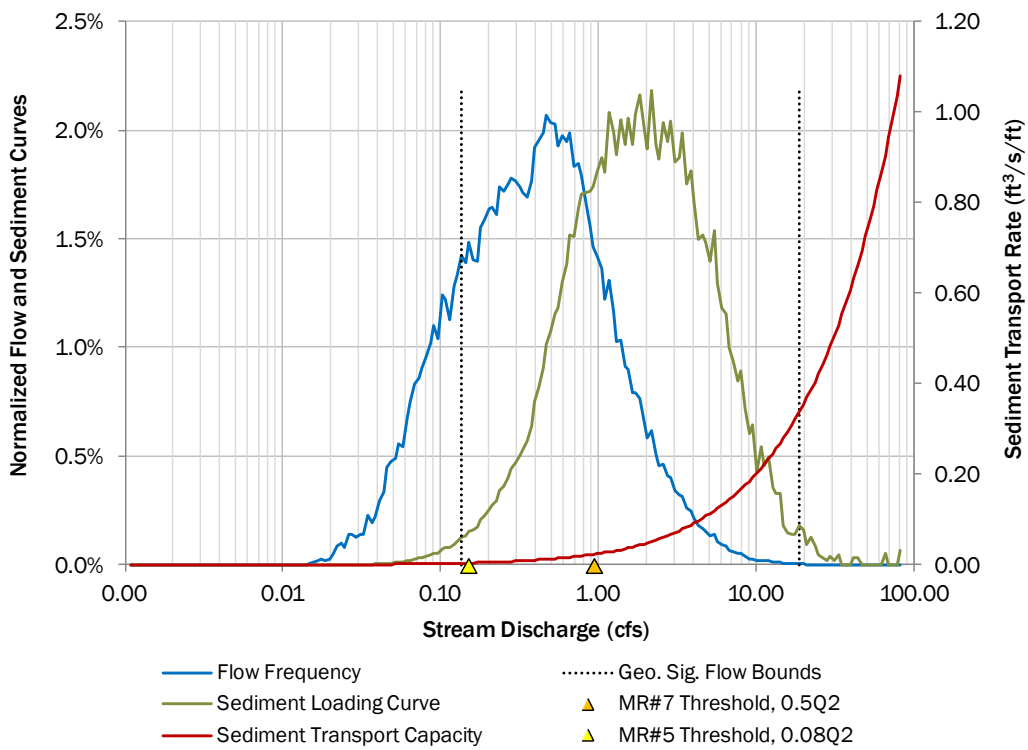

Figure 10. Example MFA results plot for upper Clarks Creek (Reach CC-R21)

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Attachment A: Maps

Map 1: Computational Stream Reaches

Map 2: Flow Output Locations

Map 3: Cross-section Locations

Map 4: Sediment Sampling Locations

Map 5: Geomorphically Significant Flow Lower Bounds

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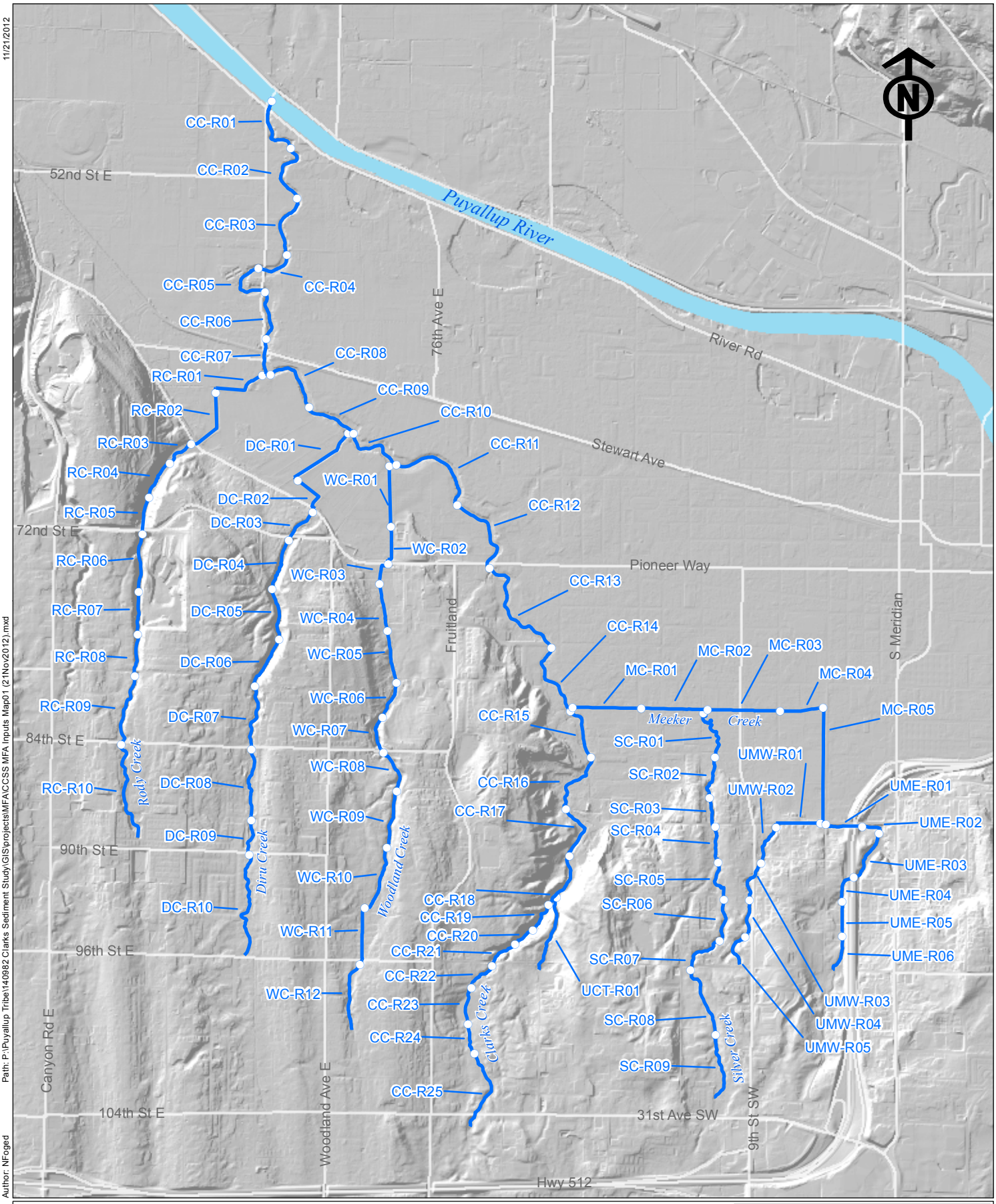

Author: NFoged

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11/21/2012

Brown AND Caldwell

1,200 0 1,200 FT

1 inch = 2,400 feet

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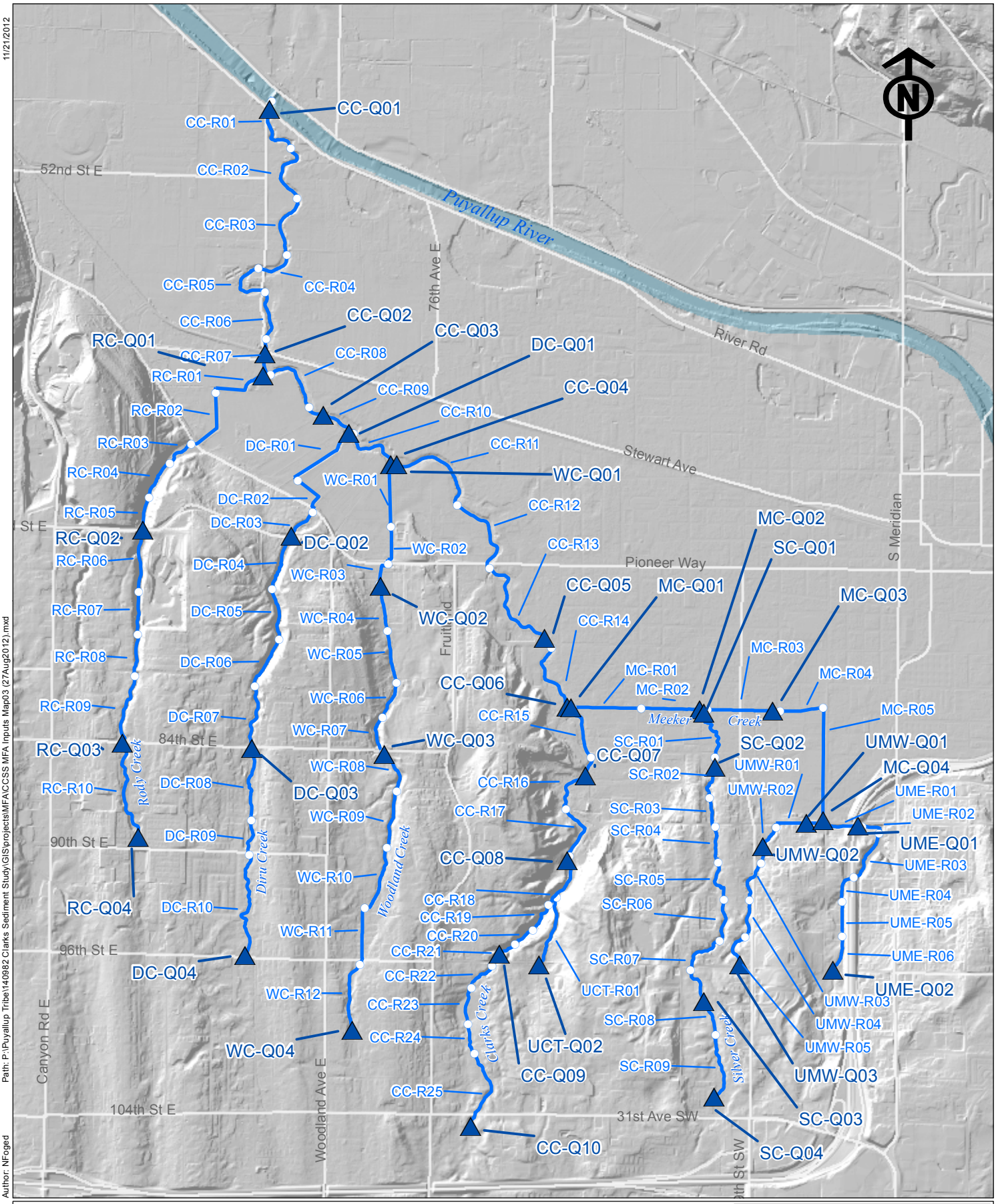
LEGEND

Evaluation Reaches

MAP 1
REACHES FOR MFA COMPUTATION

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN



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LEGEND

Flow Output Node

Evaluation Reaches

MAP 2
STREAM FLOW OUTPUT NODES

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN

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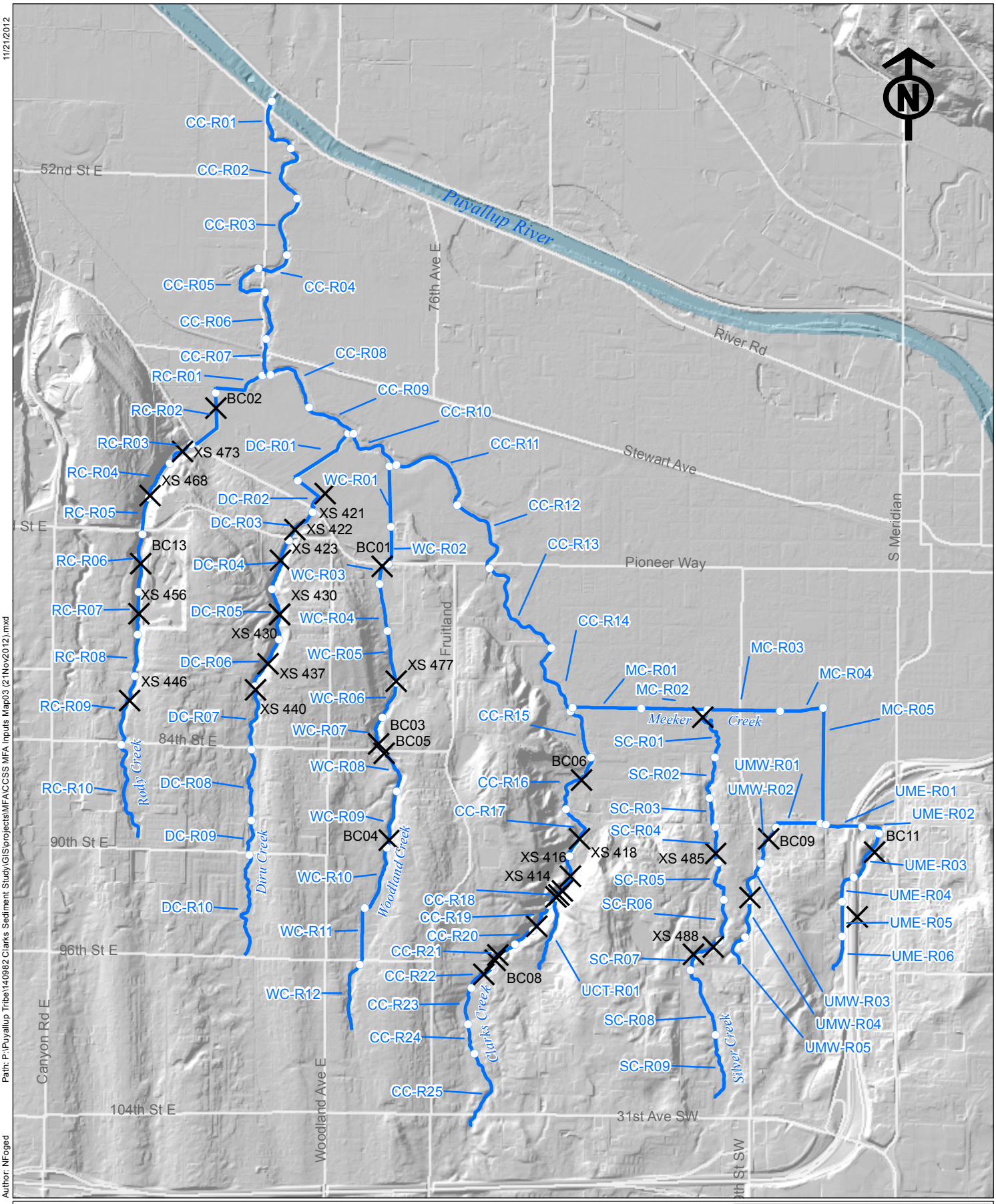
Author: NFoged



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1,200 0 1,200 FT

1 inch = 2,400 feet

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LEGEND

Evaluation Reaches

New Surveyed Cross-section

MAP 3
CROSS SECTION LOCATIONS

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN

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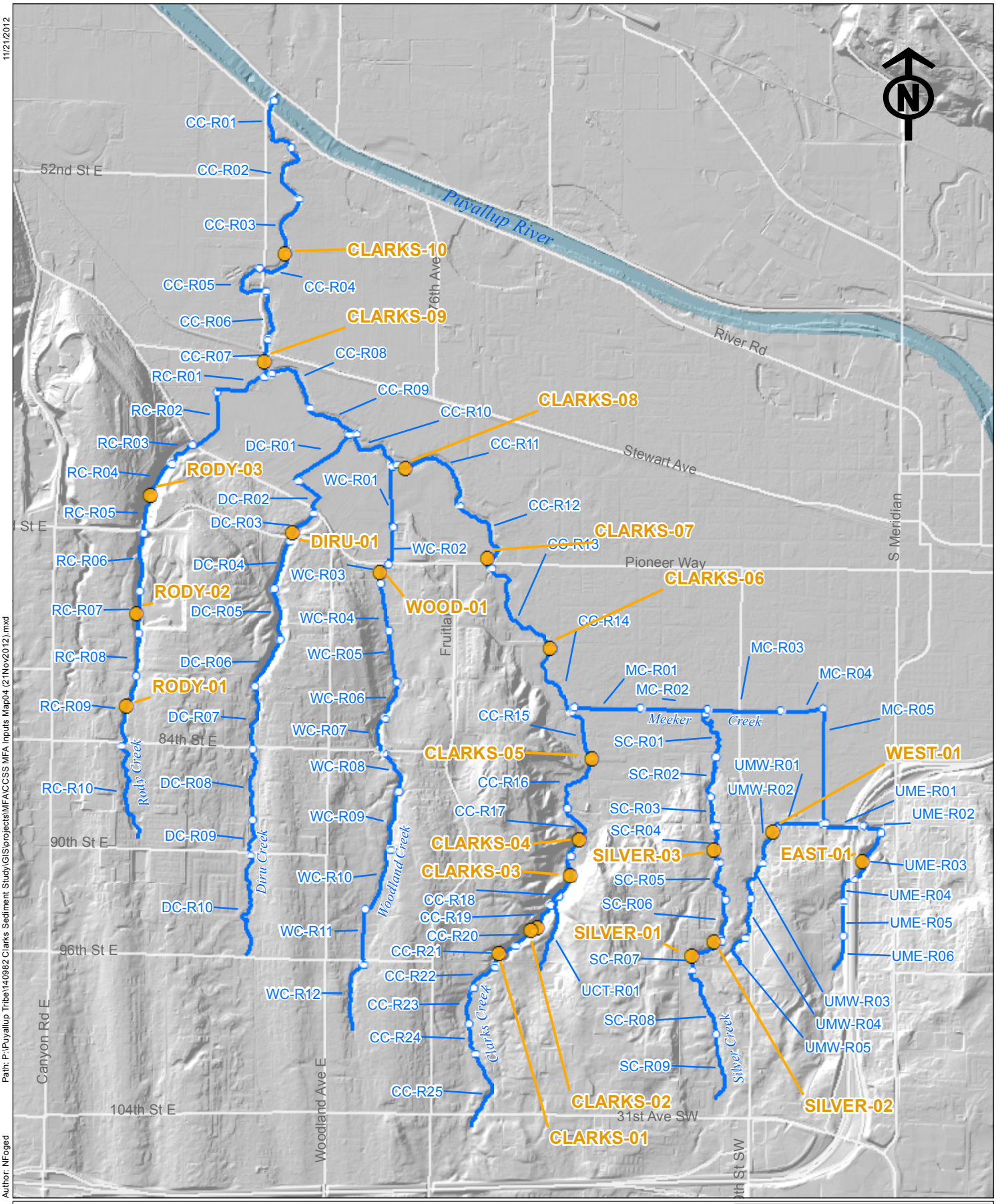
Author: NFoged



Brown AND Caldwell

1,200 0 1,200 FT

1 inch = 2,400 feet

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LEGEND

- Sediment Samples
- Evaluation Reaches

MAP 4
SEDIMENT SAMPLING LOCATIONS

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN

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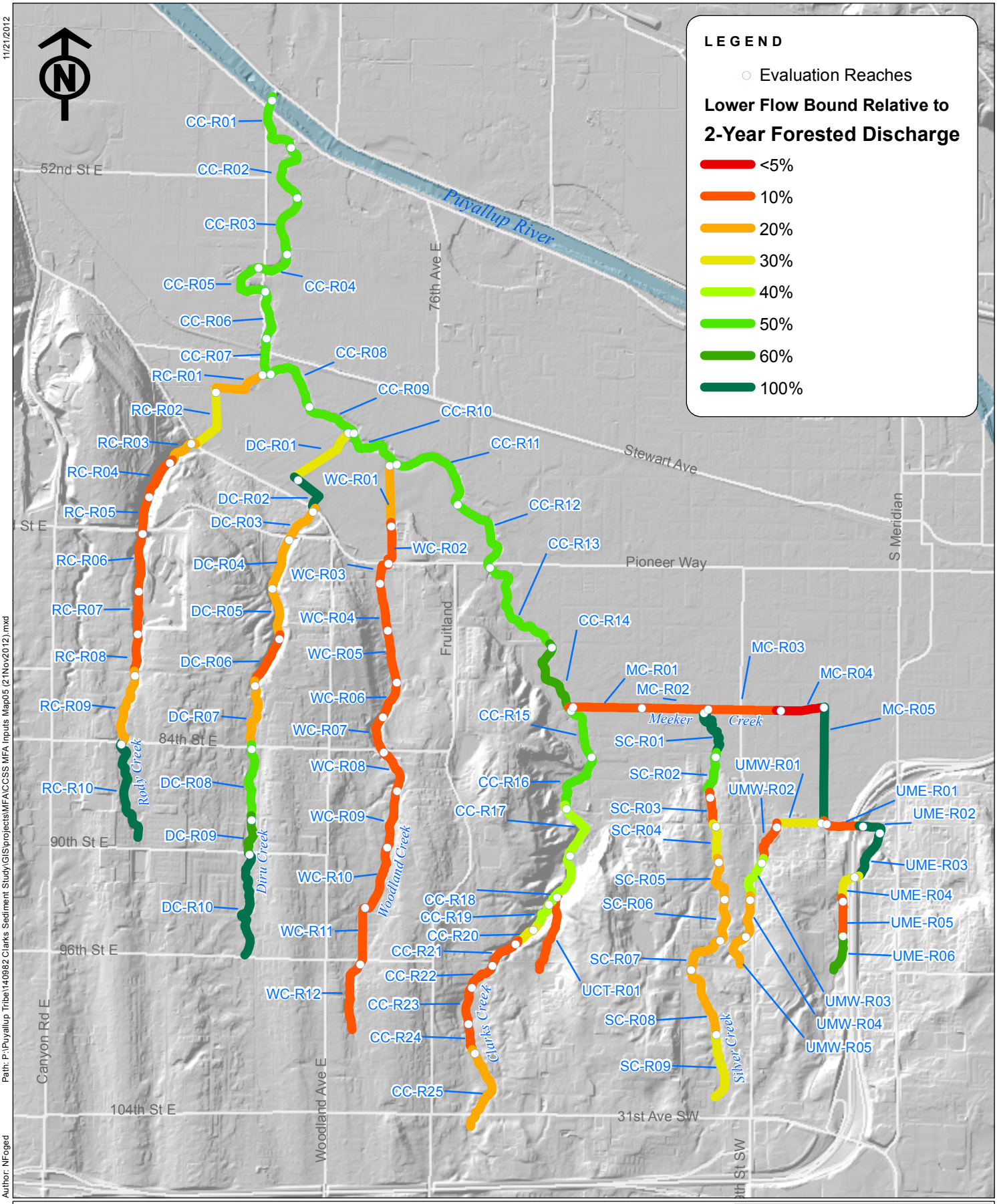

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Brown AND Caldwell

1,200 0 1,200 FT

1 inch = 2,400 feet

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MAP 4
GEO. SIG. FLOW
LOWER FLOW BOUND

CLARKS CREEK SEDIMENT REDUCTION ACTION PLAN

Attachment B: Reach Summaries

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MFA Inputs	
Reach:	CC-R01
Flow location:	CC-Q01
Cross-section:	CC.0033
Channel Slope:	0.2%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	62.44	63.78	2%
2-year Flow, Q_2	80.96	180.19	123%
50-year Flow, Q_{50}	164.22	784.17	378%
MR#7 Threshold, $0.5Q_2$	40.48	90.10	--
MR#5 Threshold, $0.08Q_2$	6.48	14.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	2.65
Depth of flow (ft)	0.02	0.05	0.28
Fraction of natural Q_2	0.0000	0.000	0.03

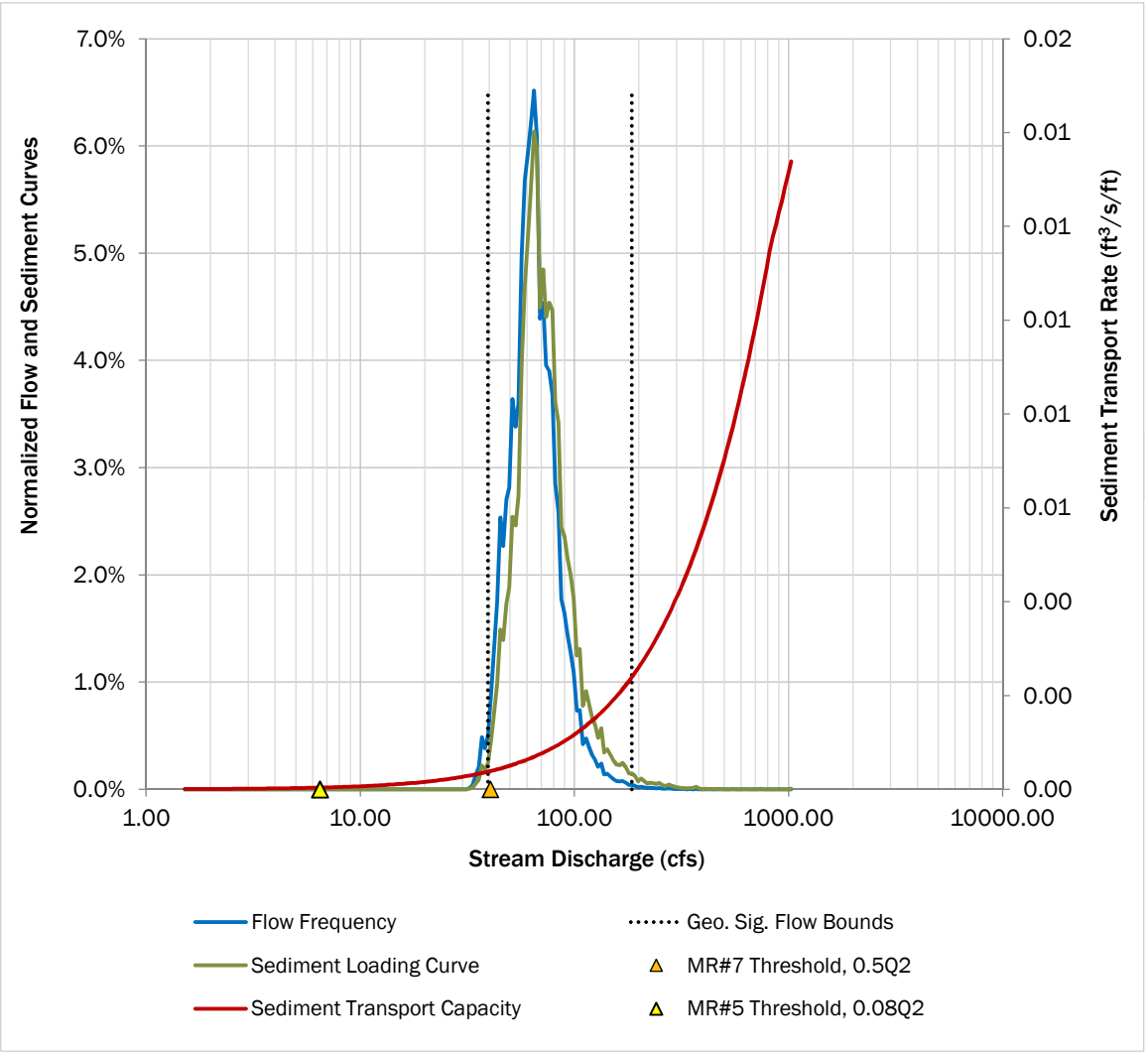
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	48,261
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	185.54
Lower flow bound for sediment loading (cfs):	39.47
Upper flow bound as a fraction of 50-year flow*:	1.13
Lower flow bound as a fraction of 2-year flow*:	0.488

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	64.69
Flow depth at effective discharge (ft):	1.49
Shear Stress at effective discharge (lb/ft^2):	0.15
Average flow velocity at effective discharge (ft/s):	2.0
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	25.2
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	CC-R02
Flow location:	CC-Q01
Cross-section:	CC.0347
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	62.44	63.78	2%
2-year Flow, Q_2	80.96	180.19	123%
50-year Flow, Q_{50}	164.22	784.17	378%
MR#7 Threshold, $0.5Q_2$	40.48	90.10	--
MR#5 Threshold, $0.08Q_2$	6.48	14.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	4.75
Depth of flow (ft)	0.03	0.09	0.90
Fraction of natural Q_2	0.0000	0.000	0.06

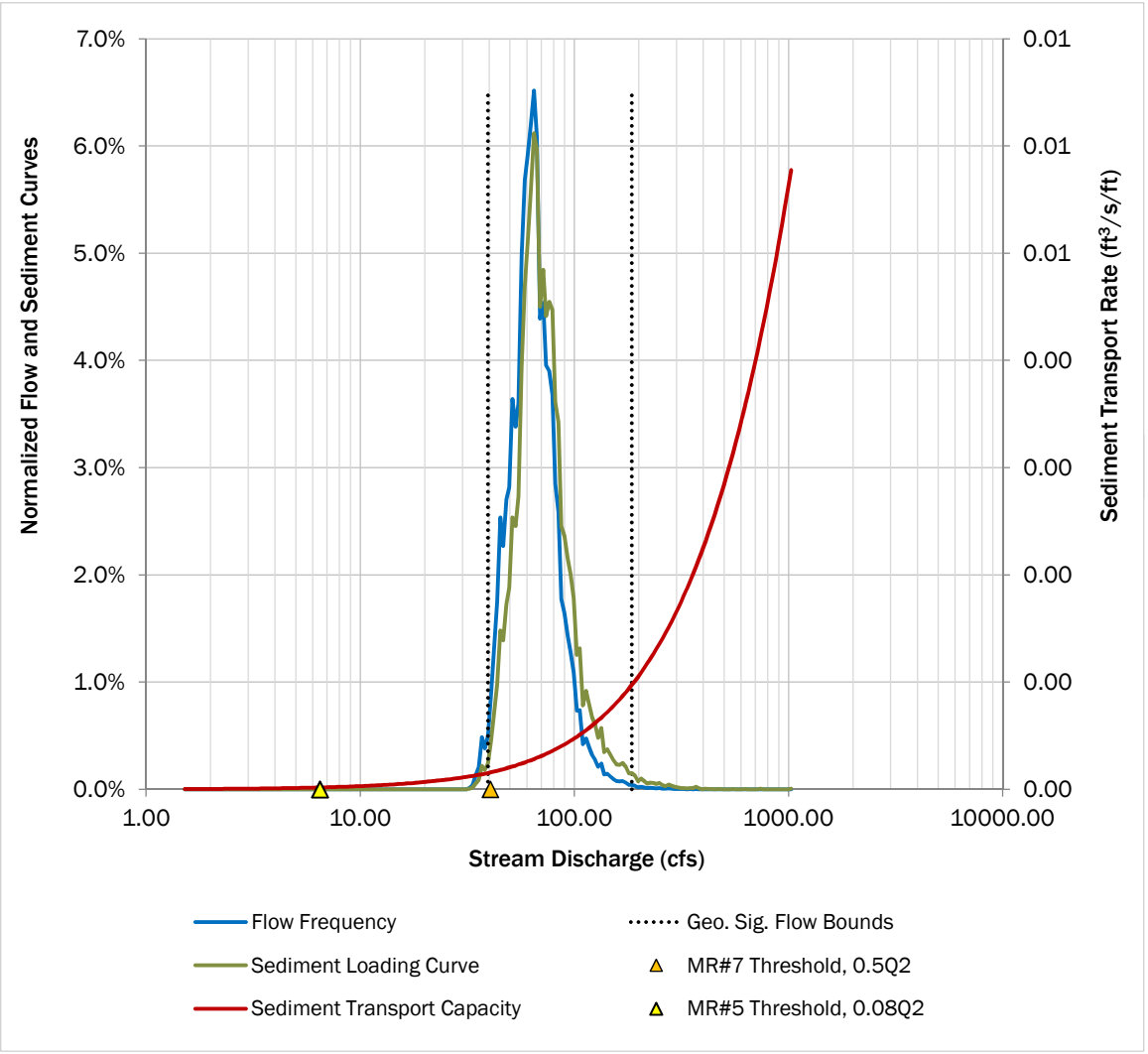
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	21,338
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	185.54
Lower flow bound for sediment loading (cfs):	39.47
Upper flow bound as a fraction of 50-year flow*:	1.13
Lower flow bound as a fraction of 2-year flow*:	0.488

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	64.69
Flow depth at effective discharge (ft):	2.21
Shear Stress at effective discharge (lb/ft^2):	0.10
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	27.3
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R03
Flow location:	CC-Q01
Cross-section:	CC.0539
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	62.44	63.78	2%
2-year Flow, Q_2	80.96	180.19	123%
50-year Flow, Q_{50}	164.22	784.17	378%
MR#7 Threshold, $0.5Q_2$	40.48	90.10	--
MR#5 Threshold, $0.08Q_2$	6.48	14.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	10.96
Depth of flow (ft)	0.05	0.11	1.23
Fraction of natural Q_2	0.0000	0.000	0.14

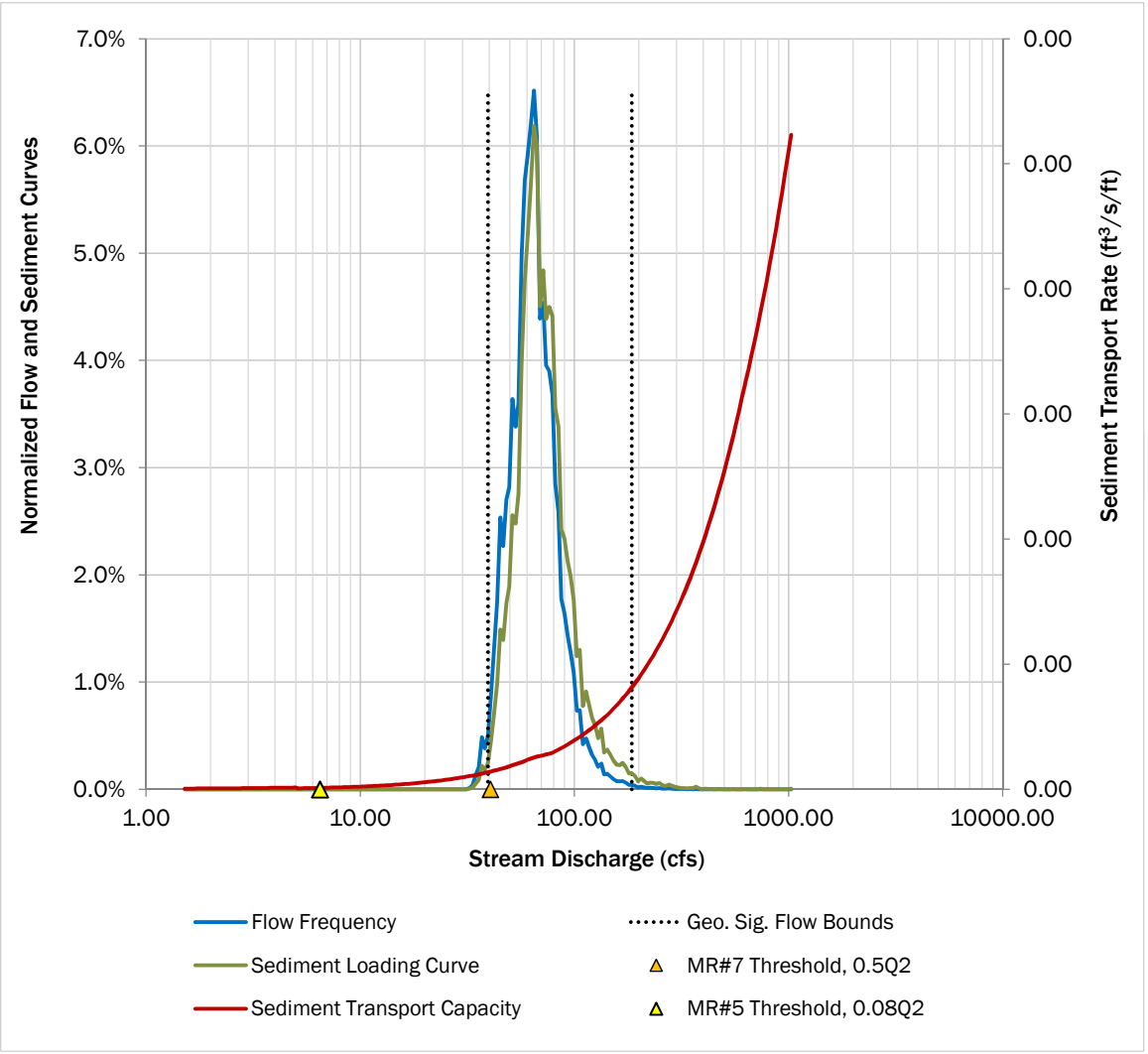
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	12,954
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	185.54
Lower flow bound for sediment loading (cfs):	39.47
Upper flow bound as a fraction of 50-year flow*:	1.13
Lower flow bound as a fraction of 2-year flow*:	0.488

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	64.69
Flow depth at effective discharge (ft):	2.16
Shear Stress at effective discharge (lb/ft^2):	0.07
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	36.9
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R04
Flow location:	CC-Q01
Cross-section:	CC.0761
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

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50-year Flow, Q_{50}	164.22	784.17	378%
MR#7 Threshold, $0.5Q_2$	40.48	90.10	--
MR#5 Threshold, $0.08Q_2$	6.48	14.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	Very Small	Very Small	Very Small
Depth of flow (ft)	Very Small	Very Small	Very Small
Fraction of natural Q_2	NA	NA	NA

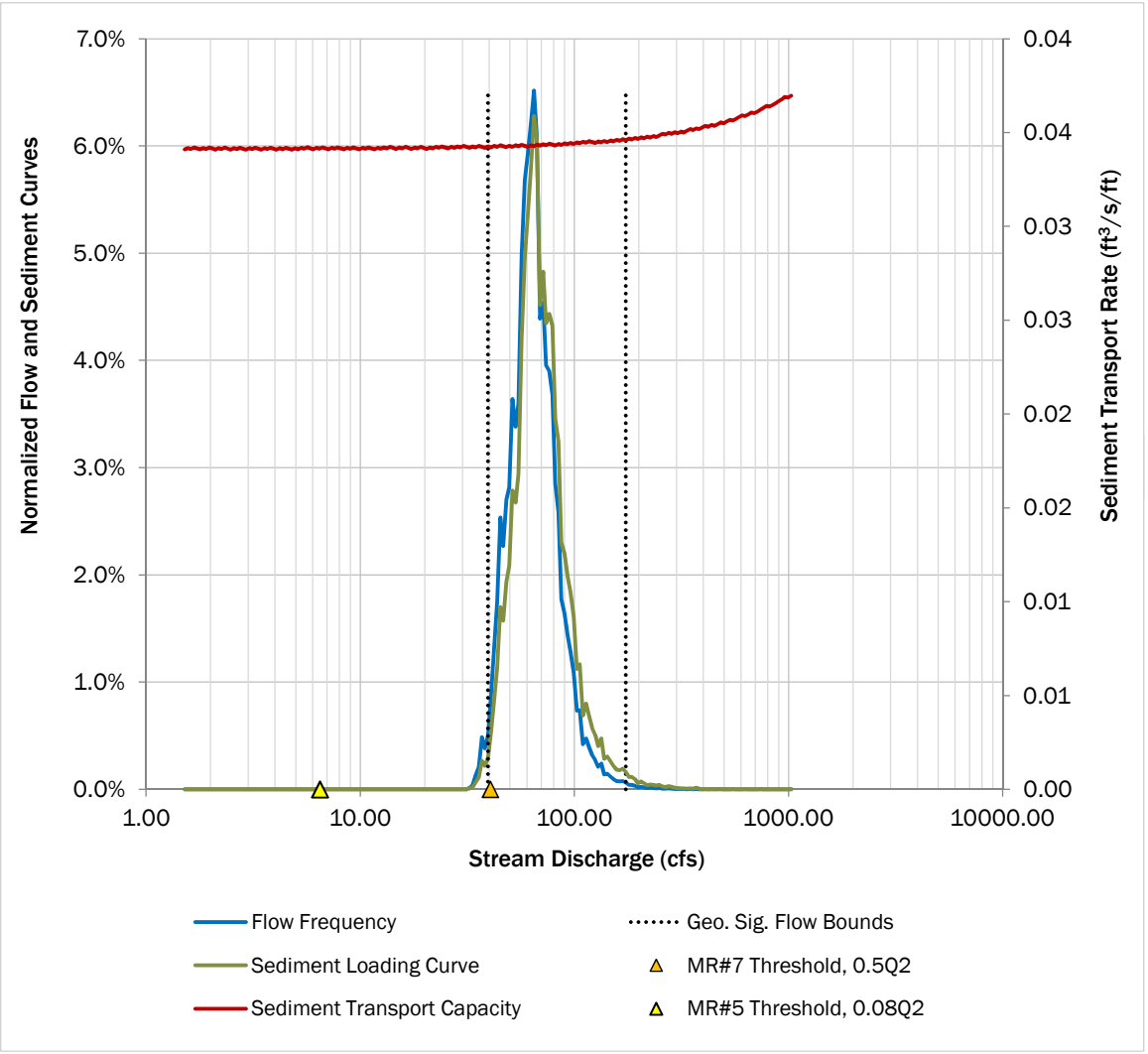
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	41,309
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	173.72
Lower flow bound for sediment loading (cfs):	39.47
Upper flow bound as a fraction of 50-year flow*:	1.06
Lower flow bound as a fraction of 2-year flow*:	0.488

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	64.69
Flow depth at effective discharge (ft):	0.18
Shear Stress at effective discharge (lb/ft^2):	0.84
Average flow velocity at effective discharge (ft/s):	7.4
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	0.4
Largest mobilized sediment:	#N/A
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	CC-R05
Flow location:	CC-Q02
Cross-section:	CC.0875
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	60.21	61.29	2%
2-year Flow, Q_2	80.69	174.65	116%
50-year Flow, Q_{50}	147.50	632.11	329%
MR#7 Threshold, $0.5Q_2$	40.35	87.33	--
MR#5 Threshold, $0.08Q_2$	6.46	13.97	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.05	9.00
Depth of flow (ft)	0.05	0.13	0.94
Fraction of natural Q_2	0.0001	0.001	0.11

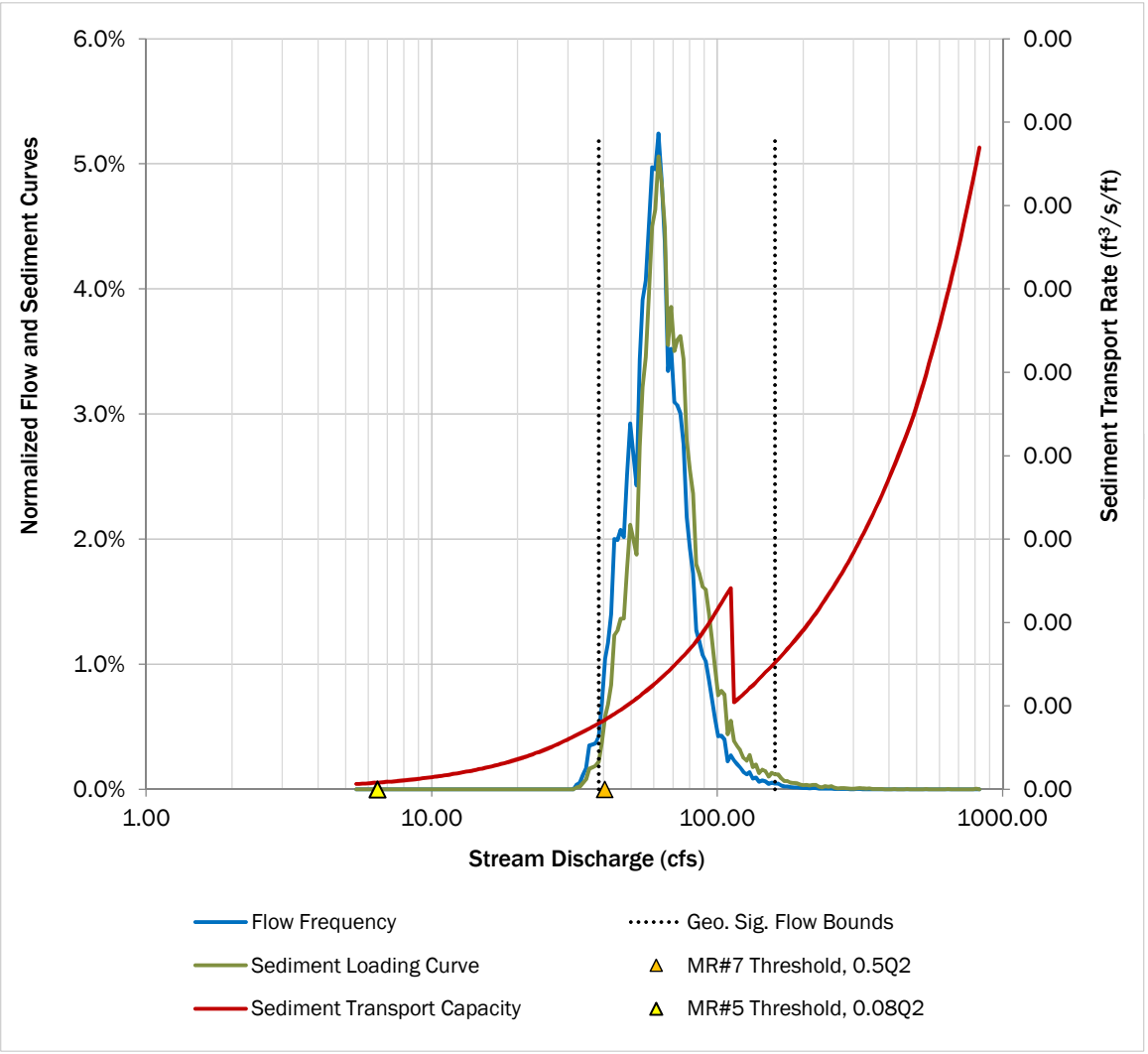
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	10,317
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	159.33
Lower flow bound for sediment loading (cfs):	38.46
Upper flow bound as a fraction of 50-year flow*:	1.08
Lower flow bound as a fraction of 2-year flow*:	0.477

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	62.30
Flow depth at effective discharge (ft):	2.24
Shear Stress at effective discharge (lb/ft^2):	0.07
Average flow velocity at effective discharge (ft/s):	1.4
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	29.2
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R06
Flow location:	CC-Q02
Cross-section:	CC.1102
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	60.21	61.29	2%
2-year Flow, Q_2	80.69	174.65	116%
50-year Flow, Q_{50}	147.50	632.11	329%
MR#7 Threshold, $0.5Q_2$	40.35	87.33	--
MR#5 Threshold, $0.08Q_2$	6.46	13.97	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	2.01
Depth of flow (ft)	0.05	0.12	1.00
Fraction of natural Q_2	0.0000	0.000	0.02

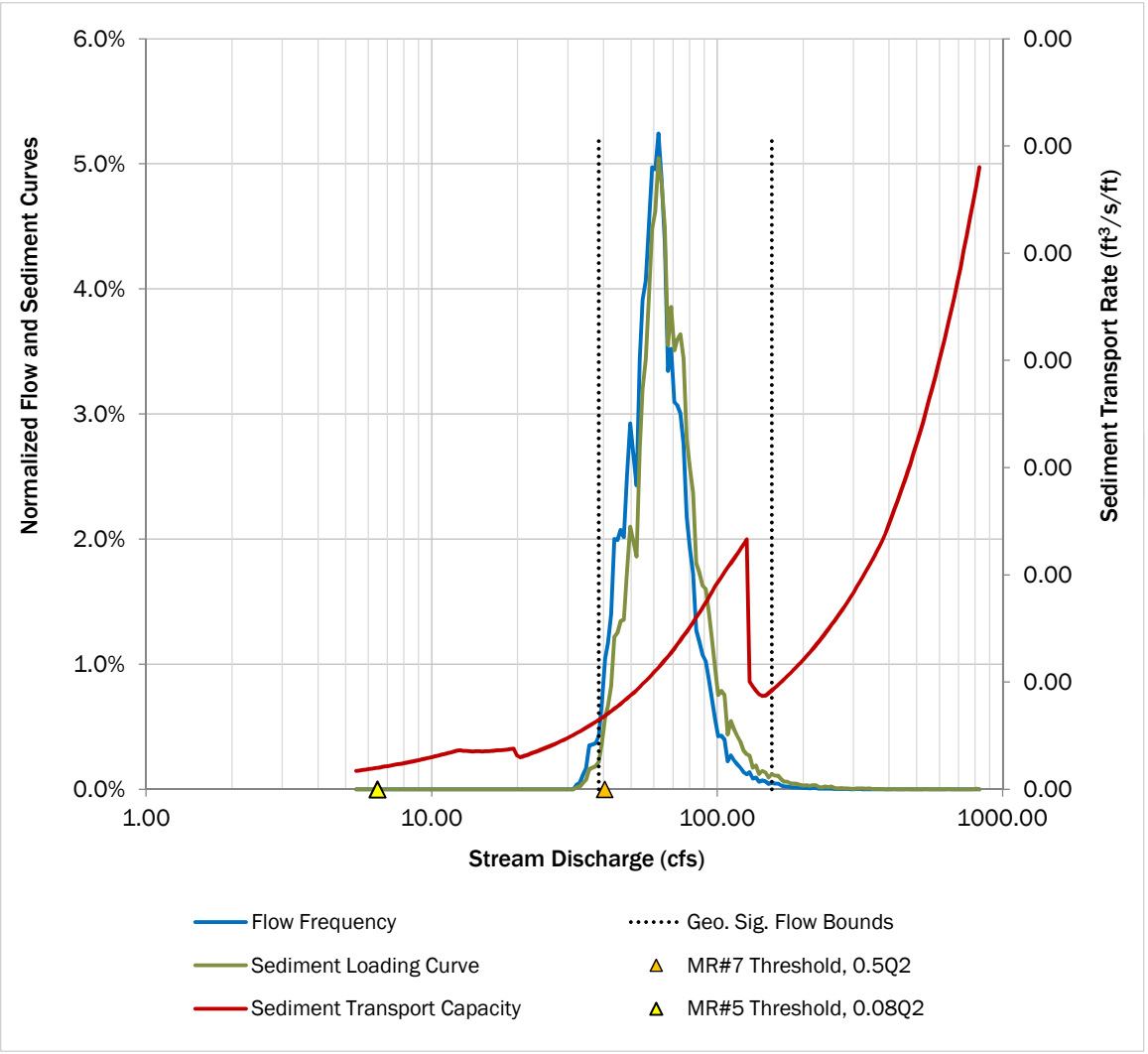
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	14,193
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	155.34
Lower flow bound for sediment loading (cfs):	38.46
Upper flow bound as a fraction of 50-year flow*:	1.05
Lower flow bound as a fraction of 2-year flow*:	0.477

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	62.30
Flow depth at effective discharge (ft):	3.64
Shear Stress at effective discharge (lb/ft^2):	0.08
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	23.0
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R07
Flow location:	CC-Q02
Cross-section:	CC.1242
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	60.21	61.29	2%
2-year Flow, Q_2	80.69	174.65	116%
50-year Flow, Q_{50}	147.50	632.11	329%
MR#7 Threshold, $0.5Q_2$	40.35	87.33	--
MR#5 Threshold, $0.08Q_2$	6.46	13.97	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	0.05	4.00
Depth of flow (ft)	0.04	0.10	0.71
Fraction of natural Q_2	0.0001	0.001	0.05

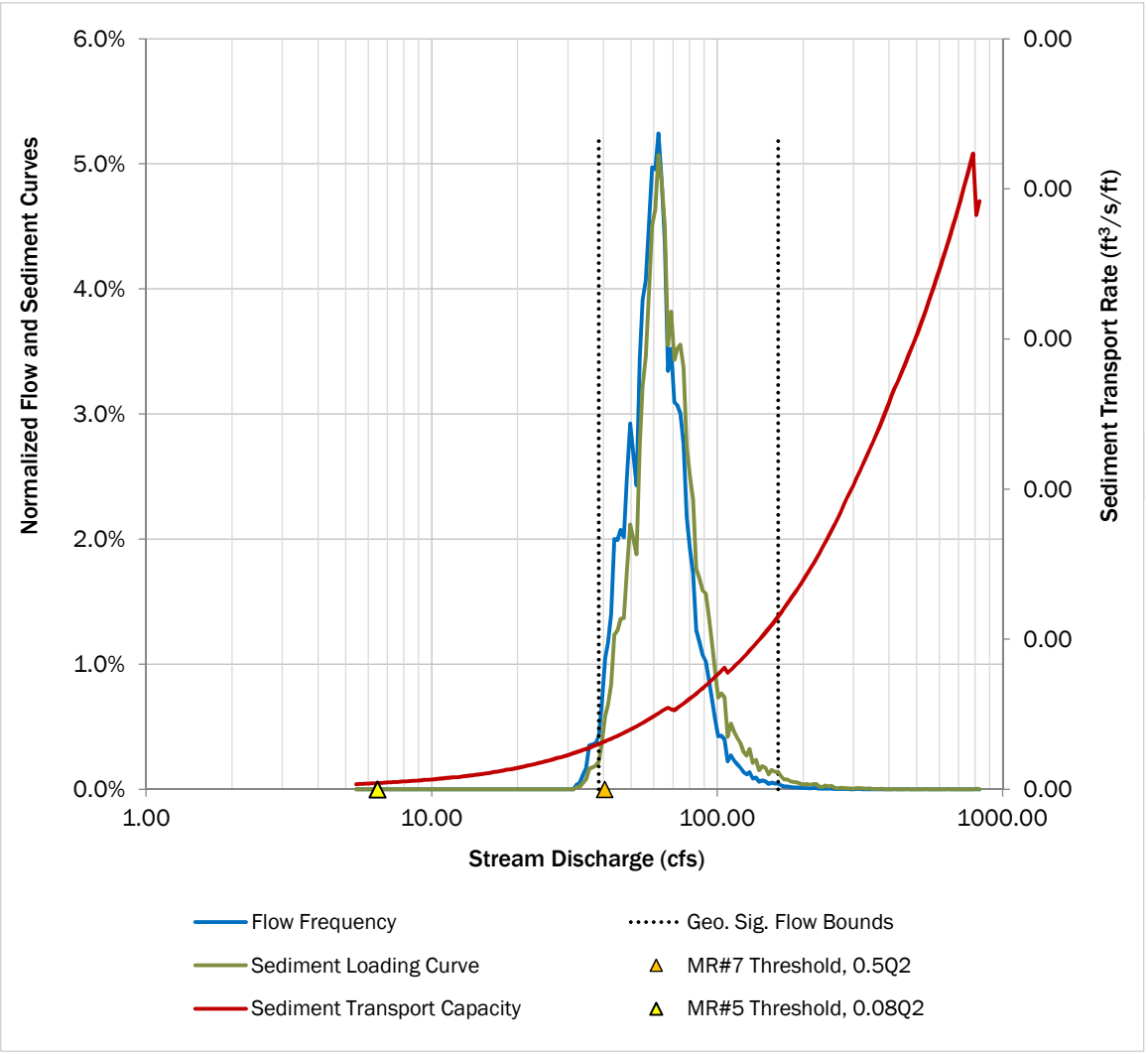
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	14,657
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	163.43
Lower flow bound for sediment loading (cfs):	38.46
Upper flow bound as a fraction of 50-year flow*:	1.11
Lower flow bound as a fraction of 2-year flow*:	0.477

