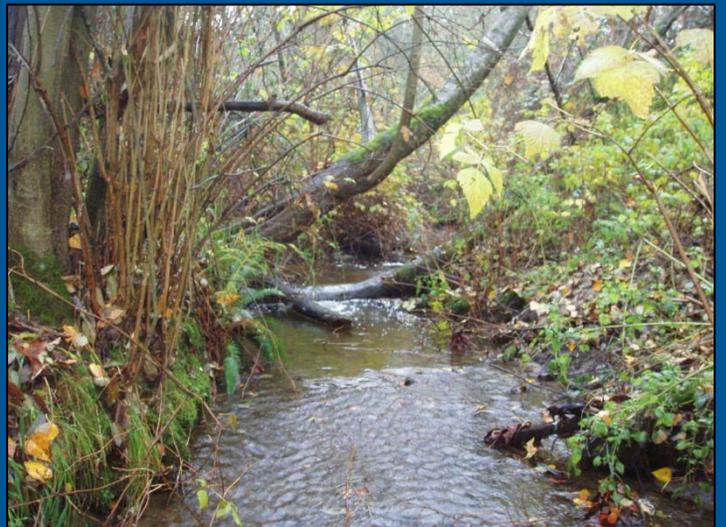


Juanita Creek Basin Geomorphic Analysis - DRAFT

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King County
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Stillwater Sciences

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1. Introduction

As part of a larger effort to characterize conditions in the Juanita Creek watershed and work toward restoration of beneficial uses, Northwest Hydraulic Consultants, Inc. (NHC) was contracted by King County (County) to perform hydraulic and geomorphic analysis on Juanita Creek and several of its major tributaries. The scope for this work included field survey and development of a HEC-RAS hydraulic model for the Juanita Creek mainstem and portions of three tributaries, evaluation of incipient motion thresholds for five “priority” reaches near King County flow gage sites, and basinwide geomorphic data collection and analysis. Stillwater Sciences (Stillwater) served as a subconsultant to NHC for geomorphology and biological issues. This report focuses on analysis and interpretation of the data collected in our geomorphic survey (documented previously in NHC, 2009; NHC, 2010a).

Under the State Water Quality Standards, designated beneficial uses of Juanita Creek include “core rearing” for native aquatic biota. Those stream reaches identified as core rearing are for the protection of spawning, rearing, and migration of salmon and trout, and other associated aquatic life. Assessment of geomorphic conditions critical to these ecological attributes was thus a focus of this characterization.

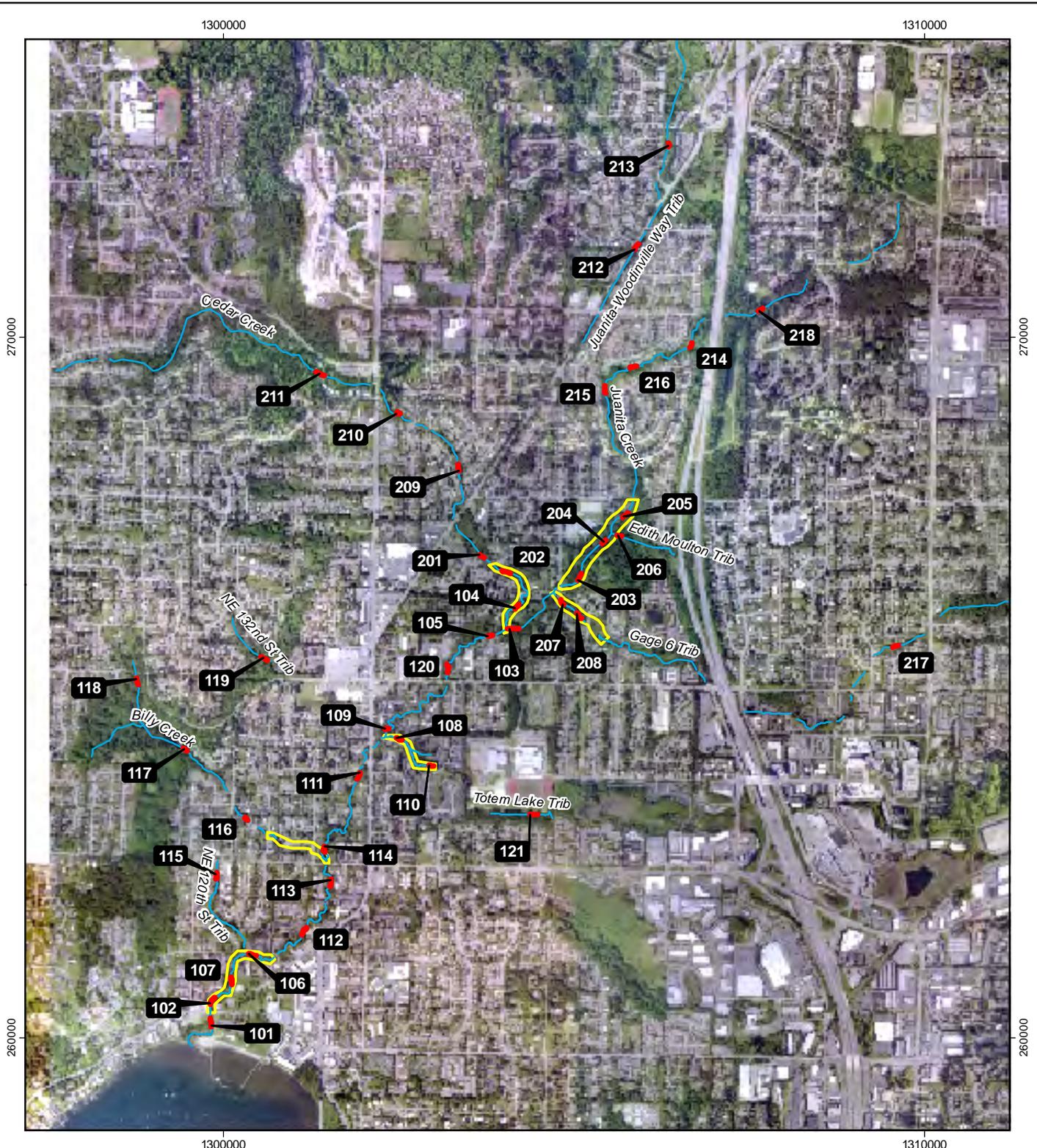
As part of this work, the NHC team observed geomorphic parameters for 39 assessment reaches on the Juanita Creek mainstem and nine tributaries (Figure 1). These parameters included:

- Bank stability
- Substrate size and distribution
- Local slope
- Bankfull channel dimensions (priority reaches only), and
- Large woody debris (LWD) and large pool frequency.

In addition to the nearly 3,800 feet of channel included in the assessment reaches, The NHC team observed LWD and large pool frequency for an additional 4,800 feet of channel length. Substrate sandiness was assessed over a total of 14,600 feet of channel length—30 percent of the open channel network in the entire basin—and included nearly half of the Juanita Creek mainstem.

Though this effort is independent of previous work in the basin, the geomorphic assessment complements and expands upon two previous studies, King County’s *Habitat Inventory and Assessment of Juanita Creek in 2000* (Rush et al., 2002) and Otak’s *Juanita Creek Basin Stabilization Study* (2000). Both earlier studies were limited to the mainstem of Juanita Creek. The King County assessment included a broad suite of habitat-related attributes: riparian condition, bank stability, adjacent land use, bankfull width and depth, aquatic habitat, pool quality, and LWD. King County sampled selected segments amounting to approximately 35 percent of the mainstem channel between the mouth and 100 meters upstream of I-405. Otak performed a qualitative, observation-based geomorphic assessment, as well as an approximate quantitative analysis based on regime theory, between NE 124th Street and I-405.

This report summarizes the results of the NHC team’s field geomorphic data collection, presents an analysis and discussion of trends, and makes recommendations for future work. Section 2 provides data summaries and analyses of trends in and correlations between the observed parameters. Section 3 provides discussion and conclusions regarding what we can infer from the geomorphic data collected, including how they relate to the support of beneficial uses. Section 4 provides recommendations for future work, both as part of the NHC team’s remaining involvement in this project (Task 400) and for future outside investigation.



Legend

-  Assessment Reaches
-  Priority Reaches

King Co. Reference Map



Juanita Creek Geomorphic Assessment - King County, WA

Juanita Creek Geomorphic Assessment Reaches

Scale - 1:24,000

1,000 500 0 1,000 2,000 Feet

coord. syst.: WA State Plane N	horz. datum: NAD 83	horz. units: feet
northwest hydraulics consultants	project no. 21726	10-Feb-2010

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Figure 1

2. Data Analysis and Trends

Field data collected for the geomorphic assessment, including photographs of each assessment reach, were collected and submitted to the County in the form of an ESRI geodatabase (NHC, 2010a). The spatial-database format facilitates mapping of results and assessment of spatial trends. The following sections provide review and analysis of the various data collected, including spatial trends (or lack thereof), potential correlations between parameters, and comparisons with past studies where applicable. The analysis is primarily qualitative, as the volume and nature of the data generally did not lend themselves to quantitative interpretation.