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	62.30
Flow depth at effective discharge (ft):	2.56
Shear Stress at effective discharge (lb/ft^2):	0.09
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	21.4
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R08
Flow location:	CC-Q03
Cross-section:	CC.1372
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	58.65	59.63	2%
2-year Flow, Q_2	77.70	161.72	108%
50-year Flow, Q_{50}	131.24	524.04	299%
MR#7 Threshold, $0.5Q_2$	38.85	80.86	--
MR#5 Threshold, $0.08Q_2$	6.22	12.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	0.06	10.00
Depth of flow (ft)	0.06	0.14	1.06
Fraction of natural Q_2	0.0001	0.001	0.13

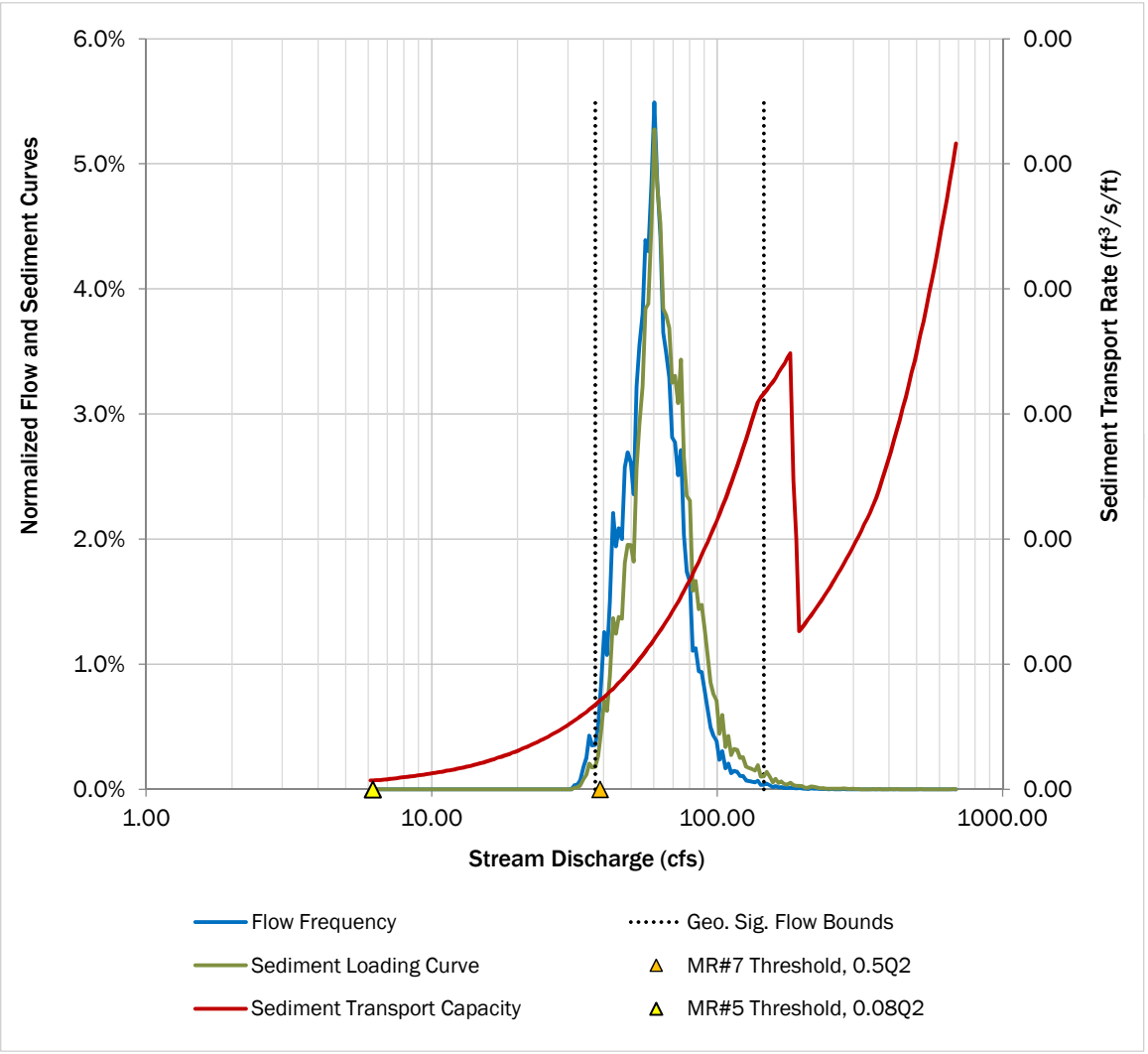
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	9,351
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	145.63
Lower flow bound for sediment loading (cfs):	37.40
Upper flow bound as a fraction of 50-year flow*:	1.11
Lower flow bound as a fraction of 2-year flow*:	0.481

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	60.26
Flow depth at effective discharge (ft):	2.23
Shear Stress at effective discharge (lb/ft^2):	0.06
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	28.7
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R09
Flow location:	CC-Q03
Cross-section:	CC.1633
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	58.65	59.63	2%
2-year Flow, Q_2	77.70	161.72	108%
50-year Flow, Q_{50}	131.24	524.04	299%
MR#7 Threshold, $0.5Q_2$	38.85	80.86	--
MR#5 Threshold, $0.08Q_2$	6.22	12.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	3.08
Depth of flow (ft)	0.05	0.14	1.13
Fraction of natural Q_2	0.0000	0.000	0.04

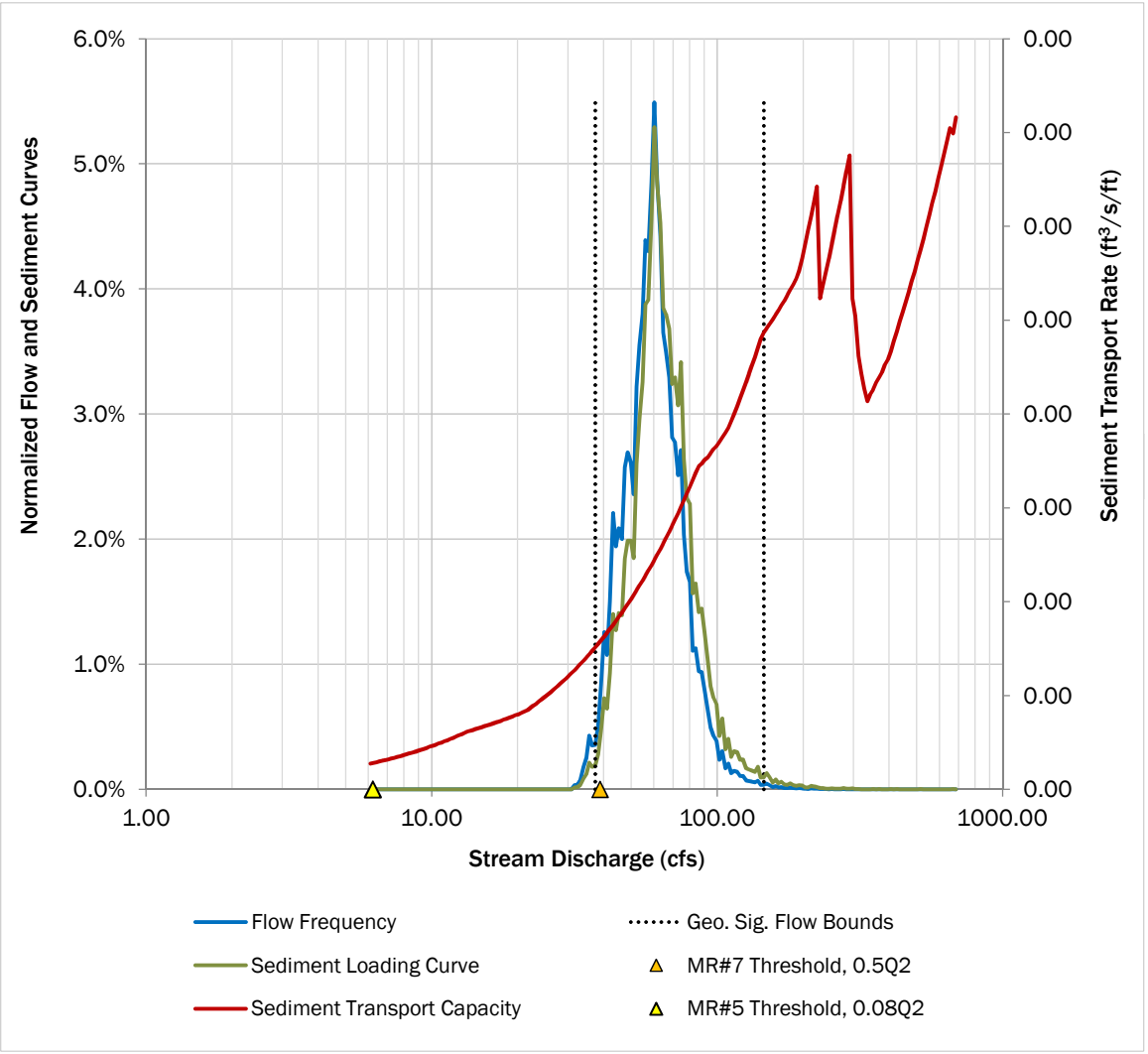
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	12,240
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	145.63
Lower flow bound for sediment loading (cfs):	37.40
Upper flow bound as a fraction of 50-year flow*:	1.11
Lower flow bound as a fraction of 2-year flow*:	0.481

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	60.26
Flow depth at effective discharge (ft):	3.94
Shear Stress at effective discharge (lb/ft^2):	0.09
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	18.5
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R10
Flow location:	CC-Q03
Cross-section:	CC.1928
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	58.65	59.63	2%
2-year Flow, Q_2	77.70	161.72	108%
50-year Flow, Q_{50}	131.24	524.04	299%
MR#7 Threshold, $0.5Q_2$	38.85	80.86	--
MR#5 Threshold, $0.08Q_2$	6.22	12.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	0.47	25.16
Depth of flow (ft)	0.12	0.47	1.90
Fraction of natural Q_2	0.0001	0.006	0.32

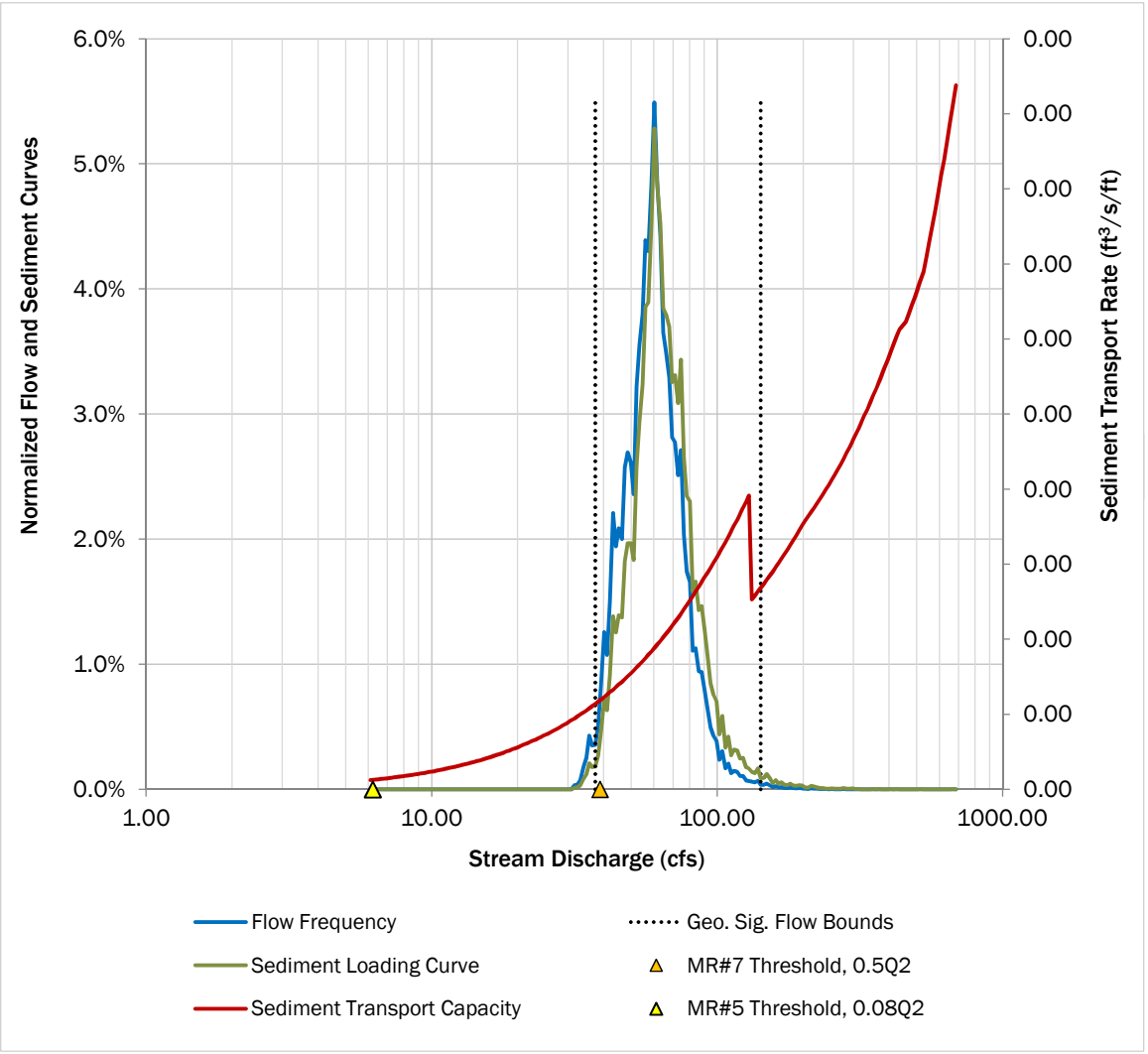
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	3,085
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	142.20
Lower flow bound for sediment loading (cfs):	37.40
Upper flow bound as a fraction of 50-year flow*:	1.08
Lower flow bound as a fraction of 2-year flow*:	0.481

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	60.26
Flow depth at effective discharge (ft):	2.89
Shear Stress at effective discharge (lb/ft^2):	0.04
Average flow velocity at effective discharge (ft/s):	1.0
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	30.2
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R11
Flow location:	CC-Q04
Cross-section:	CC.2089
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	57.21	57.97	1%
2-year Flow, Q_2	68.20	127.69	87%
50-year Flow, Q_{50}	104.61	307.84	194%
MR#7 Threshold, $0.5Q_2$	34.10	63.85	--
MR#5 Threshold, $0.08Q_2$	5.46	10.22	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.02	0.21	61.88
Depth of flow (ft)	0.20	0.49	4.24
Fraction of natural Q_2	0.0003	0.003	0.91

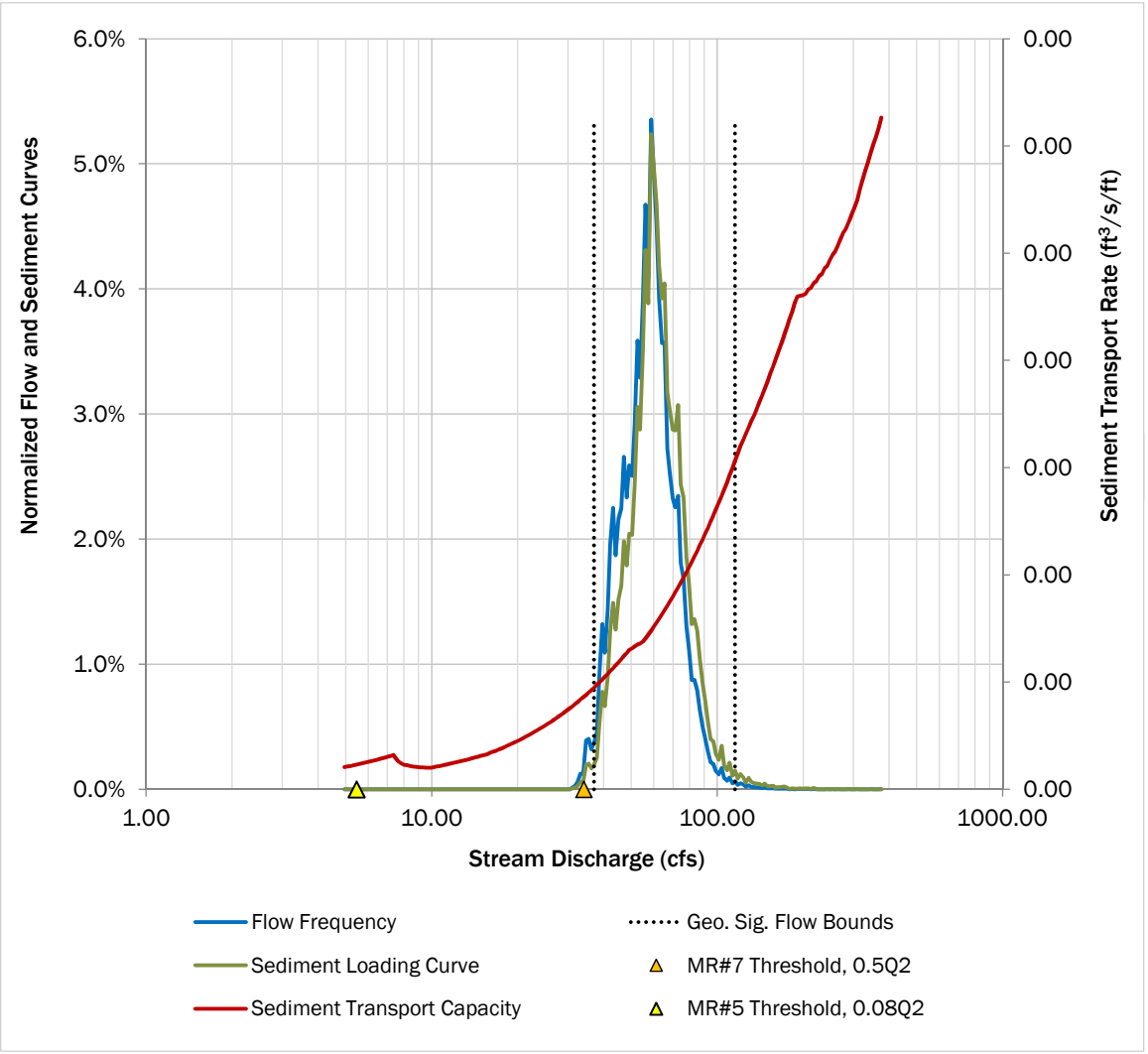
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,396
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	115.55
Lower flow bound for sediment loading (cfs):	37.06
Upper flow bound as a fraction of 50-year flow*:	1.10
Lower flow bound as a fraction of 2-year flow*:	0.543

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	58.66
Flow depth at effective discharge (ft):	4.14
Shear Stress at effective discharge (lb/ft^2):	0.02
Average flow velocity at effective discharge (ft/s):	0.8
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	35.3
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	CC-R12
Flow location:	CC-Q04
Cross-section:	CC.2605
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	57.21	57.97	1%
2-year Flow, Q_2	68.20	127.69	87%
50-year Flow, Q_{50}	104.61	307.84	194%
MR#7 Threshold, $0.5Q_2$	34.10	63.85	--
MR#5 Threshold, $0.08Q_2$	5.46	10.22	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.10	0.66	77.63
Depth of flow (ft)	0.15	0.36	3.50
Fraction of natural Q_2	0.0015	0.010	1.14

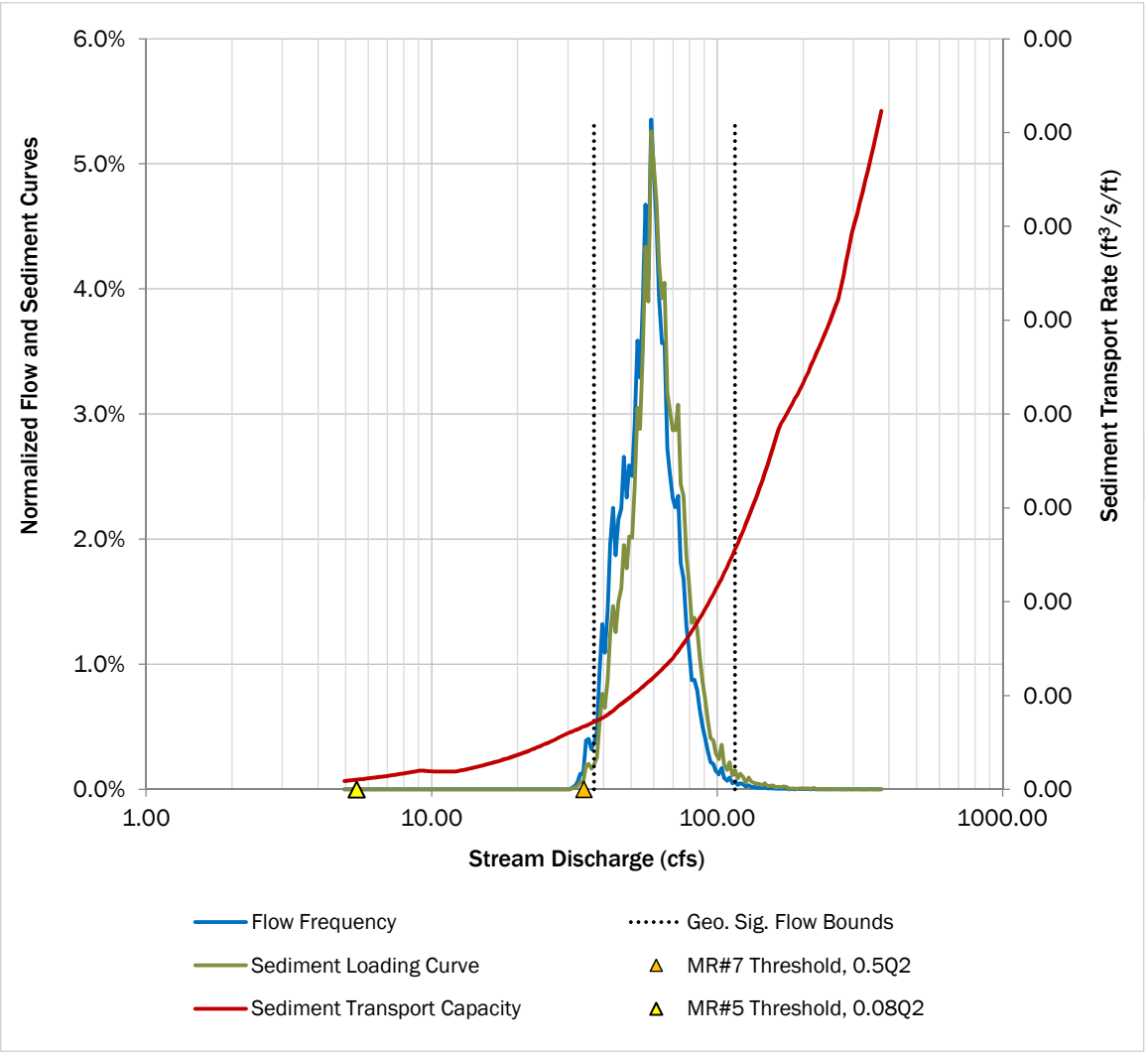
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,223
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	115.55
Lower flow bound for sediment loading (cfs):	37.06
Upper flow bound as a fraction of 50-year flow*:	1.10
Lower flow bound as a fraction of 2-year flow*:	0.543

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	58.66
Flow depth at effective discharge (ft):	3.09
Shear Stress at effective discharge (lb/ft^2):	0.02
Average flow velocity at effective discharge (ft/s):	0.8
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	39.3
Largest mobilized sediment:	*Coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	CC-R13
Flow location:	CC-Q05
Cross-section:	CC.2904
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	56.12	56.76	1%
2-year Flow, Q_2	68.34	107.41	57%
50-year Flow, Q_{50}	101.03	221.49	119%
MR#7 Threshold, $0.5Q_2$	34.17	53.71	--
MR#5 Threshold, $0.08Q_2$	5.47	8.59	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.02	0.25	39.68
Depth of flow (ft)	0.11	0.25	2.11
Fraction of natural Q_2	0.0004	0.004	0.58

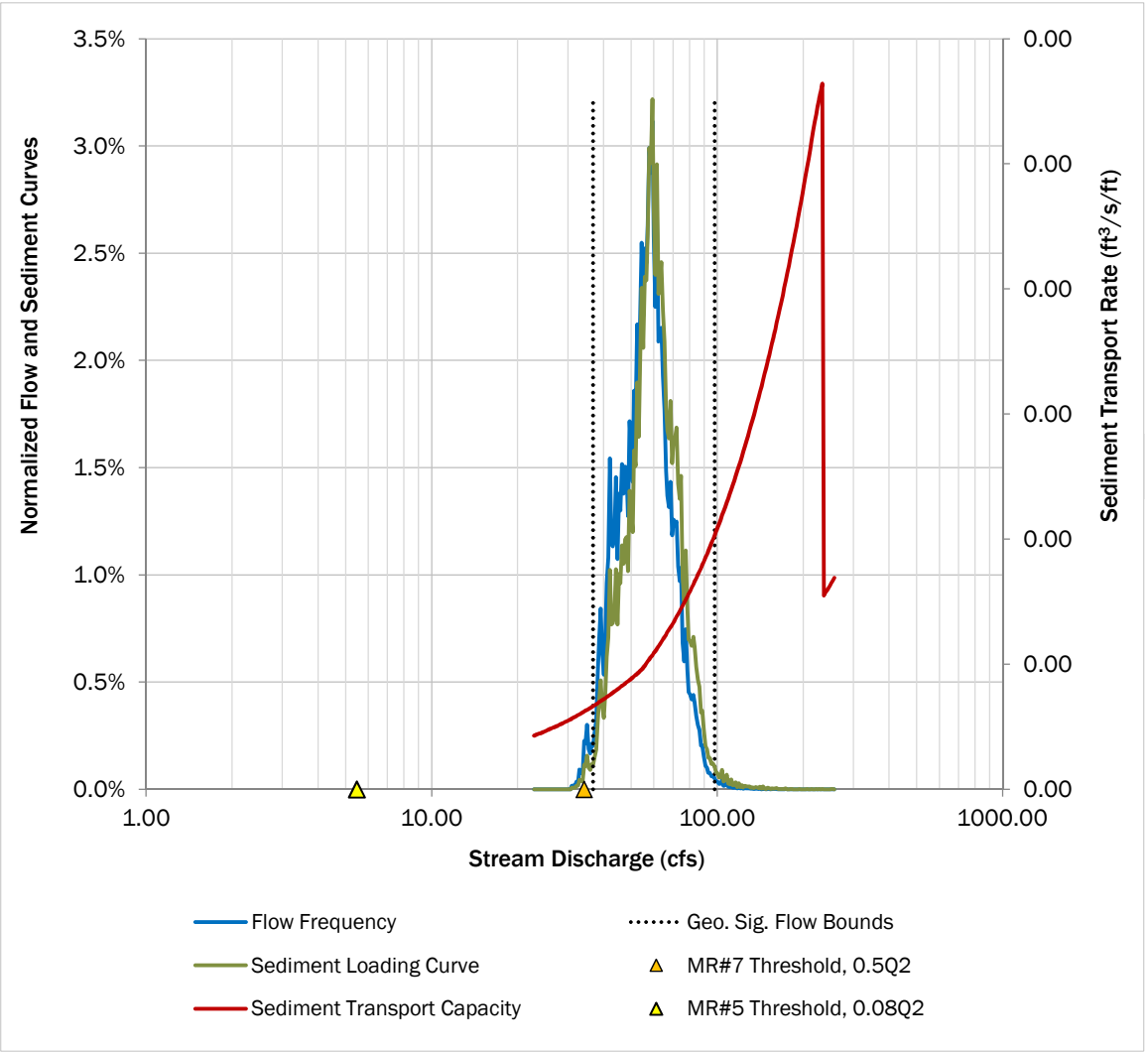
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	2,712
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	97.91
Lower flow bound for sediment loading (cfs):	36.79
Upper flow bound as a fraction of 50-year flow*:	0.97
Lower flow bound as a fraction of 2-year flow*:	0.538

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	59.29
Flow depth at effective discharge (ft):	2.46
Shear Stress at effective discharge (lb/ft^2):	0.03
Average flow velocity at effective discharge (ft/s):	0.9
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	50.1
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R14
Flow location:	CC-Q06
Cross-section:	CC.3206
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	54.16	54.44	1%
2-year Flow, Q_2	63.68	64.19	1%
50-year Flow, Q_{50}	87.97	113.98	30%
MR#7 Threshold, $0.5Q_2$	31.84	32.10	--
MR#5 Threshold, $0.08Q_2$	5.09	5.14	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	0.09	23.84
Depth of flow (ft)	0.07	0.18	1.54
Fraction of natural Q_2	0.0001	0.001	0.37

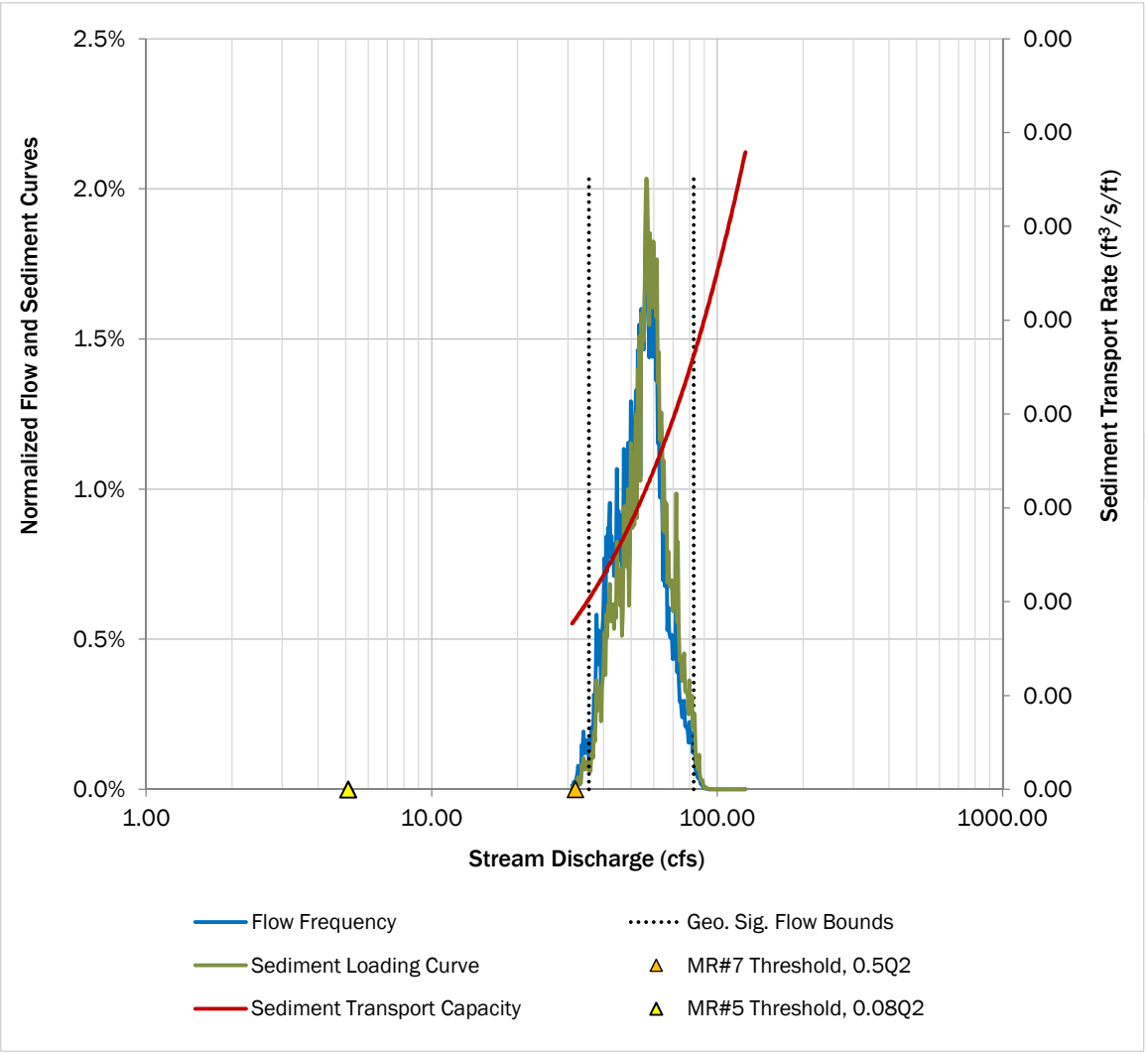
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	4,351
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	82.79
Lower flow bound for sediment loading (cfs):	35.51
Upper flow bound as a fraction of 50-year flow*:	0.94
Lower flow bound as a fraction of 2-year flow*:	0.558

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	56.57
Flow depth at effective discharge (ft):	2.10
Shear Stress at effective discharge (lb/ft^2):	0.03
Average flow velocity at effective discharge (ft/s):	0.9
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	54.2
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R15
Flow location:	CC-Q07
Cross-section:	BC06
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	13.01	13.23	2%
2-year Flow, Q_2	17.02	30.25	78%
50-year Flow, Q_{50}	27.17	81.36	199%
MR#7 Threshold, $0.5Q_2$	8.51	15.12	--
MR#5 Threshold, $0.08Q_2$	1.36	2.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.38	5.86	357.67
Depth of flow (ft)	0.40	0.99	5.07
Fraction of natural Q_2	0.0225	0.344	21.02

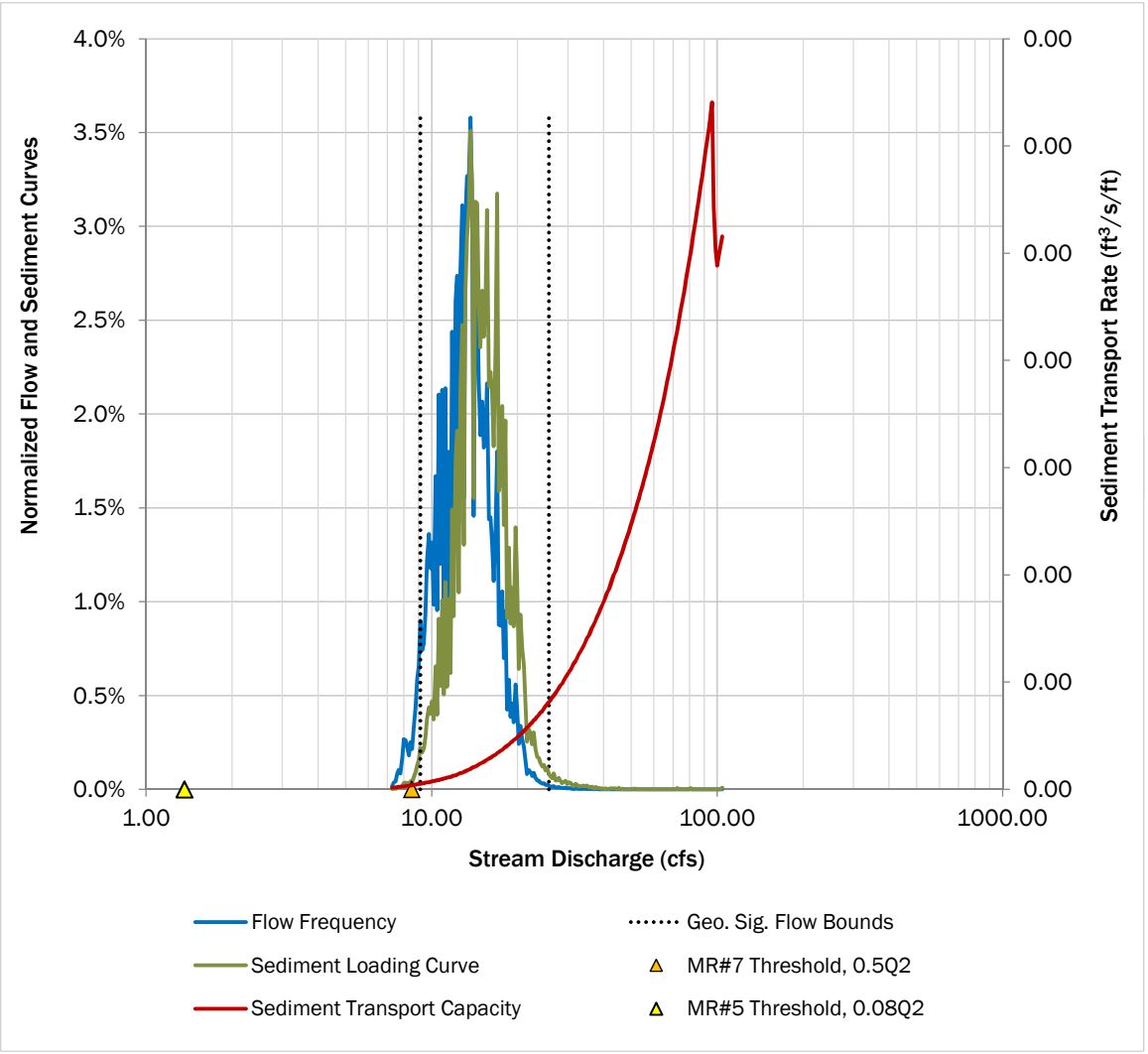
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	15
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	25.73
Lower flow bound for sediment loading (cfs):	9.14
Upper flow bound as a fraction of 50-year flow*:	0.95
Lower flow bound as a fraction of 2-year flow*:	0.537

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	13.68
Flow depth at effective discharge (ft):	1.34
Shear Stress at effective discharge (lb/ft^2):	0.00
Average flow velocity at effective discharge (ft/s):	0.3
Shear velocity at effective discharge (ft/s):	0.0
Effective width at effective discharge (ft):	59.6
Largest mobilized sediment:	*Fine sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	CC-R16
Flow location:	CC-Q07
Cross-section:	BC06
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	13.01	13.23	2%
2-year Flow, Q_2	17.02	30.25	78%
50-year Flow, Q_{50}	27.17	81.36	199%
MR#7 Threshold, $0.5Q_2$	8.51	15.12	--
MR#5 Threshold, $0.08Q_2$	1.36	2.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	9.99
Depth of flow (ft)	0.04	0.09	0.81
Fraction of natural Q_2	0.0001	0.001	0.59

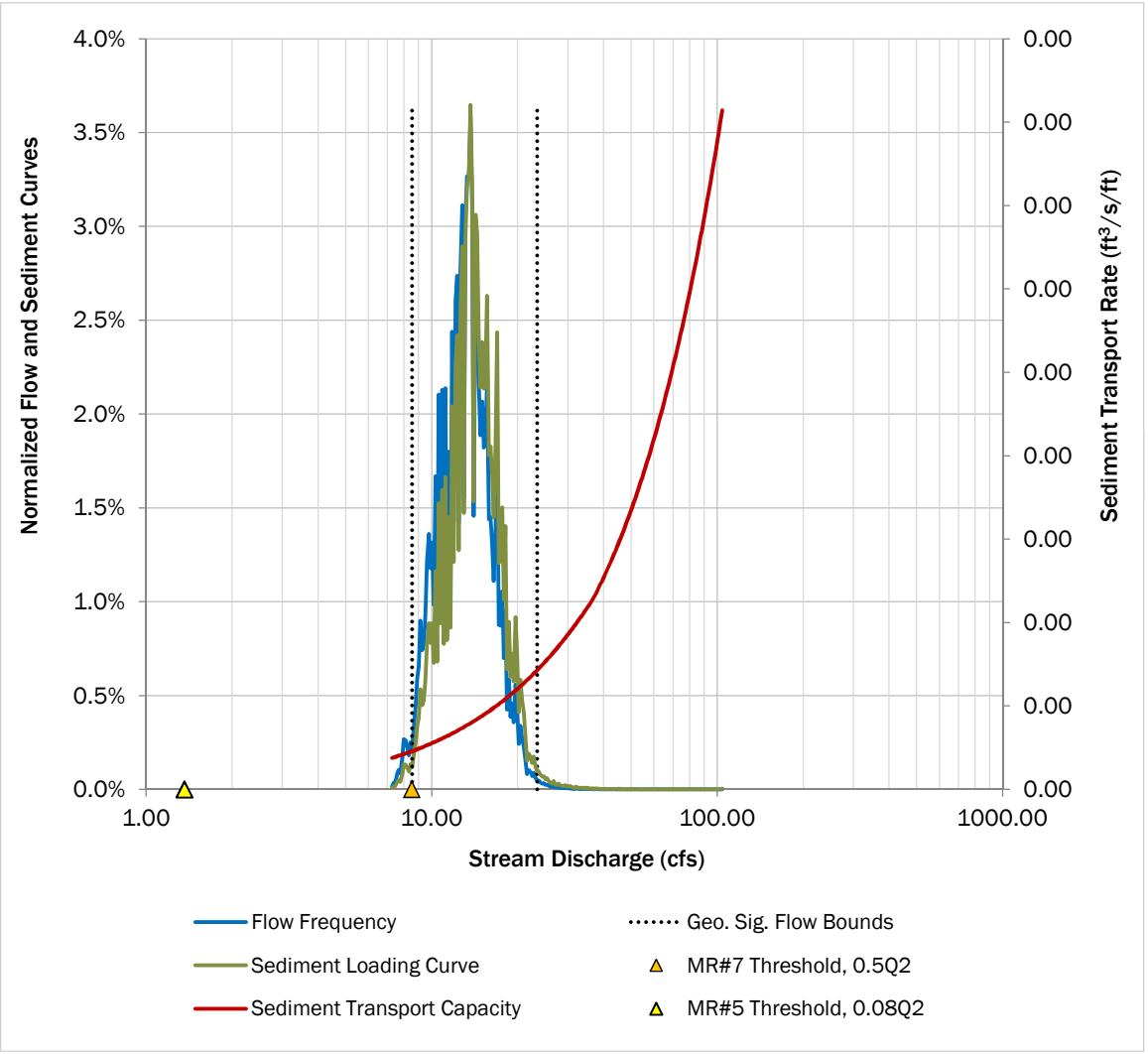
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,915
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	23.42
Lower flow bound for sediment loading (cfs):	8.54
Upper flow bound as a fraction of 50-year flow*:	0.86
Lower flow bound as a fraction of 2-year flow*:	0.502

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	13.68
Flow depth at effective discharge (ft):	0.90
Shear Stress at effective discharge (lb/ft^2):	0.03
Average flow velocity at effective discharge (ft/s):	0.7
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	47.1
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R16
Flow location:	CC-Q07
Cross-section:	BC06
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	13.01	13.23	2%
2-year Flow, Q_2	17.02	30.25	78%
50-year Flow, Q_{50}	27.17	81.36	199%
MR#7 Threshold, $0.5Q_2$	8.51	15.12	--
MR#5 Threshold, $0.08Q_2$	1.36	2.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	9.99
Depth of flow (ft)	0.04	0.09	0.81
Fraction of natural Q_2	0.0001	0.001	0.59

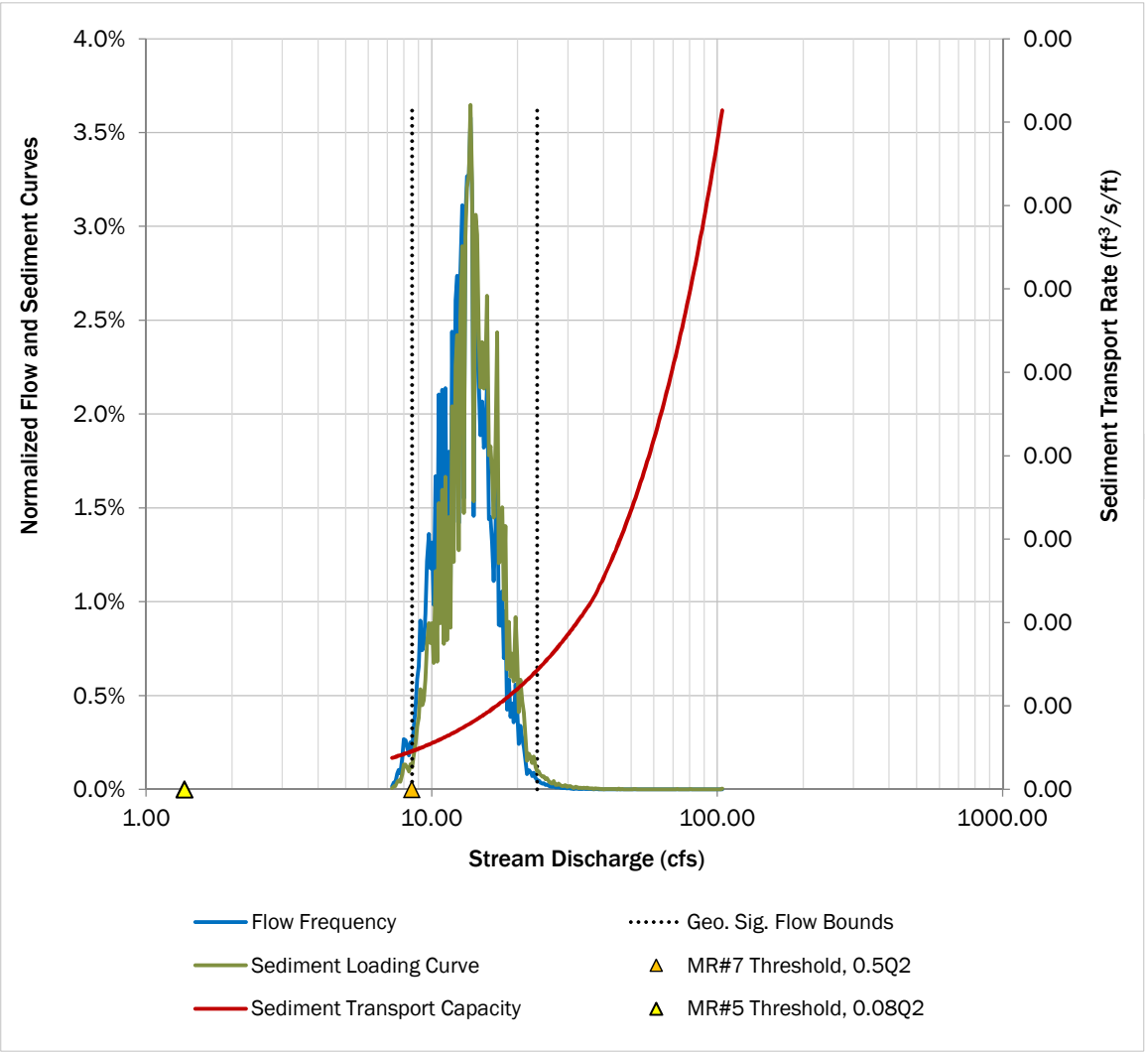
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,915
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	23.42
Lower flow bound for sediment loading (cfs):	8.54
Upper flow bound as a fraction of 50-year flow*:	0.86
Lower flow bound as a fraction of 2-year flow*:	0.502

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	13.68
Flow depth at effective discharge (ft):	0.90
Shear Stress at effective discharge (lb/ft^2):	0.03
Average flow velocity at effective discharge (ft/s):	0.7
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	47.1
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	CC-R18
Flow location:	CC-Q08
Cross-section:	XS415
Channel Slope:	3.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	3.79	3.91	3%
2-year Flow, Q_2	6.55	22.31	241%
50-year Flow, Q_{50}	15.67	74.06	373%
MR#7 Threshold, $0.5Q_2$	3.28	11.16	--
MR#5 Threshold, $0.08Q_2$	0.52	1.78	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.39	5.32
Depth of flow (ft)	0.01	0.10	0.24
Fraction of natural Q_2	0.0001	0.060	0.81

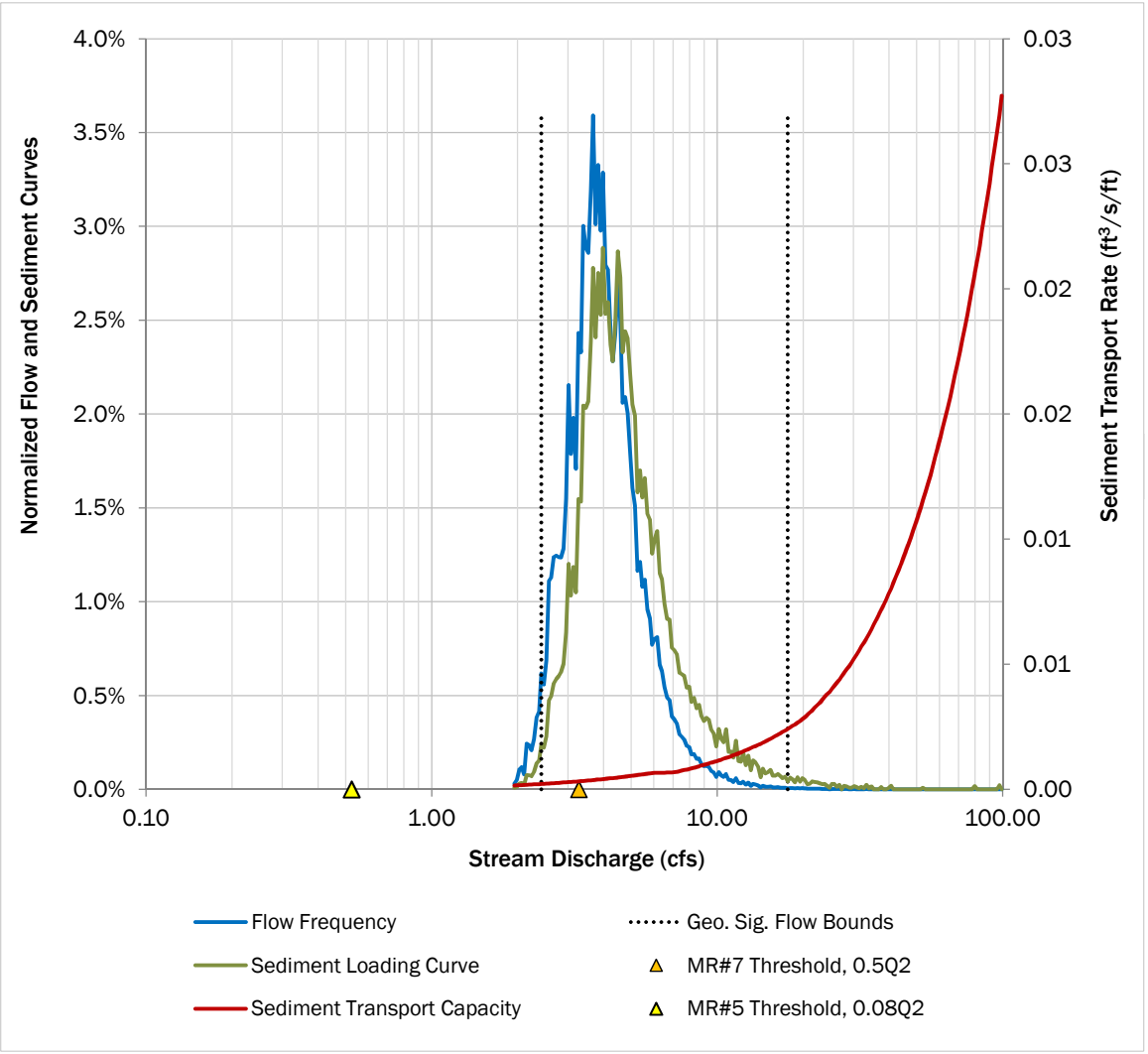
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	35,830
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	17.66
Lower flow bound for sediment loading (cfs):	2.42
Upper flow bound as a fraction of 50-year flow*:	1.13
Lower flow bound as a fraction of 2-year flow*:	0.370

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.98
Flow depth at effective discharge (ft):	0.22
Shear Stress at effective discharge (lb/ft^2):	0.24
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	29.4
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	CC-R19
Flow location:	CC-Q09
Cross-section:	XS399
Channel Slope:	5.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.33	0.38	16%
2-year Flow, Q_2	1.88	17.21	816%
50-year Flow, Q_{50}	7.58	60.24	694%
MR#7 Threshold, $0.5Q_2$	0.94	8.60	--
MR#5 Threshold, $0.08Q_2$	0.15	1.38	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.05	0.63
Depth of flow (ft)	0.01	0.07	0.17
Fraction of natural Q_2	0.0000	0.026	0.33

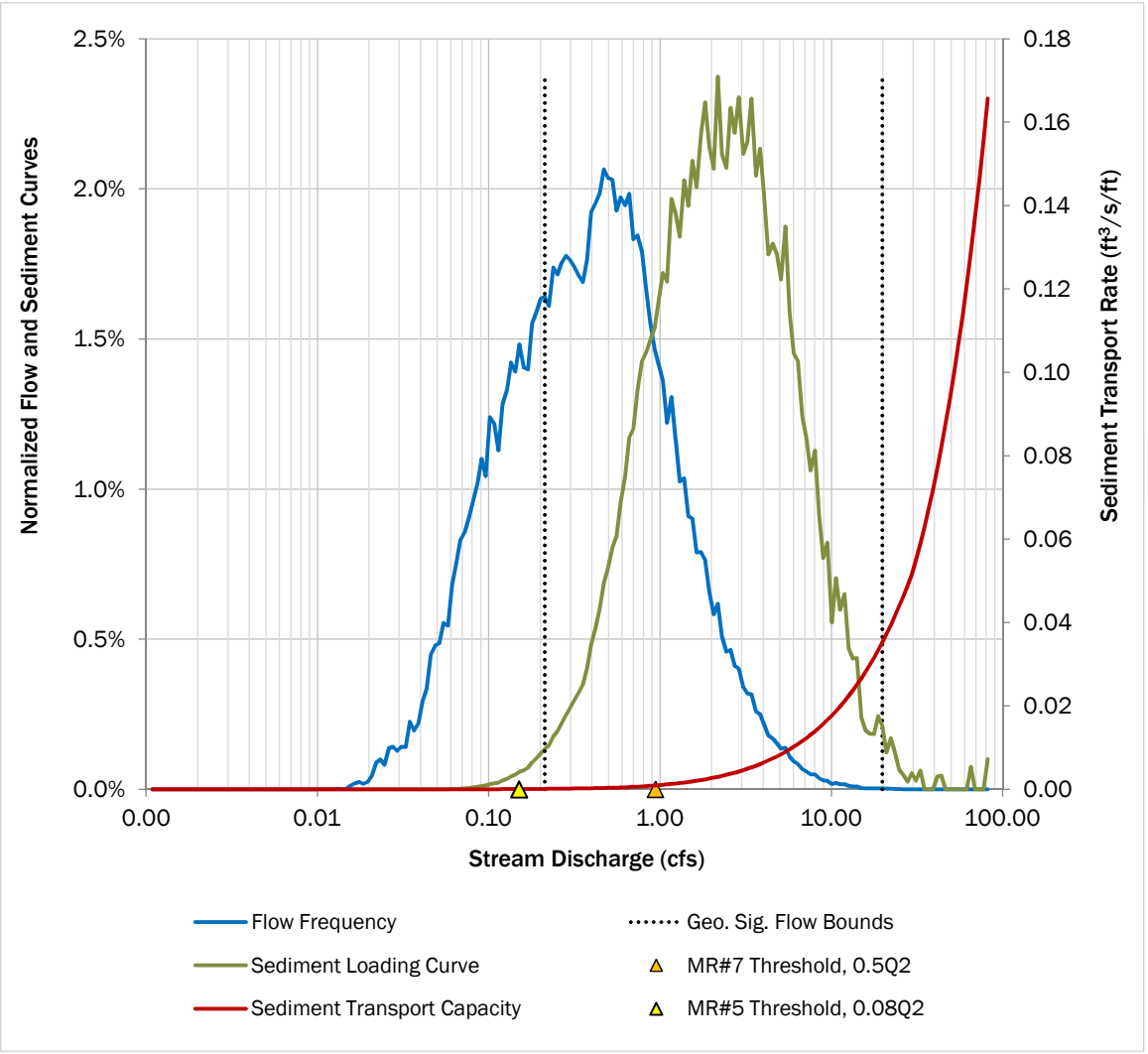
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	14,410
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	19.85
Lower flow bound for sediment loading (cfs):	0.21
Upper flow bound as a fraction of 50-year flow*:	2.62
Lower flow bound as a fraction of 2-year flow*:	0.113

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.17
Flow depth at effective discharge (ft):	0.27
Shear Stress at effective discharge (lb/ft^2):	0.52
Average flow velocity at effective discharge (ft/s):	1.8
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	7.1
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	CC-R20
Flow location:	CC-Q09
Cross-section:	XS399
Channel Slope:	5.2%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.33	0.38	16%
2-year Flow, Q_2	1.88	17.21	816%
50-year Flow, Q_{50}	7.58	60.24	694%
MR#7 Threshold, $0.5Q_2$	0.94	8.60	--
MR#5 Threshold, $0.08Q_2$	0.15	1.38	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.30	1.18
Depth of flow (ft)	0.01	0.13	0.21
Fraction of natural Q_2	0.0001	0.159	0.63

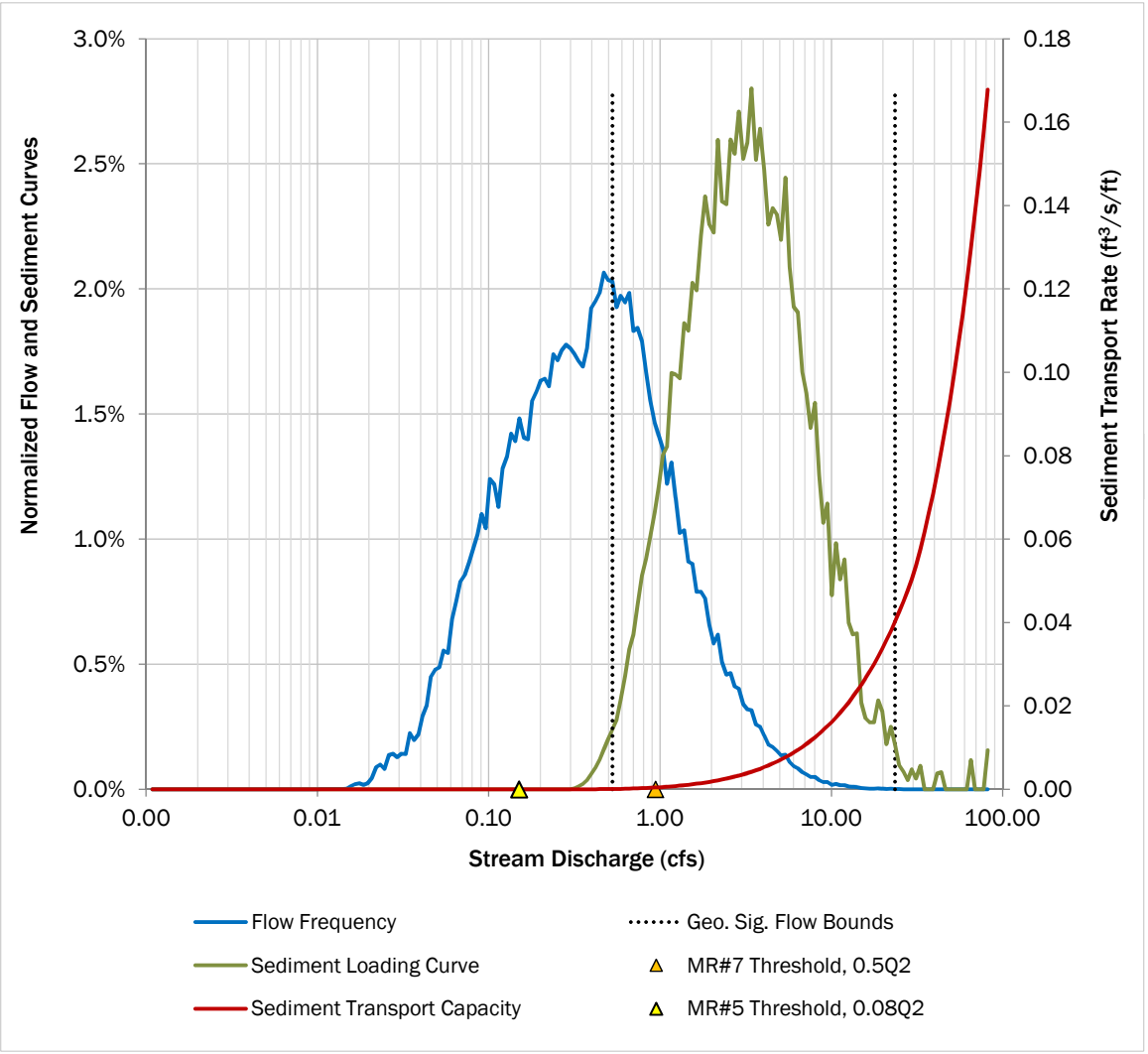
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	9,393
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	23.53
Lower flow bound for sediment loading (cfs):	0.53
Upper flow bound as a fraction of 50-year flow*:	3.10
Lower flow bound as a fraction of 2-year flow*:	0.280

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.42
Flow depth at effective discharge (ft):	0.32
Shear Stress at effective discharge (lb/ft^2):	0.67
Average flow velocity at effective discharge (ft/s):	2.2
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	7.6
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	CC-R21
Flow location:	CC-Q09
Cross-section:	XS411
Channel Slope:	11.5%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.33	0.38	16%
2-year Flow, Q_2	1.88	17.21	816%
50-year Flow, Q_{50}	7.58	60.24	694%
MR#7 Threshold, $0.5Q_2$	0.94	8.60	--
MR#5 Threshold, $0.08Q_2$	0.15	1.38	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	0.03
Depth of flow (ft)	0.00	0.08	0.16
Fraction of natural Q_2	0.0000	0.003	0.02

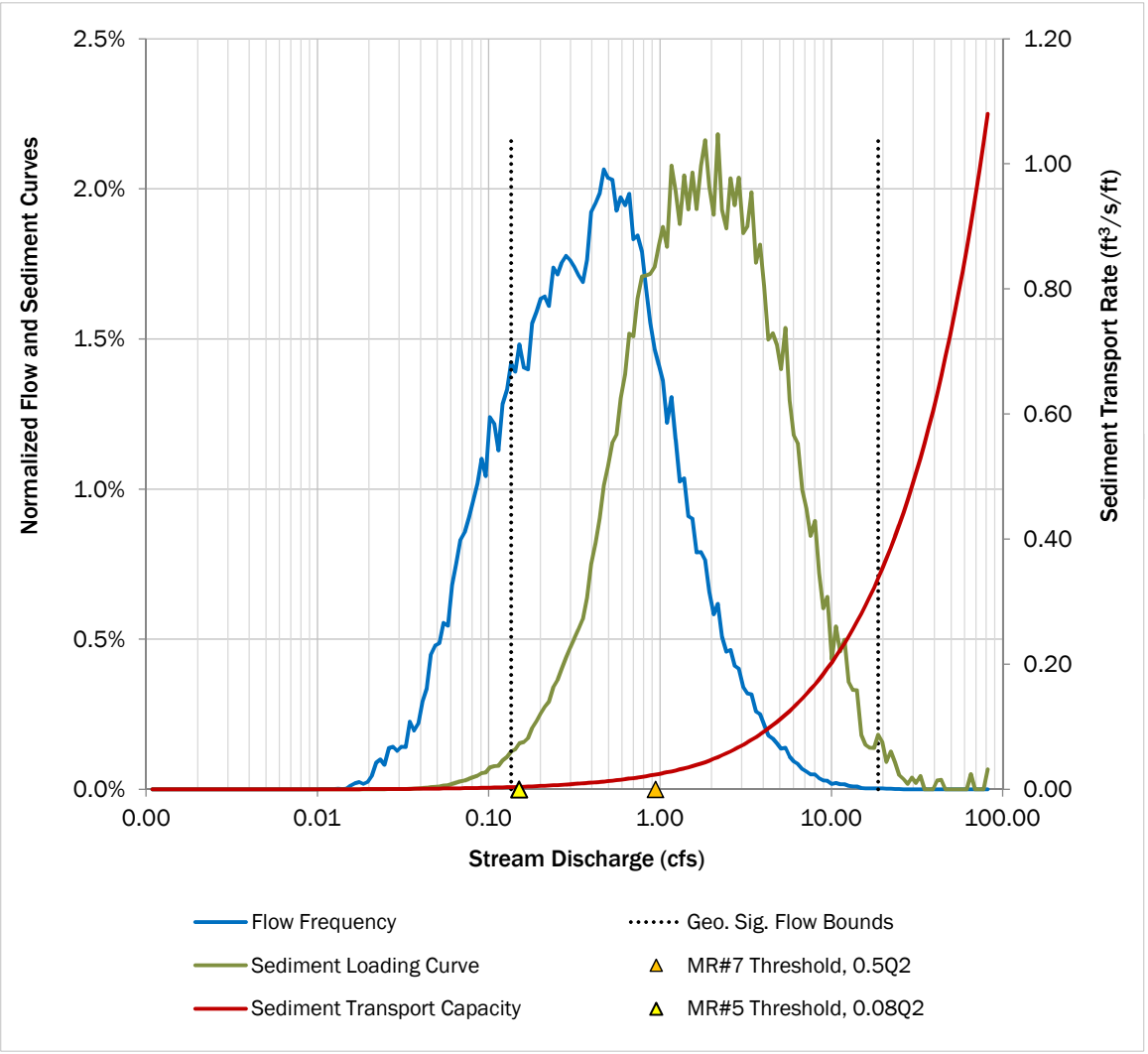
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	81,496
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	18.75
Lower flow bound for sediment loading (cfs):	0.14
Upper flow bound as a fraction of 50-year flow*:	2.47
Lower flow bound as a fraction of 2-year flow*:	0.072

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.17
Flow depth at effective discharge (ft):	0.77
Shear Stress at effective discharge (lb/ft^2):	1.90
Average flow velocity at effective discharge (ft/s):	3.8
Shear velocity at effective discharge (ft/s):	1.0
Effective width at effective discharge (ft):	2.1
Largest mobilized sediment:	*Very coarse gravel*
Largest fully suspended sediment:	*Very fine gravel*
Sediment beginning to settle out:	*Fine gravel*



MFA Inputs	
Reach:	CC-R22
Flow location:	CC-Q09
Cross-section:	BC07
Channel Slope:	6.4%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.33	0.38	16%
2-year Flow, Q_2	1.88	17.21	816%
50-year Flow, Q_{50}	7.58	60.24	694%
MR#7 Threshold, $0.5Q_2$	0.94	8.60	--
MR#5 Threshold, $0.08Q_2$	0.15	1.38	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.13
Depth of flow (ft)	0.01	0.14	0.26
Fraction of natural Q_2	0.0000	0.012	0.07

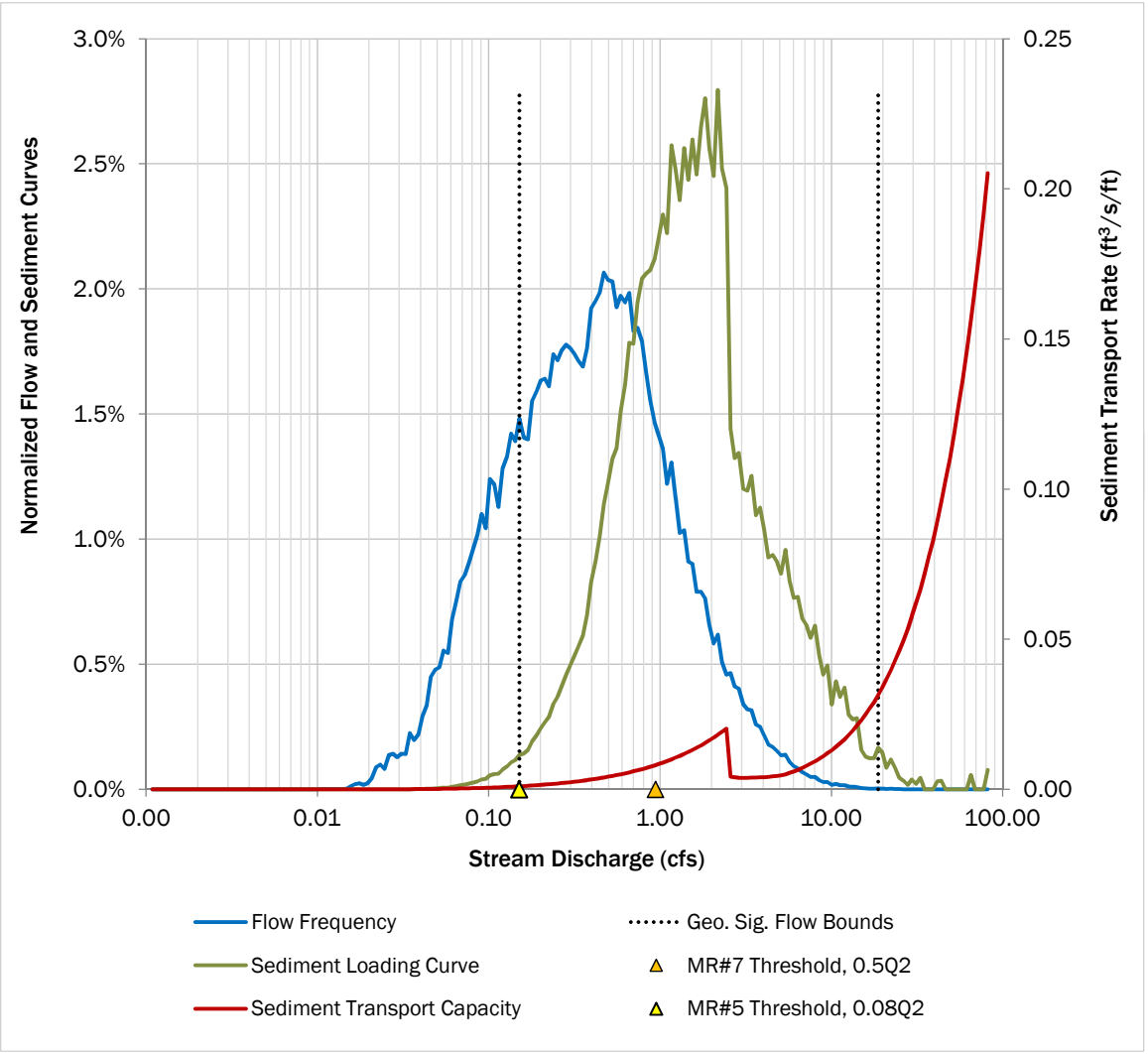
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	23,867
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	18.75
Lower flow bound for sediment loading (cfs):	0.15
Upper flow bound as a fraction of 50-year flow*:	2.47
Lower flow bound as a fraction of 2-year flow*:	0.081

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.17
Flow depth at effective discharge (ft):	0.75
Shear Stress at effective discharge (lb/ft^2):	1.12
Average flow velocity at effective discharge (ft/s):	3.4
Shear velocity at effective discharge (ft/s):	0.8
Effective width at effective discharge (ft):	2.3
Largest mobilized sediment:	*Very coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	CC-R23
Flow location:	CC-Q09
Cross-section:	BC07
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.33	0.38	16%
2-year Flow, Q_2	1.88	17.21	816%
50-year Flow, Q_{50}	7.58	60.24	694%
MR#7 Threshold, $0.5Q_2$	0.94	8.60	--
MR#5 Threshold, $0.08Q_2$	0.15	1.38	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	2.41
Depth of flow (ft)	0.04	0.10	1.18
Fraction of natural Q_2	0.0001	0.001	1.28

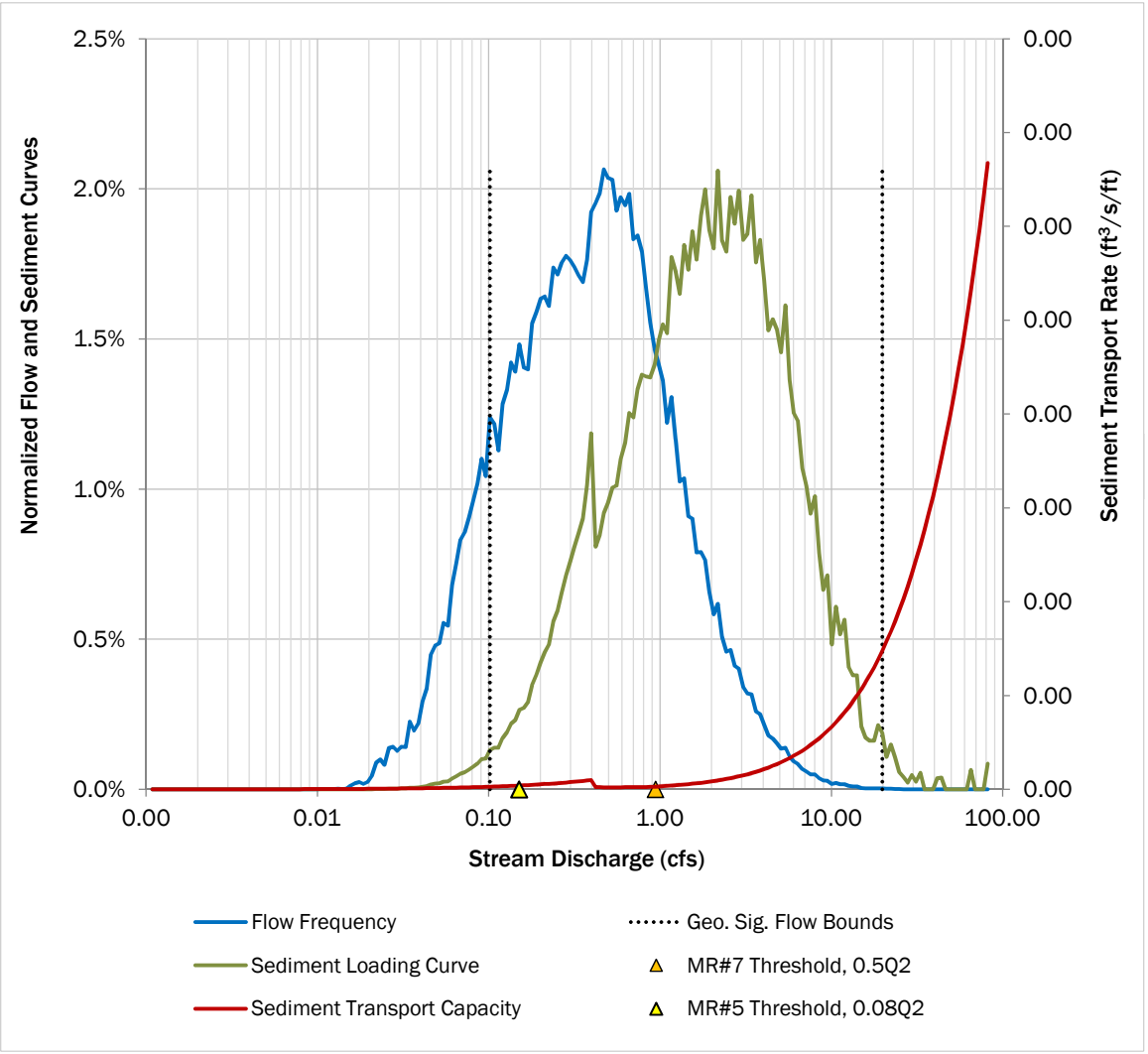
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	98
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	19.85
Lower flow bound for sediment loading (cfs):	0.10
Upper flow bound as a fraction of 50-year flow*:	2.62
Lower flow bound as a fraction of 2-year flow*:	0.054

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.17
Flow depth at effective discharge (ft):	1.15
Shear Stress at effective discharge (lb/ft^2):	0.02
Average flow velocity at effective discharge (ft/s):	0.6
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	13.3
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	CC-R24
Flow location:	CC-Q10
Cross-section:	BC07
Channel Slope:	7.4%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.19	0.23	16%
2-year Flow, Q_2	1.10	10.12	816%
50-year Flow, Q_{50}	4.46	35.44	694%
MR#7 Threshold, $0.5Q_2$	0.55	5.06	--
MR#5 Threshold, $0.08Q_2$	0.09	0.81	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.10
Depth of flow (ft)	0.01	0.12	0.23
Fraction of natural Q_2	0.0000	0.016	0.09

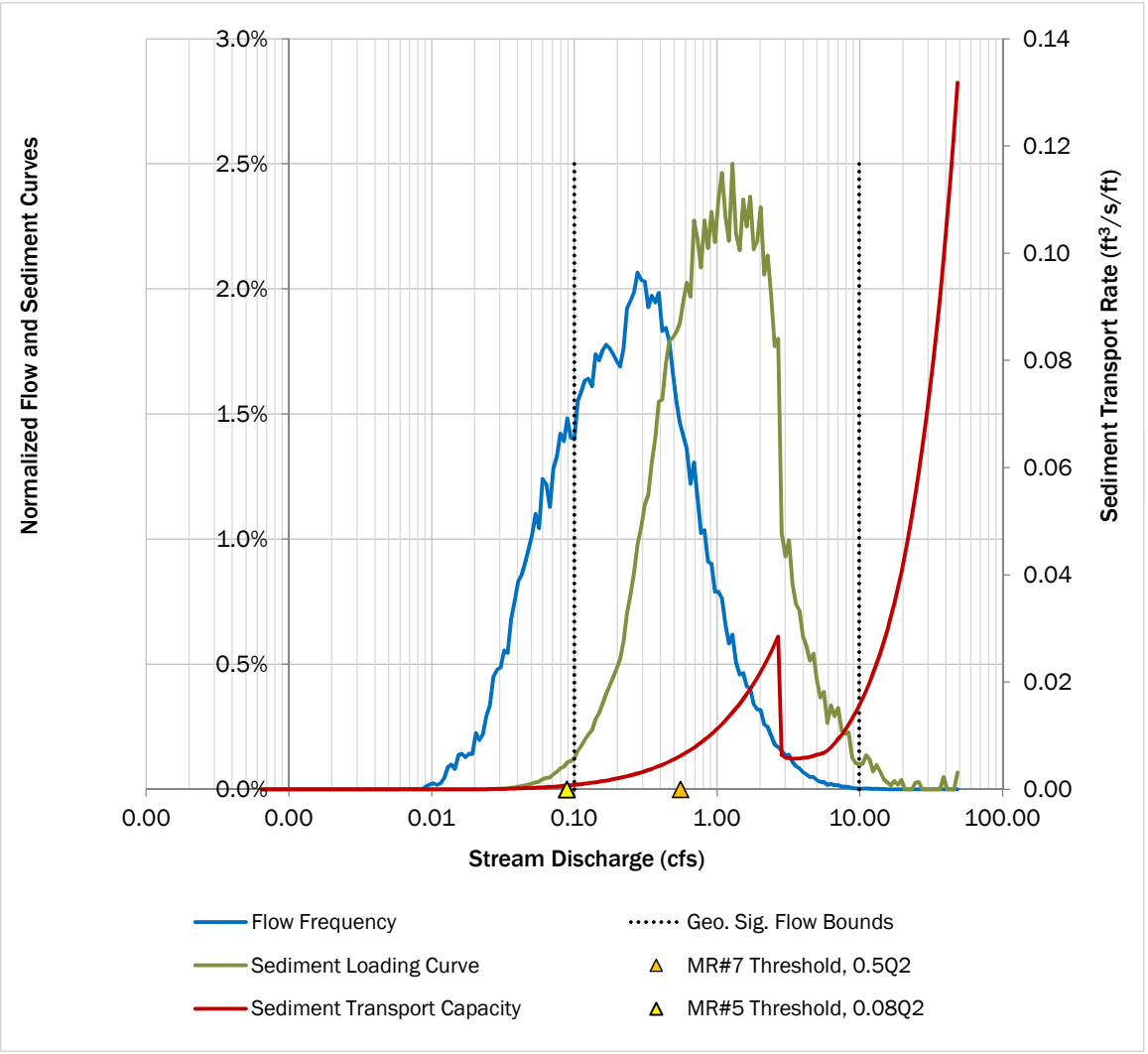
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	16,547
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	9.88
Lower flow bound for sediment loading (cfs):	0.10
Upper flow bound as a fraction of 50-year flow*:	2.21
Lower flow bound as a fraction of 2-year flow*:	0.090

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.28
Flow depth at effective discharge (ft):	0.59
Shear Stress at effective discharge (lb/ft^2):	1.01
Average flow velocity at effective discharge (ft/s):	3.2
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	1.8
Largest mobilized sediment:	*Very coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	CC-R25
Flow location:	CC-Q10
Cross-section:	BC07
Channel Slope:	1.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.19	0.23	16%
2-year Flow, Q_2	1.10	10.12	816%
50-year Flow, Q_{50}	4.46	35.44	694%
MR#7 Threshold, $0.5Q_2$	0.55	5.06	--
MR#5 Threshold, $0.08Q_2$	0.09	0.81	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.09	1.18
Depth of flow (ft)	0.03	0.29	0.77
Fraction of natural Q_2	0.0001	0.079	1.07

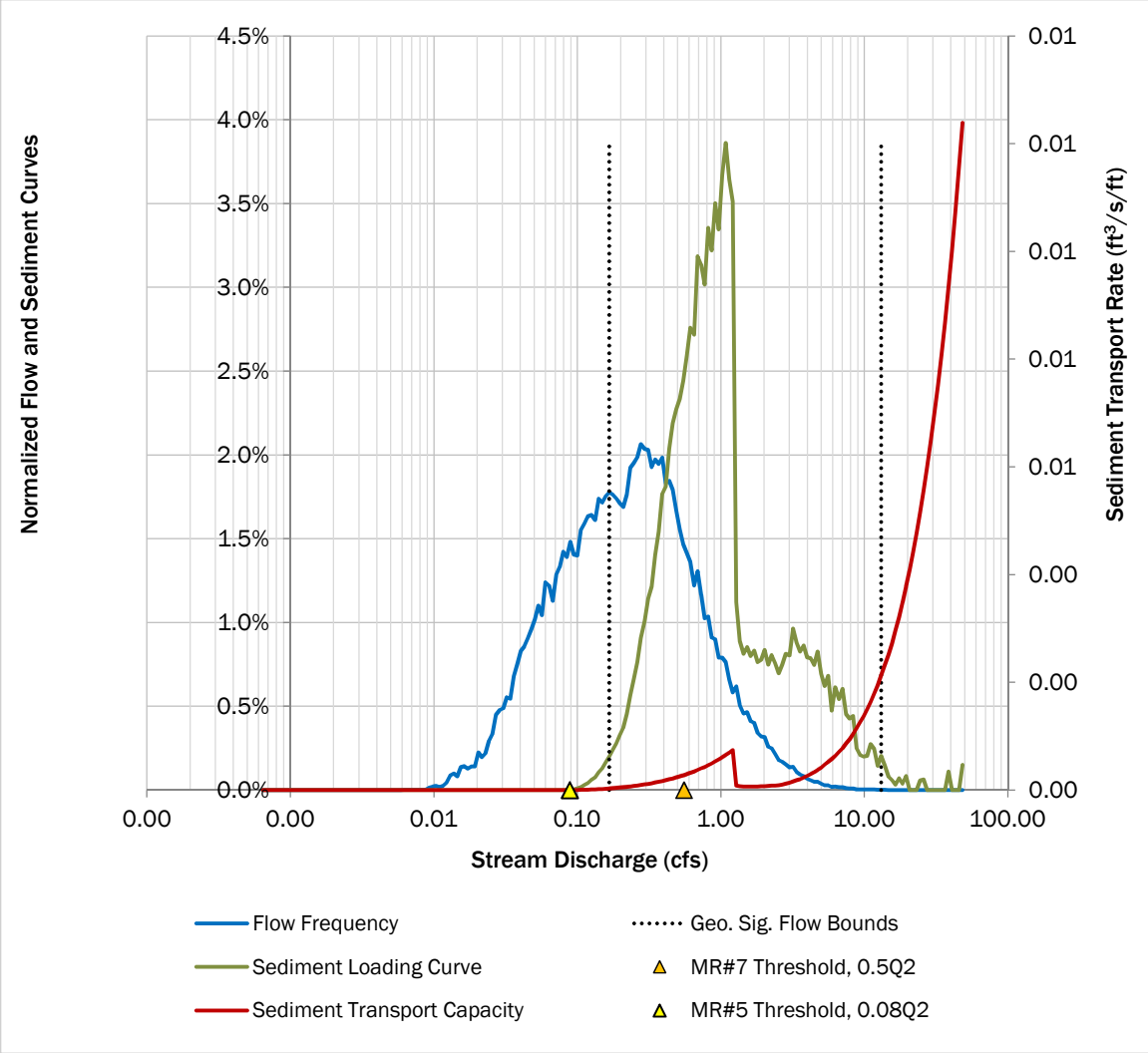
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	760
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	13.12
Lower flow bound for sediment loading (cfs):	0.17
Upper flow bound as a fraction of 50-year flow*:	2.94
Lower flow bound as a fraction of 2-year flow*:	0.151

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.08
Flow depth at effective discharge (ft):	0.74
Shear Stress at effective discharge (lb/ft^2):	0.26
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	2.3
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	DC-R01
Flow location:	DC-Q01
Cross-section:	XS421
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.47	1.61	9%
2-year Flow, Q_2	2.82	30.01	963%
50-year Flow, Q_{50}	16.56	115.08	595%
MR#7 Threshold, $0.5Q_2$	1.41	15.01	--
MR#5 Threshold, $0.08Q_2$	0.23	2.40	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	2.59
Depth of flow (ft)	0.03	0.07	0.42
Fraction of natural Q_2	0.0010	0.012	0.92

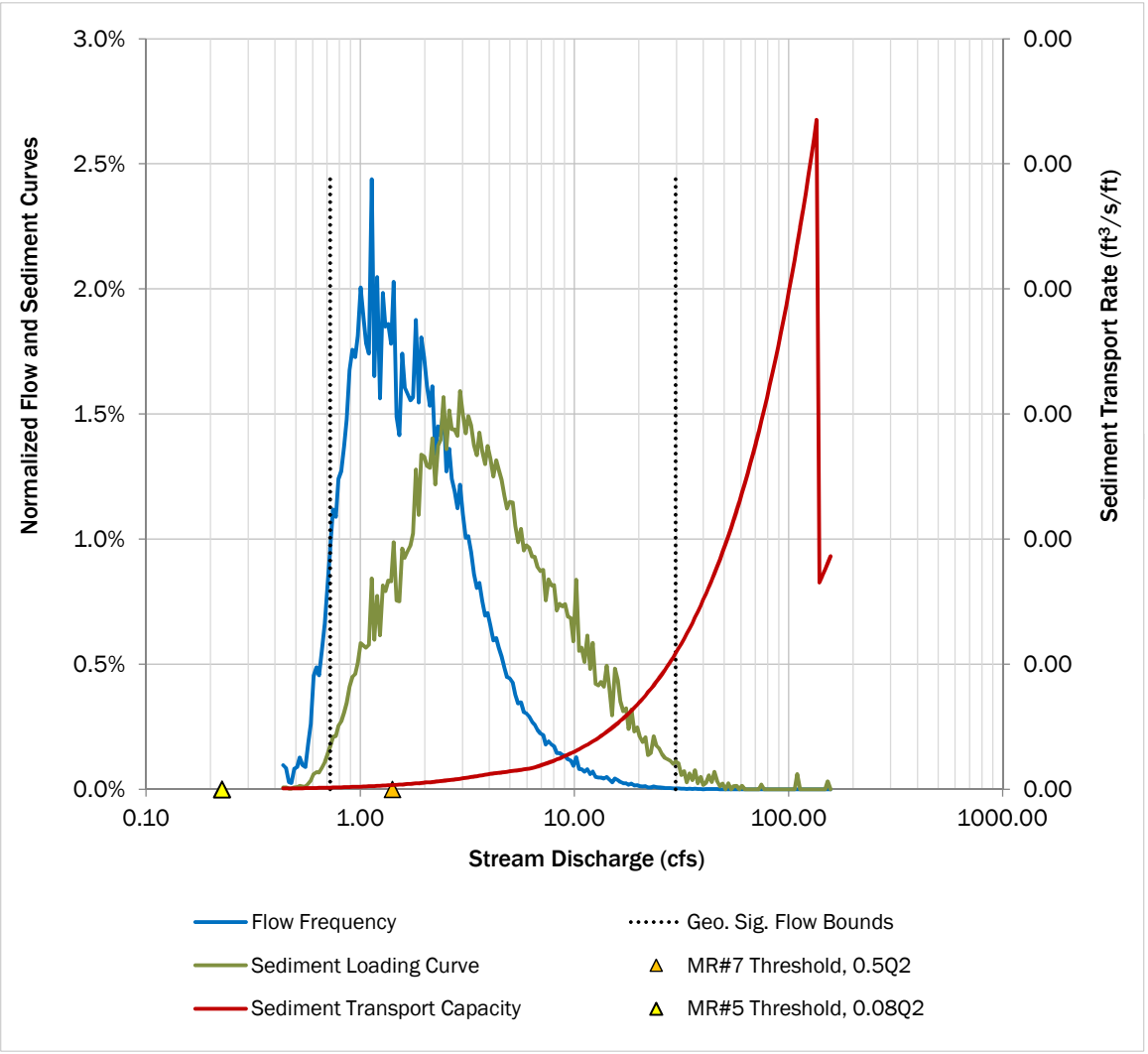
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	358
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	29.74
Lower flow bound for sediment loading (cfs):	0.72
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.256

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.93
Flow depth at effective discharge (ft):	0.45
Shear Stress at effective discharge (lb/ft^2):	0.03
Average flow velocity at effective discharge (ft/s):	0.8
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	10.6
Largest mobilized sediment:	*Very coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	DC-R02
Flow location:	DC-Q01
Cross-section:	XS421
Channel Slope:	0.8%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.47	1.61	9%
2-year Flow, Q_2	2.82	30.01	963%
50-year Flow, Q_{50}	16.56	115.08	595%
MR#7 Threshold, $0.5Q_2$	1.41	15.01	--
MR#5 Threshold, $0.08Q_2$	0.23	2.40	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	2.70	21.06
Depth of flow (ft)	0.03	0.27	0.75
Fraction of natural Q_2	0.0036	0.958	7.46

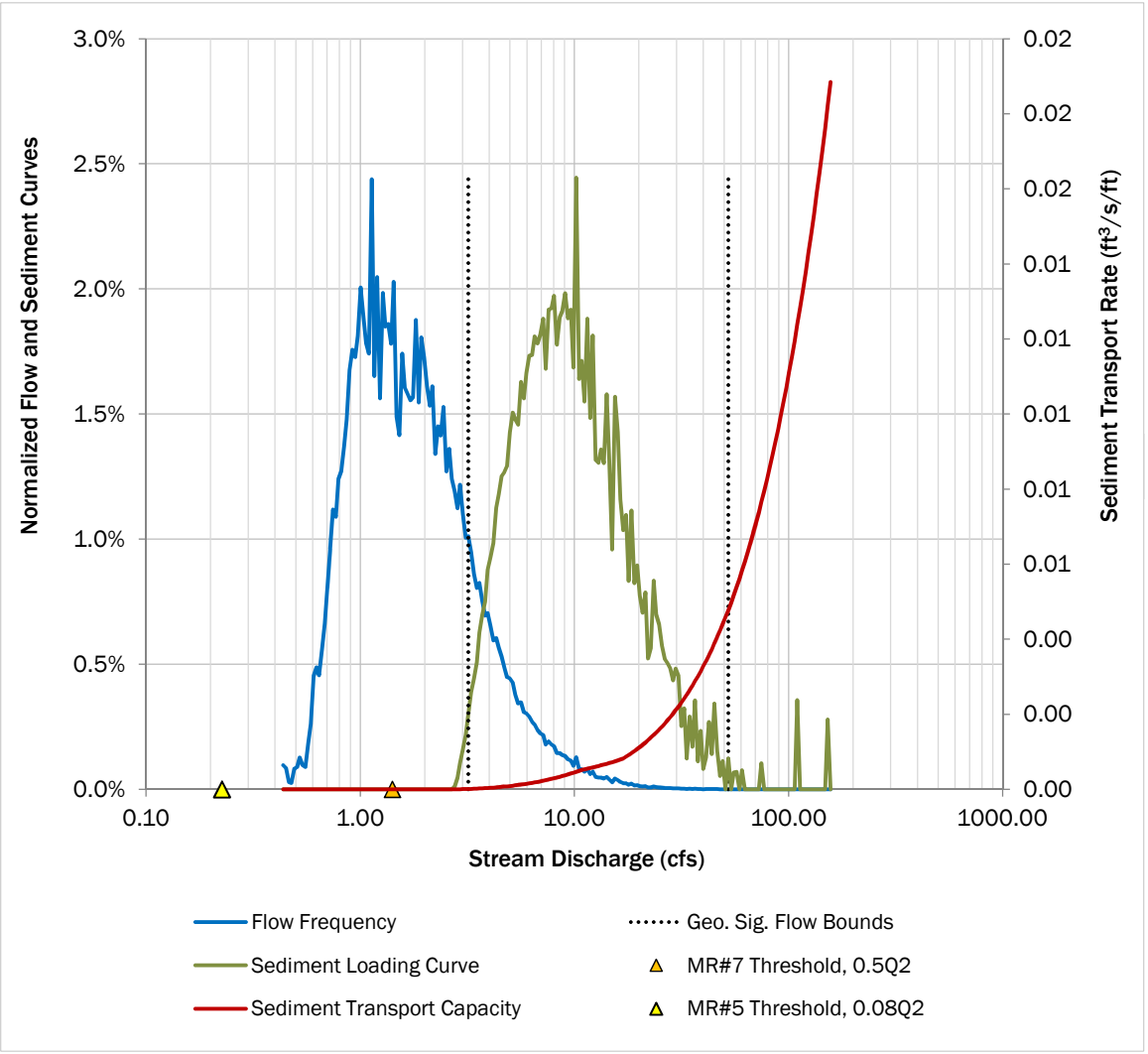
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	710
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	52.31
Lower flow bound for sediment loading (cfs):	3.20
Upper flow bound as a fraction of 50-year flow*:	3.16
Lower flow bound as a fraction of 2-year flow*:	1.134

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.20
Flow depth at effective discharge (ft):	0.51
Shear Stress at effective discharge (lb/ft^2):	0.20
Average flow velocity at effective discharge (ft/s):	2.4
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	11.0
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	DC-R03
Flow location:	DC-Q02
Cross-section:	XS422
Channel Slope:	4.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.24	1.35	9%
2-year Flow, Q_2	3.26	28.30	768%
50-year Flow, Q_{50}	13.13	95.22	625%
MR#7 Threshold, $0.5Q_2$	1.63	14.15	--
MR#5 Threshold, $0.08Q_2$	0.26	2.26	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.46
Depth of flow (ft)	0.01	0.07	0.21
Fraction of natural Q_2	0.0000	0.007	0.14

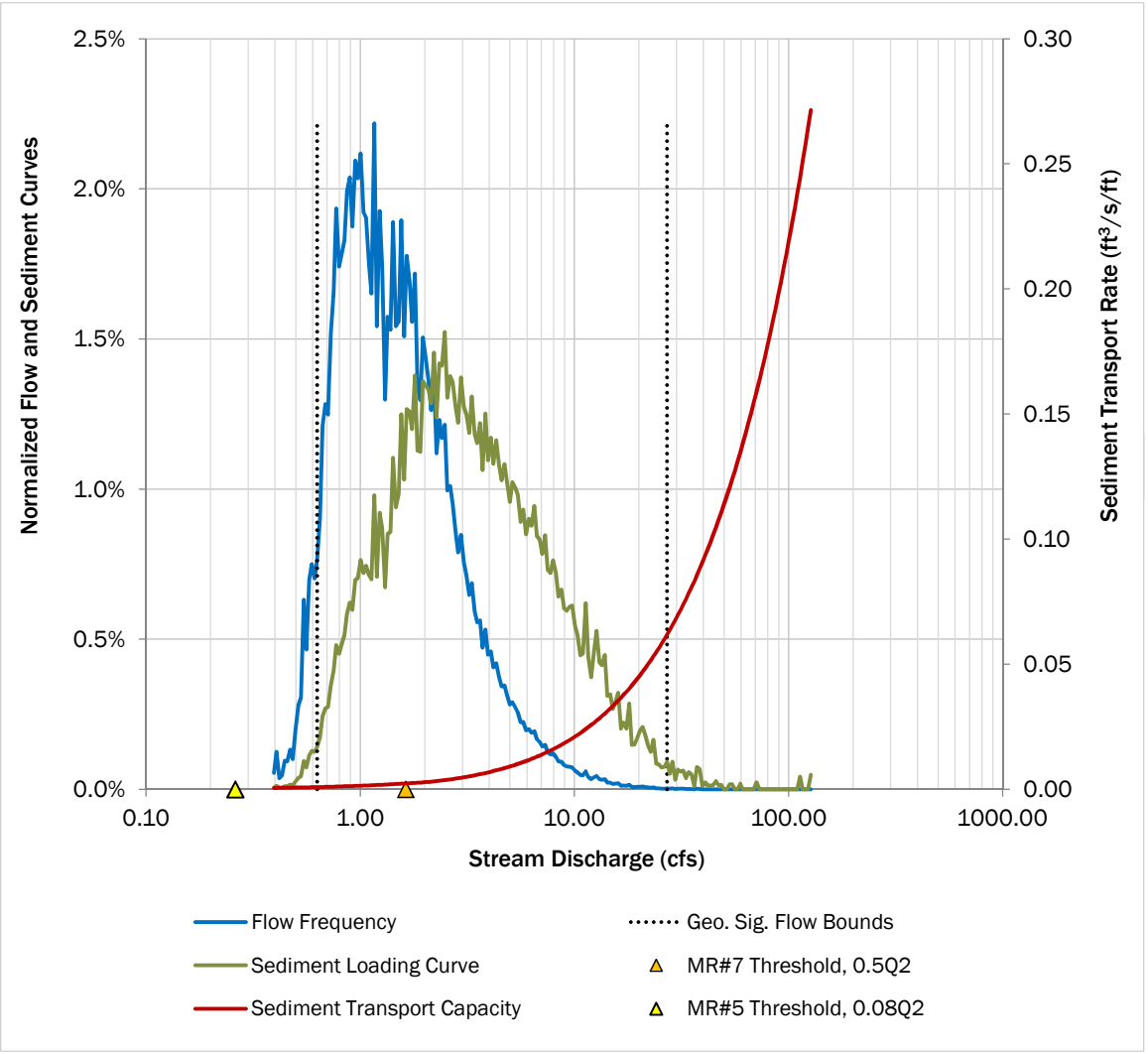
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	46,749
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	27.09
Lower flow bound for sediment loading (cfs):	0.63
Upper flow bound as a fraction of 50-year flow*:	2.06
Lower flow bound as a fraction of 2-year flow*:	0.193

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.48
Flow depth at effective discharge (ft):	0.37
Shear Stress at effective discharge (lb/ft^2):	0.50
Average flow velocity at effective discharge (ft/s):	2.3
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	6.1
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	DC-R04
Flow location:	DC-Q02
Cross-section:	XS423
Channel Slope:	4.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.24	1.35	9%
2-year Flow, Q_2	3.26	28.30	768%
50-year Flow, Q_{50}	13.13	95.22	625%
MR#7 Threshold, $0.5Q_2$	1.63	14.15	--
MR#5 Threshold, $0.08Q_2$	0.26	2.26	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.06	0.85
Depth of flow (ft)	0.01	0.10	0.21
Fraction of natural Q_2	0.0000	0.020	0.26

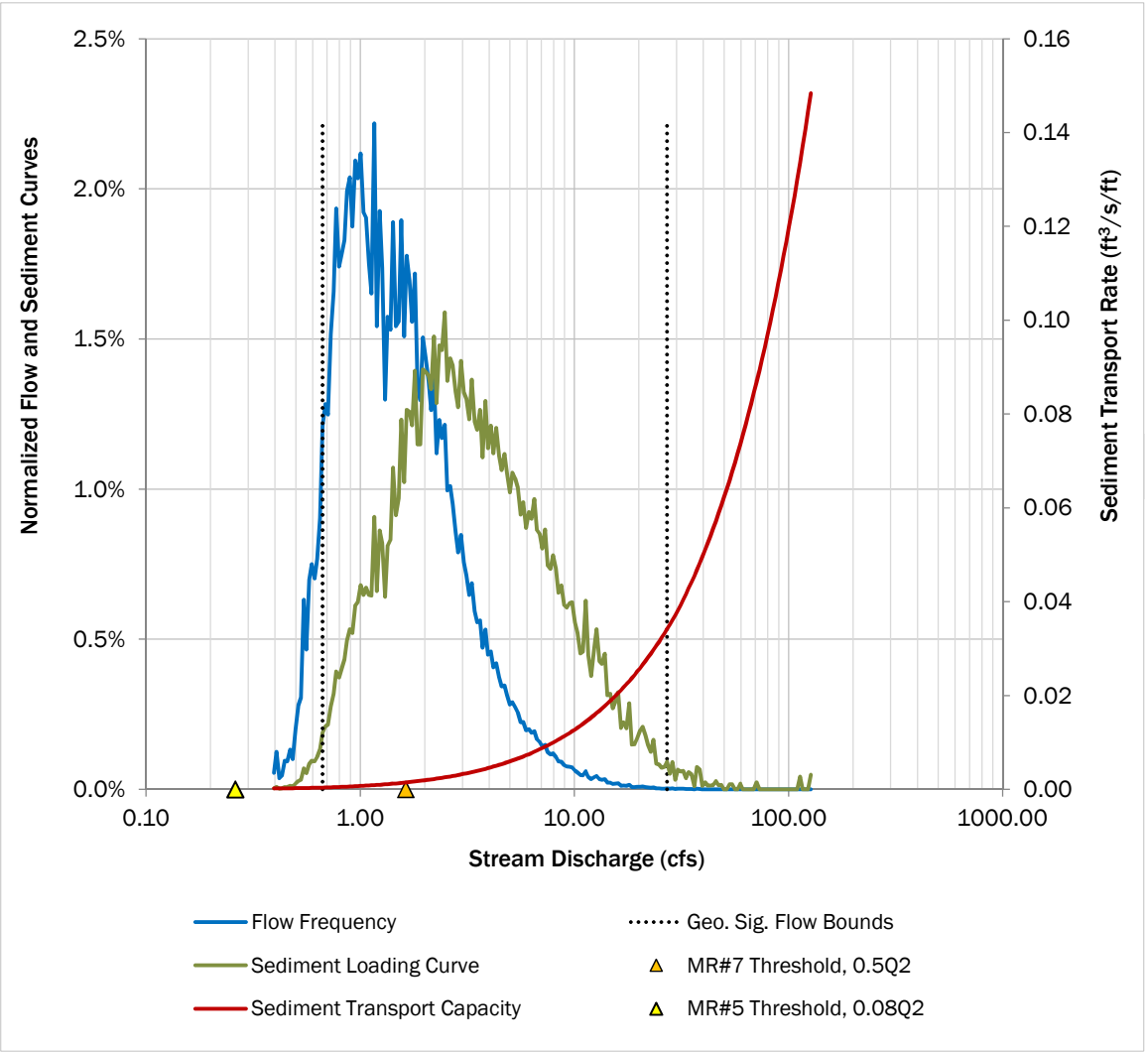
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	41,579
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	27.09
Lower flow bound for sediment loading (cfs):	0.67
Upper flow bound as a fraction of 50-year flow*:	2.06
Lower flow bound as a fraction of 2-year flow*:	0.205

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.48
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.46
Average flow velocity at effective discharge (ft/s):	1.9
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	8.2
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	DC-R05
Flow location:	DC-Q02
Cross-section:	XS430
Channel Slope:	8.0%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.24	1.35	9%
2-year Flow, Q_2	3.26	28.30	768%
50-year Flow, Q_{50}	13.13	95.22	625%
MR#7 Threshold, $0.5Q_2$	1.63	14.15	--
MR#5 Threshold, $0.08Q_2$	0.26	2.26	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.10	0.57
Depth of flow (ft)	0.00	0.10	0.18
Fraction of natural Q_2	0.0000	0.031	0.17

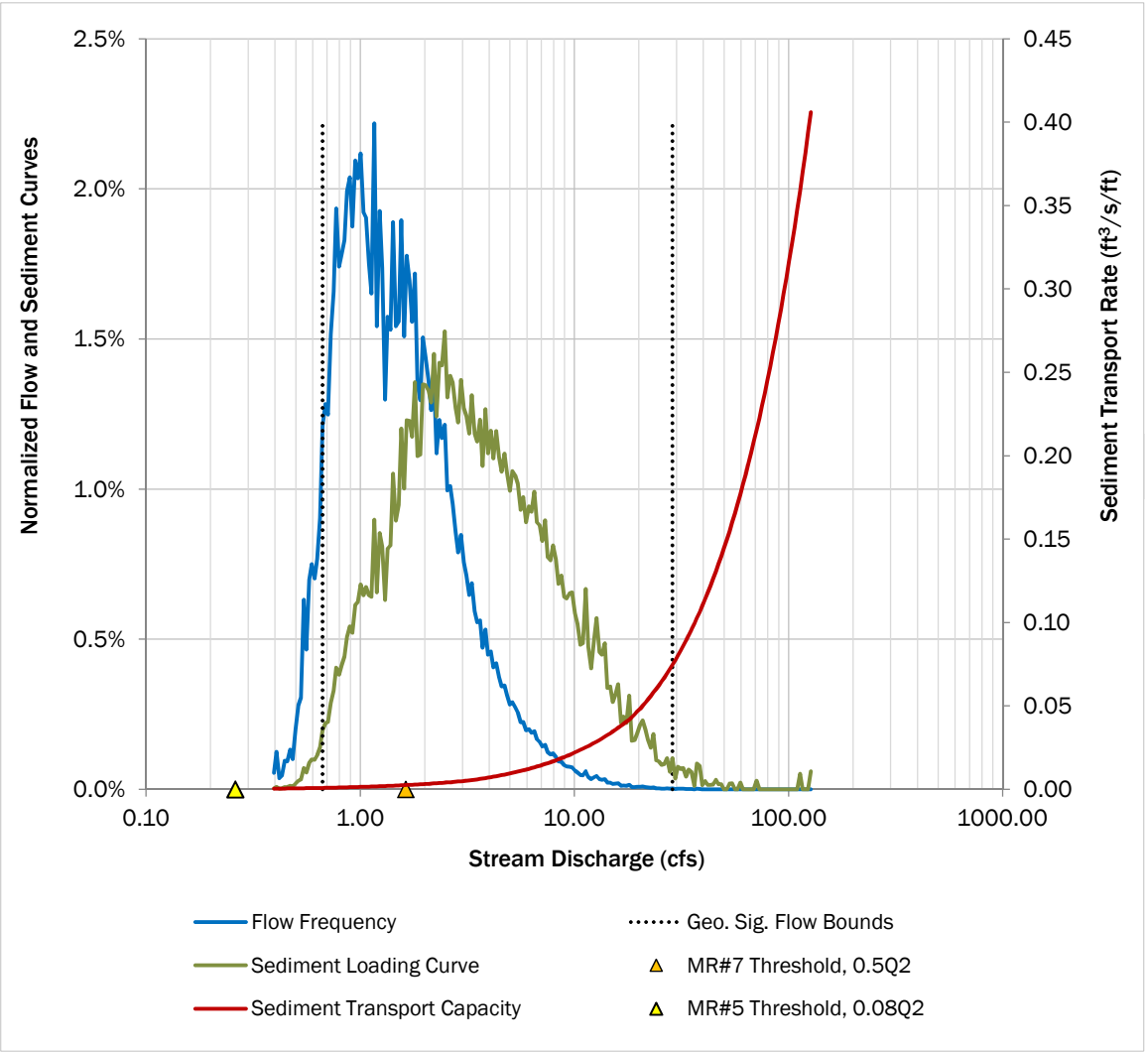
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	74,343
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.72
Lower flow bound for sediment loading (cfs):	0.67
Upper flow bound as a fraction of 50-year flow*:	2.19
Lower flow bound as a fraction of 2-year flow*:	0.205