2.1 Stream Gradient

Channel slopes in the Juanita Creek network (as calculated from a DEM) are overwhelmingly low to moderate, with two-thirds of the channel network (including the entire mainstem) having slopes less than three percent and more than one-quarter having slopes less than one percent. Slopes greater than five percent are rare and occur almost exclusively on the western tributaries coming off of the Finn Hill plateau.

Local slope was evaluated for each of the assessment reaches, either measured directly in the field or (for sites in priority reaches) computed from adjacent cross sections surveyed for the hydraulic model. DEM-computed slopes for corresponding reaches tended to be higher than observed values, though generally within measurement uncertainties. The largest errors occurred mostly on the reaches with the highest slopes. This is not surprising, as in those areas, the channel is typically narrower and thus the GIS channel network (which was used to compute slopes from the DEM) less accurate, leading to greater inaccuracies in the DEM slope computation process. Overall, DEM-derived slopes are probably reasonable for comparison and trend assessment but we do not consider them reliable for local hydraulic or sediment transport analyses.

Plate 1 shows DEM-computed slopes for the entire open channel network, with locally observed slopes also included for the assessment reaches.

2.2 Channel Substrate/Fine Sediment

The NHC team used two metrics to characterize channel substrate. First, a median gravel size (gravel D_{50}) was estimated for each assessment reach *representing only the gravel patches in the reach*; note that this is not the median bed particle size overall because it excluded sand-bedded areas. The gravel D_{50} was determined either from a 100-particle pebble count (for Tier 1 sites in priority reaches) or by visual estimate (Tier 2 sites). Complementing the gravel-size metric, the percent of the bed covered by sand was estimated and classified into one of three bins (0-33% sand, 33-67% sand, or 67-100% sand). This latter metric was evaluated both as a reach average for each of the 39 assessment reaches and by tracking spatial variability in bed sandiness over an extended portion of the channel network. The extended sandiness observations involved continuous assessment of the sandiness categories along the stream channel, delineating segments with consistent bed sandiness and locating changes in substrate composition. Plate 2 illustrates the sandiness characterizations for the assessment reaches and for the extended substrate analysis.

Bed Sediment Trends

The general trend shows fine sediment decreasing up the mainstem of Juanita Creek, though there is some variability in substrate composition throughout. Notable exceptions to this trend

are higher concentrations of fine sediment upstream of NE124th Street, likely due to backwater effects from the culvert and possibly recent activity in the creek (Jenny Gaus, personal communication), and the reach of Juanita Creek through Edith Moulton Park. The latter reach corresponds with an area of locally flatter slope and occurs downstream of a small tributary draining off of I-405 that is very unstable and appears to be a source of significant fine sediment, as evidenced by a visible sandbar deposit at the confluence (Photo 1).



Photo 1. Juanita Creek confluence with left bank tributary in Edith Moulton Park showing extensive sand deposit.

The tributary reaches generally showed a wide range of bed sand percentages (0-33% sand or 33-67% sand). Even higher amounts were observed in the aforementioned Edith Moulton Park tributary, an ephemeral channel fragment off NE 132nd Street, and the northwest tributary along Juanita-Woodinville Way. Fine sediments from this latter tributary may not be reaching the mainstem, insofar as flow at the downstream end of this segment enters a 700-foot pipe that discharges to the creek, and there was no evidence of fine sediment deposition downstream of the pipe outfall.

Gravel was present in all but three of the assessment reaches—Juanita Creek upstream of NE 124th Street (site 114), the ditch along Juanita-Woodinville Way (site 212), and the isolated tributary segment near NE 132nd Street (site 119). Median gravel sizes typically ranged from approximately 11 mm to 45 mm and tended to increase in size with upstream distance from the mouth, though this trend was by no means uniform nor consistent from site to site. These gravels are useable but on the small side of the range typically used by spawning coho salmon and steelhead; they are likely more beneficial for smaller fish such as cutthroat trout (see Table 6 in Section 3.5).

We note that Juanita Creek, like many other lowland streams, may have strong seasonal trends in bed substrate. During a field reconnaissance visit in October 2009, our impression was of much higher bed sand concentrations than were determined during the field data collection in November and December 2009, which followed some substantial storm flows. While it is possible that the preliminary (unmeasured and non-systematic) impressions were not consistent with broader stream conditions, it seems reasonable that greater amounts of fine sediment may collect during summer low flows and then be swept away or redistributed through the system by early winter storms to expose more gravel. If true, this process may have consequences for the spawning success of specific species.

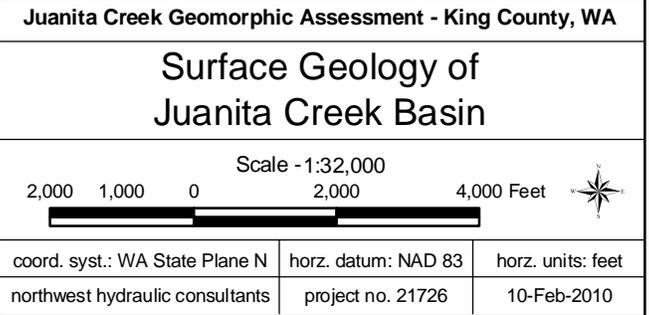
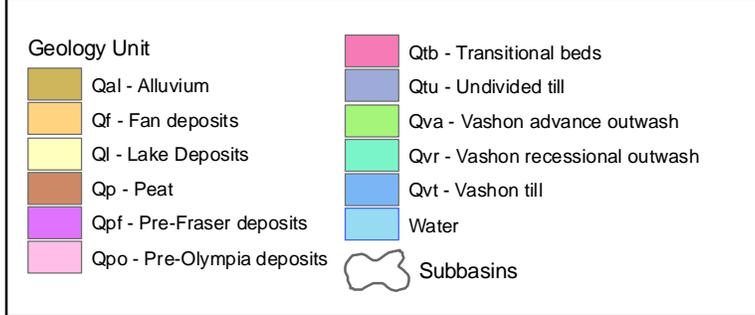
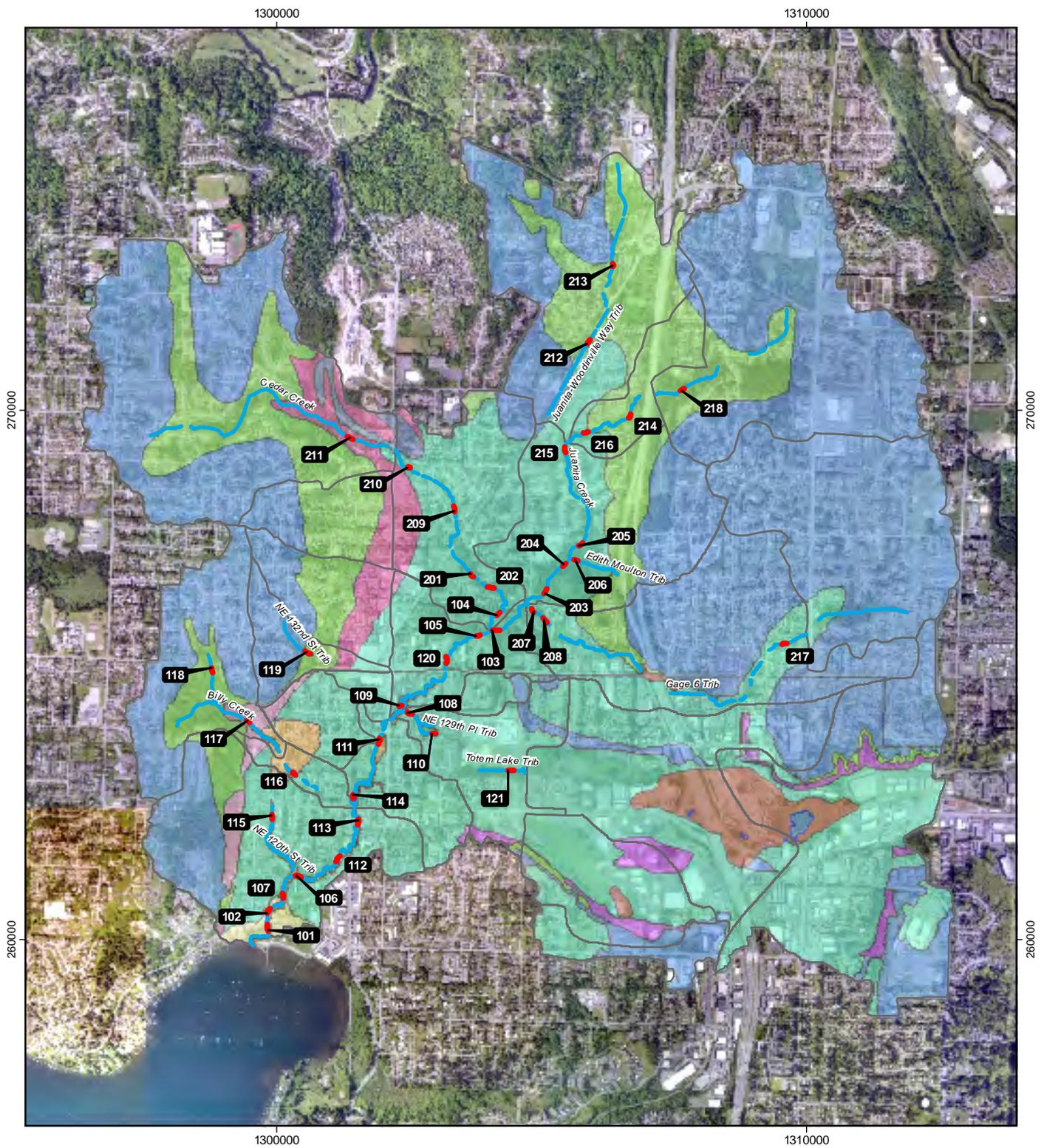
Bed Sediment and Geologic Setting