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.48
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.68
Average flow velocity at effective discharge (ft/s):	2.0
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	8.9
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	DC-R06
Flow location:	DC-Q03
Cross-section:	XS437
Channel Slope:	7.4%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.52	0.61	19%
2-year Flow, Q_2	2.50	23.18	827%
50-year Flow, Q_{50}	10.22	79.53	678%
MR#7 Threshold, $0.5Q_2$	1.25	11.59	--
MR#5 Threshold, $0.08Q_2$	0.20	1.85	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.06	0.36
Depth of flow (ft)	0.00	0.09	0.17
Fraction of natural Q_2	0.0000	0.026	0.14

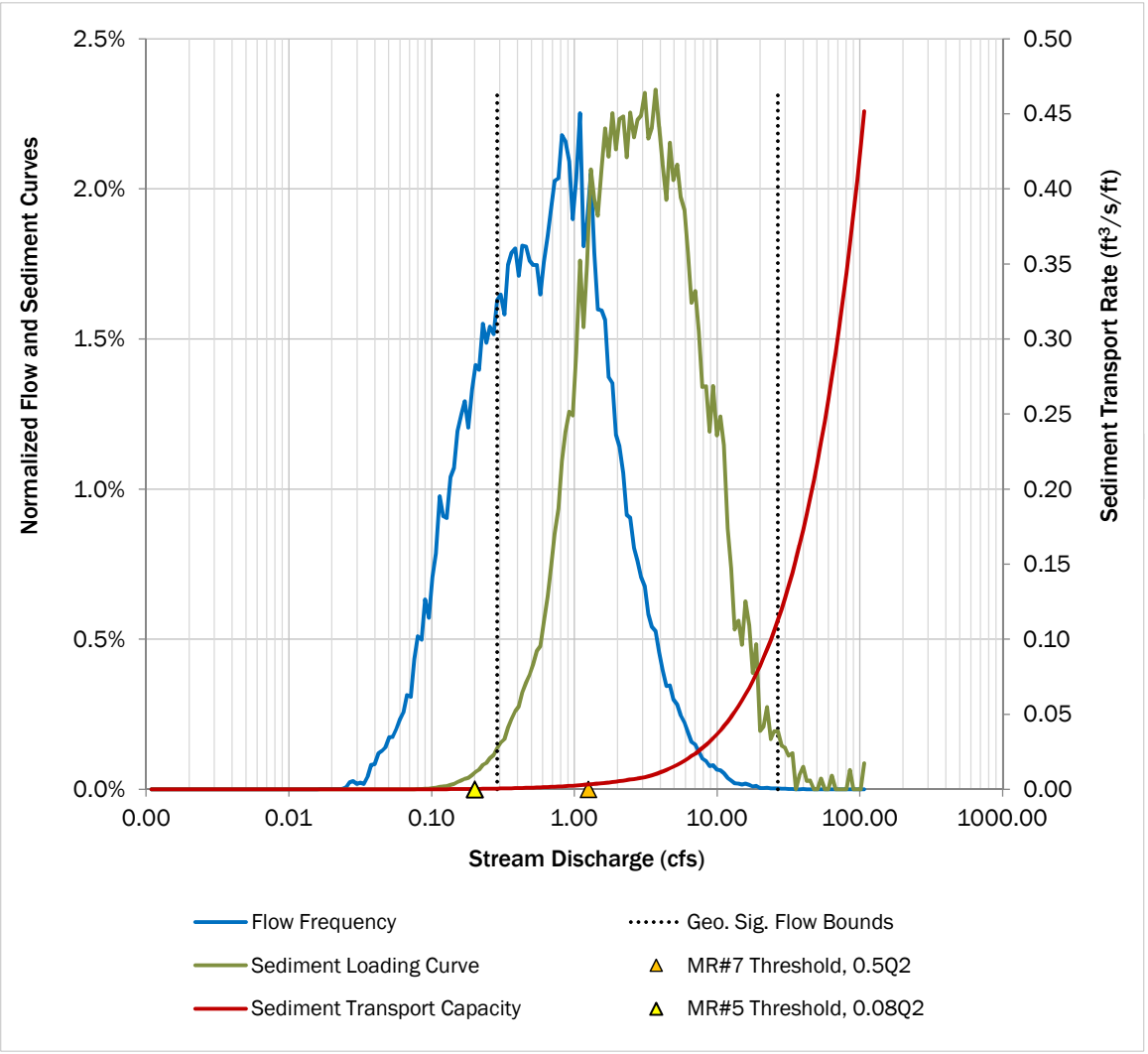
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	41,432
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	26.66
Lower flow bound for sediment loading (cfs):	0.29
Upper flow bound as a fraction of 50-year flow*:	2.61
Lower flow bound as a fraction of 2-year flow*:	0.115

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.70
Flow depth at effective discharge (ft):	0.40
Shear Stress at effective discharge (lb/ft^2):	0.95
Average flow velocity at effective discharge (ft/s):	2.6
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	6.9
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	DC-R07
Flow location:	DC-Q03
Cross-section:	XS440
Channel Slope:	5.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.52	0.61	19%
2-year Flow, Q_2	2.50	23.18	827%
50-year Flow, Q_{50}	10.22	79.53	678%
MR#7 Threshold, $0.5Q_2$	1.25	11.59	--
MR#5 Threshold, $0.08Q_2$	0.20	1.85	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.20	1.21
Depth of flow (ft)	0.01	0.07	0.13
Fraction of natural Q_2	0.0001	0.080	0.48

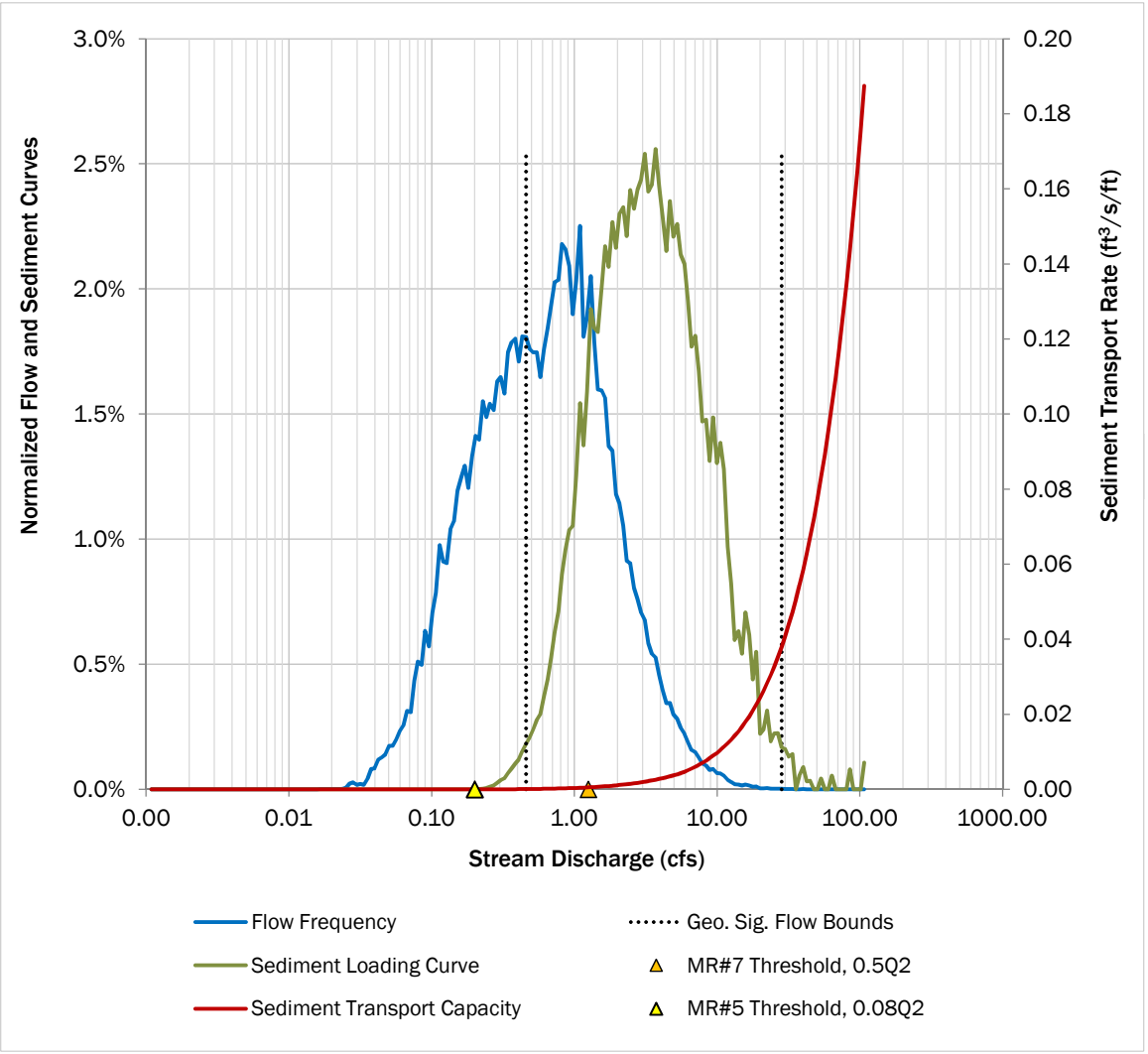
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	18,357
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.25
Lower flow bound for sediment loading (cfs):	0.46
Upper flow bound as a fraction of 50-year flow*:	2.76
Lower flow bound as a fraction of 2-year flow*:	0.183

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.70
Flow depth at effective discharge (ft):	0.21
Shear Stress at effective discharge (lb/ft^2):	0.48
Average flow velocity at effective discharge (ft/s):	1.8
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	13.3
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	DC-R08
Flow location:	DC-Q03
Cross-section:	XS440
Channel Slope:	1.9%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.52	0.61	19%
2-year Flow, Q_2	2.50	23.18	827%
50-year Flow, Q_{50}	10.22	79.53	678%
MR#7 Threshold, $0.5Q_2$	1.25	11.59	--
MR#5 Threshold, $0.08Q_2$	0.20	1.85	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.89	5.55
Depth of flow (ft)	0.02	0.13	0.30
Fraction of natural Q_2	0.0012	0.357	2.22

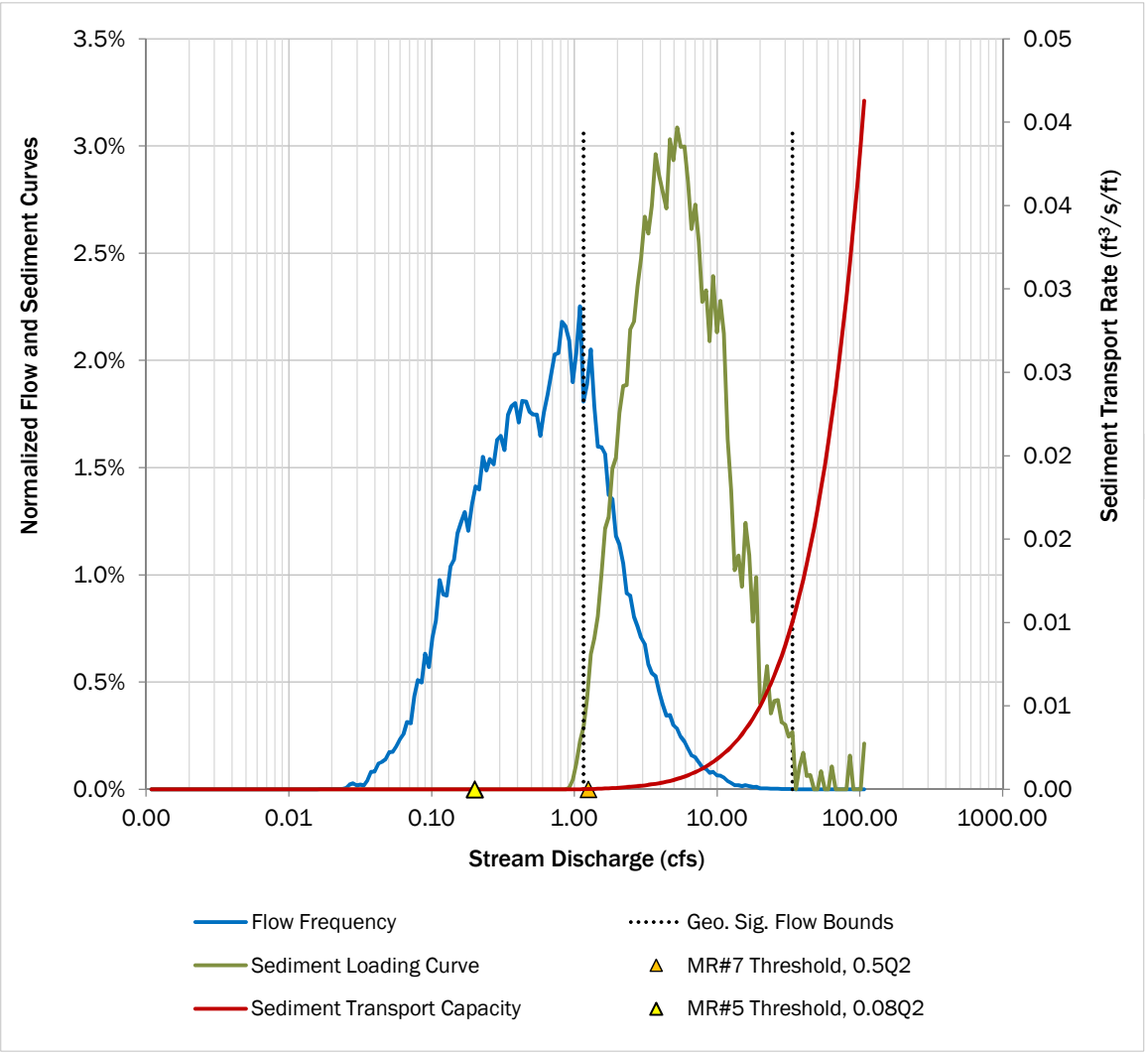
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	2,127
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	33.63
Lower flow bound for sediment loading (cfs):	1.16
Upper flow bound as a fraction of 50-year flow*:	3.29
Lower flow bound as a fraction of 2-year flow*:	0.463

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	5.25
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.26
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	14.3
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	DC-R09
Flow location:	DC-Q04
Cross-section:	XS440
Channel Slope:	2.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.37	0.44	19%
2-year Flow, Q_2	1.79	16.56	827%
50-year Flow, Q_{50}	7.30	56.81	678%
MR#7 Threshold, $0.5Q_2$	0.89	8.28	--
MR#5 Threshold, $0.08Q_2$	0.14	1.32	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.83	5.19
Depth of flow (ft)	0.01	0.12	0.29
Fraction of natural Q_2	0.0015	0.464	2.91

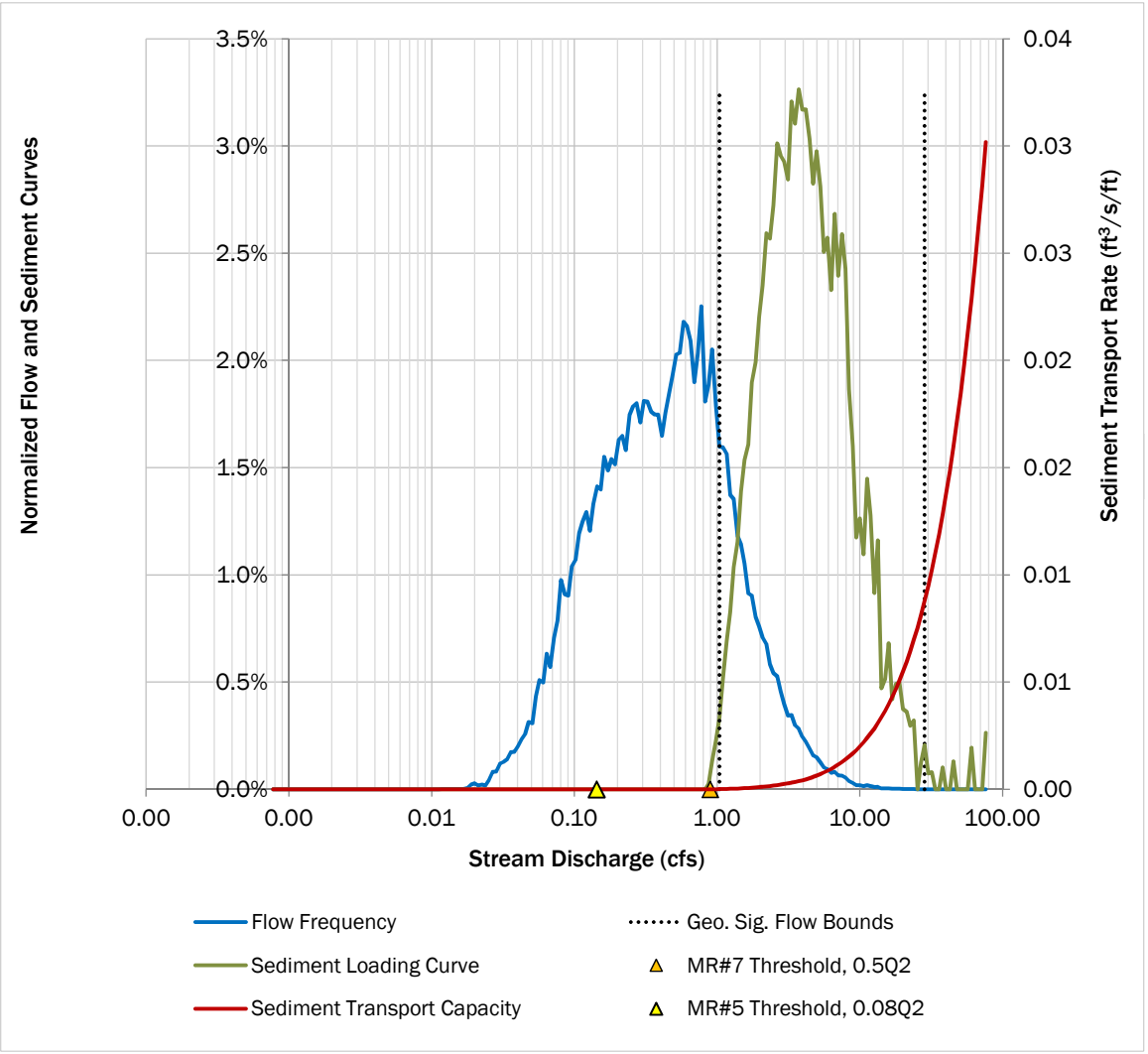
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,188
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.42
Lower flow bound for sediment loading (cfs):	1.04
Upper flow bound as a fraction of 50-year flow*:	3.89
Lower flow bound as a fraction of 2-year flow*:	0.581

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.72
Flow depth at effective discharge (ft):	0.24
Shear Stress at effective discharge (lb/ft^2):	0.22
Average flow velocity at effective discharge (ft/s):	1.5
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	13.9
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	DC-R10
Flow location:	DC-Q04
Cross-section:	XS440
Channel Slope:	1.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.37	0.44	19%
2-year Flow, Q_2	1.79	16.56	827%
50-year Flow, Q_{50}	7.30	56.81	678%
MR#7 Threshold, $0.5Q_2$	0.89	8.28	--
MR#5 Threshold, $0.08Q_2$	0.14	1.32	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	1.89	10.96
Depth of flow (ft)	0.03	0.21	0.50
Fraction of natural Q_2	0.0055	1.057	6.13

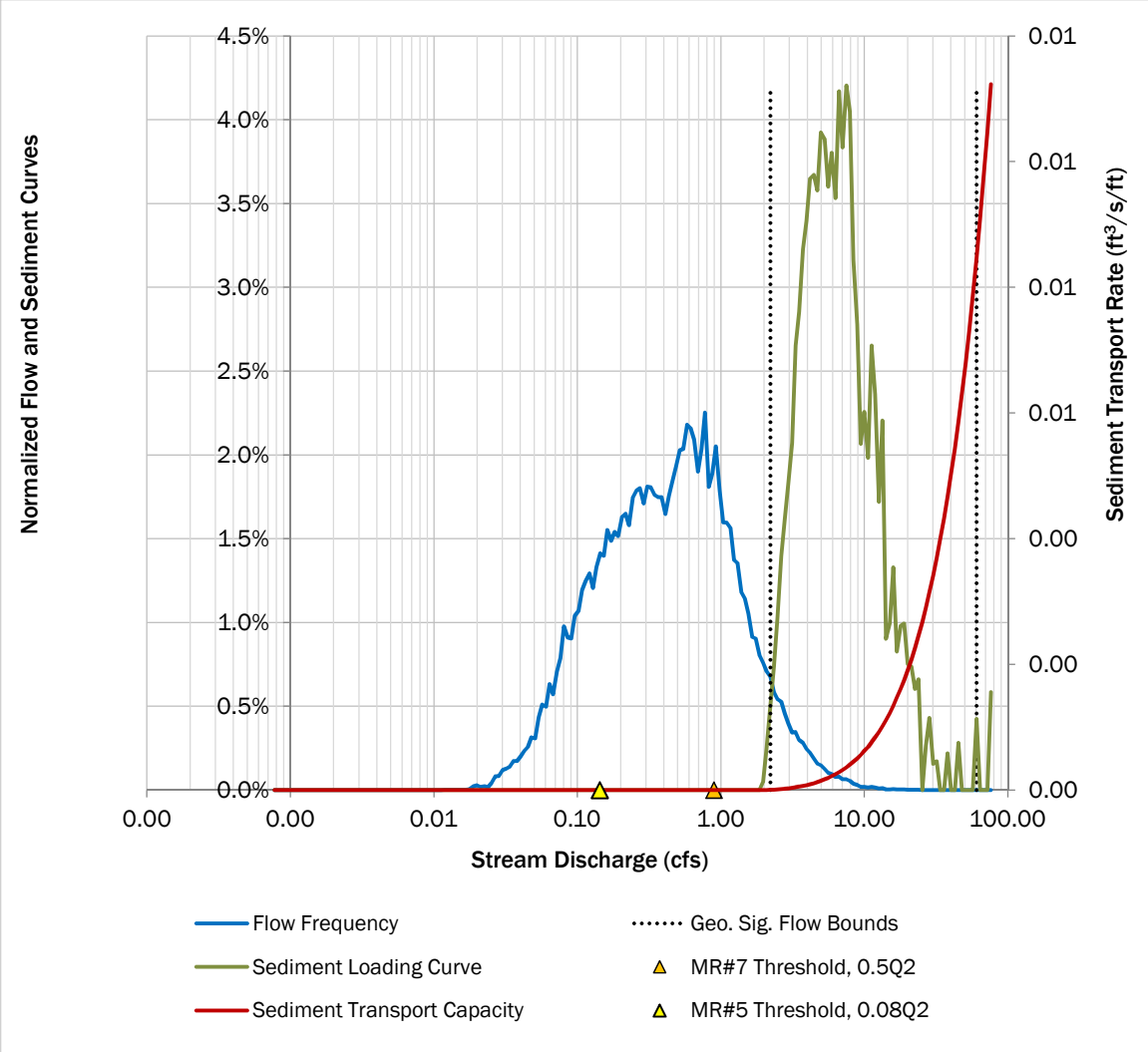
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	211
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	60.46
Lower flow bound for sediment loading (cfs):	2.21
Upper flow bound as a fraction of 50-year flow*:	8.28
Lower flow bound as a fraction of 2-year flow*:	1.236

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	7.48
Flow depth at effective discharge (ft):	0.41
Shear Stress at effective discharge (lb/ft^2):	0.22
Average flow velocity at effective discharge (ft/s):	1.5
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	14.8
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	MC-R01
Flow location:	MC-Q01
Cross-section:	MC.1296
Channel Slope:	0.2%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	2.13	1.49	-30%
2-year Flow, Q_2	8.19	55.95	583%
50-year Flow, Q_{50}	32.58	175.77	439%
MR#7 Threshold, $0.5Q_2$	4.09	27.97	--
MR#5 Threshold, $0.08Q_2$	0.66	4.48	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	0.39
Depth of flow (ft)	0.02	0.04	0.35
Fraction of natural Q_2	0.0000	0.000	0.05

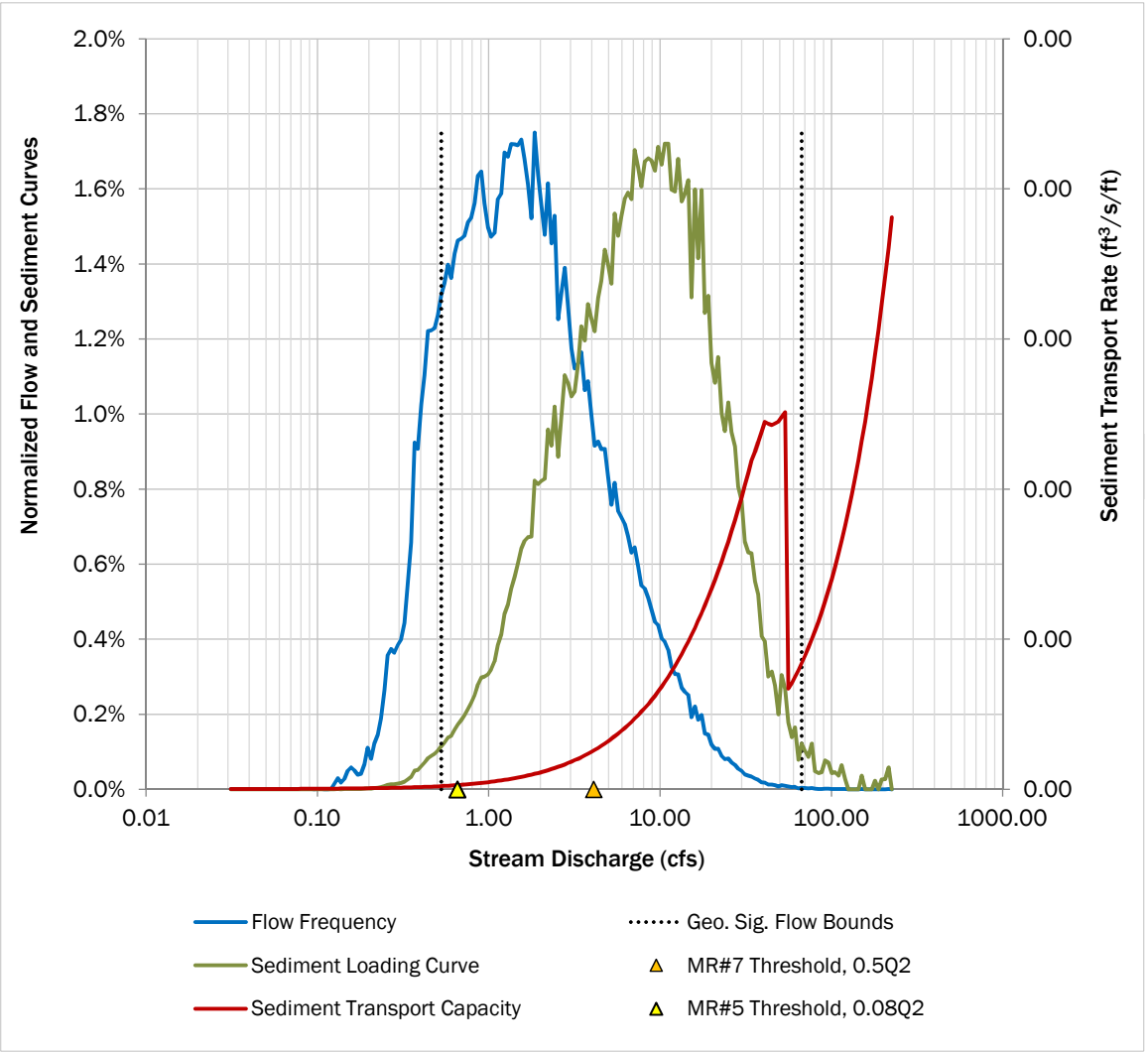
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,808
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	67.14
Lower flow bound for sediment loading (cfs):	0.53
Upper flow bound as a fraction of 50-year flow*:	2.06
Lower flow bound as a fraction of 2-year flow*:	0.064

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	11.15
Flow depth at effective discharge (ft):	1.55
Shear Stress at effective discharge (lb/ft^2):	0.14
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	8.5
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	MC-R02
Flow location:	MC-Q02
Cross-section:	MC.3860
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.44	1.01	-30%
2-year Flow, Q_2	5.53	37.78	583%
50-year Flow, Q_{50}	22.00	118.71	439%
MR#7 Threshold, $0.5Q_2$	2.77	18.89	--
MR#5 Threshold, $0.08Q_2$	0.44	3.02	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	0.96
Depth of flow (ft)	0.03	0.07	0.51
Fraction of natural Q_2	0.0001	0.001	0.17

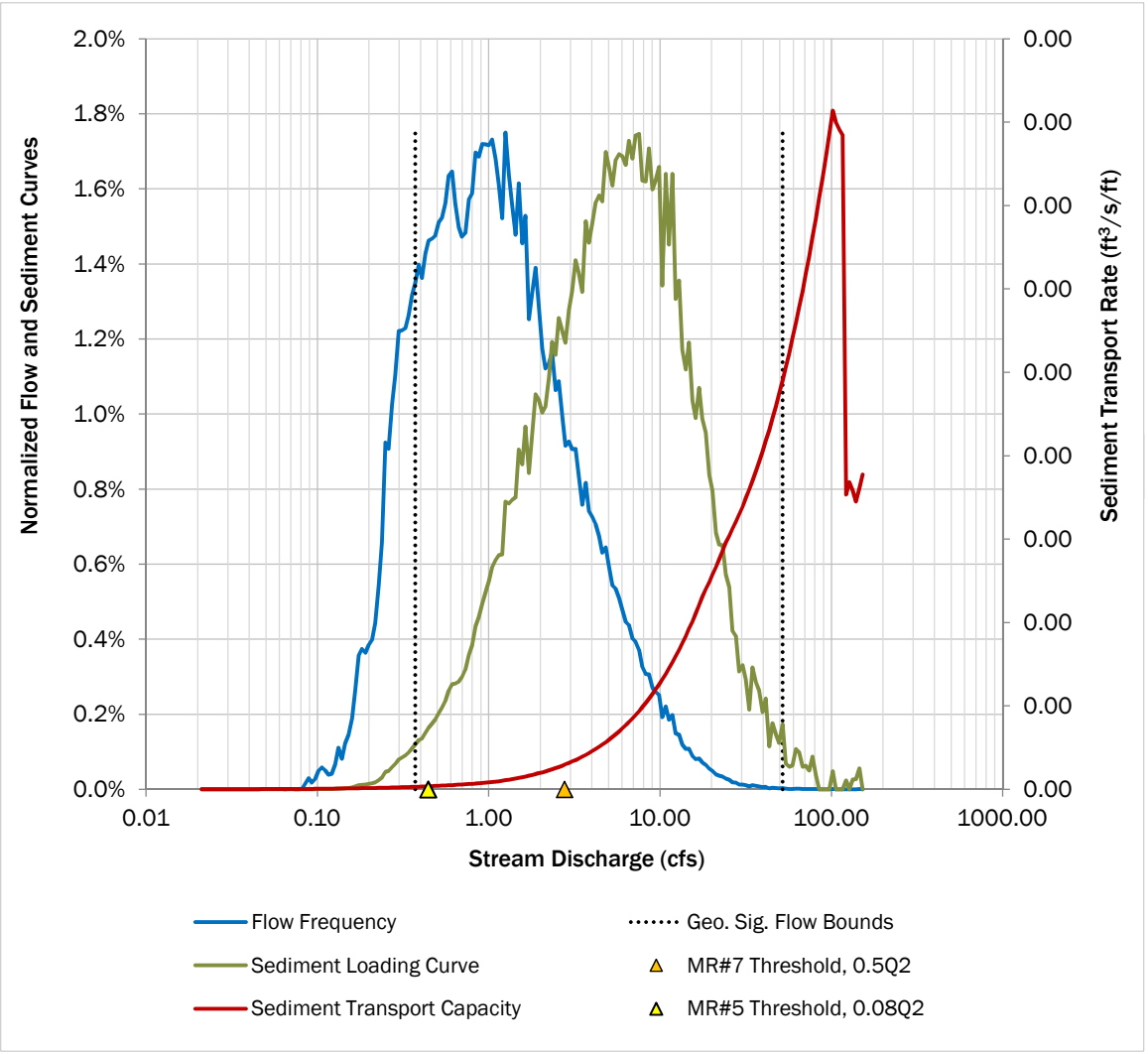
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	513
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	51.90
Lower flow bound for sediment loading (cfs):	0.37
Upper flow bound as a fraction of 50-year flow*:	2.36
Lower flow bound as a fraction of 2-year flow*:	0.067

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	7.54
Flow depth at effective discharge (ft):	1.28
Shear Stress at effective discharge (lb/ft^2):	0.07
Average flow velocity at effective discharge (ft/s):	0.9
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	9.8
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	MC-R03
Flow location:	MC-Q03
Cross-section:	MC.5962
Channel Slope:	0.2%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.98	0.46	-54%
2-year Flow, Q_2	3.60	22.96	538%
50-year Flow, Q_{50}	14.40	93.45	549%
MR#7 Threshold, $0.5Q_2$	1.80	11.48	--
MR#5 Threshold, $0.08Q_2$	0.29	1.84	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	0.60
Depth of flow (ft)	0.02	0.04	0.35
Fraction of natural Q_2	0.0001	0.001	0.17

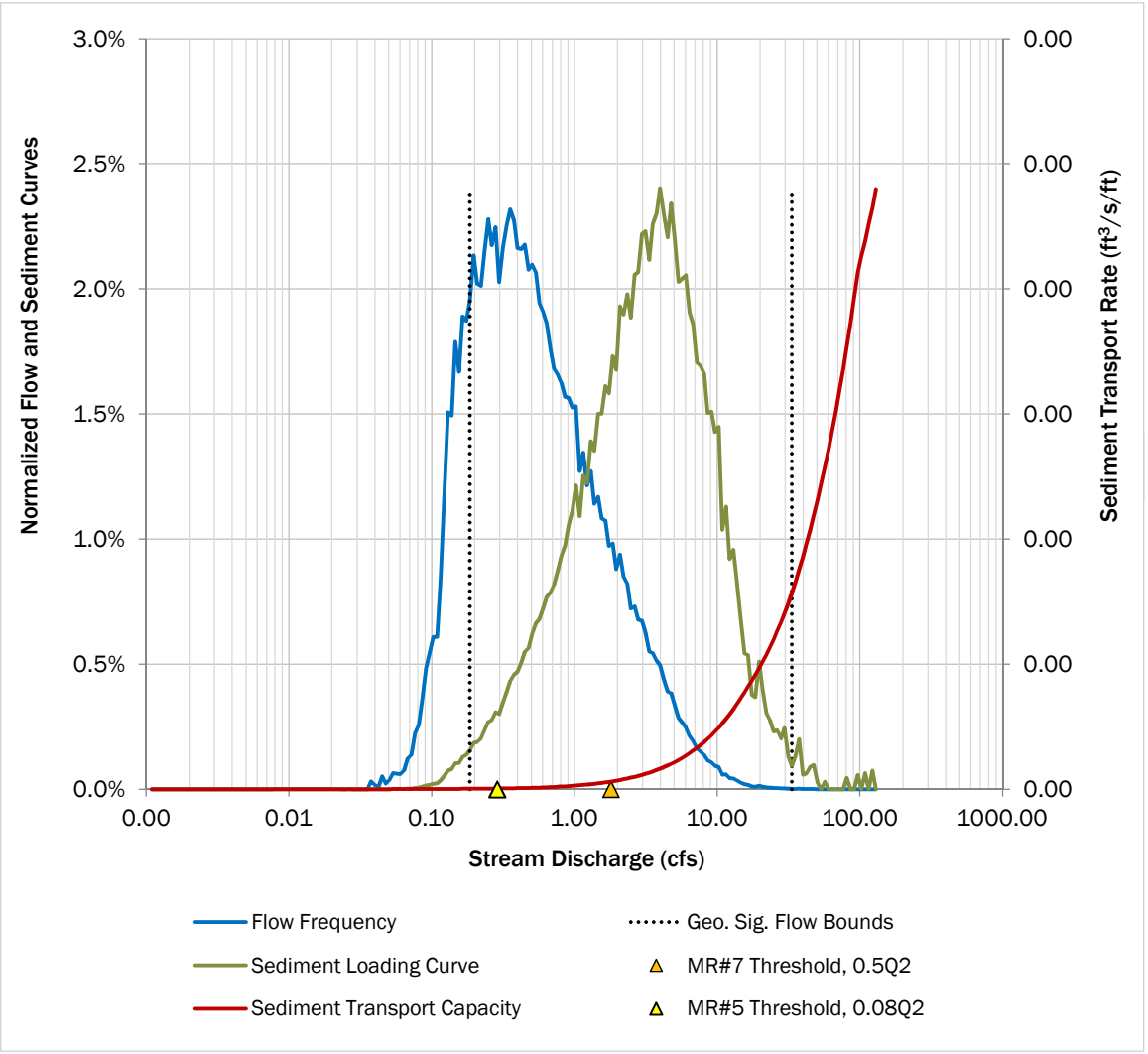
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	411
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	33.40
Lower flow bound for sediment loading (cfs):	0.19
Upper flow bound as a fraction of 50-year flow*:	2.32
Lower flow bound as a fraction of 2-year flow*:	0.052

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.99
Flow depth at effective discharge (ft):	0.76
Shear Stress at effective discharge (lb/ft^2):	0.07
Average flow velocity at effective discharge (ft/s):	0.8
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	9.2
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	MC-R04
Flow location:	MC-Q03
Cross-section:	MC.8686
Channel Slope:	0.5%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.98	0.46	-54%
2-year Flow, Q_2	3.60	22.96	538%
50-year Flow, Q_{50}	14.40	93.45	549%
MR#7 Threshold, $0.5Q_2$	1.80	11.48	--
MR#5 Threshold, $0.08Q_2$	0.29	1.84	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	0.05
Depth of flow (ft)	0.01	0.02	0.18
Fraction of natural Q_2	0.0000	0.000	0.01

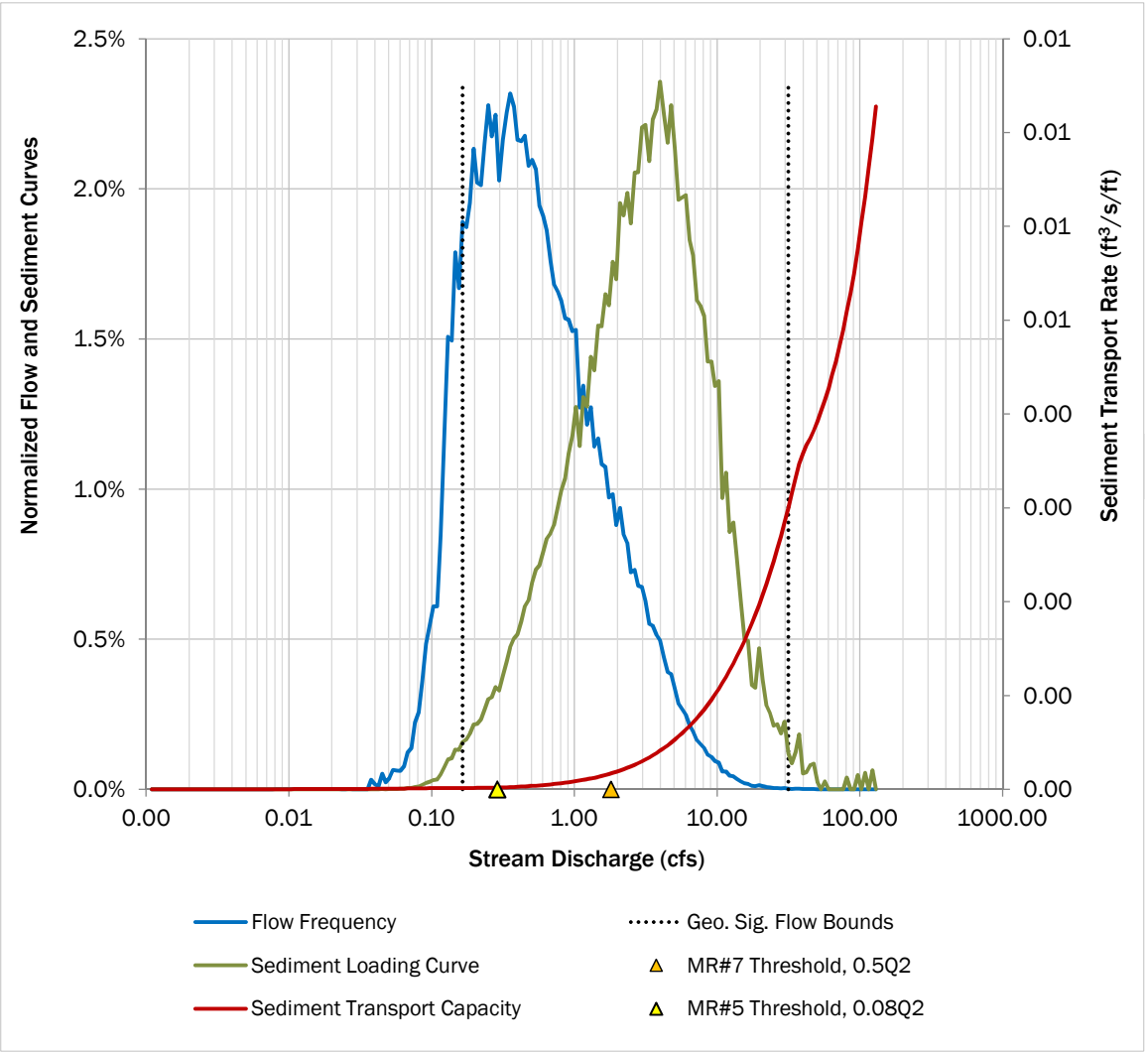
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,410
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	31.49
Lower flow bound for sediment loading (cfs):	0.16
Upper flow bound as a fraction of 50-year flow*:	2.19
Lower flow bound as a fraction of 2-year flow*:	0.046

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.99
Flow depth at effective discharge (ft):	0.90
Shear Stress at effective discharge (lb/ft^2):	0.15
Average flow velocity at effective discharge (ft/s):	1.2
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	6.2
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	MC-R05
Flow location:	MC-Q04
Cross-section:	MC.pipe
Channel Slope:	0.6%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.41	0.19	-54%
2-year Flow, Q_2	1.50	9.57	538%
50-year Flow, Q_{50}	6.00	38.93	549%
MR#7 Threshold, $0.5Q_2$	0.75	4.78	--
MR#5 Threshold, $0.08Q_2$	0.12	0.77	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	1.51	15.17
Depth of flow (ft)	0.02	0.38	1.21
Fraction of natural Q_2	0.0024	1.009	10.12

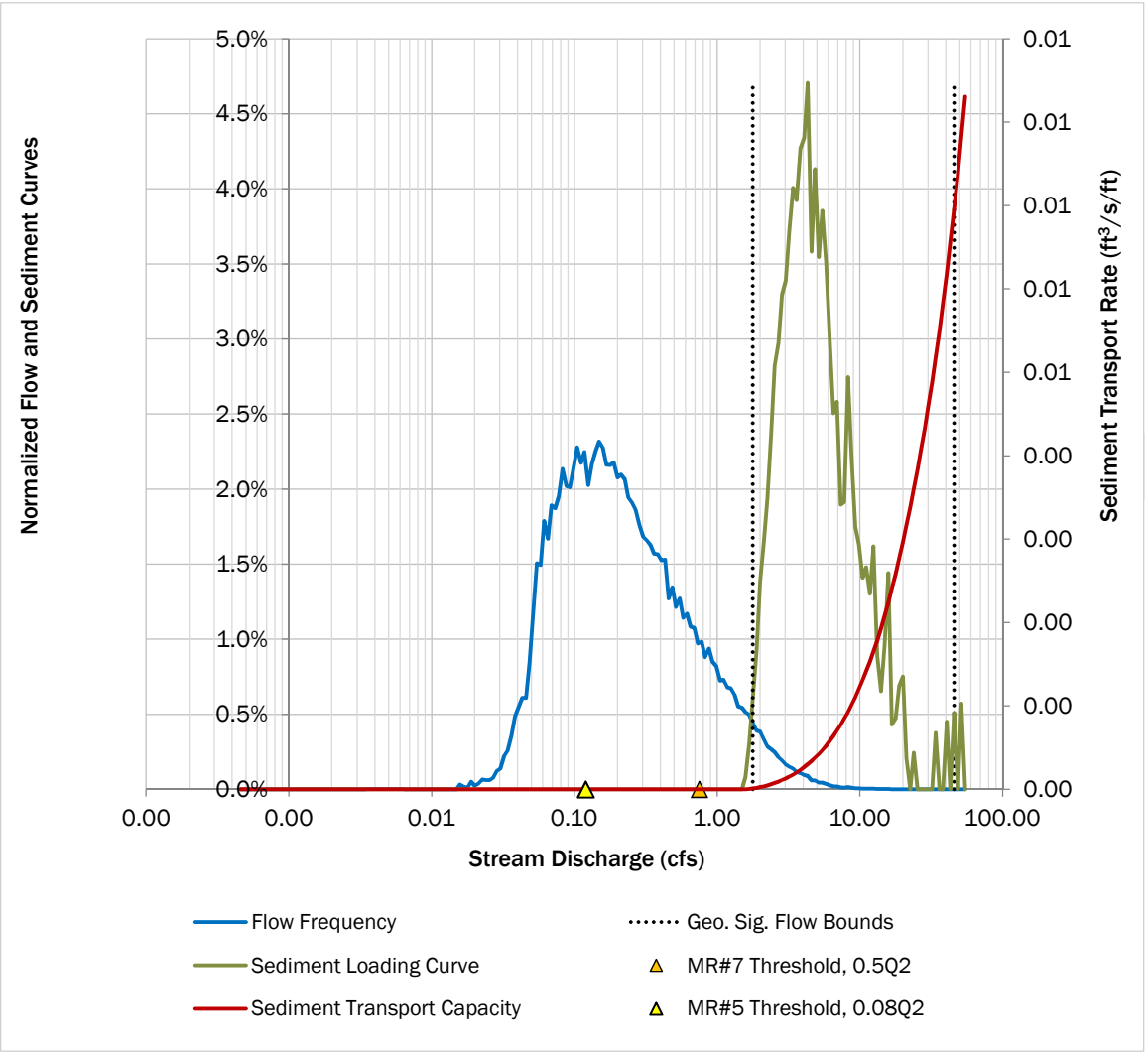
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	42
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	45.67
Lower flow bound for sediment loading (cfs):	1.78
Upper flow bound as a fraction of 50-year flow*:	7.61
Lower flow bound as a fraction of 2-year flow*:	1.186

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	4.31
Flow depth at effective discharge (ft):	0.63
Shear Stress at effective discharge (lb/ft^2):	0.16
Average flow velocity at effective discharge (ft/s):	3.6
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	2.8
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	RC-R01
Flow location:	RC-Q01
Cross-section:	BC02
Channel Slope:	0.1%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.74	1.89	8%
2-year Flow, Q_2	4.59	24.70	438%
50-year Flow, Q_{50}	14.02	91.74	554%
MR#7 Threshold, $0.5Q_2$	2.30	12.35	--
MR#5 Threshold, $0.08Q_2$	0.37	1.98	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	3.69
Depth of flow (ft)	0.04	0.11	0.84
Fraction of natural Q_2	0.0003	0.003	0.80

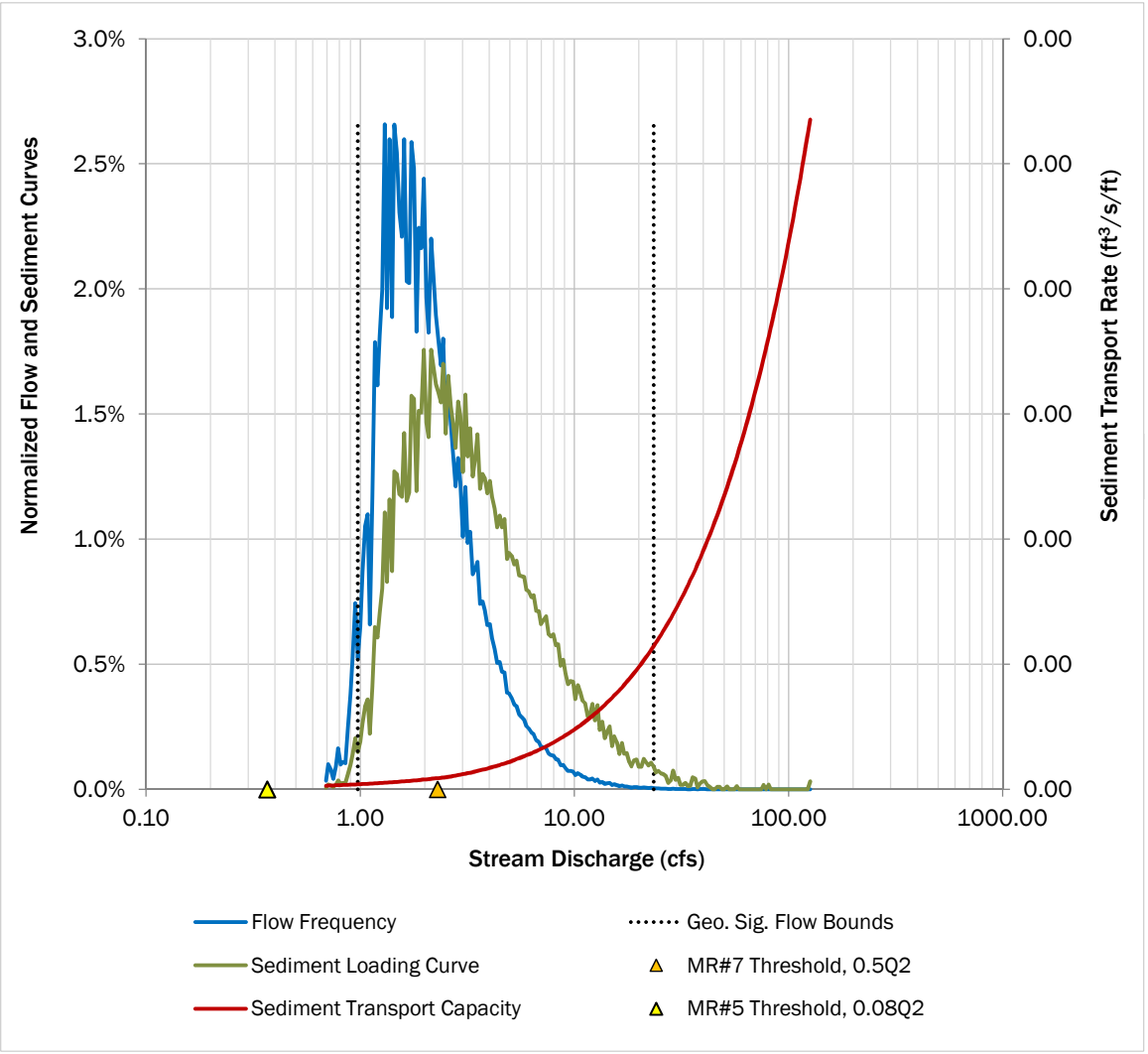
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	240
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	23.44
Lower flow bound for sediment loading (cfs):	0.97
Upper flow bound as a fraction of 50-year flow*:	1.67
Lower flow bound as a fraction of 2-year flow*:	0.212

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.98
Flow depth at effective discharge (ft):	0.67
Shear Stress at effective discharge (lb/ft^2):	0.02
Average flow velocity at effective discharge (ft/s):	0.7
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	8.5
Largest mobilized sediment:	*Coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	RC-R02
Flow location:	RC-Q01
Cross-section:	BC03
Channel Slope:	0.8%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.74	1.89	8%
2-year Flow, Q_2	4.59	24.70	438%
50-year Flow, Q_{50}	14.02	91.74	554%
MR#7 Threshold, $0.5Q_2$	2.30	12.35	--
MR#5 Threshold, $0.08Q_2$	0.37	1.98	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	1.15	12.42
Depth of flow (ft)	0.04	0.32	0.98
Fraction of natural Q_2	0.0011	0.252	2.71