The surface geology of the Juanita Creek basin (King County, 2003; City of Kirkland areas updated by Troost and Wisner, 2010) is fairly typical of the central Puget Sound lowlands. Most

of the Juanita Creek stream network, and the majority of the assessment reaches, traverses sand and gravel associated with recessional outwash deposits (Qvr) from the Vashon ice-sheet advance about 16,000 years ago. Progressing upslope, the Vashon recessional outwash is flanked by much sandier Vashon advance outwash deposits (Qva). To the west of Juanita Creek, a band of slightly older silt and clay, named transitional beds (Qtb, Qpo), is exposed below the advance outwash and topographically above the (lower, but younger) recessional outwash. As is common in this area, uplands are dominated by Vashon glacial till. Portions of the creek network itself, particularly the lower mainstem, have created narrow bands of alluvial deposits atop the underlying sediments. Figure 2 shows the surface geology for the Juanita Creek basin.

Both outwashes are good sources of relatively coarse sediment to streams, though recessional outwash tends to be exposed on flatter terrain, as in Juanita Creek, where erosive power and consequent sediment production potential is somewhat less. Advance outwash, which is more often exposed on hillslopes as here, is the predominant natural source of sand to stream channels in the region. The silt/clay transitional beds exposed on the western slopes are typically fairly erosion resistant, though can be prone to seepage and landsliding because they impede the downward percolation of groundwater from the plateaus above.

Likely as a result of vigorous rates of sediment transport throughout the watershed, the bed sediment observations generally do not appear to strongly correlate to the adjacent geologic substrate. It could, however, be a contributing factor to higher fine sediment levels observed in the Juanita-Woodinville Way and Edith Moulton Park tributaries. The NHC team found low levels of fine sediment along Billy Creek, which flows through a fairly steep ravine incised into advance outwash and has been anecdotally reported as a significant fine sediment source (Jenny Gaus, personal communication). Given the high levels of instability, however, it is clear that erosion is occurring in the Billy Creek system; the sediment is likely being transported farther downstream along the mainstem rather than being deposited locally. Geologic mapping (Troost and Wisher, 2010) shows an alluvial fan deposit on Billy Creek in the vicinity of 94th Avenue NE, where the creek first enters a pipe system. This suggests that, at least historically, large volumes of sediment were generated in the upper reaches of the tributary but not all reached Juanita Creek itself.



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Figure 2

Comparison with Previous Studies

Table 1 compares sediment characterizations for the mainstem of Juanita Creek from the earlier Otak (2000) and King County (Rush et al., 2002) studies with our recent observations. In the basin planning study, Otak assessed sediment sizes by taking four bulk samples of sediment along the mainstem at points between NE 145th St upstream of I-405 and NE 124th Street. Otak's study did not include samples downstream of NE 124th Street. King County's habitat assessment study provided only qualitative descriptions of the bed sediment.

The King County study broke the Juanita Creek mainstem into five segments, shown in Figure 3 of their report. Segment 1 spans from the mouth of Juanita Creek upstream to NE 120th Street, Segment 2 from NE 120th Street to NE 126th Street, Segment 3 from NE 126th Street to Cedar Creek, Segment 4 from Cedar Creek to NE 141st Street, and Segment 5 from NE 141st Street to approximately 100 meters east of I-405. To facilitate the limited comparisons that might be justified, the table breaks down the mainstem according to these segments. Both the King County and Otak field observations were made during the summer of 2000.

Table 1. Bed Sediment Comparison with Previous Studies

Segment	Length (ft) [†]	NHC Bed Sediment Distribution				King County Notes	Median Gravel Size (mm)	
		Observed Length (ft)	0-33% sand	33-67% sand	67-100% sand		NHC Study	Otak Study [‡]
1	2470	1960	43%	33%	24%	large unstable sediment load in segment, possibly suitable spawning gravel	11-19	n/a
2	2960	1020	45%	25%	30%	many fines on stream bottom	<4-32	9
3	4240	1490	52%	36%	12%	lots of fines	22-64	4.4-9 ^a
4	3250	2320	39%	43%	19%			
d/s 108th Ave	1030	1030	67%	15%	18%	gravels possibly suitable for spawning	32-45	n/a
u/s 108th Ave	2220	1290	16%	65%	19%	lots of fines	15-24	11
5	3690	1390	68%	30%	2%	lots of fines		
d/s I-405	3140	1040	67%	30%	2%		11-32	n/a
u/s I-405	550	350	72%	28%	--		32-45	9

[†] Length measured from GIS stream network; not entirely consistent with lengths from King County report.
[‡] D₅₀ for bulk sediment sample. Includes fine sediments and subsurface gravels in addition to surface gravels.
^a Interpolated between two sample points.

The NHC team found sediment composition to be highly variable in the lower three segments, with predominantly gravel stretches alternating with sand blankets and mixed-bed conditions. Median gravel sizes at those locations were also quite variable, though consistently larger than Otak's sampling results, as expected based on the sampling techniques. Similarly, in the upstream segment 5, this study again found substantially lower levels of fine sediment and larger gravel sizes than are suggested by the previous study results. Again, these differences are primarily a result of the different sampling techniques (surface pebble count versus bulk sample), though seasonal factors may play a small role.

Results for segment 4, including the change in bed character from gravelly to sandy upstream of 108th Avenue NE through Edith Moulton Park, were most consistent with the previous studies. This consistency, with nearly a decade between sampling periods, suggests that the fine sediment accumulation in this reach is not a transitory phenomenon. Potential sediment sources and reasons for this distinct change in bed character will be explored further in Section 3 of this report.

In general, the current study found the Juanita Creek mainstem less dominated by fine sediment than suggested by the King County study (their Table 7). In the NHC study, sands were observed to predominate in the lower segments (1 and 2 per the King County study) of the mainstem, though some gravel-dominated segments were also present. Upstream in segments 3, 4, and 5, gravels tended to dominate the streambed, with fines covering less than a third of the bed area (with the notable exception of the reach between the Edith Moulton Park and Gage 6 tributaries). No significant sand-dominated segments were observed on the mainstem upstream of Edith Moulton Park.

We emphasize that these datasets are not strictly comparable, and some of the difference in assessment of fine sediment between the King County and NHC studies may be due to the different seasons in which field work was conducted. The King County study was conducted during the low-flow summer months, while the current study observed conditions during the higher flow period in November and December.

2.3 Bankfull Channel Dimensions

Bankfull channel dimensions were measured only for assessment reaches within the County-defined priority reaches. The five priority reaches (shown on Figure 1), correspond to stream reaches in the vicinity of County flow gages for which the County was interested in more detailed hydraulic and sediment transport information. Bankfull elevations were noted in the field during NHC's hydraulic survey for all cross sections for which they could be readily defined. These were linked to the geomorphic assessment reaches by identifying the hydraulic cross section closest to (or otherwise most representative of) the assessment reach. For representative cross sections for which bankfull elevations were not identified in the field, the bankfull channel was estimated in the office from the surveyed section profile by an experienced engineer/geomorphologist.

The indicators used to identify the bankfull channel were those commonly employed in humid regions and first articulated by Williams (1978): they include the height of the valley flat—or prominent surface on the valley floor—and the observed elevation of the active floodplain, which is the surface of frequent inundation by floods and is typically the lowest level of perennial vegetation. We note that where the valley is confined by adjacent hillslopes (such as a ravine setting) or the floodplain is otherwise narrow or only poorly developed, the results at any one site can be ambiguous.

As is typical for such analyses, the results were plotted against drainage area on a log-log graph. Nearly a century of geomorphic data analysis suggest that a linear relationship (in log-log space) between bankfull channel dimensions and drainage area is commonly observed (e.g. Dunne and Leopold 1978), and that variations in such a pattern can illuminate a legacy of past watershed disturbance. In particular, relationships for streams in western Washington (Booth and Jackson 1997) show that channels with systematically increased discharges resulting from high watershed imperviousness display statistically significant larger bankfull dimensions.

Both overall patterns and some systematic diversions are expressed in the data from Juanita Creek (Figure 3).