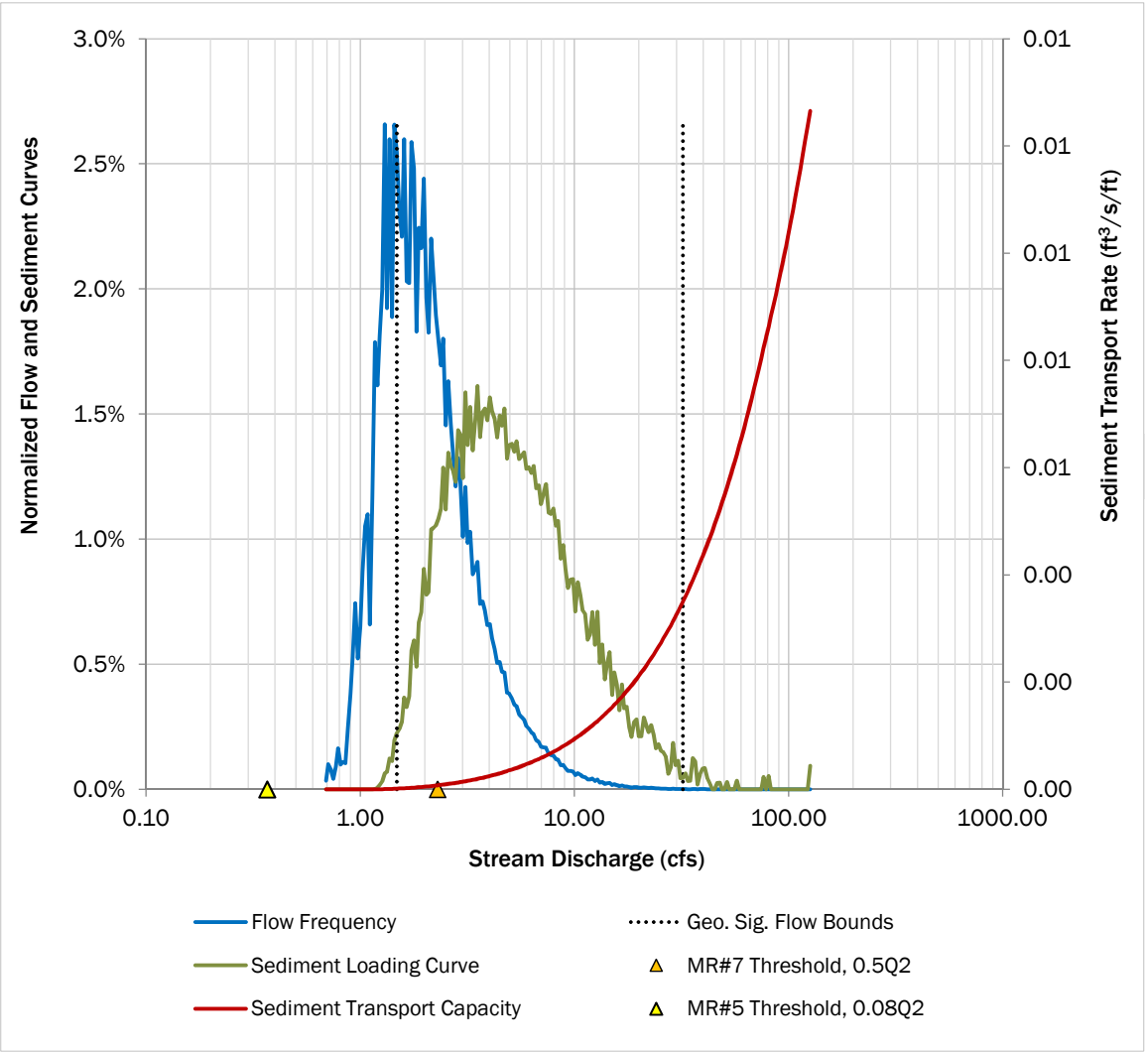
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,385
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	32.13
Lower flow bound for sediment loading (cfs):	1.48
Upper flow bound as a fraction of 50-year flow*:	2.29
Lower flow bound as a fraction of 2-year flow*:	0.323

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.53
Flow depth at effective discharge (ft):	0.55
Shear Stress at effective discharge (lb/ft^2):	0.16
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	4.8
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	RC-R03
Flow location:	RC-Q02
Cross-section:	XS473
Channel Slope:	3.6%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.64	21%
2-year Flow, Q_2	2.70	23.95	786%
50-year Flow, Q_{50}	10.85	77.63	616%
MR#7 Threshold, $0.5Q_2$	1.35	11.97	--
MR#5 Threshold, $0.08Q_2$	0.22	1.92	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.28	1.51
Depth of flow (ft)	0.01	0.09	0.17
Fraction of natural Q_2	0.0002	0.103	0.56

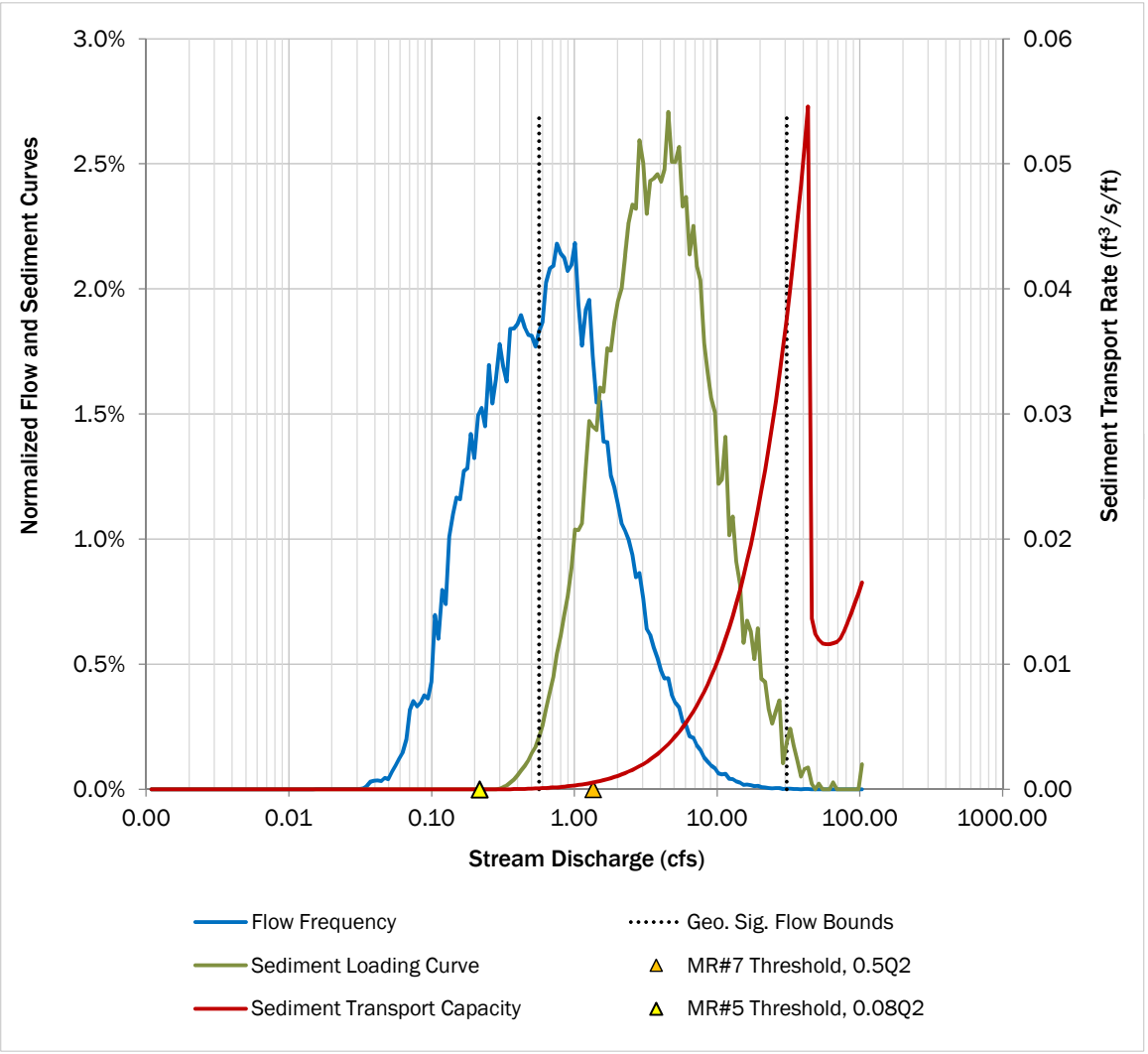
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	13,361
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	30.65
Lower flow bound for sediment loading (cfs):	0.57
Upper flow bound as a fraction of 50-year flow*:	2.83
Lower flow bound as a fraction of 2-year flow*:	0.209

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	4.54
Flow depth at effective discharge (ft):	0.28
Shear Stress at effective discharge (lb/ft^2):	0.49
Average flow velocity at effective discharge (ft/s):	2.4
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	8.6
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	RC-R04
Flow location:	RC-Q02
Cross-section:	XS468
Channel Slope:	4.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.64	21%
2-year Flow, Q_2	2.70	23.95	786%
50-year Flow, Q_{50}	10.85	77.63	616%
MR#7 Threshold, $0.5Q_2$	1.35	11.97	--
MR#5 Threshold, $0.08Q_2$	0.22	1.92	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.04	0.98
Depth of flow (ft)	0.01	0.06	0.21
Fraction of natural Q_2	0.0000	0.016	0.36

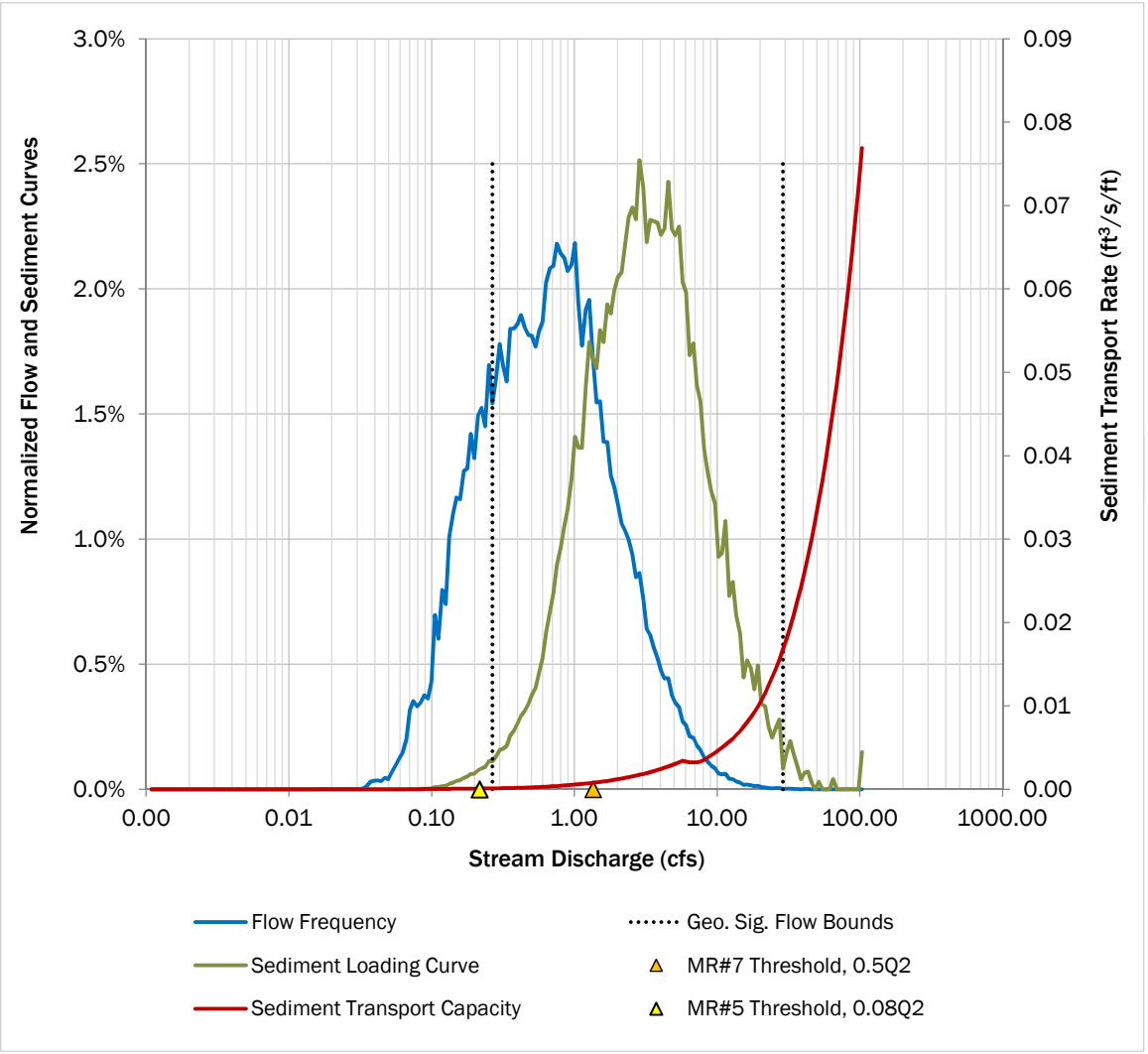
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	18,721
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.93
Lower flow bound for sediment loading (cfs):	0.27
Upper flow bound as a fraction of 50-year flow*:	2.67
Lower flow bound as a fraction of 2-year flow*:	0.099

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.86
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.40
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	12.0
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	RC-R05
Flow location:	RC-Q02
Cross-section:	XS468
Channel Slope:	12.4%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.64	21%
2-year Flow, Q_2	2.70	23.95	786%
50-year Flow, Q_{50}	10.85	77.63	616%
MR#7 Threshold, $0.5Q_2$	1.35	11.97	--
MR#5 Threshold, $0.08Q_2$	0.22	1.92	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	0.20
Depth of flow (ft)	0.00	0.04	0.10
Fraction of natural Q_2	0.0000	0.011	0.08

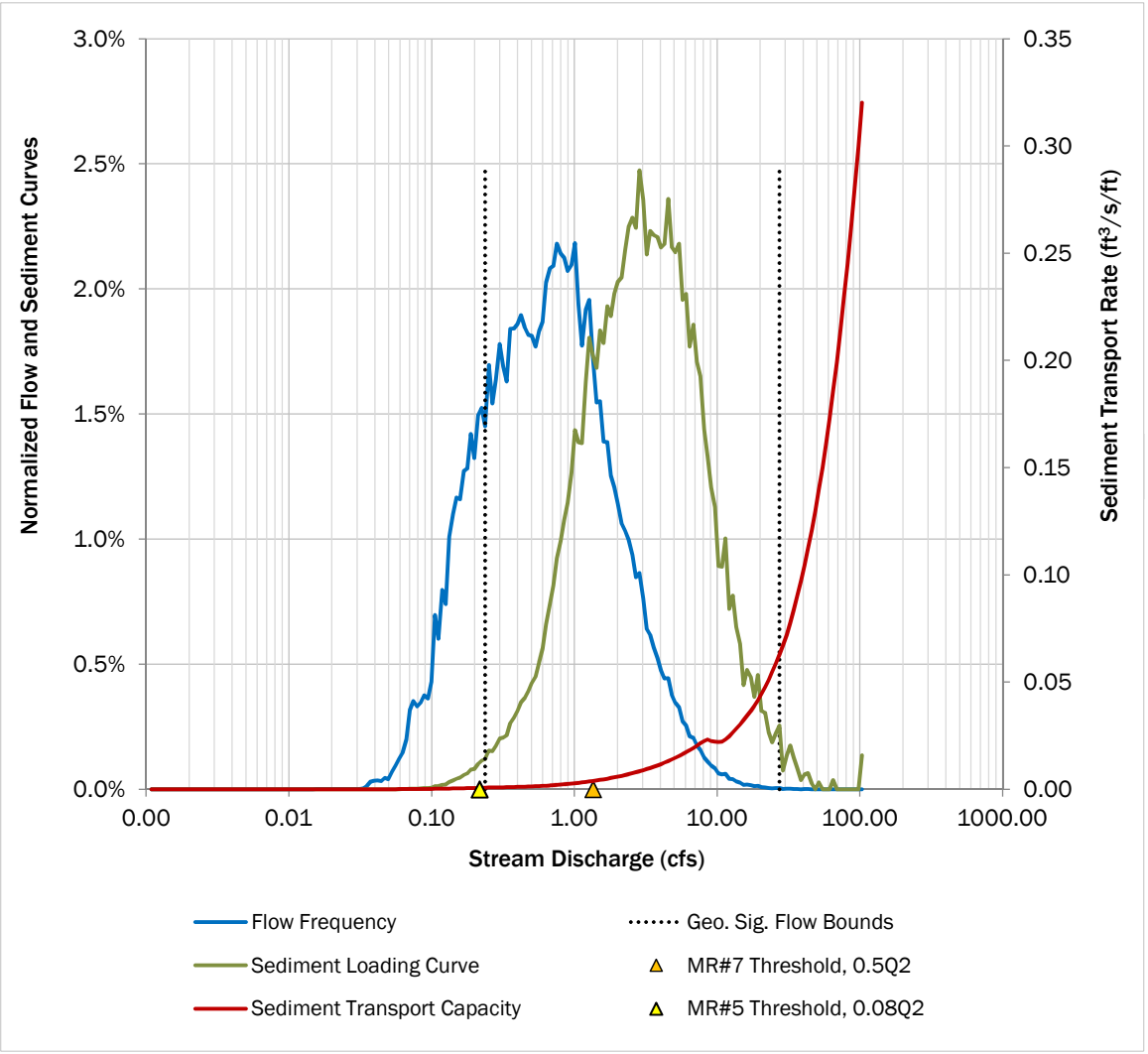
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	79,984
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	27.30
Lower flow bound for sediment loading (cfs):	0.24
Upper flow bound as a fraction of 50-year flow*:	2.52
Lower flow bound as a fraction of 2-year flow*:	0.088

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.86
Flow depth at effective discharge (ft):	0.26
Shear Stress at effective discharge (lb/ft^2):	0.91
Average flow velocity at effective discharge (ft/s):	2.3
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	10.4
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	RC-R06
Flow location:	RC-Q02
Cross-section:	BC13
Channel Slope:	4.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.64	21%
2-year Flow, Q_2	2.70	23.95	786%
50-year Flow, Q_{50}	10.85	77.63	616%
MR#7 Threshold, $0.5Q_2$	1.35	11.97	--
MR#5 Threshold, $0.08Q_2$	0.22	1.92	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.06	0.75
Depth of flow (ft)	0.01	0.07	0.18
Fraction of natural Q_2	0.0000	0.020	0.28

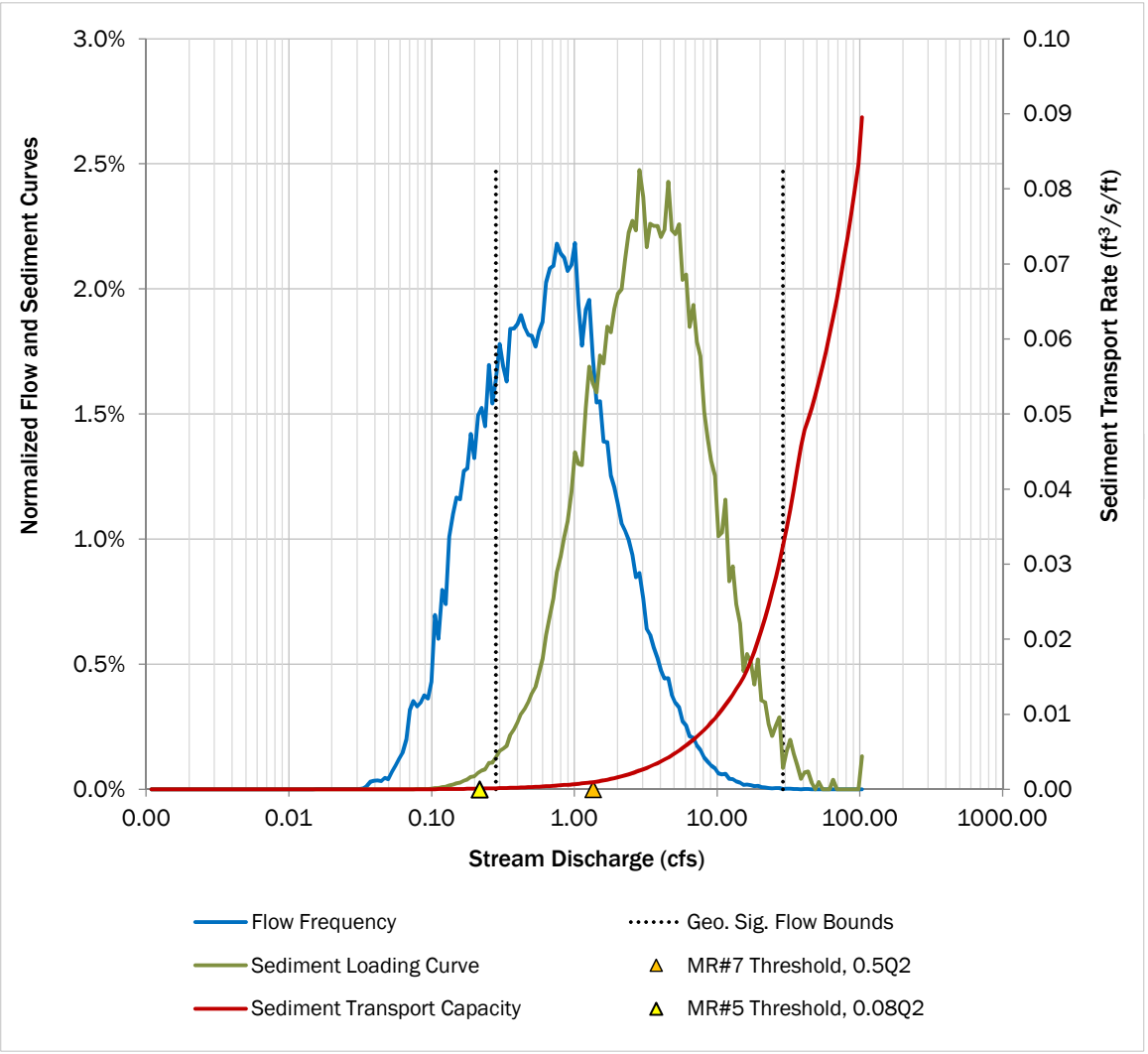
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	22,317
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.93
Lower flow bound for sediment loading (cfs):	0.28
Upper flow bound as a fraction of 50-year flow*:	2.67
Lower flow bound as a fraction of 2-year flow*:	0.104

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.86
Flow depth at effective discharge (ft):	0.30
Shear Stress at effective discharge (lb/ft^2):	0.48
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	9.8
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	RC-R07
Flow location:	RC-Q02
Cross-section:	XS456
Channel Slope:	5.1%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.64	21%
2-year Flow, Q_2	2.70	23.95	786%
50-year Flow, Q_{50}	10.85	77.63	616%
MR#7 Threshold, $0.5Q_2$	1.35	11.97	--
MR#5 Threshold, $0.08Q_2$	0.22	1.92	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.13	0.74
Depth of flow (ft)	0.01	0.13	0.25
Fraction of natural Q_2	0.0000	0.050	0.28

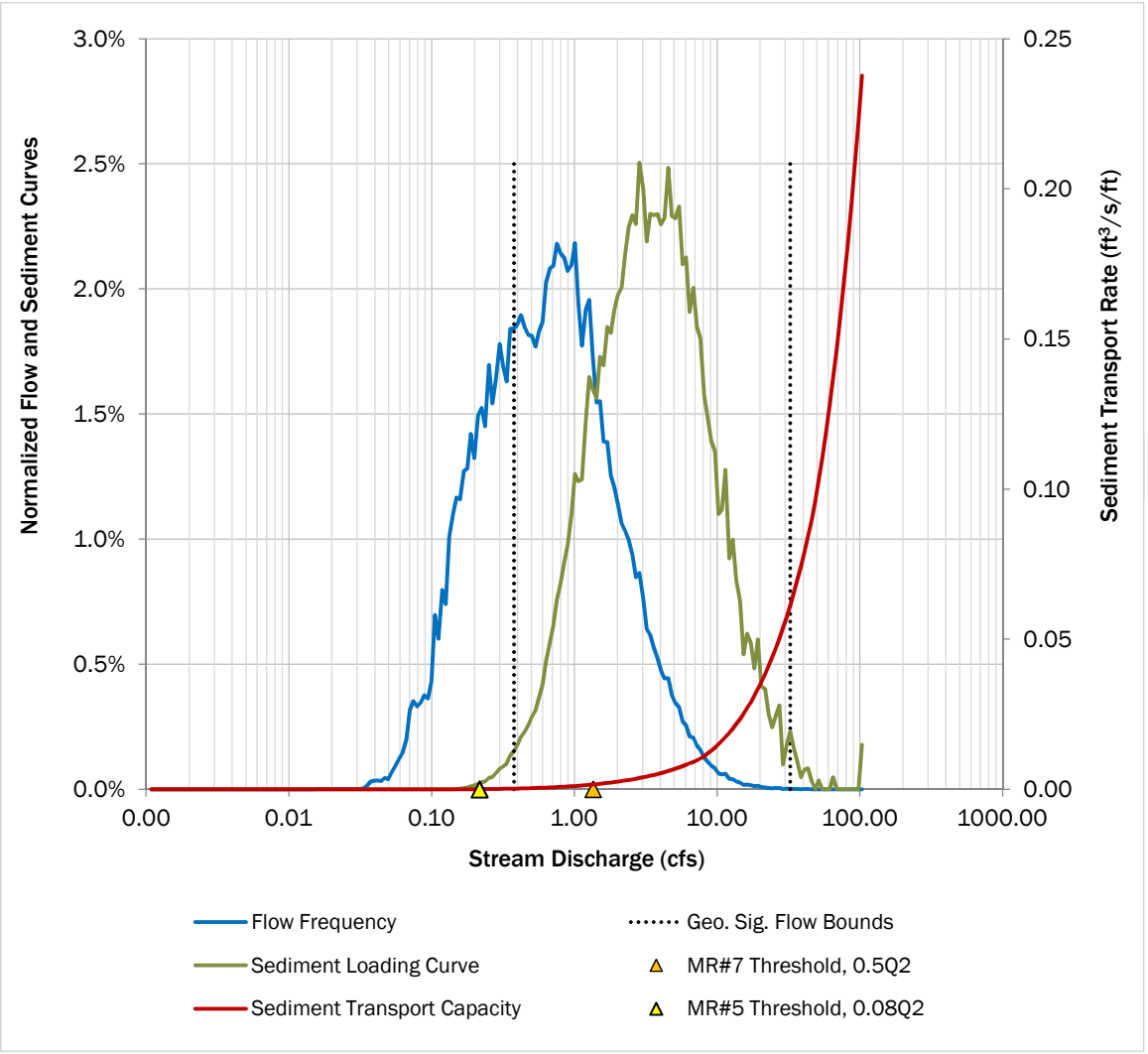
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	22,300
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	32.48
Lower flow bound for sediment loading (cfs):	0.38
Upper flow bound as a fraction of 50-year flow*:	2.99
Lower flow bound as a fraction of 2-year flow*:	0.139

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.86
Flow depth at effective discharge (ft):	0.41
Shear Stress at effective discharge (lb/ft^2):	0.64
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	6.6
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	RC-R08
Flow location:	RC-Q03
Cross-section:	XS456
Channel Slope:	7.7%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.43	0.52	22%
2-year Flow, Q_2	2.52	20.08	696%
50-year Flow, Q_{50}	9.34	67.13	619%
MR#7 Threshold, $0.5Q_2$	1.26	10.04	--
MR#5 Threshold, $0.08Q_2$	0.20	1.61	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.05	0.30
Depth of flow (ft)	0.00	0.09	0.16
Fraction of natural Q_2	0.0000	0.022	0.12

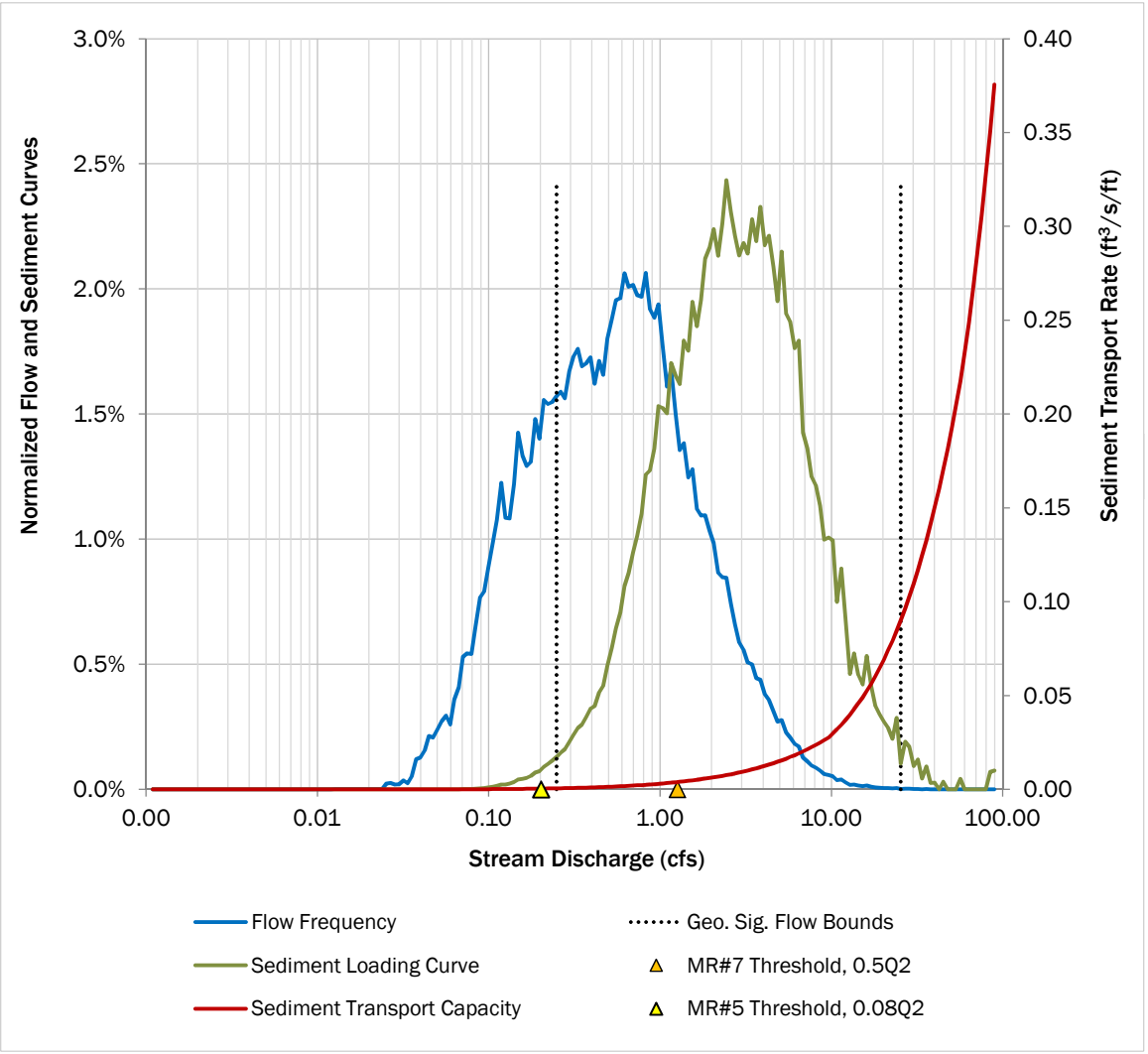
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	39,492
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	25.44
Lower flow bound for sediment loading (cfs):	0.25
Upper flow bound as a fraction of 50-year flow*:	2.72
Lower flow bound as a fraction of 2-year flow*:	0.098

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.44
Flow depth at effective discharge (ft):	0.36
Shear Stress at effective discharge (lb/ft^2):	0.85
Average flow velocity at effective discharge (ft/s):	2.4
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	5.7
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	RC-R09
Flow location:	RC-Q03
Cross-section:	XS446
Channel Slope:	3.4%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.43	0.52	22%
2-year Flow, Q_2	2.52	20.08	696%
50-year Flow, Q_{50}	9.34	67.13	619%
MR#7 Threshold, $0.5Q_2$	1.26	10.04	--
MR#5 Threshold, $0.08Q_2$	0.20	1.61	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.15	2.11
Depth of flow (ft)	0.01	0.10	0.24
Fraction of natural Q_2	0.0001	0.061	0.84

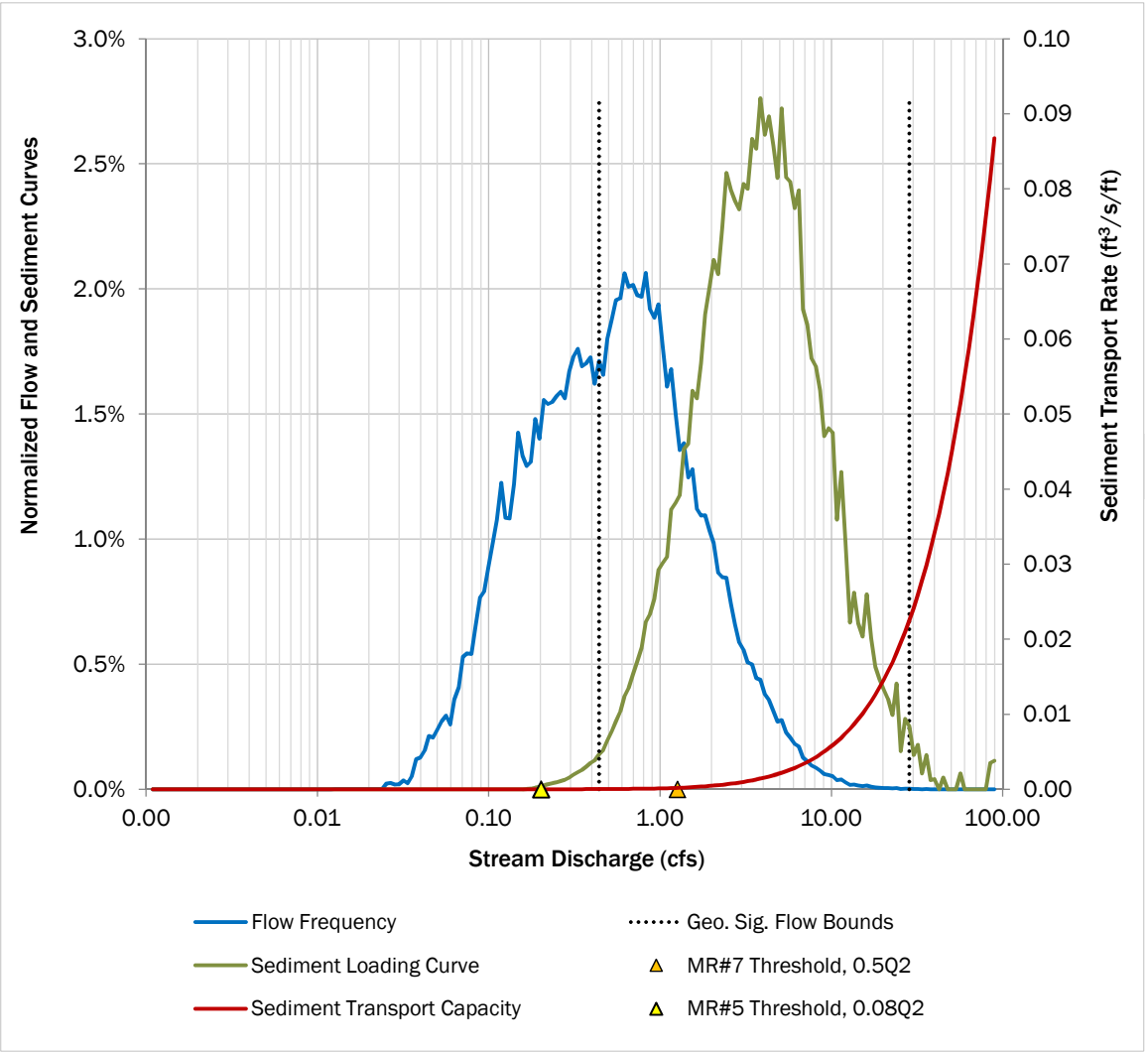
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	7,995
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.53
Lower flow bound for sediment loading (cfs):	0.44
Upper flow bound as a fraction of 50-year flow*:	3.05
Lower flow bound as a fraction of 2-year flow*:	0.174

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.86
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.38
Average flow velocity at effective discharge (ft/s):	1.6
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	13.5
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	RC-R10
Flow location:	RC-Q04
Cross-section:	XS446
Channel Slope:	0.9%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.38	0.46	22%
2-year Flow, Q_2	2.23	17.74	696%
50-year Flow, Q_{50}	8.26	59.33	619%
MR#7 Threshold, $0.5Q_2$	1.11	8.87	--
MR#5 Threshold, $0.08Q_2$	0.18	1.42	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	2.35	13.37
Depth of flow (ft)	0.03	0.30	0.64
Fraction of natural Q_2	0.0022	1.054	6.00

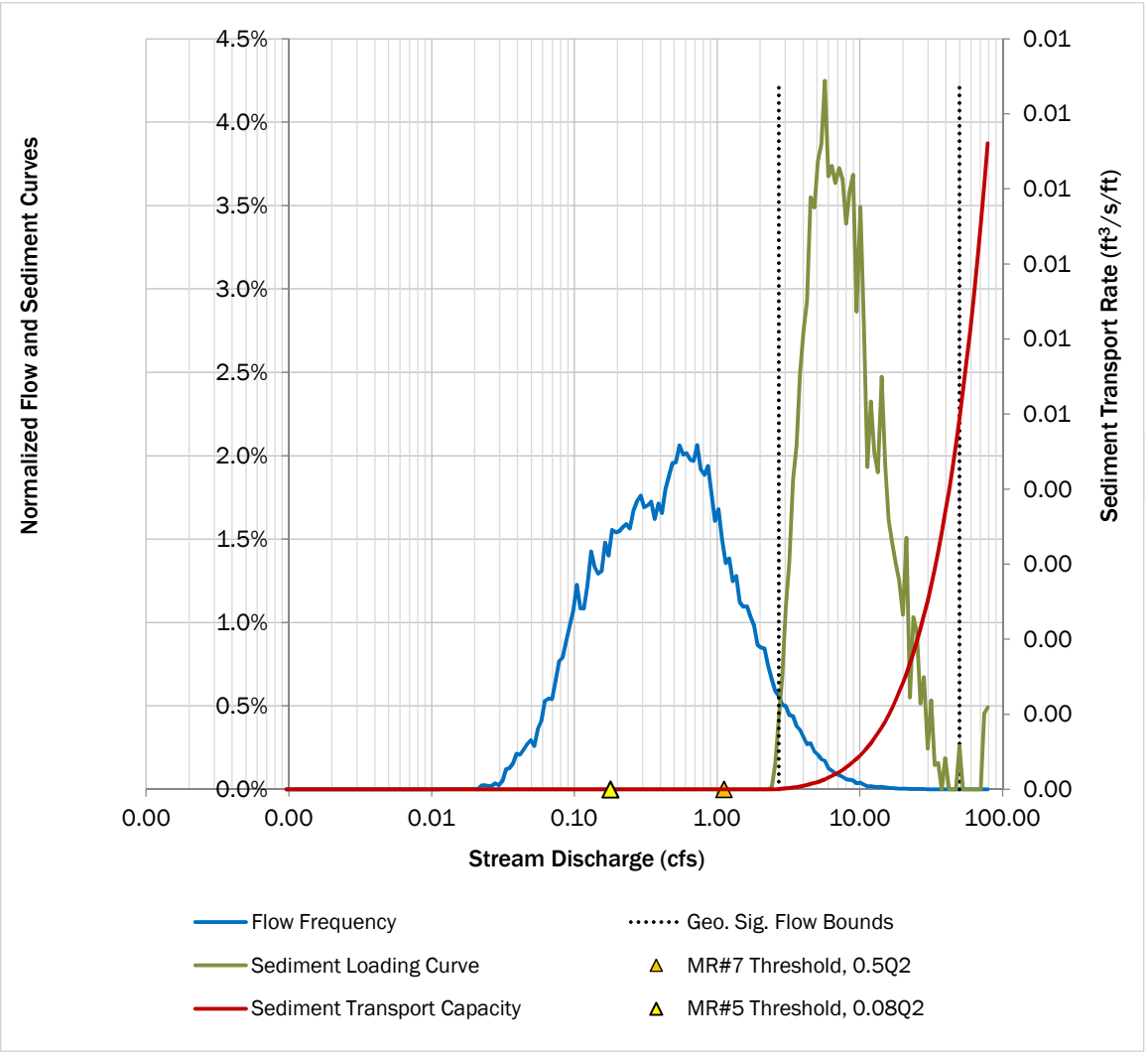
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	198
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	49.84
Lower flow bound for sediment loading (cfs):	2.70
Upper flow bound as a fraction of 50-year flow*:	6.04
Lower flow bound as a fraction of 2-year flow*:	1.212

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	5.68
Flow depth at effective discharge (ft):	0.43
Shear Stress at effective discharge (lb/ft^2):	0.17
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	14.1
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	SC-R01
Flow location:	SC-Q01
Cross-section:	XS487
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.36	0.45	22%
2-year Flow, Q_2	1.73	15.33	785%
50-year Flow, Q_{50}	6.62	57.77	772%
MR#7 Threshold, $0.5Q_2$	0.87	7.67	--
MR#5 Threshold, $0.08Q_2$	0.14	1.23	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.16	1.40	68.05
Depth of flow (ft)	0.26	0.74	3.33
Fraction of natural Q_2	0.0943	0.810	39.29

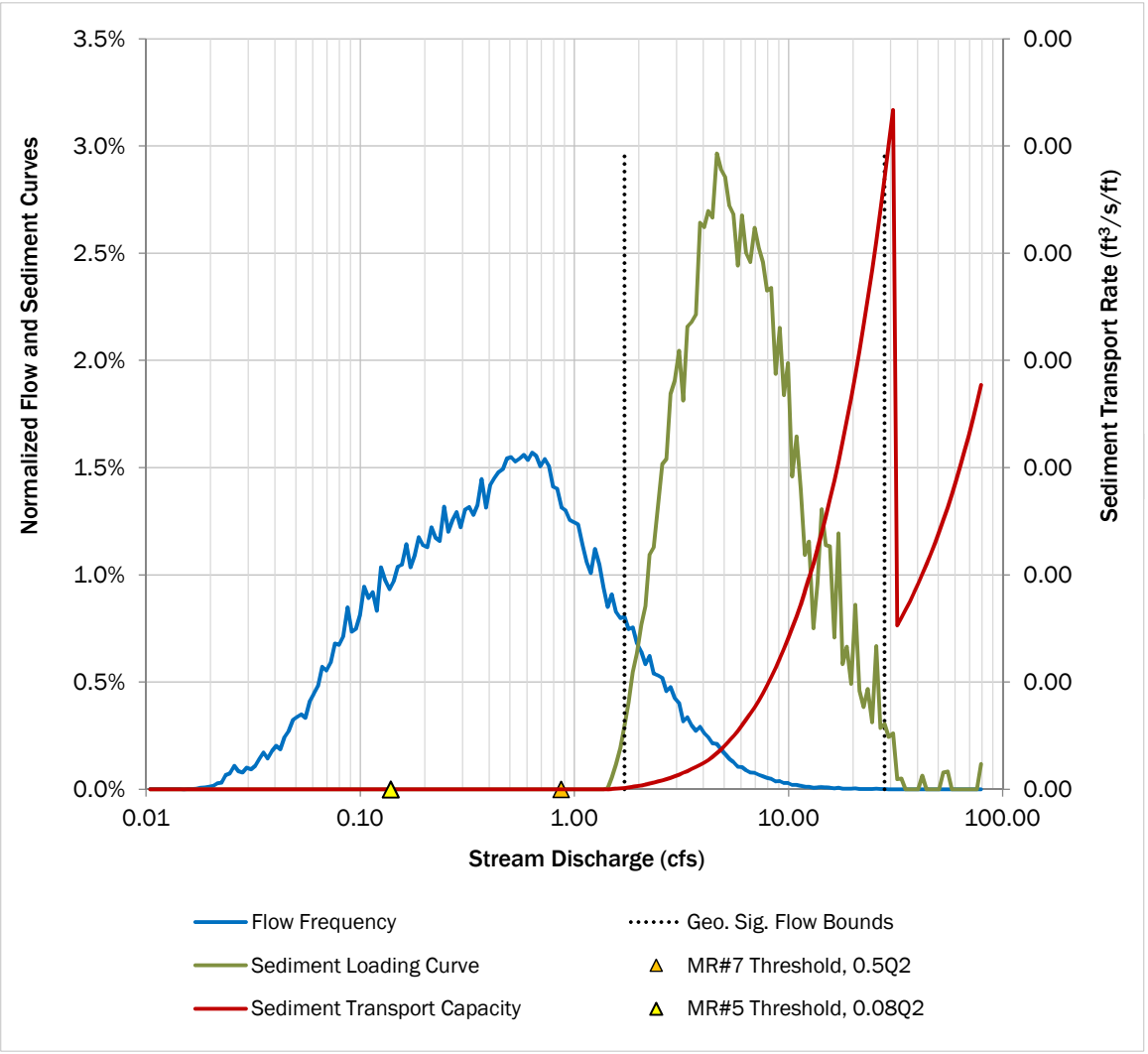
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	28.10
Lower flow bound for sediment loading (cfs):	1.71
Upper flow bound as a fraction of 50-year flow*:	4.24
Lower flow bound as a fraction of 2-year flow*:	0.989

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	4.62
Flow depth at effective discharge (ft):	1.26
Shear Stress at effective discharge (lb/ft^2):	0.00
Average flow velocity at effective discharge (ft/s):	0.4
Shear velocity at effective discharge (ft/s):	0.0
Effective width at effective discharge (ft):	17.3
Largest mobilized sediment:	*Fine sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	SC-R02
Flow location:	SC-Q01
Cross-section:	XS487
Channel Slope:	2.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.36	0.45	22%
2-year Flow, Q_2	1.73	15.33	785%
50-year Flow, Q_{50}	6.62	57.77	772%
MR#7 Threshold, $0.5Q_2$	0.87	7.67	--
MR#5 Threshold, $0.08Q_2$	0.14	1.23	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.35	2.12
Depth of flow (ft)	0.01	0.13	0.25
Fraction of natural Q_2	0.0003	0.200	1.23

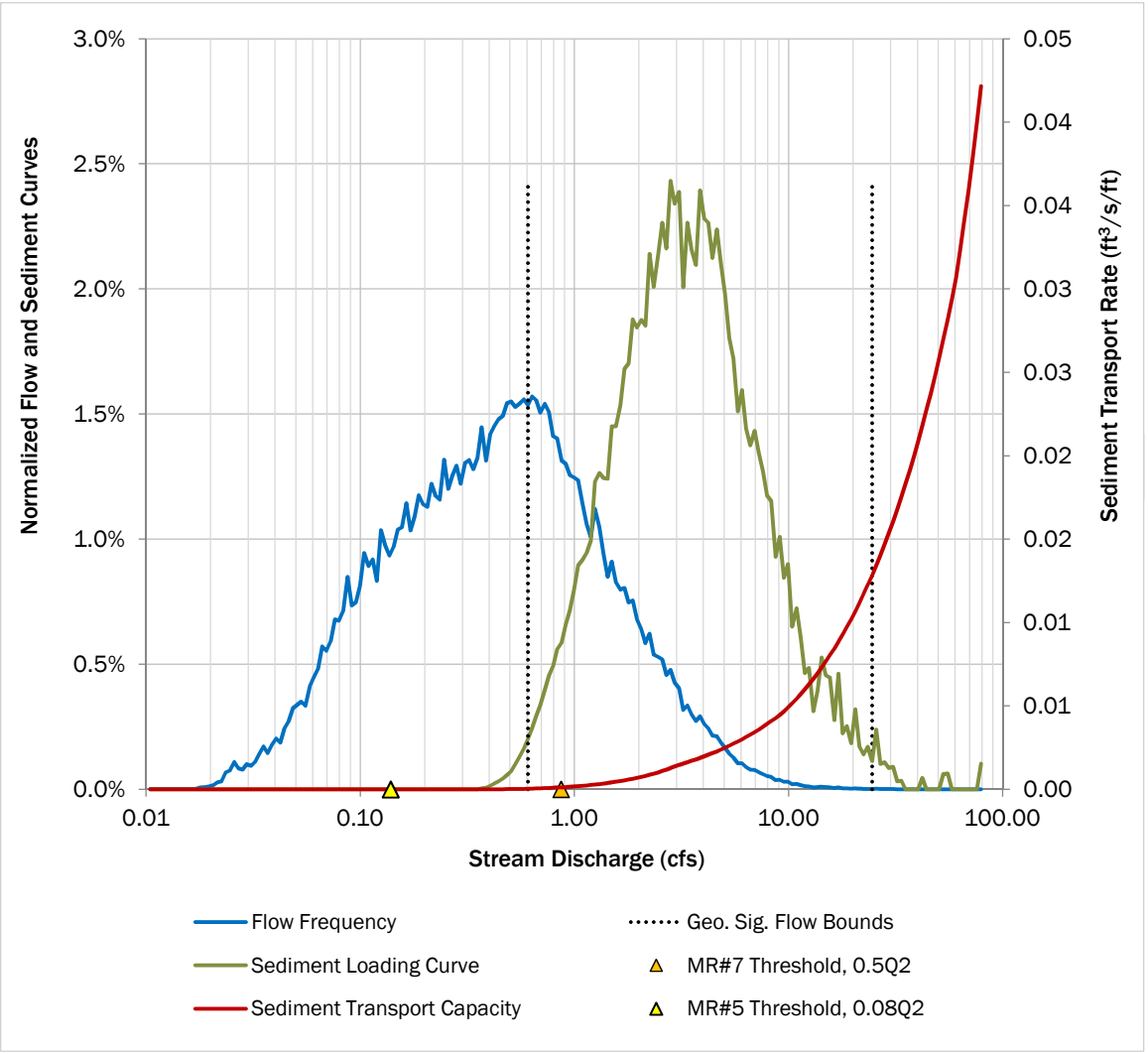
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	4,281
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	24.54
Lower flow bound for sediment loading (cfs):	0.61
Upper flow bound as a fraction of 50-year flow*:	3.71
Lower flow bound as a fraction of 2-year flow*:	0.350

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.81
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.31
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	6.6
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R03
Flow location:	SC-Q01
Cross-section:	XS485
Channel Slope:	8.3%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.36	0.45	22%
2-year Flow, Q_2	1.73	15.33	785%
50-year Flow, Q_{50}	6.62	57.77	772%
MR#7 Threshold, $0.5Q_2$	0.87	7.67	--
MR#5 Threshold, $0.08Q_2$	0.14	1.23	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.52
Depth of flow (ft)	0.01	0.10	0.34
Fraction of natural Q_2	0.0000	0.009	0.30

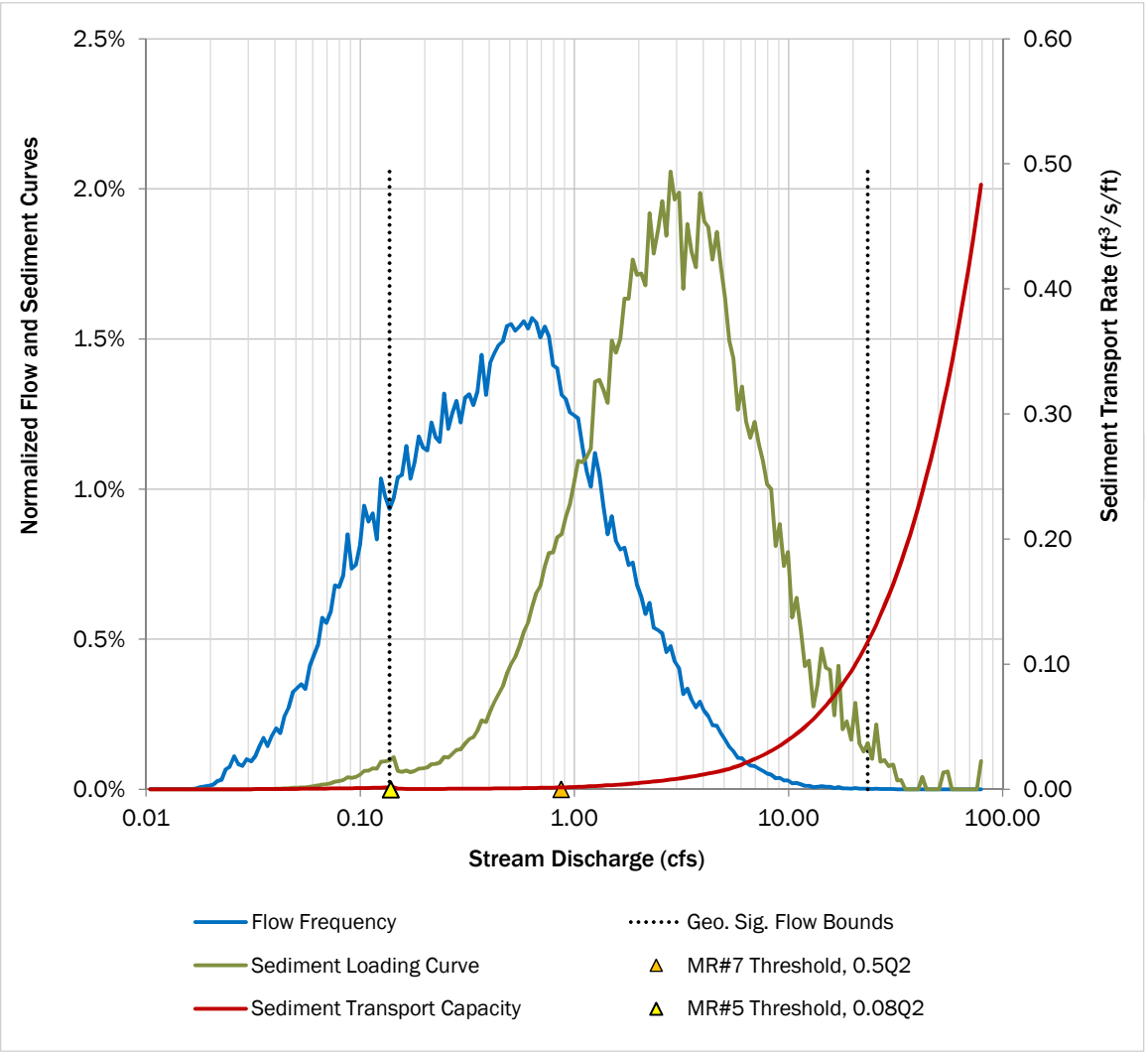
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	30,681
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	23.46
Lower flow bound for sediment loading (cfs):	0.14
Upper flow bound as a fraction of 50-year flow*:	3.54
Lower flow bound as a fraction of 2-year flow*:	0.079

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.81
Flow depth at effective discharge (ft):	0.48
Shear Stress at effective discharge (lb/ft^2):	0.80
Average flow velocity at effective discharge (ft/s):	2.7
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	6.5
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	SC-R04
Flow location:	SC-Q03
Cross-section:	XS485
Channel Slope:	2.4%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.27	0.33	22%
2-year Flow, Q_2	1.19	14.84	1144%
50-year Flow, Q_{50}	4.44	46.62	949%
MR#7 Threshold, $0.5Q_2$	0.60	7.42	--
MR#5 Threshold, $0.08Q_2$	0.10	1.19	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	1.84
Depth of flow (ft)	0.02	0.17	0.52
Fraction of natural Q_2	0.0000	0.026	1.54

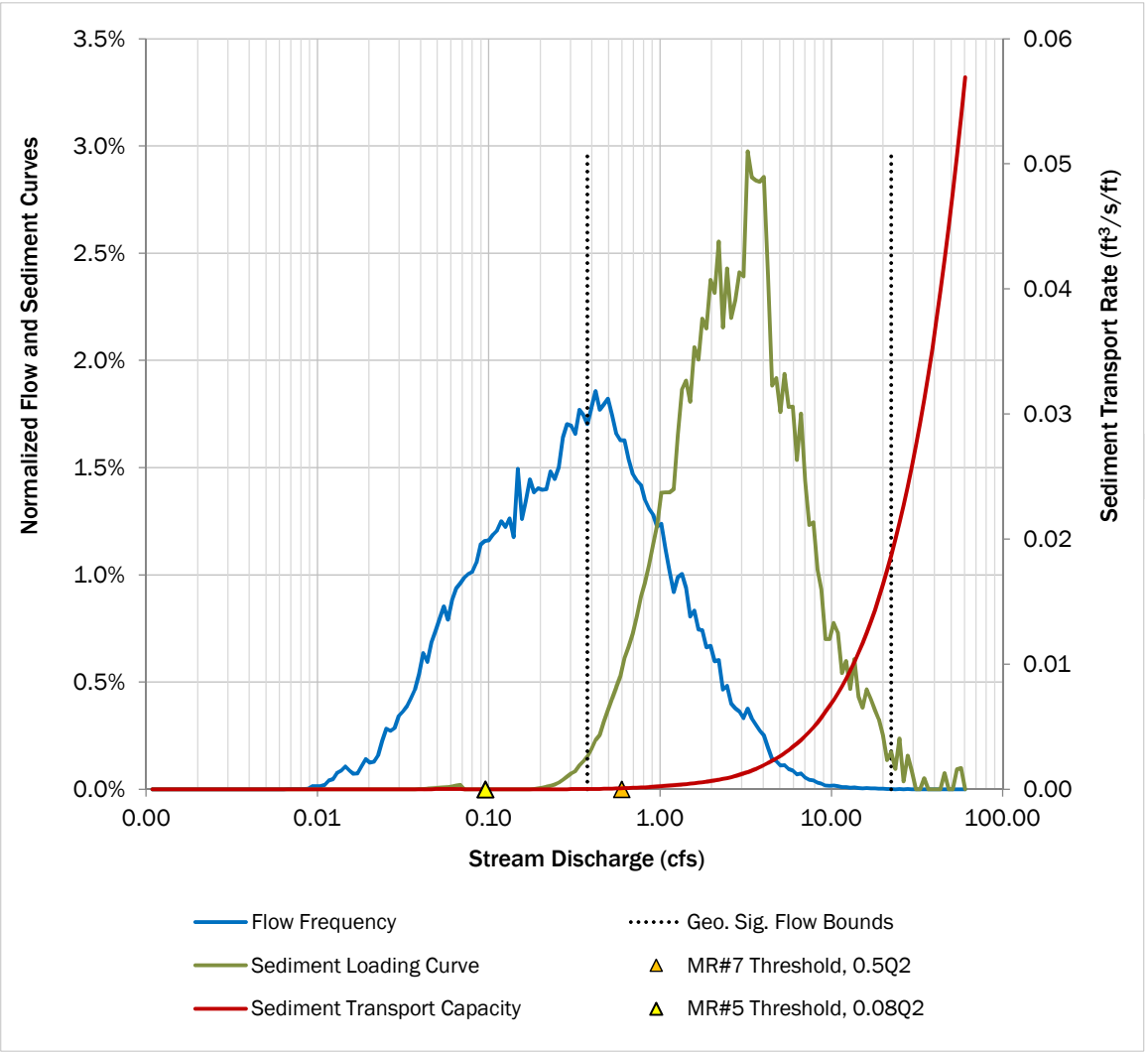
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	3,491
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	22.38
Lower flow bound for sediment loading (cfs):	0.38
Upper flow bound as a fraction of 50-year flow*:	5.04
Lower flow bound as a fraction of 2-year flow*:	0.316

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.24
Flow depth at effective discharge (ft):	0.60
Shear Stress at effective discharge (lb/ft^2):	0.35
Average flow velocity at effective discharge (ft/s):	1.8
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	7.7
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R05
Flow location:	SC-Q03
Cross-section:	XS485
Channel Slope:	3.2%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.27	0.33	22%
2-year Flow, Q_2	1.19	14.84	1144%
50-year Flow, Q_{50}	4.44	46.62	949%
MR#7 Threshold, $0.5Q_2$	0.60	7.42	--
MR#5 Threshold, $0.08Q_2$	0.10	1.19	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	1.03
Depth of flow (ft)	0.01	0.13	0.45
Fraction of natural Q_2	0.0000	0.013	0.86

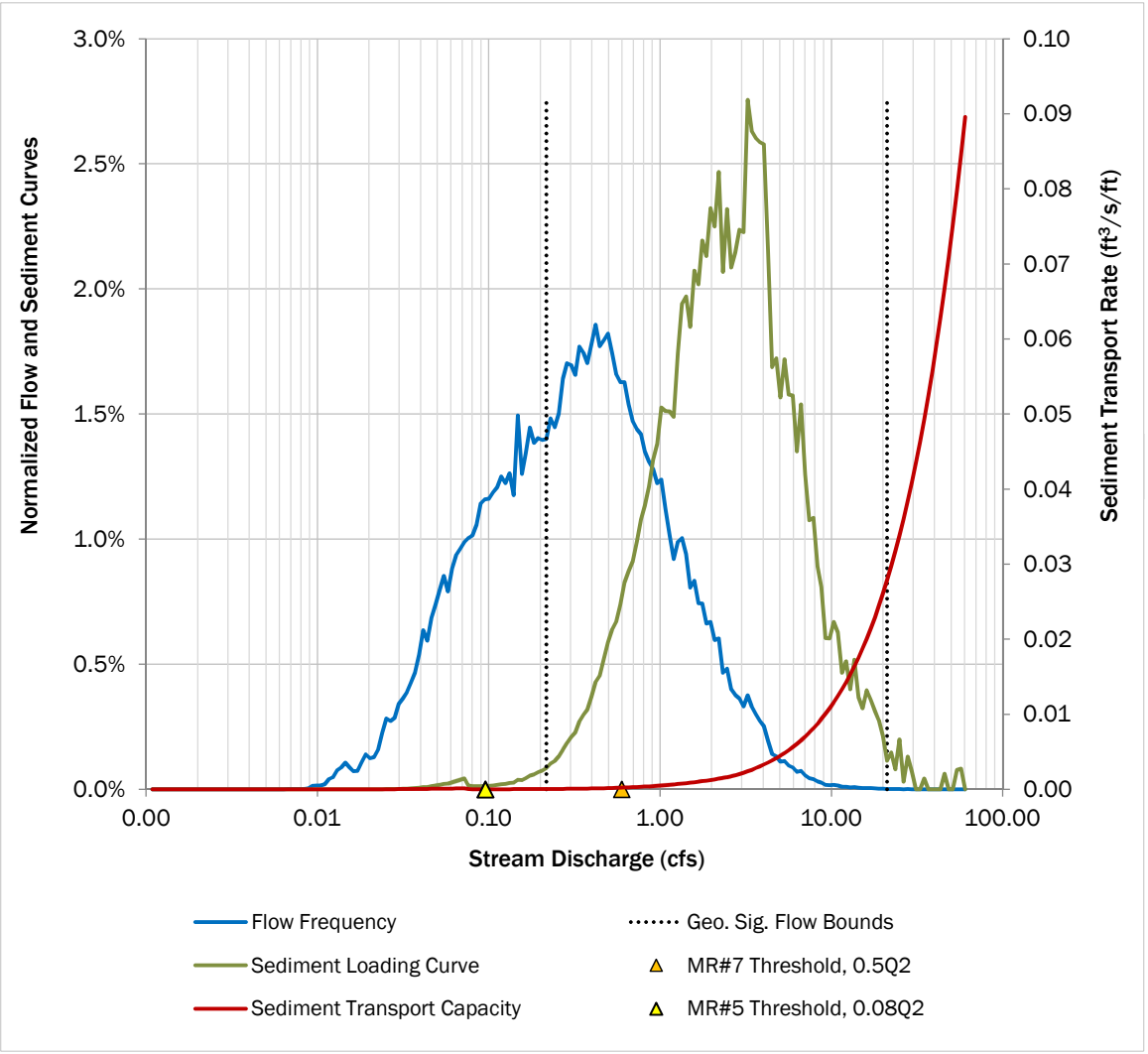
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	6,549
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	21.18
Lower flow bound for sediment loading (cfs):	0.22
Upper flow bound as a fraction of 50-year flow*:	4.77
Lower flow bound as a fraction of 2-year flow*:	0.182

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.24
Flow depth at effective discharge (ft):	0.59
Shear Stress at effective discharge (lb/ft^2):	0.46
Average flow velocity at effective discharge (ft/s):	1.8
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	7.7
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R06
Flow location:	SC-Q03
Cross-section:	XS494
Channel Slope:	3.2%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.27	0.33	22%
2-year Flow, Q_2	1.19	14.84	1144%
50-year Flow, Q_{50}	4.44	46.62	949%
MR#7 Threshold, $0.5Q_2$	0.60	7.42	--
MR#5 Threshold, $0.08Q_2$	0.10	1.19	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.10	0.53
Depth of flow (ft)	0.01	0.09	0.19
Fraction of natural Q_2	0.0001	0.080	0.45

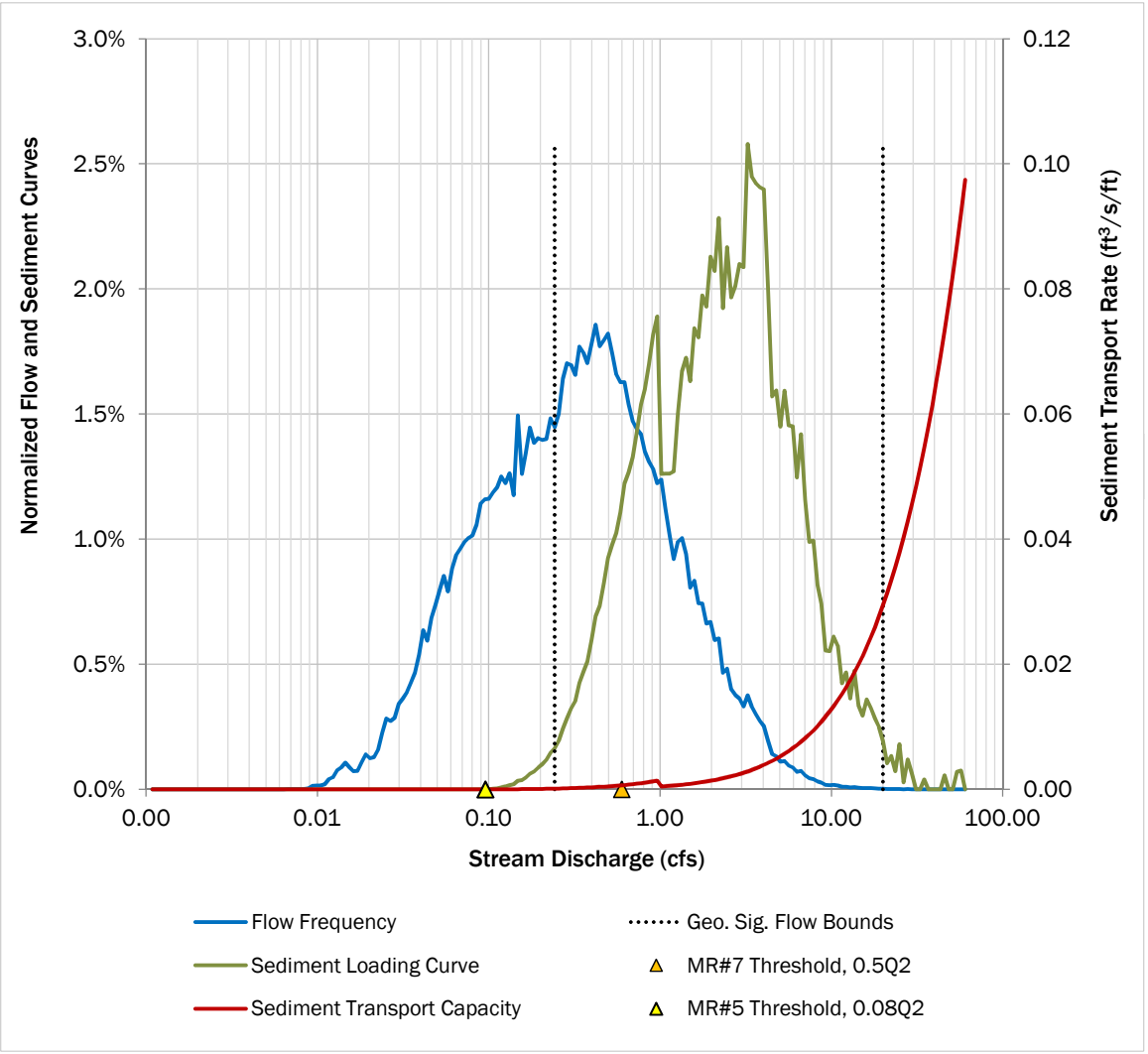
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	7,456
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	20.04
Lower flow bound for sediment loading (cfs):	0.24
Upper flow bound as a fraction of 50-year flow*:	4.51
Lower flow bound as a fraction of 2-year flow*:	0.203

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.24
Flow depth at effective discharge (ft):	0.43
Shear Stress at effective discharge (lb/ft^2):	0.49
Average flow velocity at effective discharge (ft/s):	1.9
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	6.9
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R07
Flow location:	SC-Q03
Cross-section:	XS494
Channel Slope:	6.8%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.27	0.33	22%
2-year Flow, Q_2	1.19	14.84	1144%
50-year Flow, Q_{50}	4.44	46.62	949%
MR#7 Threshold, $0.5Q_2$	0.60	7.42	--
MR#5 Threshold, $0.08Q_2$	0.10	1.19	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.13	0.40
Depth of flow (ft)	0.01	0.09	0.14
Fraction of natural Q_2	0.0001	0.109	0.33

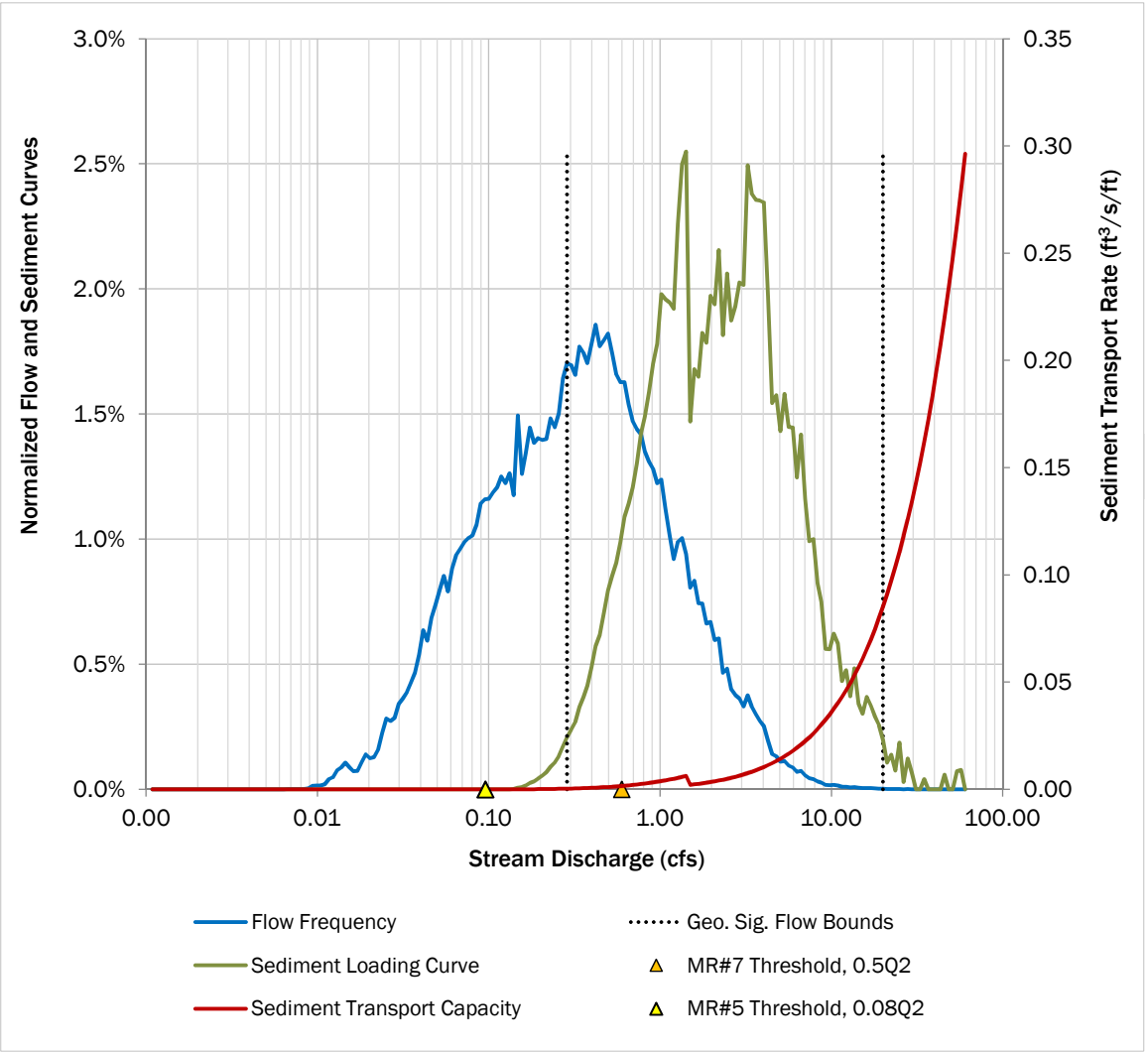
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	19,801
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	20.04
Lower flow bound for sediment loading (cfs):	0.29
Upper flow bound as a fraction of 50-year flow*:	4.51
Lower flow bound as a fraction of 2-year flow*:	0.240

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.42
Flow depth at effective discharge (ft):	0.29
Shear Stress at effective discharge (lb/ft^2):	0.52
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	6.5
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R08
Flow location:	SC-Q03
Cross-section:	XS488
Channel Slope:	3.7%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.27	0.33	22%
2-year Flow, Q_2	1.19	14.84	1144%
50-year Flow, Q_{50}	4.44	46.62	949%
MR#7 Threshold, $0.5Q_2$	0.60	7.42	--
MR#5 Threshold, $0.08Q_2$	0.10	1.19	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.06	0.74
Depth of flow (ft)	0.01	0.10	0.25
Fraction of natural Q_2	0.0001	0.048	0.62

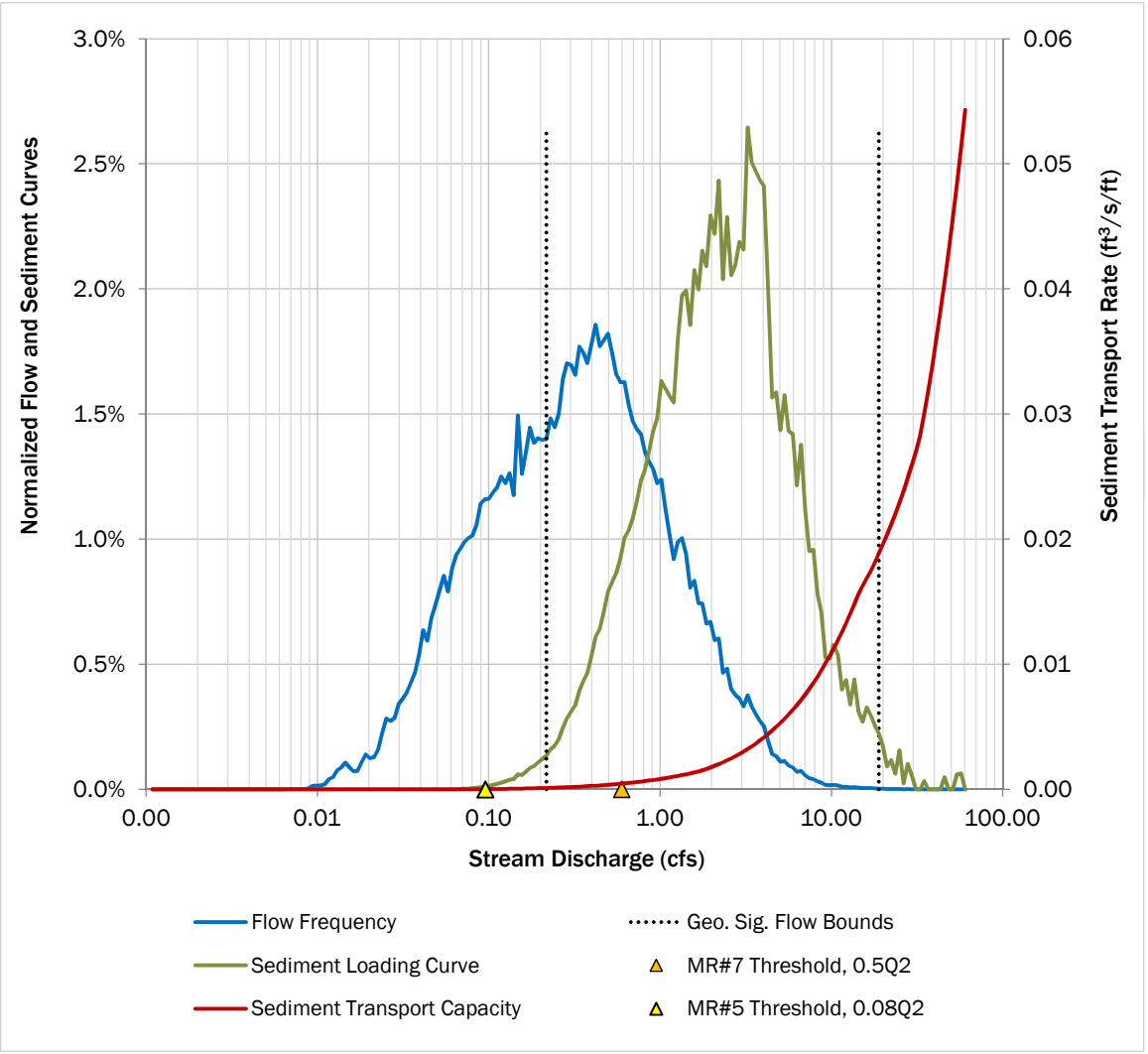
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	8,284
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	18.96
Lower flow bound for sediment loading (cfs):	0.22
Upper flow bound as a fraction of 50-year flow*:	4.27
Lower flow bound as a fraction of 2-year flow*:	0.182

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.24
Flow depth at effective discharge (ft):	0.42
Shear Stress at effective discharge (lb/ft^2):	0.49
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	6.9
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	SC-R09
Flow location:	SC-Q04
Cross-section:	XS488
Channel Slope:	2.6%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.20	0.24	22%
2-year Flow, Q_2	0.89	11.03	1144%
50-year Flow, Q_{50}	3.30	34.67	949%
MR#7 Threshold, $0.5Q_2$	0.44	5.52	--
MR#5 Threshold, $0.08Q_2$	0.07	0.88	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.12	1.59
Depth of flow (ft)	0.01	0.14	0.35
Fraction of natural Q_2	0.0002	0.139	1.79

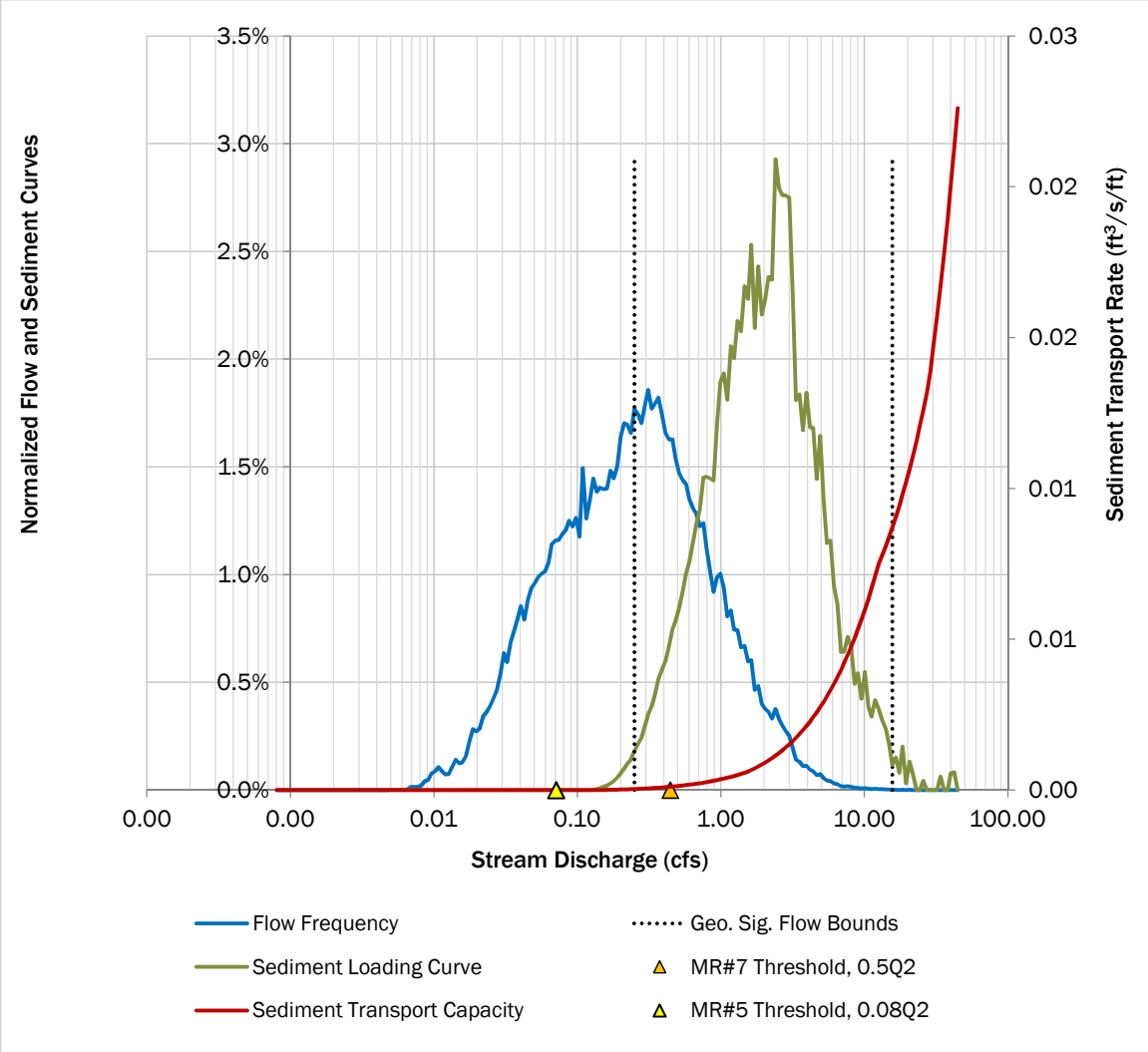
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	2,562
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	15.67
Lower flow bound for sediment loading (cfs):	0.25
Upper flow bound as a fraction of 50-year flow*:	4.74
Lower flow bound as a fraction of 2-year flow*:	0.282

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.40
Flow depth at effective discharge (ft):	0.40
Shear Stress at effective discharge (lb/ft^2):	0.32
Average flow velocity at effective discharge (ft/s):	1.8
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	6.7
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	UCT-R01
Flow location:	UCT-Q02
Cross-section:	XS411
Channel Slope:	8.5%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.09	0.10	13%
2-year Flow, Q_2	0.36	3.45	848%
50-year Flow, Q_{50}	1.63	12.19	646%
MR#7 Threshold, $0.5Q_2$	0.18	1.73	--
MR#5 Threshold, $0.08Q_2$	0.03	0.28	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.01	0.06
Depth of flow (ft)	0.01	0.11	0.22
Fraction of natural Q_2	0.0000	0.031	0.17

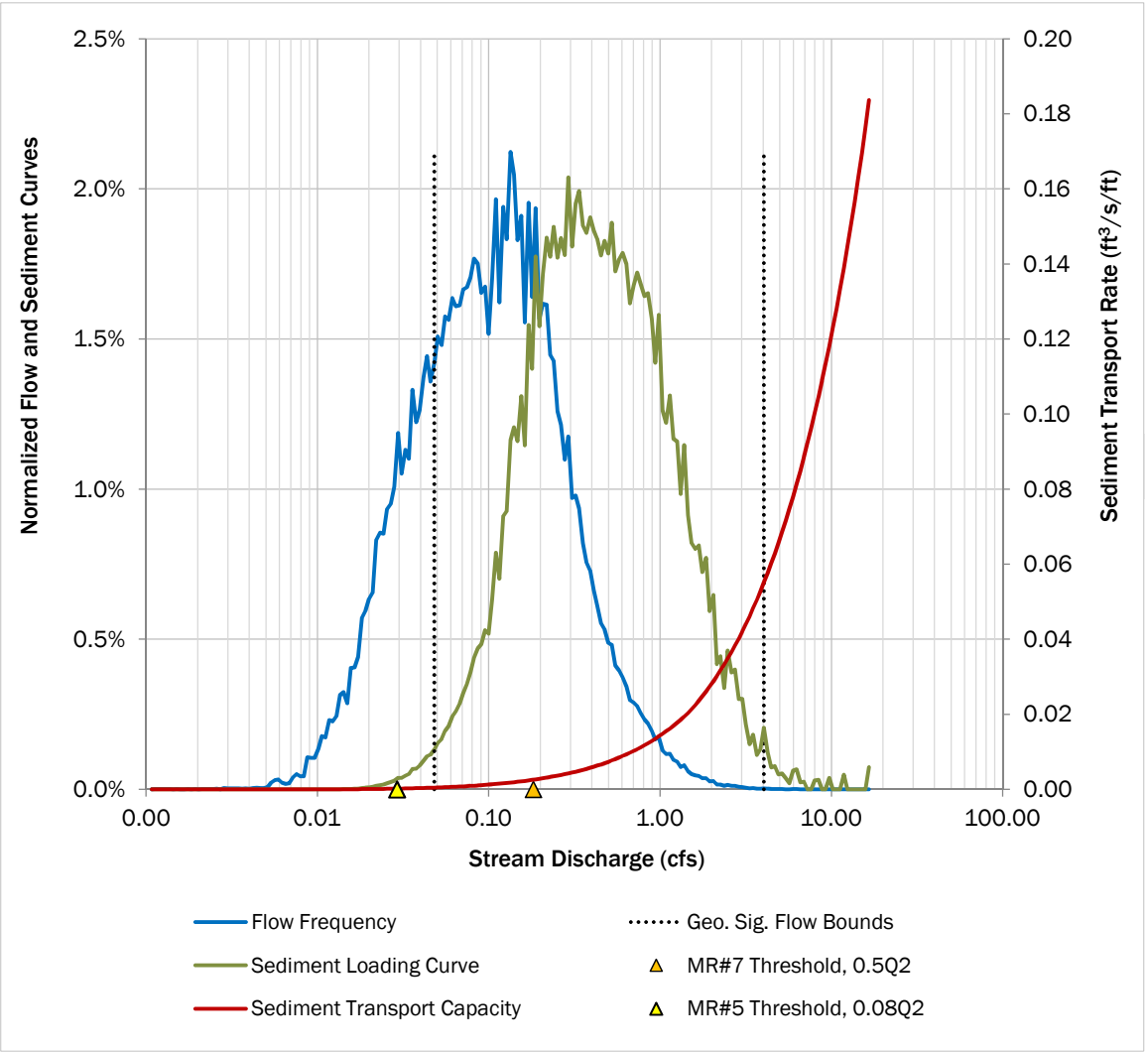
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	6,923
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	4.04
Lower flow bound for sediment loading (cfs):	0.05
Upper flow bound as a fraction of 50-year flow*:	2.48
Lower flow bound as a fraction of 2-year flow*:	0.132

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	0.29
Flow depth at effective discharge (ft):	0.38
Shear Stress at effective discharge (lb/ft^2):	0.69
Average flow velocity at effective discharge (ft/s):	2.0
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	1.1
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	UME-R01
Flow location:	UME-Q01
Cross-section:	BC11
Channel Slope:	0.4%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.00	-100%
2-year Flow, Q_2	2.56	0.00	-100%
50-year Flow, Q_{50}	9.55	21.31	123%
MR#7 Threshold, $0.5Q_2$	1.28	0.00	--
MR#5 Threshold, $0.08Q_2$	0.20	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	1.60
Depth of flow (ft)	0.01	0.02	0.24
Fraction of natural Q_2	0.0001	0.001	0.63

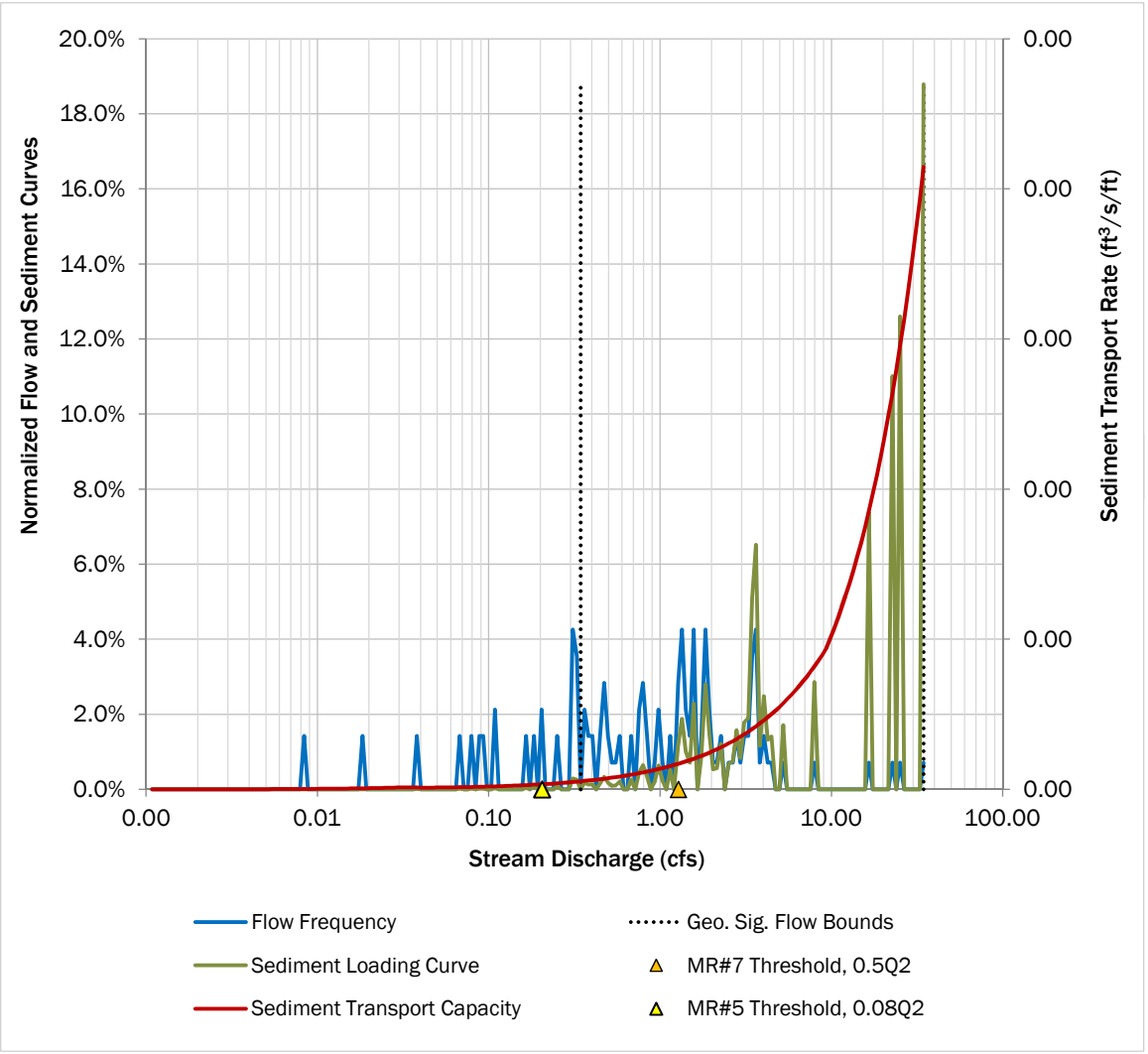
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	0
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	34.54
Lower flow bound for sediment loading (cfs):	0.34
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	0.135

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	34.54
Flow depth at effective discharge (ft):	0.67
Shear Stress at effective discharge (lb/ft^2):	0.09
Average flow velocity at effective discharge (ft/s):	1.4
Shear velocity at effective discharge (ft/s):	0.2
Effective width at effective discharge (ft):	66.8
Largest mobilized sediment:	*Very fine gravel*
Largest fully suspended sediment:	*Fine sand*
Sediment beginning to settle out:	*Medium sand*



MFA Inputs	
Reach:	UME-R02
Flow location:	UME-Q01
Cross-section:	BC11
Channel Slope:	0.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.00	-100%
2-year Flow, Q_2	2.56	0.00	-100%
50-year Flow, Q_{50}	9.55	21.31	123%
MR#7 Threshold, $0.5Q_2$	1.28	0.00	--
MR#5 Threshold, $0.08Q_2$	0.20	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	20.65	171.31
Depth of flow (ft)	0.05	0.58	1.34
Fraction of natural Q_2	0.0056	8.074	66.99

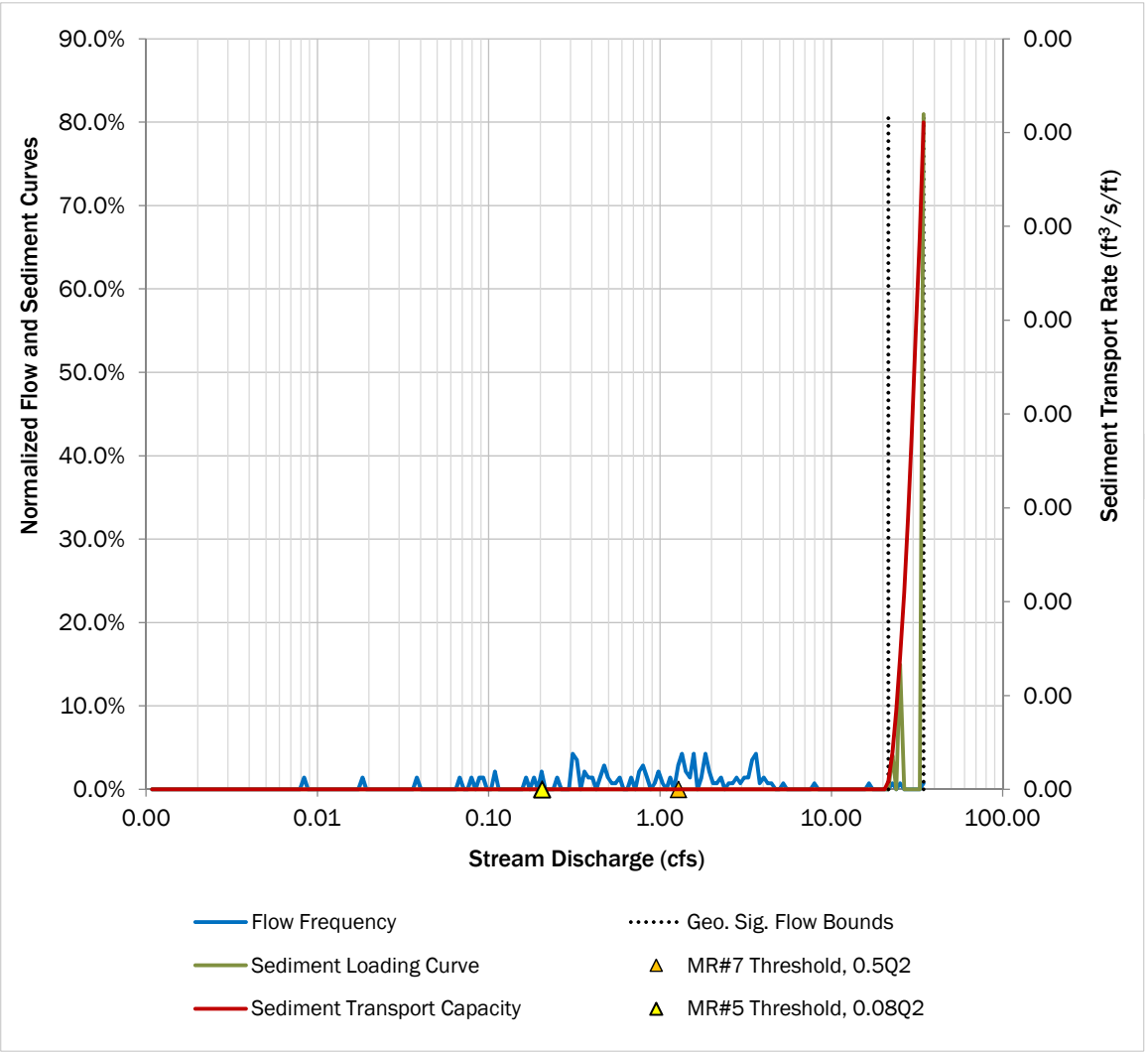
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	0
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	34.54
Lower flow bound for sediment loading (cfs):	21.56
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	8.430

**Flows based on "Natural" conditions*

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	34.54
Flow depth at effective discharge (ft):	0.70
Shear Stress at effective discharge (lb/ft^2):	0.13
Average flow velocity at effective discharge (ft/s):	1.3
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	68.9
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	UME-R03
Flow location:	UME-Q01
Cross-section:	BC11
Channel Slope:	6.1%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.00	-100%
2-year Flow, Q_2	2.56	0.00	-100%
50-year Flow, Q_{50}	9.55	21.31	123%
MR#7 Threshold, $0.5Q_2$	1.28	0.00	--
MR#5 Threshold, $0.08Q_2$	0.20	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.80	4.89
Depth of flow (ft)	0.01	0.14	0.25
Fraction of natural Q_2	0.0001	0.315	1.91

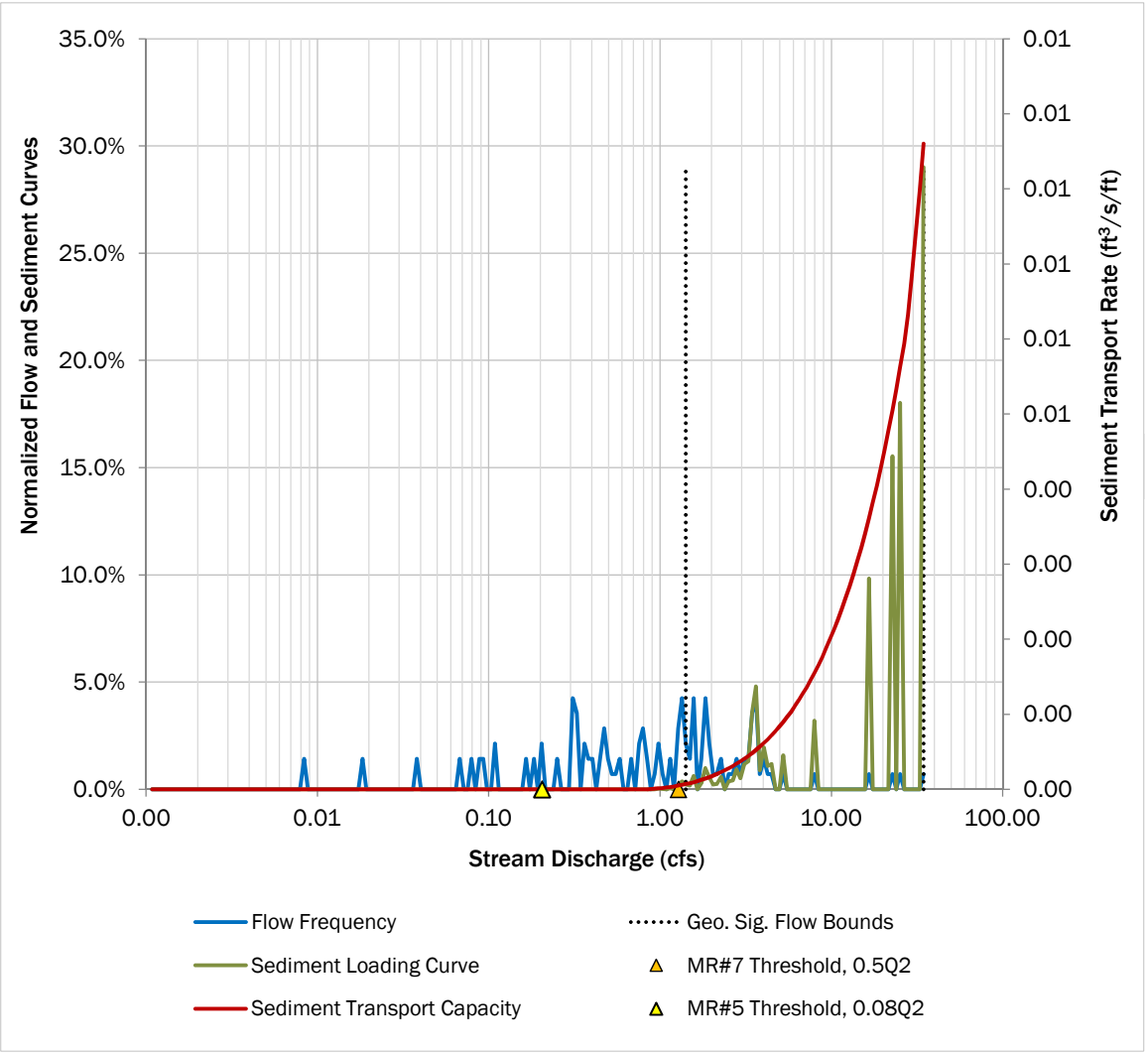
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	10
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	34.54
Lower flow bound for sediment loading (cfs):	1.41
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	0.553

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	34.54
Flow depth at effective discharge (ft):	0.46
Shear Stress at effective discharge (lb/ft^2):	0.83
Average flow velocity at effective discharge (ft/s):	2.8
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	55.8
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	UME-R04
Flow location:	UME-Q02
Cross-section:	BC12
Channel Slope:	1.3%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.16	0.00	-100%
2-year Flow, Q_2	0.77	0.00	-100%
50-year Flow, Q_{50}	2.86	6.39	123%
MR#7 Threshold, $0.5Q_2$	0.38	0.00	--
MR#5 Threshold, $0.08Q_2$	0.06	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.11	1.80
Depth of flow (ft)	0.03	0.36	0.98
Fraction of natural Q_2	0.0002	0.150	2.34

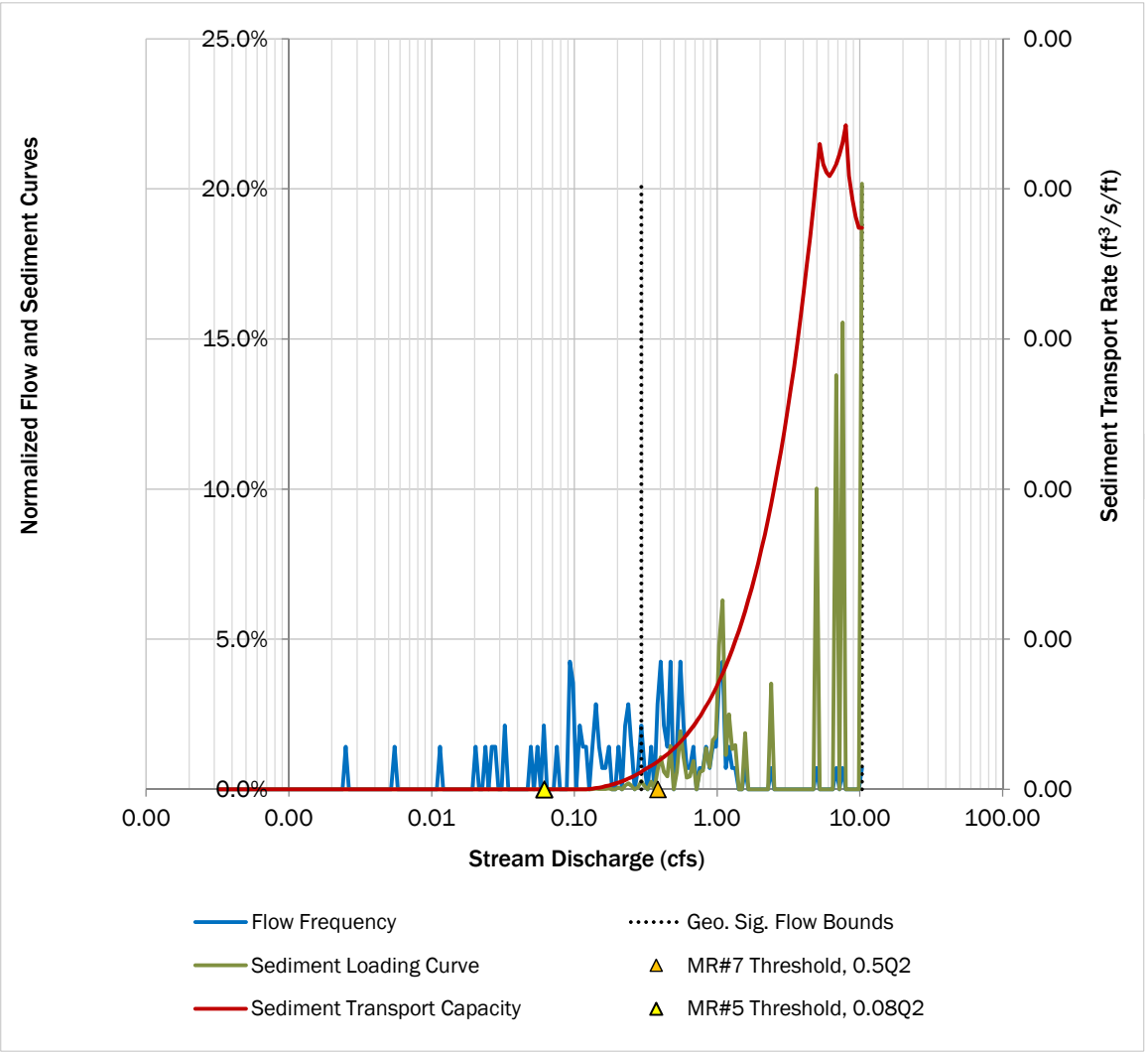
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	10.36
Lower flow bound for sediment loading (cfs):	0.29
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	0.383

**Flows based on "Natural" conditions*

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.36
Flow depth at effective discharge (ft):	1.84
Shear Stress at effective discharge (lb/ft^2):	0.38
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	10.2
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	UME-R05
Flow location:	UME-Q02
Cross-section:	BC12
Channel Slope:	6.0%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.16	0.00	-100%
2-year Flow, Q_2	0.77	0.00	-100%
50-year Flow, Q_{50}	2.86	6.39	123%
MR#7 Threshold, $0.5Q_2$	0.38	0.00	--
MR#5 Threshold, $0.08Q_2$	0.06	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	0.15
Depth of flow (ft)	0.01	0.16	0.30
Fraction of natural Q_2	0.0000	0.035	0.20