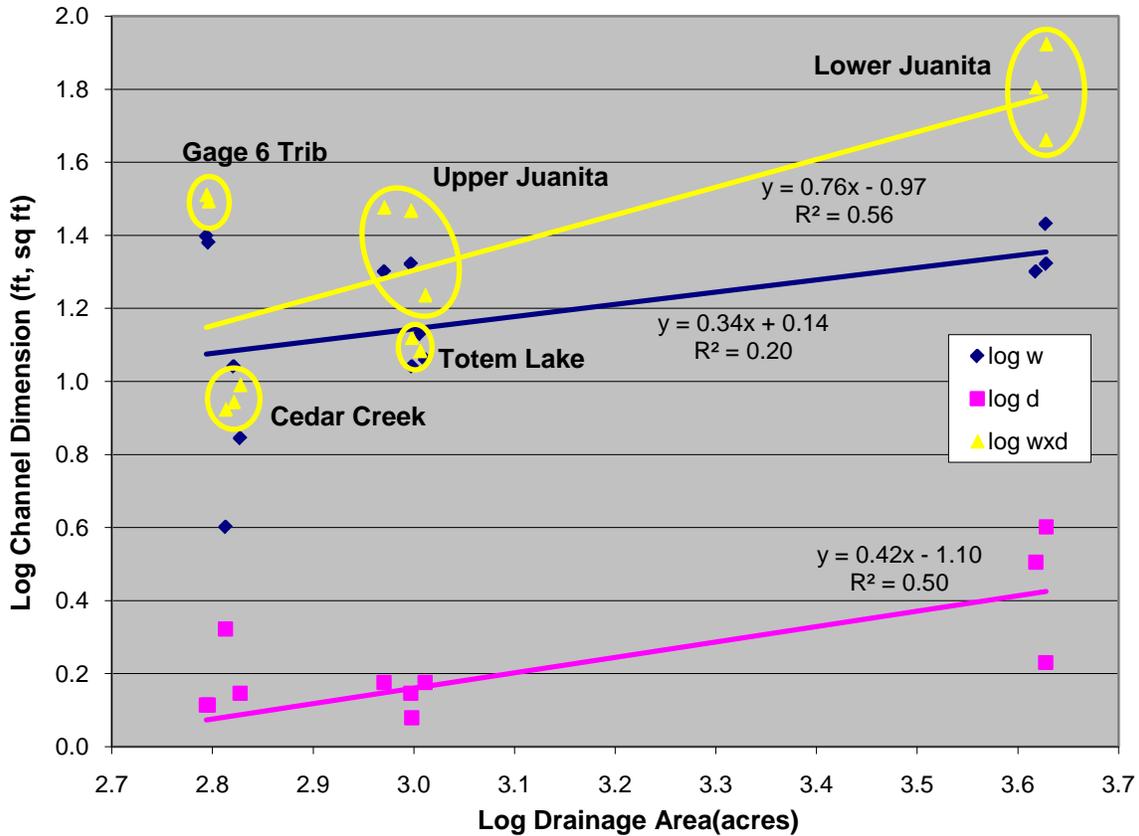


Figure 3. Plot of bankfull dimensions (width, depth, and bankfull area [= w × d]) for the five priority reaches. Labels highlight the grouping of the bankfull area points by priority reach.

As we have observed in other such studies, the variability in both width and depth is greater than that of their product (i.e. bankfull area), but even those data show only a fair correlation with drainage area ($r^2 = 0.56$). This is likely explained, however, by the presence of two different “populations” of channels amongst the five priority reaches with respect to peak flows: namely, Gage 6 tributary relative to Cedar Creek (50 to 100 percent greater discharges) and Upper Juanita relative to Totem Lake tributary (15 to 50 percent greater discharges). Removing the two “higher discharge” reaches results in a very coherent trend with respect to the channel area-drainage area relationship—an r^2 very close to 1.0 (0.96) and regression equations with exponents (i.e. the multiplicative factor of x) that closely match published ranges. It is thus reasonable to infer that the Gage 6 Tributary and Upper Juanita Creek have seen a disproportionately high magnitude of channel expansion within the Juanita Creek stream network as a result of historic watershed changes.

2.4 Bank Stability

Bank stability was evaluated for each geomorphic assessment reach using the method of Henshaw and Booth (2000). This method, which applies to straight alluvial reaches, uses qualitative indicators of frequency and severity of bank erosion to classify the reach into one of four stability categories (Table 2). For this assessment, a fifth category (Armored) was added for reaches where an appropriately alluvial site could not be identified. The need for bank armoring is typically an indicator of some level of instability in the past, although it generally precludes active bank erosion.

Table 2. Bank Stability Classification Criteria (from Henshaw and Booth, 2000)

Class	Category	Indicators
4	Stable	<ul style="list-style-type: none"> • Perennial vegetation to waterline • No raw or undercut banks • No recently exposed roots • No tree falls
3	Slightly Unstable	<ul style="list-style-type: none"> • Perennial vegetation to waterline in most places • Some scalloping of banks • Minor erosion and/or bank undercutting • Recently exposed tree roots rare but present
2	Moderately Unstable	<ul style="list-style-type: none"> • Perennial vegetation to waterline sparse (mainly scoured or stripped by lateral erosion) • Bank held by hard points (trees, boulders) and eroded back elsewhere) • Extensive erosion and bank undercutting • Recently exposed tree roots and fine root hairs common
1	Completely Unstable	<ul style="list-style-type: none"> • No perennial vegetation at waterline • Banks held only by hard points • Severe erosion of both banks • Recently exposed tree roots common • Tree falls and/or severely undercut trees common
0 [†]	Armored	<ul style="list-style-type: none"> • Banks held by constructed features (rip-rap, retaining wall, etc.)
[†] Not included in original classification scheme.		

Banks of the assessment reaches evaluated by the NHC team fell predominantly into the moderately unstable category: 16 reaches were classified moderately unstable, 9 slightly unstable, 6 completely unstable, 3 stable, and 5 were noted as armored. Even allowing for subjectivity in the classifications, the Juanita Creek stream network is clearly an unstable system. Plate 3 shows stability classifications for the 39 assessment reaches.

Stability Trends and Correlations

There are no apparent spatial trends in bank stability along the mainstem of Juanita Creek, where reaches were largely classified as moderately unstable. The major western (right bank) tributaries—Billy Creek and Cedar Creek—both showed more instability in their upper reaches. The Edith Moulton Park tributary, receiving runoff primarily from I-405, was also classified as completely unstable. In contrast, all assessment reaches on the Totem Lake and Juanita-Woodinville Way tributaries were classified as either stable (accounting for two of the three stable reaches) or slightly unstable. Mainstem assessment reaches immediately downstream of those two tributary confluences were also more stable than surrounding reaches.

The magnitude of bank erosion shows no correlation with local channel slope, but the patterns do suggest the influence of both hydrologic alteration and geologic substrate. Areas of high unit-area discharge, either modeled or inferred by land-cover patterns, are known or likely for Upper Juanita immediately below I-405, the Gage 6 Tributary, and the Edith Moulton Park tributary. These correspond to sites of moderate or high observed bank instability (214 and 216, 208 and 207, and 206).

The geologic material in which the channels are incised is also a likely contributing factor for several of the moderately and/or highly unstable sites that cross the Vashon advance outwash, a very sandy deposit that has been long-recognized for its susceptibility to channel incision (Booth, 1990). These include the upper mainstem (sites 214 and 216) and upper Billy Creek

(site 118). Notable exceptions to this association of high instability with this geologic deposit are Juanita Creek upstream of I-405 (site 218) and the Juanita-Woodinville Way tributary (sites 212 and 213). Other parts of the channel network, generally lying in the headwater reaches of the individual tributaries, also cross this deposit but were not surveyed as part of this study. Where draining highly impervious areas, however, they may also be contributing presently unrecognized high loads of sandy sediment.

Comparison with Previous Studies

Both the Otak (2000) and King County (Rush et al., 2002) reports included some assessment of stability for their assessment sites on the Juanita Creek mainstem, though the methods were different in all three studies. Otak’s report included geomorphic field notes as well an approximate quantitative analysis based on regime theory, in which stable channel widths were calculated (assuming existing slopes, dominant discharges, and sediment sizes) and compared with measured widths to determine whether a reach was eroding or aggrading (unstable), or in approximate equilibrium (stable). King County made an assessment of bank stability at regular intervals and computed an overall percent stability for each segment. This approach obscures variability within the 2,500- to 4,500-foot segments (of which 25 to 50 percent was actually assessed) and does not attempt to discern relative degrees of instability.

Table 3 compares the NHC team’s stability classifications with the Otak and King County assessments, from downstream to upstream along the mainstem. Our assessments are fairly consistent with the field observations from the Otak report for most reaches, but we note that Otak’s field and quantitative assessments were not internally consistent. (The latter analysis concluded that the mainstem of the creek was either stable or aggrading upstream of 108th Avenue NE and generally tending to widen or erode between the 108th Avenue NE crossing and NE 124 Street.) The King County results suggest an overall more stable channel than either of the other two studies, but direct comparisons are difficult given the different assessment scales and techniques.

Table 3. Bank Stability Comparison with Previous Studies

NHC Site	NHC Stability Class	Otak Field Notes	Otak Bed Stability	KC % Stable
101	Armored	Outside study area	Outside study area	43
102	Moderately Unstable	Outside study area	Outside study area	43
107	Slightly Unstable	Outside study area	Outside study area	43
106	Moderately Unstable	Outside study area	Outside study area	43
112	Completely Unstable	Outside study area	Outside study area	68
113	Armored	Outside study area	Outside study area	68
114	Moderately Unstable	Bend with small point bar. Severe erosion on outside of bend. Sand and gravel in channel	Eroding, Unstable	68
111	Slightly Unstable	Severe bank erosion, scalloped bank, sand and gravel in channel	Eroding, Unstable (interpolated)	90
109	Moderately Unstable	Thick sand and gravel in channel. Severe right bank erosion and back stepping. Large gravel bars and thick sand in channel	Eroding, Unstable (interpolated)	90
120	Armored	n/a	n/a	90
105	Moderately Unstable	n/a	Depositional at all flows	90

NHC Site	NHC Stability Class	Otak Field Notes	Otak Bed Stability	KC % Stable
103	Moderately Unstable	n/a		75
203	Moderately Unstable	Ravine-like through school park with banks up to 20' high	n/a	75
204	Moderately Unstable	Channel widening, sand and gravel bars, braided secondary channels through and around bars, shallow banks	n/a	75
205	Moderately Unstable	Channel widening, sand and gravel bars, braided secondary channels through and around bars, shallow banks	Depositional, stable at 2-yr flow	75
215	Slightly Unstable	Thick sand and gravel deposits/bars in channel	Stable	73
216	Completely Unstable	Thick sand deposits in channel	n/a	73
214	Moderately Unstable	Sand deposits associated with wood debris jams, upstream bank erosion, bank failure, and sloughing	n/a	73
218	Slightly Unstable	Banks scalloped and undercut	Depositional or stable	73

2.5 Incipient Motion Analysis

Channel stability and sediment transport capacity along the five priority reaches in the Juanita Creek system (see Section 2.3) were assessed by performing an incipient motion analysis, utilizing Shields criterion. As with the bankfull channel dimensions, this analysis applies only to the priority reach (Tier 1) geomorphic assessment sites. This section provides a brief summary the incipient motion analysis approach and results—more detailed information is available in a separate memorandum (NHC, 2010b).

Approach

The Shields criterion is the standard method for evaluation of incipient motion and is based on laboratory and field observation of sediment mobilization and measured flow characteristics (USACE, 1994). Required input for the analysis includes computed bed shear stress and measured surface bed-sediment grain size.

Bed shear stress along each assessment site within the priority reaches was computed using the HEC-RAS hydraulic model developed for the system. Cross-sections for the HEC-RAS model were surveyed at relatively wide intervals, so channel structure such as pools and riffles was not well-captured. This situation can lead to over-estimates of computed flow velocities and bed shear stress within HEC-RAS, especially at lower discharges. To compensate, NHC performed two tasks. First, additional cross-sections were interpolated in the vicinity of the Tier 1 assessment reaches and the resulting computed shear stresses were averaged. Second, we partitioned the bed shear stress into two components, total shear stress and grain shear stress. Grain shear stress is the portion of shear exerted on the bed grains resulting in sediment mobilization, while total shear stress, which is computed by HEC-RAS, is associated with the entire cross-section.

To estimate the threshold at which sediment is mobilized, the Shields criterion was utilized. As part of this analysis a dimensionless Shields number (τ^*) is computed using the following relation:

$$\tau^* = \frac{\tau_0}{(\rho_s - \rho)gD}$$

Here, τ^* is the critical Shields stress (constant value determined from the literature), τ_0 is the grain shear stress at incipient motion, ρ_s and ρ are the densities of sediment and water, respectively, g is gravitational acceleration, and D is a representative grain size diameter.

The equation above was then used to compute the shear stress (τ_0) responsible for mobilization of four grain size classes: coarse sand ($D = 5$ mm), small gravel ($D = 10$ mm), the gravel D_{50} at the site (median gravel size), and the gravel D_{90} at the site (diameter that exceeds 90 percent of those sampled). The shear stress for incipient motion computed using the Shields criterion was then compared with the grain shear stress (derived from total shear stress computed by HEC-RAS) for discharges ranging from 10 percent of the 2-year to the 500-year flow.

Flow Ranges for Sediment Transport

The range of flows for which the four sediment size classes are mobilized is illustrated in Table 4, and summaries of the findings for each of the priority reaches, from upstream to downstream, are provided below. The reader is directed to NHC’s technical memorandum (2010b) for more detailed information on incipient motion thresholds, including critical shear stresses and associated flows. Our results indicate that the gravel D_{90} is never mobilized up to the 500-year flow, nor is even the gravel D_{50} in half of the Tier 1 assessment reaches. Note that, as elsewhere in this report, the gravel D_{50} (and D_{90}) refer to the size distribution of surface gravels in each assessment reach—excluding fine sediments—and not to the reach’s overall bed particle size distribution. Thus, in sandier reaches, much more than 50 percent of the bed may be mobile at (and even below) the threshold of motion for the gravel D_{50} . For reference, Table 4 includes the level of sandiness (see Section 2.2) of each assessment reach.

Table 4. Bed Characteristics and Transport Flow Ranges

Priority Reach	NHC Site	Sand %	D_{50} (mm)	D_{90} (mm)	Largest Size Class Mobilized at Flow Quantile [†]							
					$\frac{1}{2}$ of 1.01	1.01	1.5	2	5	10	25	100
Upper Juanita	205	33-67%	19	69								
Upper Juanita	204	0-33%	24	44								
Upper Juanita	203	33-67%	15	33								
Gage 6 Trib	208	0-33%	43	101								
Gage 6 Trib	207	0-33%	33	79								
Cedar Creek	202	0-33%	21	39								
Cedar Creek	104	33-67%	19	32								
Totem Lk Trib	110	0-33%	25	50								
Totem Lk Trib	108	0-33%	15	36								
Lower Juanita	106	33-67%	15	128								
Lower Juanita	107	33-67%	12	35								
Lower Juanita	102	0-33%	19	38								

[†] Return interval (years), annual series.

Yellow = All sand ($D=5$ mm); Olive = Small gravels ($D=10$ mm); Gray = D_{50} ; Purple = D_{90}

Upper Mainstem

All sands were computed as mobilized at relatively low discharges in this priority reach. The median gravel size is transported from the upper portion of the reach (Site 205) at the 2-year flow, but may be trapped in the middle portion of the reach (Site 204). Site 203, at the downstream end of the priority reach, is characterized by finer gravels and correspondingly lower bed slope and energy gradient than the middle of the reach. Gravels greater than 10 mm in size are constrained from moving out of this reach by backwater from the 108th Avenue NE culvert. Sand and fine gravel, however, were computed as mobilized above the 1.25-year flow and thus may contribute to downstream deposition.

Gage 6 Tributary

The Gage 6 Tributary is a steep reach with a bed slope of approximately 2.7 percent. Gravels up to 30 mm are readily mobilized in the upper portion of the priority reach (Site 208) by discharges greater than the 1.25-year flow. The downstream end of the reach (Site 207) is backwatered by the 108th Avenue NE culvert at the 1.01-year flow, causing a reduction in bed shear stress up to the 50-year flow and limiting transport to sands between the 5- and 50-year flows. At most flows, however, sand and gravel up to 20 mm are readily mobilized throughout the reach and likely transported downstream to the mainstem, though the gravel D_{50} s (highest among Tier 1 assessment reaches) were computed as immobile.

Cedar Creek

The Cedar Creek priority reach lies between two culverts; however, the downstream culvert causes no backwater even at very large, infrequent discharges. Sand and fine gravels were computed as mobilized at the 1.01-year event and higher, but the gravel D_{50} is not mobilized at discharges less than the 100-year flow at the upstream end of the reach (Site 202). At the downstream end of the reach (Site 104), the gravel D_{50} is mobilized at much lower flows. Hydraulic conditions do not constrain this tributary from delivering sand and gravel to the mainstem.

Totem Lake Tributary

Sand is mobilized in this priority reach at relatively low discharges, and discharges greater than the 2-year flow are competent to move small gravels. Sediment was observed to be coarser at the upstream end of the priority reach (Site 110), where the gravel D_{50} is not mobilized because the energy grade line tends to be low due to adverse bed slope coming out of the culvert. At the downstream end of the reach (Site 108), the gravel D_{50} is mobilized at the 10-year flow, and sediment delivery downstream is not impeded by backwater. This reach was observed to have consistently low sand substrate, which may be caused by upstream sand deposition in wetlands and a detention pond.

Lower Mainstem

Gravels in this priority reach are smaller than the other priority reaches, and at the upper end of the reach (Site 106), the gravel D_{50} is mobilized at much lower flows than computed elsewhere in the network. Beginning in the middle portion of the reach, backwater from the Juanita Drive culvert begins to limit transport at the 1.5-year flow. At the mid-reach site 107, the gravel D_{50} is mobilized only at discharges between the 1.01- and 1.5-year flows, and only sands and very fine gravels are expected to be transported downstream to Lake Washington.

Comparison with Previous Studies

It is difficult to compare this incipient motion analysis with the Otak data and regime calculations (see Section 2.4), because Otak focused solely on the mainstem above NE 124th Street, collected sediment data during the low-flow season instead of the high-flow season, and

collected only four point bulk sediment samples in contrast to our approach of conducting pebble counts of surface gravels at each site. Furthermore, Otak used simplified hydraulics and hydrology compared to the present study.