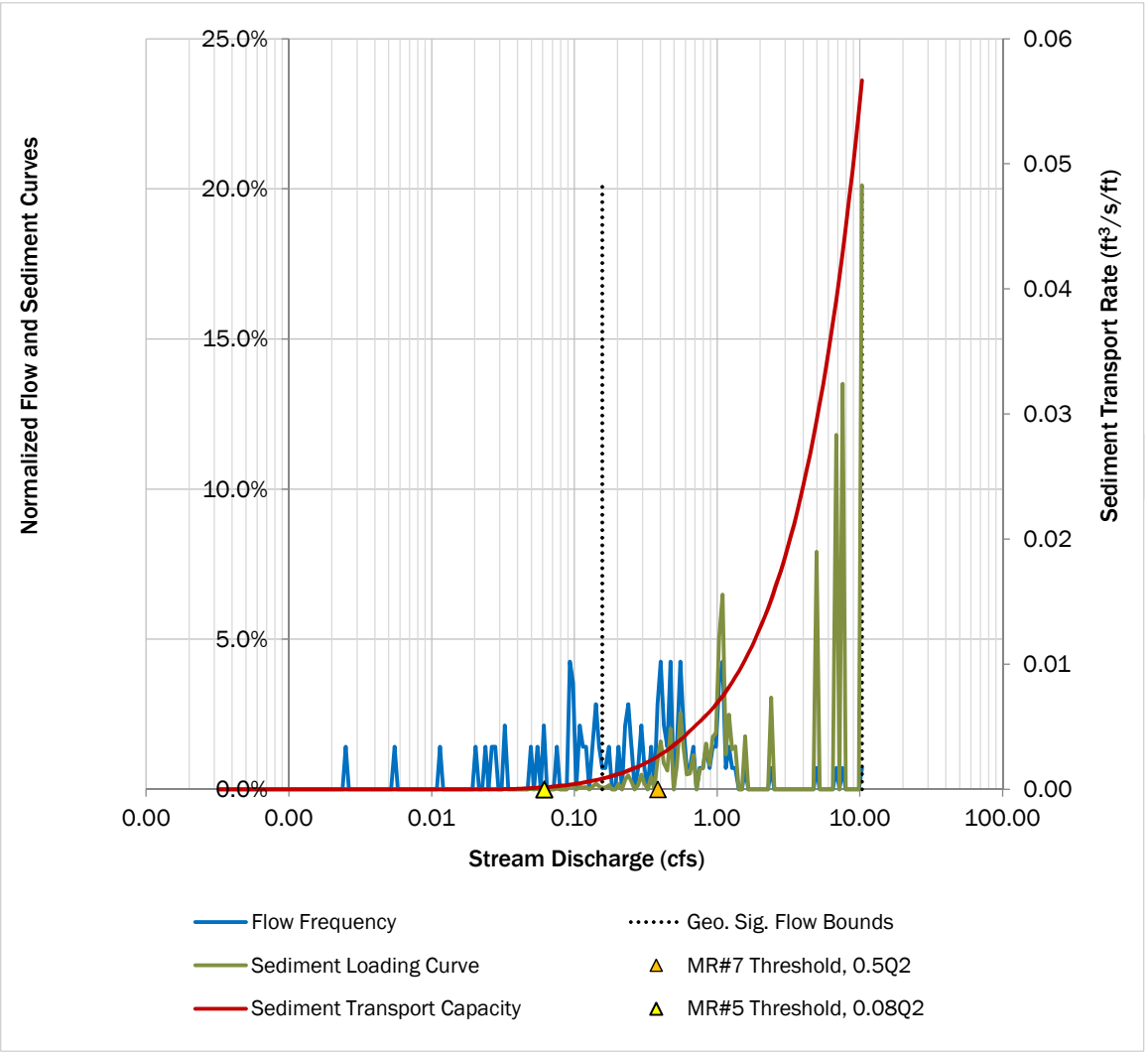
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	8
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	10.36
Lower flow bound for sediment loading (cfs):	0.16
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	0.205

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.36
Flow depth at effective discharge (ft):	1.37
Shear Stress at effective discharge (lb/ft^2):	1.81
Average flow velocity at effective discharge (ft/s):	4.6
Shear velocity at effective discharge (ft/s):	1.0
Effective width at effective discharge (ft):	4.6
Largest mobilized sediment:	*Very coarse gravel*
Largest fully suspended sediment:	*Very fine gravel*
Sediment beginning to settle out:	*Fine gravel*



MFA Inputs	
Reach:	UME-R06
Flow location:	UME-Q02
Cross-section:	BC11
Channel Slope:	3.9%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.16	0.00	-100%
2-year Flow, Q_2	0.77	0.00	-100%
50-year Flow, Q_{50}	2.86	6.39	123%
MR#7 Threshold, $0.5Q_2$	0.38	0.00	--
MR#5 Threshold, $0.08Q_2$	0.06	0.00	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.29	4.82
Depth of flow (ft)	0.01	0.11	0.26
Fraction of natural Q_2	0.0002	0.382	6.28

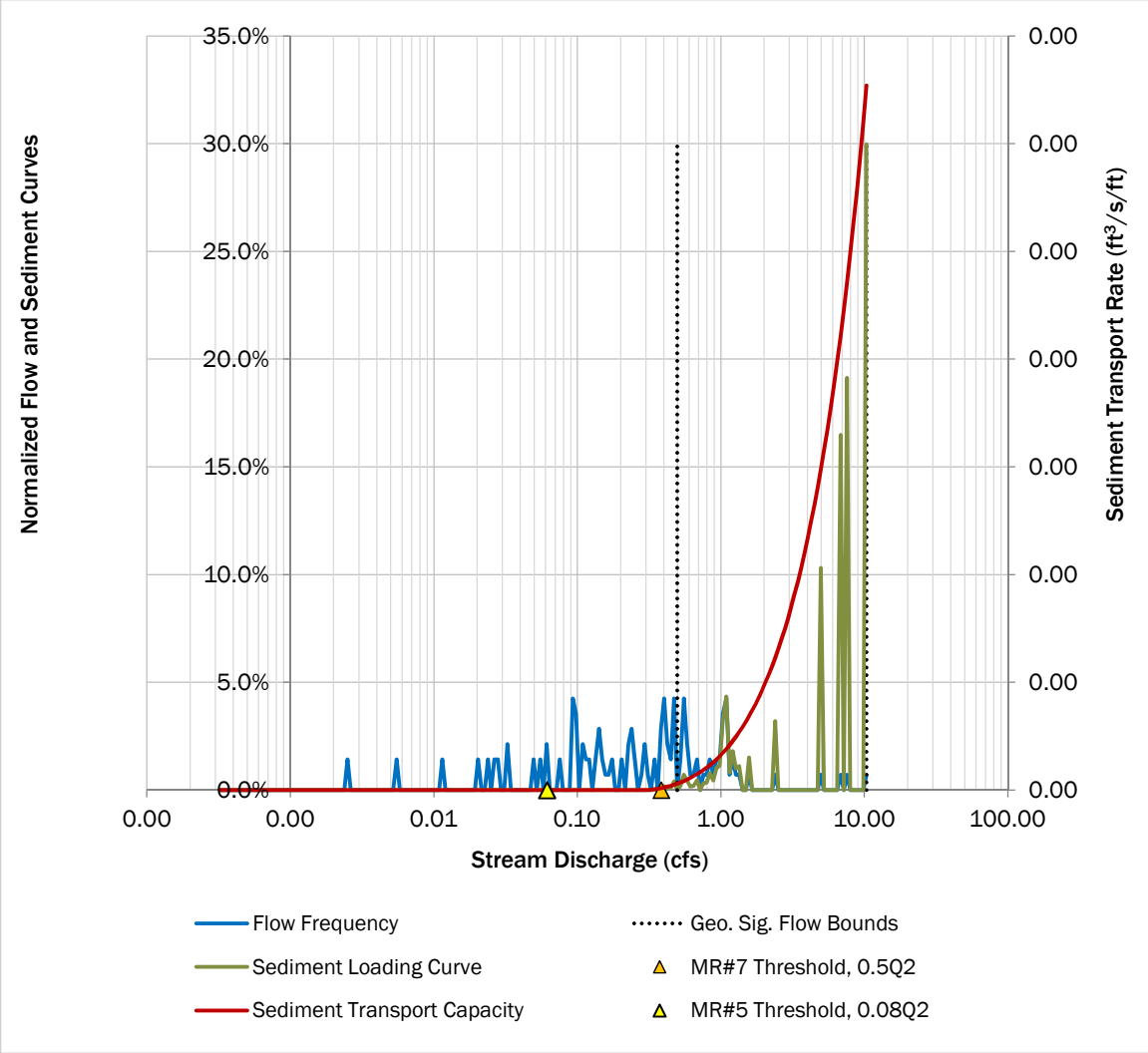
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	10.36
Lower flow bound for sediment loading (cfs):	0.50
Upper flow bound as a fraction of 50-year flow*:	3.62
Lower flow bound as a fraction of 2-year flow*:	0.647

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.36
Flow depth at effective discharge (ft):	0.34
Shear Stress at effective discharge (lb/ft^2):	0.35
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	41.4
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	UMW-R01
Flow location:	UMW-Q01
Cross-section:	BC09
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.14	0.16	15%
2-year Flow, Q_2	0.74	7.36	890%
50-year Flow, Q_{50}	3.00	24.79	725%
MR#7 Threshold, $0.5Q_2$	0.37	3.68	--
MR#5 Threshold, $0.08Q_2$	0.06	0.59	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.01	0.16	26.31
Depth of flow (ft)	0.15	0.46	3.54
Fraction of natural Q_2	0.0082	0.218	35.40

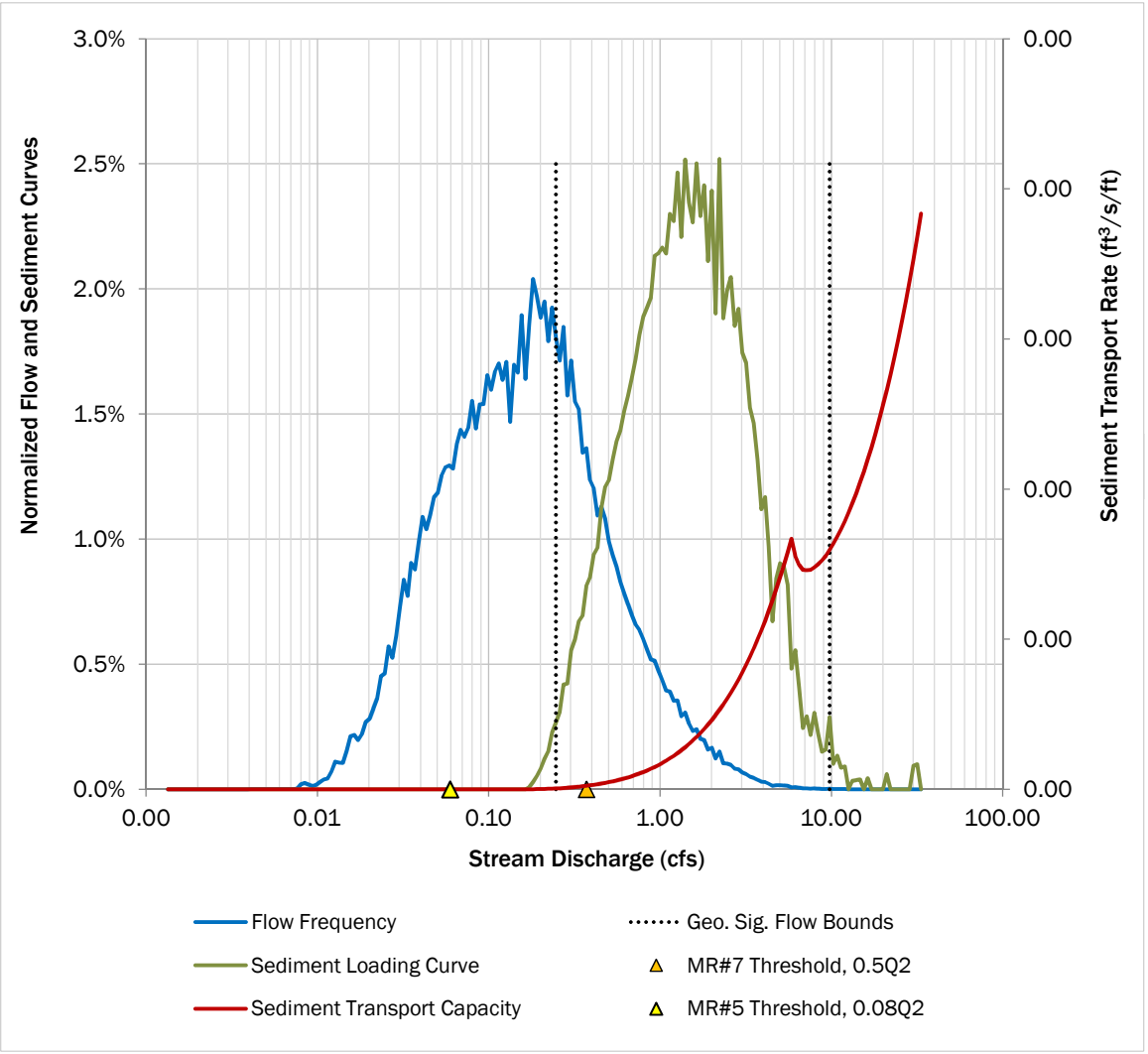
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	3
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	9.77
Lower flow bound for sediment loading (cfs):	0.25
Upper flow bound as a fraction of 50-year flow*:	3.25
Lower flow bound as a fraction of 2-year flow*:	0.331

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.22
Flow depth at effective discharge (ft):	1.13
Shear Stress at effective discharge (lb/ft^2):	0.01
Average flow velocity at effective discharge (ft/s):	0.5
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	6.7
Largest mobilized sediment:	*Coarse sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	UMW-R02
Flow location:	UMW-Q02
Cross-section:	BC09
Channel Slope:	4.4%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.11	0.13	15%
2-year Flow, Q_2	0.60	5.95	890%
50-year Flow, Q_{50}	2.43	20.05	725%
MR#7 Threshold, $0.5Q_2$	0.30	2.98	--
MR#5 Threshold, $0.08Q_2$	0.05	0.48	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.21
Depth of flow (ft)	0.01	0.09	0.24
Fraction of natural Q_2	0.0000	0.026	0.36

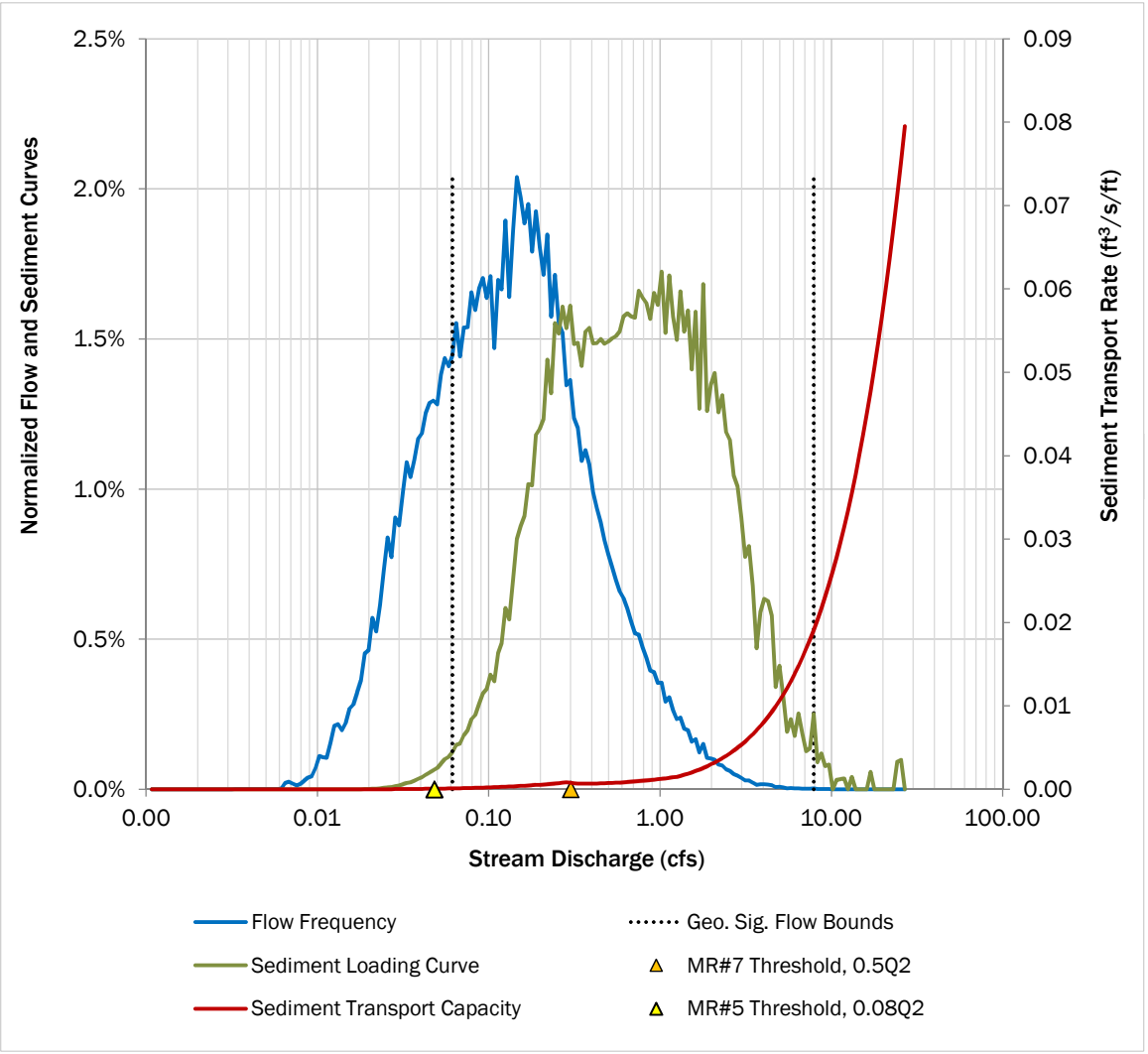
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	3,136
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	7.88
Lower flow bound for sediment loading (cfs):	0.06
Upper flow bound as a fraction of 50-year flow*:	3.24
Lower flow bound as a fraction of 2-year flow*:	0.102

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.02
Flow depth at effective discharge (ft):	0.41
Shear Stress at effective discharge (lb/ft^2):	0.34
Average flow velocity at effective discharge (ft/s):	1.7
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	4.6
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	UMW-R03
Flow location:	UMW-Q02
Cross-section:	BC10
Channel Slope:	5.1%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.11	0.13	15%
2-year Flow, Q_2	0.60	5.95	890%
50-year Flow, Q_{50}	2.43	20.05	725%
MR#7 Threshold, $0.5Q_2$	0.30	2.98	--
MR#5 Threshold, $0.08Q_2$	0.05	0.48	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.14	0.64
Depth of flow (ft)	0.01	0.13	0.23
Fraction of natural Q_2	0.0001	0.240	1.06

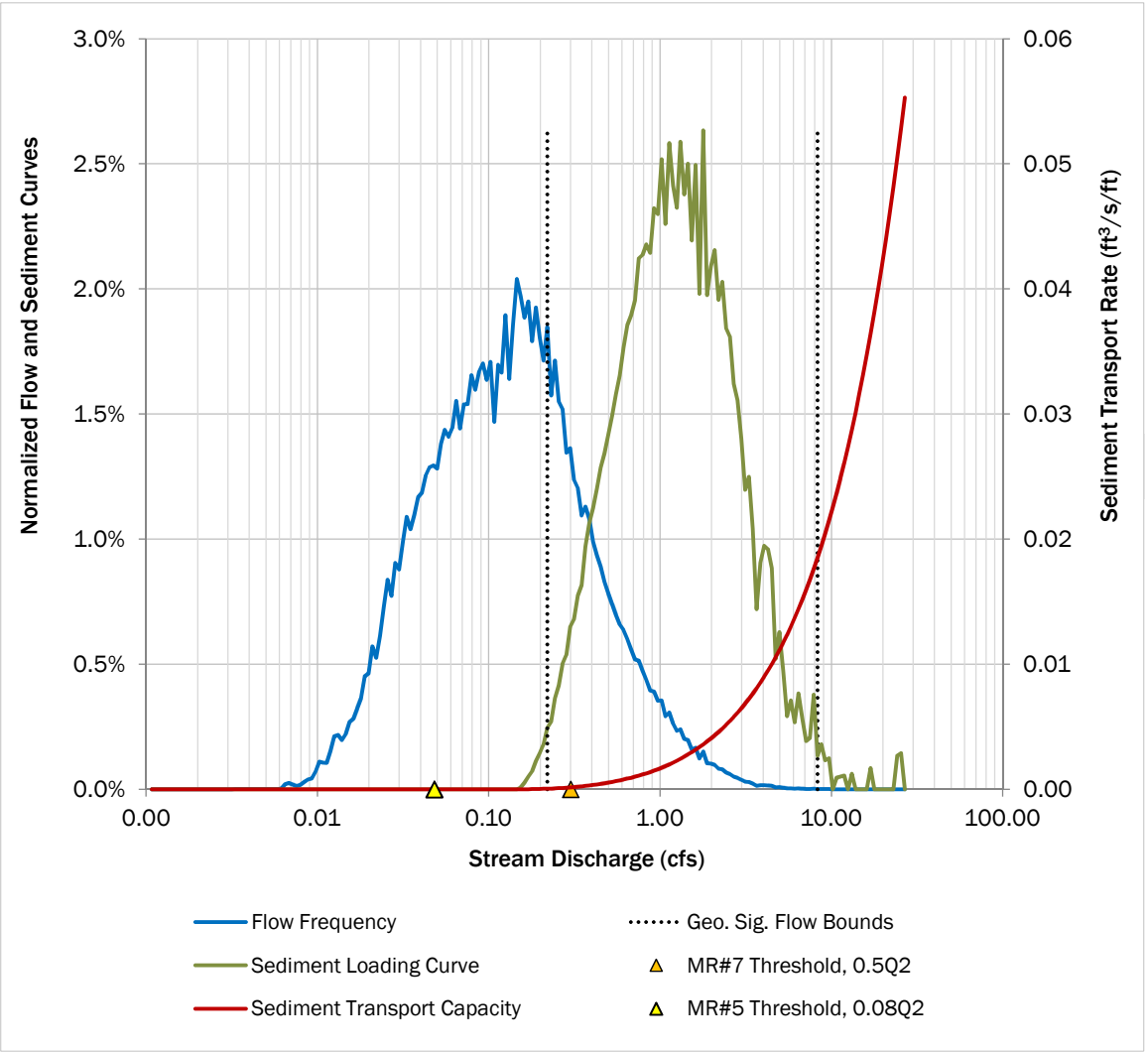
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	2,148
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	8.30
Lower flow bound for sediment loading (cfs):	0.22
Upper flow bound as a fraction of 50-year flow*:	3.41
Lower flow bound as a fraction of 2-year flow*:	0.366

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	1.79
Flow depth at effective discharge (ft):	0.35
Shear Stress at effective discharge (lb/ft^2):	0.61
Average flow velocity at effective discharge (ft/s):	2.3
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	4.0
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	UMW-R04
Flow location:	UMW-Q03
Cross-section:	BC10
Channel Slope:	4.6%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.05	0.06	15%
2-year Flow, Q_2	0.27	2.71	890%
50-year Flow, Q_{50}	1.11	9.12	725%
MR#7 Threshold, $0.5Q_2$	0.14	1.35	--
MR#5 Threshold, $0.08Q_2$	0.02	0.22	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	0.32
Depth of flow (ft)	0.01	0.07	0.18
Fraction of natural Q_2	0.0001	0.096	1.17

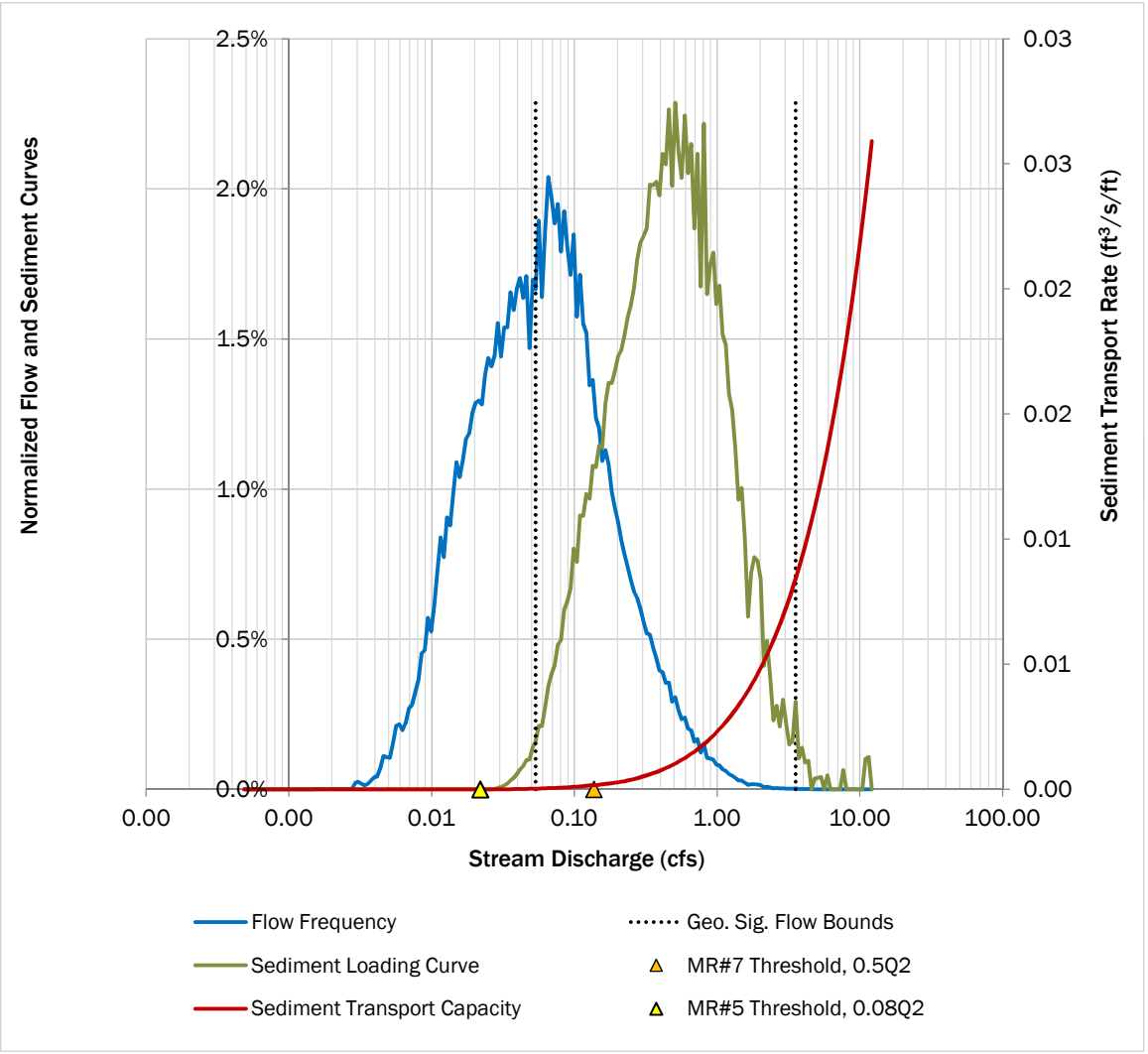
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,032
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	3.55
Lower flow bound for sediment loading (cfs):	0.05
Upper flow bound as a fraction of 50-year flow*:	3.21
Lower flow bound as a fraction of 2-year flow*:	0.196

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	0.51
Flow depth at effective discharge (ft):	0.22
Shear Stress at effective discharge (lb/ft^2):	0.33
Average flow velocity at effective discharge (ft/s):	1.5
Shear velocity at effective discharge (ft/s):	0.4
Effective width at effective discharge (ft):	2.8
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	UMW-R05
Flow location:	UMW-Q03
Cross-section:	BC12
Channel Slope:	5.9%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.05	0.06	15%
2-year Flow, Q_2	0.27	2.71	890%
50-year Flow, Q_{50}	1.11	9.12	725%
MR#7 Threshold, $0.5Q_2$	0.14	1.35	--
MR#5 Threshold, $0.08Q_2$	0.02	0.22	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.03	0.15
Depth of flow (ft)	0.01	0.16	0.30
Fraction of natural Q_2	0.0000	0.097	0.54

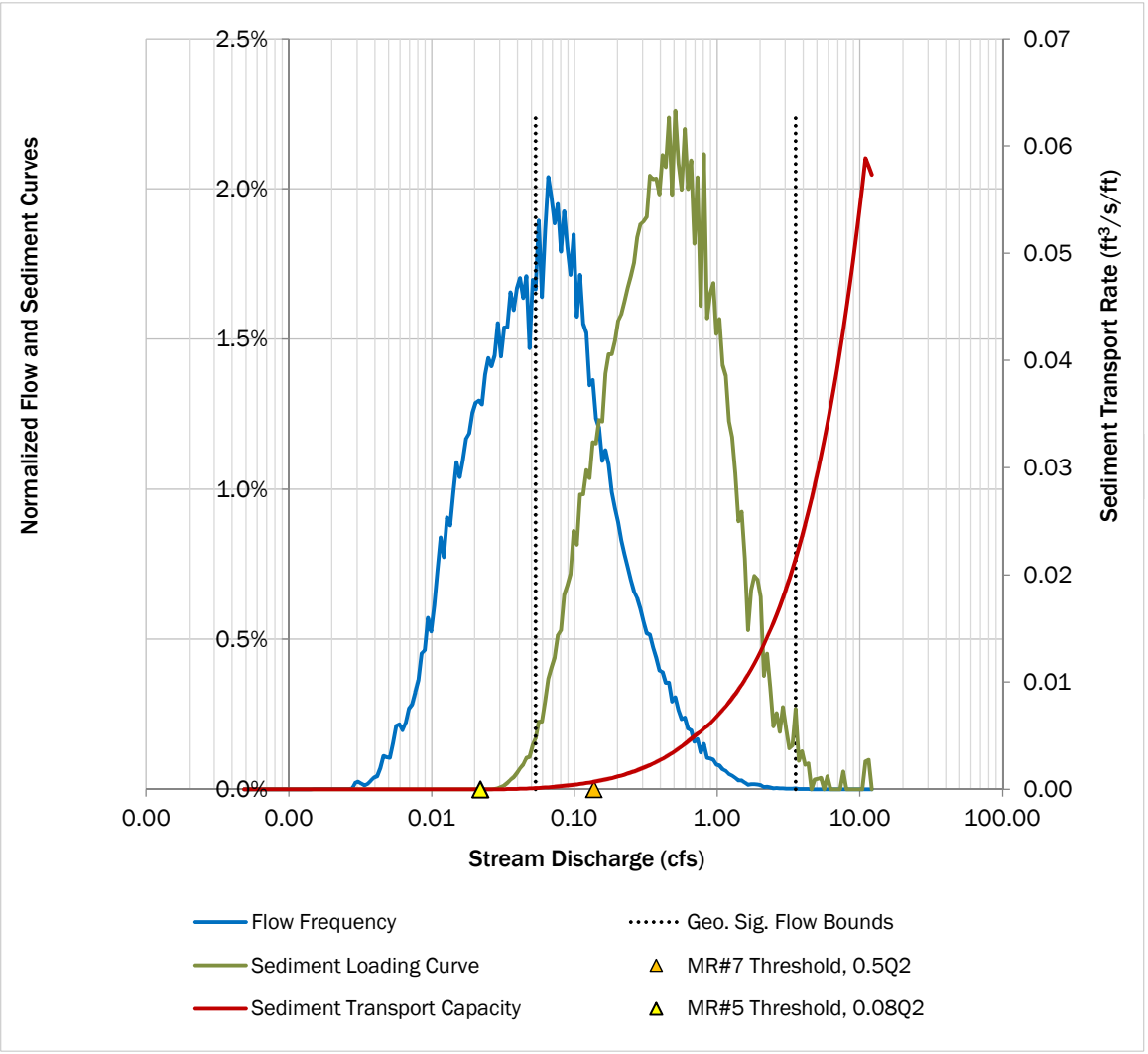
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	1,746
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	3.55
Lower flow bound for sediment loading (cfs):	0.05
Upper flow bound as a fraction of 50-year flow*:	3.21
Lower flow bound as a fraction of 2-year flow*:	0.196

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	0.51
Flow depth at effective discharge (ft):	0.47
Shear Stress at effective discharge (lb/ft^2):	0.62
Average flow velocity at effective discharge (ft/s):	2.2
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	1.4
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R01
Flow location:	WC-Q01
Cross-section:	BC01
Channel Slope:	0.0%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.30	1.44	11%
2-year Flow, Q_2	8.25	59.68	623%
50-year Flow, Q_{50}	30.73	233.27	659%
MR#7 Threshold, $0.5Q_2$	4.13	29.84	--
MR#5 Threshold, $0.08Q_2$	0.66	4.77	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.12	1.01	34.82
Depth of flow (ft)	0.52	0.98	3.07
Fraction of natural Q_2	0.0150	0.122	4.22

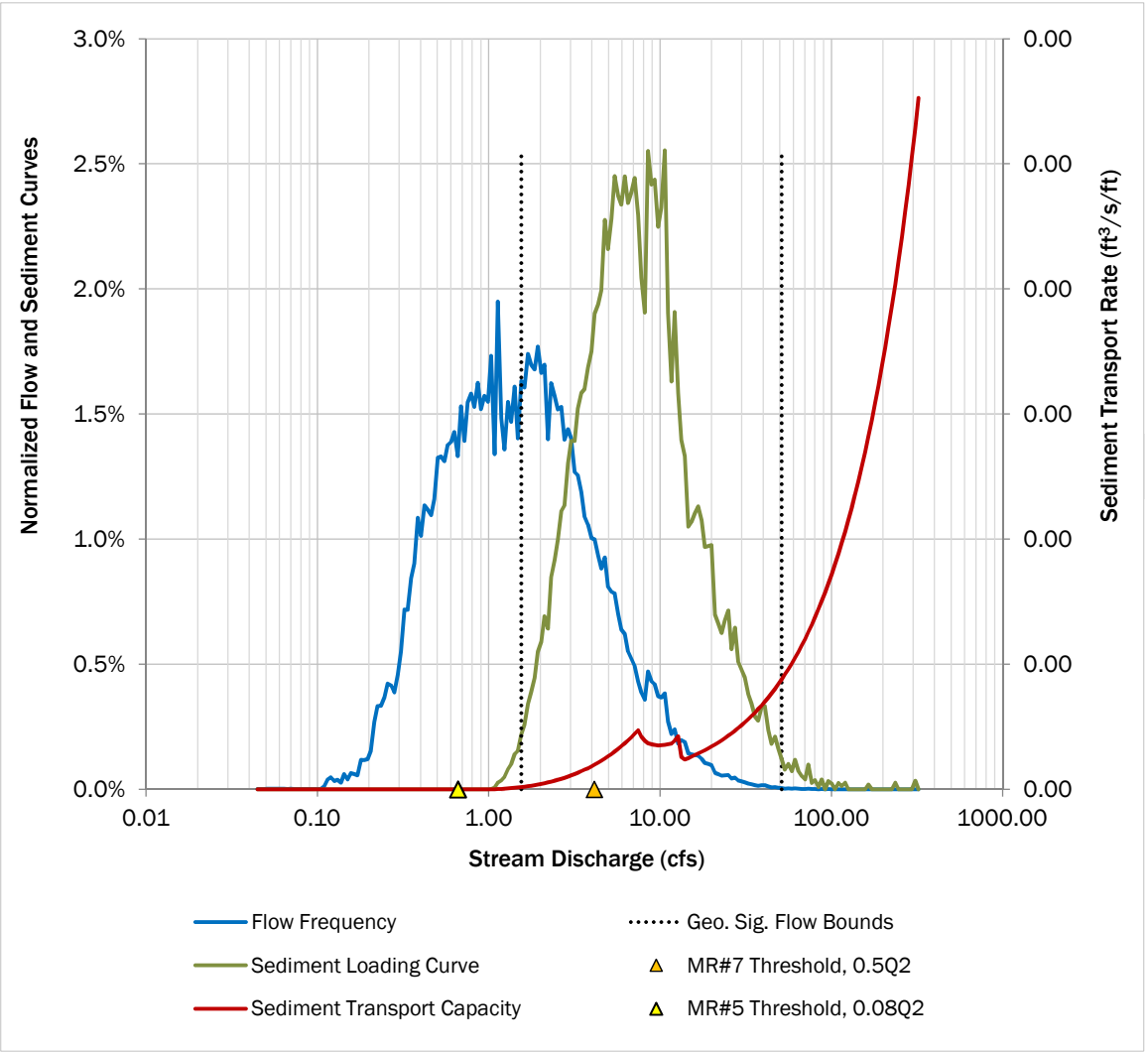
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	6
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	51.27
Lower flow bound for sediment loading (cfs):	1.55
Upper flow bound as a fraction of 50-year flow*:	1.67
Lower flow bound as a fraction of 2-year flow*:	0.187

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.66
Flow depth at effective discharge (ft):	2.69
Shear Stress at effective discharge (lb/ft^2):	0.01
Average flow velocity at effective discharge (ft/s):	0.5
Shear velocity at effective discharge (ft/s):	0.1
Effective width at effective discharge (ft):	19.6
Largest mobilized sediment:	*Medium sand*
Largest fully suspended sediment:	*Very fine sand*
Sediment beginning to settle out:	*Fine sand*



MFA Inputs	
Reach:	WC-R02
Flow location:	WC-Q01
Cross-section:	BC01
Channel Slope:	0.3%
Sediment sample:	Class 3
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	1.30	1.44	11%
2-year Flow, Q_2	8.25	59.68	623%
50-year Flow, Q_{50}	30.73	233.27	659%
MR#7 Threshold, $0.5Q_2$	4.13	29.84	--
MR#5 Threshold, $0.08Q_2$	0.66	4.77	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.00	0.18
Depth of flow (ft)	0.01	0.03	0.35
Fraction of natural Q_2	0.0000	0.000	0.02

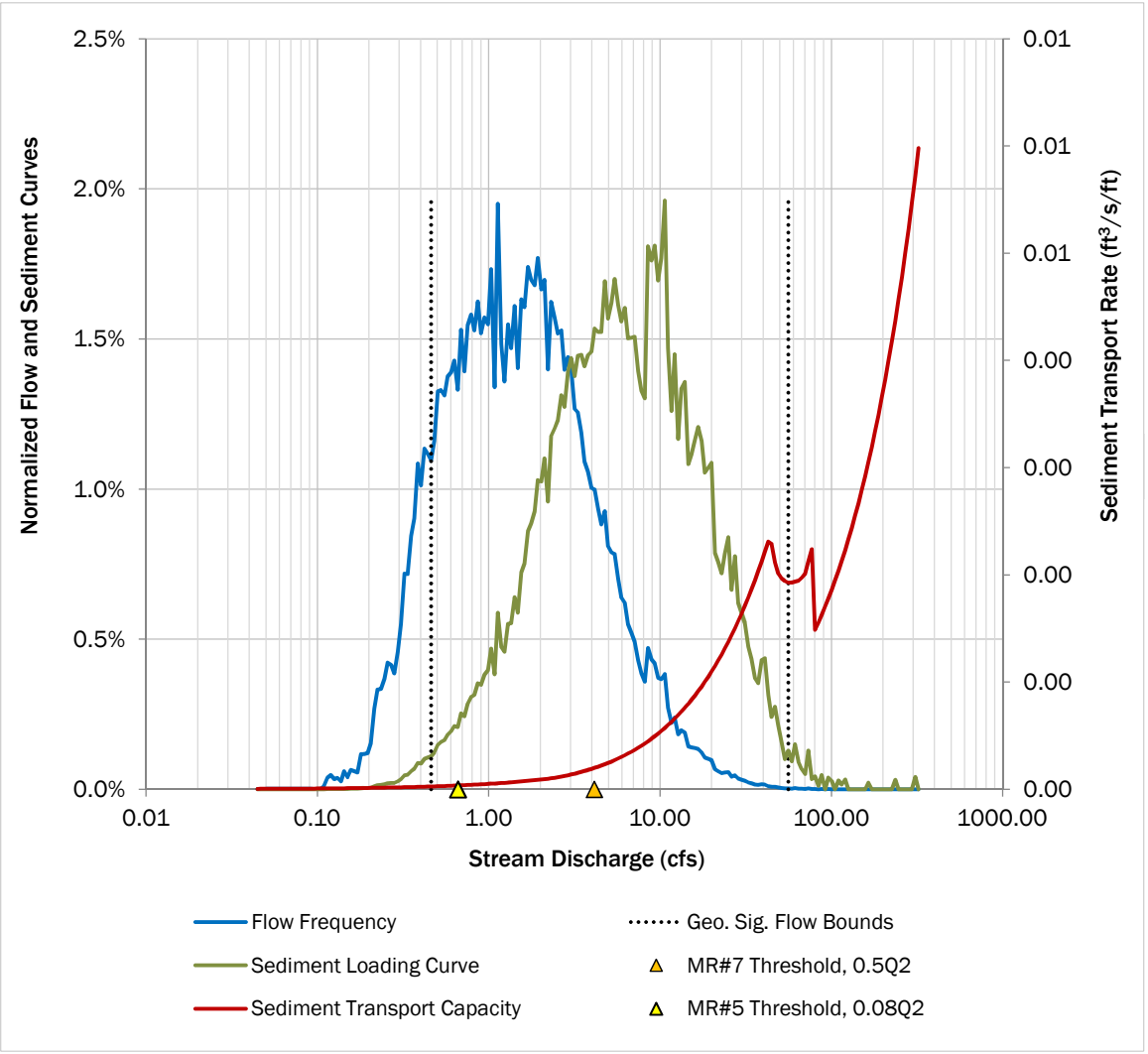
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	2,484
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	56.08
Lower flow bound for sediment loading (cfs):	0.46
Upper flow bound as a fraction of 50-year flow*:	1.83
Lower flow bound as a fraction of 2-year flow*:	0.056

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	10.66
Flow depth at effective discharge (ft):	1.21
Shear Stress at effective discharge (lb/ft^2):	0.13
Average flow velocity at effective discharge (ft/s):	2.1
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	8.5
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	WC-R03
Flow location:	WC-Q02
Cross-section:	BC01
Channel Slope:	0.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.87	1.01	16%
2-year Flow, Q_2	6.03	36.24	501%
50-year Flow, Q_{50}	22.72	154.67	581%
MR#7 Threshold, $0.5Q_2$	3.02	18.12	--
MR#5 Threshold, $0.08Q_2$	0.48	2.90	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	3.71	26.56
Depth of flow (ft)	0.07	0.80	1.62
Fraction of natural Q_2	0.0004	0.615	4.40

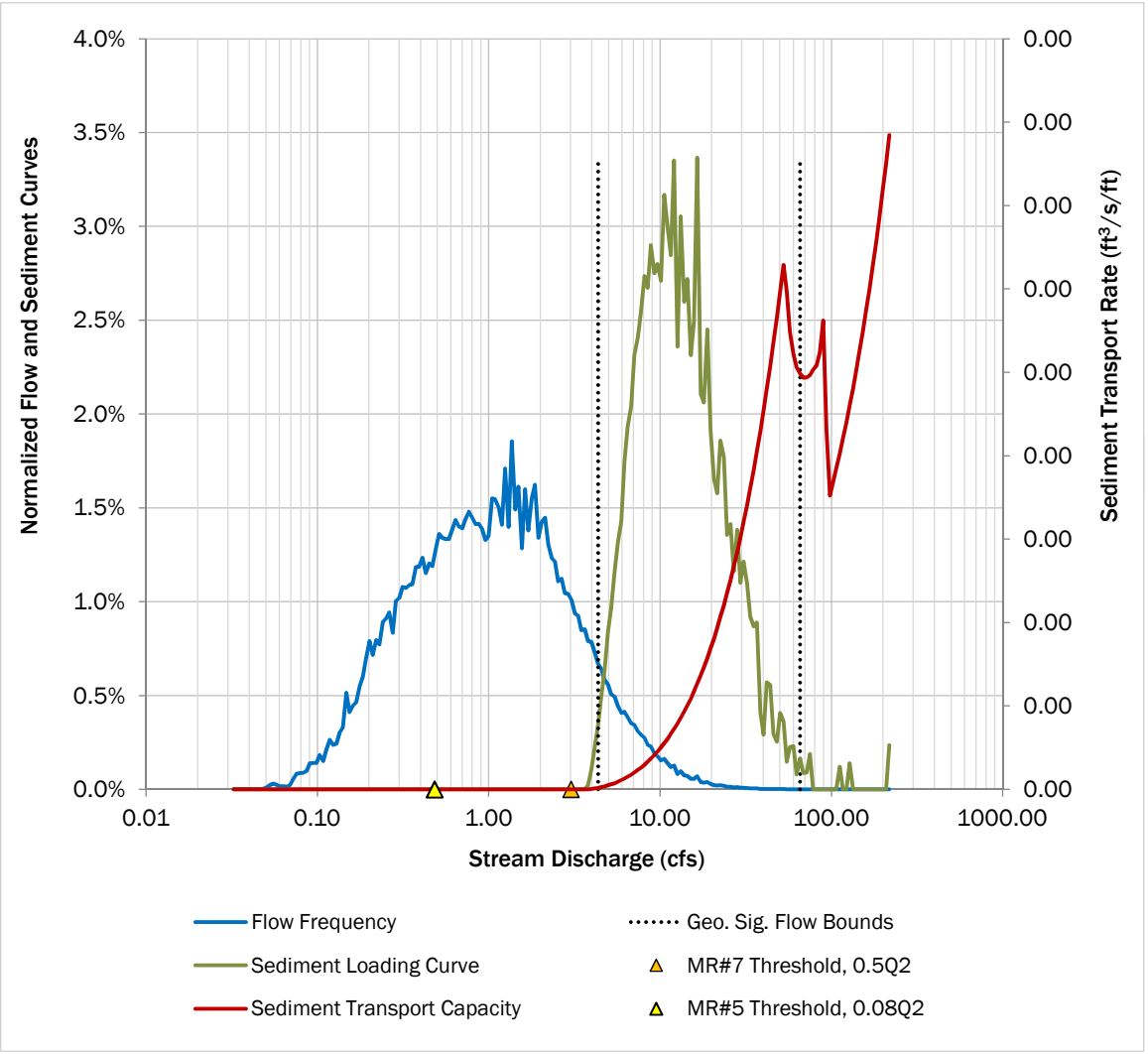
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	301
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	65.60
Lower flow bound for sediment loading (cfs):	4.34
Upper flow bound as a fraction of 50-year flow*:	2.89
Lower flow bound as a fraction of 2-year flow*:	0.720

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	16.51
Flow depth at effective discharge (ft):	1.33
Shear Stress at effective discharge (lb/ft^2):	0.21
Average flow velocity at effective discharge (ft/s):	2.7
Shear velocity at effective discharge (ft/s):	0.3
Effective width at effective discharge (ft):	8.9
Largest mobilized sediment:	*Fine gravel*
Largest fully suspended sediment:	*Medium sand*
Sediment beginning to settle out:	*Coarse sand*



MFA Inputs	
Reach:	WC-R04
Flow location:	WC-Q02
Cross-section:	BC01
Channel Slope:	3.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.87	1.01	16%
2-year Flow, Q_2	6.03	36.24	501%
50-year Flow, Q_{50}	22.72	154.67	581%
MR#7 Threshold, $0.5Q_2$	3.02	18.12	--
MR#5 Threshold, $0.08Q_2$	0.48	2.90	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.77
Depth of flow (ft)	0.01	0.12	0.38
Fraction of natural Q_2	0.0000	0.004	0.13

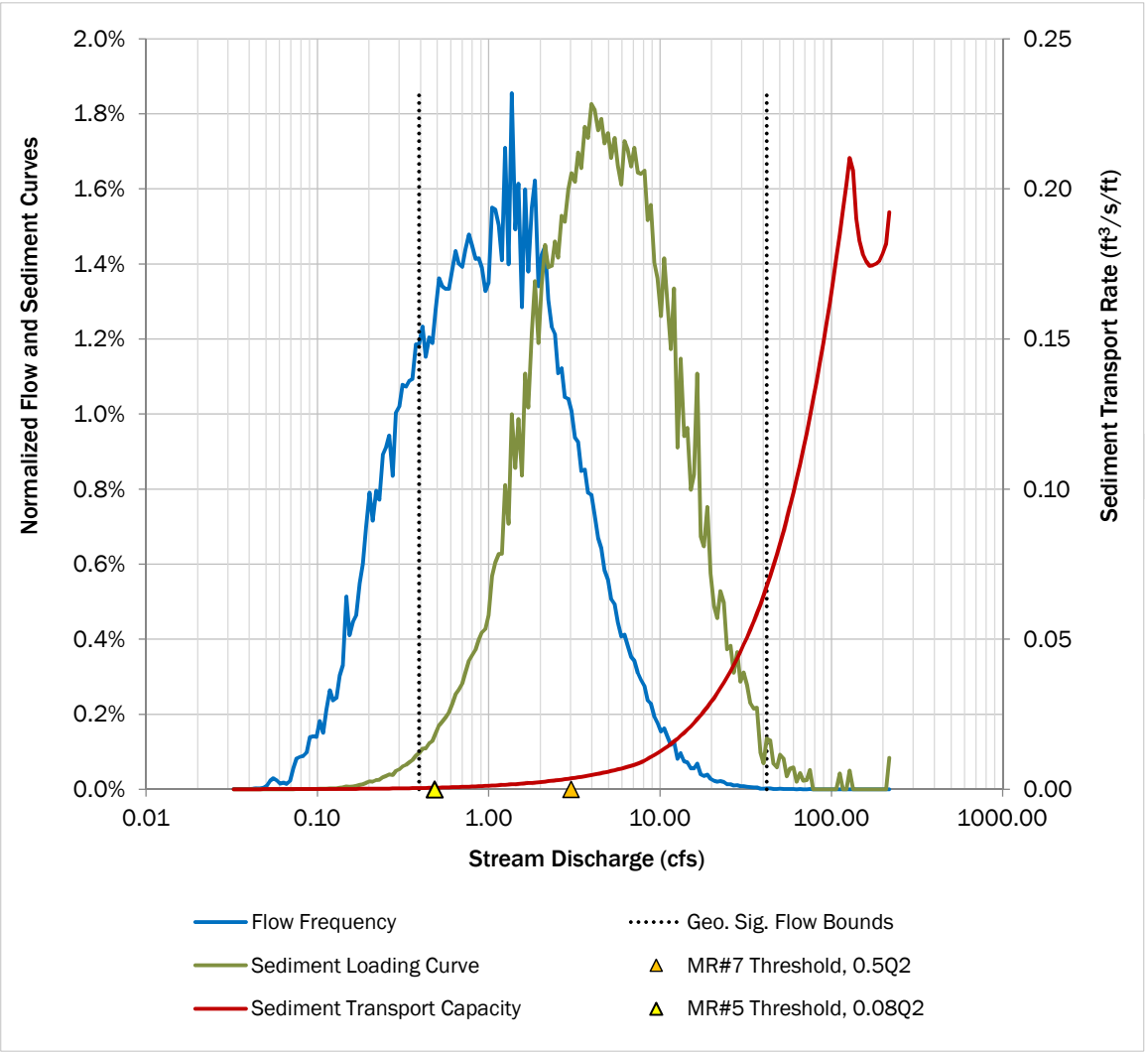
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	28,930
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	42.03
Lower flow bound for sediment loading (cfs):	0.39
Upper flow bound as a fraction of 50-year flow*:	1.85
Lower flow bound as a fraction of 2-year flow*:	0.065

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.97
Flow depth at effective discharge (ft):	0.62
Shear Stress at effective discharge (lb/ft^2):	0.49
Average flow velocity at effective discharge (ft/s):	3.2
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	5.4
Largest mobilized sediment:	*Medium gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	WC-R05
Flow location:	WC-Q02
Cross-section:	XS477
Channel Slope:	4.4%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.87	1.01	16%
2-year Flow, Q_2	6.03	36.24	501%
50-year Flow, Q_{50}	22.72	154.67	581%
MR#7 Threshold, $0.5Q_2$	3.02	18.12	--
MR#5 Threshold, $0.08Q_2$	0.48	2.90	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.09	0.48
Depth of flow (ft)	0.01	0.06	0.12
Fraction of natural Q_2	0.0000	0.015	0.08

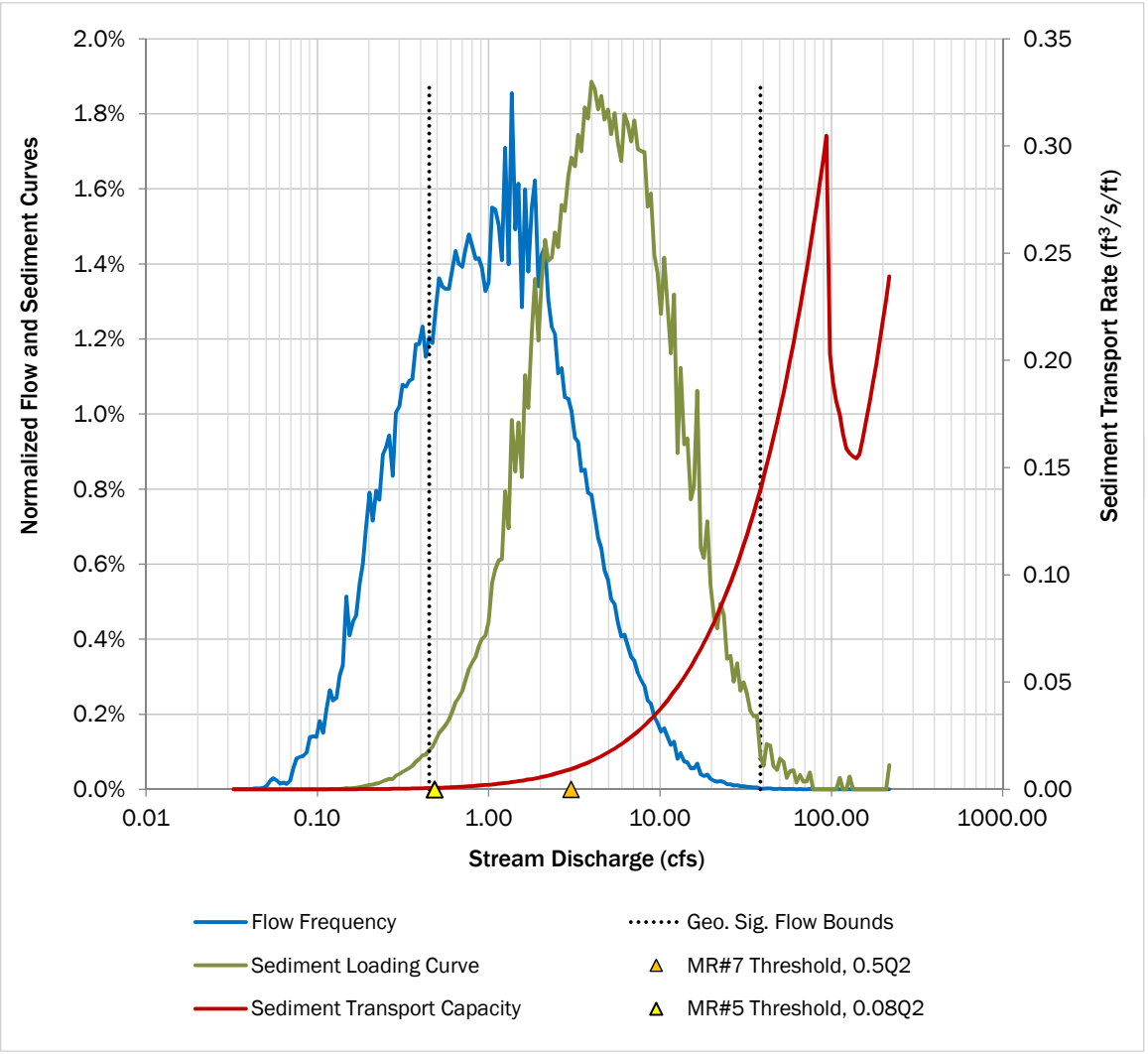
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	54,005
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	38.45
Lower flow bound for sediment loading (cfs):	0.45
Upper flow bound as a fraction of 50-year flow*:	1.69
Lower flow bound as a fraction of 2-year flow*:	0.074