2.6 Pools and Large Woody Debris

The scope of the current analysis is generally limited to physical geomorphology. However, recognizing that the County's overall goal for Juanita Creek is to restore (or improve) habitat and ecological function, the field assessment was taken as an opportunity to collect additional data that may be useful for later biological assessment and analysis. In this study, the NHC team counted LWD and large pools within the assessment reaches and in the "access reach" segments traversed to reach those assessment reaches. LWD, defined as wood greater than 12 inches in diameter and 10 feet in length, was classified into bins based on pieces per approximately 100 feet (after McBride and Booth, 2005). Large pools, defined as those having a residual depth greater than or equal to the bankfull depth, were counted and their locations recorded. For both LWD and large pool dimensions, measurements were approximate visual assessments only. Plate 4 illustrates LWD and large pool distribution in the areas of the stream network evaluated for this study.

The total channel length over which LWD and large pools were evaluated was approximately 8,600 feet. As expected based on previous work on Juanita Creek, LWD was scarce to non-existent throughout the stream network. Only one reach, just upstream of NE 124th Street near the Billy Creek confluence, had more than five pieces per 100 feet. More than 40 percent of the assessed channel length had no pieces of LWD at all.

Our geomorphic survey identified 29 large pools, which appears to be fairly consistent with King County's findings in the 2002 report. (That report counted all pools; comparison is based on the number of pools identified in the study greater than 0.5 meters deep.) This study did not attempt to evaluate habitat quality of the pools identified.

King County's 2002 Habitat Assessment report provides a much more thorough and comprehensive evaluation of habitat parameters for the Juanita Creek mainstem than was attempted in this study. The reader is directed to that study for more detailed analysis and interpretation, including assessment relative to "properly functioning conditions." King County also recently conducted a B-IBI analysis for seven sites in the Juanita Creek basin, finding that, with the exception of one site on lower Cedar Creek, conditions were generally poor (Berge and Burkey, 2009).

3. Discussion and Conclusions

Restoration of beneficial uses or properly functioning conditions in a profoundly disturbed system such as Juanita Creek requires recognition and rehabilitation of an array of inter-related physical, chemical, and biological conditions. Going into this study, previous work on Juanita Creek suggested that the most significant physical problems in the system are an altered hydrologic regime (specifically increased magnitude and duration of high flows), pervasive channel instability, excessive fine sediment in the bed, and lack of habitat structure and complexity. This section will focus on what the current study tells us about the extent and possible causes of those problems, as well as other issues recognized in the course of our work.

3.1 Hydrology

Increases in magnitude and duration of high flows due to urbanization of the watershed are undoubtedly the primary contributing factor to, if not the root cause of, the widespread channel instability and fine sediment issues in the Juanita Creek watershed. Our work on this study to

date has not included extensive hydrologic analysis; thus, this discussion is somewhat limited by a lack of full understanding of the basin hydrology. Where possible, we have incorporated the hydrologic data that were available and our knowledge of typical hydrologic response to watershed soils and imperviousness.

Of the six major tributaries to Juanita Creek (Upper Juanita, Cedar Creek, Totem Lake Tributary, Gage 6 Tributary, Billy Creek, and Juanita-Woodinville Way Tributary), we currently have peak flow information for four (Table 5).

Table 5. Juanita Creek Tributary Peak Flows

Tributary	Drainage Area (ac)	Peak Flow (cfs) by Return Interval					
		1.01-yr	2-yr	5-yr	10-yr	25-yr	100-yr
Upper Juanita	1040	21	48	64	74	86	103
Totem Lake	1025	15	33	46	57	71	95
Cedar Creek	675	16	31	41	49	58	74
Gage 6	625	39	56	67	76	86	103

Despite having the smallest drainage area, the Gage 6 Tributary shows the highest peak flows. On a unit-area basis, the Gage 6 Tributary flows are two to three times those for Upper Juanita and Cedar Creek for flows up to the 10-year discharge, which are generally more important in determining geomorphic response than larger but more infrequent events. Cedar Creek and Upper Juanita produce virtually the same flows per unit area. Totem Lake Tributary flows are notably lower, most likely due to flow attenuation by upstream wetlands and detention.

Billy Creek has similar soils and land use to Cedar Creek, so its watershed would likely produce similar flows. The Juanita-Woodinville Way tributary has similar land use but a higher percentage of outwash soils than the other upland areas, so unit-area flows would probably be similar to or slightly lower than Upper Juanita. A significant portion of the Edith Moulton Park tributary drainage is occupied by I-405, suggesting that peak flows would be quite high, possibly closer to the Gage 6 Tributary on a unit-area basis.

Based on the available information, the Gage 6 Tributary stands out as a problem area, though the entire Juanita Creek basin has undoubtedly been subject to significant flow increases. King County’s HSPF model of the basin provides a key tool for further investigation of basin hydrology to extend our understanding of how the hydrologic regime has been affected and where the greatest needs—and best opportunities—for flow control may exist.

3.2 Channel Stability

The NHC team’s observations confirm that bank instability is a pervasive problem through almost the entire watershed, perhaps even more so than suggested by earlier studies. As discussed in Section 2.4, the most unstable reaches observed tend to be associated with areas of high discharges and (in many cases) more erosive geologic substrates.

For the mainstem, the non-geologic factors that contribute to ongoing instability include the (presumed) historic and ongoing increases in watershed imperviousness (and the flow increases that accompany them); channel confinement throughout much of the mainstem corridor, forcing discharges into abnormally narrow channels; and the high volumes of water that provide ample force to erode channel banks that are not at an equilibrium width or slope for the prevailing flow regime.

The Juanita-Woodinville Way and Totem Lake tributaries are the only significant exceptions to the generally basinwide instability. Despite draining a large (roughly 25 percent of the entire Juanita

Creek basin) and highly impervious watershed, all three sites on the Totem Lake tributary were relatively stable. As mentioned above, the Totem Lake basin contains several wetlands and a regional detention pond that attenuate high flows, and peak discharges per unit area are significantly lower than for the other major tributaries.

3.3 Fine Sediment

In contrast to channel stability, results of this study suggest that fine sediment is somewhat less pervasive throughout the channel network than previously reported, though the observed amounts almost certainly reflect substantial degradation of aquatic habitat (see Section 3.5). Surface gravel patches were present throughout most of the stream network and dominant over more than half of the channel length observed. We hypothesize that there is a seasonal trend in the surface expression of fine sediment, with sediments accumulating during the low flow season, then transported downstream as flow levels increase in the fall and winter. This would be consistent with the differences in fine sediments observed in previous studies (during low-flow season) and the current study (where field work was conducted in late fall). As will be discussed further in Section 3.4, Juanita Creek regularly sees flows capable of moving even coarse sands, but due to hydraulic limitations, gravel movement may be very limited in many parts of the system.

Given the widespread instability in the system, a primary source of fine sediment is likely bank erosion. Photo 2 shows examples of bank erosion from three different parts of the basin.



Photo 2. Examples of bank erosion throughout the Juanita Creek stream network: a) Juanita Creek just above Cedar Creek (site 103), b) Upper Billy Creek (site 118), c) Gage 6 Tributary (site 208)

Currently, bank erosion is occurring almost everywhere in the basin, so there is no “smoking gun” in terms of fine sediment source locations. It would be reasonable to expect, however, that reaches in erosive geologic substrate would have the highest potential for continued erosion, particularly if subject to very high flows or continued increases in flows. This would point to Billy Creek, the upper reaches of Cedar Creek, the upper mainstem, and potentially the Juanita-Woodinville Way tributary as areas of particular concern.

Three locations stand out as hot spots for fine sediment deposition: Juanita Creek upstream of NE 124th Street, Juanita Creek through Edith Moulton Park, and the Edith Moulton Park tributary. The two mainstem reaches are in relatively flat stretches upstream of culverts and near confluences with steeper tributaries with high sediment-production potential. As previously mentioned, the reach upstream of NE 124th Street was subject to recent activity in the creek, so it is unclear whether the deposition in that reach is more transitory. Comparisons with the King County and Otak studies, however, show that the Edith Moulton Park reach upstream of 108th Avenue NE has shown similar depositional character for at least the past decade.

Given significant basinwide fine sediment loads, high sand content in the lower mainstem is expected and cannot really be addressed locally; rather, reduction in upstream sediment would be necessary to limit deposition in these areas. The mixed pattern of bed sediment (i.e. patches of sand, gravel, and mixed bed sediments) in the lower mainstem downstream of NE 124th Street (and possibly even 108th Avenue NE) affirms that large amounts of sand are in transport, and local hydraulics control specific locations of deposition versus continued downstream transport.

Again, the Totem Lake Tributary appears to be the exception to the otherwise basinwide trend. With low levels of fine bed sediment, relatively stable banks, and upstream wetlands capable of capturing sediment from farther up in the watershed, Totem Lake Tributary is unlikely to be a significant source of fine sediment to Juanita Creek.

3.4 Sediment Transport and Hydraulic Regime

With the HEC-RAS model developed in this study, NHC was able to perform more extensive and continuous hydraulic analysis than has previously been reported. Results of the hydraulic modeling were instrumental in the incipient motion analysis (Section 2.5) and are also useful for identifying the influence of hydraulic constraints that may not be readily apparent.