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.97
Flow depth at effective discharge (ft):	0.40
Shear Stress at effective discharge (lb/ft^2):	0.84
Average flow velocity at effective discharge (ft/s):	3.4
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	3.8
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R06
Flow location:	WC-Q03
Cross-section:	XS477
Channel Slope:	5.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.70	0.82	17%
2-year Flow, Q_2	5.41	31.99	491%
50-year Flow, Q_{50}	19.47	142.84	633%
MR#7 Threshold, $0.5Q_2$	2.71	15.99	--
MR#5 Threshold, $0.08Q_2$	0.43	2.56	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.07	0.35
Depth of flow (ft)	0.01	0.05	0.11
Fraction of natural Q_2	0.0000	0.012	0.07

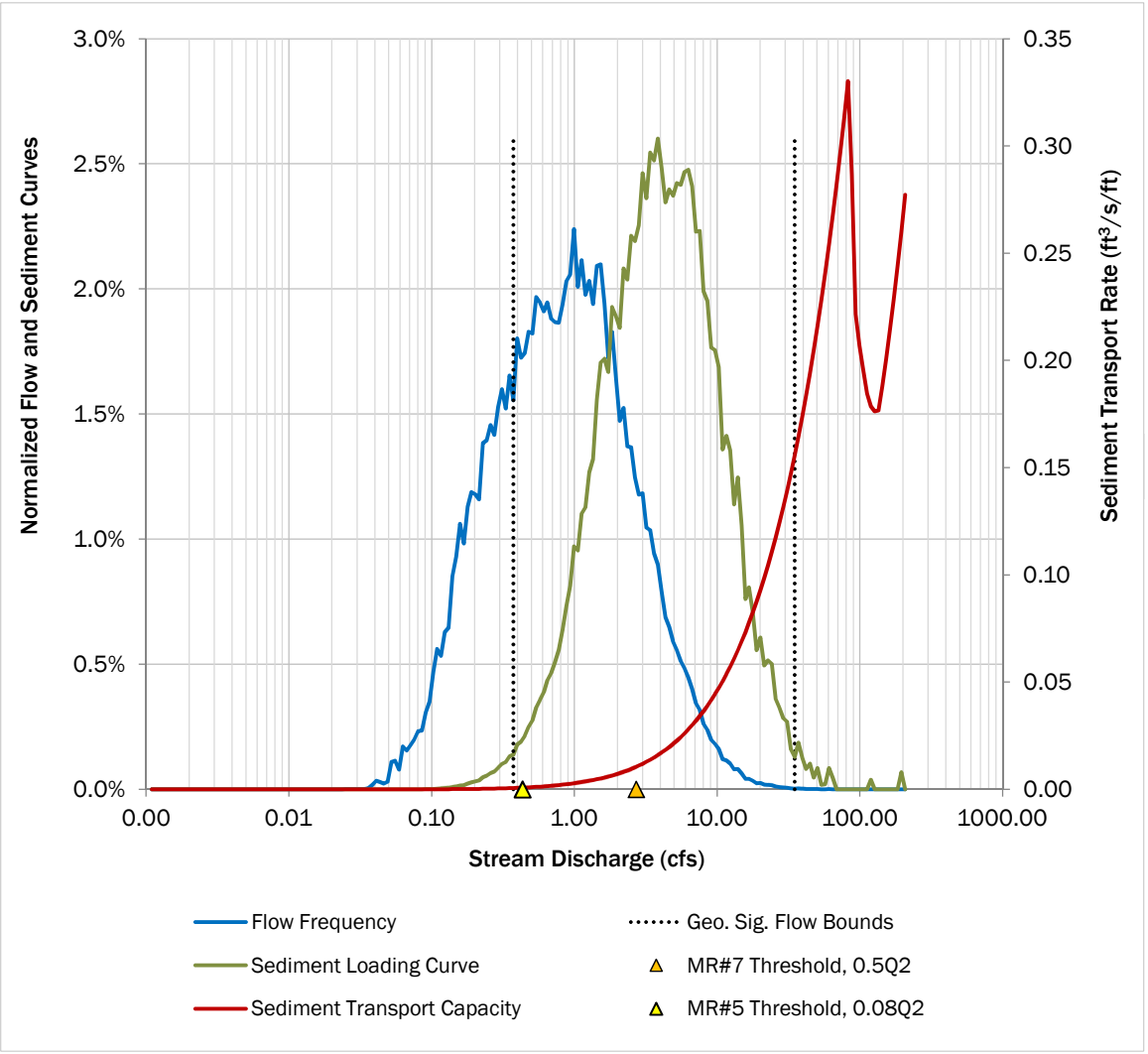
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	54,498
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	34.97
Lower flow bound for sediment loading (cfs):	0.37
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.069

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.84
Flow depth at effective discharge (ft):	0.40
Shear Stress at effective discharge (lb/ft^2):	0.97
Average flow velocity at effective discharge (ft/s):	3.2
Shear velocity at effective discharge (ft/s):	0.7
Effective width at effective discharge (ft):	3.8
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R07
Flow location:	WC-Q03
Cross-section:	BC03
Channel Slope:	7.1%
Sediment sample:	Class 1
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.70	0.82	17%
2-year Flow, Q_2	5.41	31.99	491%
50-year Flow, Q_{50}	19.47	142.84	633%
MR#7 Threshold, $0.5Q_2$	2.71	15.99	--
MR#5 Threshold, $0.08Q_2$	0.43	2.56	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.09	0.30
Depth of flow (ft)	0.01	0.09	0.14
Fraction of natural Q_2	0.0000	0.017	0.06

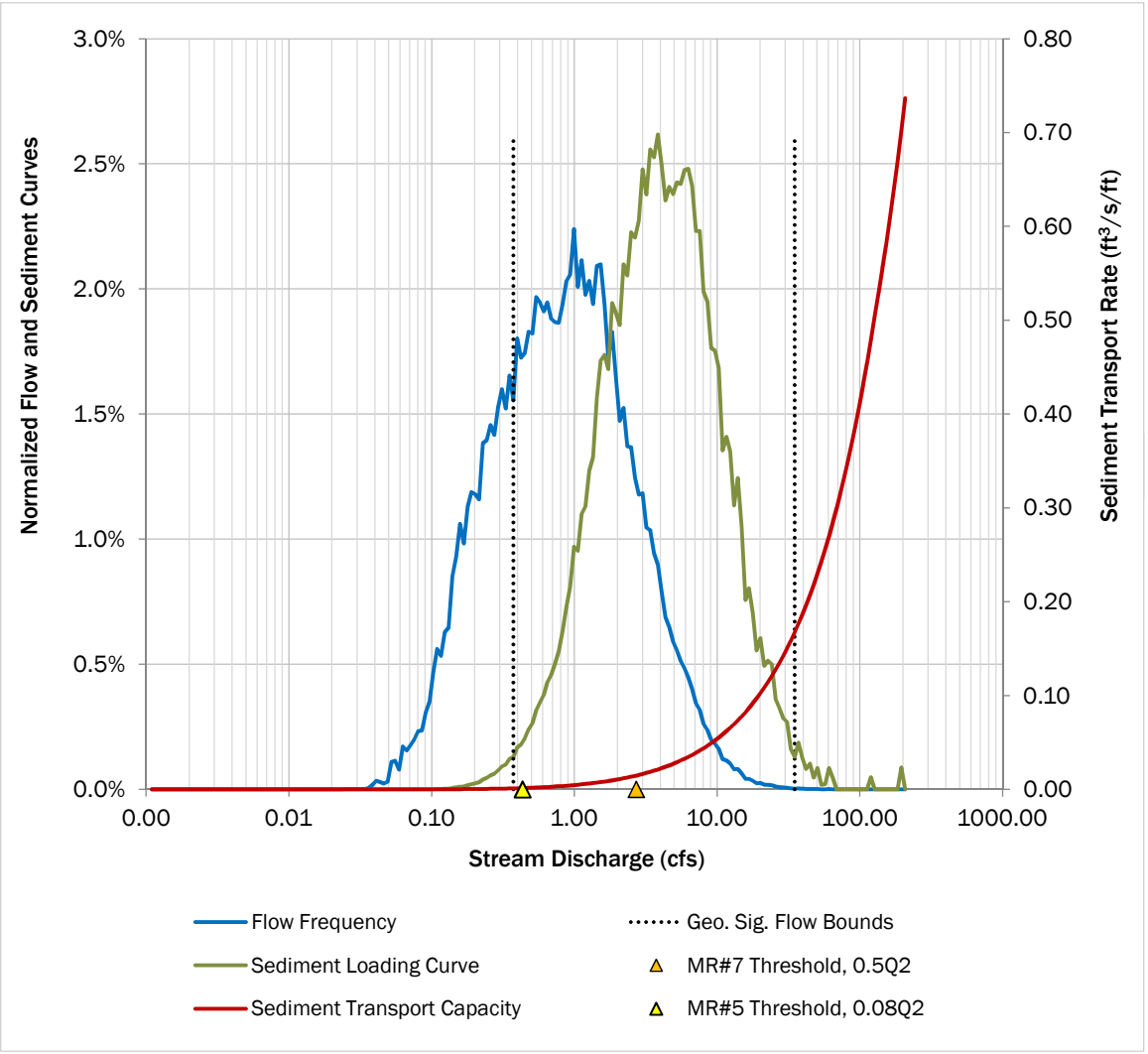
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	80,606
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	34.97
Lower flow bound for sediment loading (cfs):	0.37
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.069

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.84
Flow depth at effective discharge (ft):	0.45
Shear Stress at effective discharge (lb/ft^2):	1.27
Average flow velocity at effective discharge (ft/s):	3.1
Shear velocity at effective discharge (ft/s):	0.8
Effective width at effective discharge (ft):	4.2
Largest mobilized sediment:	*Very coarse gravel*
Largest fully suspended sediment:	*Very fine gravel*
Sediment beginning to settle out:	*Fine gravel*



MFA Inputs	
Reach:	WC-R08
Flow location:	WC-Q03
Cross-section:	BC05
Channel Slope:	3.1%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.70	0.82	17%
2-year Flow, Q_2	5.41	31.99	491%
50-year Flow, Q_{50}	19.47	142.84	633%
MR#7 Threshold, $0.5Q_2$	2.71	15.99	--
MR#5 Threshold, $0.08Q_2$	0.43	2.56	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.02	0.27
Depth of flow (ft)	0.01	0.12	0.31
Fraction of natural Q_2	0.0000	0.004	0.05

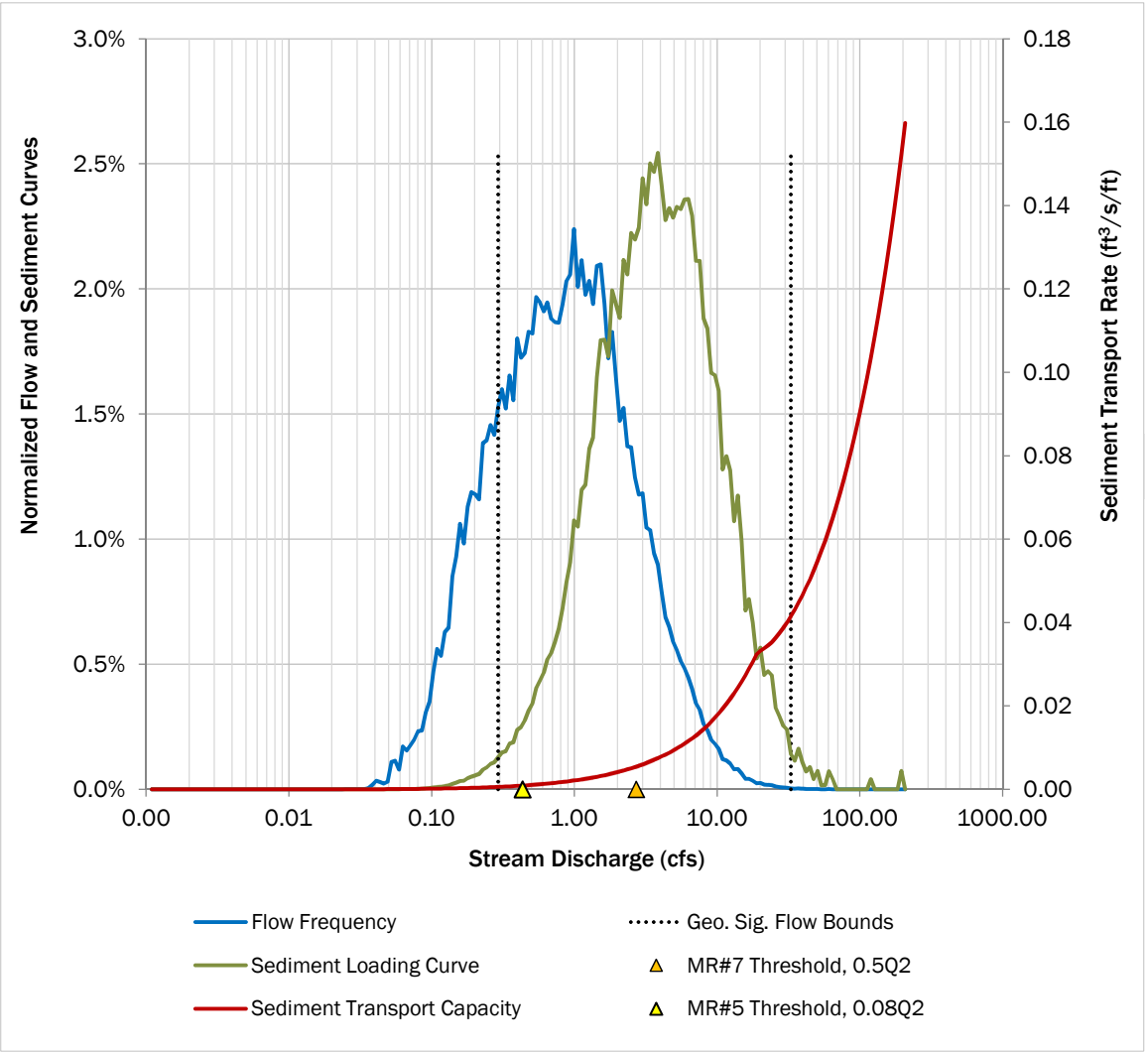
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	27,720
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	32.89
Lower flow bound for sediment loading (cfs):	0.29
Upper flow bound as a fraction of 50-year flow*:	1.69
Lower flow bound as a fraction of 2-year flow*:	0.054

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.84
Flow depth at effective discharge (ft):	0.84
Shear Stress at effective discharge (lb/ft^2):	0.72
Average flow velocity at effective discharge (ft/s):	2.5
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	4.0
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R09
Flow location:	WC-Q03
Cross-section:	BC04
Channel Slope:	4.5%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.70	0.82	17%
2-year Flow, Q_2	5.41	31.99	491%
50-year Flow, Q_{50}	19.47	142.84	633%
MR#7 Threshold, $0.5Q_2$	2.71	15.99	--
MR#5 Threshold, $0.08Q_2$	0.43	2.56	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.04	0.32
Depth of flow (ft)	0.01	0.07	0.15
Fraction of natural Q_2	0.0000	0.008	0.06

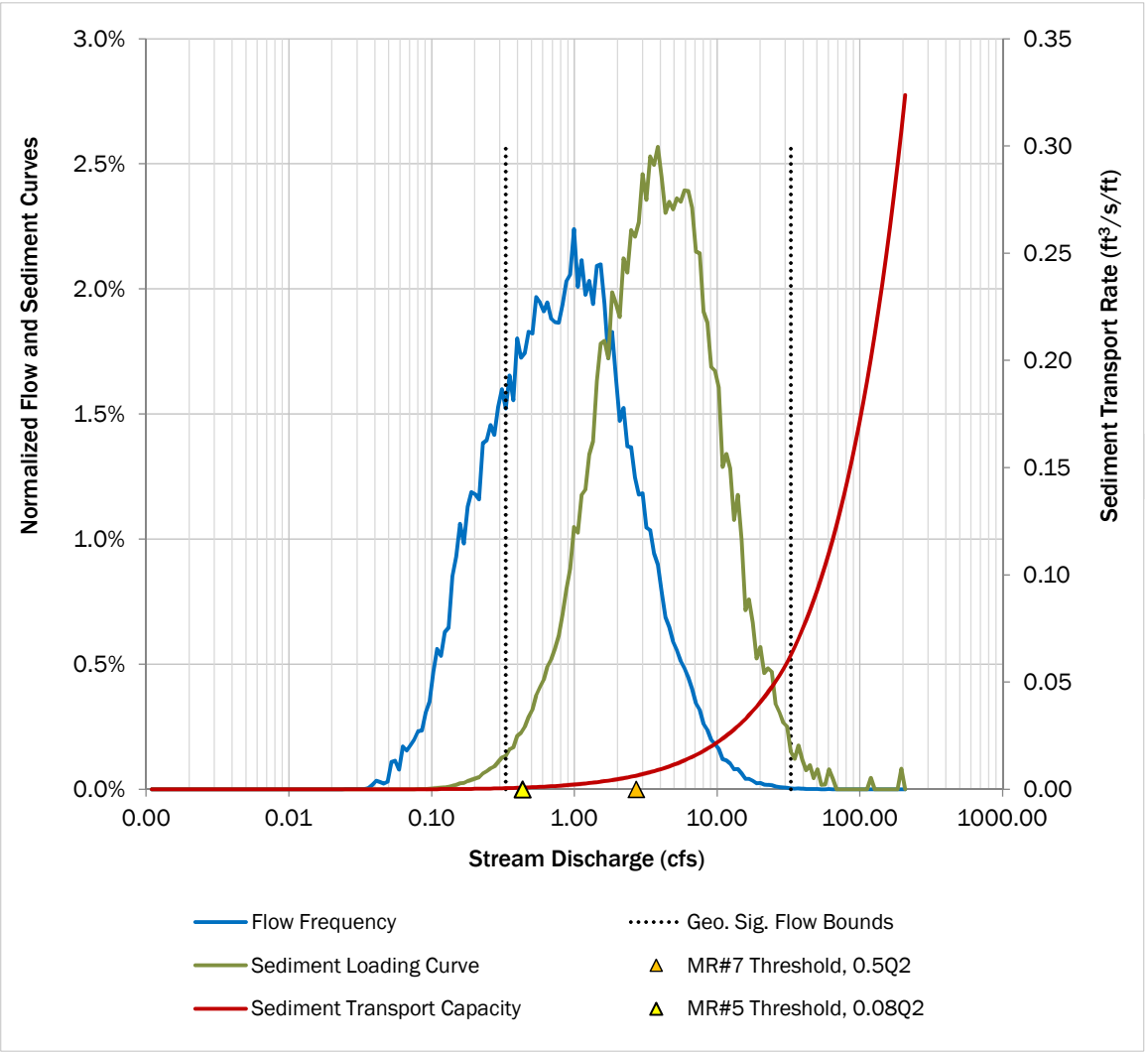
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	43,361
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	32.89
Lower flow bound for sediment loading (cfs):	0.33
Upper flow bound as a fraction of 50-year flow*:	1.69
Lower flow bound as a fraction of 2-year flow*:	0.061

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	3.84
Flow depth at effective discharge (ft):	0.47
Shear Stress at effective discharge (lb/ft^2):	0.80
Average flow velocity at effective discharge (ft/s):	2.5
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	5.3
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R10
Flow location:	WC-Q04
Cross-section:	BC04
Channel Slope:	3.4%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.62	17%
2-year Flow, Q_2	4.11	24.29	491%
50-year Flow, Q_{50}	14.79	108.49	633%
MR#7 Threshold, $0.5Q_2$	2.06	12.15	--
MR#5 Threshold, $0.08Q_2$	0.33	1.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.08	0.57
Depth of flow (ft)	0.01	0.09	0.20
Fraction of natural Q_2	0.0000	0.019	0.14

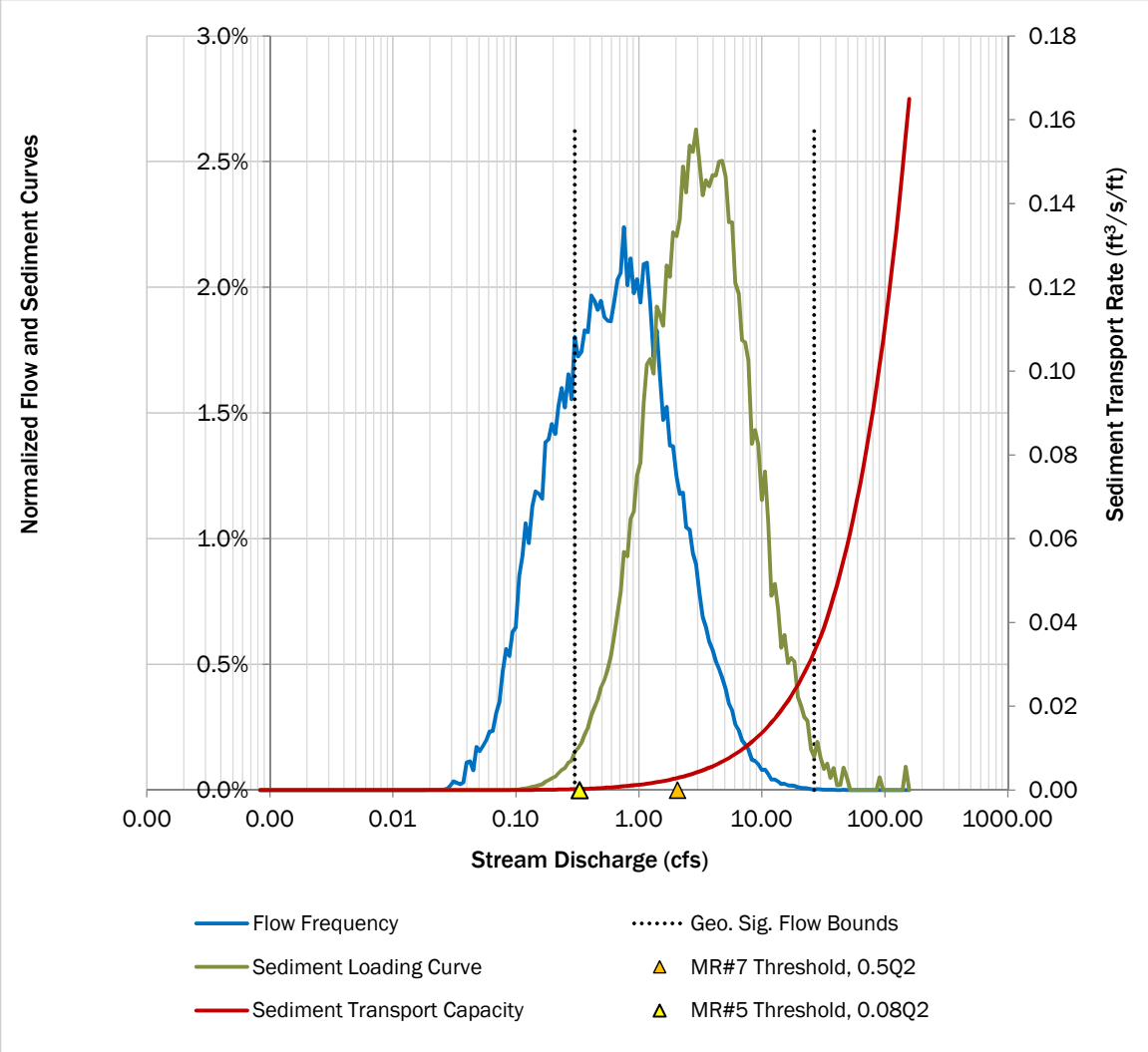
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	17,968
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	26.57
Lower flow bound for sediment loading (cfs):	0.30
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.073

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.92
Flow depth at effective discharge (ft):	0.42
Shear Stress at effective discharge (lb/ft^2):	0.54
Average flow velocity at effective discharge (ft/s):	2.3
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	4.8
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



MFA Inputs	
Reach:	WC-R11
Flow location:	WC-Q04
Cross-section:	BC04
Channel Slope:	4.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.62	17%
2-year Flow, Q_2	4.11	24.29	491%
50-year Flow, Q_{50}	14.79	108.49	633%
MR#7 Threshold, $0.5Q_2$	2.06	12.15	--
MR#5 Threshold, $0.08Q_2$	0.33	1.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.06	0.44
Depth of flow (ft)	0.01	0.08	0.17
Fraction of natural Q_2	0.0000	0.016	0.11

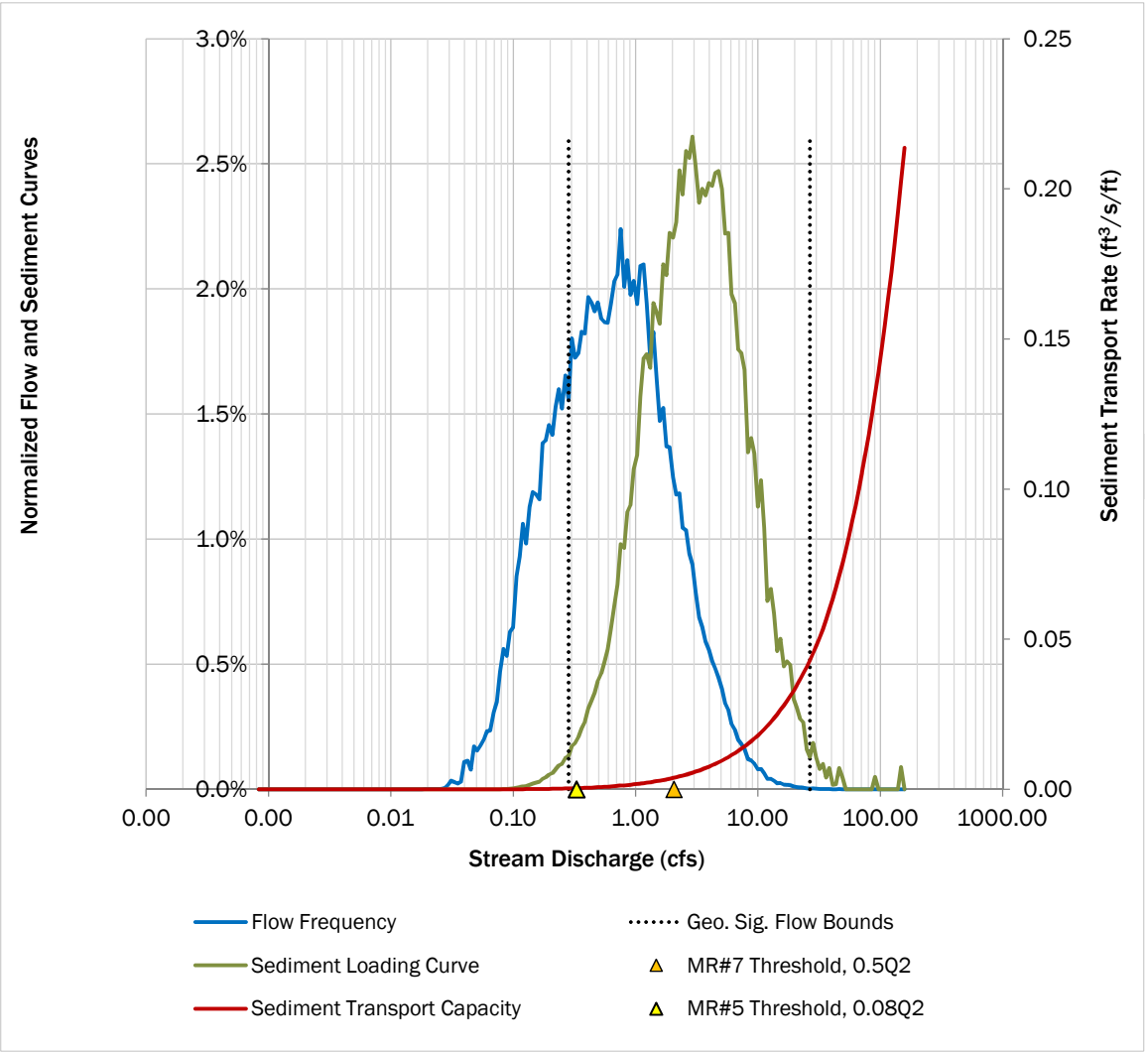
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	23,523
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	26.57
Lower flow bound for sediment loading (cfs):	0.28
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.069

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.92
Flow depth at effective discharge (ft):	0.40
Shear Stress at effective discharge (lb/ft^2):	0.62
Average flow velocity at effective discharge (ft/s):	2.4
Shear velocity at effective discharge (ft/s):	0.6
Effective width at effective discharge (ft):	4.7
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Very coarse sand*
Sediment beginning to settle out:	*Very fine gravel*



MFA Inputs	
Reach:	WC-R12
Flow location:	WC-Q04
Cross-section:	BC04
Channel Slope:	3.0%
Sediment sample:	Class 2
Flow scenario:	Existing

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Low-flow Hydrology

Parameter	Natural	Existing	% Change
Median (50% exceedence)	0.53	0.62	17%
2-year Flow, Q_2	4.11	24.29	491%
50-year Flow, Q_{50}	14.79	108.49	633%
MR#7 Threshold, $0.5Q_2$	2.06	12.15	--
MR#5 Threshold, $0.08Q_2$	0.33	1.94	--

Incipient Motion of Sediments

Parameter	Incipient Motion		
	D_{16}	D_{50}	D_{84}
Flow rate (cfs)	0.00	0.09	0.68
Depth of flow (ft)	0.01	0.10	0.22
Fraction of natural Q_2	0.0000	0.022	0.17

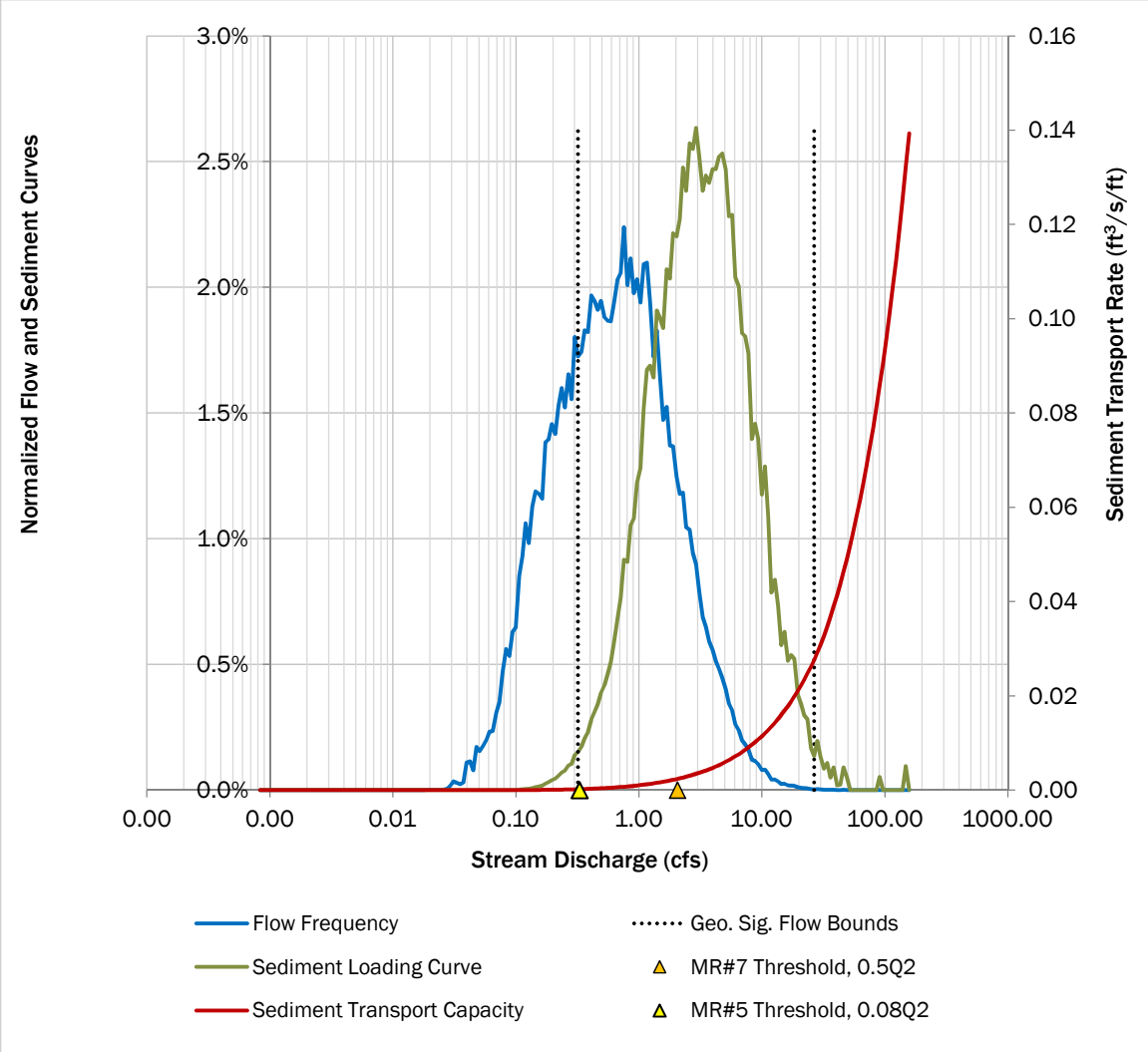
Geomorphically Significant Flows

Total area under sediment loading curve (t/yr):	15,030
Desired level of control (percent of loading curve):	98%
Upper flow bound for sediment loading (cfs):	26.57
Lower flow bound for sediment loading (cfs):	0.32
Upper flow bound as a fraction of 50-year flow*:	1.80
Lower flow bound as a fraction of 2-year flow*:	0.078

*Flows based on "Natural" conditions

Effective Discharge Conditions

Flow at the peak rate of sediment loading (cfs):	2.92
Flow depth at effective discharge (ft):	0.43
Shear Stress at effective discharge (lb/ft^2):	0.50
Average flow velocity at effective discharge (ft/s):	2.2
Shear velocity at effective discharge (ft/s):	0.5
Effective width at effective discharge (ft):	4.9
Largest mobilized sediment:	*Coarse gravel*
Largest fully suspended sediment:	*Coarse sand*
Sediment beginning to settle out:	*Very coarse sand*



Attachment C: Tabulated Results

Geomorphically Significant Flow Bounds and Regulatory Thresholds

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Table C-1. Geomorphically Significant Flow Ranges for Clarks Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
CC-R01	164.2	185.5	113%	81.0	39.5	49%	40.48	6.48
CC-R02	164.2	185.5	113%	81.0	39.5	49%	40.48	6.48
CC-R03	164.2	185.5	113%	81.0	39.5	49%	40.48	6.48
CC-R04	164.2	173.7	106%	81.0	39.5	49%	40.48	6.48
CC-R05	147.5	159.3	108%	80.7	38.5	48%	40.35	6.46
CC-R06	147.5	155.3	105%	80.7	38.5	48%	40.35	6.46
CC-R07	147.5	163.4	111%	80.7	38.5	48%	40.35	6.46
CC-R08	131.2	145.6	111%	77.7	37.4	48%	38.85	6.22
CC-R09	131.2	145.6	111%	77.7	37.4	48%	38.85	6.22
CC-R10	131.2	142.2	108%	77.7	37.4	48%	38.85	6.22
CC-R11	104.6	115.5	110%	68.2	37.1	54%	34.10	5.46
CC-R12	104.6	115.5	110%	68.2	37.1	54%	34.10	5.46
CC-R13	101.0	97.9	97%	68.3	36.8	54%	34.17	5.47
CC-R14	88.0	82.8	94%	63.7	35.5	56%	31.84	5.09
CC-R15	27.2	25.7	95%	17.0	9.1	54%	8.51	1.36
CC-R16	27.2	23.4	86%	17.0	8.5	50%	8.51	1.36
CC-R17	15.7	17.0	108%	6.6	2.5	38%	3.28	0.52
CC-R18	15.7	17.7	113%	6.6	2.4	37%	3.28	0.52
CC-R19	7.6	19.8	262%	1.9	0.2	11%	0.94	0.15
CC-R20	7.6	23.5	310%	1.9	0.5	28%	0.94	0.15
CC-R21	7.6	18.8	247%	1.9	0.1	7%	0.94	0.15
CC-R22	7.6	18.8	247%	1.9	0.2	8%	0.94	0.15
CC-R23	7.6	19.8	262%	1.9	0.1	5%	0.94	0.15
CC-R24	4.5	9.9	221%	1.1	0.1	9%	0.55	0.09
CC-R25	4.5	13.1	294%	1.1	0.2	15%	0.55	0.09
UCT-R01	1.6	4.0	248%	0.4	0.0	13%	0.18	0.03

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Table C-2. Geomorphically Significant Flow Ranges for Diru Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
DC-R01	16.6	29.7	180%	2.8	0.7	26%	1.41	0.23
DC-R02	16.6	52.3	316%	2.8	3.2	113%	1.41	0.23
DC-R03	13.1	27.1	206%	3.3	0.6	19%	1.63	0.26
DC-R04	13.1	27.1	206%	3.3	0.7	20%	1.63	0.26
DC-R05	13.1	28.7	219%	3.3	0.7	20%	1.63	0.26
DC-R06	10.2	26.7	261%	2.5	0.3	11%	1.25	0.20
DC-R07	10.2	28.3	276%	2.5	0.5	18%	1.25	0.20
DC-R08	10.2	33.6	329%	2.5	1.2	46%	1.25	0.20
DC-R09	7.3	28.4	389%	1.8	1.0	58%	0.89	0.14
DC-R10	7.3	60.5	828%	1.8	2.2	124%	0.89	0.14

Table C-3. Geomorphically Significant Flow Ranges for Meeker Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
MC-R01	32.6	67.1	206%	8.2	0.5	6%	4.09	0.66
MC-R02	22.0	51.9	236%	5.5	0.4	7%	2.77	0.44
MC-R03	14.4	33.4	232%	3.6	0.2	5%	1.80	0.29
MC-R04	14.4	31.5	219%	3.6	0.2	5%	1.80	0.29
MC-R05	6.0	45.7	761%	1.5	1.8	119%	0.75	0.12
UMW-R01	3.0	9.8	325%	0.7	0.2	33%	0.37	0.06
UMW-R02	2.4	7.9	324%	0.6	0.1	10%	0.30	0.05
UMW-R03	2.4	8.3	341%	0.6	0.2	37%	0.30	0.05
UMW-R04	1.1	3.5	321%	0.3	0.1	20%	0.14	0.02
UMW-R05	1.1	3.5	321%	0.3	0.1	20%	0.14	0.02

Table C-4. Geomorphically Significant Flow Ranges for Rody Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
RC-R01	14.0	23.4	167%	4.6	1.0	21%	2.30	0.37
RC-R02	14.0	32.1	229%	4.6	1.5	32%	2.30	0.37
RC-R03	10.8	30.6	283%	2.7	0.6	21%	1.35	0.22
RC-R04	10.8	28.9	267%	2.7	0.3	10%	1.35	0.22
RC-R05	10.8	27.3	252%	2.7	0.2	9%	1.35	0.22
RC-R06	10.8	28.9	267%	2.7	0.3	10%	1.35	0.22
RC-R07	10.8	32.5	299%	2.7	0.4	14%	1.35	0.22
RC-R08	9.3	25.4	272%	2.5	0.2	10%	1.26	0.20
RC-R09	9.3	28.5	305%	2.5	0.4	17%	1.26	0.20
RC-R10	8.3	49.8	604%	2.2	2.7	121%	1.11	0.18

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Table C-5. Geomorphically Significant Flow Ranges for Silver Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
SC-R01	6.6	28.1	424%	1.7	1.7	99%	0.87	0.14
SC-R02	6.6	24.5	371%	1.7	0.6	35%	0.87	0.14
SC-R03	6.6	23.5	354%	1.7	0.1	8%	0.87	0.14
SC-R04	4.4	22.4	504%	1.2	0.4	32%	0.60	0.10
SC-R05	4.4	21.2	477%	1.2	0.2	18%	0.60	0.10
SC-R06	4.4	20.0	451%	1.2	0.2	20%	0.60	0.10
SC-R07	4.4	20.0	451%	1.2	0.3	24%	0.60	0.10
SC-R08	4.4	19.0	427%	1.2	0.2	18%	0.60	0.10
SC-R09	3.3	15.7	474%	0.9	0.2	28%	0.44	0.07

Table C-6. Geomorphically Significant Flow Ranges for Woodland Creek

Reach	Upper bound			Lower bound				
	50-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 50-year forested	2-year discharge forested conditions (cfs)	Calculated geomorphically significant flow bound (cfs)	Geo. sig. flow bound as a percentage of 2-year forested	50% of 2-year forested discharge	8% of 2-year forested discharge
WC-R01	30.7	51.3	167%	8.3	1.5	19%	4.13	0.66
WC-R02	30.7	56.1	183%	8.3	0.5	6%	4.13	0.66
WC-R03	22.7	65.6	289%	6.0	4.3	72%	3.02	0.48
WC-R04	22.7	42.0	185%	6.0	0.4	7%	3.02	0.48
WC-R05	22.7	38.5	169%	6.0	0.4	7%	3.02	0.48
WC-R06	19.5	35.0	180%	5.4	0.4	7%	2.71	0.43
WC-R07	19.5	35.0	180%	5.4	0.4	7%	2.71	0.43
WC-R08	19.5	32.9	169%	5.4	0.3	5%	2.71	0.43
WC-R09	19.5	32.9	169%	5.4	0.3	6%	2.71	0.43
WC-R10	14.8	26.6	180%	4.1	0.3	7%	2.06	0.33
WC-R11	14.8	26.6	180%	4.1	0.3	7%	2.06	0.33
WC-R12	14.8	26.6	180%	4.1	0.3	8%	2.06	0.33

Appendix F: LID Design Concepts

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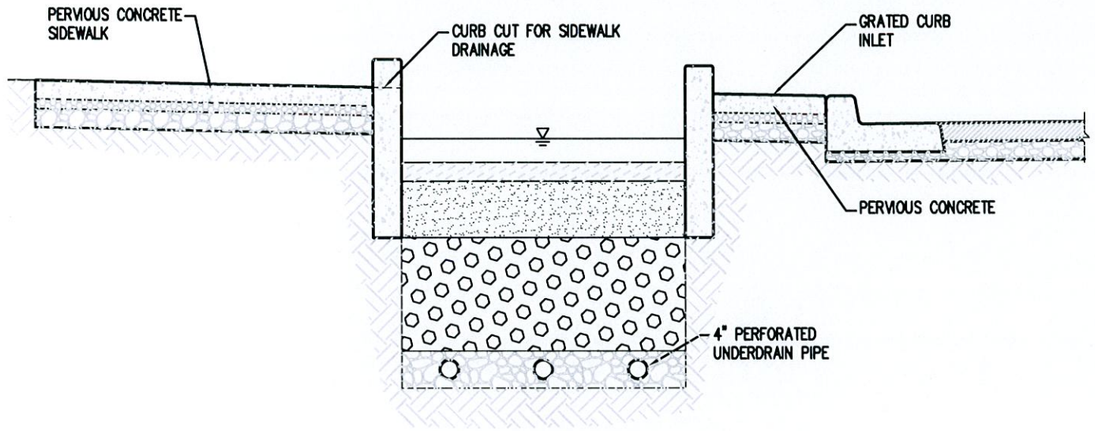
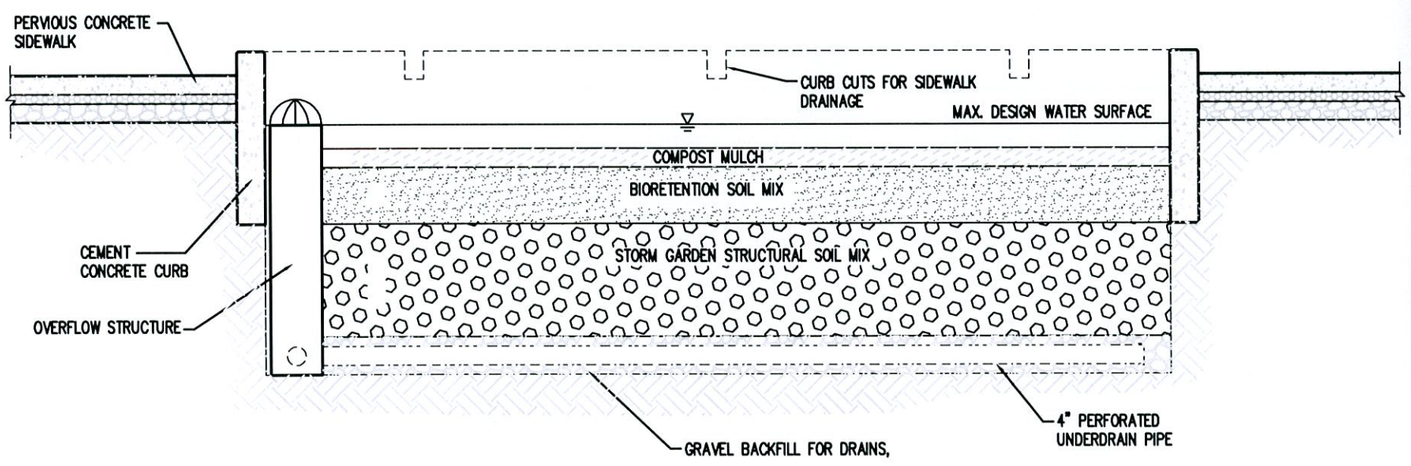




AHBL

Urban Bioretention Boxes

LID Approaches for Clark's Creek Basin

USES CURB CUTS FOR INLETS.

CAN BE PLACED MID–BLOCK.

USE STANDARD BIORENTION CELLS
WITH UNDERDRAINS IF SOIL IS POOR
WITHOUT UNDERDRAINS IF SOIL INFILTRATES

CAN BE CUT INTO EXISTING STREETS WITHOUT REVISING PAVEMENT SECTION.

USES A STRUCTURED CURB INLET.

PROVIDES TRAFFIC CALMING AND ENHANCES PEDESTRIAN SAFETY.

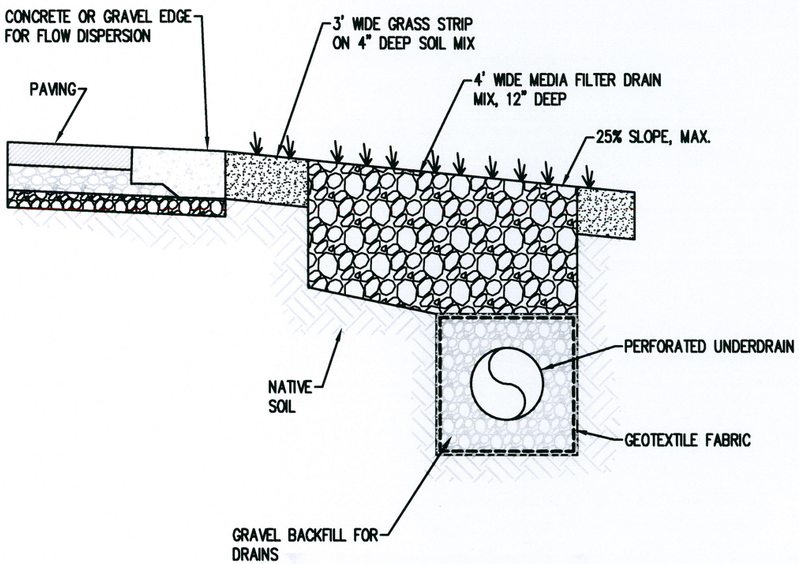
USE STANDARD BIORENTION CELLS AND CONNECT WITH TRENCH DRAIN THROUGH CURB RAMP.

CAN BE CUT INTO EXISTING STREETS WITHOUT REVISING PAVEMENT SECTION.

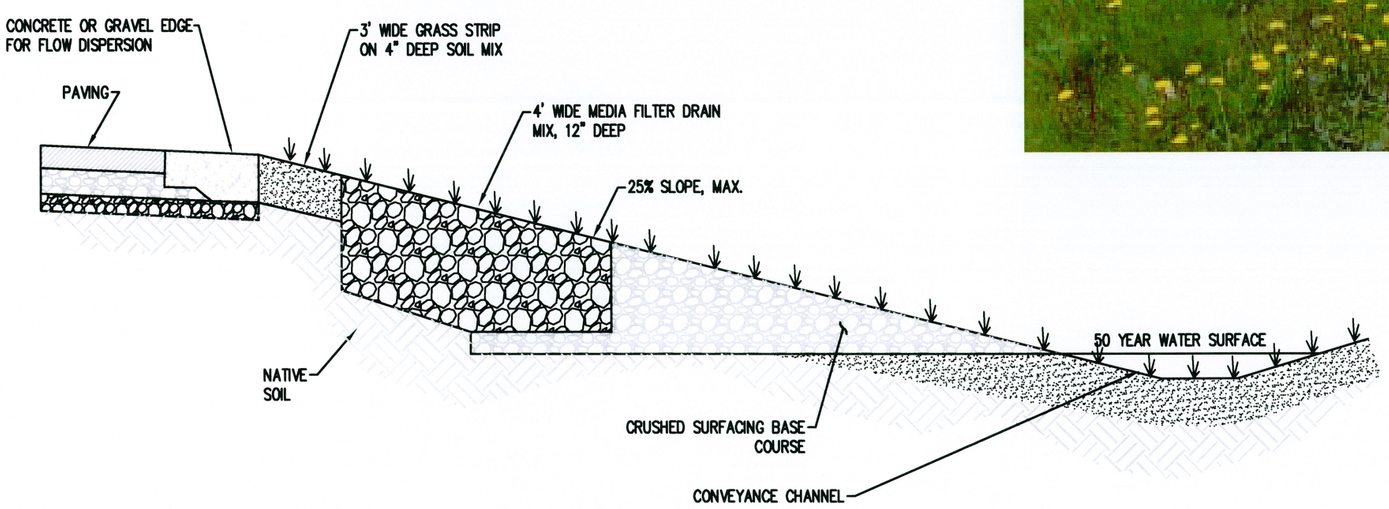
AHBL

Curb Bulb with Bioretention

LID Approaches for Clark's Creek Basin



CROSS-SECTION WITH UNDERDRAIN

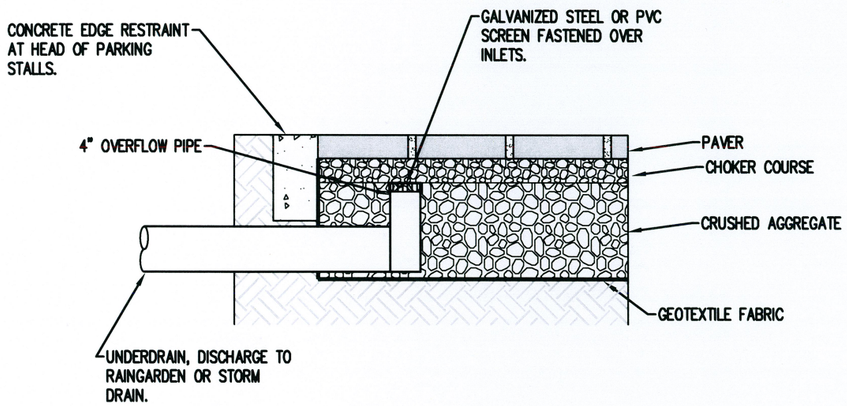


CROSS-SECTION WITHOUT UNDERDRAIN

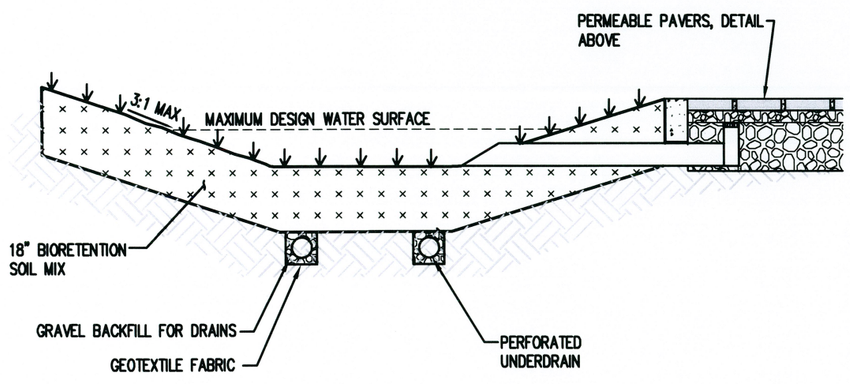
AHBL

Media Filter Drain

LID Approaches for Clark's Creek Basin



PERMEABLE PAVERS



BIORETENTION CELL

AHBL

Pervious Pavers Draining to Bioretention

LID Approaches for Clark's Creek Basin