One of the more interesting, and perhaps unexpected, findings is the extent to which backwater effects from various culverts, mainly along the mainstem, limit downstream sediment transport, especially of gravels. By acting as grade controls and slowing flows such that gravel movement is restricted, the culverts are likely limiting incision and helping to maintain local accumulation of bed gravels. Thus, it could be argued that the presence of these restrictive culverts is actually helping to maintain the physical structure of the system. On the other hand, limited sediment transport capacity through these culverts may create a “sediment-hungry” flow downstream of the culverts and lead to additional downstream bank erosion. Scour pools and widened channel sections were observed at the downstream face of several culverts, as is typical of hydraulic flow restrictions, but stability observations do not obviously support exaggerated downstream erosion beyond the immediate vicinity of the culverts.

The incipient motion analysis pointed to the Juanita Drive and 108th Avenue NE (on both Juanita Creek and the Gage 6 Tributary) culverts as the most significant barriers to sediment transport in the priority reaches. Outside the priority reaches, model profiles suggest that the consecutive crossings of NE 128th Street, 100th Avenue NE, and NE 129th Place and (to a lesser extent) the NE 124th Street crossing may also act as sediment barriers.

Given the fact that some of these culverts experience significant backwater even at relatively low flows, it is possible they would be targeted for replacement, either as flood control or fish passage improvements. This bears a caution that replacement of these culverts may have unintended consequences in terms of increased downstream sediment loads, loss of gravels, and potentially bed incision in addition to the channel widening that is already occurring. It appears that some of the culverts are acting as hydraulic brakes, and thus may be serving at least part of the hydraulic function of the pools and large wood that are almost entirely lacking throughout the Juanita Creek system.

3.5 Habitat Structure and Complexity

The LWD and large pool data collected in this study corroborate earlier working assumptions that existing conditions in Juanita Creek are far from ideal in terms of providing instream habitat of sufficient quantity and quality to support native fish species and other biota. Native salmon and trout require cool, well-oxygenated water and complex physical habitat conditions to successfully complete their life cycle. The King County habitat assessment (Rush et al., 2002) completed in

2000 reached similar conclusions. It broadly characterized existing conditions and made recommendations for additional studies, including the current one.

While area estimates of spawning habitat have not been quantified, visual estimates of the spatial extent of sand and fines that cover the stream bed (based on data from this study) strongly suggest that such habitat is limited and is a significant factor in limiting the productivity of native fish populations. Gravel patches of sufficient size and porosity vary as a function of the size of the spawning adults. When these areas are compromised by the chronic intrusion of fine materials, it significantly reduces their quality. Fine sediments (less than 0.86 mm in diameter) that exceed just 10 percent (by weight) of the bed substrate significantly reduce survival of incubating eggs deposited by native fishes. At about 15- to 20-percent fine sediment, egg-to-fry emergence survival drops off precipitously through limitation of intergravel dissolved oxygen and entombment of fry before they emerge (Quinn, 2005). The species-specific preference for spawning gravel sizes and spatial area are provided in Table 6 below (Saldi-Caromile et al., 2004). Note that suitable spawning habitat is determined by a mix of water depth, velocity, and substrate size and presumed porosity.

Table 6. Channel Conditions Required for Spawning Criteria for some Salmonids

Species	Minimum Depth (m)	Velocity (m/s)	Substrate Mix Size Range (mm)	Mean Redd Area (m²)	Req'd Area per Spawning Pair (m²)
Fall chinook salmon	0.24	0.30 - 0.91	13 - 102	5.1	20.1
Spring chinook salmon	0.24	0.30 - 0.91	13 - 102	3.3	13.4
Summer chinook salmon	0.30	0.32 - 1.09	13 - 102	5.1	20.1
Chum salmon	0.18	0.46 - 1.01	13 - 102	2.3	9.2
Coho salmon	0.18	0.30 - 0.91	13 - 102	2.8	11.7
Pink salmon	0.15	0.21 - 1.01	13 - 102	0.6	0.6
Sockeye salmon	0.15	0.21 - 1.07	13 - 102	1.8	6.7
Kokanee	0.06	0.15 - 0.91	13 - 102	0.3	0.15
Steelhead	0.24	0.40 - 0.91	6 - 102	4.4 - 5.4	n/a
Rainbow trout	0.18	0.48 - 0.91	6 - 52	0.2	n/a
Cutthroat trout	0.06	0.11 - 0.72	6 - 102	0.09 - 0.9	n/a

While the results of this study suggest that sand covers less bed surface area than reported in previous studies, they nonetheless suggest strongly that spawning habitats that would allow expected survival of incubating eggs are limited within the watershed. Independent of hydrologic alterations, this condition alone will limit survival and rebuilding of native fish populations within the basin. Seasonal fluxes of fine sediment out of gravel-bedded reaches may provide transient spawning habitats, but subsequent deposition of new fines transported from upstream and deposited overtop of established redds will still reduce survival of eggs and alevins.

As was previously reported in the King County survey (Rush et al., 2002), the data from the present study affirm that overall habitat complexity is poor within Juanita Creek and limits the degree to which native aquatic biota might recover to a reasonable approximation of their inherent potential. Deep pools are rare and the distance between pools is very long, challenging both adult and juvenile fish to take advantage of such holding and rearing habitat during critical low-flow months.

The frequency of large wood in the channel is also critically low, which limits available holding and rearing habitats, especially for juvenile salmonids. Wood provides hydraulic roughness and

increases micro-habitat scale upwelling and down-welling areas that can help increase nutrient availability, moderate elevated temperatures, and increase intergravel dissolved oxygen. Although an abundance of undersized culverts, particularly along the mainstem, has provided some degree of structural stability to the channel that might otherwise have been more severely compromised as well, the absence of critical habitat elements is clearly documented in the present data set.

3.6 Critical Reaches

Critical reaches are those that our data suggest may be the biggest problem areas or those that may have the most potential for improvement. The latter group would also include sites that appear to present opportunities for cost-effective solutions, for example, where undeveloped area remains in the watershed that may be preserved to prevent additional future flow increases. Again, additional hydrologic data will provide a wealth of information to further refine these preliminary lists.

Problem Areas

Table 7 summarizes the locations that our data suggest are among the most significant problem areas in the Juanita Creek basin. Specific problems and potential causes have been discussed in the previous sections. To the extent feasible, these areas should be prioritized as targets for mitigation projects.

Table 7. Significant Problem Areas

Location	NHC Site(s)	Category				
		Hydrology	Bank Stability	Fine Sediment	Sediment Transport	Habitat (LWD/Pools) [†]
Juanita Creek u/s of 108 th NE (Edith Moulton Park)	203, 204		✓	✓	✓	✓
Edith Moulton Park trib	206	✓ [‡]	✓	✓		
Gage 6 Trib	207, 208	✓	✓		✓	✓
Juanita Creek u/s of NE 124th	114		✓	✓		
Juanita Creek d/s I-405	214, 216		✓			
Billy Creek	116, 117, 118		✓			✓
Upper Cedar Creek	210, 211		✓	✓		✓
[†] Based on limited data collected in this study; not intended as a complete list.						
[‡] Assumed; data not available.						

Opportunity Areas

Locations listed in Table 8 are not necessarily the biggest problem areas in the basin, but rather areas where we perceive potential opportunities for mitigation projects or preventive actions that could limit future degradation to the system. Additional information, such as publicly-owned property, could point to other opportunity areas.

Table 8. Opportunity Areas

Location	NHC Site(s)	Category	Description
Juanita Creek u/s of I-405	218	Flow control, habitat	Preserve undeveloped forested areas in watershed, forested riparian corridor
Upper Cedar Creek	211	Habitat	Preserve forested riparian corridor
Cedar Creek d/s of Juanita-Woodinville Way	201	Habitat	Preserve forested riparian corridor
Upper Billy Creek	117, 118	Habitat	Preserve forested riparian corridor
NE 120 th Street trib	n/a	Flow control, habitat	Preserve undeveloped forested areas in watershed
Edith Moulton Park trib	206	Flow control, sediment	Potential restoration, undeveloped floodplain/riparian corridor in park
Juanita Creek through Edith Moulton Park	203, 204	Flow control, habitat	Potential restoration, undeveloped floodplain/riparian corridor in park
Gage 6 trib d/s of I-405	n/a	Flow control	Potential for increased wetland storage

Limited Return Areas

An important corollary to the identification of critical reaches is the identification of areas where mitigation efforts are likely to provide limited improvement to Juanita Creek. The Totem Lake Tributary stands out from this analysis. While the Totem Lake basin almost certainly has internal problems and may be a primary culprit in water quality issues on Juanita Creek, from a hydrologic and geomorphic standpoint, it does not appear to have a significant negative impact on Juanita Creek. Investment in improvements would thus be expected to provide little or no return in terms of measurable improvement on Juanita Creek.

Also, as discussed previously, fine sediment loads in lower Juanita Creek are dominated by sediment generated elsewhere in the basin and transported down the stream network. Thus, until upstream sediment sources can be addressed, any downstream sediment control measures would be only stop-gap solutions likely to be quickly overwhelmed.

4. Recommendations for Future Work

The results and conclusions of this study generally corroborate earlier work on the mainstem and expand our view of the system into some of the tributary channels. This study clearly identifies some critical areas for which specific solutions can begin to be developed but also points to needs for further investigation, both of physical parameters addressed in this study and other areas (e.g. biological and water quality assessments) well beyond our scope.

4.1 Phase II Analyses

The scope for this work includes an allowance for a second phase (Task 400) to begin to identify and evaluate management actions to address the identified problems in the Juanita Creek basin. This section suggests a proposed approach for that work, based on the results of the hydraulic and geomorphic analyses.

Potential Management Actions

Management actions, which potentially encompass physical projects, regulatory changes, and public education and outreach, should be considered in the context of 1) addressing existing problems in the Juanita Creek basin and 2) moving toward the goal of restoration of beneficial

uses in the stream. The primary problems identified in this and previous studies are high flow peaks and durations, channel instability, fine sediment accumulation on the streambed, and lack of habitat structure and complexity. Management actions targeting flow control, instream energy dissipation, bank stabilization, and/or establishment of off-channel habitat and refugia are among the more promising avenues to addressing one or more of the major issues.

Given that the basin is already highly developed and undeveloped space is scarce, the opportunity for more traditional approaches to flow control such as regional detention may be limited. Instead, so-called “alternative stormwater management techniques” such as distributed storage and infiltration, possibly utilizing portions of the public street right-of-way, have the potential to reduce runoff near its source while improving water quality. Infiltration, in particular, may have significant potential in the Juanita Creek basin given the high percentage of outwash soils. It is highly unlikely that even a large investment in traditional and alternative flow control could restore forested flow regimes in Juanita Creek or its tributaries. Therefore, instead of aspiring to this unrealistic goal, efforts should be made to identify alternative flow regime targets that will result in reasonably stable channels and significantly improved aquatic habitat. This identification would provide the basis for estimating the locations and sizes of required flow control facilities.

There are a number of approaches to energy dissipation and bank stabilization that are also consistent with establishment of physical habitat structure. Provided they are designed correctly for an appropriate flow regime, projects employing large woody debris, boulders, and various types of bank plantings can successfully stabilize banks and redirect flows, as well as encourage development of pools and create shelter and lower velocity refugia. In steeper reaches, use of wood and rock to create step-pool channel geometries can similarly reduce flow energy, create habitat structure, and provide some attenuation of peak flows.

Opportunities for floodplain restoration are limited in the Juanita Creek basin because development in many areas extends nearly to the creek. Where buffer areas still exist, however, re-establishing connection between the creek and floodplain enhances storage, promotes creation of off-channel habitat and recruitment of LWD, and provides an area for fine sediment deposition.

Otak’s 2000 study provided a series of potential stabilization measures, many similar to the types of projects outlined above. The Otak report recommends application of a set of stream stabilization and enhancement techniques to both specific and generic locations along the Juanita Creek mainstem. Site-specific recommendations were targeted at existing instream facilities and included: 1) removal of sediment from the existing Highland Woods pond located just upstream of I-405, 2) abandonment of a gravel-filled sediment pond on the upstream side of NE 124th Street, and 3) construction of new floodplain storage and habitat enhancements in the ravine upstream of NE 140 Street. Generic techniques fell into four categories:

- Stream channel restoration, including establishment of meanders, stable cross sections, and pool-riffle sequences;
- Stabilization of debris flows from steep banks by protecting toes of slopes, tightlining stormwater outfalls, and vegetating earth slips and slumps;
- Streambank protection using various "soft" engineering techniques; and
- Flow modification using weirs and deflectors to modify and redirect flow energy.

We are not aware at this time the extent to which Otak’s proposed measures may have been implemented or attempted by the City of Kirkland in the past decade. Some evidence of restoration projects was observed in our field assessment (e.g. channel/meander restoration in the park north of Juanita Drive), though not at the scale and frequency recommended by Otak’s report.

Evaluation Metrics

In order to evaluate the effectiveness of potential solutions and compare them to existing conditions and other alternatives, it is important to develop a set of metrics that: effectively represents the (not always readily quantifiable) variables of interest; is capable of distinguishing between desirable and undesirable conditions; and, ideally, can be linked to habitat function or ecological health. Where models can be used to reasonably represent alternative actions, metrics that can be computed or derived directly from model data have the advantage of being useful in a predictive capacity; i.e. they can be used to assess an unobservable “with project” condition.

Quantitative metrics can be readily identified for evaluation of hydrologic, sediment-transport, and stability impacts. In past work, NHC has used metrics quantifying the frequency and duration of bed-entraining flows and the effective energy of the stream to characterize geomorphology. Several of these metrics were based on those developed by Booth et al. (2001) on Puget Sound lowland streams and by Doyle et al. (2000) to distinguish channel stability on Midwestern streams. For Juanita Creek, we would suggest several hydro-geomorphic metrics:

- **F_{qe}**: Disturbance frequency of spawning gravels, i.e. frequency of flows capable of mobilizing spawning gravel, as an average number of events per year.
- **T_{qe}**: Cumulative duration of spawning gravel entraining flows, after Booth et al.’s $T_{Q_{mean}}$ Or $T_{0.5yr}$
- **Effective energy**: Average annual effective work (to entrain bed sediments) per unit width, calculated from the integral of unit effective stream power
- **T_{0.5yr}**: Cumulative duration of flows exceeding the “half-year” discharge (i.e. flow that is exceeded on average twice a year). Metric proposed by Booth et al. (2001) that tracks well with B-IBI and is not sensitive to basin area (as is the analogous $T_{Q_{mean}}$)

These metrics have been found to be robust and capable of providing relative assessments of hydrologic and/or geomorphic conditions compared to some threshold or reference condition. Except as it can be manifested in changes to flows, velocities, or channel dimensions, physical habitat is more difficult to quantify with such metrics.

For evaluation of actions aimed at physical habitat creation, use of something like the National Marine Fisheries Service (NMFS) Matrix of Pathways and Indicators (NOAA, 1996) to set targets or estimate improvement toward defined “properly functioning conditions” may be a more useful evaluation tool. This was the approach used to characterize 2000 conditions in Juanita Creek in King County’s habitat assessment (Rush et al., 2002).

Evaluation Approaches

To kick off Phase II, we recommend a workshop with King County (and City of Kirkland) staff to share and transfer knowledge regarding specific hydrology, geomorphology, and habitat issues and concerns in Juanita Creek, as well as solutions that may have already been proposed, considered, or attempted in the basin. The product of that meeting would be a list of locations and potential actions to be evaluated and a list of metrics by which they would be evaluated.

Using this list as a starting point, the NHC team will evaluate the effectiveness of proposed actions or combinations of actions in improving hydrologic, stability, sediment, and habitat conditions both locally and downstream. To the extent that the proposed actions or their effects on the channel can be represented in the HSPF model, that will be a primary evaluation tool. The specific metrics proposed above can all be computed from HSPF-simulated time-series and measured channel properties and then compared with existing conditions, potentially a desirable reference condition, and other solutions.

Proposed actions or parts of actions that cannot be effectively modeled, such as habitat quality, would be qualitatively evaluated by appropriate experts (at the County, Stillwater, or NHC) and some sort of ranking system devised to assess relative benefits.

4.2 Additional Field Investigation

The data collected in this study are much more spatially extensive than had been previously collected on Juanita Creek. This has provided opportunity for broader assessment of the basin but also raised additional questions.

Substrate comparisons with previous studies suggested the possibility of a seasonal trend in fine sediment accumulation. A similar sediment observation program to what was undertaken for this study in the spring and/or summer of 2010 would provide a set of comparable data from which the presence and magnitude of that trend could be better characterized.

The incipient motion analyses completed for this study required assumptions regarding the relationship of forces acting to mobilize the bed particles (grain shear) with total shear in the cross section. To the extent that the County anticipates using these results further, our assumptions may be best verified by field studies of incipient motion of different gravel sizes in priority reaches.

We also believe that a more continuous bank stability assessment, along the lines of our extended substrate analysis would be especially enlightening. The assessment reach characterization performed in this study was more of a snapshot approach, with the thought that we might observe broader spatial trends in bank stability. Absent these, a more extensive coverage emphasizing variability along a reach may reveal trends that could not be discerned from the current dataset. An extended stability dataset could also be correlated with the extended substrate data and hydraulic conditions to evaluate some of the relationships suggested in this report.

4.3 Other Areas

As stated in the Introduction, this study is only a part of a larger investigation and effort to restore beneficial uses in Juanita Creek. While we believe it contributes to the understanding of physical factors affecting the creek's ability to support native biota—hydrology, geomorphology, and (at a limited level) physical habitat—chemical and biological factors are well beyond our scope. Similar efforts to this study in those areas, if not already underway, will be integral to developing a comprehensive basin plan and management approach. Observations of juvenile fish within the system indicate that limited populations of native fish are able to successfully spawn and rear in the system. Eventually understanding specific locations of these habitats and other factors that currently limit expansion of these populations will allow for a more focused restoration effort.

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